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Air Pollution Effects on Forests: A Guide to Species Ecology, Ecosystem Services, and Responses to Nitrogen and Sulfur Deposition Herbs (Volume 2)



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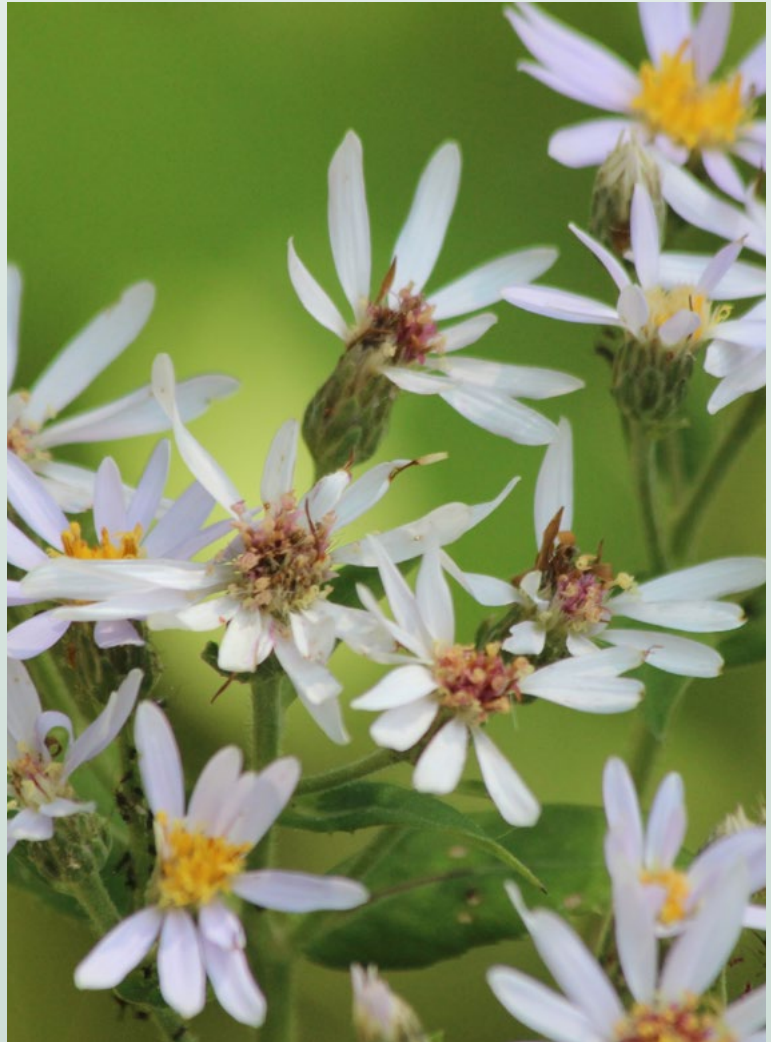
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Air Pollution Effects on Forests: A Guide to Species Ecology, Ecosystem Services, and Responses to Nitrogen and Sulfur Deposition

Herbs (Volume 2)



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CONTENTS

AUTHORS.....	4
EXECUTIVE SUMMARY	10
CHAPTER 1: INTRODUCTION	12
1.0 <i>Actaea rubra</i> (red baneberry)	23
2.0 <i>Alliaria petiolata</i> (garlic mustard).....	26
3.0 <i>Andropogon gerardii</i> (big bluestem)	29
4.0 <i>Andropogon glomeratus</i> (bushy beardgrass)	32
5.0 <i>Andropogon virginicus</i> (broomsedge bluestem)	35
6.0 <i>Apocynum androsaemifolium</i> (spreading dogbane).....	38
7.0 <i>Aquilegia canadensis</i> (red columbine).....	41
8.0 <i>Asarum canadense</i> (Canadian wild ginger)	44
9.0 <i>Athyrium filix-femina</i> (common lady fern).....	47
10.0 <i>Bouteloua curtipendula</i> (sideoats grama)	50
11.0 <i>Bouteloua gracilis</i> (blue grama).....	53
12.0 <i>Bromus ciliatus</i> (fringed brome).....	56
13.0 <i>Bromus inermis</i> (smooth brome).....	59
14.0 <i>Carex pensylvanica</i> (Pennsylvania sedge).....	62
15.0 <i>Cirsium arvense</i> (Canada thistle)	65
16.0 <i>Cirsium vulgare</i> (bull thistle).....	68
17.0 <i>Conyza canadensis</i> (Canadian horseweed).....	70
18.0 <i>Dactylis glomerata</i> (orchardgrass).....	73
19.0 <i>Danthonia spicata</i> (poverty oatgrass).....	75
20.0 <i>Dryopteris carthusiana</i> (spinulose woodfern)	78
21.0 <i>Echinacea angustifolia</i> (purple coneflower)	81
22.0 <i>Elymus canadensis</i> (Canada wildrye).....	84
23.0 <i>Elymus trachycaulus</i> (slender wheatgrass).....	87
24.0 <i>Elymus virginicus</i> (Virginia wildrye)	90
25.0 <i>Eryngium yuccifolium</i> (rattlesnake master)	92
26.0 <i>Eupatorium compositifolium</i> (dogfennel).....	95
27.0 <i>Eurybia macrophylla</i> (bigleaf aster).....	98
28.0 <i>Euthamia graminifolia</i> (flat-top goldentop).....	101
29.0 <i>Fragaria virginiana</i> (wild strawberry).....	104
30.0 <i>Galium triflorum</i> (fragrant bedstraw).....	107
31.0 <i>Geranium maculatum</i> (spotted geranium).....	110
32.0 <i>Geum triflorum</i> (old man's whiskers).....	113
33.0 <i>Glycyrrhiza lepidota</i> (American licorice).....	116
34.0 <i>Goodyera pubescens</i> (downy rattlesnake plantain).....	119
35.0 <i>Gymnocarpium dryopteris</i> (western oakfern).....	122

36.0 <i>Hepatica nobilis</i> (sharplobe hepatica)	125
37.0 <i>Hesperostipa comata</i> (needle and thread)	128
38.0 <i>Juncus arcticus</i> ssp. <i>littoralis</i> (mountain rush)	131
39.0 <i>Juncus effusus</i> (soft rush)	134
40.0 <i>Koeleria macrantha</i> (prairie junegrass)	137
41.0 <i>Leersia oryzoides</i> (rice cutgrass)	140
42.0 <i>Liatis pycnostachya</i> (prairie blazing star)	143
43.0 <i>Maianthemum canadense</i> (Canada mayflower)	146
44.0 <i>Microstegium vimineum</i> (Nepalese browntop)	149
45.0 <i>Muhlenbergia cuspidata</i> (plains muhly)	152
46.0 <i>Muhlenbergia glomerata</i> (spiked muhly)	155
47.0 <i>Oligoneuron rigidum</i> (stiff goldenrod)	158
48.0 <i>Osmorhiza claytonii</i> (Clayton's sweetroot)	161
49.0 <i>Peltandra virginica</i> (arrow arum)	164
50.0 <i>Poa compressa</i> (Canada bluegrass)	167
51.0 <i>Poa pratensis</i> (Kentucky bluegrass)	170
52.0 <i>Polygonum cespitosum</i> (Oriental lady's thumb)	173
53.0 <i>Pteridium aquilinum</i> (western brackenfern)	176
54.0 <i>Rudbeckia hirta</i> (black-eyed Susan)	179
55.0 <i>Salvia lyrata</i> (lyreleaf sage)	182
56.0 <i>Schizachyrium scoparium</i> (little bluestem)	184
57.0 <i>Solidago canadensis</i> (Canada goldenrod)	187
58.0 <i>Solidago missouriensis</i> (Missouri goldenrod)	190
59.0 <i>Solidago nemoralis</i> (gray goldenrod)	193
60.0 <i>Sorghastrum nutans</i> (yellow prairie grass)	196
61.0 <i>Spartina pectinata</i> (prairie cordgrass)	199
62.0 <i>Sporobolus cryptandrus</i> (sand dropseed)	202
63.0 <i>Symphyotrichum ericoides</i> (white heath aster)	205
64.0 <i>Symphyotrichum laeve</i> (smooth blue aster)	208
65.0 <i>Symphyotrichum lanceolatum</i> (white panicle aster)	211
66.0 <i>Thalictrum dioicum</i> (early meadow-rue)	213
67.0 <i>Urtica dioica</i> (American stinging nettle)	216
68.0 <i>Verbascum thapsus</i> (common mullein)	219
69.0 <i>Veronicastrum virginicum</i> (Culver's root)	222
70.0 <i>Woodwardia virginica</i> (Virginia chainfern)	225
71.0 <i>Zizia aurea</i> (Golden alexanders)	228
A1. <i>Agoseris glauca</i> (pale agoseris)	231
A2. <i>Agrimonia rostellata</i> (beaked agrimony)	232
A3. <i>Allium cernuum</i> (nodding onion)	233
A4. <i>Allium stellatum</i> (autumn onion)	234
A5. <i>Allium tricoccum</i> (ramp)	235

A6. <i>Anemone quinquefolia</i> (wood anemone).....	236
A7. <i>Antennaria neglecta</i> (field pussytoes).....	237
A8. <i>Antennaria plantaginifolia</i> (woman's tobacco)	238
A9. <i>Arctium minus</i> (lesser burdock).....	239
A10. <i>Aristolochia serpentaria</i> (Virginia snakeroot)	240
A11. <i>Asplenium platyneuron</i> (ebony spleenwort)	241
A12. <i>Boehmeria cylindrica</i> (smallspike false nettle)	242
A13. <i>Calamagrostis stricta</i> (slimstem reedgrass)	243
A14. <i>Campanula rotundifolia</i> (bluebell bellflower)	244
A15. <i>Carex albicans</i> (whitening sedge).....	245
A16. <i>Carex albursina</i> (white bear sedge).....	246
A17. <i>Carex arctata</i> (drooping woodland sedge).....	247
A18. <i>Carex blanda</i> (eastern woodland sedge).....	248
A19. <i>Carex brunnescens</i> (brownish sedge)	249
A20. <i>Carex communis</i> (fibrousroot sedge)	250
A21. <i>Carex debilis</i> (white edge sedge).....	251
A22. <i>Carex disperma</i> (softleaf sedge).....	252
A23. <i>Carex gracillima</i> (graceful sedge)	253
A24. <i>Carex hirsutella</i> (fuzzy wuzzy sedge)	254
A25. <i>Carex laxiculmis</i> (spreading sedge)	255
A26. <i>Carex pedunculata</i> (longstalk sedge).....	256
A27. <i>Carex radiata</i> (eastern star sedge)	257
A28. <i>Carex rosea</i> (rosy sedge)	258
A29. <i>Carex swanii</i> (Swan's sedge).....	259
A30. <i>Carex tetanica</i> (rigid sedge).....	260
A31. <i>Carex virescens</i> (ribbed sedge).....	261
A32. <i>Cerastium arvense</i> (field chickweed)	262
A33. <i>Chenopodium album</i> (lambsquarters).....	263
A34. <i>Cinna latifolia</i> (drooping woodreed)	264
A35. <i>Circaea canadensis</i> (enchanter's nightshade)	265
A36. <i>Circaea lutetiana</i> (broadleaf enchanter's nightshade)	266
A37. <i>Clintonia borealis</i> (bluebead)	267
A38. <i>Cryptotaenia canadensis</i> (Canadian honewort)	268
A39. <i>Deparia acrostichoides</i> (silver false spleenwort).....	269
A40. <i>Desmodium canadense</i> (showy ticktrefoil)	270
A41. <i>Desmodium nudiflorum</i> (nakedflower ticktrefoil)	271
A42. <i>Desmodium perplexum</i> (perplexed ticktrefoil)	272
A43. <i>Dicentra cucullaria</i> (dutchman's breeches).....	273
A44. <i>Dichanthelium ovale</i> (eggleaf rosette grass)	274
A45. <i>Dryopteris cristata</i> (crested woodfern)	275
A46. <i>Elymus hystrix</i> (eastern bottlebrush grass).....	276

A47. <i>Epifagus virginiana</i> (beechdrops).....	277
A48. <i>Erechtites hieraciifolia</i> (American burnweed)	278
A49. <i>Euphorbia corollata</i> (flowering spurge).....	279
A50. <i>Galium concinnum</i> (shining bedstraw).....	280
A51. <i>Geum canadense</i> (white avens)	281
A52. <i>Geum virginianum</i> (cream avens)	282
A53. <i>Helianthus giganteus</i> (giant sunflower)	283
A54. <i>Helianthus grosseserratus</i> (sawtooth sunflower).....	284
A55. <i>Hexastylis virginica</i> (Virginia heartleaf)	285
A56. <i>Houstonia purpurea</i> (Venus' pride)	286
A57. <i>Hydrophyllum canadense</i> (bluntleaf waterleaf)	287
A58. <i>Hydrophyllum virginianum</i> (eastern waterleaf)	288
A59. <i>Lespedeza procumbens</i> (trailing lespedeza)	289
A60. <i>Lespedeza repens</i> (creeping lespedeza)	290
A61. <i>Lysimachia quadriflora</i> (fourflower yellow loosestrife).....	291
A62. <i>Lysimachia quadrifolia</i> (whorled yellow loosestrife).....	292
A63. <i>Melampyrum lineare</i> (narrowleaf cowwheat)	293
A64. <i>Milium effusum</i> (American milletgrass)	294
A65. <i>Mitella nuda</i> (naked miterwort).....	295
A66. <i>Muhlenbergia sobolifera</i> (rock muhly)	296
A67. <i>Murdannia keisak</i> (wartremoving herb).....	297
A68. <i>Oligoneuron riddellii</i> (Riddell's goldenrod).....	298
A69. <i>Onoclea sensibilis</i> (sensitive fern)	299
A70. <i>Oryzopsis asperifolia</i> (roughleaf ricegrass).....	300
A71. <i>Osmunda claytoniana</i> (interrupted fern)	301
A72. <i>Oxalis dillenii</i> (slender yellow woodsorrel).....	302
A73. <i>Pedimelum esculentum</i> (large Indian breadroot).....	303
A74. <i>Phegopteris connectilis</i> (long beechfern)	304
A75. <i>Phryma leptostachya</i> (American lopseed).....	305
A76. <i>Phytolacca americana</i> (American pokeweed)	306
A77. <i>Pilea pumila</i> (Canadian clearweed).....	307
A78. <i>Poa cuspidata</i> (early bluegrass).....	308
A79. <i>Polygonatum biflorum</i> (smooth Solomon's seal)	309
A80. <i>Polygonatum pubescens</i> (hairy Solomon's seal).....	310
A81. <i>Polygonum virginianum</i> (jumpseed)	311
A82. <i>Polypodium appalachianum</i> (Appalachian polypody).....	312
A83. <i>Prenanthes racemosa</i> (purple rattlesnakeroot)	313
A84. <i>Prosartes lanuginosa</i> (yellow fairybells).....	314
A85. <i>Pulsatilla patens</i> (eastern pasqueflower).....	315
A86. <i>Pycnanthemum virginianum</i> (Virginia mountainmint).....	316
A87. <i>Ranunculus hispidus</i> (bristly buttercup)	317

A88. <i>Ranunculus recurvatus</i> (blisterwort)	318
A89. <i>Sanguinaria canadensis</i> (bloodroot)	319
A90. <i>Sanicula canadensis</i> (Canadian blacksnakeroot)	320
A91. <i>Sanicula marilandica</i> (Maryland sanicle)	321
A92. <i>Sanicula odorata</i> (clustered blacksnakeroot)	322
A93. <i>Saururus cernuus</i> (lizard's tail)	323
A94. <i>Scutellaria elliptica</i> (hairy skullcap)	324
A95. <i>Sericocarpus tortifolius</i> (Dixie whitetop aster)	325
A96. <i>Silphium asteriscus</i> (starry rosinweed)	326
A97. <i>Silphium compositum</i> (kidneyleaf rosinweed)	327
A98. <i>Solidago bicolor</i> (white goldenrod)	328
A99. <i>Solidago caesia</i> (wreath goldenrod)	329
A100. <i>Solidago flexicaulis</i> (zigzag goldenrod)	330
A101. <i>Solidago odora</i> (anisescented goldenrod)	331
A102. <i>Streptopus lanceolatus</i> (twistedstalk)	332
A103. <i>Stylosanthes biflora</i> (sidebeak pencilflower)	333
A104. <i>Symphyotrichum ciliolatum</i> (Lindley's aster)	334
A105. <i>Symphyotrichum oolentangiense</i> (skyblue aster)	335
A106. <i>Symphyotrichum patens</i> (late purple aster)	336
A107. <i>Symphyotrichum sericeum</i> (western silver aster)	337
A108. <i>Symphyotrichum undulatum</i> (wavyleaf aster)	338
A109. <i>Thalictrum dasycarpum</i> (purple meadow-rue)	339
A110. <i>Thalictrum thalictroides</i> (rue anemone)	340
A111. <i>Tiarella cordifolia</i> (heartleaf foamflower)	341
A112. <i>Tragia urens</i> (wavyleaf noseburn)	342
A113. <i>Trientalis borealis</i> (starflower)	343
A114. <i>Trillium erectum</i> (red trillium)	344
A115. <i>Trillium grandiflorum</i> (white trillium)	345
A116. <i>Trillium sessile</i> (toadshade)	346
A117. <i>Uvularia grandiflora</i> (largeflower bellwort)	347
A118. <i>Uvularia sessilifolia</i> (sessileleaf bellwort)	348
A119. <i>Veronica hederifolia</i> (ivyleaf speedwell)	349
A120. <i>Viola canadensis</i> (Canadian white violet)	350
A121. <i>Viola hastata</i> (halberdleaf yellow violet)	351
A122. <i>Viola pubescens</i> (downy yellow violet)	352
A123. <i>Viola rotundifolia</i> (roundleaf yellow violet)	353
A124. <i>Viola sororia</i> (common blue violet)	354
A125. <i>Woodwardia areolata</i> (netted chainfern)	355
A126. <i>Zigadenus elegans</i> (mountain deathcamas)	356
A127. <i>Zizia aptera</i> (meadow zizia)	357

EXECUTIVE SUMMARY

Anthropogenic emissions of reactive nitrogen (N) and sulfur (S) from combustion and the use of N fertilizers have increased the deposition of these chemicals from the atmosphere to North American ecosystems. Atmospheric deposition is a major contributor to the eutrophication, nutrient nitrogen enhancement, and acidification of terrestrial and aquatic ecosystems. In most of the United States, the rate of deposition (kg/ha/yr) has been several times greater than pre-industrial levels under which plant and animal species evolved. Fortunately, largely due to emissions reductions since the 1990s, levels of N and S deposition have been steadily decreasing in many parts of the United States, which is a success story for air quality policy. However, despite these decreases, deposition in many areas of the United States remains above critical loads (thresholds of harm) for many sensitive species and ecosystems.

Herbaceous plants (herbs) are vascular plants that do not form woody tissue and are typified by the diversity of grasses and sedges, wildflowers, and ferns found in terrestrial and aquatic ecosystems. Herbaceous plants are dominant in grasslands and wetlands and nearly ubiquitous in the understory of forests. They typically comprise most of the plant biodiversity in these ecosystems even though they may be only a small fraction of the total biomass. Herbaceous plants are affected by acidification and/or nutrient enrichment of soils, which can be caused by N and S deposition. Soil acidification (mostly from S deposition but also from N deposition) can mobilize aluminum in forms that are toxic to plant roots in the soil, decrease the availability of phosphorus, deplete the ecosystem of important cations like calcium, magnesium, and potassium needed for plant growth, and damage plant roots. Nutrient N enrichment can induce vigorous growth in some, often weedy, species that can in turn reduce light levels to the soil and cause competitive exclusion of many, often native, species. Both changes in soil chemistry and increased competition can reduce the biodiversity of the herbaceous plant community.

This report assesses the risks from N and S deposition on 198 herbaceous plant species of the continental United States. Information for each species has been compiled from several peer-reviewed Federal and non-Federal sources. Seventy-one species are featured in detail. For each featured species, we provide information on seven topics: the (1) distribution and conservation status, (2) species characteristics and habitat, (3) wildlife and livestock uses, (4) other ecosystem services, (5) traditional ecological knowledge, (6) responses to N and S deposition, climate, soil pH, including interactions, (7) critical loads (CLs; deposition rates below which harm does not occur), confidence in the CLs, and geographic areas where CLs exceeded modeled deposition estimates for 2019–2021. The remaining 127 species did not have easily accessible ecological and ecosystem services information. For each of these species, we provide maps for topics (1) and (7) in the appendix. This report is part of a three-volume series covering the N and S deposition responses of trees (vol. 1), herbs (this vol. 2), and lichens (vol. 3).

Many herbaceous species are vulnerable to N and S deposition, and therefore many of the ecological processes and ecosystem services which they support can be affected by current and future deposition. Of the 198 species assessed, we provided N critical loads for 179 species, all of which have been experiencing exceedances over some portion of their range; and we provided S critical loads for 167 species of which 147 have been experiencing exceedances. Critical loads for some species varied by geography, while critical loads for others were relatively constant across their distribution ranges. Confidence in these critical loads varied but were generally moderate to high for N and low to moderate for S.

Overall, we find that N and S critical loads for herbs are still exceeded as of 2019–2021 in many places in the United States (**fig. ES1**), and in these places, ecological functions and ecosystem services provided by herbaceous communities may be at risk.

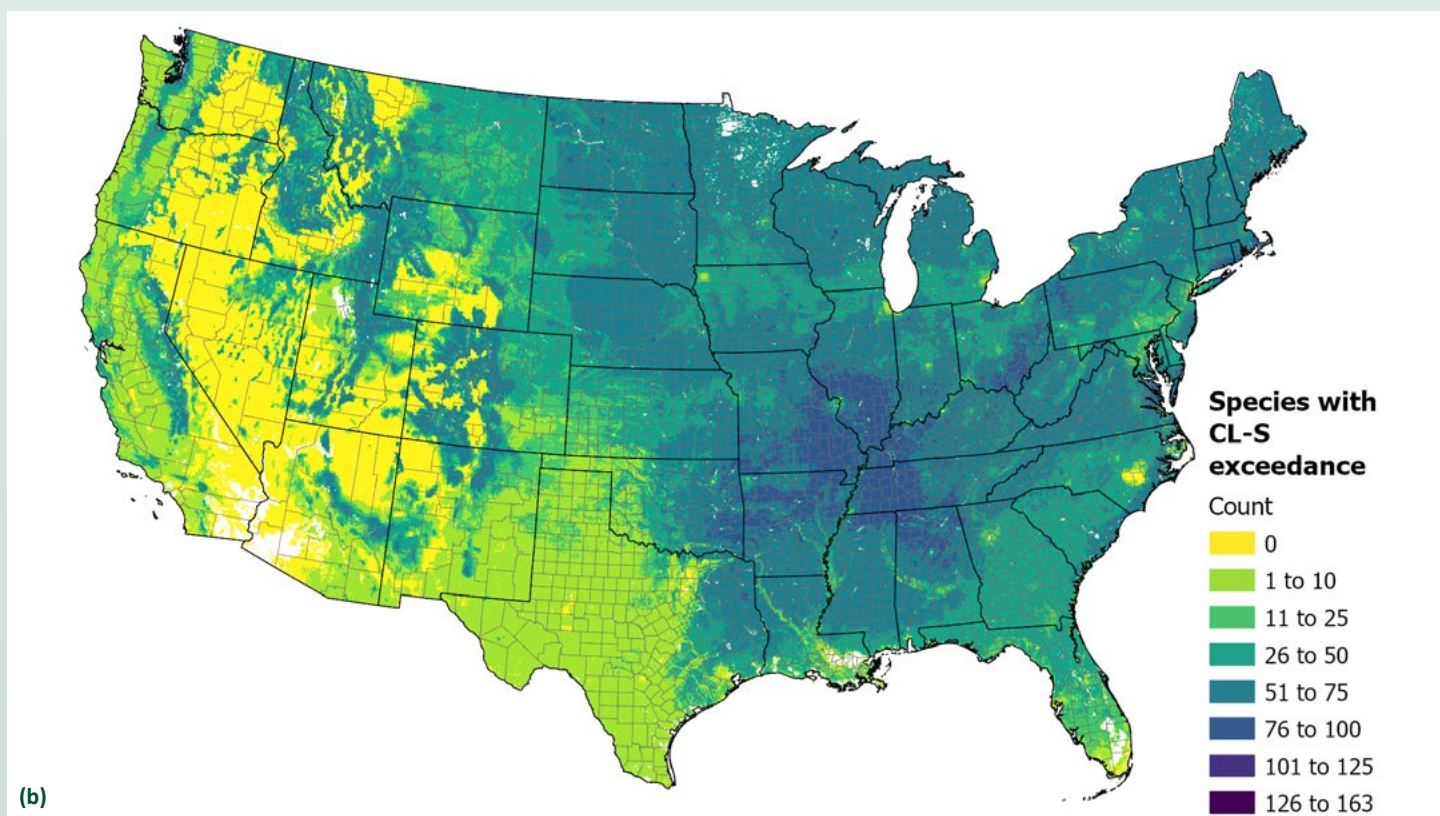
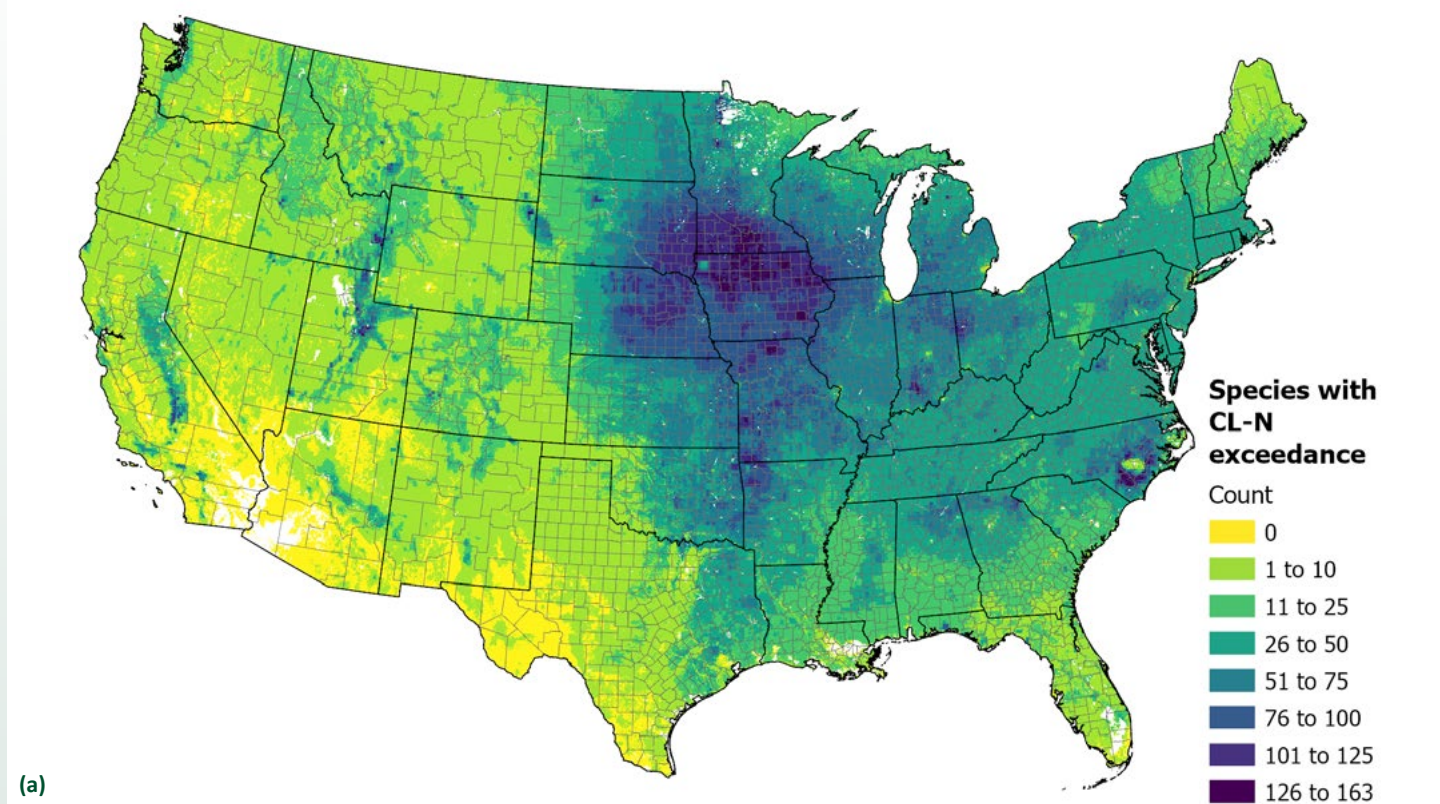


Figure ES1. Number of herbaceous species where TDEP modeled deposition exceeds critical loads for (a) N and (b) S. A total of 198 herbaceous species were evaluated. Species environmental hulls, i.e., areas with suitable environmental conditions, were used to map species potential distributions. Low critical loads for sulfur and high species diversity in western mountain regions contributed to a high number of exceedances of sulfur deposition there.

CHAPTER 1: INTRODUCTION

1.1 Overview and Background

Herbaceous plants include numerous annual, biennial, and perennial species that do not accumulate woody tissue. They have a variety of growth forms, including graminoids (grasses and grass-like plants), forbs (broadleaf flowering plants), and ferns; all from diverse evolutionary lineages. Lacking woody tissue, many are short-lived and short in stature compared to trees. Perennial herbaceous species, however, can live for decades and even centuries. Some examples include tallgrass prairie grasses such as big bluestem (Featured Species section 3.0), rattlesnake master (25.0), and little bluestem (56.0) as well as forest herbs such as common lady fern (9.0), Canada mayflower (43.0), and stiff goldenrod (47.0).

Herbaceous species are most conspicuous in grasslands and wetlands. However, they are also common in forests, comprising most of the plant biodiversity in forests, despite making up less than 1% of forest biomass (Gilliam 2007). Within the forest understory, herbaceous communities represent an essential component of forest ecosystems despite their small physical stature (Gilliam 2014) (**fig. 1**). These include forage, nesting sites, and habitat for a broad range of animal and insect species. Because of these diverse roles, many human uses, and their intrinsic value as part of nature's biodiversity, herbaceous species are an important taxonomic group to conserve and sustain.

Numerous anthropogenic and natural stressors impact herbaceous species across the United States including extreme weather, disturbances such as wildfires, flooding, landslides, land use changes, invasive species, and atmospheric deposition. For example, most prairie grassland communities in the United States that have not been converted to croplands have been shaped by cattle and sheep grazing (Samson and Knopf 1994). Atmospheric deposition of nitrogen is a primary stressor to herbaceous species in grasslands and forests because of its wide-ranging and multi-faceted impacts (Bobbink et al. 2010, Pardo et al. 2011a, Pardo et al. 2011b). Nitrogen deposition can lead to increased plant growth rates, especially among fast-growing native and invasive species, or decreased growth rates depending on the amount of deposition and sensitivity of the species. Increasing N deposition can lead to a variety of interacting effects that ultimately reduce herb community diversity (Tilman 1997, Gilliam 2006, Hautier et al. 2009, Simkin et al. 2016). Nitrogen deposition can also have a variety of other effects



Figure 1. Herbaceous plants contribute to the biological diversity and ecological integrity of natural ecosystems.

on terrestrial ecosystems, including soil acidification (compounded by sulfur deposition), soil nitrate (NO_3^-) saturation, shifts in belowground mycorrhizal communities, and increases in nitrate leaching that impair downstream water quality. Adverse ecosystem effects from N and S deposition have led to changes in air quality policies worldwide.

Elevated N and S deposition in the Eastern United States, parts of the Western United States (Fenn et al. 2004) and many other regions worldwide is a result of high atmospheric N and S emissions from combustion and over-application of N-rich fertilizers (which can volatilize to the atmosphere) (Galloway et al. 2004, Burns 2011). Emissions of N- and S-containing air pollutants can travel long distances before being deposited to the environment where they can cause the multitude of effects described above.

Since the 1990s, steady declines in emissions of oxidized N (NO_x) and S (SO_x) to the atmosphere and associated declines in oxidized N and S deposition across much of the eastern United States have occurred (**fig. 2**) (Burns 2011, Lloret and Valiela 2016, EPA 2018, Gilliam et al. 2019). Although these declines are clearly a major success story, total N (oxidized and reduced) and S deposition remain relatively high across much of the eastern United States compared to preindustrial levels. In many areas, N and S deposition remain above levels that affect sensitive herbaceous species and communities (Pardo et al. 2011a, Pardo et al. 2011b, Clark et al. 2013,

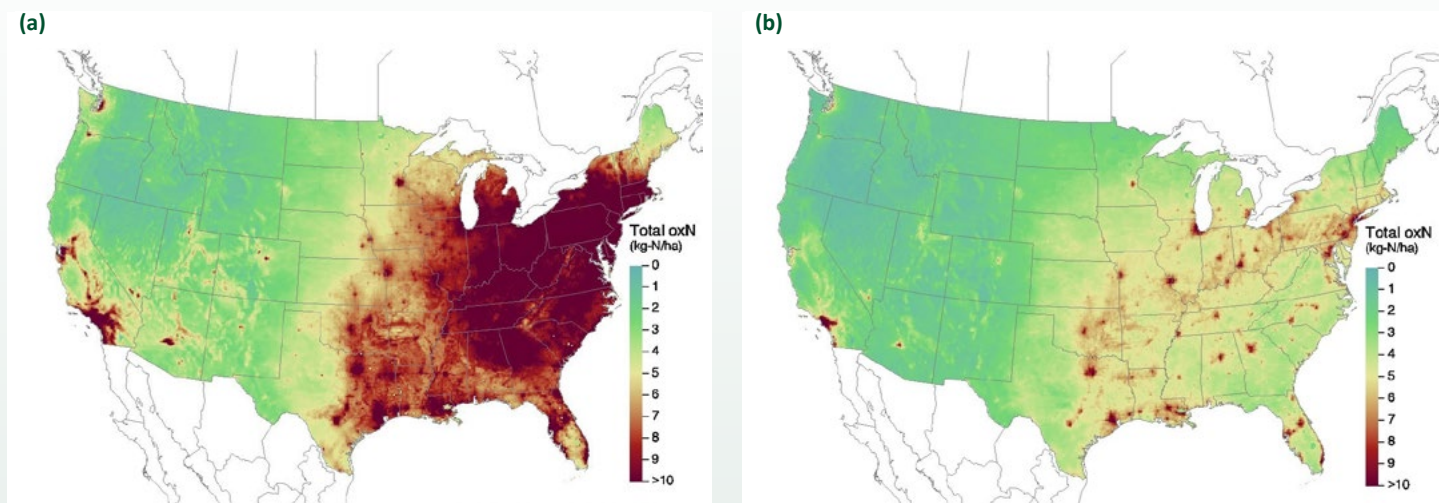


Figure 2. Wet inorganic nitrogen deposition from (a) 2000 and (b) 2019 (reprinted with permission from Gilliam et al. 2024).

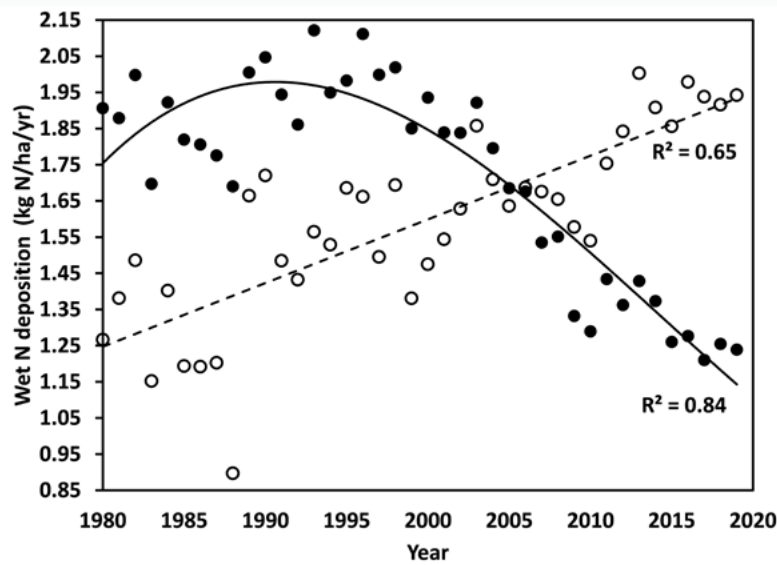
Simkin et al. 2016, Clark et al. 2019). In addition, there has been an abrupt shift in the dominant forms of N in atmospheric deposition. Prior to the 1990s, N deposition was dominated by oxidized forms (nitrates and nitric acid, represented chemically as NO_3^- and HNO_3) resulting from atmospheric transformations of nitrogen oxides (NO and NO_2) emitted during combustion. In recent decades, improved pollution controls and energy efficiencies for power generation, industry, transportation, and buildings, have been accompanied by a gradual decrease in the deposition of oxidized forms of N. At the same time, reduced forms of N (ammonia gas and ammonium ions, or NH_x), primarily from agricultural sources, have been increasing as a proportion of total N deposition (**fig. 3**).

This change toward reduced-N dominance is concerning because reduced N may potentially have greater impacts to ecosystems per kg N than oxidized N (Carter et al. 2017). Reduced N is “higher” in the N-cascade, or the sequence of transformations that N-atoms undergo during movement through the environment (**fig. 4**) (Galloway et al., 2003). For example, soil acidification results from NH_4^+ nitrification which produces two protons (H^+) per molecule of NH_4^+ , and eutrophication results from the uptake of NH_4^+ or nitrified NH_4^+ as NO_3^- . On the other hand, oxidized forms of N affect terrestrial biodiversity mainly through eutrophication, although some acidification also occurs through the leaching of NO_3^- (which is much more mobile in the soil than NH_4^+) with buffering cations. Additional complexities emerge from NO_x tending to travel further downwind than NH_x . These potential differences in effect are strongly mediated by soil processes and soil pH which modify the form of N once it is deposited (Stevens et al. 2011). Whether oxidized or reduced N has a larger or smaller effect on herbaceous species is still an active area

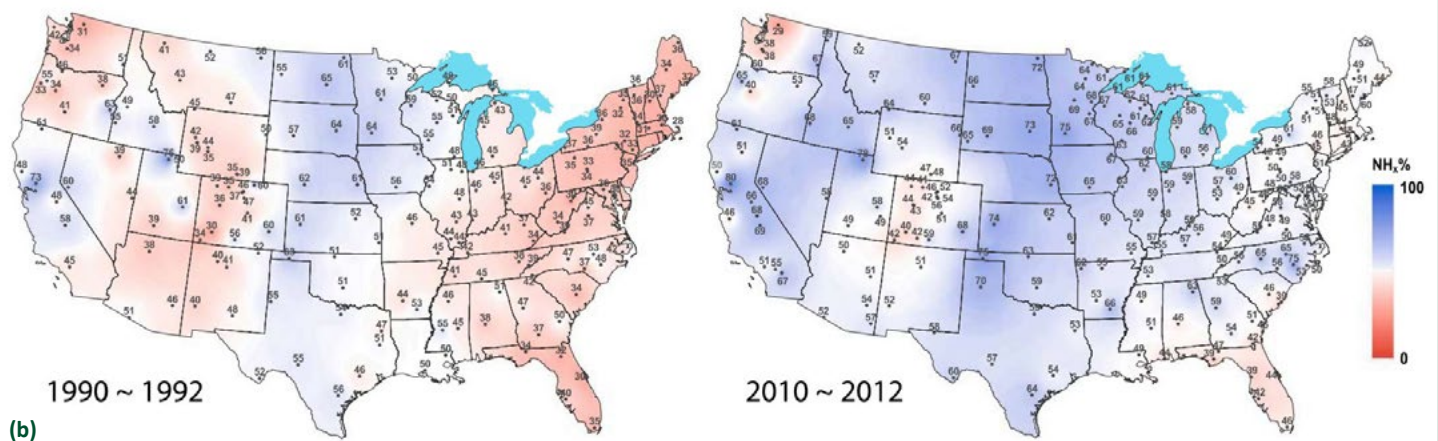
of research and remains unresolved. Furthermore, declines in N deposition are not uniform throughout the United States. Nitrogen deposition has declined less rapidly in the West and Midwest and may even be increasing in some areas (Houlton et al. 2012).

In this report, we summarize and expand upon the potential impacts from N and S deposition on the herbaceous species assessed in a recent national study (Clark et al. 2019). We show how the probability of occurrence of each species responds to N deposition and S deposition, and we assess the risk for a decline in probability of occurrence based on modeled estimates of current N and S deposition. In our study, the probability of occurrence is a simple measure of the likelihood of finding a species across the landscape.

Of the 198 species reported in Clark et al. (2019), we feature 71 species for which information about physical characteristics, distribution, ecology, and ecosystem services was readily available in the Forest Service Fire Effects Information System (FEIS). We characterized seven topics for each of these species: the (1) distribution and conservation status, (2) species characteristics and habitat, (3) wildlife and livestock uses, (4) other ecosystem services, (5) traditional ecological knowledge, (6) responses to N and S deposition, temperature, precipitation, soil pH, and interactions, and (7) N and S critical loads, the associated confidence in those estimates, and geographic areas where critical loads were exceeded as of 2019–2021 (see **table 1**). This report is not intended to be a comprehensive assessment of all known information about these plants, but rather a synopsis of several of the more recent and comprehensive individual studies and databases.



(a)



(b)

Figure 3. (a) Wet deposition of NO_3^- -N (closed symbols) and NH_4^+ -N (open symbols) averaged throughout continental United States. Reprinted with permission from Gilliam et al. 2024. (b) Percentage of wet N deposition as oxidized nitrogen (NO_3^- , red) versus reduced nitrogen (NH_4^+ , blue) in 1990–1992 (left) versus 2010–2012 (right). Reprinted with permission from Li et al. 2016.

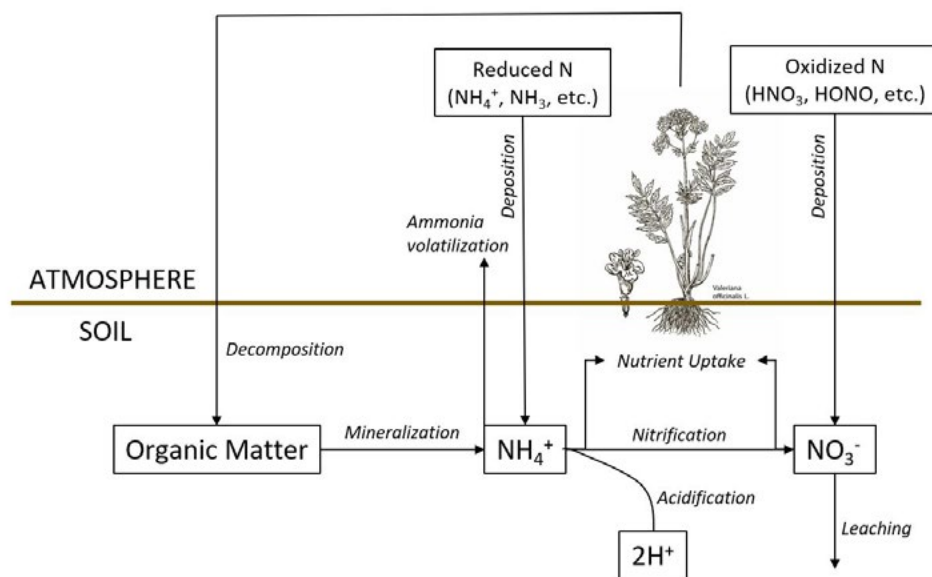


Figure 4. Flowchart of a portion of the N-cascade, the sequence of nitrogen transformations that nitrogen atoms undergo during movement through the environment.

The remaining 127 species which did not have entries in the FEIS are covered in the Appendix. For each of the species in the Appendix, we provide maps for topics (1) and (7).

1.2 Methods and Data Sources

Information about the seven topics described above comes from peer-reviewed sources summarized in Table 1.

Table 1. Summary of source information for this report.

Topic	Information Provided	Source
(1) Distribution and conservation status	Description and map of the known range of species from the USDA PLANTS database, site locations used to determine critical loads, and global and State conservation rankings.	USDA NRCS PLANTS database https://plants.usda.gov/home Clark et al. (2019), Simkin et al. (2016), and Russell et al. (2022) NatureServe https://explorer.natureserve.org/
(2) Species characteristics and habitat	Description of the physical characteristics of the species, habitat requirements, life history, and response to disturbances. Photograph of the species.	Fire Effects Information System (FEIS, http://www.feis-crs.org/feis/) Forestry images repository of the University of Georgia Center for Invasive Species and Ecosystem Health (http://www.forestryimages.org/index.cfm).
(3) Wildlife and livestock uses	Description of the uses of the species by wildlife and livestock.	Fire Effects Information System (FEIS, http://www.feis-crs.org/feis/)
(4) Ecosystem services	Description of additional ecosystem services provided by the species.	Fire Effects Information System (FEIS, http://www.feis-crs.org/feis/)
(5) Traditional ecological knowledge (TEK)	Generalized summary of traditional uses of the species by Indigenous cultures of North America.	North American Ethnobotany database (http://naeb.brit.org/)
(6) Responses to nitrogen and sulfur	Description and figures of the effect of various environmental drivers on the probability of occurrence for the species. Environmental drivers assessed were N deposition, S deposition, soil pH, temperature, precipitation, and specific interactions.	From Clark et al. (2019) supplementary figure 1. https://static-content.springer.com/esm/art%3A10.1038%2Fs41477-019-0442-8/MediaObjects/41477_2019_442_MOESM4_ESM.pdf
(7) Critical loads and exceedances	Description and maps of the N and S critical loads from Clark et al. (2019) applied to the known species' range. An assessment of confidence in the N and S critical loads. Description and maps of N and S critical load exceedances using modeled total deposition estimates for 2019–2021.	Derived from Clark et al. (2019), Simkin et al. (2016), and Russell et al. (2022) Derived from Clark et al. (2019) Derived from Clark et al. (2019) and TDEP (https://www.epa.gov/cmaq/estimating-atmospheric-deposition-cmaq)

Distribution and conservation status

We show the species distribution across the continental United States at a county and point scale. County data comes from the USDA PLANTS database and indicates historic records of known occurrences of the species at the county level. Point location data are from Clark et al. (2019), and Russell et al. (2022), and represent geographically explicit observations from scientific studies. The data from Clark et al. (2019) (derived from Simkin et al. (2016)) were used to develop the original species models and critical loads. The data from Russell et al. (2022) comes from National Park Service Vegetation Mapping Inventory and indicate areas where the models and critical loads may apply (see Critical Loads and Exceedances section below). Species' global and State conservation rankings were queried from NatureServe Explorer at <https://explorer.natureserve.org/>.

Species characteristics and habitat, wildlife and livestock uses, and ecosystem services

For these sections we summarize the extensive information available in the USDA Forest Service Fire Effects Information System (FEIS) (USDAFS 2016). Although the FEIS was designed to help forest managers manage the effects of wildland fire, it is a broader resource, with detailed information on species botanical characteristics, habitat, geographic distribution, soil preferences, associations with other plant species, importance to wildlife and livestock, derived commercial products, and land management and agricultural uses. Each FEIS species entry is fully referenced to the source literature, resulting in a database of more than 1,200 species and 80,000 references. Despite the breadth of the FEIS, most herbaceous plant species in North America do not have a FEIS entry. Most trees are covered, but most herbs are not. Thus, to maintain consistency of data sources across species in this guide, we constrained the featured species to 71 out of 198 species in Clark et al. (2019). To retrieve information from the FEIS database, see <http://www.feis-crs.org/feis/>.

Traditional ecological knowledge

From a cultural perspective, traditional uses of plants are an important component of traditional ecological knowledge (TEK). TEK is the vast body of knowledge associated with populations connected to their ancestral homelands and maintaining lifestyles and cultural characteristics shaped by their relationships to the plants, animals, places, and other natural elements of their environment ([https://www.fws.gov/media/traditional-](https://www.fws.gov/media/traditional-ecological-knowledge-fact-sheet)

[ecological-knowledge-fact-sheet](https://www.fws.gov/media/traditional-ecological-knowledge-fact-sheet)). TEK evolves continuously as it incorporates knowledge from the past and present.

From a land management perspective, TEK is forward looking, a key principle being to account for the needs of the next seven generations by safeguarding resources and maintaining the highest standards of stewardship. TEK has been central to land management paradigms under which Indigenous people have successfully interacted with their environment in North America for thousands of years. Federal agencies recognize the value of TEK and incorporate it into land management practices. The USDA Forest Service recognizes the importance of Indigenous consultation and collaboration when it comes to the preservation, utilization, and publication of TEK and is committed to working with Tribes to appropriately disseminate this information.

Traditional uses of plants by Indigenous peoples of North America described in this guide focus on herbs as medicine, food, and textiles. TEK is place-based and specific to individual cultures and populations; therefore, knowledge of the specific techniques for preparing herbs for medicinal and culinary uses are critical to their efficacy and safety. Here, to respect the proprietary nature of TEK, we provide only generalized uses, abstracted from more detailed entries in the North American Ethnobotany database sponsored by the University of Michigan-Dearborn, <http://naeb.brit.org/>.

Responses to nitrogen and sulfur

Modeled species responses to N and S deposition and other environmental variables are from supplemental fig. 1 in Clark et al. (2019). No modifications were made to that analysis. Those authors assessed the responses of 348 species to N and S deposition from 15,223 plots across the continental United States. The probability of occurrence of each species was analyzed in relation to various combinations of five environmental variables: N deposition, S deposition, temperature, precipitation, and soil pH. Here, we cover the 198 species with the most robust responses to N and S deposition (Clark et al. 2019). For each of these 198 species, we present only the response models for the significant variables and interactions. For example, the effect of N deposition on broomsedge bluestem (*Andropogon virginicus*) depends on soil pH (**fig. 5a**). At pH > 5.5, the probability of occurrence increases with N deposition up to roughly 12 kg N/ha/yr and then decreases at higher N deposition levels. At lower pH, N deposition has less influence on the probability of occurrence and probability of occurrence is the highest

at lower N deposition levels (e.g., above 8-10 kg N/ha/yr). Like N deposition effects, S deposition effects on broomsedge bluestem also depends on the soil pH (**fig. 5b**). At higher pH (≥ 5.1) the probability of occurrence decreases with increasing S deposition, but under very acidic conditions (≤ 4.7) S deposition has little effect. The probability of occurrence of broomsedge bluestem is also

affected independently by precipitation and temperature (**figs. 5c and 5d**, respectively).

To assess confidence in the species N and S response models, and thus by extension the N and S critical loads (see next section), we established a simple scoring system based on the information in Clark et al. (2019).

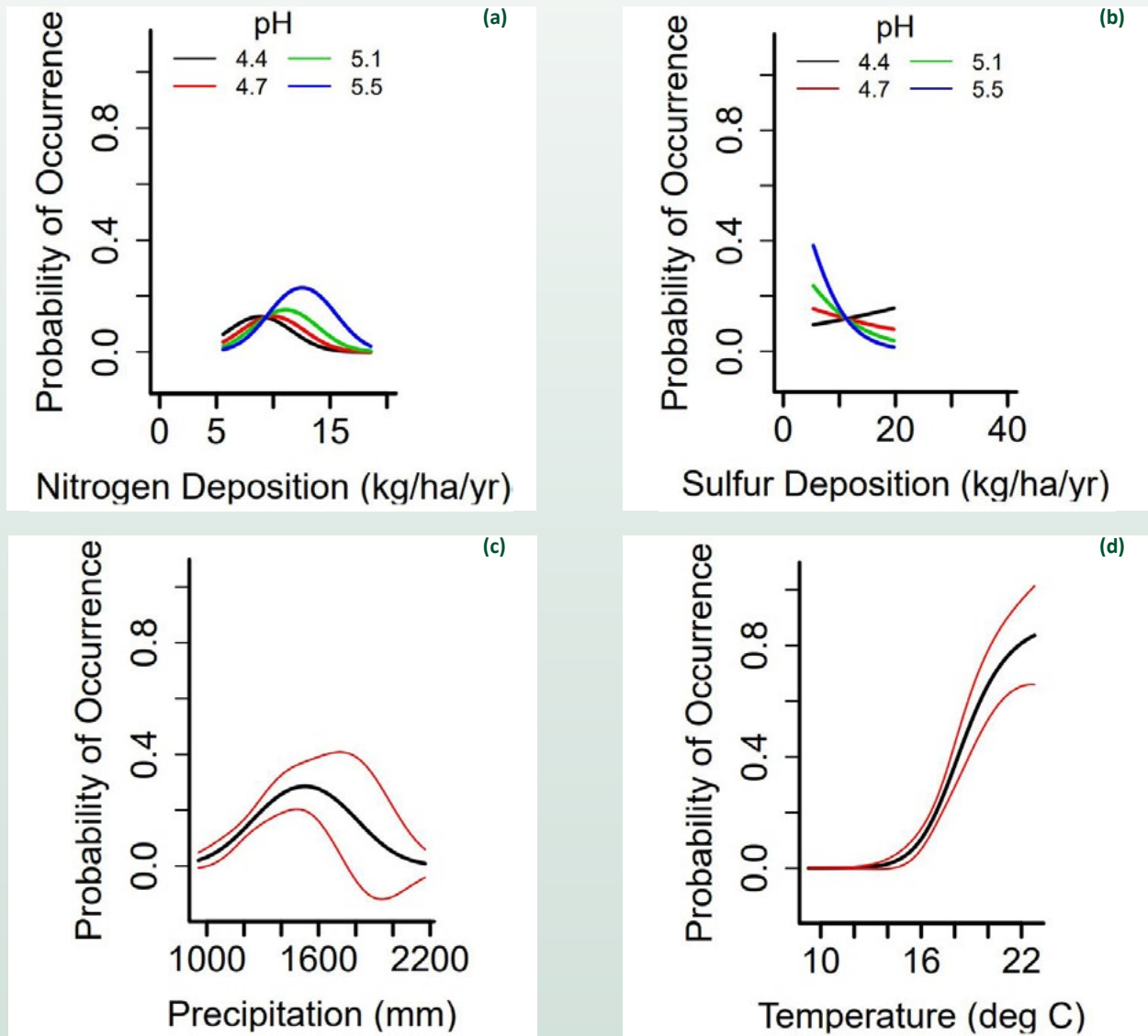


Figure 5. Examples of response curves for broomsedge bluestem (*Andropogon virginicus*). These are provided in the section “Responses to Nitrogen and Sulfur” for featured species and include for this species: (a) the interactive effect of soil pH on the probability of occurrence of broomsedge bluestem with increasing N deposition; (b) the interactive effect of soil pH on the probability of occurrence of broomsedge bluestem with increasing S deposition; (c) the effect of precipitation on the probability of occurrence of broomsedge bluestem; (d) the effect of temperature on the probability of occurrence of broomsedge bluestem. For interaction plots, quartiles are shown for the interaction (e.g., pH in a and b).

The scoring system utilizes four statistics: the coefficient of determination of the statistical model, the area under the curve, the variance inflation factor for N or S, and the bivariate correlation between N and S (**Table 2**). Each of these statistics gives slightly different information on the skill (ability) of the model in Clark et al. (2019) to estimate the critical load for that species. Here are the descriptions and confidence cut-offs:

Coefficient of Determination (R^2). The R^2 measures the fraction of total variation explained in the statistical model and varies from 0 to 1.0 (0% to 100% of the variation). If more variation is explained, we are more confident in the results. Ecological studies are inherently variable due to the large number of unmeasured factors that affect plant species occurrences; thus, we assumed that high confidence was associated with $R^2 > 0.25$, low with $R^2 < 0.1$, and moderate confidence was in between. There are no well-established rules for R^2 in the ecological literature, thus we derived reasonable cutoffs based on our expert knowledge.

Area Under the Curve (AUC). The AUC is similar in concept to R^2 but specific to binary responses such as the presence or absence of the species. An AUC of 0.5 means that the model is no better at predicting a presence or absence than random chance and thus is a poor score, while an AUC of 1.0 indicates perfect skill in prediction. We assumed that high confidence was associated with AUC > 0.8 , low confidence was associated with an AUC < 0.7 , and moderate confidence was in between. These cutoffs are commonly used in statistical studies. AUC is more statistically robust for the analysis in Clark et al. (2019), but because more people are familiar with R^2 we provide both for context.

Variance Inflation Factor (VIF-S, VIF-N). The VIF assesses how independent a dependent variable is relative to other variables, with larger numbers denoting less independence (VIFs range from 1 to infinity). The less

independent a variable is, the less confident we are in the statistical relationships of that variable. We assessed VIFs as described in Volume 1 of this General Technical Report (GTR) series (Clark et al. 2021), referencing (Horn et al. (2018). Statistical studies suggest that a VIF > 10 is very low confidence (O’Brien 2010). To be conservative, and consistent with Volume 1 and Horn et al. (2018), we assumed that low confidence was associated with a VIF > 5 , high confidence was associated with a VIF < 3 , and moderate confidence was in between.

Bivariate Correlation (N-S Correlation, r). The bivariate correlation is similar to the VIF, but rather than being multivariate (e.g., assessing how N is related to many other variables simultaneously) the bivariate correlation focuses on a particular relationship of concern — in this case, whether N and S are independent of one another in the model. Like VIFs, lower numbers for r denote higher confidence. We assumed that high confidence was associated with $r < 0.4$, low confidence was associated with $r > 0.7$, and moderate confidence was in between. As with the other measures, there are no established rules for r , but these cutoffs are commonly used in statistical studies.

For each of the featured species in Chapter 2, we present the individual confidence scores, and then aggregate those into an overall confidence. In cases with a consistent rating, that rating is used. In cases where there are adjacent ratings (e.g., moderate for R^2 , high for AUC and VIF), we generally use a range (e.g., moderate-to-high). In cases where ratings are not adjacent (e.g., low for R^2 , high for AUC and VIF), we generally use the intermediate designation (e.g., moderate). In some cases (e.g., with one factor that was very poor) the authors judged how to weigh the confidence. Note that in this volume the VIFs were rerun using a general model common across species as in Horn et al. (2018). The original VIFs in Clark et al. (2019) were calculated for the best model for each species, which may have included interactions and could inflate the VIFs of the main effects.

Table 2. Confidence scoring system for S and N deposition response models.

Metric	Low Confidence	Moderate Confidence	High Confidence
R^2	< 0.1	$0.1 \leq x < 0.25$	≥ 0.25
AUC	< 0.7	$0.7 \leq x < 0.8$	≥ 0.8
VIF-N or VIF-S	≥ 5	$3 \leq x < 5$	< 3
N-S correlation	≥ 0.7	$0.4 \leq x < 0.7$	< 0.4

Critical loads and exceedances

A critical load (CL) is the N or S deposition at the point where the modeled probability of occurrence begins to decrease, accounting for temperature, precipitation, and soil pH (e.g., the critical load could be lower under more acidic soil conditions). Critical loads are estimated from the responses to N and S deposition described above. The response models to N and S deposition for the 198 species in this manuscript are published in Clark et al. (2019). The response models showed either an increasing, decreasing, or threshold response to N deposition, and either an increasing or decreasing relationship to S deposition. The CL for an increasing relationship is set at the highest level of deposition experienced by the species in the model and an exceedance represents deposition levels outside of model parameters that may or may not cause harm to the species. The CL for a decreasing relationship is set at the lowest level of deposition experienced by the species in the model and an exceedance represents a decline in probability of occurrence with increasing N. A threshold response indicates that the probability of occurrence initially increases at lower levels of deposition before reaching a peak and decreasing at higher levels of deposition. The CL for a threshold relationship is set at the peak probability of occurrence and an exceedance represents a decline in probability of occurrence with increasing N.

We prepared maps of species' CLs for the known point occurrences from the N and S response models. National scale datasets of N and S deposition, temperature, precipitation, and soil pH were used to map the spatial variation in CLs. If a species is found in a particular location, it is likely that it could also be found nearby, or even a county or state away if the environmental conditions are similar. Therefore, we expanded the CL map to the species' 'environmental hull', i.e., the geographic area inclusive of the ranges of temperature, precipitation, soil pH, S deposition and N deposition observed at the known point occurrences. The method for calculating the 'environmental hull', also known as a 'convex hull', is illustrated in **fig. 6**. Areas that do not have known locations, but that have similar environmental conditions (e.g., yellow star, **fig. 6**), are included in the hull. Areas that are quite different (e.g., red star, **fig. 6**), from the underlying dataset are excluded from the hull. Critical loads and exceedances are considered reliable inside the environmental hull. Distances to the environmental hull are estimated with Mahalanobis distances, which is a common approach where distance is based on units of standard deviations that allows for estimation of an

overall distance from axes that are in different units (e.g., temperature and precipitation) Note: known counties from the USDA PLANTS database were not used to calculate the environmental hull because precise location data are needed to extract corresponding environmental data. Further details are available in the National Critical Loads Database (v.3.21, <https://nadp.slh.wisc.edu/clad-national-critical-load-database/>).

Note that for many species there are two distinct CLs for S deposition; one often being <2 kg-S/ha/yr and one >10 kg-S/ha/yr. This is caused by a change in the direction of the response of the probability of occurrence with a secondary environmental variable. The example in **Fig. 7** for *Actaea rubra* shows that in areas with higher N deposition there is a decreasing relationship with S (dark blue), and thus the CL is set to the lowest deposition experienced by the species. In areas with lower levels of N deposition there is an increasing relationship with S (light blue) and the critical load is set at the highest level of deposition experienced by the species. Although the shift of critical load appears stark in the maps, the rate of decline for decreasing responses becomes more gradual as the secondary threshold is approached, so even if the critical load is exceeded, the expected impact on the probability of occurrence is low before it shifts to an increasing relationship. This is discussed in Clark et al. (2019) as a "see-saw" species and occurs because S was modeled only as a linear main effect and as a simple interaction with pH ($S \cdot \text{pH}$) and/or N ($S \cdot \text{N}$).

To map CL exceedance (i.e., the risk of a decrease in the probability of occurrence of a species), the CL spatial data layer was subtracted from the modeled pollutant deposition surface across each species' range. A three-year average of the National Atmospheric Deposition Program's Total Deposition Model (TDep) from 2019–2021 was used to estimate total N or total S deposition (NADP 2023 <https://nadp.slh.wisc.edu/committees/tdep/>). TDep fuses measurement and modeling to estimate total N and total S, integrating deposition measurements with output from the Community Multi-scale Air Quality (CMAQ) chemical transport model (Schwede and Lear 2014). Nitrogen deposition measurements include NH_4^+ (wet), NO_3^- (wet/dry) and HNO_3 (dry), and sulfur deposition measurements include SO_4^{2-} (wet) and SO_2 (dry). Exceedances are categorized in seven bins. Negative values represent areas below the critical load (and thus not currently at risk of harm). Positive values indicate the amount of deposition that needs to be removed to eliminate the risk of harm to a species.

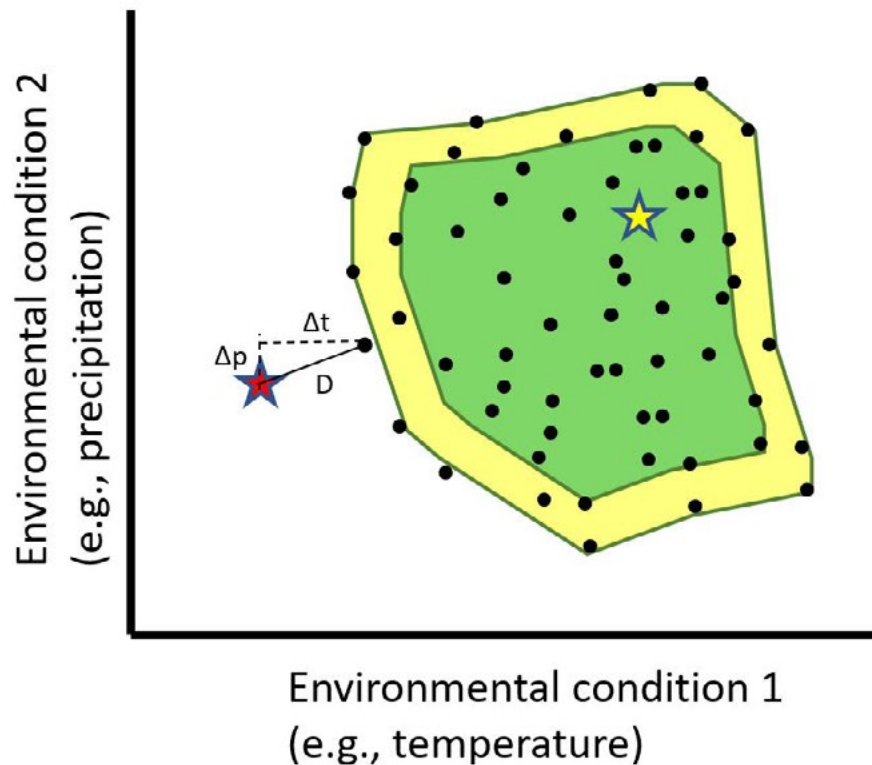
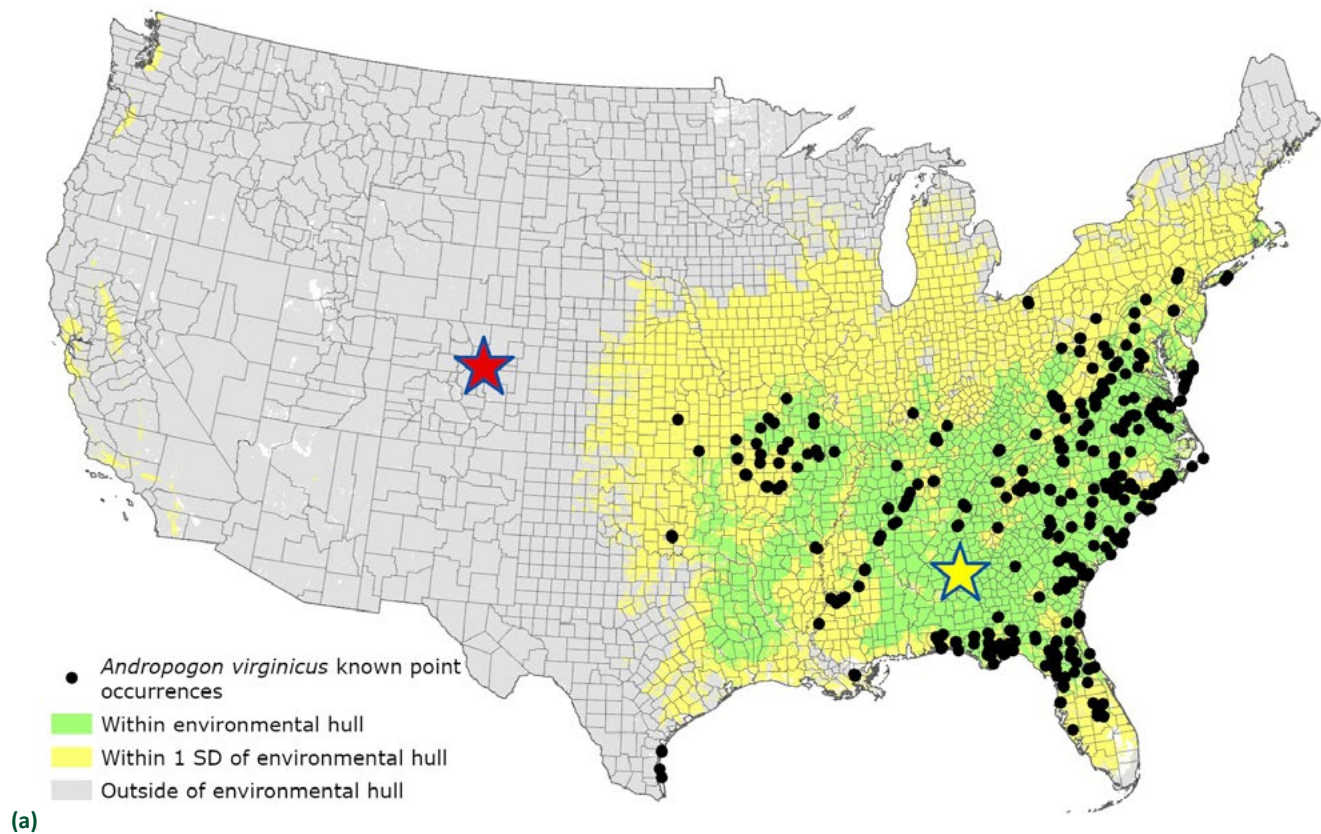


Figure 6. (a) The environmental hull for broomsedge bluestem (*Andropogon virginicus*). The environmental conditions at the known point occurrences are used to estimate the environmental hull. The hull defines the environmental space sampled. Then we may compare other areas (stars) that were not sampled with the environmental hull. For some areas, the conditions will be similar (e.g., yellow star, inside the environmental hull, Mahalanobis distance (D) < 0). (b) For others it may be quite different (red star, outside the environmental hull, $D > 0$, example for 2 dimensions). For areas outside the environmental hull, we may then decompose the minimum distance to the hull surface to determine which variable(s) are responsible for $D > 0$ (in the example, temperature). The yellow areas (a) and band (b) represent areas that are within one standard deviation (SD) of the environmental hull. These are areas that are likely similar to, though not inside, the environmental hull.

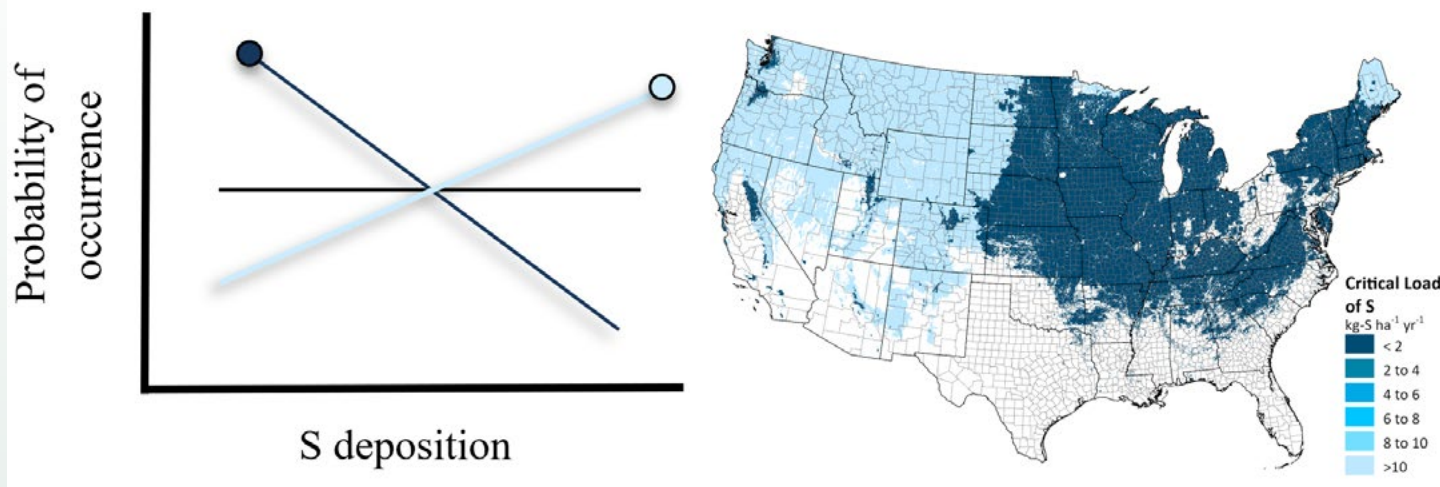


Figure 7. Illustration of how interactions could lead to large swings in the estimated critical load for sulfur. For example, a species with an S*N interaction could have a negative relationship at high N (dark-blue line), which then transitions to a flat relationship at intermediate N (black line) and to a positive relationship with low N (light-blue line).

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1.0 *Actaea rubra* (red baneberry)

Distribution and Conservation Status

Red baneberry is a native perennial forb found in Alaska and south through the Coast Range and the Sierra Nevada in California, Rocky Mountains, Arizona, and New Mexico. In the East and Midwest, its distribution extends to New Jersey, Indiana, Iowa, and Kansas. It is critically imperiled in Indiana, imperiled in Ohio and Pennsylvania, and vulnerable in Illinois and Arizona (fig. 1.1).

Species Characteristics and Habitat

Red baneberry is 1 to 3 feet tall with one to several branched stems. The leaves have sharp teeth and lobed edges, and alternate and two to three times compound. Flowers bloom in a terminal or axillary raceme. They have small white petals with a rose scented fragrance and showy stamens.

In Colorado and Utah, red baneberry's growth is fair to good on sandy loam, loam and clay loam soils and poor to fair on gravel, sand, clay, and dense clay. It grows best on deep, organic and acidic, and grows poorly on saline or sodic soils. The flowers are pollinated by many insects. These flowers can be self-fertile but are not capable of apomixis. Red baneberry's name comes from a poisonous

glycoside (protoanemonin) found in all parts of the plant but most concentrated in the berries and root. Symptoms of poisoning for humans include gastroenteritis, stomach cramps, headache, dizziness, vomiting, diarrhea and circulatory failure. Fire kills aboveground parts of red baneberry. The caudex appears to survive fires, although fire response information is lacking.

Wildlife and Livestock Uses

In Montana, elk eat red baneberry foliage in the fall because it remains green after early frosts. In Utah, mule deer will occasionally eat red baneberry in the fall. White-tailed deer consume a moderate amount of red baneberry. It is not normally grazed unless other forage is scarce. Many bird species consume red baneberry including the yellow-bellied sapsucker, American robin, wood thrush, gray-cheeked thrush, brown thrasher, gray catbird, and grouse. Some small mammals also eat the berries including deer mice, white-footed mice, red squirrel, eastern chipmunks, and red-backed voles. Red baneberry is not important to livestock because it is not usually abundant, and its energy and protein value are rated as poor.

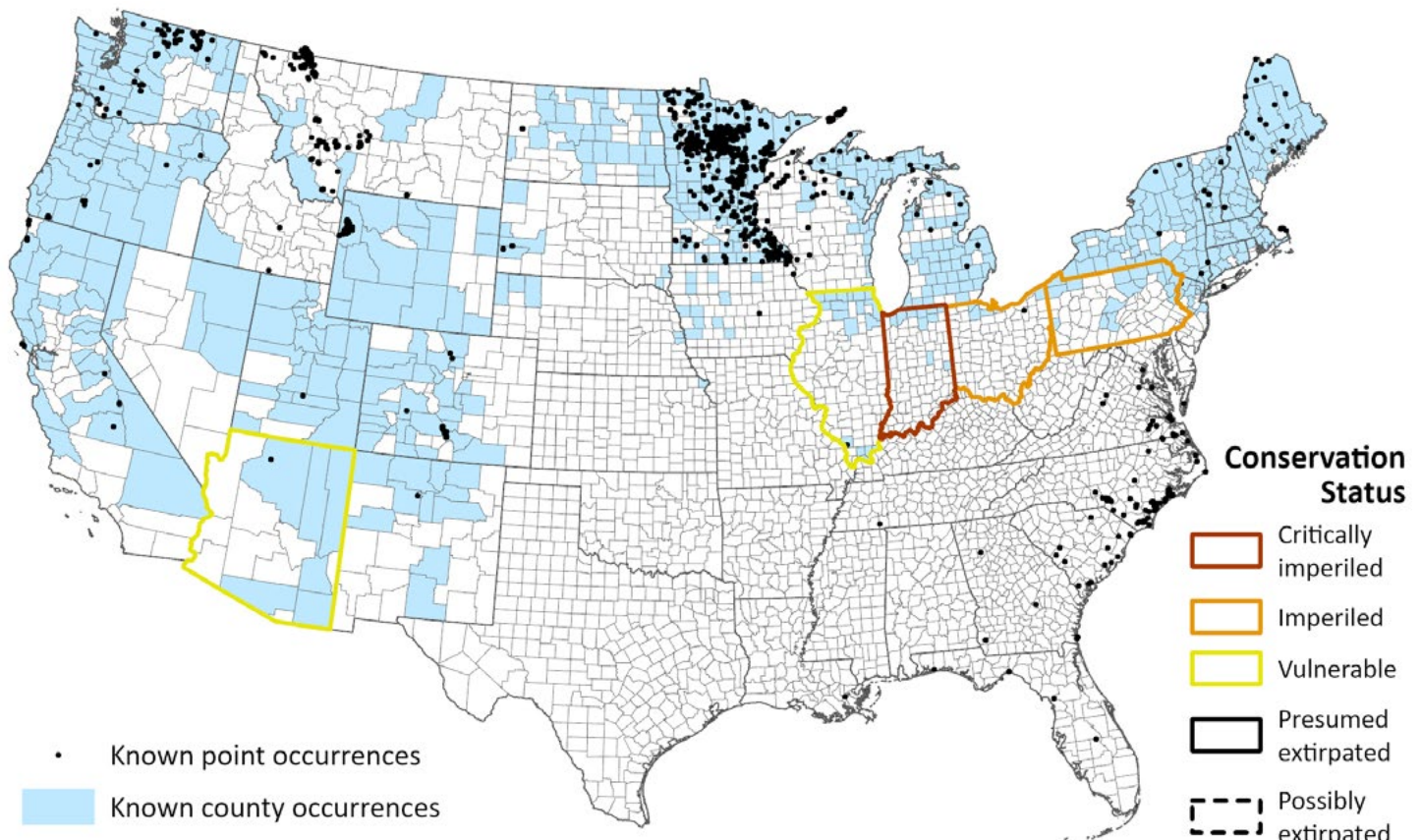


Figure 1.1. Distribution and state-level conservation status of *Actaea rubra*. Known point occurrences were used to assess species deposition responses and critical loads.

Ecosystem Services

In a few western states, red baneberry is known for having low to moderate value for erosion control and revegetation potential, with moderate biomass production. Growth is good on gentle slopes and fair on steeper slopes. Red baneberry has attractive foliage and brilliantly bright berries, which grows easily in woodland gardens and are very attractive when interspersed with ferns.

Traditional Ecological Knowledge

Traditional uses of red baneberry include medicinal formulas to treat colds, coughs, stomach pains, arthritis, syphilis, rheumatism, excessive menstrual flow, emaciation, loss of appetite (a weak root decoction acts as a stimulant), and boils and wounds (a compress of chewed leaves stimulates blood flow).



Fruit and foliage of red baneberry.
Rob Routledge, Sault College, Bugwood.org.

Responses to Nitrogen and Sulfur

The probability of occurrence for red baneberry is most dependent on the interactive effect of N and S deposition (fig. 1.2a) and the interactive effect of N and pH (fig. 1.2b). With higher S deposition (≥ 9.9 kg S/ha/yr), the probability of occurrence decreases with N addition: with lower S deposition the probability of occurrence increases with N deposition (fig. 1.2a). The probability of detecting red baneberry decreases under more acidic soil conditions (pH ≤ 4.8) with increasing N deposition. Under less acidic conditions (pH ≥ 5.8), red baneberry increases with N deposition up to roughly 10-12 kg N/ha/yr then decreases with N deposition above that (fig. 1.2b). The climate effects are shown in Figure 1.2c (precipitation) and Figure 1.2d (temperature). The probability of occurrence increases with increasing precipitation and peaks at temperatures around 4 °C within the species’ sampled range. Confidence in these relationships is moderate despite a high correlation between N and S ($r = 0.8$, low confidence) because the VIFs are low (VIF-N = 1.8, VIF-S = 1.3; both high confidence), and the model is reasonable ($R^2 = 0.158$, AUC = 0.74; both moderate confidence).



Flower of red baneberry.
Steven Katovich, Bugwood.org.

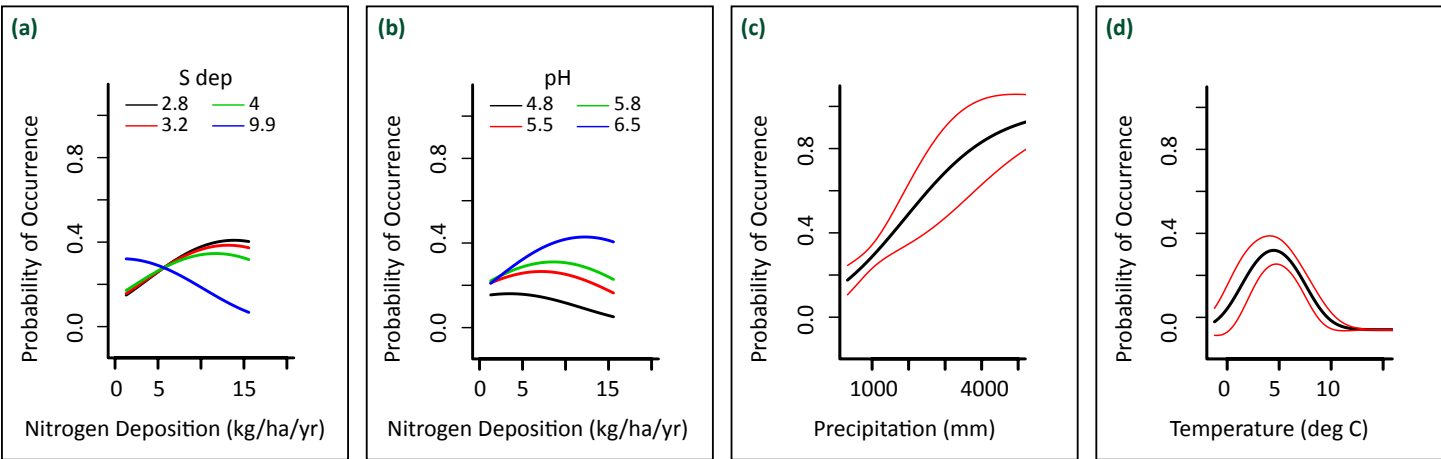


Figure 1.2. Effects of various environmental variables on the probability of occurrence of *Actaea rubra*: a) N x S interaction, b) N x pH interaction, c) precipitation, d) temperature.

Critical Loads and Exceedances

The environmental hull for red baneberry covers the northern half of the United States with a gap around eastern Pennsylvania. Critical load of N values are below 2 kg N/ha/yr across most of the east, 6 to 8 kg N/ha/yr in the northeast and eastern-Midwest, and >10 kg N/ha/yr in the Midwest and west. Exceedances of the N CL are

across the east and eastern-Midwest based on 2019–2021 TDep total N deposition. The eastern and midwestern part of the distribution has a S CL of 0.4 kg S/ha/yr and the western section of the distribution has a S CL of 39.4 kg S/ha/yr. The areas of the lower CL are all in exceedance based on 2019–2021 TDep total S deposition.

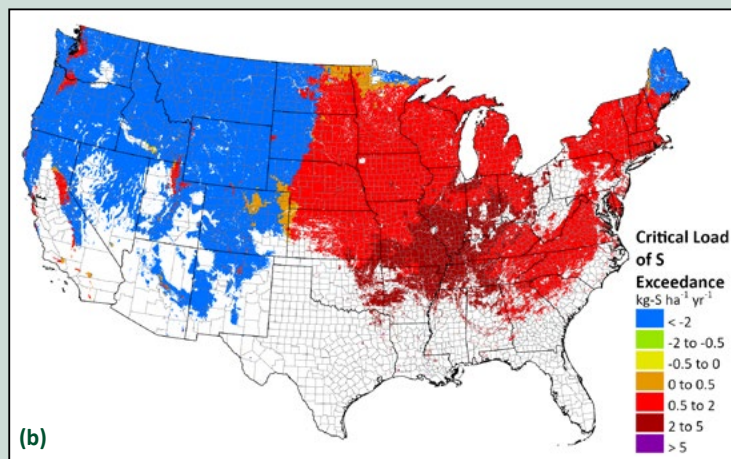
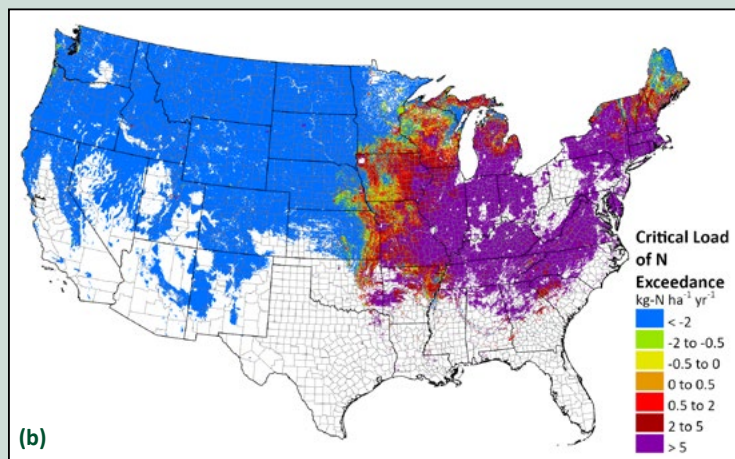
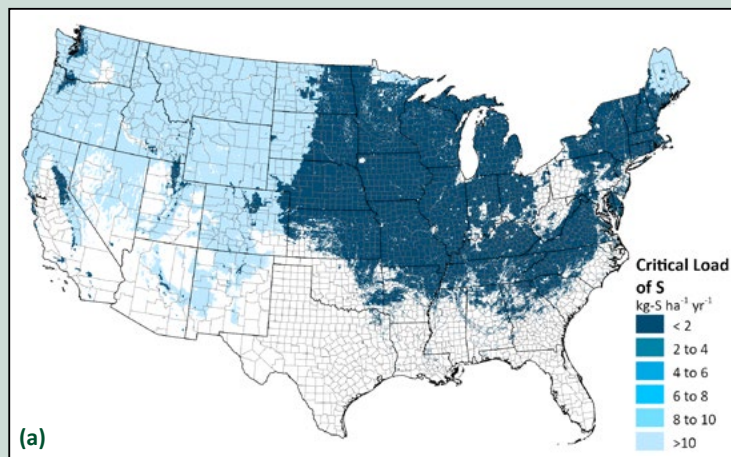
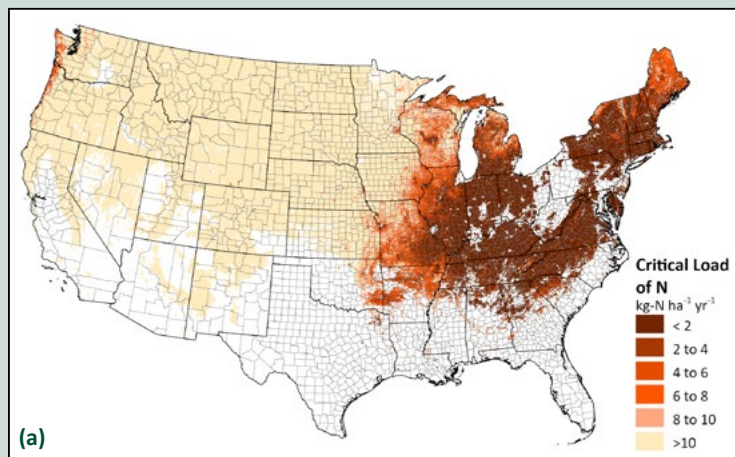


Figure 1.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Actaea rubra* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 1.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Actaea rubra* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

2.0 *Alliaria petiolata* (garlic mustard)

Distribution and Conservation Status

Garlic mustard is an introduced biennial, or occasional winter annual, forb of deciduous forests and woodlands. It was first introduced in New York in 1868 and has become well established throughout much of the Northeast, Midwest and Rocky Mountain regions of the United States, as well as in Alaska (fig 2.1).

Species Characteristics and Habitat

Garlic mustard is an established, cool-season, monocarpic plant with a taproot growth form. Mature garlic mustard plants grow upright with flowering stems up to 4 feet tall. The seedlings develop into rosettes up to 4 inches in diameter. Each rosette typically produces one single flowering stem, although multiple stems can occur.

Garlic mustard has also been found growing in oak forests, savannas, prairie, xeric upland eastern deciduous forests,

and mesic upland eastern deciduous forests. It is known to grow larger with greater biomass in habitats with more light and is capable of self-pollination in addition to cross-fertilization, making it a prolific plant. It is often top-killed when exposed to fire.

Wildlife and Livestock Uses

Animals are known to promote seed dispersal and the spread of garlic mustard. White-tailed deer and livestock species are known to forage on garlic mustard. Garlic mustard is dangerous to many species of butterfly eggs laid on the plant. This can result in larval development being inhibited or fatal, making garlic mustard a population sink for these butterfly species, especially the West Virginia white butterfly. Garlic mustard is edible and is known to be high in vitamin A and C.

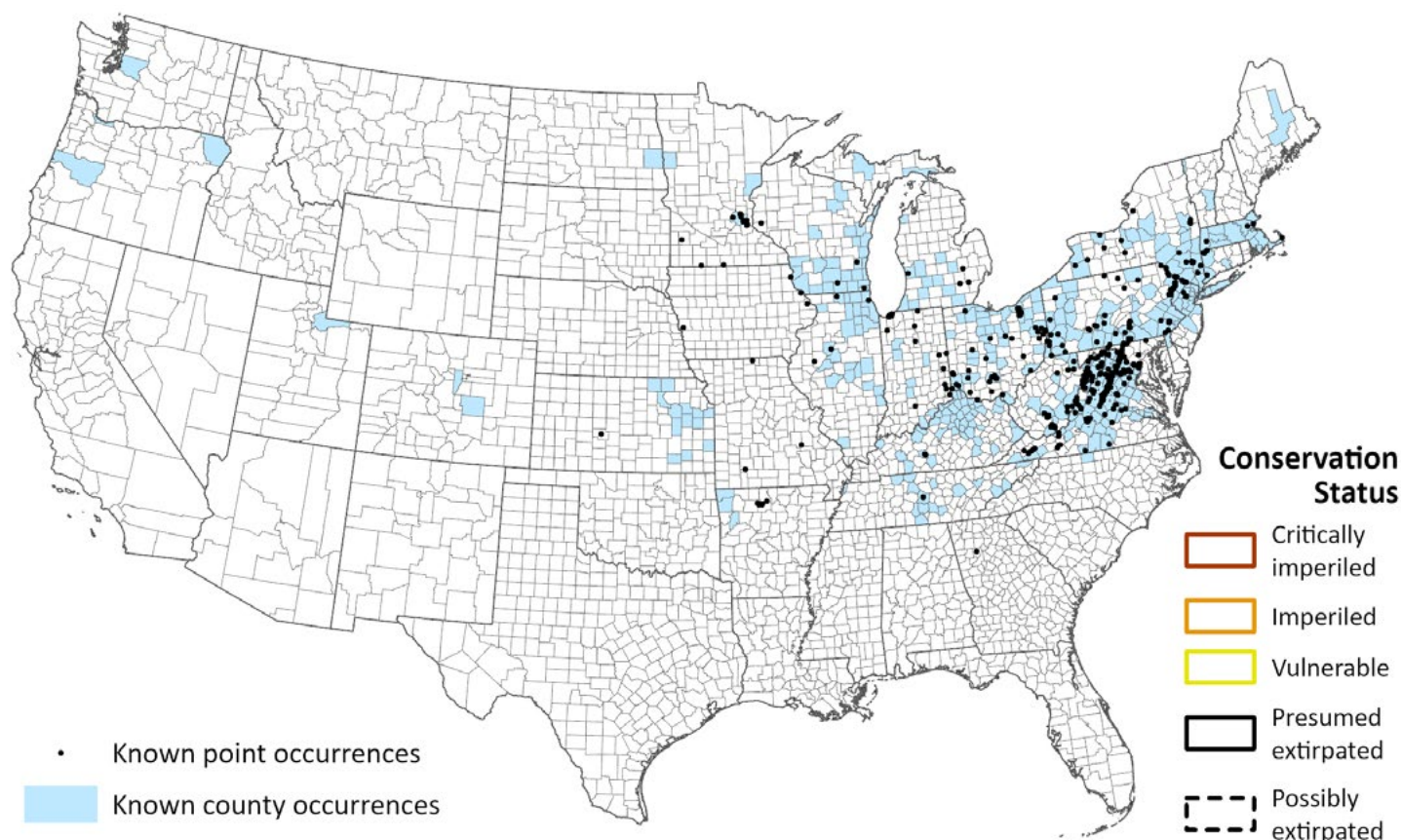


Figure 2.1. Distribution and state-level conservation status of *Alliaria petiolata*. Known point occurrences were used to assess species deposition responses and critical loads.

Traditional Ecological Knowledge

Garlic mustard is edible and is high in vitamins A and C. It has traditional uses as a green vegetable and a medicinal herb in Europe.

Responses to Nitrogen and Sulfur

The probability of occurrence for garlic mustard increases with N deposition (fig. 2.2a). There is also an interaction between S deposition and soil pH (fig. 2.2b): S deposition reduces the probability of occurrence more if the soil is also more acidic (pH ≤ 5.9). The climate effects are shown in Figure 2.2c (precipitation) and Figure 2.2d (temperature). The probability of occurrence decreases with increasing precipitation up to 1500 mm (but note wide confidence bands) and peaks at a temperature of 11 °C within the species' sampled range. Confidence in the N and S relationships is moderate-to-high due to the low VIF (VIF-N = 1.2, VIF-S = 1.1; both high confidence), the good overall model ($R^2 = 0.244$, AUC = 0.86; moderate and high confidence, respectively), and a moderate N-S correlation ($r=0.69$, moderate confidence).



Foliage of garlic mustard.

Chris Evans, University of Illinois, Bugwood.org.

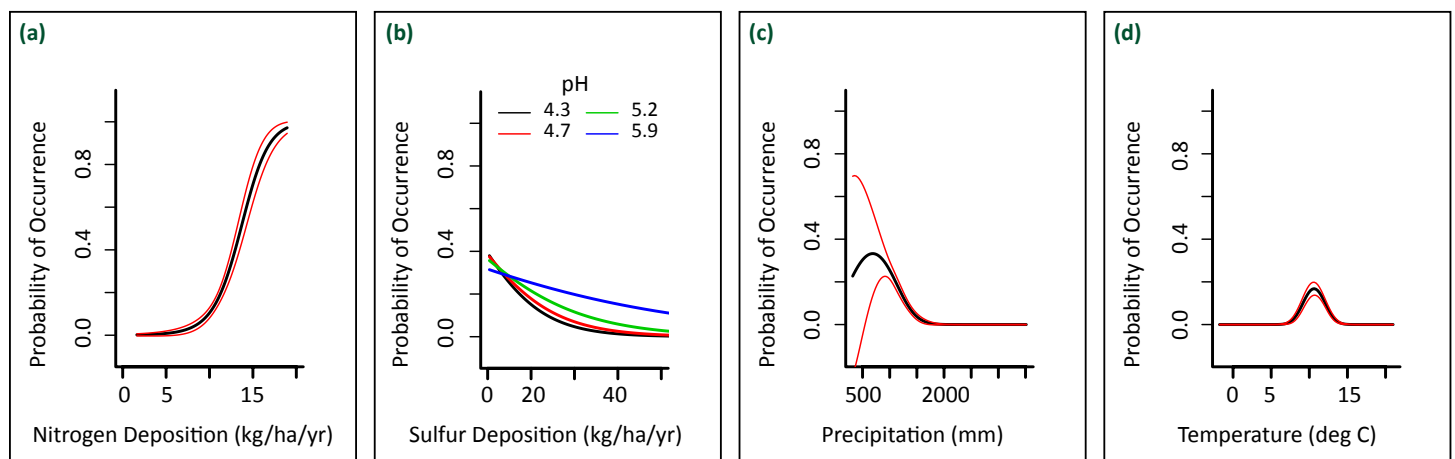


Figure 2.2. Effects of various environmental variables on the probability of occurrence of *Alliaria petiolata*: a) N deposition, b) S x pH interaction, c) precipitation, d) temperature.

Critical Loads and Exceedances

The environmental hull for garlic mustard covers the northeastern United States. Nitrogen critical load values are all below 2 kg N/ha/yr and are exceeded across the range based on 2019–2021 TDep total N deposition. The eastern part of the distribution has a S CL of 0.4 kg S/ha/yr and the northwestern section of the distribution has a S CL of 42.5 kg S/ha/yr. The areas of the lower CL are all in exceedance based on 2019–2021 TDep total S deposition, while the areas with the higher CL are not expected to be at risk.



Flower of garlic mustard.
Chris Evans, University of
Illinois, Bugwood.org.

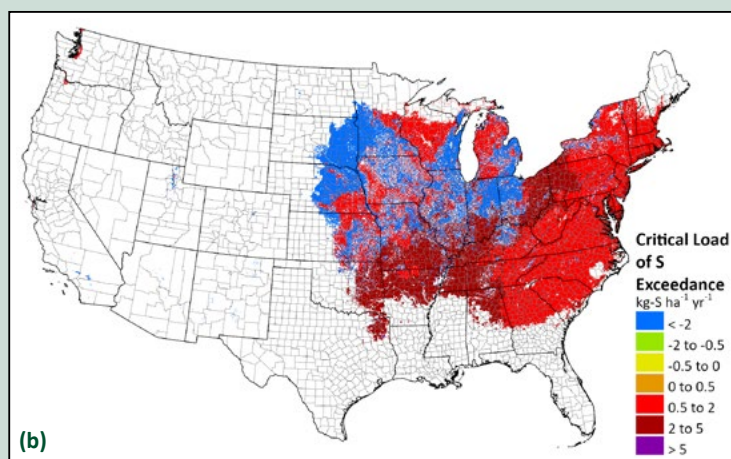
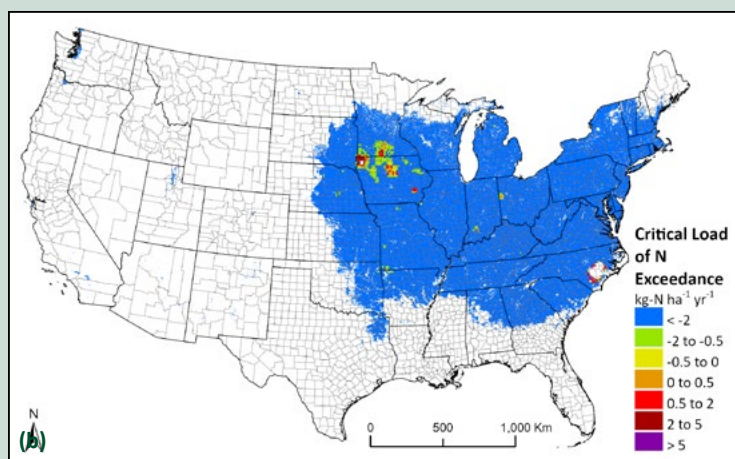
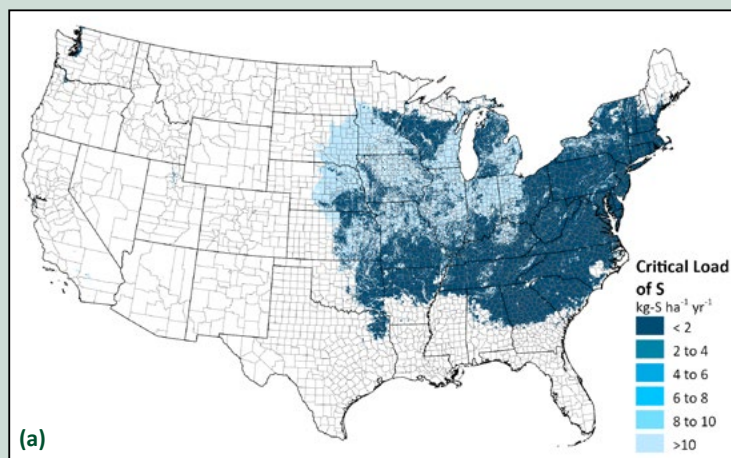
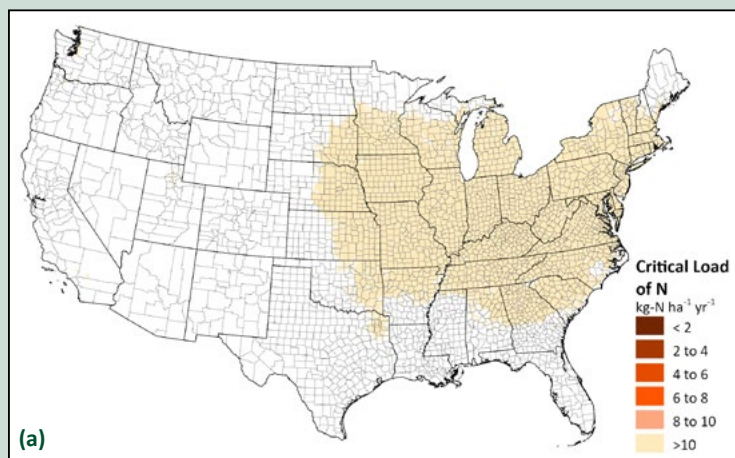


Figure 2.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Alliaria petiolata* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 2.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Alliaria petiolata* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

3.0 *Andropogon gerardii* (big bluestem)

Distribution and Conservation Status

Big bluestem is a native perennial grass that is widespread in all but a few western states and is most conspicuous in the tallgrass and mixed-grass prairie regions. It is distributed throughout Montana and Wyoming south to Arizona, and eastward to Florida and Maine. Big bluestem is listed as vulnerable in Wyoming (fig. 3.1).

Species Characteristics and Habitat

Big bluestem is tall, upright, warm-season, usually rhizomatous, sod-forming plant. The flowering stalks are stout, rough, and solid, reaching heights of over 10 feet tall in a favorable growing season. Big bluestem stands exhibit many colors from steel gray to deep red.

Soil moisture is one of the most important factors determining big bluestem's prevalence in an ecosystem. It develops best on mesic sites in true prairies and mixed-grass prairie regions on fertile silt and clay loam soils of lowlands. In the West, within the mixed-grass prairie region, it is a climax grass in well-watered lowlands. This is a result of big bluestem's deep, coarse, root system which effectively extracts moisture from silty or clayey soils. Big

bluestem is shade tolerant, and its leaves remain green and function with only 5 to 10 percent of full sunlight. It can survive in a range of other limiting soil factors such as shallow depth, low pH, and low fertility. Historically, fires were frequent in the tallgrass prairie and were critical in maintaining such grasslands.

Wildlife and Livestock Uses

Big bluestem offers food and cover for several wildlife and livestock and species. It provides shelter for nesting birds and insects. A variety of birds eat the seeds. It is palatable, especially the new growth, nutritious, and livestock prefer it over other grasses on summer ranges. Palatability decreases as the grass cures, making big bluestem less palatable during the winter. Crude protein content of 16-18% is maintained from May through August but drops below 6% in September and October. It is often harvested as pasture grass and for haymaking.

Ecosystem Services

Big bluestem is cut for hay in early to midsummer before the nutritive quality decreases. It is a top choice for erosion control plantings on sites with moderately well

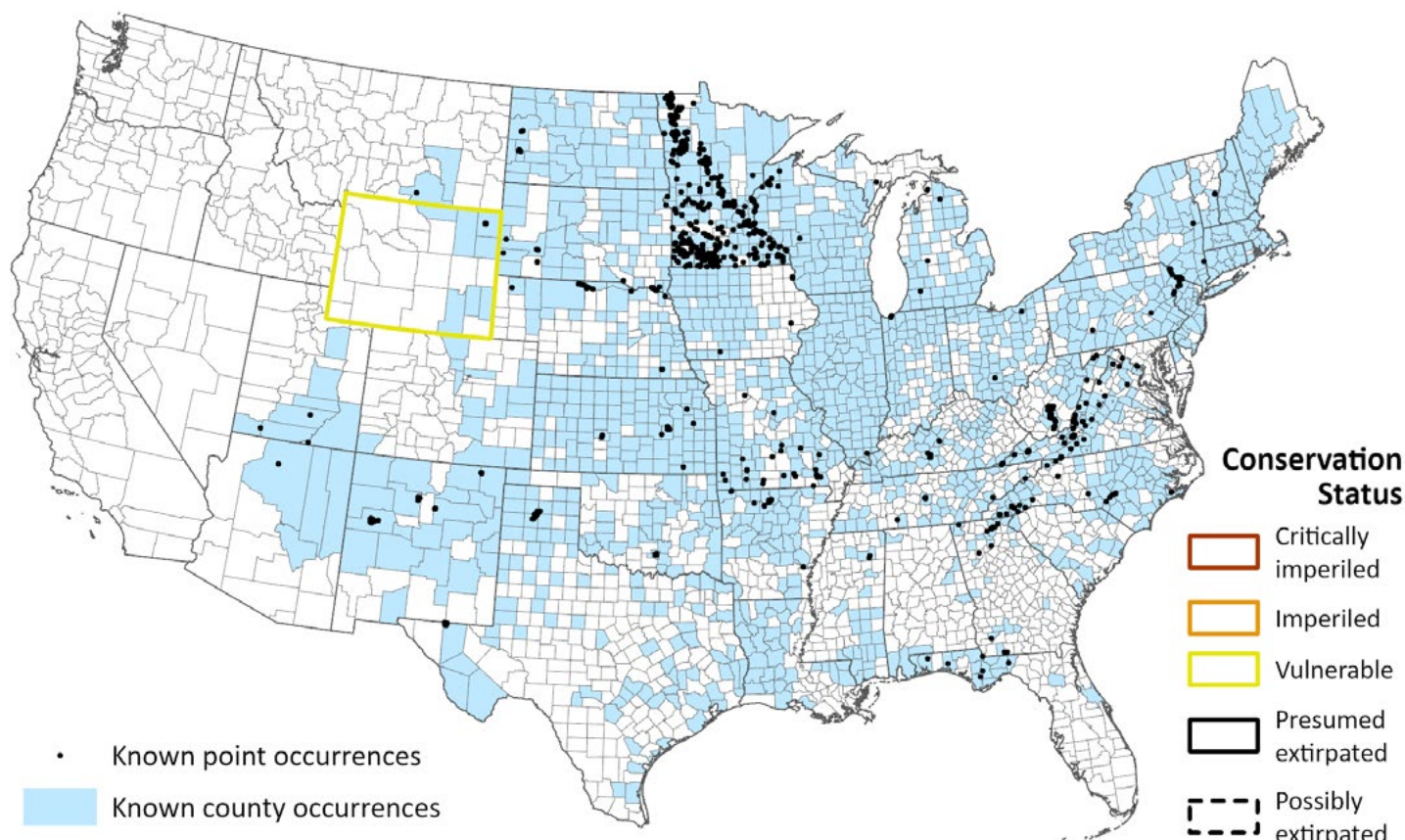


Figure 3.1. Distribution and state-level conservation status of *Andropogon gerardii*. Known point occurrences were used to assess species deposition responses and critical loads.

drained to excessively well drained soils, and it restores disturbed prairie sites. It is mixed with other native prairie species for prairie restoration and highway revegetation. Although it grows best in moist soils, it can be used for mine reclamation, logging road restoration and other restoration areas with sandy or drought conditions.

Traditional Ecological Knowledge

Big bluestem is used medicinally to treat stomach aches, induce urination, and reduce fever and pain. It is also used as a textile, for example on poles to support earth coverings of lodges, to cover fruit during ripening, and to place under fruit while drying. Moistened grasses can be laid onto hot stones to help prevent steam from escaping during pit cooking. Stiff jointed stems can be used by children to make arrows for toy bows.



Flowers of big bluestem.
Chris Evans, University of Illinois, Bugwood.org.

Responses to Nitrogen and Sulfur

The probability of occurrence of big bluestem depends on complex interactions between the variables tested. N deposition increases the probability of occurrence up to between 10 kg N/ha/yr and 15 kg N/ha/yr, and this increase is weakly dependent on soil pH (fig. 3.2a). The probability of occurrence for big bluestem decreases with increasing S deposition (fig. 3.2b). There is an interaction between S and pH that yields nonsensical results (Clark et al. 2019) (fig. 3.2c). The probability of occurrence increases under more alkaline conditions (fig. 3.2d). The climate effects are shown in Figure 3.2e (precipitation) and Figure 3.2f (temperature). The probability of occurrence decreases with increasing precipitation and

is greatest at temperatures below 7 °C, peaking at 0 °C within the species' sampled range. Confidence in the N and S relationships is moderate-to-high given the VIFs (VIF-N = 1.1, VIF-S 1.2; both high confidence), moderate N-S correlation ($r=0.55$; moderate confidence) and high model performance ($R^2 = 0.427$, AUC = 0.88; both high confidence).

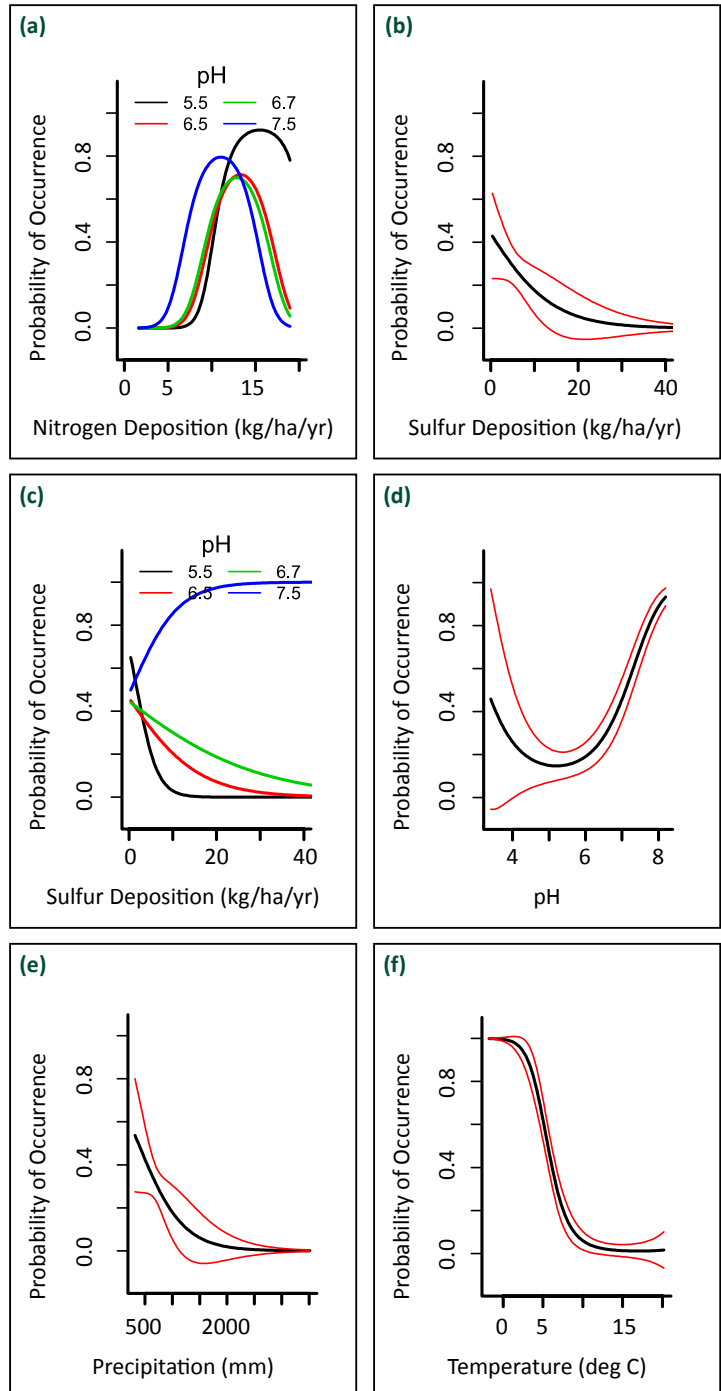


Figure 3.2. Effects of various environmental variables on the probability of occurrence of *Andropogon gerardii*: a) N x pH interaction, b) S deposition, c) S x pH interaction, d) pH, e) precipitation, f) temperature.

Critical Loads and Exceedances

The environmental hull for big bluestem covers most of the US outside of the Southwest with a CL-N between 8-10 kg N/ha/yr in the high desert and >10 kg N/ha/yr across the rest of the range. Exceedances of N CLs based on 2019–2021 TDep total N deposition are limited to high deposition areas in the Midwest, California's Central Valley, and agricultural areas in North Carolina. The eastern United States and mountainous areas of the West have a S CL of 0.4 kg S/ha/yr and the western plains and high desert have a CL-S of 41.7 kg S/ha/yr. The areas with lower CLs are all in exceedance based on 2019–2021 TDep total S deposition, while the areas with the higher CLs are not expected to be at risk.



Stems and fruits of big bluestem.
Chris Evans, University of Illinois, Bugwood.org.

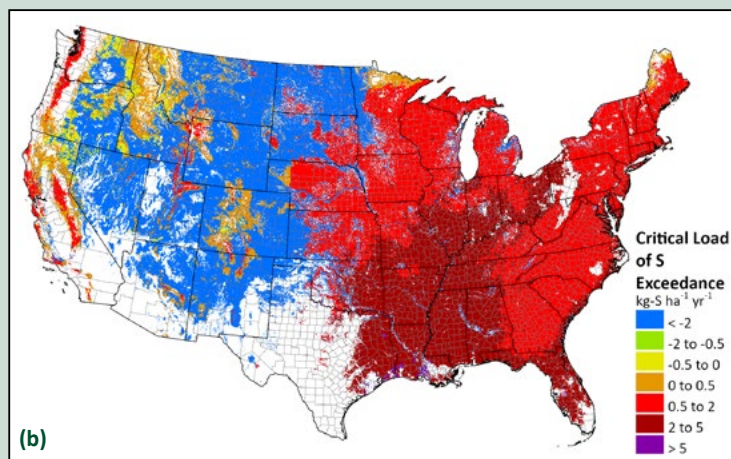
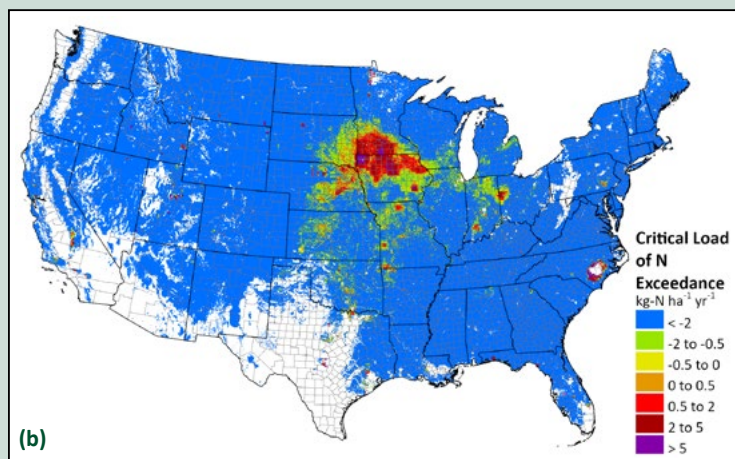
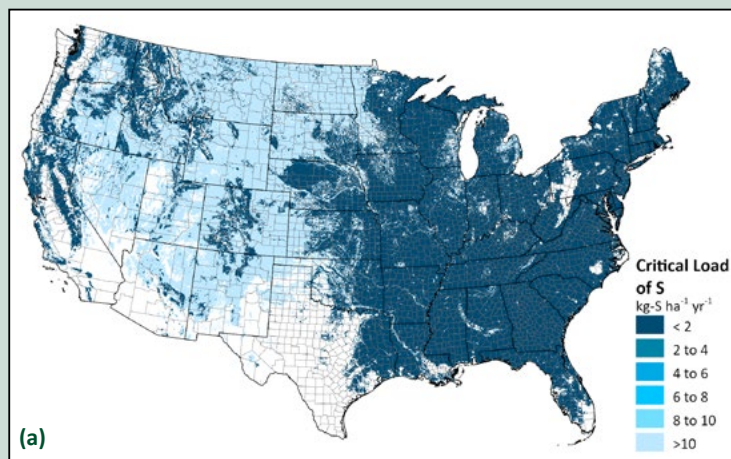
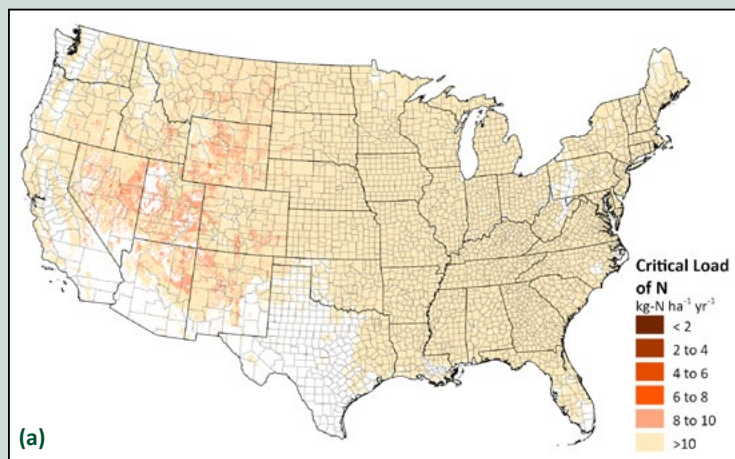


Figure 3.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Andropogon gerardii* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 3.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Andropogon gerardii* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

4.0 *Andropogon glomeratus* (bushy beardgrass)

Distribution and Conservation Status

Bushy beardgrass is a native perennial grass of the eastern United States, especially the southern States, and west to California. It is critically imperiled in Ohio, imperiled in Utah, and vulnerable in Pennsylvania and New York (fig. 4.1). It is a persistent, warm-season, low-growing bunchgrass.

Species Characteristics and Habitat

Bushy beardgrass culms are upright, 20 inches to 5.25 feet tall, flattened, with broad keeled, overlapping lower sheaths and the flat tufts often forming dense, usually glaucous clumps. It blooms from late summer through autumn. Bushy beardgrass can be differentiated from other warm season grasses by its thick, large, reddish brown, terminal inflorescence composed of paired silky racemes and its compressed blue green foliage. The casings are occasionally villous, with elongate blades and a thick and feathery inflorescence. The fruit and seed period starts in the fall and finishes in the winter.

Bushy beardgrass is found in low roadsides, moist pinelands, the borders of brackish and freshwater marshes, sloughs, and wet ditches. The USDA Hardiness Zones for bushy beardgrass are 5 to 10. Bushy beardgrass withstands hot climates and coastal conditions when consistent moisture is present. It is found in irregularly to seasonally flooded or saturated loamy soil. Bushy beardgrass is not salt tolerant and normally will not grow at levels above 0.5 parts per thousand. It does not tolerate heavy shade, but it can grow in light shade conditions and tolerate low fertility areas.

Wildlife and Livestock Uses

Finches, juncos, and tree sparrows eat the seeds. White-tailed deer and rabbits consume the plant. Bushy beardgrass also provides cover for mottled ducks and fawns of white-tailed deer. Although it rates low as a forage grass, bushy beardgrass can be used as forage for livestock. It is most palatable during the early spring. The palatability is increased after a late winter burn.

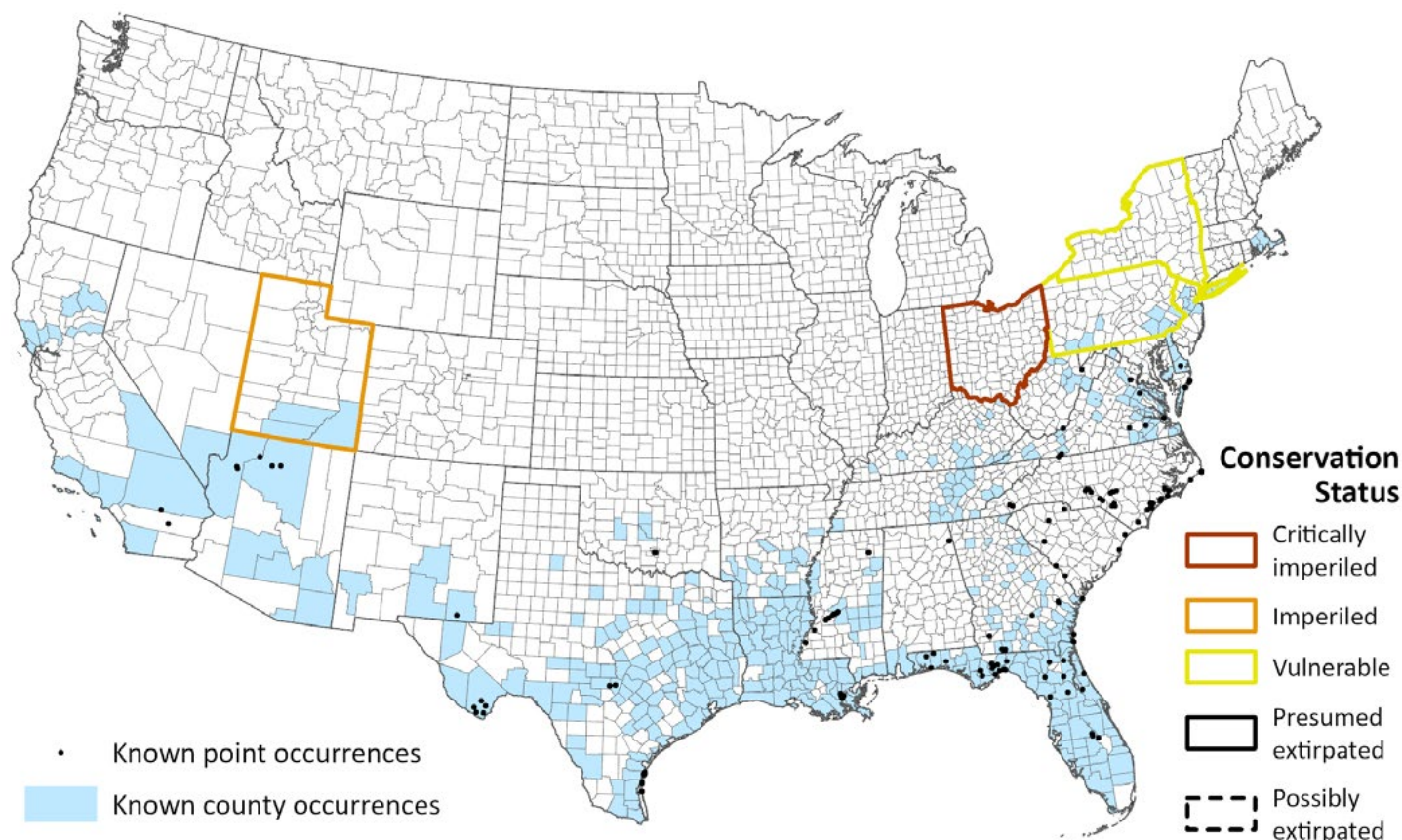


Figure 4.1. Distribution and state-level conservation status of *Andropogon glomeratus*. Known point occurrences were used to assess species deposition responses and critical loads.

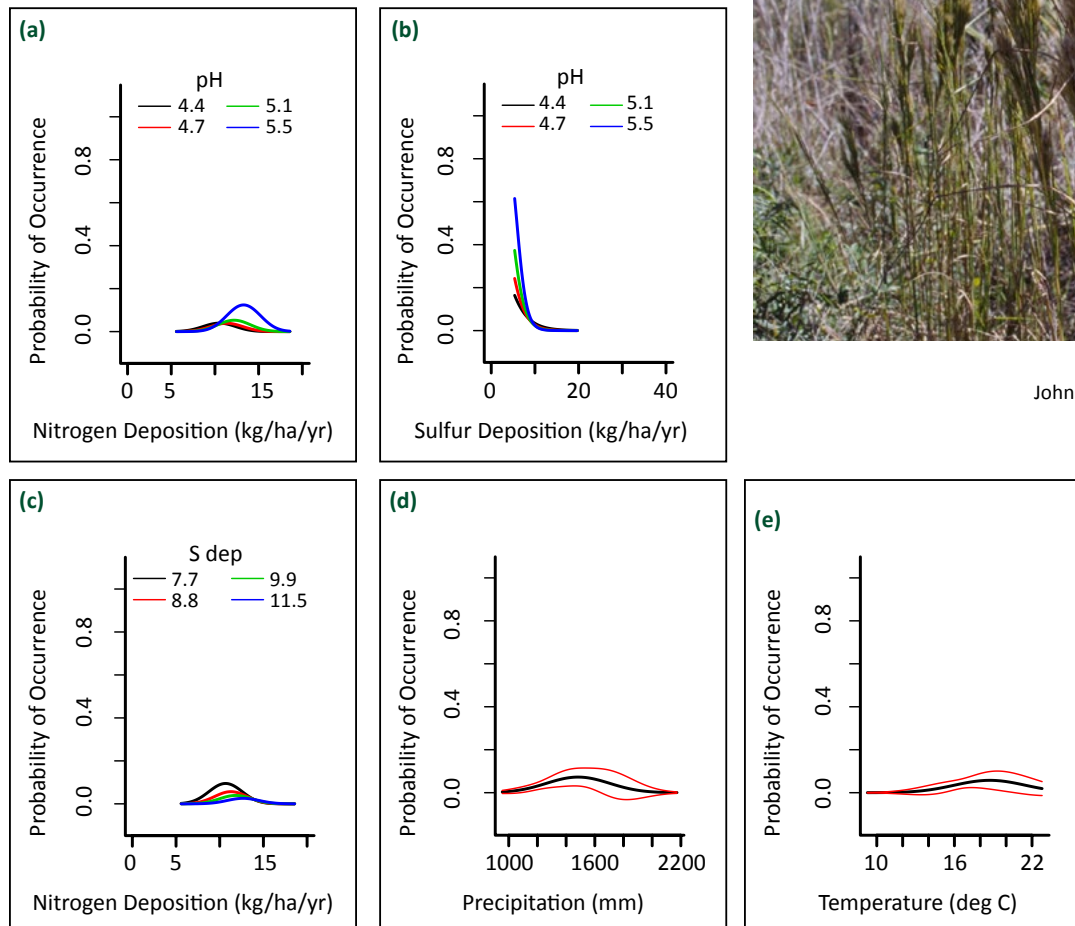
Ecosystem Services

Bushy beardgrass is used as a decorative grass in landscapes because of its impressive plumes that turn a rust color in late fall and early winter. It is recommended for golf courses, around pond edges, stream banks and other wet sites.

Responses to Nitrogen and Sulfur

The probability of occurrence of bushy beardgrass is affected by complex interactions between the variables tested. The response to N deposition depends on soil pH (fig. 4.2a): at higher pH (≥ 5.5), the probability of occurrence increases above roughly 10 kg N/ha/yr and then decreases above roughly 12 kg N/ha/yr. Under more acidic conditions the probability of occurrence remains low and unresponsive to N deposition. The response to S deposition also depends on soil pH (fig. 4.2b): at higher pH (≥ 5.5), the probability of occurrence is relatively high and declines steeply with increasing S deposition. At lower soil pH, the probability of occurrence is lower and less responsive to S. There is also an interaction between

N and S deposition (fig. 4.2c), whereby at higher S deposition (>7.7 kg S/ha/yr) the probability of occurrence is low and unresponsive to N deposition, and under low S deposition (≤ 7.7 kg S/ha/yr) the probability of occurrence increases above roughly 10 kg N/ha/yr and then decreases above roughly 12 kg N/ha/yr. The climate effects are shown in Figure 4.2d (precipitation) and Figure 4.2e (temperature). The probability of occurrence increases broadly between 1200 mm and 1900 mm precipitation and temperatures between 16 °C and 22 °C within the species' sampled range. Confidence in the N and S relationships is moderate, with good model performance ($R^2 = 0.184$, $AUC = 0.82$; moderate and high confidence, respectively), low VIFs ($VIF-N = 1.4$, $VIF-S = 1.4$; both high confidence), but a high N-S correlation ($r=0.82$; low confidence).



Plants of bushy beardgrass.
John Ruter, University of Georgia, Bugwood.org.

Figure 4.2. Effects of various environmental variables on the probability of occurrence of *Andropogon glomeratus*: a) N x pH interaction, b) S x pH interaction, c) N x S interaction, d) precipitation, e) temperature.

Critical Loads and Exceedances

The environmental hull for bushy beardgrass covers the southeastern United States and the southern northeastern States. N CL values are >10 kg N/ha/yr across most of the range with a few areas between 8 and 10 kg N/ha/yr across the South. Exceedances of N CLs based on 2019–2021 TDep total N deposition exist in high N deposition areas associated with agriculture in Missouri, Arkansas, Mississippi, and North Carolina. The S CL is 4 to 6 kg S/ha/yr across most of the range with values of 19.7 kg S/ha/yr in some northeastern coastal areas. The S CL is in exceedance based on 2019–2021 TDep total S deposition in small areas along the Gulf Coast.

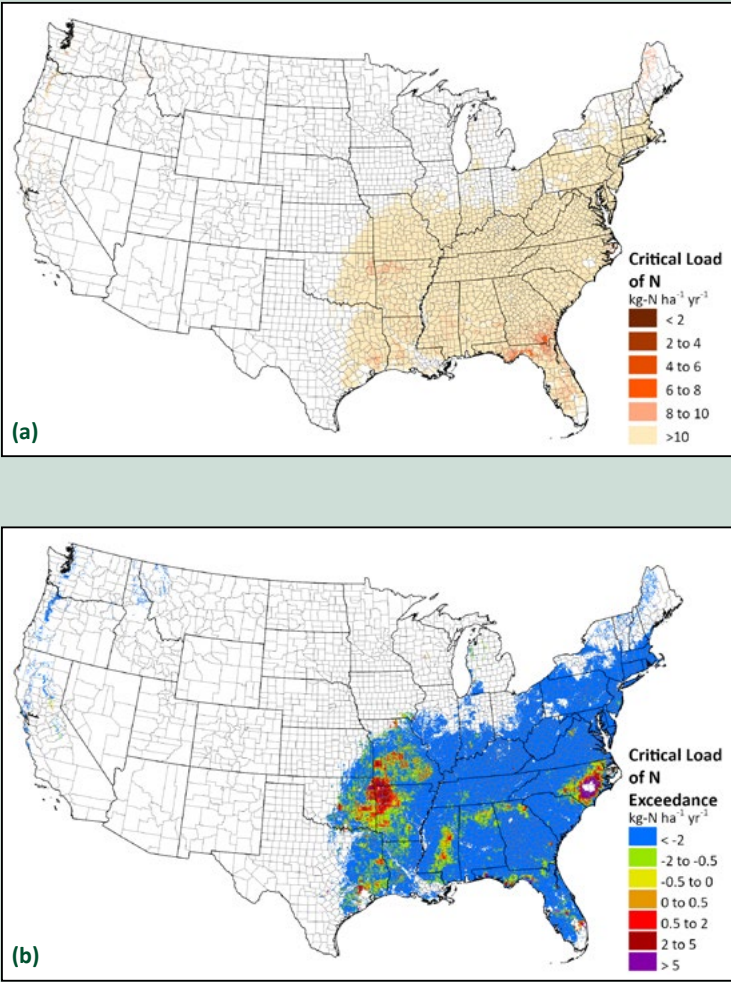


Figure 4.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Andropogon glomeratus* and (b) the exceedance of N critical loads based on TDep 2019–2021 total N deposition.

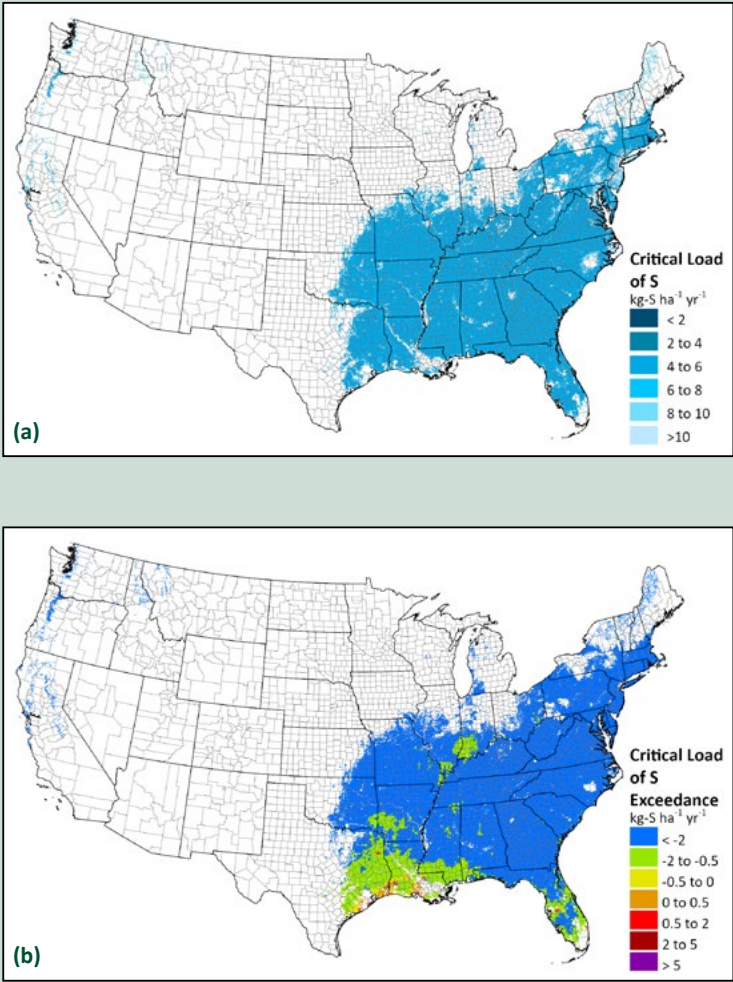


Figure 4.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Andropogon glomeratus* and (b) the exceedance of S critical loads based on TDep 2019–2021 total S deposition.

5.0 *Andropogon virginicus* (broomsedge bluestem)

Distribution and Conservation Status

Broomsedge bluestem is a native perennial grass of the eastern half of the United States and California (fig. 5.1). In the southeastern United States, it grows where the annual mean precipitation is at least 25 inches.

Species Characteristics and Habitat

Broomsedge bluestem is a 2 to 4 feet tall, warm-season bunchgrass that usually grows in small clumps. The leaves are flat to partly folded, 10 to 15 inches long and less than an inch wide. The fringed ligule is less than an inch long. The majority of the plant is a pale greenish yellow and the flattened basal leaf sheaths are colorless or yellow. Flowering starts when plants are 2 or 3 years old and continues afterward.

Broomsedge bluestem's primary mode of reproduction is sexual. It is a prolific producer of small seeds on the upper half of the plant that are distributed by the wind and easily become established on uncovered soil.

Broomsedge bluestem is considered a pasture weed. It commonly invades inadequately managed pasture lands and increases on deteriorating ranges because of its poor palatability. It also invades uninhibited cropland, roadsides, overgrazed range, and logged-over pinelands and often procedures a continuous cover within 4 or 5 years of abandonment.

Wildlife and Livestock Uses

Broomsedge bluestem is usually considered poor forage for wildlife. It has very low nutrition values except in its early growth stages. Prescribed burning significantly increases nutritional value. When seeds from other plants are not available, small birds take and eat the seeds from the flowering stalks during the winter. Broomsedge bluestem's main value to wildlife is as bird nesting cover. It is heavily foraged throughout the spring and early summer in locations where it is prolific, such as abandoned fields. Besides that, it is not a particularly important cattle forage.

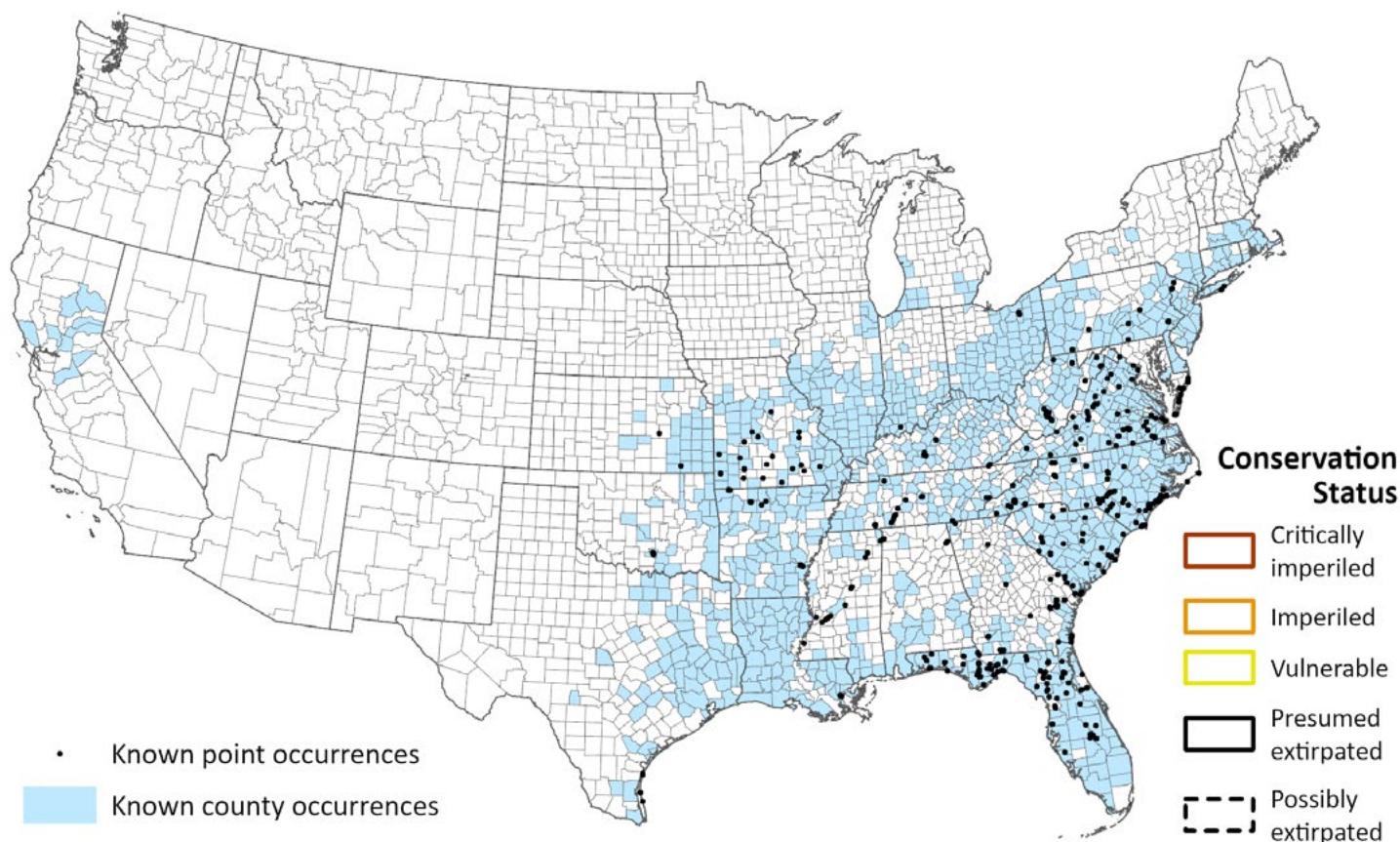


Figure 5.1. Distribution and state-level conservation status of *Andropogon virginicus*. Known point occurrences were used to assess species deposition responses and critical loads.

Ecosystem Services

Broomsedge bluestem is a frequent colonizer of abandoned coal strip mines and quarries, and regularly becomes the dominant ground cover. Broomsedge bluestem is utilized as a decorative plant. It is suggested for golf courses and residential landscaping because of its low maintenance and low water requirement. The foliage turns a reddish orange in the autumn and holds this color through winter dormancy, thus adding color to the winter landscape.

Responses to Nitrogen and Sulfur

The probability of occurrence of broomsedge bluestem is affected by complex interactions between N deposition and pH (fig. 5.2a) and between S deposition and pH (fig. 5.2b). At higher pH (≥ 5.5), the probability of occurrence increases with N deposition up to approximately 12 kg N/ha/yr and then decreases with N deposition above that (fig. 5.2a). At lower pH, the effect of N deposition is weaker, i.e., the probability of occurrence is generally lower and decreases at lower N deposition levels. Conversely, at higher pH (≥ 4.7), the probability of occurrence decreases with S deposition (fig. 5.2b). Under very acidic conditions (pH ≤ 4.4) the probability of occurrence is lower and increases slightly with increasing S deposition. The climate effects are shown in Figure 5.2c (precipitation) and Figure 5.2d (temperature). The probability of occurrence peaks broadly at 1500 mm precipitation and increases rapidly above 16 °C up to 22 °C within the species' sampled range. Confidence in the N and S relationships is moderate, with good model performance ($R^2 = 0.331$, $AUC = 0.87$; both high

confidence), low VIFs (VIF-N = 1.4, VIF-S = 1.4; both high confidence), but a high N-S correlation ($r=0.82$, low confidence).



Plant and flower of broomsedge bluestem.
Ohio State Weed Lab, Ohio State University.

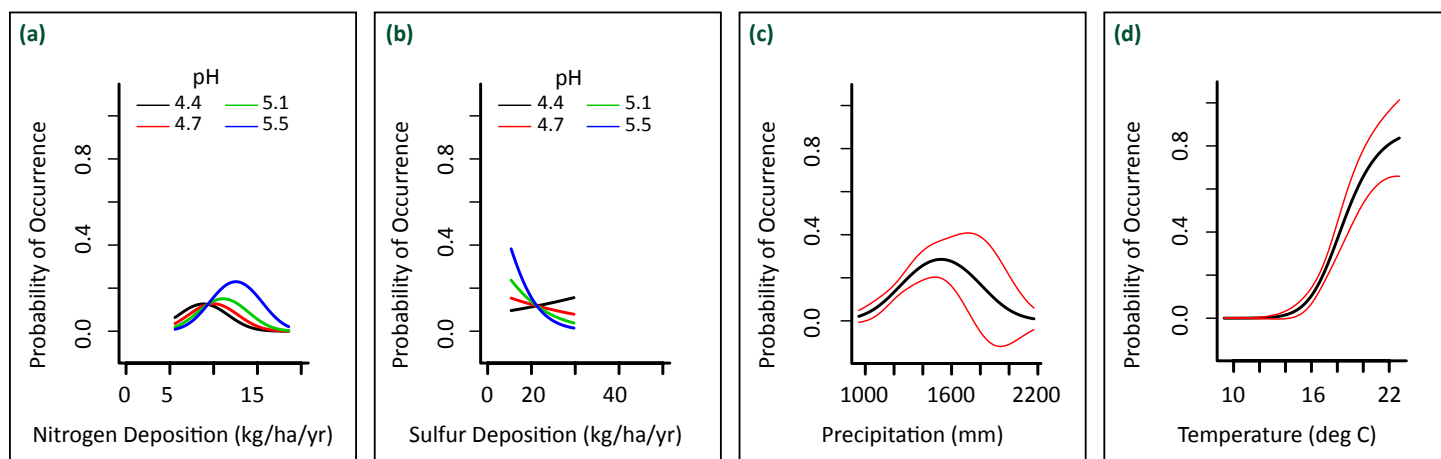


Figure 5.2. Effects of various environmental variables on the probability of occurrence of *Andropogon virginicus*: a) N x pH interaction, b) S x pH interaction, c) precipitation, d) temperature.

Critical Loads and Exceedances

The environmental hull for broomsedge bluestem covers the southeastern United States and most of the northeastern United States. Nitrogen CLs are above 10 kg N/ha/yr across most of the species' range with pockets of areas between 4-8 kg N/ha/yr. Exceedances of N CLs based on 2019–2021 TDep total N deposition are scattered across the range and are most common along the Appalachian Mountain range where deposition is higher with elevation. A S CL of 5.4 kg S/ha/yr is consistent across most of the species' range with a higher value of 19.7 kg S/ha/yr in some coastal areas. There are some exceedances of the S CL based on 2019–2021 TDep total S deposition in southern Louisiana and central Florida.

Plant of broomsedge bluestem.
John Ruter, University of Georgia, Bugwood.org.

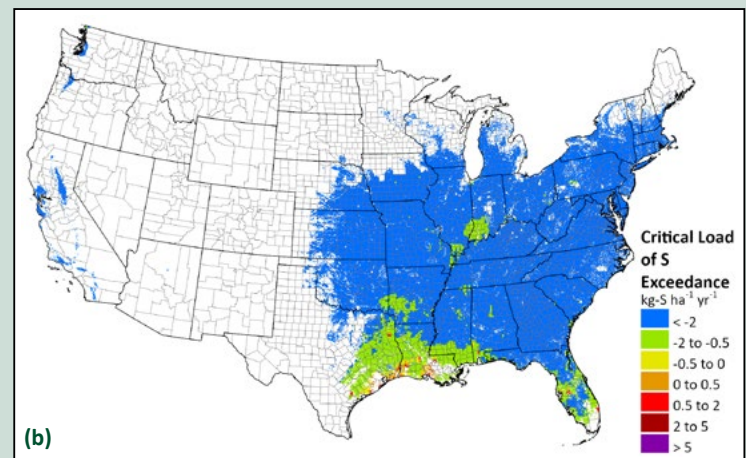
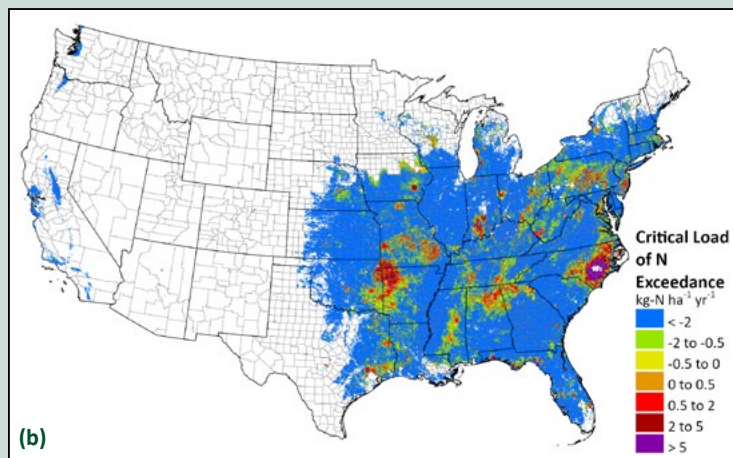
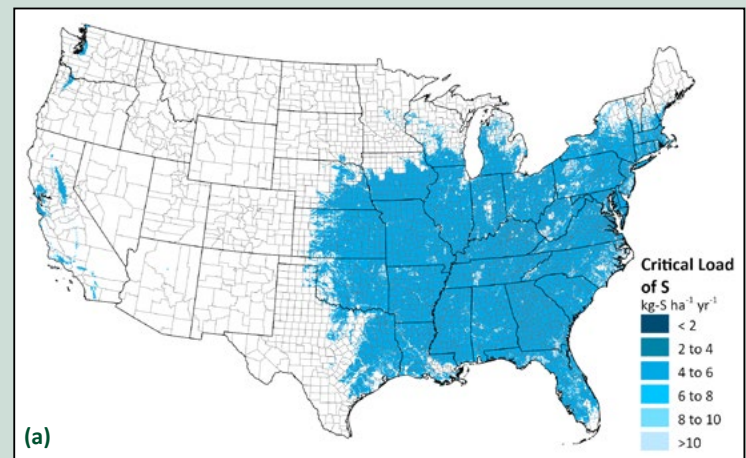
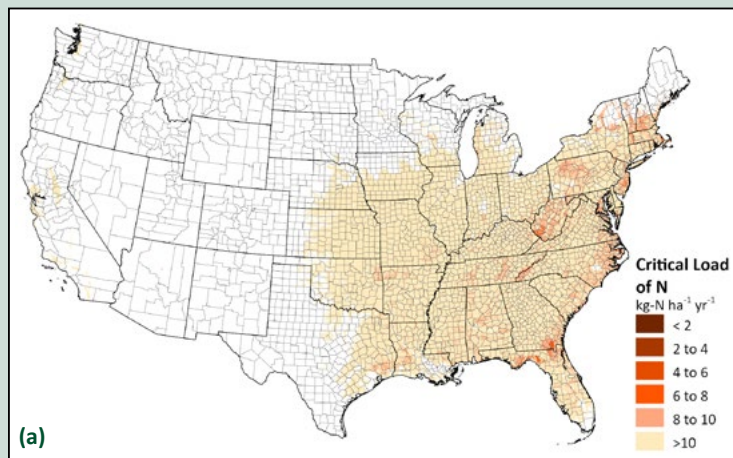


Figure 5.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Andropogon virginicus* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 5.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Andropogon virginicus* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

6.0 *Apocynum androsaemifolium* (spreading dogbane)

Distribution and Conservation Status

Spreading dogbane is a widely distributed native perennial forb of North America, occurring in every state except Hawaii, Kansas, Louisiana, Mississippi, Florida, and South Carolina. It is critically imperiled in Delaware and vulnerable in North Carolina and Utah (fig. 6.1).

Species Characteristics and Habitat

Spreading dogbane can grow to 40 inches in height. Stems are upright and diffusely branched, glabrous, and lack a central axis. Spreading dogbane has rhizomes that have been noted at depths greater than 10 inches and are located primarily in mineral soil. Leaves are opposite, spreading or drooping, glabrous above and pubescent beneath. Leaves range in size up to ½-inch in length and up to 2 inches wide.

Spreading dogbane is frequently found in dry, open areas, especially after a disturbance. Although it is most common in dry, open areas, it can also be found in riparian zones and shady, moist areas with clayey soils. Spreading

dogbane is located at elevations ranging from sea level to 11,000 feet with temperatures ranging from 18 to 90 °F and pH levels of 5.0 to 7.7. Vegetative reproduction happens through rhizomes. Fire likely top-kills spreading dogbane. The deeply buried rhizomes makes complete destruction of spreading dogbane by fire unlikely. The subterranean parts of the plant may allow it to withstand high temperatures and frequent fires.

Wildlife and Livestock Uses

Spreading dogbane is occasionally grazed by wildlife but is considered poisonous to domestic livestock. A large portion of the diet of elk in Idaho includes the leaves and flowers of spreading dogbane from late June to early October. Stomach content analyses of Rocky Mountain goats in Montana revealed trace amounts of spreading dogbane during the fall months. Spreading dogbane is used as nest-building sites for crab spiders, forage for forest-dwelling ground squirrels, and is utilized by bees for honey production.

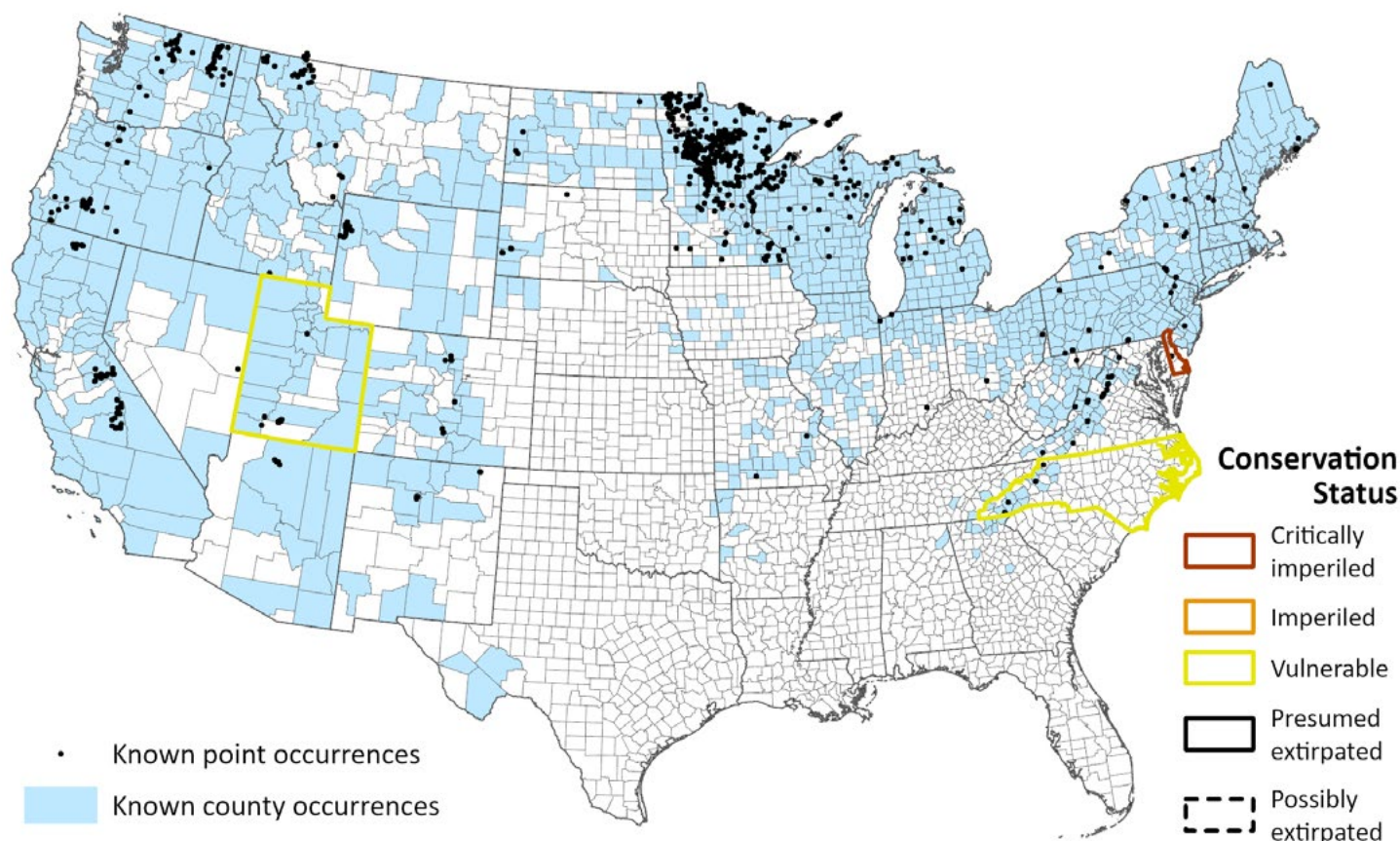


Figure 6.1. Distribution and state-level conservation status of *Apocynum androsaemifolium*. Known point occurrences were used to assess species deposition responses and critical loads.

Traditional Ecological Knowledge

There are many medicinal uses of spreading dogbane as an analgesic, anticonvulsive, cold remedy, ear and eye medicine, heart medicine, hemostat, cathartic, poison, pediatric aid, treatment for vertigo, gynecological aid, anthelmintic, dermatological aid, liver and kidney aid, and as a ceremonial medicine. Traditional textile uses of spreading dogbane include the manufacture of fish nets and cordage and fine sewing threads when preferred plants are not readily available.

Responses to Nitrogen and Sulfur

The probability of occurrence for spreading dogbane is mostly dependent on the interaction between N and S deposition (fig. 6.2a). At lower S deposition (<10.7 kg S/ha/yr), the probability of occurrence increases with N deposition up to roughly 8 kg N/ha/yr and then decreases above that. At high levels of S deposition (≥ 10.7 kg S/ha/yr), the probability of occurrence is lower and N deposition has little effect. The effect of S deposition also depends on pH (fig. 6.2b), though only weakly. The probability of occurrence decreases as S deposition increases, and decreases more steeply under lower soil pH conditions. Of the variables tested, the only significant climate variable is precipitation (fig. 6.2c). The probability of occurrence decreases with increasing precipitation

within the species' sampled range. Confidence in the N and S relationships is moderate, with good model performance ($R^2 = 0.129$, $AUC = 0.74$; both moderate confidence), low VIFs ($VIF-N = 1.3$, $VIF-S = 1.4$; both high confidence), but a high N-S correlation ($r=0.8$, low confidence).



Flowers of spreading dogbane.
Rob Routledge, Sault College, Bugwood.org.

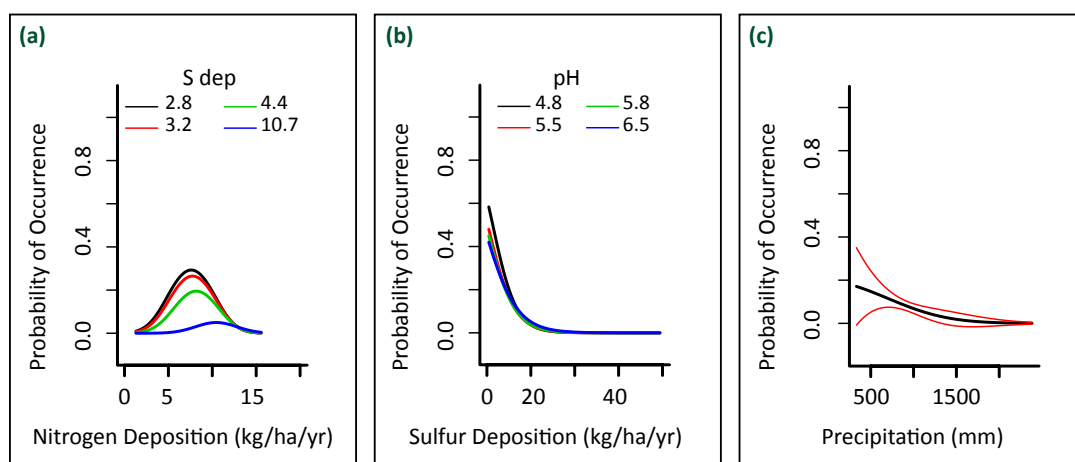


Figure 6.2. Effects of various environmental variables on the probability of occurrence of *Apocynum androsaemifolium*: a) N x S interaction, b) S x pH interaction, c) precipitation.

Critical Loads and Exceedances

The environmental hull for spreading dogbane covers the northern half of the United States. Nitrogen CLs are between 6–8 kg N/ha/yr across the western United States and between 8–12 kg N/ha/yr in the eastern United States. Exceedances of N CLs based on 2019–2021 TDep total N deposition occur in the Midwest, along California’s Central Valley, and in agriculturally intensive areas in the Southeast. A S CL of 0.4 kg S/ha/yr is consistent across most of the species’ range with a higher value of 39.4 kg S/ha/yr in a band from Iowa to Pennsylvania. There areas with the lower S CL are all in exceedance, while the areas with the higher critical load are not at risk based on 2019–2021 TDep total S deposition.



Leaves of spreading dogbane.
Dave Powell, USDA Forest Service (retired), Bugwood.org.

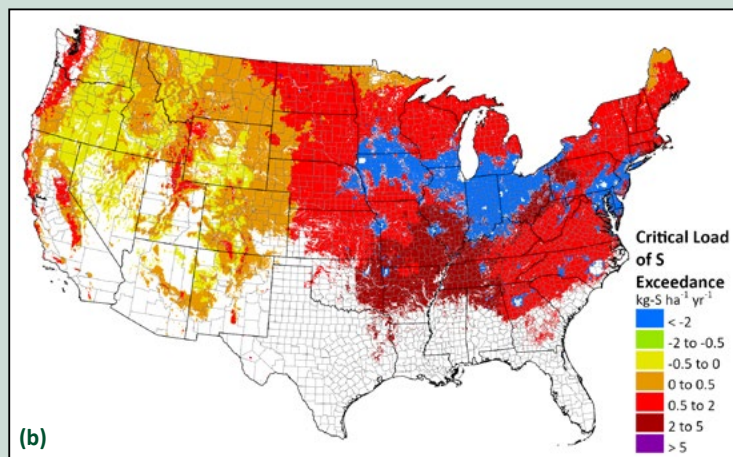
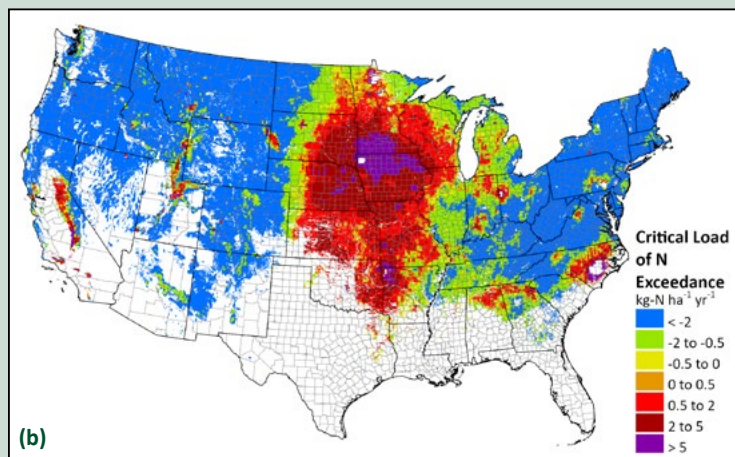
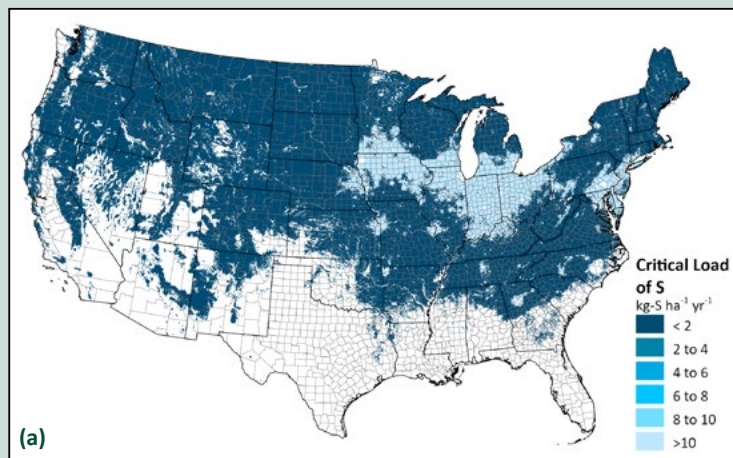
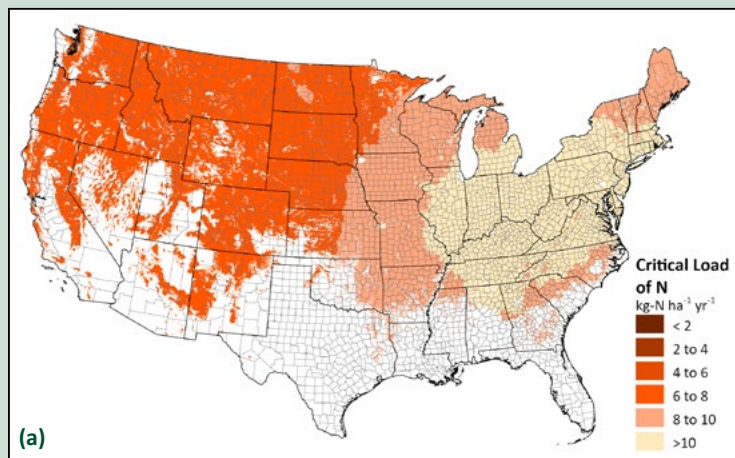


Figure 6.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Apocynum androsaemifolium* and (b) the exceedance of N critical loads based on TDep 2019–2021 total N deposition.

Figure 6.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Apocynum androsaemifolium* and (b) the exceedance of S critical loads based on TDep 2019–2021 total S deposition.

7.0 *Aquilegia canadensis* (red columbine)

Distribution and Conservation Status

Red columbine is a native perennial forb that grows in rocky woods from the United States northern border in the Central States to the east coast, south to Florida and Texas. It is critically imperiled in Florida and Mississippi and imperiled in Delaware (fig. 7.1).

Species Characteristics and Habitat

It is 12 to 30 inches tall with a short, straight subterranean stem and fibrous, short-lived roots. It grows from a stout caudex with compound leaves that are distinctly divided into obovate leaflets. Flowering occurs from March to July. The sepals are petal-like and red; the petals are yellow and become redder at the tip of the spur. The stamens are long, and the fruit is straight, with five parallel ascending follicles with ultimately out-curving summits. Fruits form from June to August, and the seeds are released in early to mid autumn.

Red columbine commonly grows in open sites that are steep and rocky but moist, such as wooded cliffs of streams, wooded hills, streambanks, and banks and slopes of deep ravines. It can grow in thin soils over multiple types of bedrock and on gravelly glacial moraines. It grows best in slightly acidic, loose soil with a mixture of organic matter. Red columbine is moderately shade intolerant and starts to grow in early spring. It reproduces from seeds and can survive fire disturbance.

Wildlife and Livestock Uses

Red columbine has little importance as a forage species. Hummingbirds pollinate red columbine and depend on it for nectar. It is palatable for domestic sheep, poorly palatable for cattle, and completely unpalatable for horses.

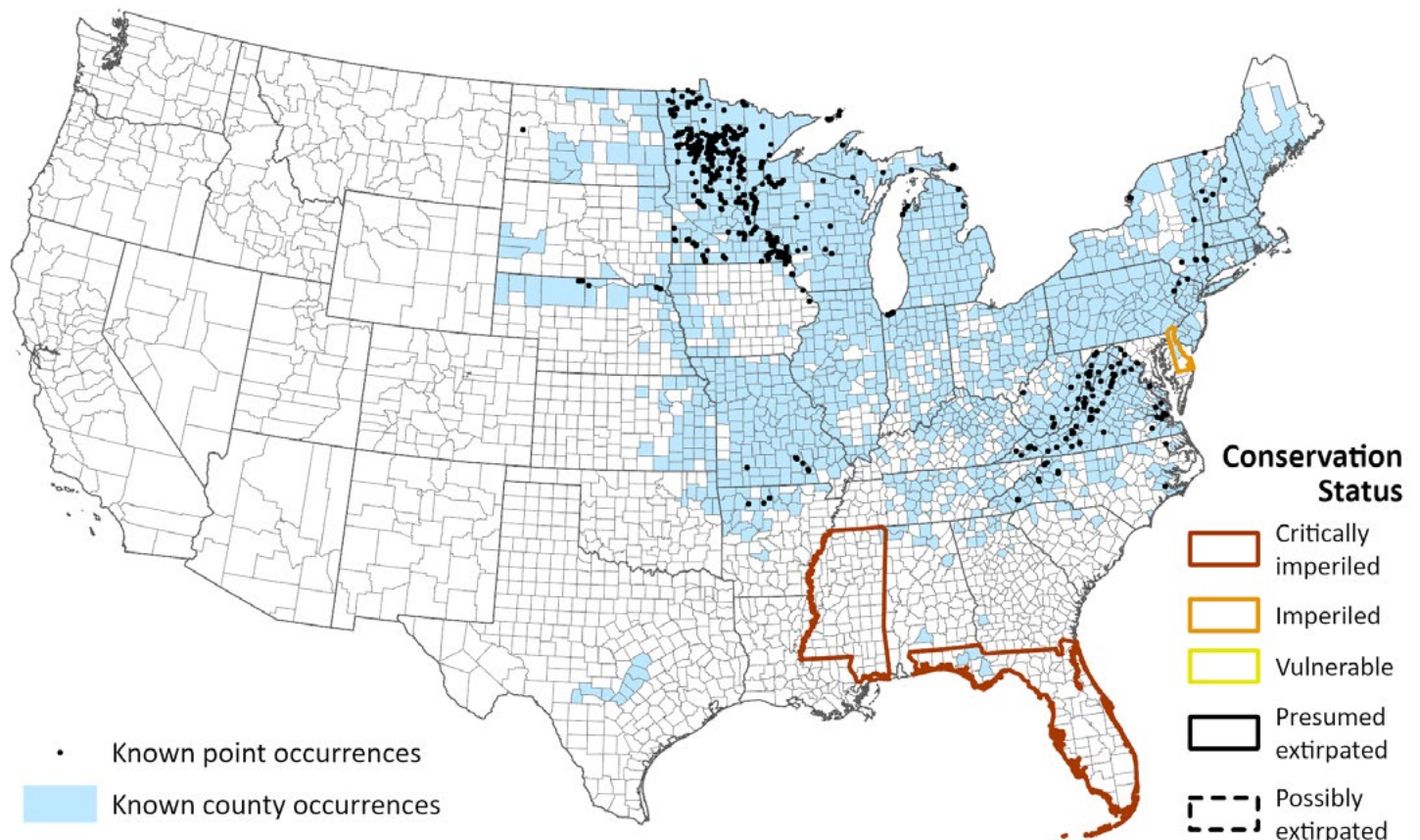


Figure 7.1. Distribution and state-level conservation status of *Aquilegia canadensis*. Known point occurrences were used to assess species deposition responses and critical loads.

Ecosystem Services

Red columbine is used in a variety of traditional medicines.

Traditional Ecological Knowledge

Red columbine is used in an infusion to treat heart conditions, headaches, and fever, and in decoctions for diarrhea and other gastrointestinal issues. The seeds may be used in ceremonial medicines and to add fragrance to perfumes or smoking tobacco.

Responses to Nitrogen and Sulfur

The probability of occurrence for red columbine depends on several variables. The effect of N deposition depends on soil pH (fig. 7.2a). At higher pH (≥ 5.5), the probability of occurrence increases with N deposition up to roughly 7.5 to 10 kg N/ha/yr. At lower soil pH (≤ 4.8), the probability of occurrence is lower and there is little effect from N deposition. The effect of S deposition is weakly dependent on soil pH (fig. 7.2b): as soil pH decreases, the effect of S deposition is stronger. The climate effects are shown in Figure 7.2c (precipitation) and Figure 7.2d (temperature). The probability of occurrence decreases slightly between 750 mm and 1500 mm precipitation and increases with increasing temperatures within the species' sampled range. Confidence in the N and S relationships is moderate, with good model performance ($R^2 = 0.118$, AUC = 0.74; both moderate confidence), low VIFs (VIF-N = 1.4, VIF-S = 1.4; both high confidence), but a high N-S correlation ($r=0.81$, low confidence).



Flower of red columbine.
Chris Evans, University of Illinois, Bugwood.org.

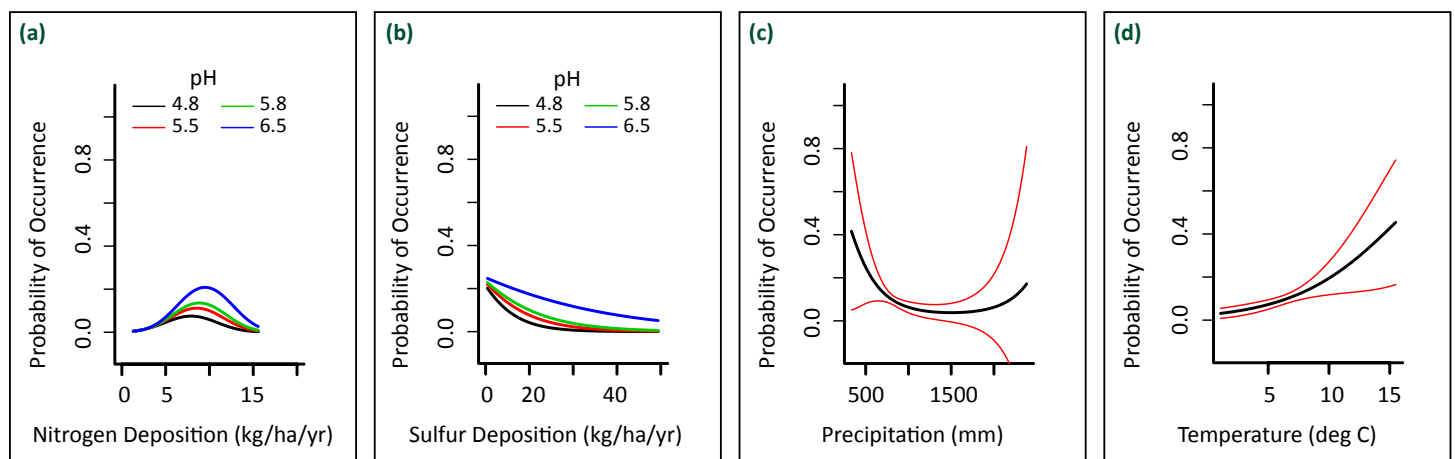


Figure 7.2. Effects of various environmental variables on the probability of occurrence of *Aquilegia canadensis*: a) N x pH interaction, b) S x pH interaction, c) precipitation, d) temperature.

Critical Loads and Exceedances

The environmental hull for red columbine covers the eastern United States and mountainous areas of the West. N CLs are primarily between 8-10 kg N/ha/yr with some lower values along the Appalachian Mountains and higher values in the northern United States. Exceedances of N CLs, based on 2019–2021 TDep total N deposition, occur across most of the eastern United States and in some of the higher mountains of the West. A S CL of 0.4 kg S/ha/yr is consistent across most of the species' range with a higher value of 39.4 kg S/ha/yr in the North Dakota area and the lower elevations of the western mountains. The areas with the lower S CL are all in exceedance, while the areas with the higher critical load are not at risk based on 2019–2021 TDep total S deposition.

Leaves and flowers
of red columbine.
Chris Evans, University
of Illinois, Bugwood.org.

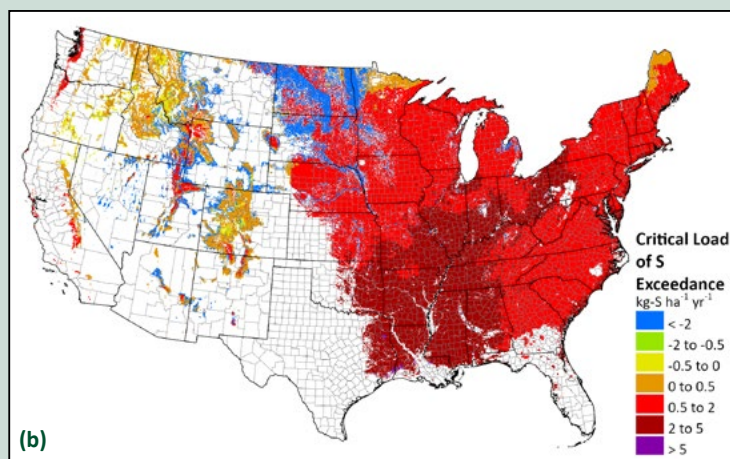
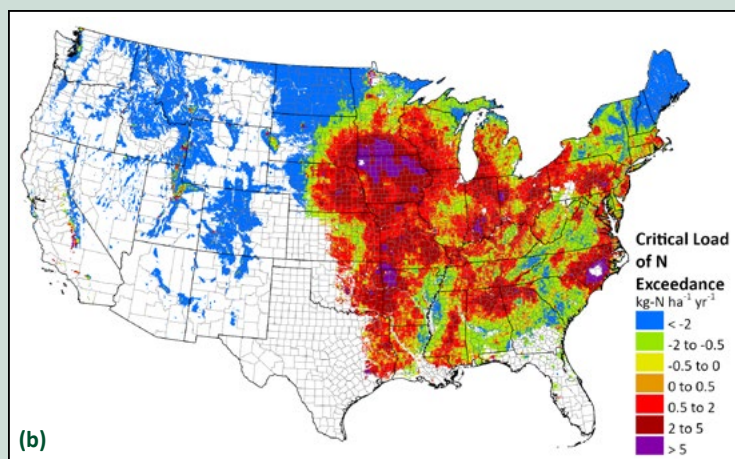
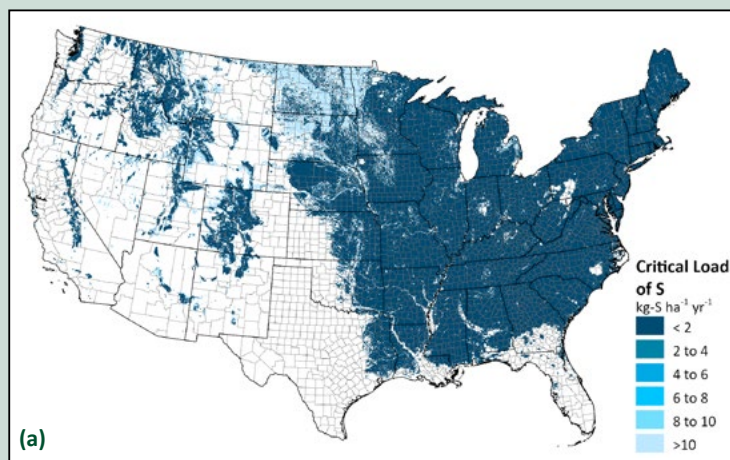
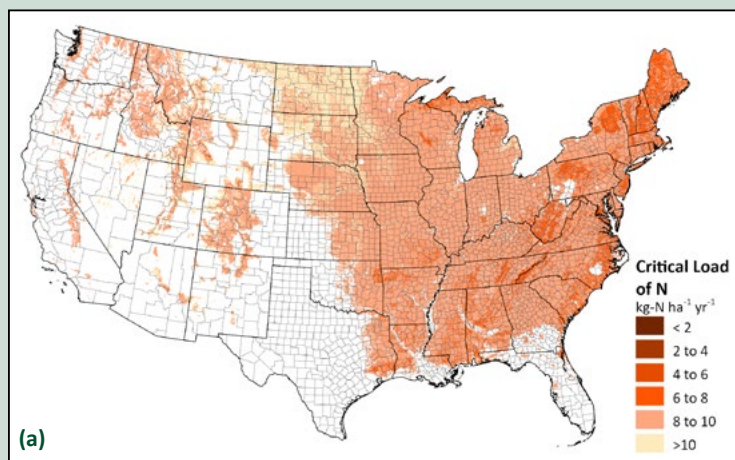


Figure 7.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Aquilegia canadensis* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 7.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Aquilegia canadensis* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

8.0 *Asarum canadense* (Canadian wild ginger)

Distribution and Conservation Status

Canadian wild ginger is a native perennial forb that grows from the northern border of the United States, south to North Carolina, northern Alabama, and northern Louisiana. It is critically imperiled in Louisiana, imperiled in South Dakota, and vulnerable in Illinois, Mississippi, and Kansas (fig. 8.1).

Species Characteristics and Habitat

Canadian wild ginger leaves are produced by the rhizomes and are cordate-rotund to cordate-reniform, mostly 3 to 4.7 inches wide (larger at maturity), and hairy, particularly around the petioles and calyx. The singular, short, reddish-brown flowers are 0.8 to 1.5 inches and grow between the pair of leaves. The fruit is capsular and opens irregularly. The seeds of Canadian wild ginger are large, ovoid, and wrinkled.

Wildlife Uses

Canadian wild ginger is an alternative food source for the pipevine swallowtail butterfly.

Traditional Ecological Knowledge

North American Indigenous cultures recognize medicinal uses of Canadian wild ginger as a treatment for scarlet fever, colds, fevers, urinary disorders, and heart conditions, earaches, as well as stomachache and abdominal cramps. It is also used as fish bait and to flavor meat or fish.

Responses to Nitrogen and Sulfur

The probability of occurrence of Canadian wild ginger depends on several variables. The effect of N deposition depends on soil pH (fig. 8.2a): at higher pH (≥ 5.4), the probability of occurrence is greater and slightly increases

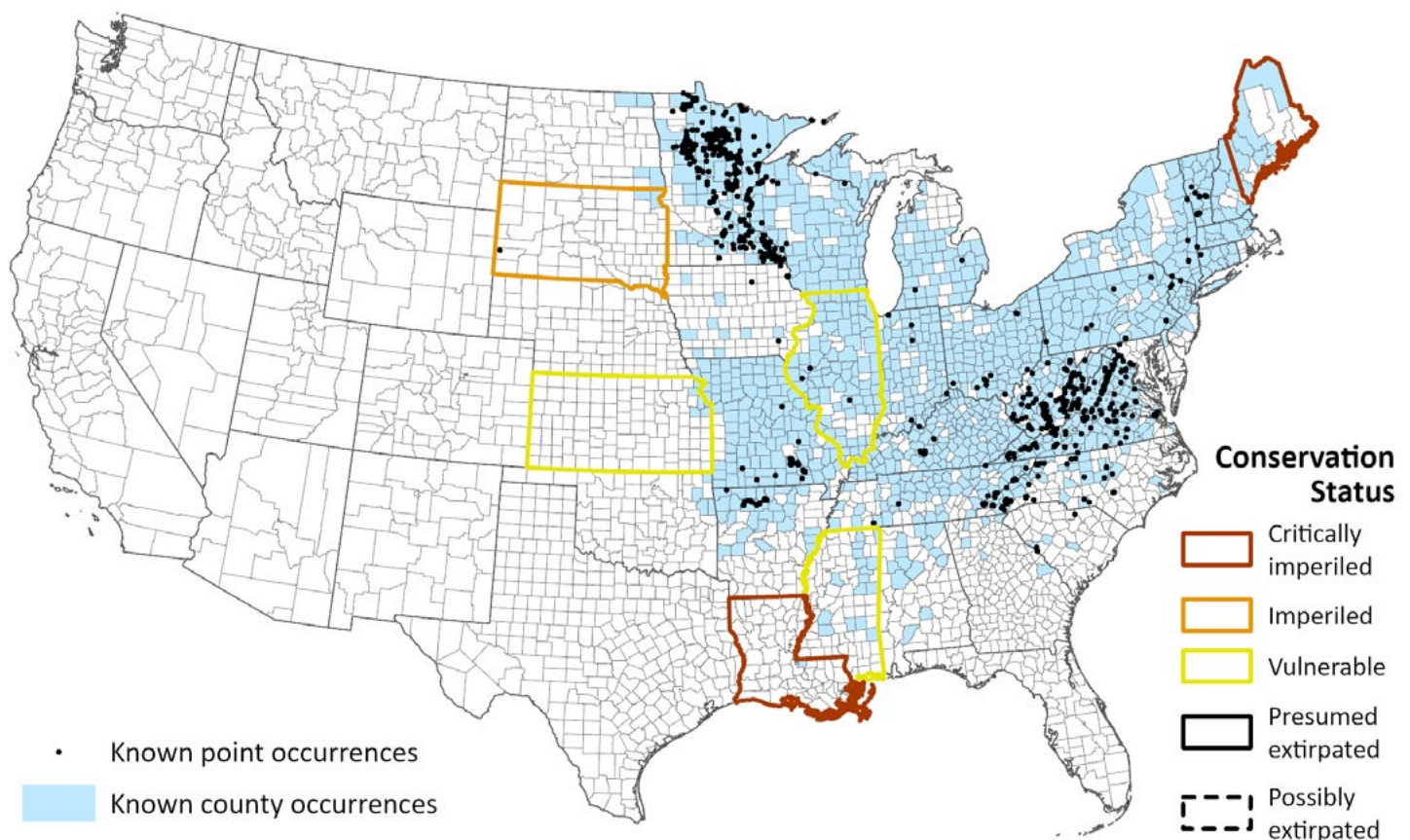


Figure 8.1. Distribution and state-level conservation status of *Asarum canadense*. Known point occurrences were used to assess species deposition responses and critical loads.

with N deposition, whereas at lower pH the species is less common and N deposition has little effect. The effect of S deposition also depends on soil pH (fig. 8.2b): at low pH (≤ 5.4), the probability of occurrence increases with S deposition but at high pH (≥ 5.9), it decreases. This counterintuitive result is likely explained by the N-S correlation. Of the variables tested, the only significant climate variable is precipitation (fig. 8.2c). The probability of occurrence decreases with increasing precipitation within the species' sampled range. Confidence in the N and S relationships is moderate, with good model performance ($R^2 = 0.138$, $AUC = 0.76$; both moderate confidence), low VIFs ($VIF-N = 1.3$, $VIF-S = 1.2$; both high confidence), but a high N-S correlation ($r=0.80$, low confidence).



Leaves of Canadian wild ginger.
Chris Evans, University of Illinois, Bugwood.org.



Flower of Canadian wild ginger.
John Ruter.

Critical Loads and Exceedances

The environmental hull for Canadian wild ginger covers the eastern United States and mountainous areas of the West. The N CL is 18.8 kg N/ha/yr across the species' range. Exceedances of N CLs based on 2019–2021 TDep total N deposition are small and focused in the highest deposition areas of the Midwest and North Carolina. A S CL of 0.4 kg S/ha/yr is consistent across the Midwest and Mountain West, while it has a S CL of 39.4 kg S/ha/yr in the Southeast and Northeast. Areas with the lower S CL have exceedances based on 2019–2021 TDep total S deposition across the Midwest but are not in exceedance in most of the East.

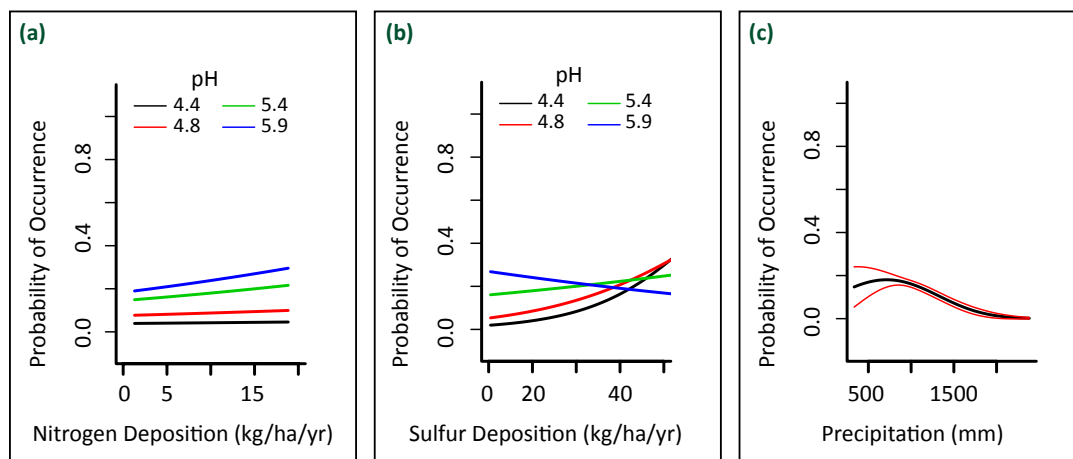


Figure 8.2. Effects of various environmental variables on the probability of occurrence of *Asarum canadense*:
a) N x pH interaction, b) S x pH interaction, c) precipitation.

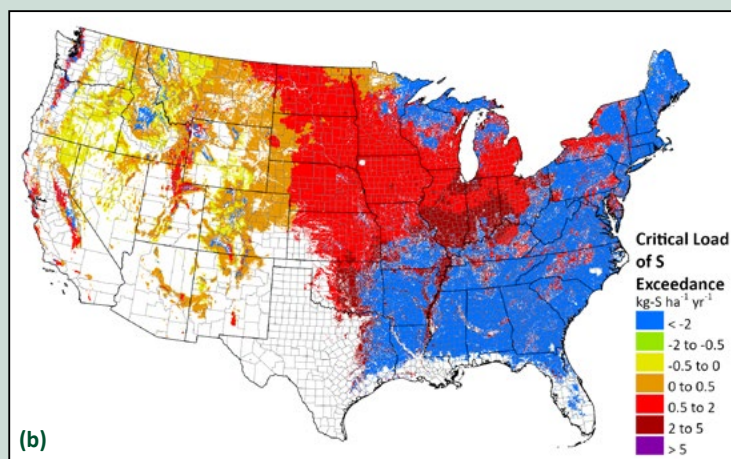
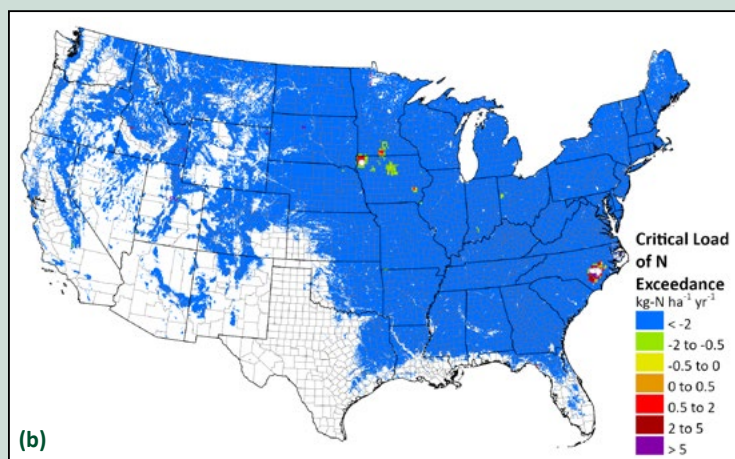
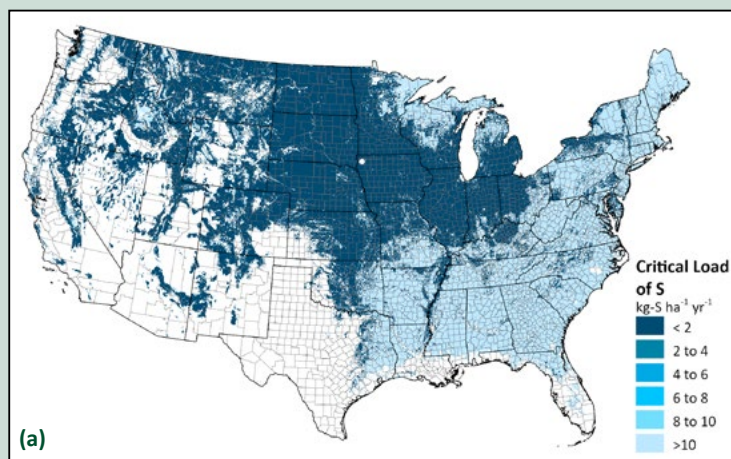
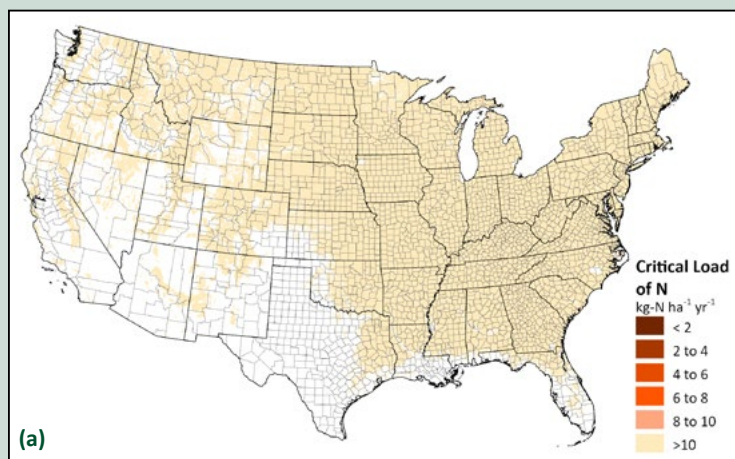


Figure 8.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Asarum canadense* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 8.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Asarum canadense* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

9.0 *Athyrium filix-femina* (common lady fern)

Distribution and Conservation Status

Common lady fern is a native perennial fern that grows from Alaska, south and east to all of the states of the continental United States. It is imperiled in Wyoming and vulnerable in North Dakota (fig. 9.1).

Species Characteristics and Habitat

Common lady fern's tufted, erect fronds may grow to 6 feet while the plant spreads vegetatively from stout, chaffy rhizomes. The sori are curved and covered with an indusium attached to one side.

Common lady fern can inhabit cracks and crevices around rocks. More often it grows as a main plant on perennially wet soil with other herbs. Common lady fern grows in meadows, open thickets, moist woods, and sometimes in swamps. It can survive severe battering if roots are protected and in constant contact with water. It sprouts from rhizomes following a fire.

Wildlife and Livestock Uses

The fronds of common lady fern provide food for grizzly bears. Roosevelt elk eat common lady fern in the autumn on the Olympic Peninsula, but it is not a chief food species. In the Olympic National Forest of Washington, it is recognized as fair elk and deer food. Common lady fern produces filicic acid and therefore may be poisonous to some types of livestock.

Traditional Ecological Knowledge

Traditional medicinal uses include a compound decoction of the roots as an anti-diuretic and an infusion of the stems as a general analgesic.

Responses to Nitrogen and Sulfur

The probability of occurrence for common lady fern depends on several variables. The effect of N deposition depends on S deposition (fig. 9.2a). With low to moderate S deposition (≤ 11.7 kg S/ha/yr), the probability of

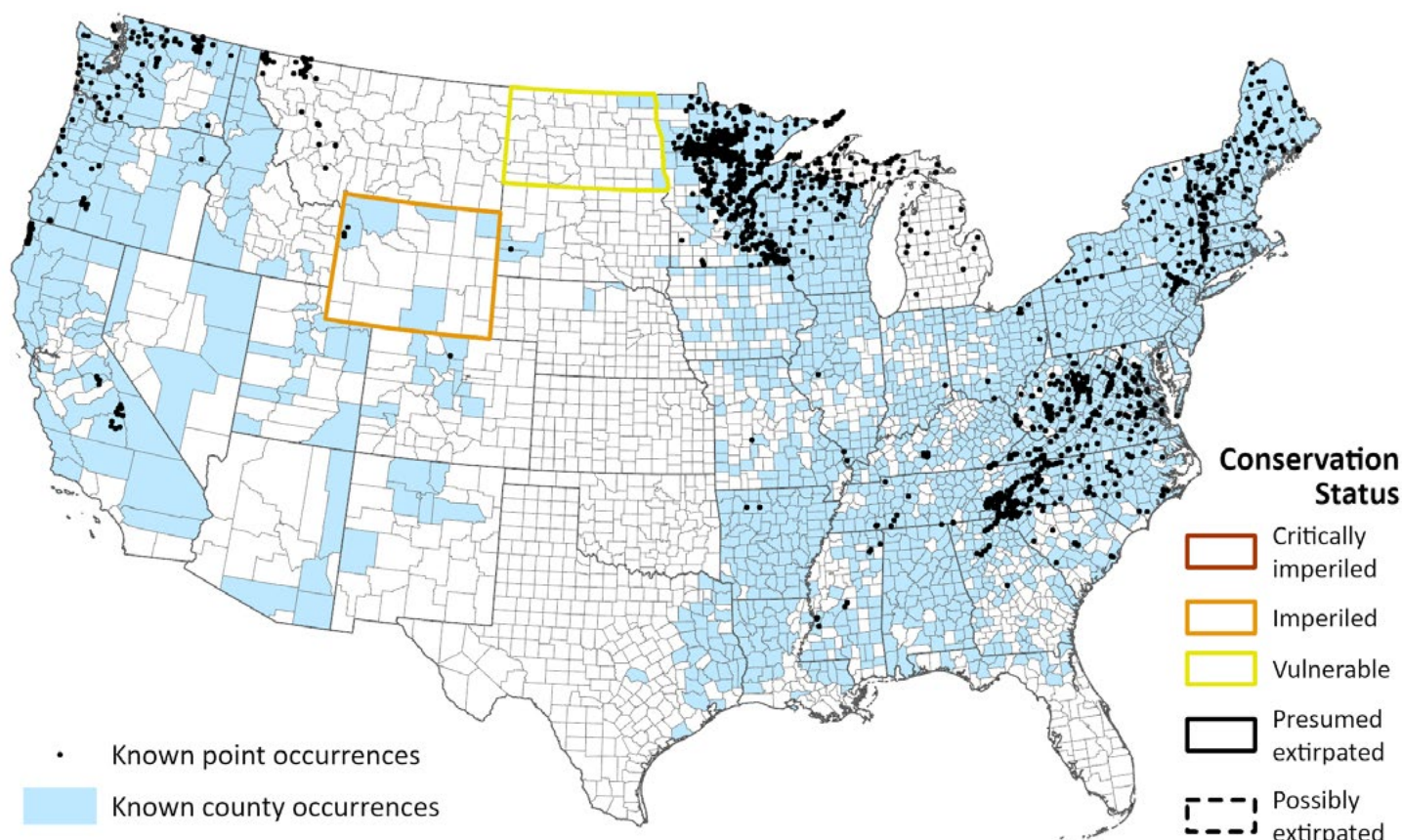


Figure 9.1. Distribution and state-level conservation status of *Athyrium filix-femina*. Known point occurrences were used to assess species deposition responses and critical loads.

occurrence increases with N deposition up to 10-12 kg N/ha/yr and then decreases with N deposition above that. At high S deposition (≥ 14.2 kg S/ha/yr), the probability of occurrence is low, and the effect of N is weaker. The probability of occurrence decreases with S deposition (fig. 9.2b). The climate effects are shown in Figure 9.2c (precipitation) and Figure 9.2d (temperature). The probability of occurrence increases with increasing precipitation and decreases with decreasing temperatures within the species' sampled range. Confidence in the N and S relationships is moderate, with good model performance ($R^2 = 0.148$, $AUC = 0.77$; both moderate confidence), low VIFs ($VIF-N = 1.3$, $VIF-S = 1.2$; both high confidence), but with a high N-S correlation ($r=0.80$, low confidence).



Plant of common lady fern.

Chris Evans, University of Illinois, Bugwood.org.



Foliage of common lady fern.

Chris Evans, University of Illinois, Bugwood.org.

Critical Loads and Exceedances

Suitable environmental conditions for common lady fern covers the eastern United States and mountainous areas of the West. The N CL is ≥ 10 kg N/ha/yr across the species' range. Exceedances of N CLs based on 2019–2021 TDep total N deposition occur in the Midwest, North Carolina, and a few hotspots near eastern cities. A S CL of 0.4 kg S/ha/yr is consistent across the species' range. The S CL is in exceedance based on 2019–2021 TDep total S deposition across the East and most of the West, excluding some western high desert regions.

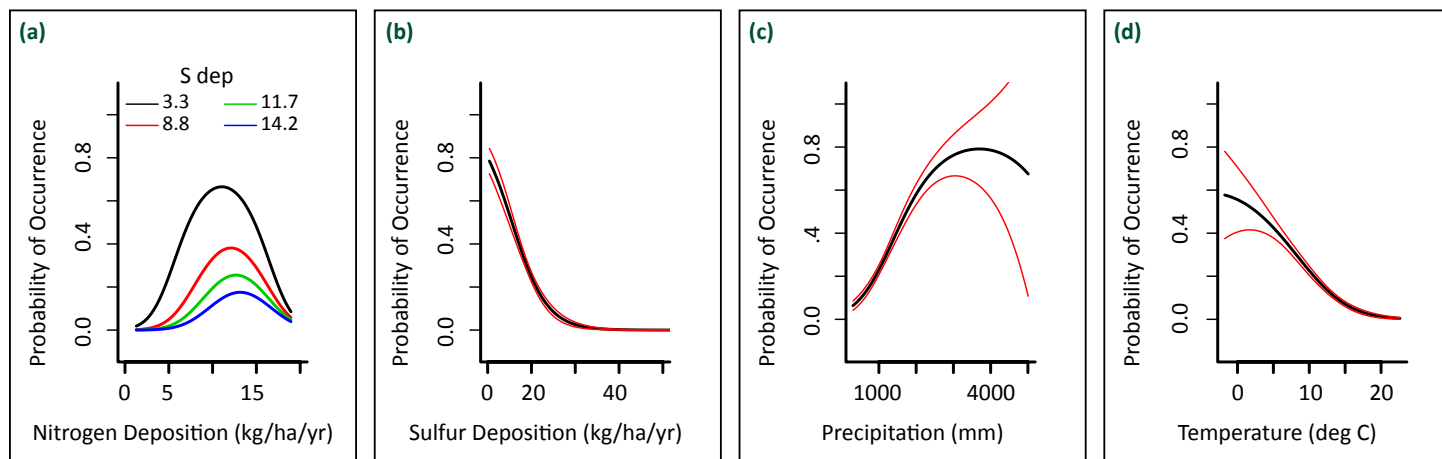


Figure 9.2. Effects of various environmental variables on the probability of occurrence of *Athyrium filix-femina*: a) N x S interaction, b) S deposition, c) precipitation, d) temperature.

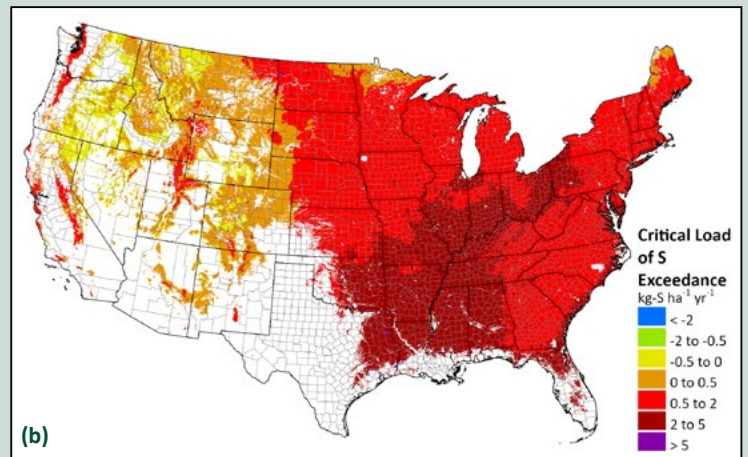
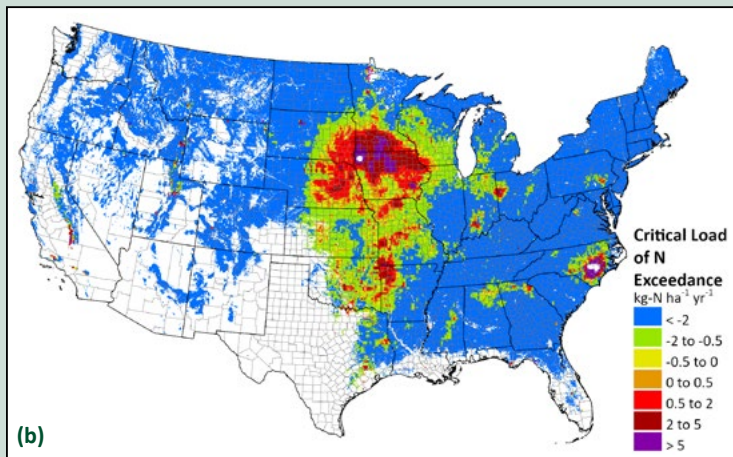
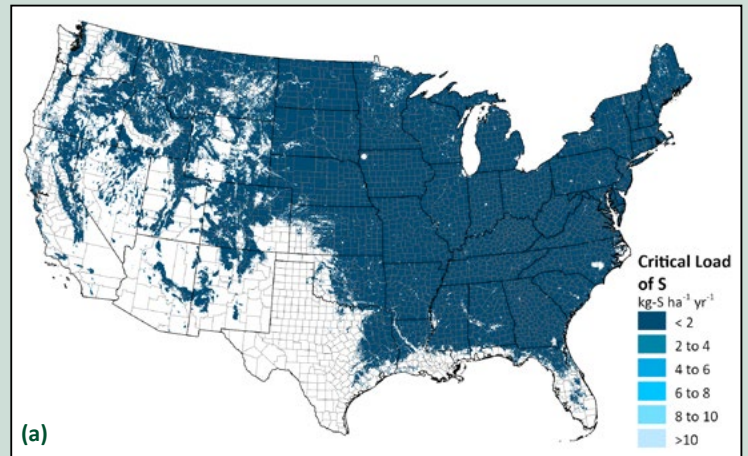
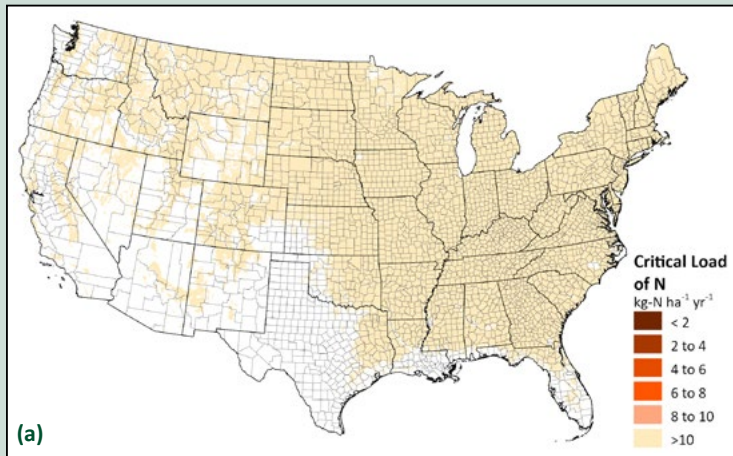


Figure 9.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Athyrium filix-femina* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 9.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Athyrium filix-femina* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

10.0 *Bouteloua curtipendula* (sideoats grama)

Distribution and Conservation Status

Sideoats grama is a native perennial grass that can be found in every state excluding Nevada, Alaska and Hawaii (fig. 10.1).

Species Characteristics and Habitat

It is a medium-sized, warm-season bunchgrass, 3 to 39 inches tall, and the largest and roughest textured of the grama grasses. Its color is bluish green, sometimes with a purplish cast in the spring, changing over time to a reddish-brown or straw color. Its leaves are coarse, straight, stiff, and mostly basal. Ten to 30 small spikes are borne along one side of each central seed stalk. These spikes fall when mature, leaving long, zigzagging stalks.

In the eastern United States, sideoats grama usually grows in dry woods, while in the western States it grows in dry prairies and sandhills. It is a main species in grasslands of the Great Plains, and in desert grasslands of the Southwest. Sideoats grama is adapted to warm-moist and hot-dry sites, but not cold, cool, warm-dry, or hot-moist

sites. It has a modest tolerance to saline soils but grows successfully on calcareous or alkaline soils. Sideoats grama reproduces apomictically or sexually. It is drought resilient.

Wildlife Uses

Sideoats grama offers exceptional nesting cover for an assortment of songbirds and is willingly used by several small mammals. It is highly edible and nutritious. All classes of livestock readily consume it during the late spring and summer. The leaves are usually consumed first before the stems are, as they are more palatable.

Ecosystem Services

Sideoats grama establishes swiftly and delivers excellent erosion control. It is frequently seeded on ranges in the southern Plains to decrease wind erosion, lessen soil temperatures and evaporation, and aid in weed control. Sideoats grama is frequently included in native seed mixes for prairie recovery and is broadly used for reseeding ranges.

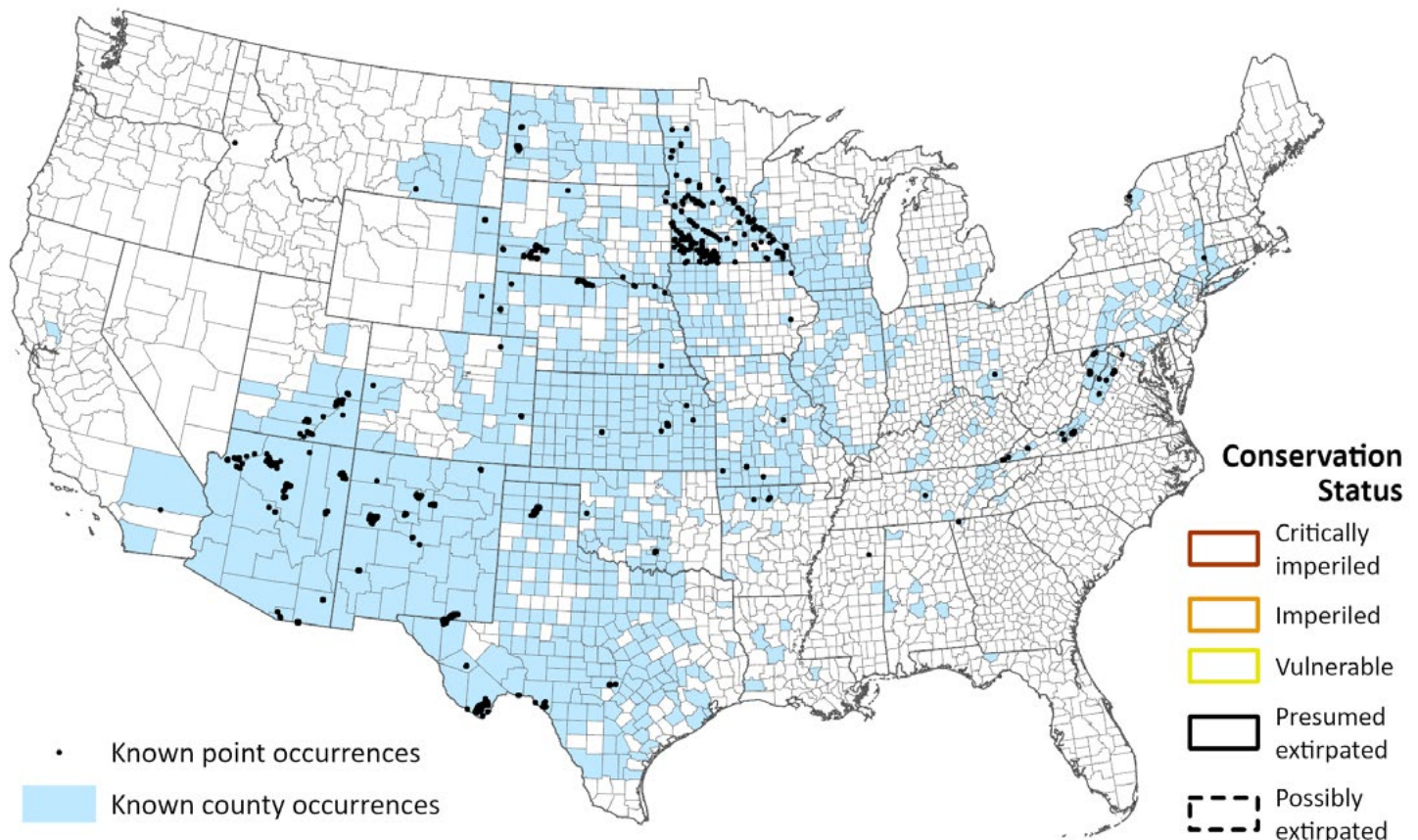


Figure 10.1. Distribution and state-level conservation status of *Bouteloua curtipendula*. Known point occurrences were used to assess species deposition responses and critical loads.

Traditional Ecological Knowledge

Traditional uses of sideoats grama among North American Indigenous cultures included making hairbrushes and brooms from dried bundles of grass, and laying moistened grasses onto hot stones helps prevent steam from escaping during pit cooking.

Responses to Nitrogen and Sulfur

The probability of occurrence for sideoats grama mainly depends on the interaction between N deposition and soil pH (fig. 10.2a). The probability of occurrence increases with N deposition up to 10-12 kg N/ha/yr, with stronger effects at higher soil pH. Sideoats grama is more abundant under moderately alkaline



Flowers of sideoats grama.
Chris Evans, University of Illinois, Bugwood.org.



Plant of sideoats grama.
Howard F. Schwartz, Colorado State University, Bugwood.org.

conditions (fig. 10.2b). The climate effects are shown in Figure 10.2c (precipitation) and Figure 10.2d (temperature). The probability of occurrence decreases with increasing precipitation up to 900 mm and peaks at temperatures around 9 °C within the species’ sampled range. Confidence in the N and S relationships is high, with good model performance ($R^2 = 0.338$, $AUC = 0.85$; both high confidence), low VIFs ($VIF-N = 1.2$, $VIF-S = 1.8$; both high confidence), and a low N-S correlation ($r=0.35$).

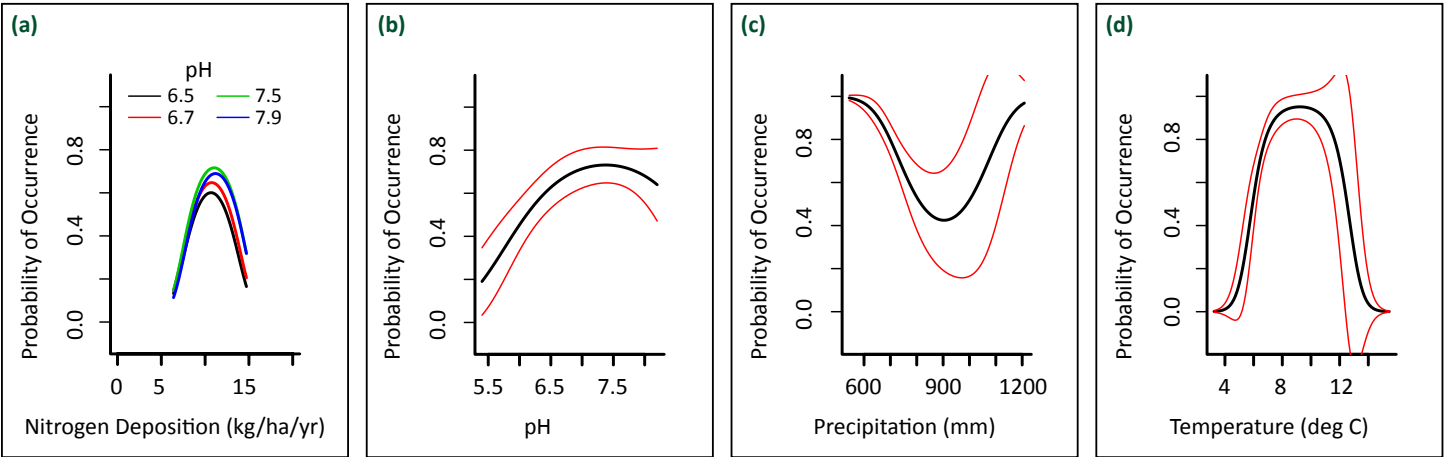


Figure 10.2. Effects of various environmental variables on the probability of occurrence of *Bouteloua curtipendula*: a) N x pH interaction, b) pH, c) precipitation, d) temperature.

Critical Loads and Exceedances

The environmental hull for sideoats grama covers the northern two-thirds of the United States excluding the west coast and Maine. N CL values are all >10 kg N/ha/yr across most of the range with a few areas between 8

and 10 kg N/ha/yr in the Northeast. Exceedances of N CLs based on 2019–2021 TDep total N deposition exist in high N deposition areas in most midwestern States and along the Appalachian Mountains. No responses to S deposition have been observed.

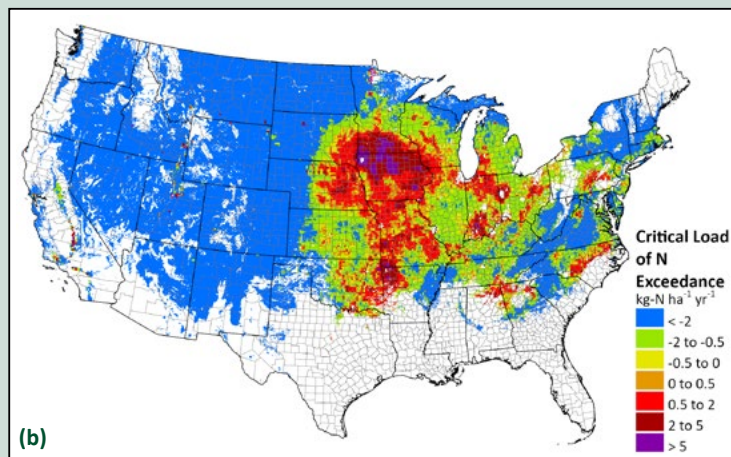
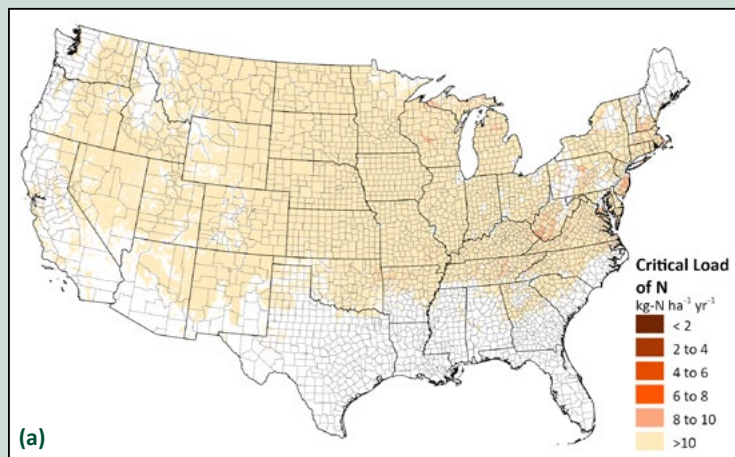


Figure 10.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Bouteloua curtipendula* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

11.0 *Bouteloua gracilis* (blue grama)

Distribution and Conservation Status

Blue grama is a native perennial grass found throughout the Rocky Mountains, Great Plains, Midwest and some eastern states. It grows on sagebrush steppes, salt-desert shrub communities, dry prairies and sandhills in the Northeast, evergreen oak woodlands and semi-desert grasslands in the Southwest, ponderosa pine communities, and the Great Plains. However, in Michigan it spreads like an invasive plant. It is critically imperiled in Florida, Louisiana, Michigan, and Connecticut, imperiled in New York, Pennsylvania, Maryland, and Georgia, and vulnerable in Illinois, Indiana, West Virginia, and Mississippi (fig. 11.1).

Species Characteristics and Habitat

Blue grama is compactly tufted and its height ranges from 6 to 12 inches. Roots of individual blue grama plants generally extend 12 to 18 inches from the edge of the plant and 3 to 6 feet deep. Blue grama patches

occasionally form ring patterns as it develops a crown that is pedestaled on roots that extend about 1 inch above the soil. As a result of the root exposure, plants can lose vigor and die from parasites and diseases. Blue grama is solid-stemmed, and the flowering stems normally grow 7 to 18 inches tall. The leaves are flat and taper to a point. It can grow as a bunchgrass and can form thick mats which often results in an open sod character. Its seeds are dispersed by wind, insects, ingestion by large herbivores, and by gripping to animal hides, fur, and feathers.

The elevational distribution of blue grama in North America has a range of 985 to 9,850 feet. It generally requires 8 to 15 inches of annual precipitation. Blue grama shows good drought, fair salinity, and moderate alkalinity tolerances. It grows on clay, silt, fine loams, loams, sandy loams, sand, and gravelly soils and is cold tolerant. Although it is top-killed by fire, blue grama has variable fire tolerance, surviving better when it is dormant but experiencing some damage.

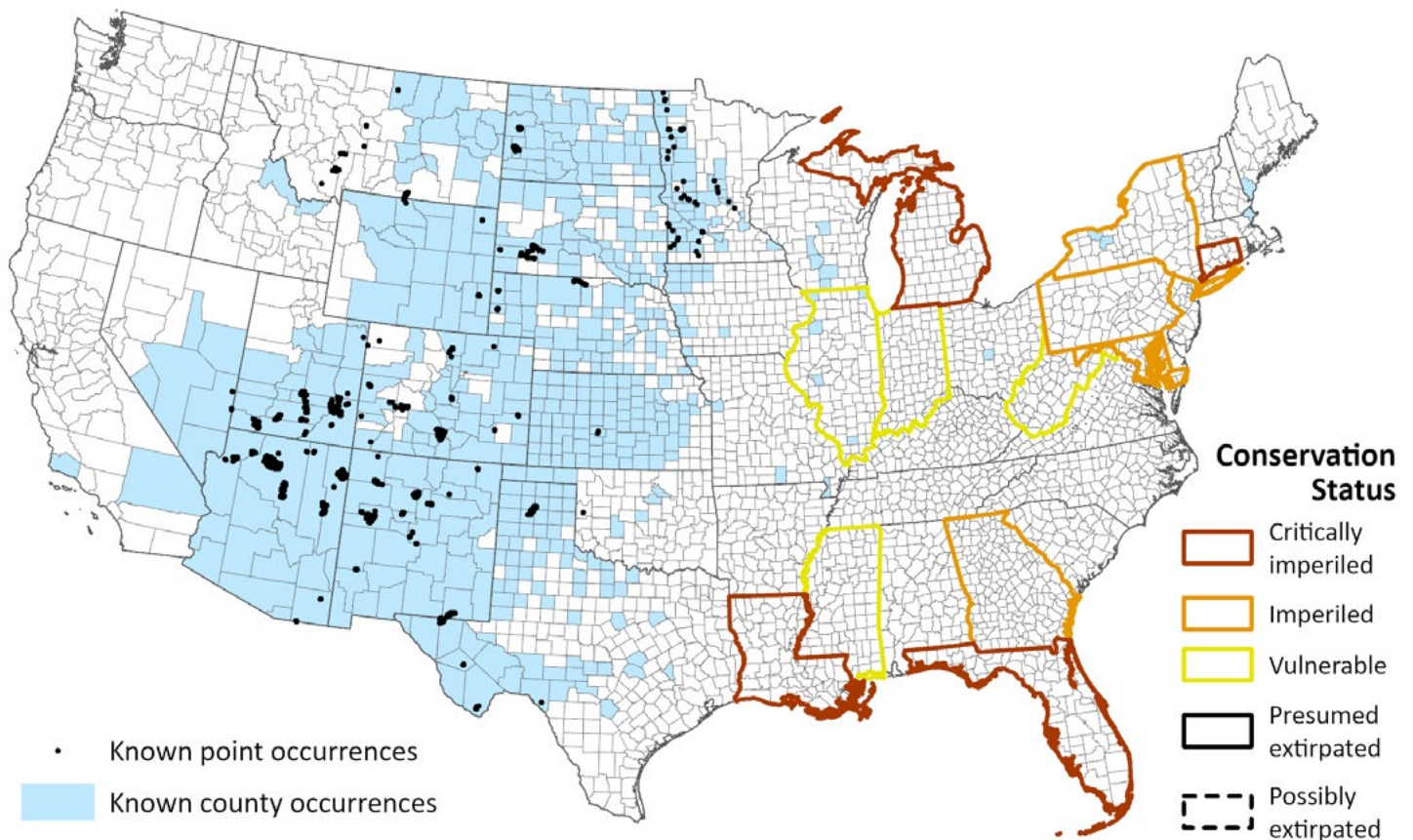


Figure 11.1. Distribution and state-level conservation status of *Bouteloua gracilis*. Known point occurrences were used to assess species deposition responses and critical loads.

Wildlife and Livestock Uses

Blue grama is a significant forage for mule deer, good forage for pronghorns, and impacts seasonal bison movements. Scaled quail and a variety of songbirds eat the seeds. The seeds and stems provide an important food source for small mammals such as prairie dogs, pocket gophers, and black-tailed jackrabbits in the Great Plains. Flower heads and seeds are highly palatable forage for grasshoppers. It is excellent forage for all types of domestic livestock. It provides valuable forage for cattle and sheep. Blue grama makes up about 40% of cattle diet on the shortgrass steppe.

Ecosystem Services

Blue grama is helpful for reclaiming and controlling erosion in arid and semiarid regions. It forms sod, is a low maintenance turf grass, and is useful in revegetating mined lands.



Flowers of blue grama.

Dave Powell, USDA Forest Service (retired), Bugwood.org.

Traditional Ecological Knowledge

The stems can be used as comb and broom material.

Responses to Nitrogen and Sulfur

The probability of occurrence of blue grama depends on several variables. The effect of N deposition depends on S deposition (fig. 11.2a). At low S deposition (≤ 2.6 kg S/ha/yr), the probability of occurrence increases with N deposition, but under higher S deposition (≥ 3.7 kg S/ha/yr), the probability of occurrence decreases with N deposition. The effect of N deposition also depends on soil pH (fig. 11.2b). The probability of occurrence decreases as N deposition increases, and the amount of decrease is greater under lower pH. The climate effects are shown in Figure 11.2c (precipitation) and Figure 11.2d (temperature). The probability of occurrence increases with decreasing precipitation (but note widening confidence bands) and increases with increasing temperature between 6 °C and 10 °C within the species' sampled range. Confidence in the N and S relationships is moderate, with good model performance ($R^2 = 0.268$, AUC = 0.86, high confidence for both), low VIFs (VIF-N = 1.5, VIF-S = 2.1, both high confidence), a high N-S correlation ($r=0.71$, low confidence).

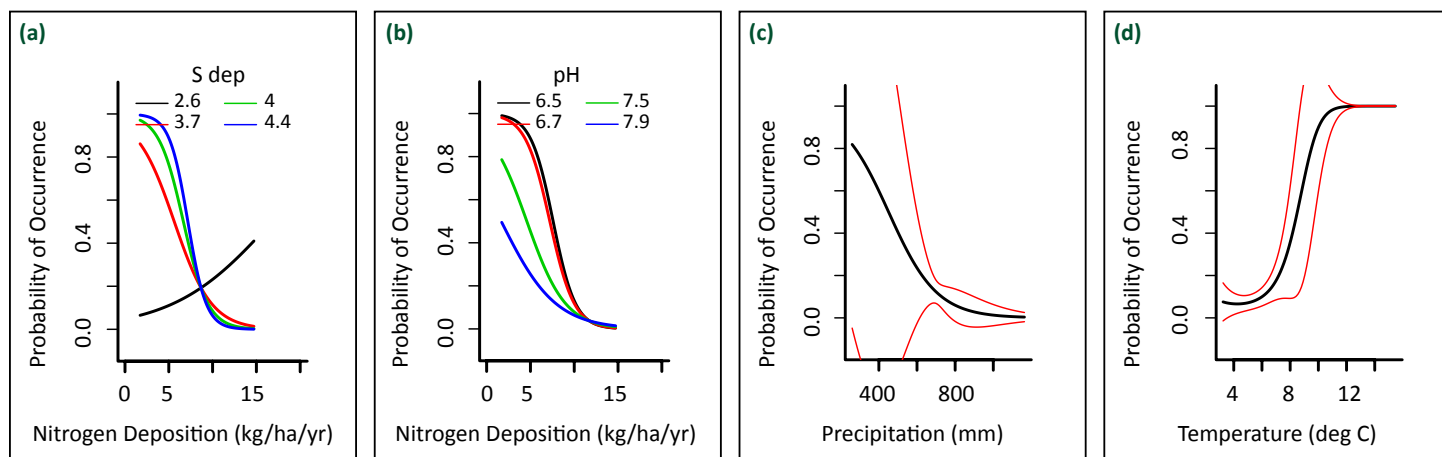


Figure 11.2. Effects of various environmental variables on the probability of occurrence of *Bouteloua gracilis*: a) N x S interaction, b) N x pH interaction, c) precipitation, d) temperature.

Critical Loads and Exceedances

The environmental hull for blue grama covers the western United States and northern Midwest States. The N CL is ≥ 10 kg N/ha/yr in the West and ≤ 2 kg N/ha/yr in the eastern part of its range. Exceedances of N CLs based on 2019–2021 TDep total N deposition occur in the lower CL regions. The S CL is 0.4 kg S/ha/yr in the western part of the species' range and is 13.3 kg S/ha/yr in the West. Modeled total S deposition from TDep 2019–2021 shows that the S CL is in exceedance in areas with the lower CL in the Midwest, East, and central California.



Stems and fruits
of blue grama.
Karen A. Rawlins.

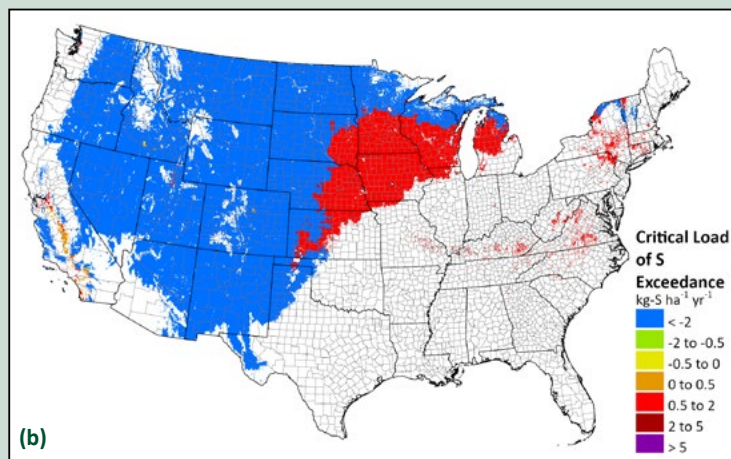
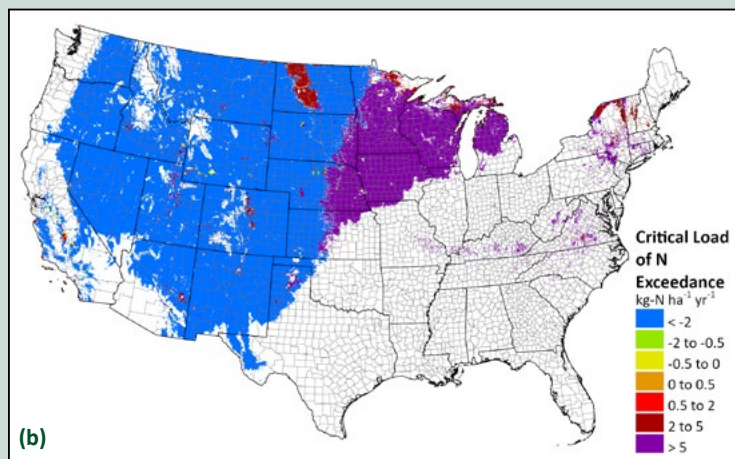
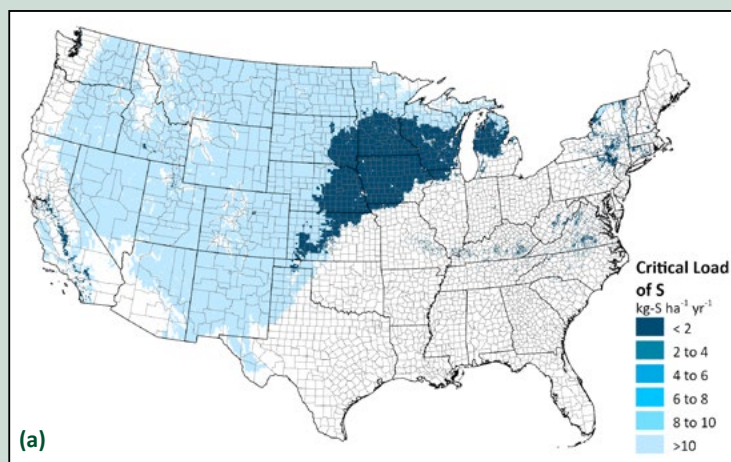
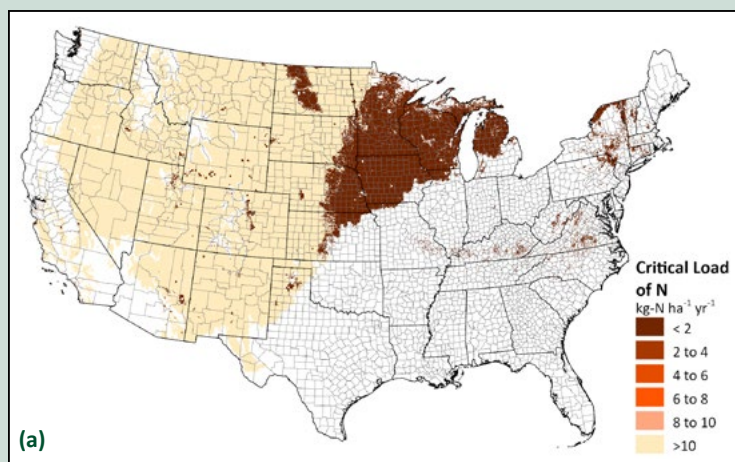


Figure 11.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Bouteloua gracilis* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 11.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Bouteloua gracilis* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

12.0 *Bromus ciliatus* (fringed brome)

Distribution and Conservation Status

Fringed brome is a native perennial grass that grows from Alaska south to California and east through the western States and Great Plains. It occurs discontinuously through the midwestern, northeastern, and east coast states. It is critically imperiled in Missouri, imperiled in Illinois and Idaho, and vulnerable in Iowa (fig. 12.1).

Species Characteristics and Habitat

Fringed brome is non-rhizomatous, and usually tufted. The root system of fringed brome is well developed. The leaf blades are flat, up to ½-inch wide and 6 to 10 inches long. The panicle is narrow and elongate, ranging from 2 to 7 inches with branches ascending and drooping near the end.

Fringed brome occurs in various habitats such as woodlands, forest openings, thickets, grasslands, shrublands, prairies, meadows, marshes, bogs, fens, and stream and lake margins. Loam, silty loam, and sand is where fringed brome grows best but it occurs on stony or

rocky surfaces as well. Its preferred soil pH ranges from 4.8 to 7.9. It reproduces solely from seeds. The seeds are non-dormant and have high germination rates. Fringed brome has low tolerance to fires of moderate and high severity.

Wildlife and Livestock Uses

In Arizona and New Mexico, fringed brome is an important forage species for deer, elk and livestock during the summer. Small mammals, turkeys and other birds rely on the seeds as an important source of food. Pocket gophers in Colorado find the fringed brome to be an ideal habitat. Fringed brome has fair energy content and poor protein for wildlife and livestock. In Wyoming, it is considered one of the best range grasses and is browsed by many types of livestock.

Ecosystem Services

Fringed brome can help to control erosion and aids in short-term revegetation. It is excellent for long-term revegetation.

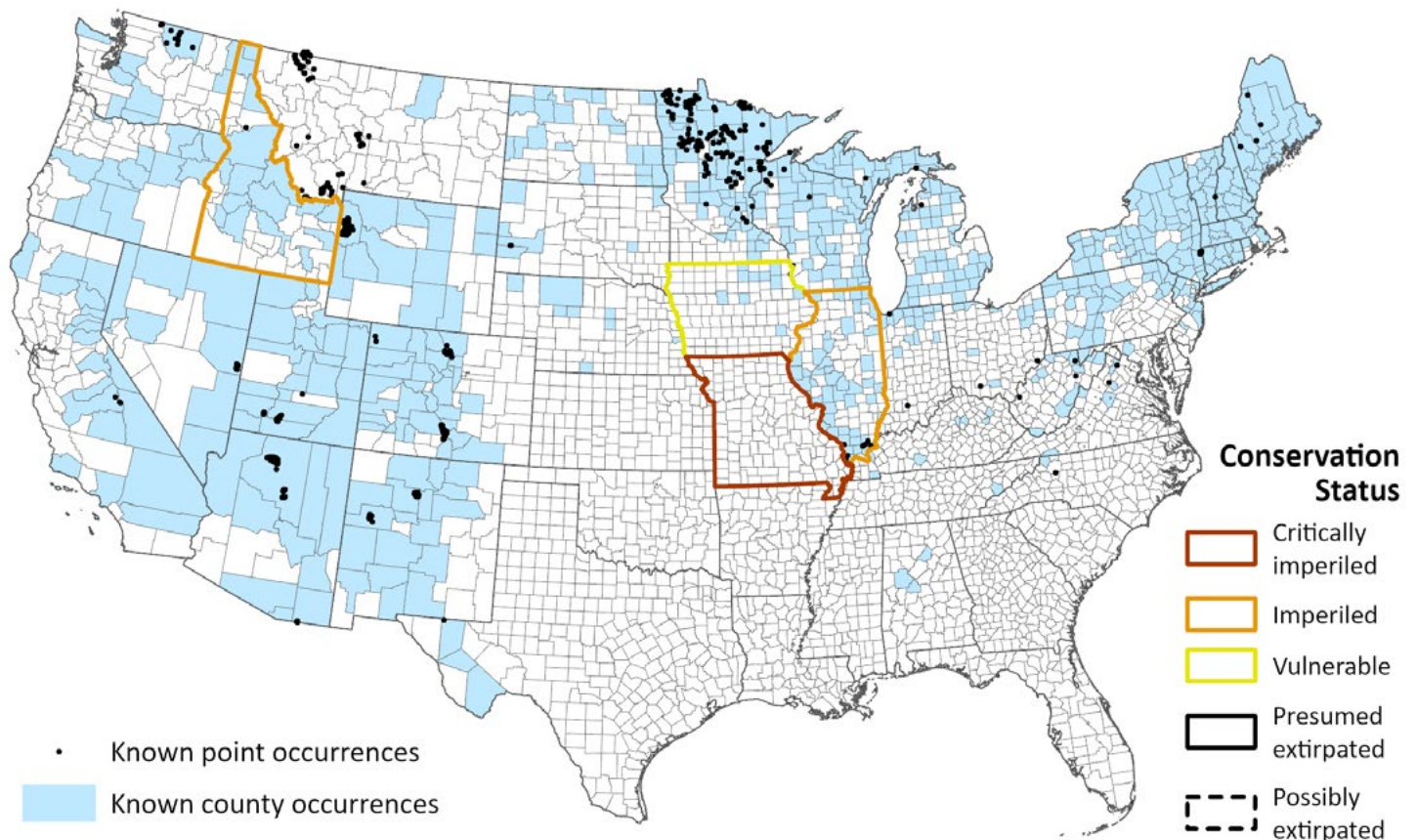


Figure 12.1. Distribution and state-level conservation status of *Bromus ciliatus*. Known point occurrences were used to assess species deposition responses and critical loads.

Traditional Ecological Knowledge

A traditional agricultural practice prior to planting season involves soaking corn in a medicinal decoction of the plant.

Responses to Nitrogen and Sulfur

The probability of occurrence for fringed brome depends on several variables, including S deposition (fig. 12.2a) and the interaction between N and S deposition (fig. 12.2b). The effect of S deposition is pronounced with a strong decrease in the probability of occurrence as S deposition approaches 5 kg S/ha/yr. At high S deposition (≥ 3.7 kg S/ha/yr), the species is rarely observed, and the effect of N deposition is weaker. Under lower S deposition (≤ 1.8 kg S/ha/yr), the probability of occurrence begins increasing with N deposition around 3-5 kg N/ha/yr and then decreases above 7 kg N/ha/yr. The climate effects



Fruits of fringed brome.

Dave Powell, USDA Forest Service (retired), Bugwood.org.

are shown in Figure 12.2c (precipitation) and Figure 12.2d (temperature). The probability of occurrence peaks broadly at 1000 mm precipitation and increases with temperatures above 6 °C within the species' sampled range. Confidence in the N and S relationships is moderate, with good model performance ($R^2 = 0.158$, $AUC = 0.78$; both moderate confidence), low VIFs ($VIF-N = 1.3$, $VIF-S = 1.4$; both high confidence), and a high N-S correlation ($r=0.76$, low confidence).

Critical Loads and Exceedances

The environmental hull for fringed brome covers the northern half United States outside of western, coastal areas. The N CL is 4-8 kg N/ha/yr in the West and ≥ 8 -10 kg N/ha/yr in the eastern part of its range. Exceedances of N CLs based on 2019–2021 TDep total N deposition occur across the Midwest, agricultural areas in North Carolina, the California Central Valley, and the valleys between Salt Lake City, UT and Bozeman, MT. The S CL is 0.4 kg S/ha/yr in the western, southeast, and northeast part of the species' range, and is 27.6 kg S/ha/yr in a band across the Midwest. Modeled sulfur deposition for 2019–2021 (TDep) indicates that S CLs are in exceedance in areas with the lower CL in the Midwest and East, and within central California and mountainous areas of the West.

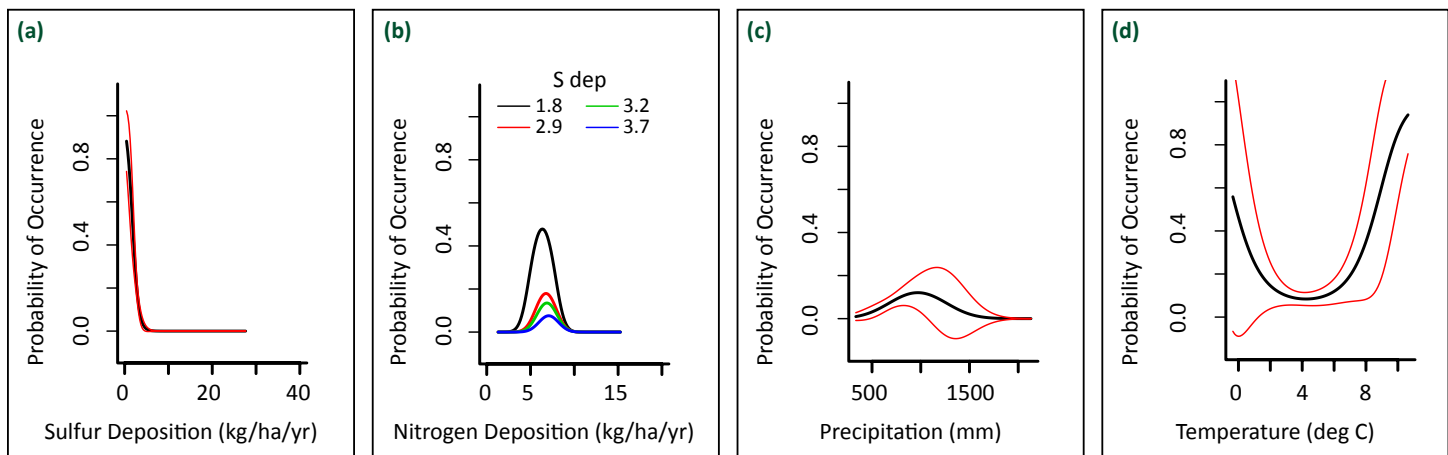


Figure 12.2. Effects of various environmental variables on the probability of occurrence of *Bromus ciliatus*: a) S deposition, b) N x S interaction, c) precipitation, d) temperature.

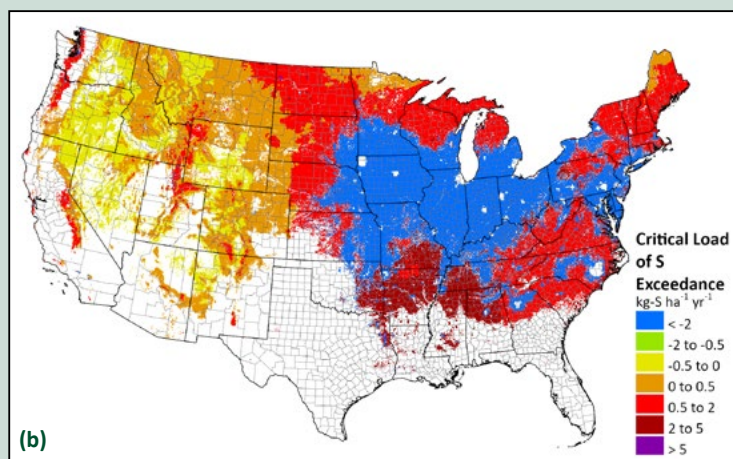
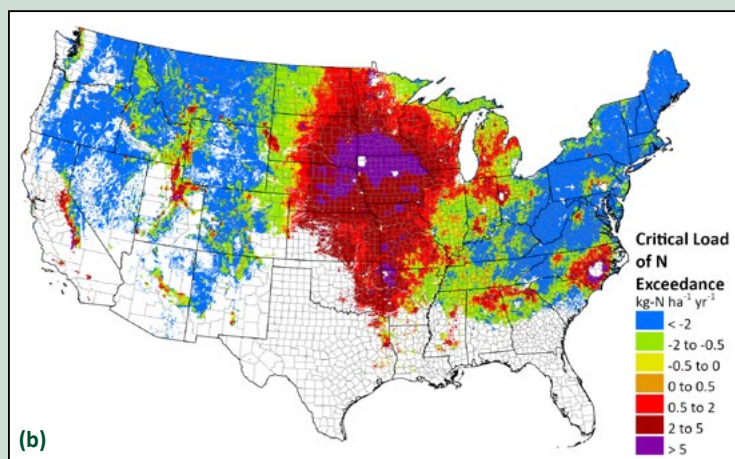
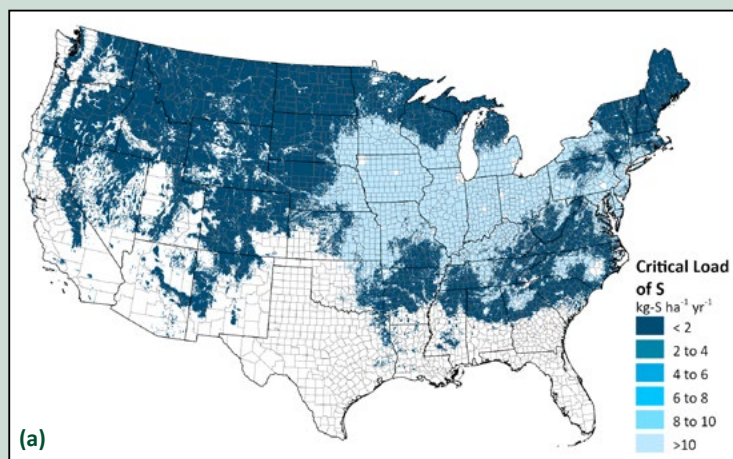
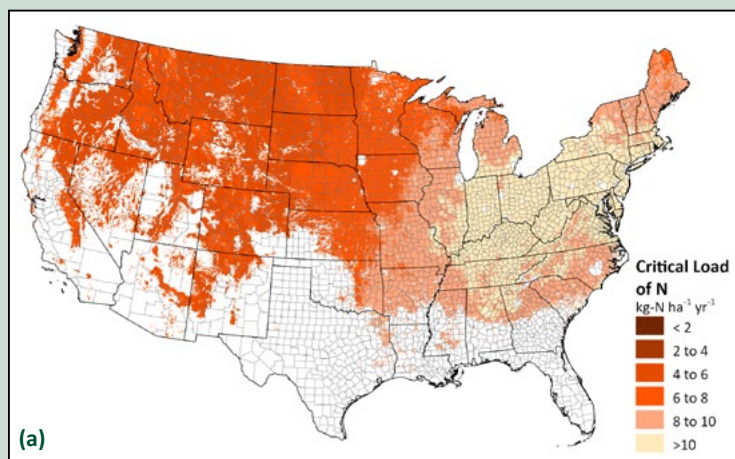


Figure 12.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Bromus ciliatus* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 12.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Bromus ciliatus* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

13.0 *Bromus inermis* (smooth brome)

Distribution and Conservation Status

Smooth brome is a nonnative perennial grass that occurs throughout North America. It is critically imperiled in North and South Carolina and vulnerable in Nebraska and Iowa (fig. 13.1).

Species Characteristics and Habitat

It is native to Eurasia and can be weedy and invasive in most ecosystems, often displacing native plants if not correctly maintained. Smooth brome is a leafy, cool-season grass ranging in height from 2 to 4 feet. It grows several basal and stem leaves that range in length from 4 to 10 inches, extends by rhizomes, and can be sod-forming. The flower head develops a distinctive rich purplish-brown color when mature.

Smooth brome prefers acidic to slightly alkaline, well drained, clay loam soils with high fertility. It also grows well on lighter textured soils where adequate moisture and fertility are sustained. It grows best in a pH range of 6.0 to 7.5. It can survive through droughts and extreme

temperatures. Smooth brome is vulnerable to disease in locations with high humidity. Grasshoppers and seedling disease are factors that may deter establishment.

Wildlife and Livestock Uses

Elk consume smooth brome in the winter for food. Mule deer in central Utah have been known to eat it occasionally, but deer utilization of smooth brome is normally considered good. Geese and small rodents such as pocket gophers also use it for forage. Smooth brome cultivars have been bred for nutritional quality and adaptation to certain climates. As a result, smooth brome is one of the most essential exotic forage grasses in the United States and is extensively planted in pastures and rangelands.

Ecosystem Services

Smooth brome is highly palatable in its early stages of growth. Palatability and nutritional quality decrease quickly after flowering. Smooth brome has been widely used for site rehabilitation. It can tolerate cold

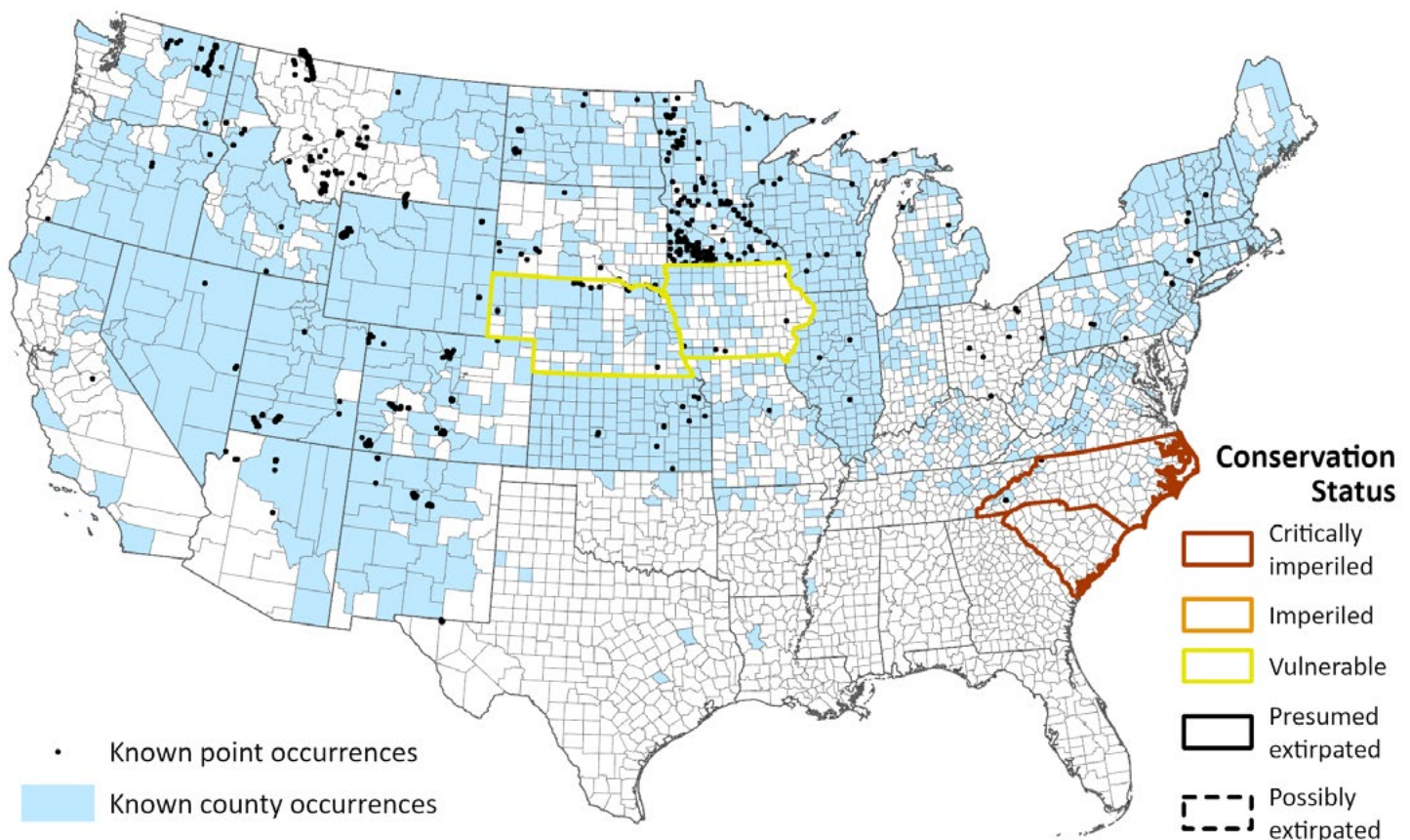


Figure 13.1. Distribution and state-level conservation status of *Bromus inermis*. Known point occurrences were used to assess species deposition responses and critical loads.

temperatures, droughts, and is resistant to saline soils. The ability of most cultivars to spread through rhizomes makes smooth brome a good soil binder and excellent for erosion control and streambank and stream bottom stabilization throughout the United States. Smooth brome has also been effective in restoring mined lands, game ranges, roadsides, and ski areas. It can survive fire by sprouting from its extensive rhizome network. Smooth brome may be used for hay, pasture, or silage.



Fruits of smooth brome.
John M. Randall.

Responses to Nitrogen and Sulfur

The probability of occurrence of smooth brome depends on several variables. The effect of N deposition depends somewhat on soil pH (fig. 13.2a): N deposition increases the probability of occurrence, and it increases more under alkaline than acidic conditions. The effect of S deposition is not contingent on other variables and leads to a decrease in the probability of occurrence (fig. 13.2b). The climate effects are shown in Figure 13.2c (precipitation) and Figure 13.2d (temperature). The probability of occurrence decreases sharply with increasing precipitation and increases with increasing temperatures within the species' sampled range. Confidence in the N and S relationships is moderate-to-high, with good model performance ($R^2 = 0.24$, AUC = 0.83; moderate and high confidence, respectively), low VIFs (VIF-N = 1.1, VIF-S = 1.2), and a moderate N-S correlation ($r=0.55$, moderate confidence).

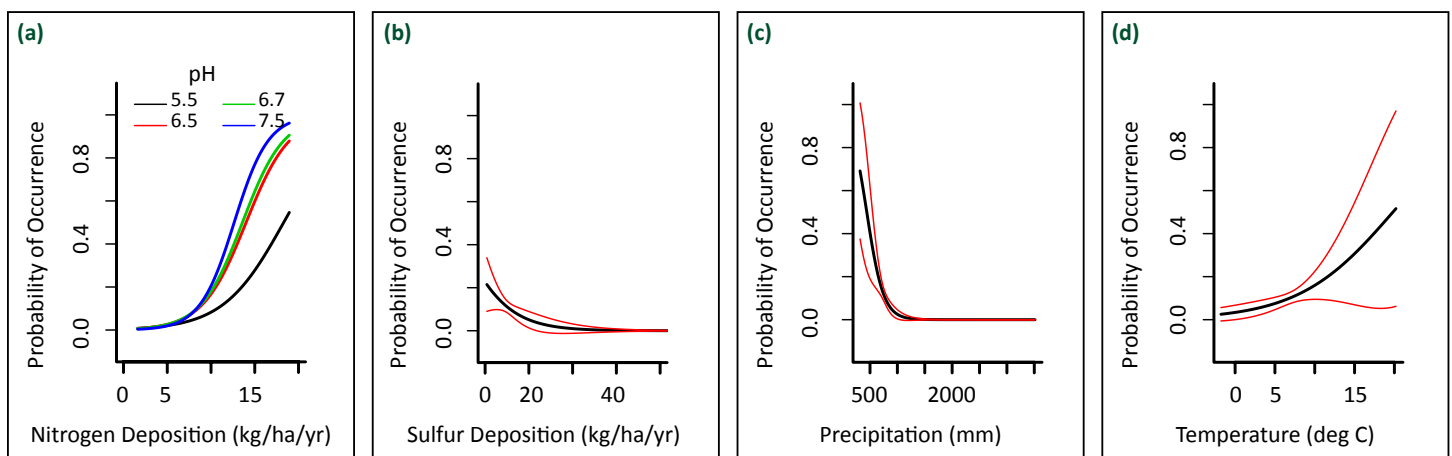


Figure 13.2. Effects of various environmental variables on the probability of occurrence of *Bromus inermis*: a) N x pH interaction, b) S deposition, c) precipitation, d) temperature.

Critical Loads and Exceedances

The environmental hull for smooth brome covers the northern half of the United States. It is mostly absent west of the coastal ranges in CA, OR, and WA and from central and western Montana and areas of the Midwest. The N CL is ≥ 10 kg N/ha/yr across the whole range. Exceedances of N CLs based on 2019–2021 TDep total N deposition are limited to small regions in the Midwest. The S CL is 0.4 kg S/ha/yr across the species' range. The S CL is in exceedance based on 2019–2021 TDep total S deposition in the Midwest and East, and within central California and mountainous areas of the West.



Flowers of smooth brome. Ohio State Weed Lab, Ohio State University.

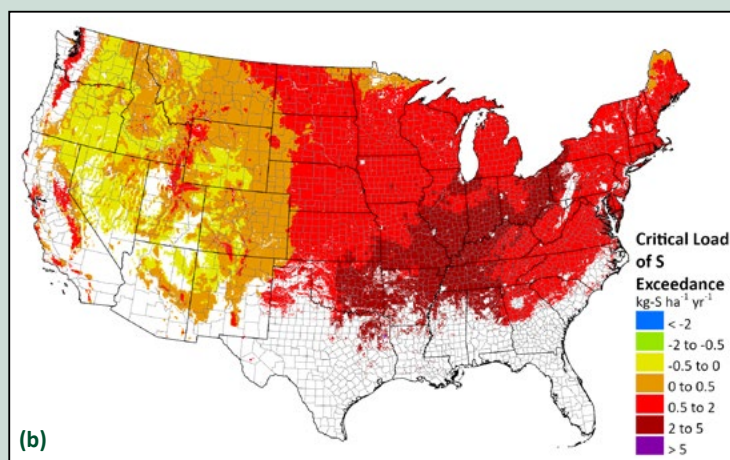
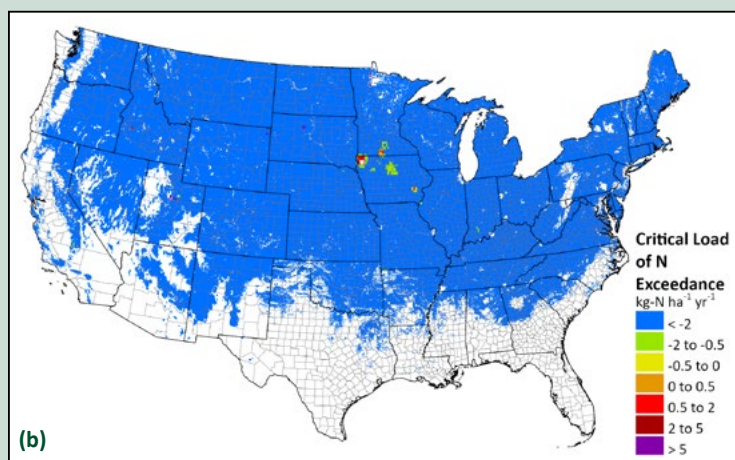
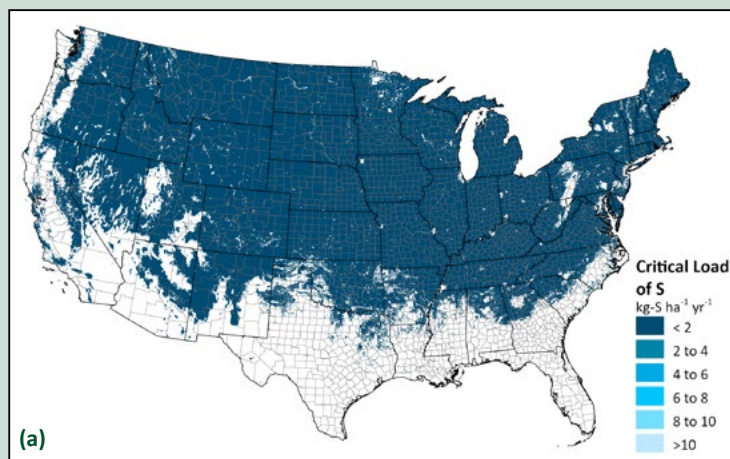
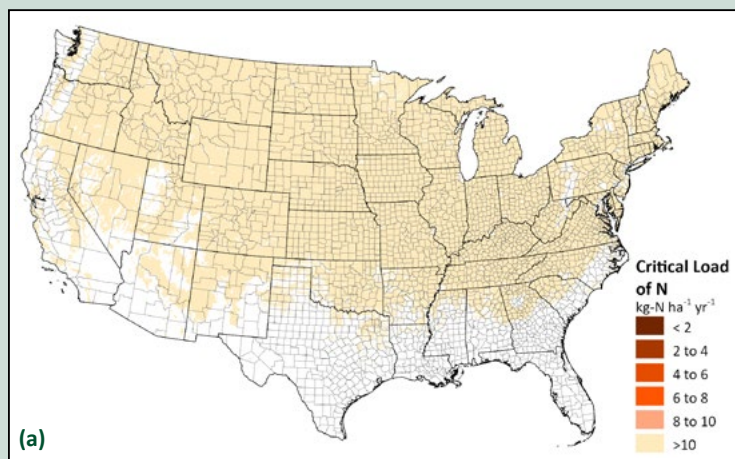


Figure 13.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Bromus inermis* and (b) the exceedance of N critical loads based on TDep 2019–2021 total N deposition.

Figure 13.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Bromus inermis* and (b) the exceedance of S critical loads based on TDep 2019–2021 total S deposition.

14.0 *Carex pensylvanica* (Pennsylvania sedge)

Distribution and Conservation Status

Pennsylvania sedge is a native perennial sedge that inhabits upland plains grass-dominated ecosystems. It grows from the eastern seaboard and the northern United States border west to North Dakota and Missouri. It is vulnerable in Illinois, Missouri, and Arkansas (fig. 14.1).

Species Characteristics and Habitat

It is grass-like, rhizomatous, and low-growing. The leaves are long and narrow ranging from 4 to 18 inches in length, and the stems are about the same height. Pennsylvania sedge inhabits upland plains grass-dominated ecosystems.

It is a sturdy competitor that slows invasion of trees and shrubs and is increased by grazing. It can be dominant in meadows in the Great Lakes region and frequent in forest understories. Pennsylvania sedge occurs on well-drained sites and grows in soils ranging from clay, silty clay loam, sandy loams, to alluvial deposits. It can grow in soil types that are slightly acidic, relatively infertile, of coarse or fine texture. However, it grows best in dry, deciduous forests

and grasslands or other dry, open areas. It is moderately shade tolerant. The cool, early part of the growing season before other prairie grasses begin growth is when Pennsylvania sedge grows most rapidly. It reproduces mainly by vegetative means. Fires generally top-kill Pennsylvania sedge. However, it is unlikely to survive or regenerate after hot fires because its roots and rhizomes do not permeate deep into the soil.

Wildlife Uses

Pennsylvania sedge offers shelter for migratory waterfowl and sandhill cranes. Ducks use it for nesting material and some cover. Pennsylvania sedge also provides nesting habitat, cover, and grounds for mating rituals for sharp-tailed grouse, prairie chickens, and mallards.

Ecosystem Services

Pennsylvania sedge commonly establishes on disturbed locations through intense rhizome production. It occupies burned and/or clear-cut plots and forms pure stands.

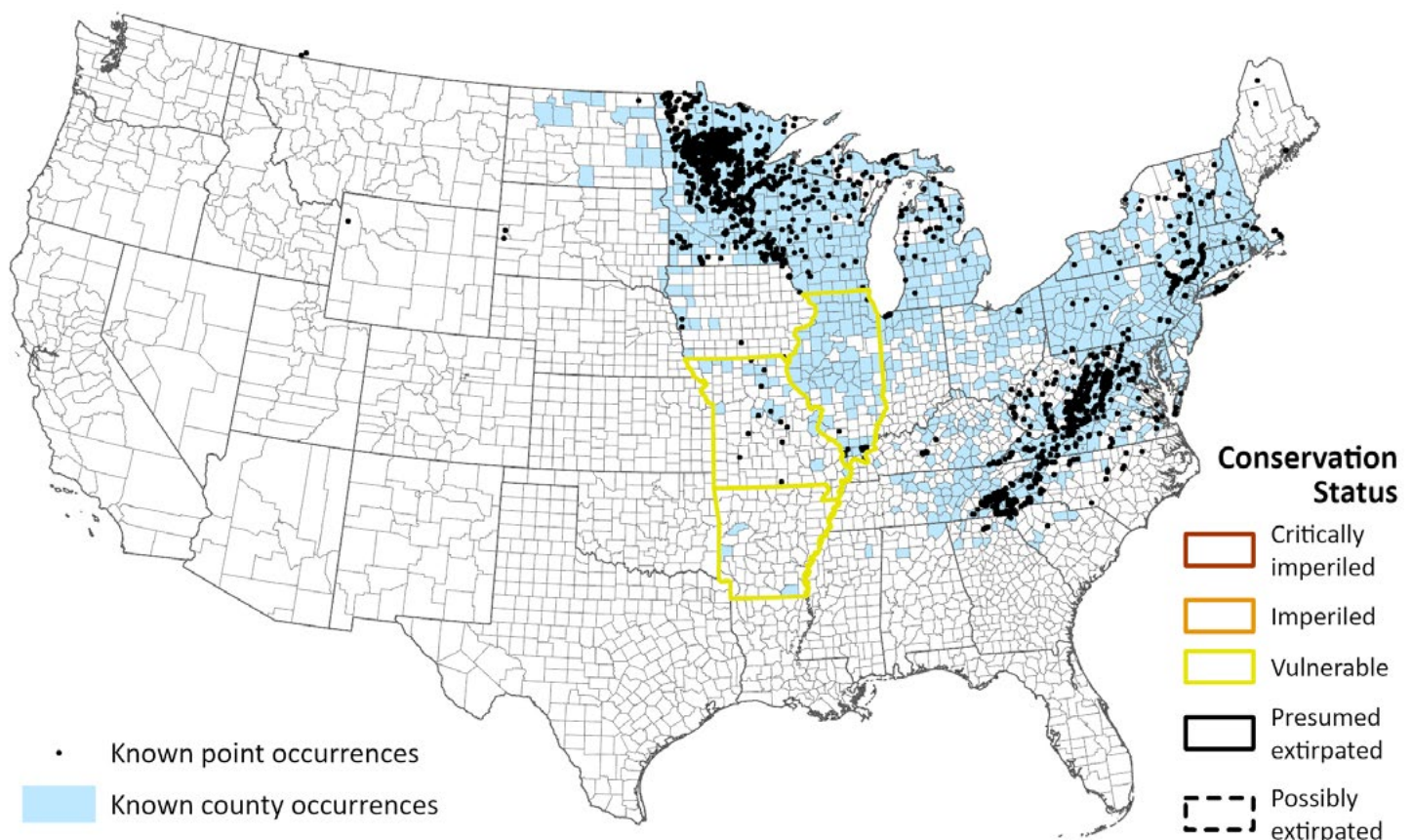


Figure 14.1. Distribution and state-level conservation status of *Carex pensylvanica*. Known point occurrences were used to assess species deposition responses and critical loads.

Responses to Nitrogen and Sulfur

The probability of occurrence for Pennsylvania sedge depends on many variables. The effect of N deposition depends on S deposition (fig. 14.2a). At lower S deposition (≤ 9.6 kg S/ha/yr) the probability of occurrence strongly increases with N deposition around 3-6 kg N/ha/yr and then decreases above 9-11 kg N/ha/yr. At higher S deposition the effects are more muted and occur at higher N deposition levels. The effect of N deposition also depends weakly on soil pH: the probability of occurrence is slightly higher under more acidic conditions (fig. 14.2b). S deposition decreases the probability of occurrence (fig. 14.2c). The climate effects are shown in Figure 14.2d (precipitation) and Figure 14.2e (temperature). The probability of occurrence decreases up to 1500 mm precipitation and then increases above that. It peaks around 8 °C within the species' sampled range. Confidence in the N and S relationships is moderate, with good model performance ($R^2 = 0.208$, AUC = 0.8;

moderate and high confidence, respectively), low VIFs (VIF-N = 1.3, VIF-S = 1.2; both high confidence), and a high N-S correlation ($r=0.78$, low confidence).



Plants of Pennsylvania sedge.
Elmer Verhasselt, Bugwood.org.

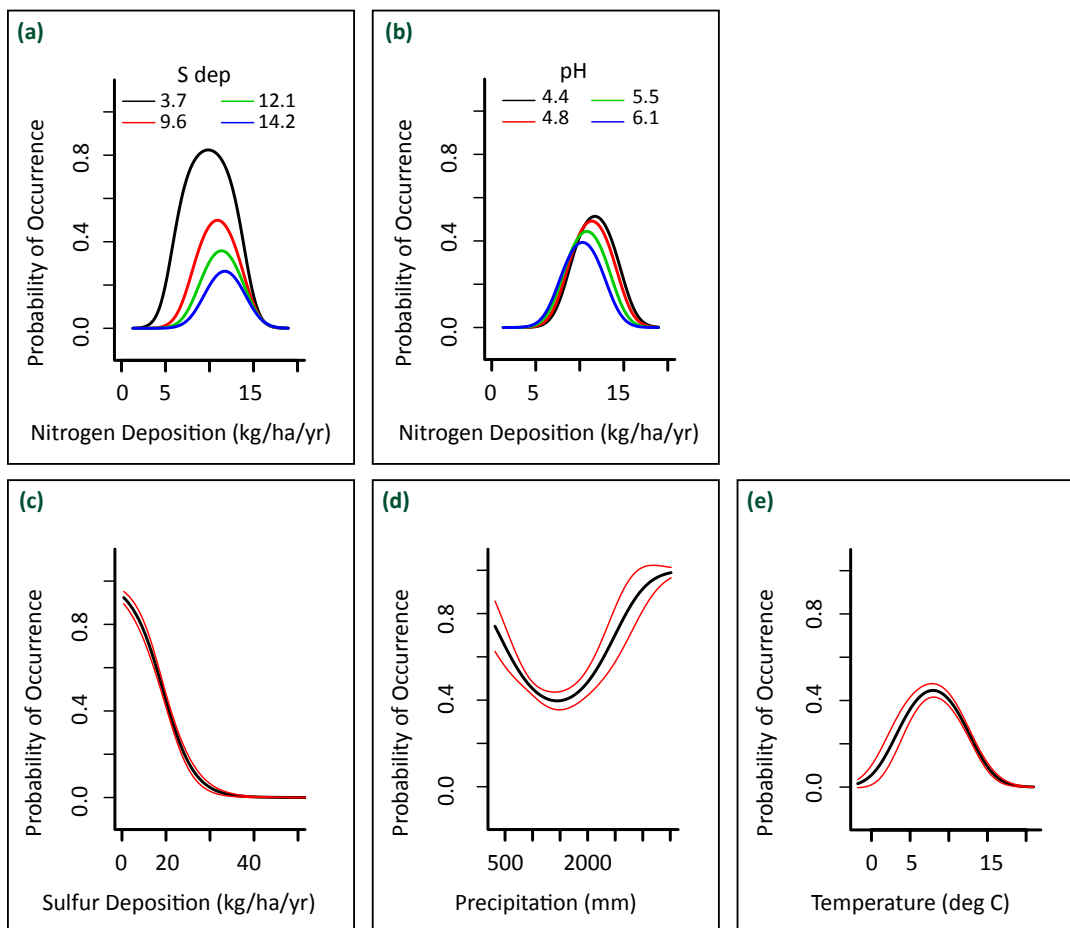


Figure 14.2. Effects of various environmental variables on the probability of occurrence of *Carex pensylvanica*: a) N x S interaction, b) N x pH interaction, c) S deposition, d) precipitation, e) temperature.

Critical Loads and Exceedances

The environmental hull for Pennsylvania sedge covers the Midwest and eastern United States and mountainous areas of the West. The N CL is ≥ 10 kg N/ha/yr in the East and 6 to 10 kg N/ha/yr in the Midwest and West. Exceedances of N CLs based on 2019–2021 TDep total N deposition are high in the Midwest, in North Carolina, the California Central Valley, and the Salt Lake City air corridor. The S CL is 0.4 kg S/ha/yr across the species' range with small pockets with a S CL of 41.7 kg S/ha/yr around cities in a band from Iowa to Pennsylvania. The S CL is in exceedance based on 2019–2021 TDep total S deposition across the entire range with the lower CL.



Flowers of Pennsylvania sedge.
Elmer Verhasselt, Bugwood.org.

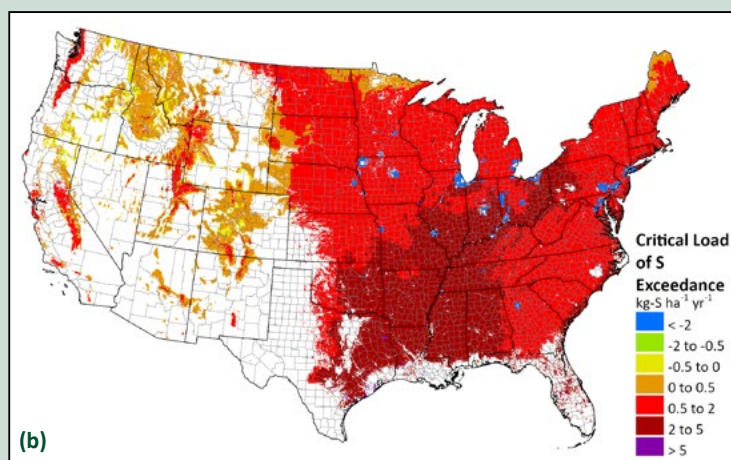
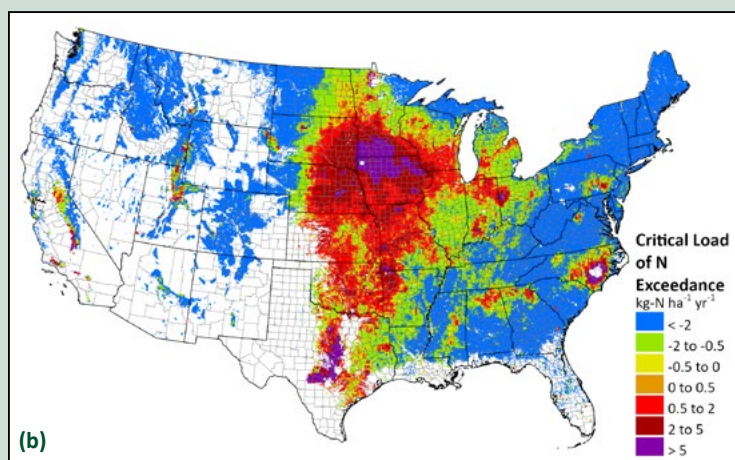
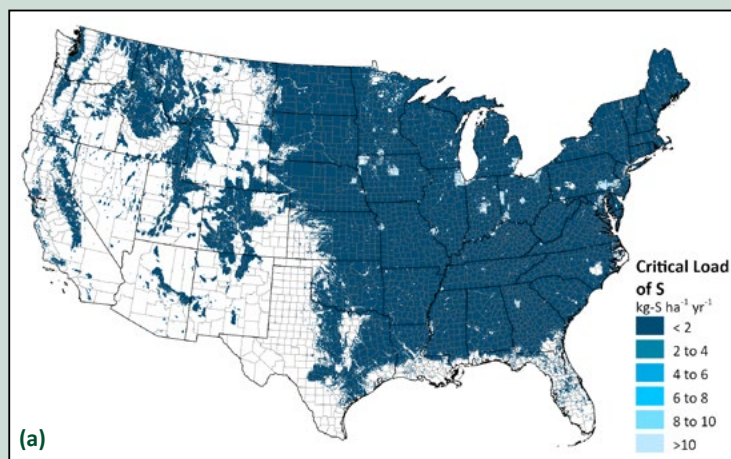
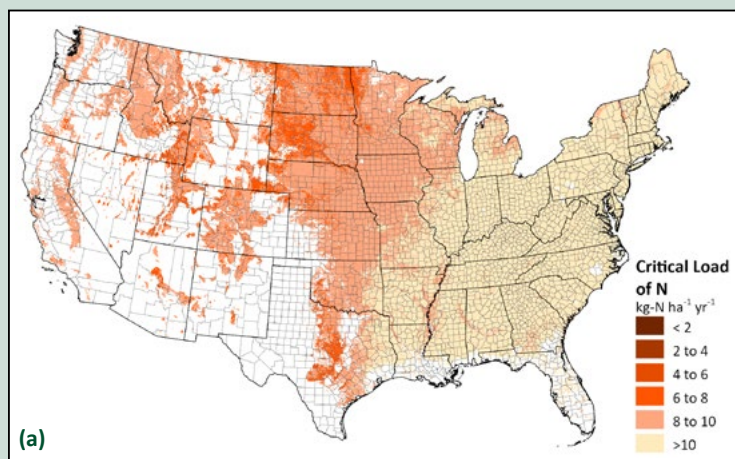


Figure 14.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Carex pensylvanica* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 14.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Carex pensylvanica* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

15.0 *Cirsium arvense* (Canada thistle)

Distribution and Conservation Status

Canada thistle is a nonnative perennial forb that grows from Alaska south to California and New Mexico, and west to Kansas, Arkansas, and to North Carolina (fig. 15.1). It was likely introduced to the United States from southeastern Europe and the eastern Mediterranean area in the 1600s. It likely arrived here as a contaminant of crop seed and/or in the ballast of a ship.

Species Characteristics and Habitat

Canada thistle occurs in many upland herbaceous communities within its range, particularly prairie communities and riparian habitats. It is mostly found in disturbed areas as part of the initial post-disturbance plant community along roadsides, railroads, streambanks, ditches, lakeshores, seashores, sand dunes and other open sandy areas, clear-cuts and forest openings, and in wet and wet-mesic grasslands and prairie potholes. Canada thistle may change the fire ecology of the site in which it occurs by its abundant, flammable, aboveground biomass. Fire kills the aboveground portion of the plant,

while the roots can survive severe fires. It is susceptible to shading and grows best when no competing vegetation is present. Canada thistle is a serious weed despite the large number of insects that are found in and on the plant.

Wildlife and Livestock Uses

Canada thistle provides shelter for endangered Columbian white-tailed deer in Washington during the summer and plays a minor role in the diet of mule deer. Livestock usually dislike and avoid Canada thistle as a food source, and it may decrease their appetite for favorable plants in the same area. Grazing lambs reject it because of its spines.

Traditional Ecological Knowledge

Among North American Indigenous cultures, Canada thistle is known to be both edible and medicinal. The roots and shoots are most tender and flavorful when eaten in the spring. Medicinal uses include the treatment of worms in children (root decoction) and as mouthwash for infants (leaf infusion). It can also be used to treat poison-ivy rash.

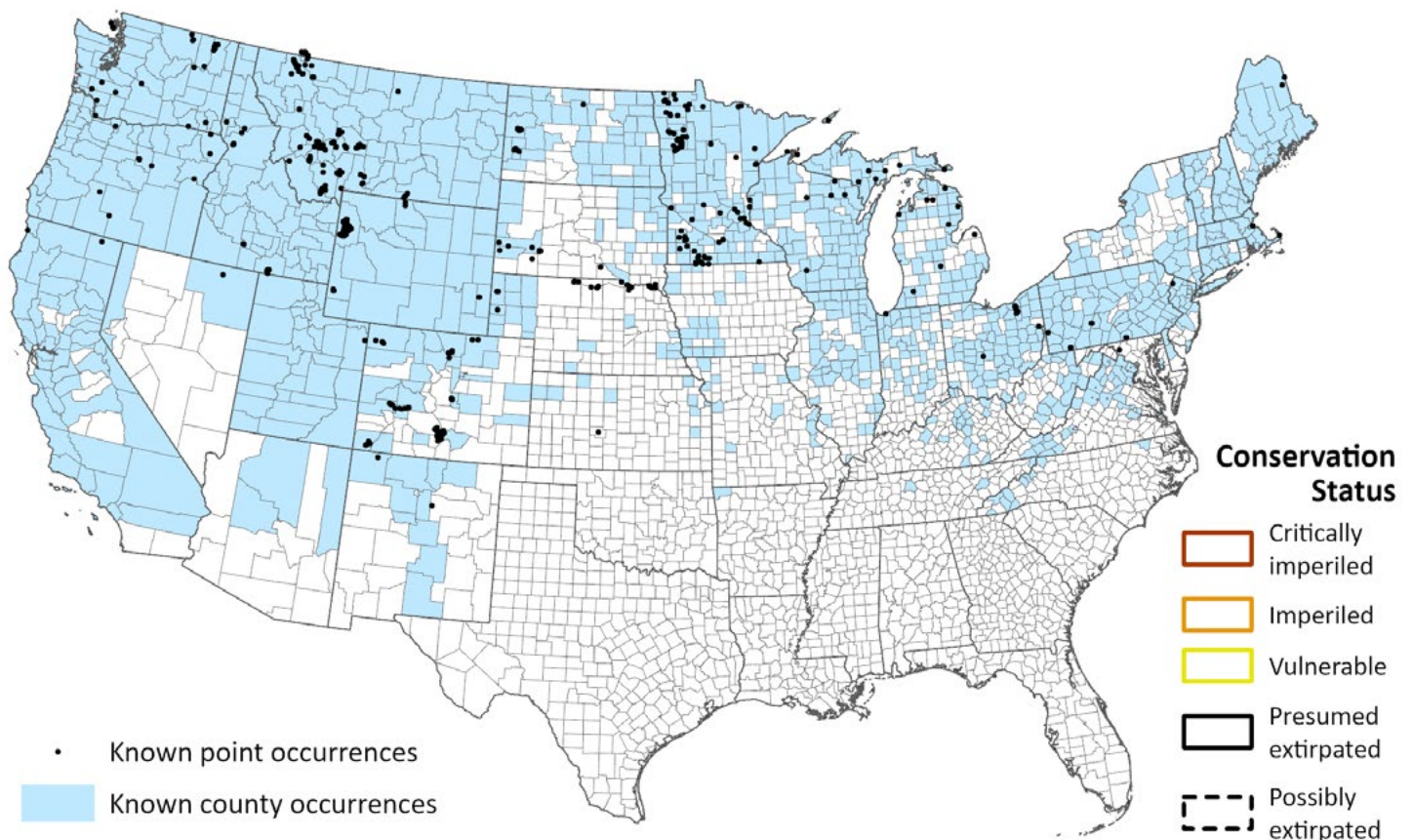


Figure 15.1. Distribution and state-level conservation status of *Cirsium arvense*. Known point occurrences were used to assess species deposition responses and critical loads.

Responses to Nitrogen and Sulfur

The probability of occurrence for Canada thistle depends on the interaction between N deposition and soil pH (fig. 15.2a). At lower pH (≤ 6.2), the probability of occurrence decreases with N deposition, but under higher soil pH (≥ 7.2), the probability of occurrence increases slightly then decreases above deposition of 5 kg N/ha/yr. The climate effects are shown in Figure 15.2b (precipitation) and Figure 15.2c (temperature). The probability of occurrence decreases with increasing precipitation and peaks broadly at 7 °C within the species' sampled range. Confidence in the N and S relationships is moderate, with good model performance ($R^2 = 0.106$, $AUC = 0.75$; both moderate confidence), low VIFs ($VIF-N = 1.2$, $VIF-S = 1.2$; both high confidence), and a high N-S correlation ($r=0.71$, low confidence).



Flowers of Canada thistle.

Jan Samanek, Phytosanitary Administration, Bugwood.org.

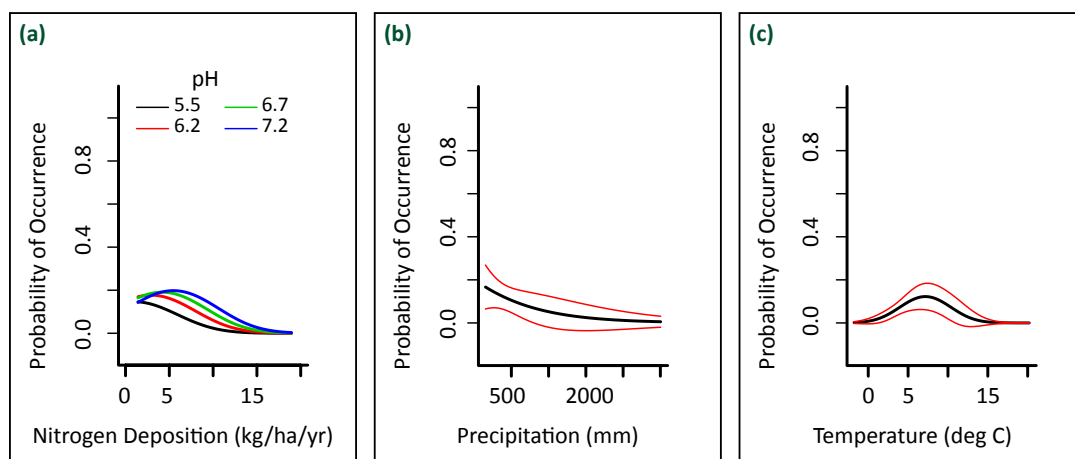


Figure 15.2. Effects of various environmental variables on the probability of occurrence of *Cirsium arvense*: a) N x pH interaction, b) precipitation, c) temperature.

Critical Loads and Exceedances

The environmental hull for Canada thistle covers the northern half of the United States south into the mountainous desert Southwest. The N CL is mostly ≤ 2 kg N/ha/yr in the East and 4-8 kg N/ha/yr in the West. Exceedances of N CLs based on 2019–2021 TDep total N deposition are high in the East and in mountainous areas of the West.



Foliage of Canada thistle.

Jan Samanek, Phytosanitary Administration, Bugwood.org.

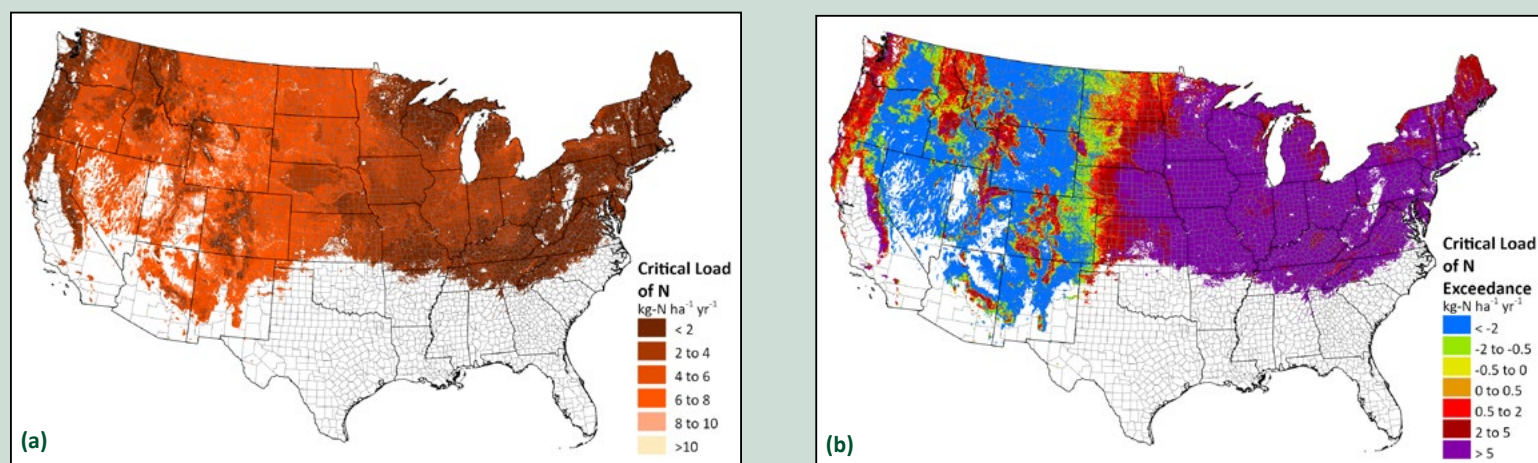


Figure 15.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Cirsium arvense* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

16.0 *Cirsium vulgare* (bull thistle)

Distribution and Conservation Status

Bull thistle is a nonnative biennial forb that is found on every continent except Antarctica (fig. 16.1). It is thought to have been introduced to North America during colonial times.

Species Characteristics and Habitat

Bull thistle initially forms a single rosette up to 3 inches in diameter and a taproot up to 28 inches long. The main taproot grows many, smaller lateral roots instead of spreading. The stems grow 1 to 6.5 feet tall at maturity with spines and many spreading branches. The lobes of the leaves are tipped with stout spines. The flowers are bisexual and reproduce and spread only from the seed. Bull thistle seeds have a fluffy pappus that is suitable for wind dispersal.

Although bull thistle can grow in a wide range of environments, it can become quite weedy in recently or repeatedly disturbed areas like pastures, overgrazed

rangelands. It is also found in recently burned forests, forest clearings, roadsides, ditches, and fences. Bull thistle prefers dry and wet soils and is most common on moist soils with wide ranging pH values. However, it is rare on soils of pH between 4.8- 5.0. Bull thistle thrives in fields exposed to nitrogen fertilization but does not respond to potassium or phosphorus. The detritus of bull thistle is known to impede the growth of other plants because of nutrient immobilization during litter breakdown.

Wildlife and Livestock Uses

Bull thistle is a known food of grizzly bears. Bees and butterflies enjoy bull thistle flower nectar. Goldfinches not only eat the seeds but also use the thistledown as nesting materials. Grazing animals typically avoid mature bull thistle because of its spines but the seedlings are consumed by domestic goats, domestic sheep, mice and voles. It has no known significant nutritive value for livestock.

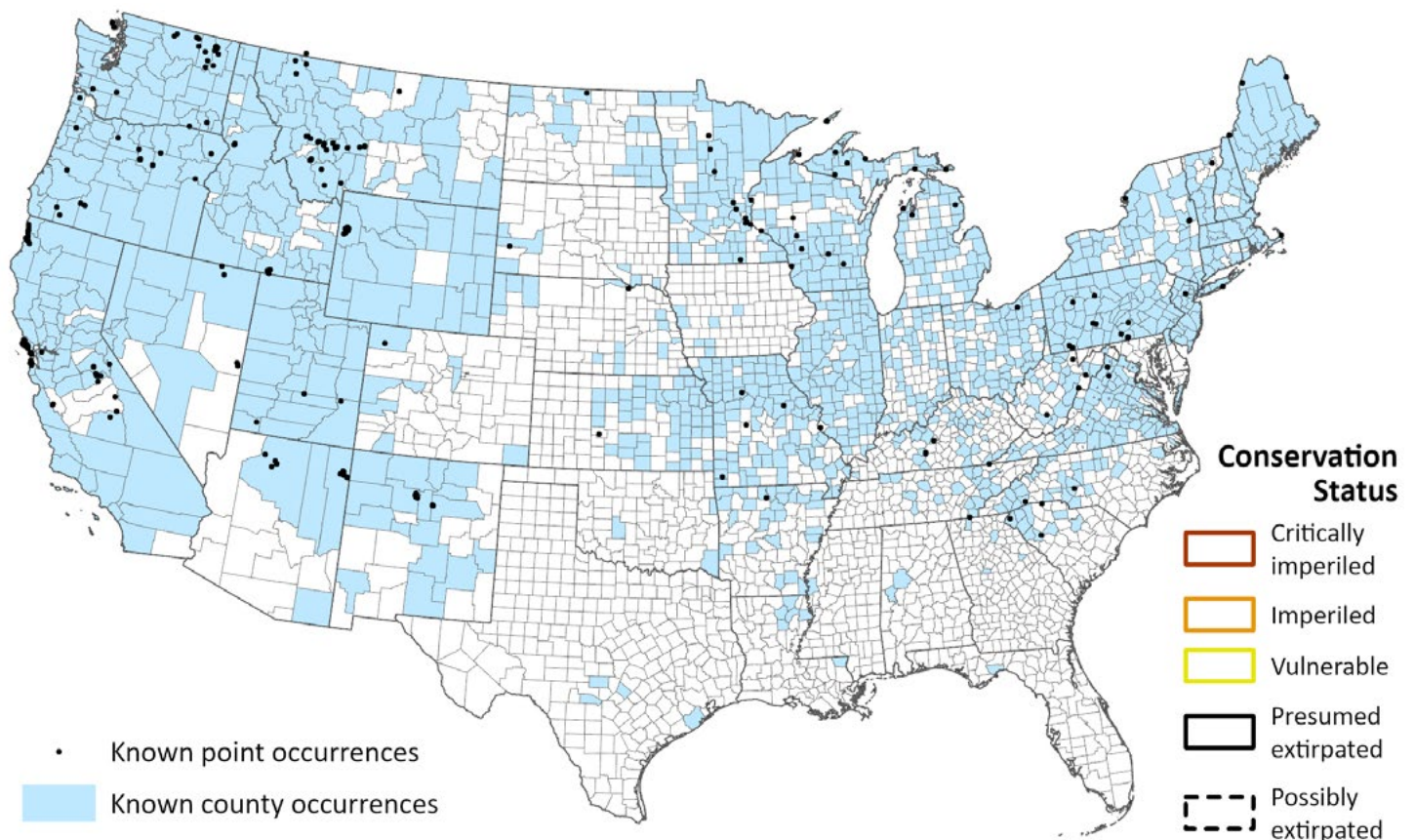


Figure 16.1. Distribution and state-level conservation status of *Cirsium vulgare*. Known point occurrences were used to assess species deposition responses and critical loads.

Traditional Ecological Knowledge

Traditional medicinal uses of bull thistle include treatments for several ailments. A warm infusion of the roots can aid indigestion caused by overeating, and an infusion of leaves can be taken for neuralgia.



Flower of bull thistle.

Loke T. Kok, Virginia Polytechnic Institute and State University, Bugwood.org.

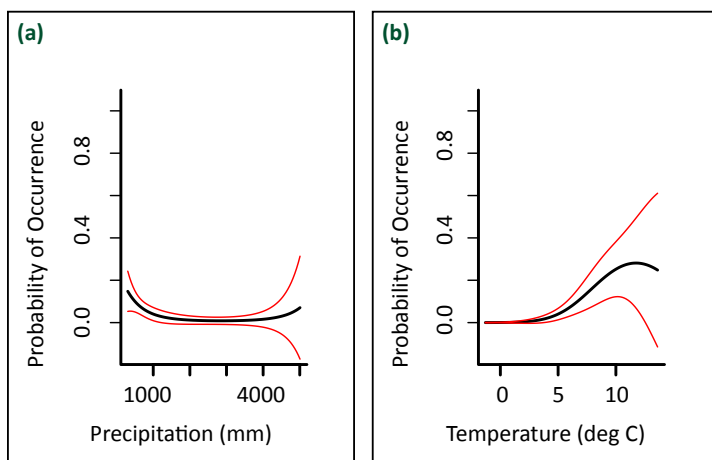


Figure 16.2. Effects of various environmental variables on the probability of occurrence of *Cirsium vulgare*: a) precipitation, b) temperature.

Responses to Nitrogen and Sulfur

Bull thistle is not vulnerable to N or S deposition under the levels of deposition assessed. The climate effects are shown in Figure 16.2a (precipitation) and Figure 16.2b (temperature). The species is somewhat unresponsive to precipitation and the probability of occurrence has a u-shaped response to temperature (but note widening confidence bands at lowest temperatures) within the species' sampled range. Confidence in N and S relationships (or lack thereof) is moderate, with good model performance ($R^2 = 0.123$, $AUC = 0.77$; both moderate confidence), low VIFs ($VIF-N = 1.3$, $VIF-S = 1.3$; both high confidence), and a high N-S correlation ($r=0.78$, low confidence).

Critical Loads and Exceedances

The environmental hull for bull thistle covers the eastern United States excluding Florida across the non-arid areas of the West and Midwest. There are no responses to N or S deposition.



Plant of bull thistle.

Loke T. Kok, Virginia Polytechnic Institute and State University, Bugwood.org.

17.0 *Conyza canadensis* (Canadian horseweed)

Distribution and Conservation Status

Canadian horseweed is a native annual forb that can be found throughout the continental United States (fig. 17.1). It is an introduced plant in Alaska.

Species Characteristics and Habitat

Canadian horseweed is a tall member of the sunflower family with one or multiple, unbranched stems, 1 to 5 feet in height. The leaf edges are ciliate and serrate. The numerous flower heads are very small, 0.08 to 0.16 inches tall and 0.12 to 0.28 inches wide. The rays are white or purplish and very small, only reaching 0.02 to 0.04 inches in length. The fruit is an achene with a white bristly pappus.

Canadian horseweed inhabits grasslands and moist disturbed sites such as riparian and wetland areas. It prefers slightly acidic to neutral soils with pH ranging

4.8 to 7.2 in areas. Canadian horseweed is an effective colonizer of disturbed soils due to its abundance of windborne seeds. It can germinate in the winter or summer if there is enough warmth and moisture in the soil. Pests of agricultural crops such as alfalfa and cotton live on Canadian horseweed which serves as a host. Control efforts should be focused during late fall and early spring when plants are young. If Canadian thistle is not killed by chemical burn, it will re-grow and be less susceptible to herbicides later.

Traditional Ecological Knowledge

There are multiple traditional medicinal uses of Canadian horseweed. An infusion of the leaves can be used to treat diarrhea and childbirth-related hemorrhage and to reduce fevers. It can also be used as a cough and cold medicine and to treat stomach aches.

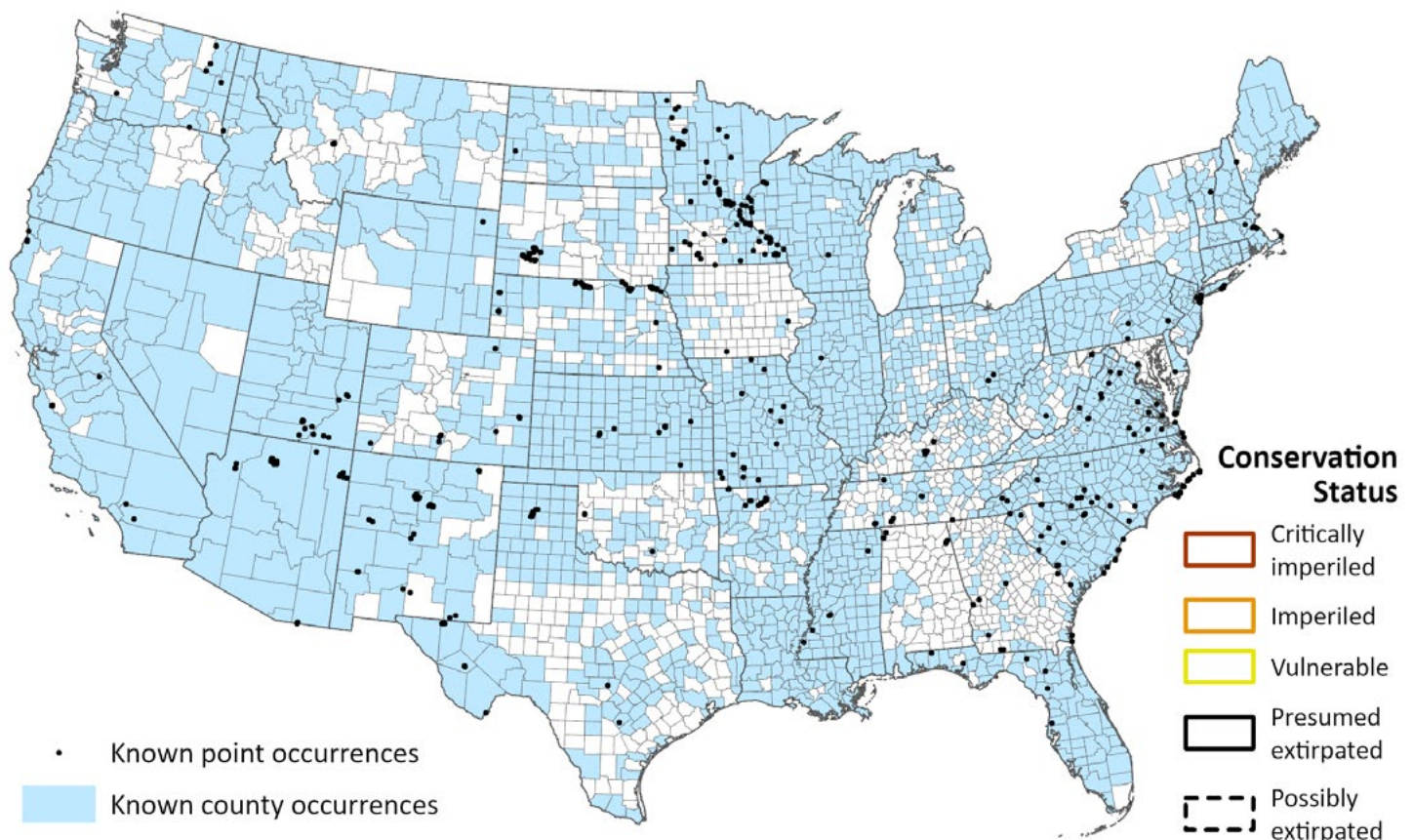


Figure 17.1. Distribution and state-level conservation status of *Conyza canadensis*. Known point occurrences were used to assess species deposition responses and critical loads.

Responses to Nitrogen and Sulfur

The probability of occurrence for Canadian horseweed depends on several variables. The effect of N deposition depends on soil pH (fig. 17.2a). At high pH (≤ 6.7), the species is virtually absent and not responsive to N deposition. Under lower soil pH the probability of occurrence is greater and decreases with N deposition. The effect of N deposition also depends on S deposition (fig. 17.2b). At high S deposition the species decreases with N deposition and at lower S deposition the species is largely absent and unresponsive. The climate effects are shown in Figure 17.2c (precipitation) and Figure 17.2d (temperature). The probability of occurrence is relatively insensitive to precipitation and increases with increasing temperatures (but note widening confidence bands) within the species' sampled range. Confidence in the N and S relationships is moderate-to-high, with good model performance ($R^2 = 0.223$, $AUC = 0.82$; moderate and high confidence, respectively), low VIFs ($VIF-N = 1.0$, $VIF-S = 1.4$; both high confidence), and a low N-S correlation ($r=0.24$, high confidence).



Plants of Canadian horseweed.

Charles T. Bryson, USDA Agricultural Research Service, Bugwood.org.

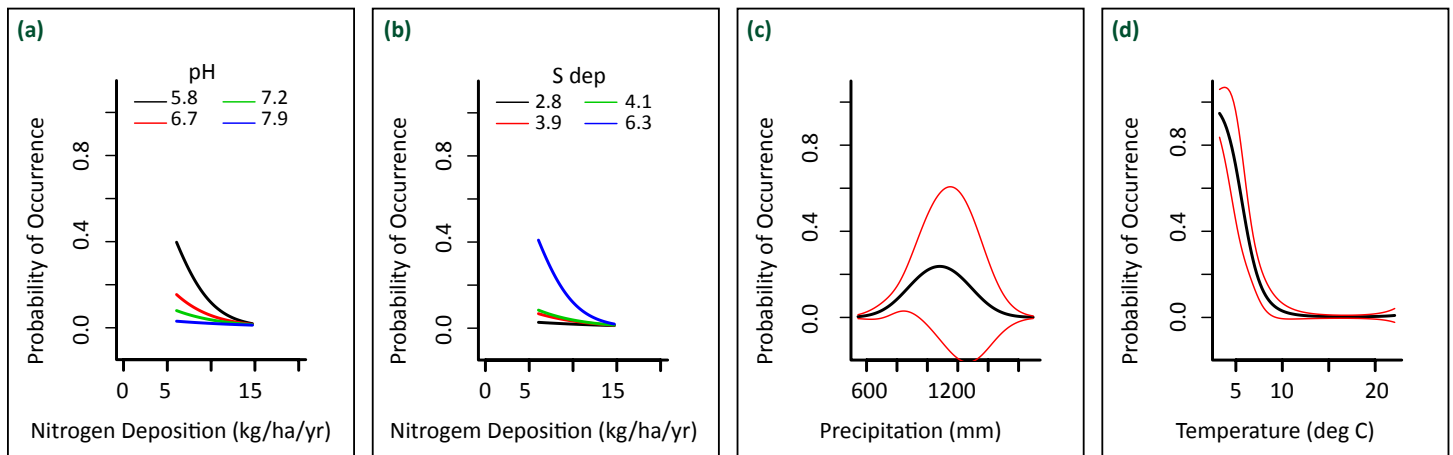


Figure 17.2. Effects of various environmental variables on the probability of occurrence of *Conyza canadensis*: a) N x pH interaction, b) N x S interaction, c) precipitation, d) temperature.

Critical Loads and Exceedances

The environmental hull for Canadian horseweed covers the entire United States outside of the Desert Southwest. The N CL is 6-8 kg N/ha/yr in the East, Midwest, and mountain West, and ≥ 10 kg N/ha/yr at lower elevations in the West. Exceedances of N CLs based on 2019–2021 TDep total N deposition are high in East and exist in the highest elevation locations in the West. The S CL is 15.0 kg S/ha/yr across most of the species' range with small pockets with a S CL of 2.2 kg S/ha/yr in the East with a larger section in Maryland and New Jersey. The S CL is in exceedance based on 2019–2021 TDep total S deposition in geographic areas with lower CLs.



Flowers of Canadian horseweed.
Wendy VanDyk Evans,
Bugwood.org.

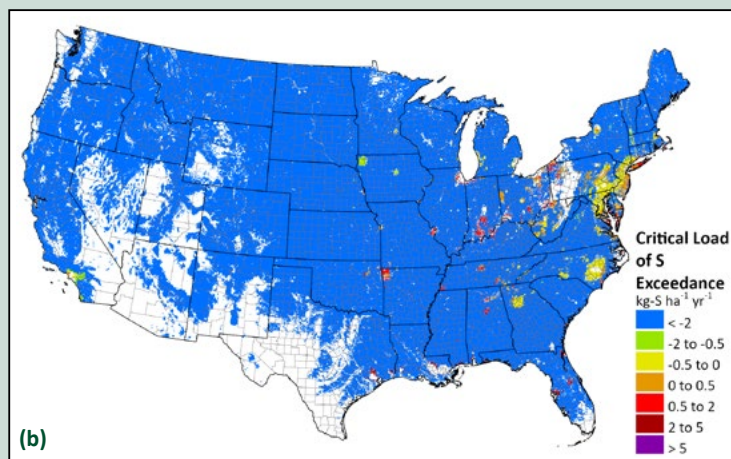
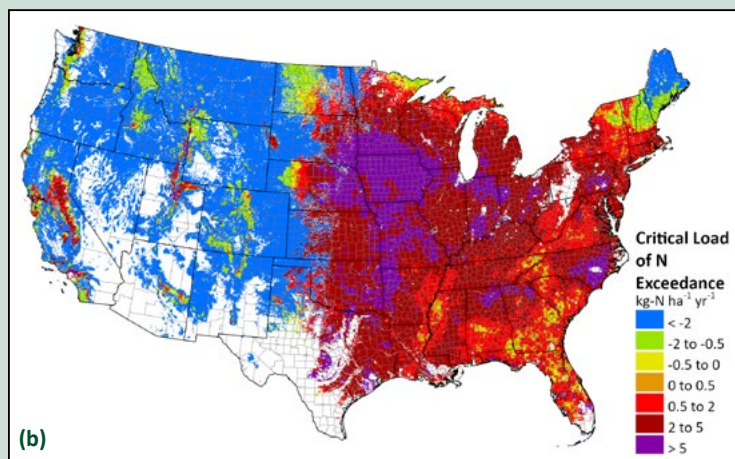
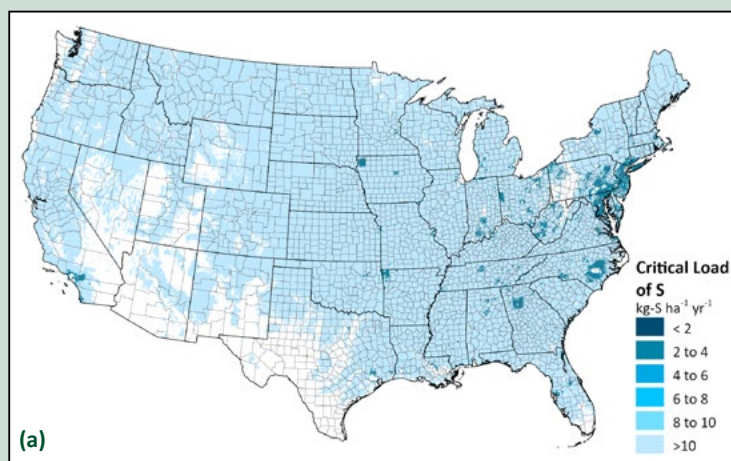
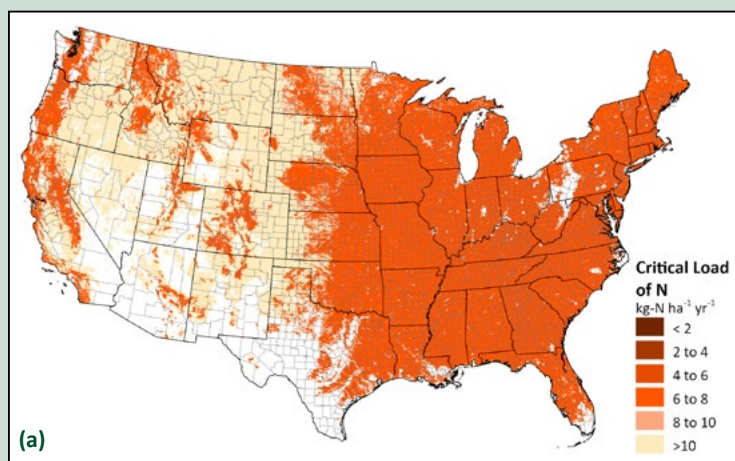


Figure 17.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Conyza canadensis* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 17.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Conyza canadensis* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

18.0 *Dactylis glomerata* (orchardgrass)

Distribution and Conservation Status

Orchardgrass is an introduced perennial grass of the continental U.S. and Alaska. It grows well throughout the Appalachian Mountains and thrives in Maryland, Pennsylvania, West Virginia, Virginia, Kentucky, and Tennessee (fig. 18.1).

Species Characteristics and Habitat

Orchardgrass is a cool-season, non-rhizomatous, bunchgrass growing 1 to 4 feet tall. It has upright, glabrous culms with blades 4 to 16 inches long, and up to 0.5 inch wide.

Orchardgrass prefers well-drained, rich fertile soils with plenty of precipitation and moderate temperatures. It is very shade tolerant. It grows well in shallow to deep soils and various soil textures ranging from clay to gravelly loams. It does not perform well in saline soils or areas with high water tables. Orchardgrass prefers a pH range of 5.8 – 7.0. Most of the root development occurs in the top 3 inches of soil although roots can grow as deep as 18 inches, creating a dense sod of medium-sized roots.

Orchardgrass reproduces primarily by seed and by tiller formation. Seed germination is principally controlled by moisture; the plant usually germinates in the fall in either light or dark conditions. The seeds collect on animals, a mechanism of long-distance transport. Although orchardgrass is invasive, it is not as successful as other invasive plants. After burning, orchardgrass is known to remain stable or even increase. Orchardgrass reacts well to nitrogen fertilizers, and moderately well to co-planting with legumes.

Wildlife and Livestock Uses

Orchardgrass is highly palatable and somewhat nutritious to deer, elk, bighorn sheep, cattle, domestic sheep and domestic goats. The evergreen basal rosette is good winter forage for deer and elk. In early spring and summer, cattle will eat orchardgrass preferentially, up to 50% of their diet. In the winter, wild turkeys graze on orchardgrass. Poults and insects use it as a source of shelter. Rabbits use orchardgrass for shelter and food. Canada geese consume the leaves and seeds.

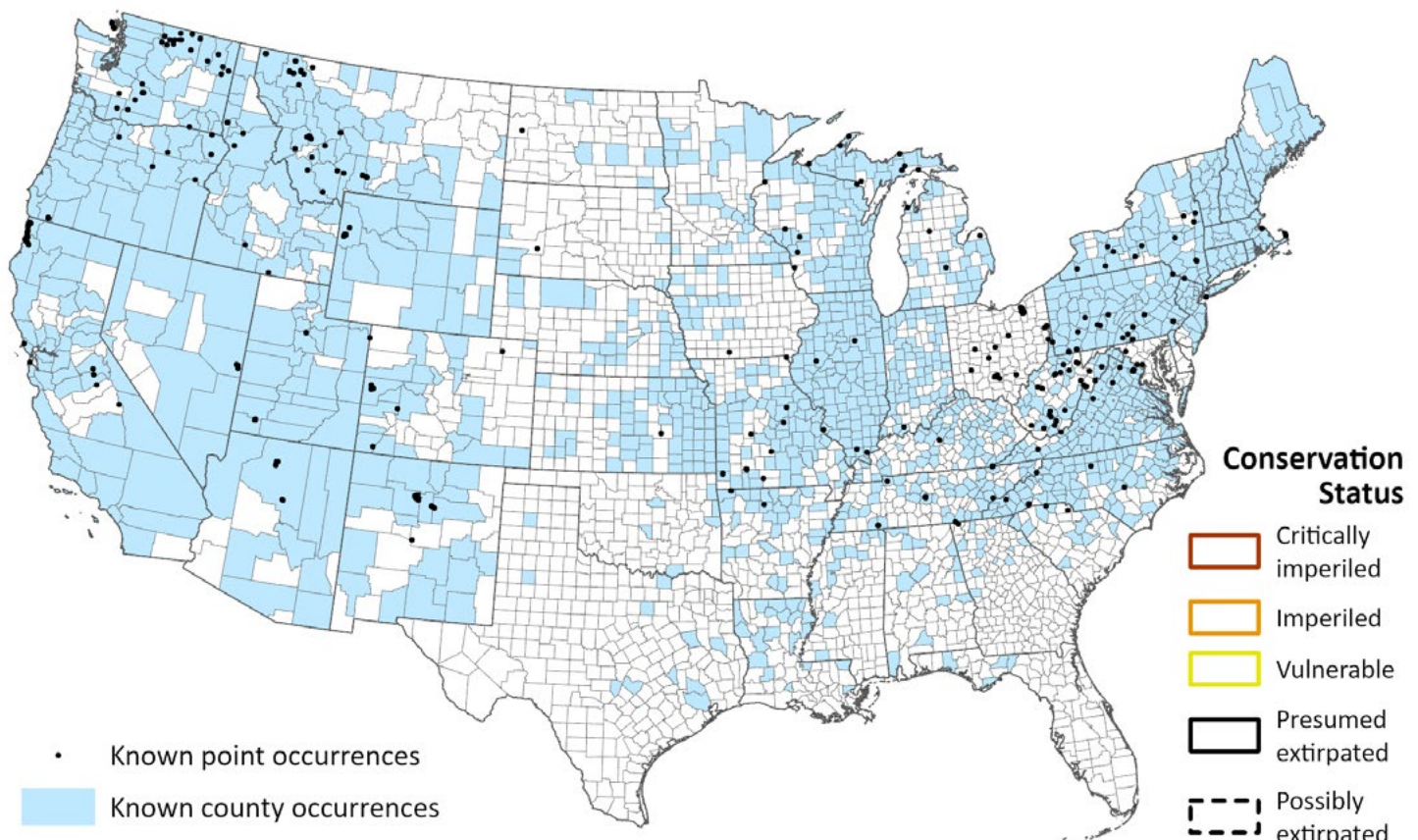


Figure 18.1. Distribution and state-level conservation status of *Dactylis glomerata*. Known point occurrences were used to assess species deposition responses and critical loads.

Ecosystem Services

Orchardgrass can be planted in areas that have been logged and burned to revegetate the area, offer a vegetative cover for soil stabilization and provide forage for cattle and wildlife. On rangelands it is used to increase forage production. Its dense connection of non-rhizomatous roots allows it to have good erosion control. It can also be used for pasture, hay, and silage.

Responses to Nitrogen and Sulfur

Orchardgrass is tolerant to N or S deposition under levels of deposition assessed. Of the variables tested, the species only responds to temperature (fig. 18.2a). The probability of occurrence increases with increasing temperatures within the species' sampled range. Confidence in the N and S relationships (or lack thereof) is moderate-to-high, with good model performance ($R^2 = 0.101$, AUC = 0.71; both moderate confidence), low VIFs (VIF-N = 1.2, VIF-S = 1.3; both high confidence), and a moderate N-S correlation ($r=0.69$, moderate confidence).

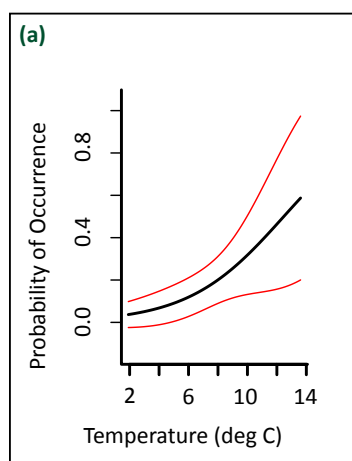


Figure 18.2. Effects of various environmental variables on the probability of occurrence of *Dactylis glomerata*: a) temperature.

Critical Loads and Exceedances

The environmental hull for orchardgrass covers the northern two-thirds of the United States. No response to current levels of N or S deposition in this broad area has been observed and thus there are no known CL exceedances.



Plants of orchardgrass.
Catherine Herms, The Ohio State University, Bugwood.org.



Flowers of orchardgrass.
OSU Extension slide archives Ohio State University.

19.0 *Danthonia spicata* (poverty oatgrass)

Distribution and Conservation Status

Poverty oatgrass is a native perennial grass that occurs in most grasslands, shrublands, and forested habitats. It grows throughout most of the United States except California, Nevada and Utah. It is critically imperiled in Nebraska, imperiled in Kansas and Oregon, and vulnerable in Iowa and Wyoming (fig. 19.1).

Species Characteristics and Habitat

It is a cool-season bunchgrass with fibrous roots lacking rhizomes or stolons. Most of the above ground vegetation grows as a crowded basal clump of leaves.

Poverty oatgrass can establish and prosper on particularly nutrient poor and moisture lacking locations, like roadsides. However, it usually occupies low fertility, sandy or rocky, well-drained soils of old fields, pastures, roadsides, and woodland limits characterized by low soil moisture. Poverty oatgrass can also occupy acidic soils, with pH ranging from 4.5-4.7, making it an excellent indicator of low-fertility agricultural and pasture lands.

As a result, the presence of poverty oatgrass and its increase in the absence of fire indicates deteriorating soil conditions and overuse. Poverty oatgrass spreads by seed and by tillering. It has adapted to fire by tillering and establishing from seed after top-kill.

Wildlife and Livestock Uses

Poverty oatgrass offers reasonable cover for small mammals, small nongame birds, and upland game birds throughout Wyoming. It is important to wildlife and livestock in the early seasons. This is because during the growing season poverty oatgrass becomes unpalatable to livestock.

Ecosystem Services

Poverty oatgrass binds soil and prevents erosion. It can also prevent extreme nutrient leaching. Poverty oatgrass is found as a frequent secondary successor and erosion controller in fire-disturbed areas and clearings in the eastern United States. It has low nutritional value.

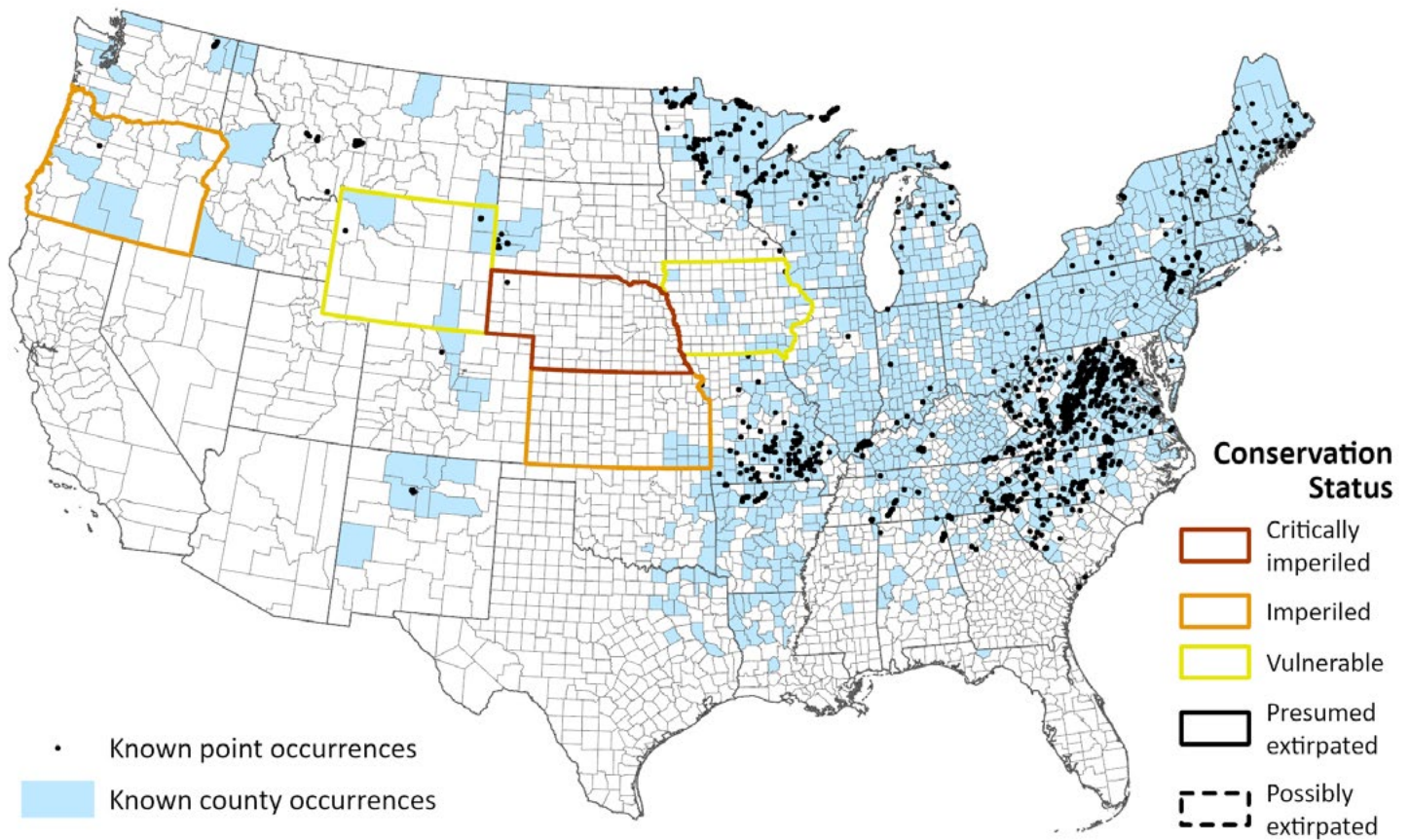


Figure 19.1. Distribution and state-level conservation status of *Danthonia spicata*. Known point occurrences were used to assess species deposition responses and critical loads.

Responses to Nitrogen and Sulfur

The probability of occurrence for poverty oatgrass depends on several variables. The effect of N deposition depends on S deposition (fig. 19.2a): at lower S deposition (≤ 7.9 kg S/ha/yr), N deposition leads to a large increase in the probability of occurrence up to 10 kg N/ha/yr. Above 10 kg N/ha/yr, the probability of occurrence decreases. At higher S deposition, poverty oatgrass is less responsive to N deposition. There is also a strong effect of soil pH on the effect of S deposition (fig. 19.2b). The probability of occurrence is higher at lower pH (≤ 5.1) and decreases more sharply at lower pH values with S deposition. At higher pH (≥ 5.8), the effect of S deposition is weaker. The effect of N deposition is only weakly dependent on soil pH (fig. 19.2c). The climate effects are

shown in Figure 19.2d (precipitation) and Figure 19.2e (temperature). The probability of occurrence peaks at 800 mm precipitation and 12 °C within the species' sampled range. Confidence in the N and S relationships is moderate, with good model performance ($R^2 = 0.1$, AUC = 0.73; both moderate confidence), low VIFs (VIF-N = 1.3, VIF-S = 1.2; both high confidence), and a high N-S correlation ($r=0.75$, low confidence).

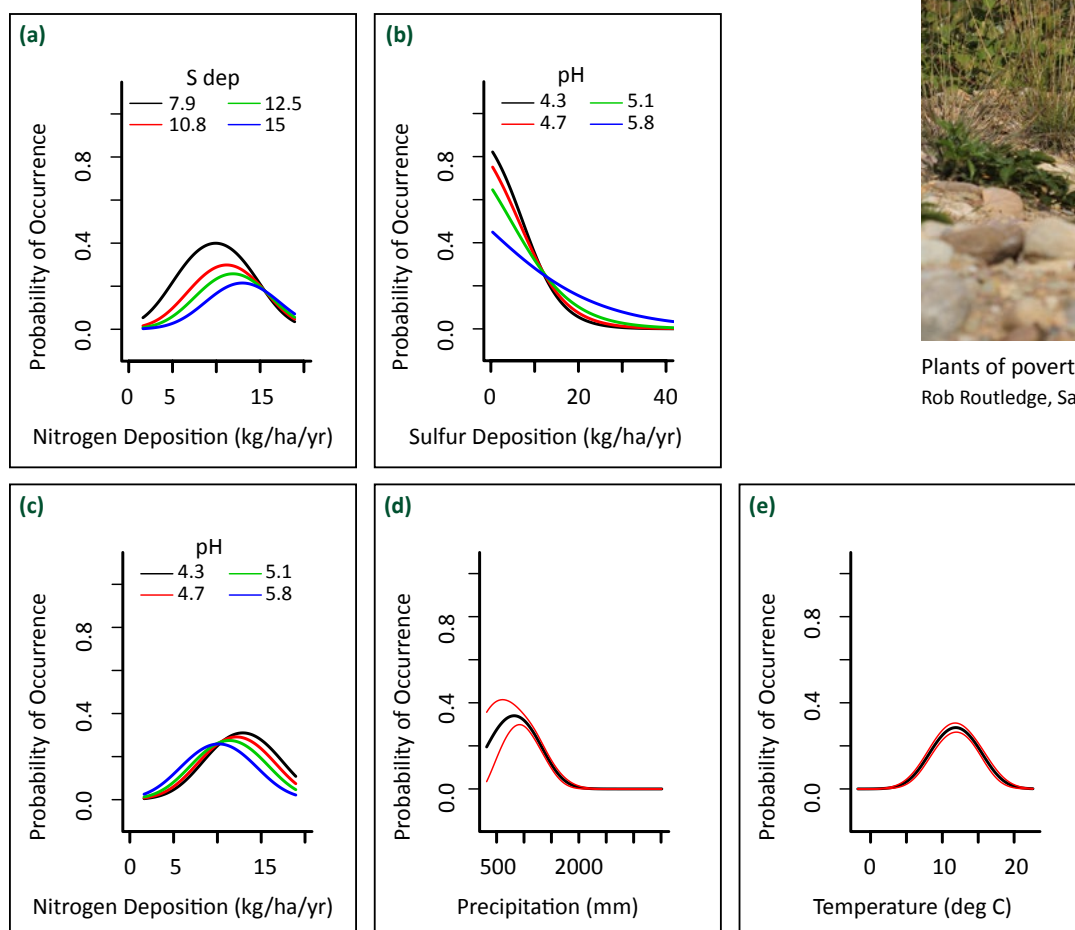


Figure 19.2. Effects of various environmental variables on the probability of occurrence of *Danthonia spicata*: a) N x S interaction, b) S x pH interaction, c) N x pH interaction, d) precipitation, e) temperature.



Plants of poverty oatgrass.
Rob Routledge, Sault College, Bugwood.org.

Critical Loads and Exceedances

The environmental hull for poverty oatgrass covers the entire United States excluding the desert Southwest. The N CL is 8 to >10 kg N/ha/yr in the East and 2-6 kg N/ha/yr in the Midwest and West. Based on 2019–2021 TDep total N deposition, N CLs are exceeded in the Midwest, higher elevation locations in the West, and in agricultural

areas of the Southeast. The S CL is 0.4 kg S/ha/yr across the eastern and western parts of the species' range with and 41.7 kg S/ha/yr in midwestern States. The S CL is in exceedance based on 2019–2021 TDep total S deposition in the lower CL regions of the East and higher elevations in the West.

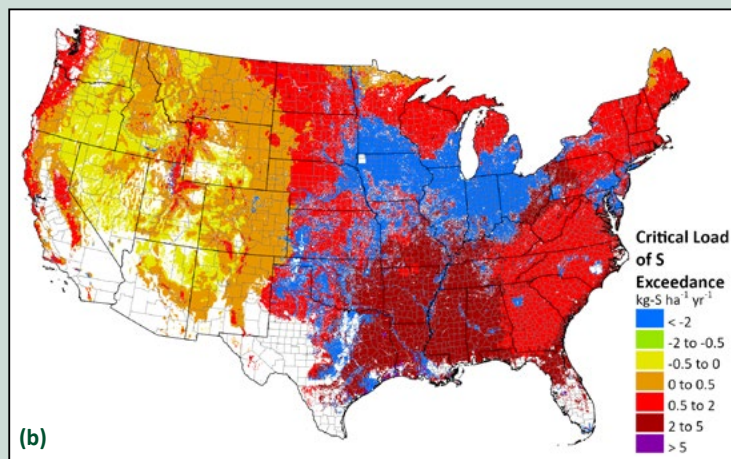
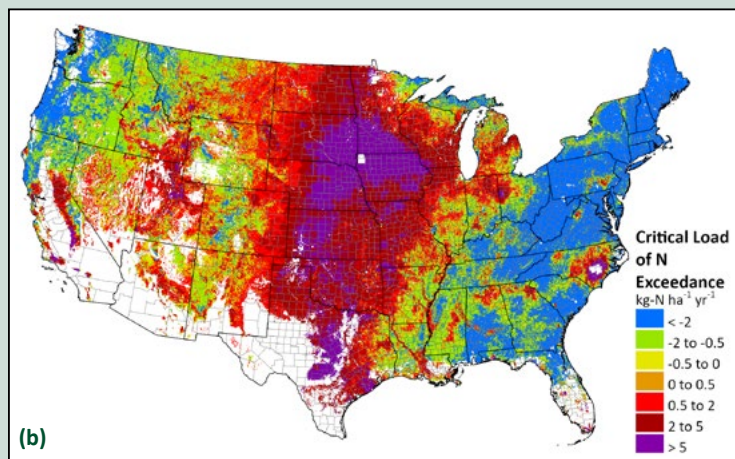
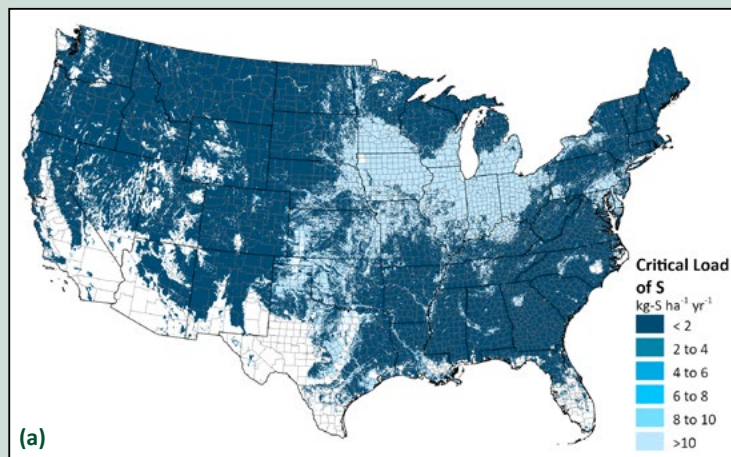
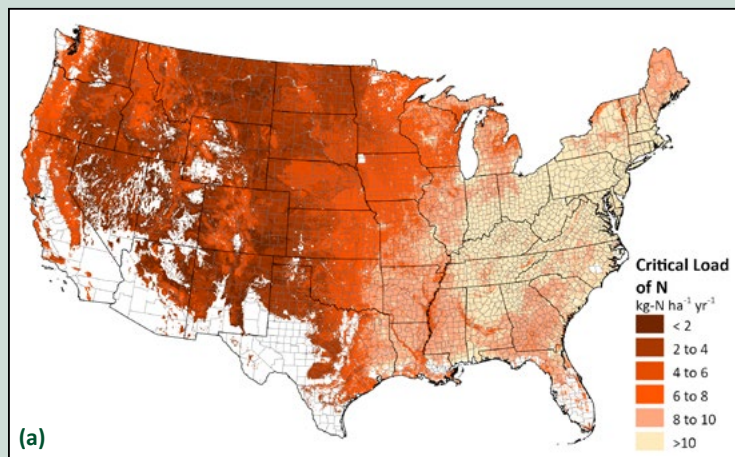


Figure 19.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Danthonia spicata* and (b) the exceedance of N critical loads based on TDep 2019–2021 total N deposition.

Figure 19.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Danthonia spicata* and (b) the exceedance of S critical loads based on TDep 2019–2021 total S deposition.

20.0 *Dryopteris carthusiana* (spinulose woodfern)

Distribution and Conservation Status

Spinulose woodfern is a perennial fern native to North America. It is found in cool, moist, rich, often rocky forests and woodlands, closed-canopy forests, thickets and swamp found throughout western Massachusetts, New York, Pennsylvania, and Michigan, and south along the Appalachian Mountains through North Carolina, South Carolina, Tennessee, and Alabama. In the West, it is found in Washington, Oregon, and perhaps Idaho and Montana. It is critically imperiled in Wyoming, South Dakota, Tennessee, Alabama, Georgia, and South Carolina, imperiled in Washington, Nebraska, Mississippi, and North Carolina, and vulnerable in North Dakota, Illinois, and Kentucky (fig. 20.1).

Species Characteristics and Habitat

Spinulose woodferns are part of a group of closely related terrestrial ferns with large, 2-to 4-pinnately branched

fronds creating a widely arching crown, growing from a short, stout rhizome. Tiny, roundish spores are produced in groups of indusia on the undersides of the fronds

Spinulose woodfern prefers soils that are shallow, rocky, acidic, nutrient-poor, and organic-rich. It is found in seasonally flooded habitats where soils are perpetually moist. Woodferns are generally shade tolerant. They reproduce both by these spores and by vegetative means. Spinulose woodfern can endure and sprout after a low-severity surface fire when soil moisture has inhibited heat damage to the rhizomes. Woodferns are likely to be top-killed by fire, and sometimes completely killed.

Wildlife Uses

Spinulose woodfern is an ideal forage for moose. Blue grouse will consume spinulose woodfern in the winter.

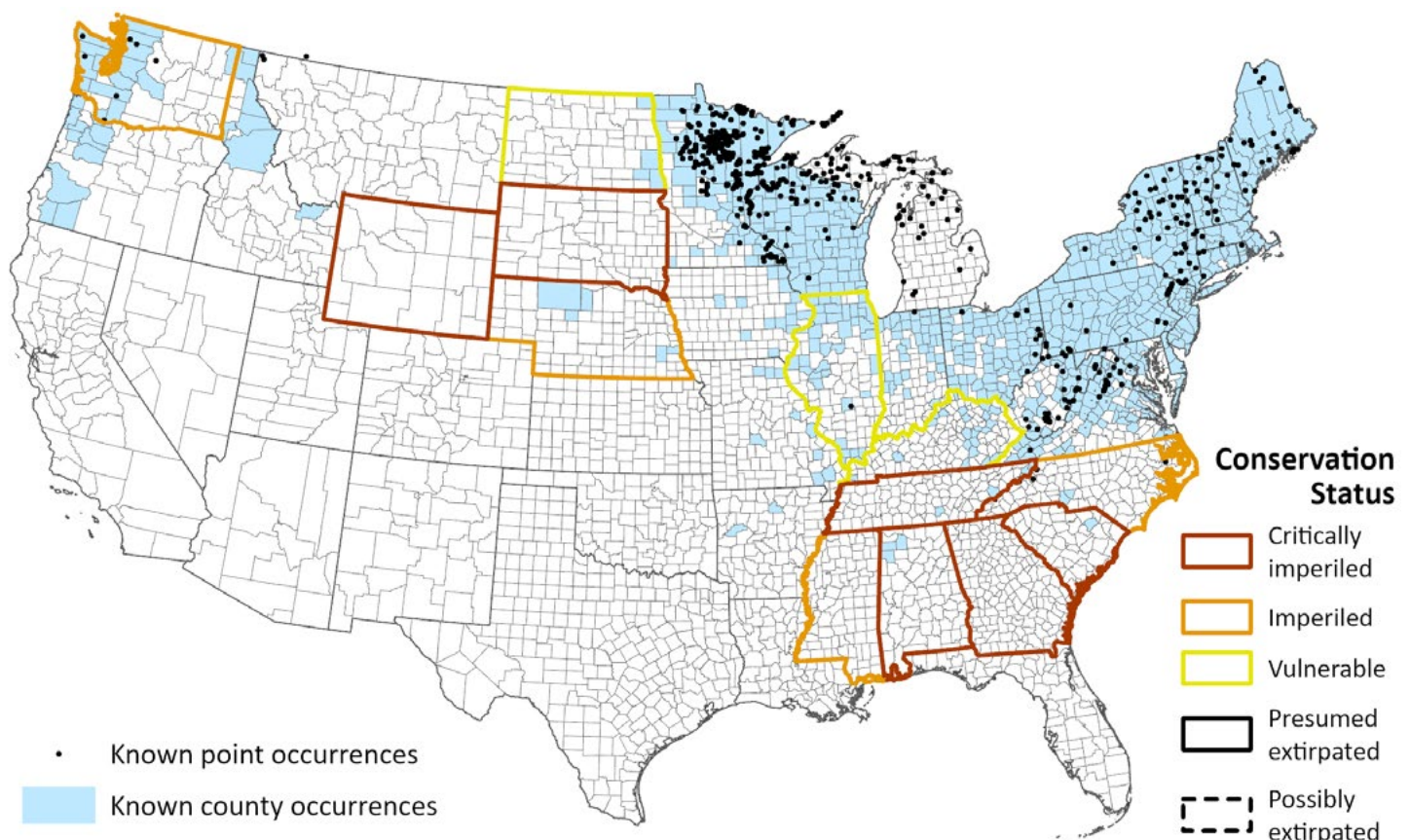


Figure 20.1. Distribution and state-level conservation status of *Dryopteris carthusiana*. Known point occurrences were used to assess species deposition responses and critical loads.

Traditional Ecological Knowledge

Spinulose woodfern is a traditional food source. Old leafstalks on the underground stems can be roasted, peeled and the inner portion eaten. In spring, the young, curled fronds can be boiled and eaten like asparagus. It is also used as an antidote for shellfish poisoning. The root contains filicin, an effective treatment for tapeworms.

Responses to Nitrogen and Sulfur

The probability of occurrence for spinulose woodfern depends on several variables. The effect of N deposition depends on soil pH (fig. 20.2a). At lower soil pH the probability of occurrence decreases at higher N

deposition levels (e.g., 10 kg N/ha/yr) and at higher soil pH the probability of occurrence decreases at lower N deposition levels (e.g., 5 kg N/ha/yr). There is also a nonsensical interaction between S deposition and soil pH, which is likely due to correlations and non-independence of S relative to other factors (fig. 20.2b). The climate effects are shown in Figure 20.2c (precipitation) and Figure 20.2d (temperature). The probability of occurrence peaks broadly at 1250 mm precipitation and decreases above 4 °C within the species’ sampled range. Confidence in the N and S relationships is moderate, with good model performance ($R^2 = 0.108$, $AUC = 0.71$; both moderate confidence), low VIFs ($VIF-N = 1.4$, $VIF-S = 1.4$; both high confidence), and a high N-S correlation ($r=0.82$, moderate confidence).



Foliage of spinulose woodfern.
Rob Routledge, Sault College, Bugwood.org.



Indusia on back of frond of spinulose woodfern.
Rob Routledge, Sault College, Bugwood.org.

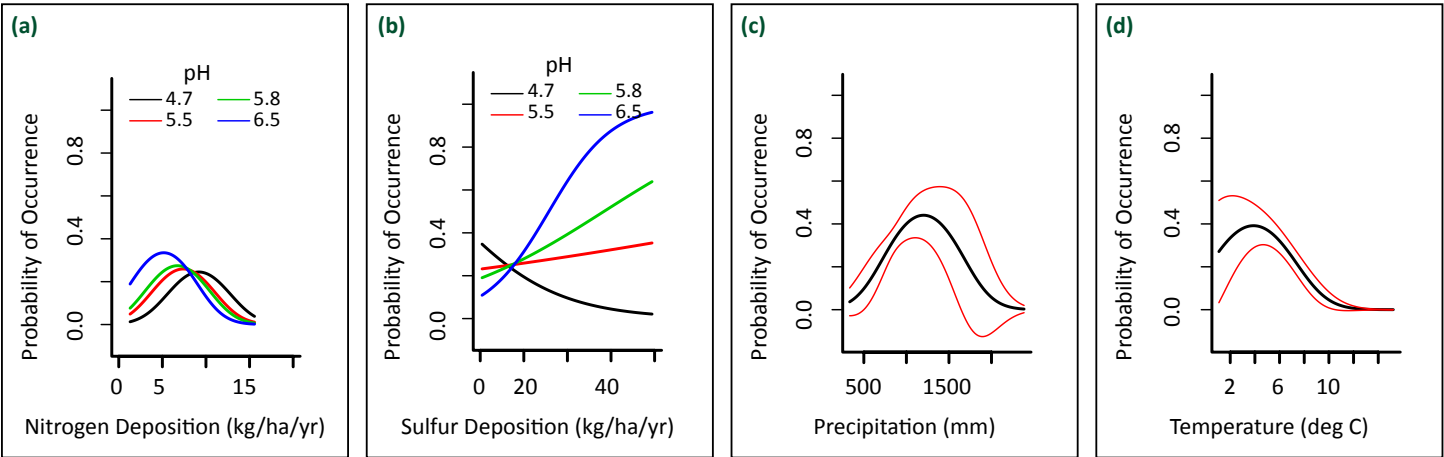


Figure 20.2. Effects of various environmental variables on the probability of occurrence of *Dryopteris carthusiana*: a) N x pH interaction, b) S x pH interaction, c) precipitation, d) temperature.

Critical Loads and Exceedances

The environmental hull for spinulose woodfern covers the eastern and midwestern United States and higher elevations in the West. The N CL is 2–6 kg N/ha/yr in the central part of the species' range and 8–10 kg N/ha/yr along the edges of the range. Exceedances of N CLs based on 2019–2021 TDep total N deposition occur across the

Midwest, higher elevation locations in the West, and scattered in eastern states. The S CL is 0.4 kg S/ha/yr across the eastern and southern States. The S CL is 39.4 kg S/ha/yr in midwestern and western States. The S CL is in exceedance based on 2019–2021 TDep total S deposition in the lower CL regions of the East and South, and west of the coastal ranges in Washington and Oregon.

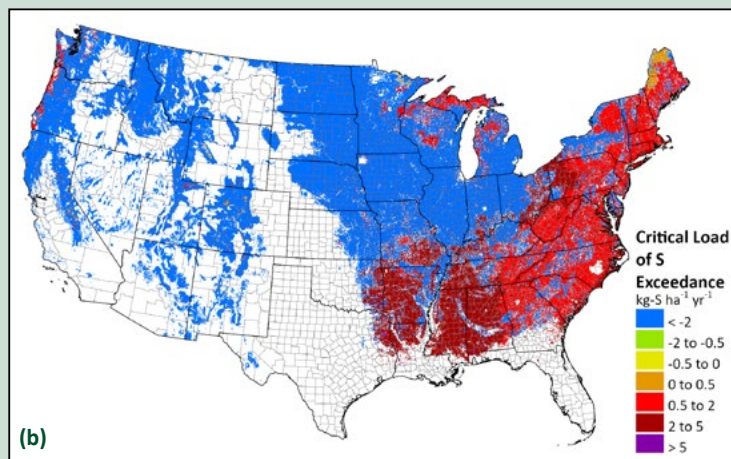
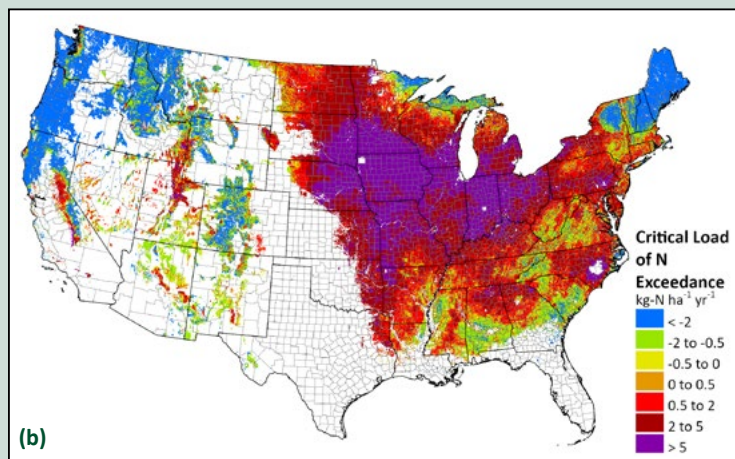
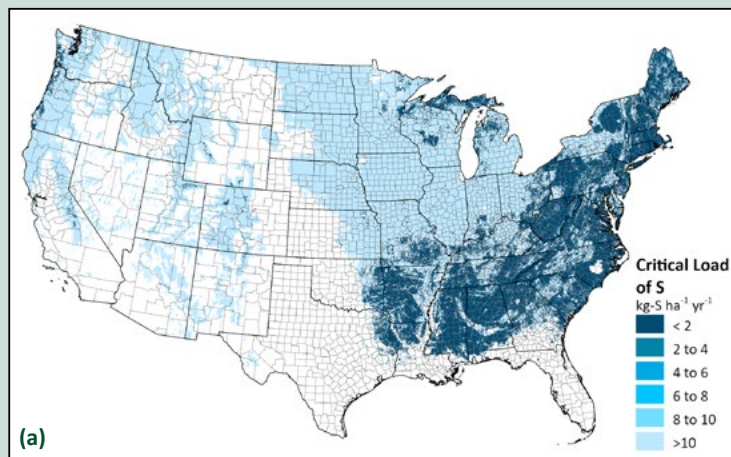
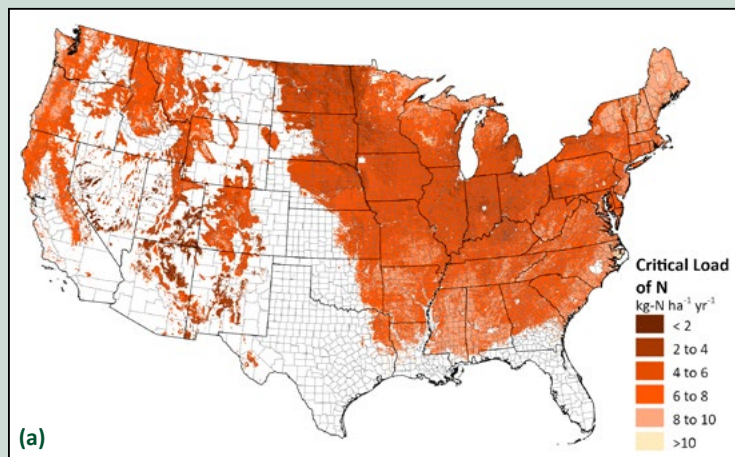


Figure 20.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Dryopteris carthusiana* and (b) the exceedance of N critical loads based on TDep 2019–2021 total N deposition.

Figure 20.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Dryopteris carthusiana* and (b) the exceedance of S critical loads based on TDep 2019–2021 total S deposition.

21.0 *Echinacea angustifolia* (purple coneflower)

Distribution and Conservation Status

Purple coneflower is a native perennial forb that grows in the Great Plains region. Its range stretches from Texas to Canada and from the Rocky Mountains into Missouri. It is critically imperiled in Missouri, imperiled in Colorado, and vulnerable in Wyoming and Iowa (fig. 21.1).

Species Characteristics and Habitat

It is a warm season plant and grows up to 2.5 feet tall. Purple coneflower has a delicate tap root which extends 5 to 6 feet into the soil. The leaves are oblong with 3 to 5 nerves and alternate. The leaves at the base are between 2 to 10 inches in length and up to 2 inches wide. Purple coneflower has spreading or drooping, light pink to pale purple flowers with distinctively yellow pollen grains that bloom from June to July. The flowers are up to 2 inches long and up to 0.20 inches wide. The fruits are small, dark, 4-angled achenes. The seed heads are found on no more than 5 stems, which project 6 to 10 inches above the leaves.

It grows best in alkaline soils with limited organic matter on dry, sandy, and exposed sites. It is often found in glacial till plains and in dark, calcareous clays and gray, sandy loams. Purple coneflower is pollinated by insects. It reproduces by seed and will sprout after removal of the top 6 to 8 inches of root material during cultivation. The seeds germinate on the surface of warm, moist soils during spring months. Purple coneflower is likely to be top-killed during a fire. After a spring fire, about 40% of purple coneflower seeds can develop into seedlings.

Wildlife and Livestock Uses

Purple coneflower provides nutritious forage. In Montana, it is known as a warm season, prolific plant, palatable to grazing animals. Although many other animals graze it, white-tailed deer, eastern cottontails, and ground squirrels find it undesirable, and it is inedible to cattle. Purple coneflower has been combined with the feed of malnourished cows and horses to kindle appetite.

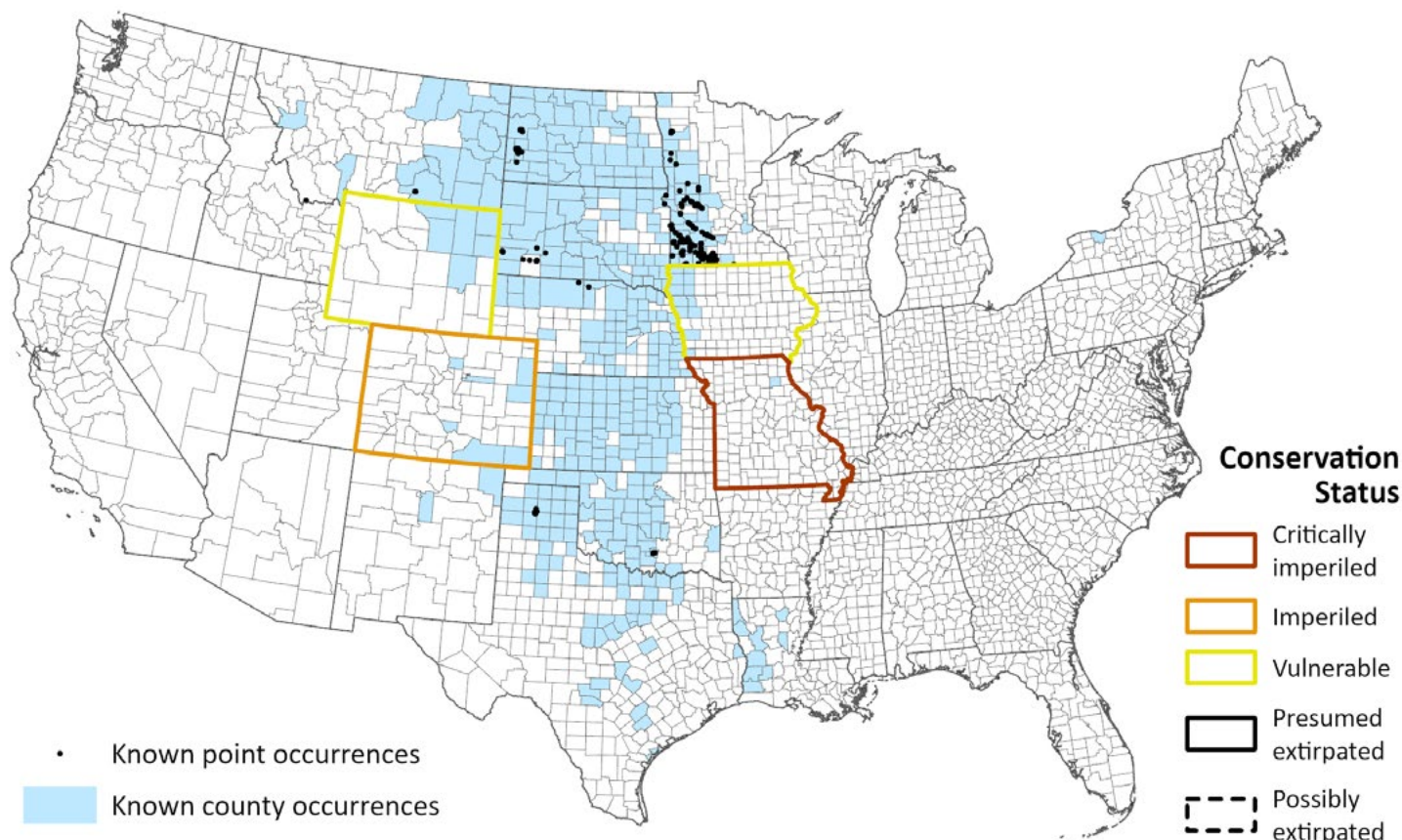


Figure 21.1. Distribution and state-level conservation status of *Echinacea angustifolia*. Known point occurrences were used to assess species deposition responses and critical loads.

Ecosystem Services

Purple coneflower is used in prairie restoration projects in the Great Plains region and for the revegetation of coal mine spoils. The discovery of large, highly active polysaccharide molecules in purple coneflower that contain immunostimulatory properties has led to its widespread commercial use in teas and cold remedies.

Traditional Ecological Knowledge

Purple coneflower has multiple traditional medicinal uses including prevention of convulsions, as a digestive aid, treatment of coughs and sore throats (chewed root) and headaches (smoked); anesthetizing the arms and hands (compress of crushed roots), remedying enlarged glands (compress), curing tonsillitis, treating smallpox (roots

combined with blazing star and boiled to create a tea), and conditioning the hair (combed with the seeds). The chewed root activates saliva and helps prevent thirst. It is also used to treat snake bites and infections.

Responses to Nitrogen and Sulfur

Purple coneflower is not responsive to N deposition but shows a strong decrease with S deposition (fig. 21.2a). Of the variables tested, the only other significant effects are for soil pH (fig. 21.2b) and temperature (fig. 21.2c). The probability of occurrence increases with increasing pH and peaks narrowly at 7.5 °C within the species' sampled range. Confidence in the N and S relationships is moderate-to-high, with very good model performance ($R^2 = 0.359$, $AUC = 0.86$; both high confidence), low VIFs ($VIF-N = 1.9$, $VIF-S = 2.6$; both high confidence), and a moderate N-S correlation ($r=0.61$).



Flower of purple coneflower.
John Ruter, University of Georgia, Bugwood.org.



Stems and flowers of purple coneflower.
Chris Evans, University of Illinois, Bugwood.org.

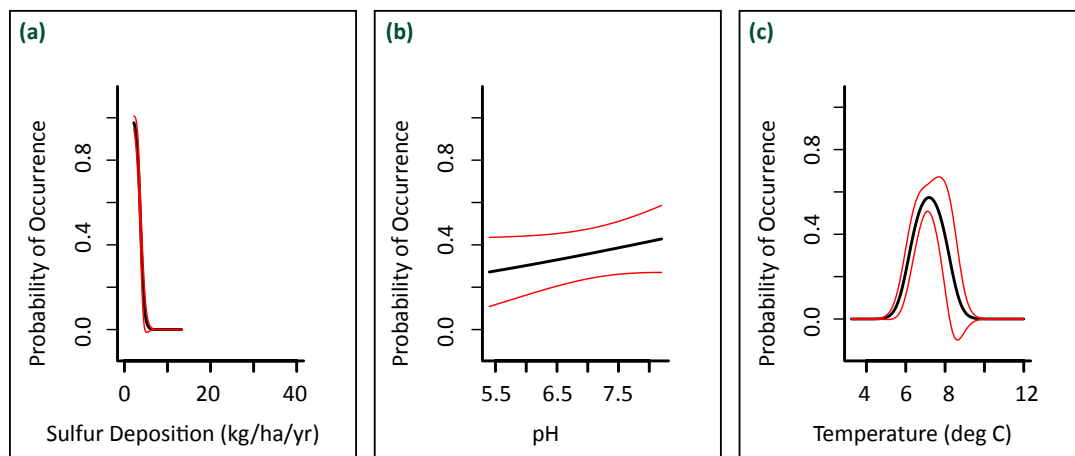


Figure 21.2. Effects of various environmental variables on the probability of occurrence of *Echinacea angustifolia*: a) S deposition, b) pH, c) temperature.

Critical Loads and Exceedances

The environmental hull for purple coneflower covers the less-mountainous areas of the northwestern United States. There is no N CL defined for this species based on

current data. The S CL is 2.2 kg S/ha/yr across the entire range. The S CL is in exceedance based on 2019–2021 TDep total S deposition in small pockets of areas in the northern Midwest.

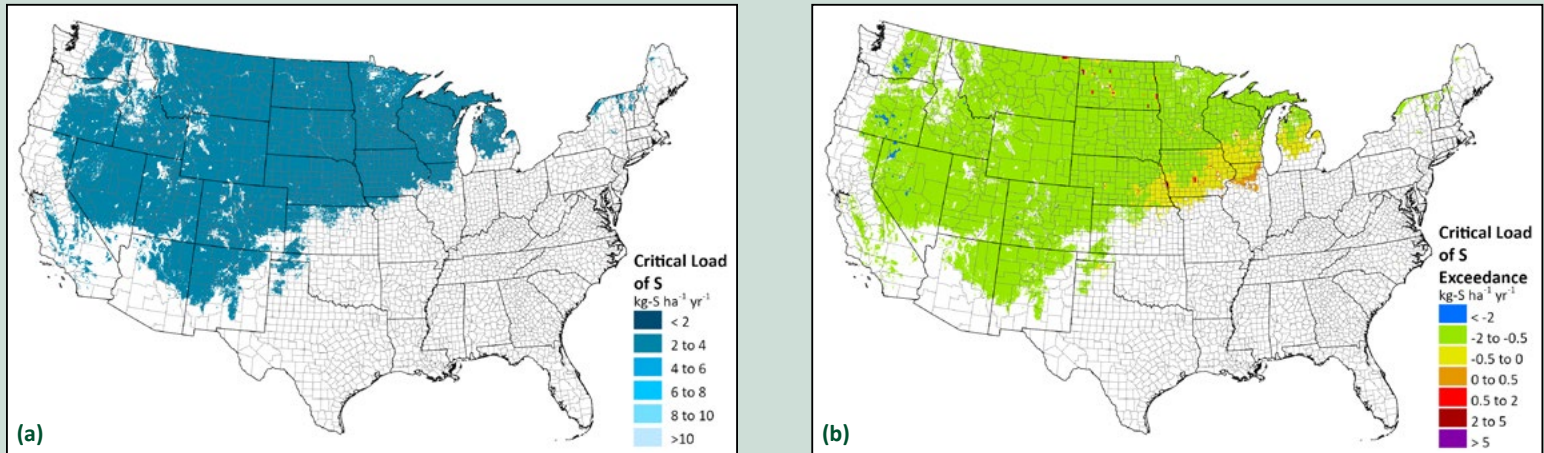


Figure 21.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Echinacea angustifolia* and (b) the exceedance of S critical loads based on TDep 2019–2021 total S deposition.

22.0 *Elymus canadensis* (Canada wildrye)

Distribution and Conservation Status

Canada wildrye is a native perennial grass that grows in Alaska and throughout the continental United States except the extreme Southeast. It is commonly found in the Minnesota sand prairies and grows along roadsides, adjacent to croplands, pastures, and woodlands in southeastern Iowa. It is critically imperiled in Wyoming and Virginia (fig. 22.1).

Species Characteristics and Habitat

Canada wildrye is a cool season, drought intolerant bunchgrass. It is coarse and robust, growing from 2 to 5 feet tall. Culms are hollow, with stems becoming tough and woody once mature. It is a rhizomatous species, yet the rhizomes are rare and often less than 2 inches long. In prairie lowlands it forms a shallow, wide-spreading root system that may exceed 2 feet on all sides. The roots are thin, highly branched, tough and wiry, and usually found within the first 2.5 feet of soil. The leaf blades are flat,

broad, and rough, growing between 6 to 12 inches long. The inflorescence is a spike normally about 6 inches tall with sharp awns.

Canada wildrye prefers mesic, lowland soils, but is adapted to a wide variety of soils such as gravelly, sandy, silty, or clayey soils and areas of low soil fertility, especially those low in phosphorus. It reproduces through seed or vegetative means. Canada wildrye is typically top-killed by fire. The rough stems and leaves of Canada wildrye make it less susceptible to prolonged burning. Postfire establishment occurs principally through seed germination and, to a lesser extent, vegetative production of the root crown.

Wildlife and Livestock Uses

In Utah and Nevada, cougars often feed on Canada wildrye. In Missouri, cottontail rabbits consume it. Canada wildrye provides good habitat for many bird species by

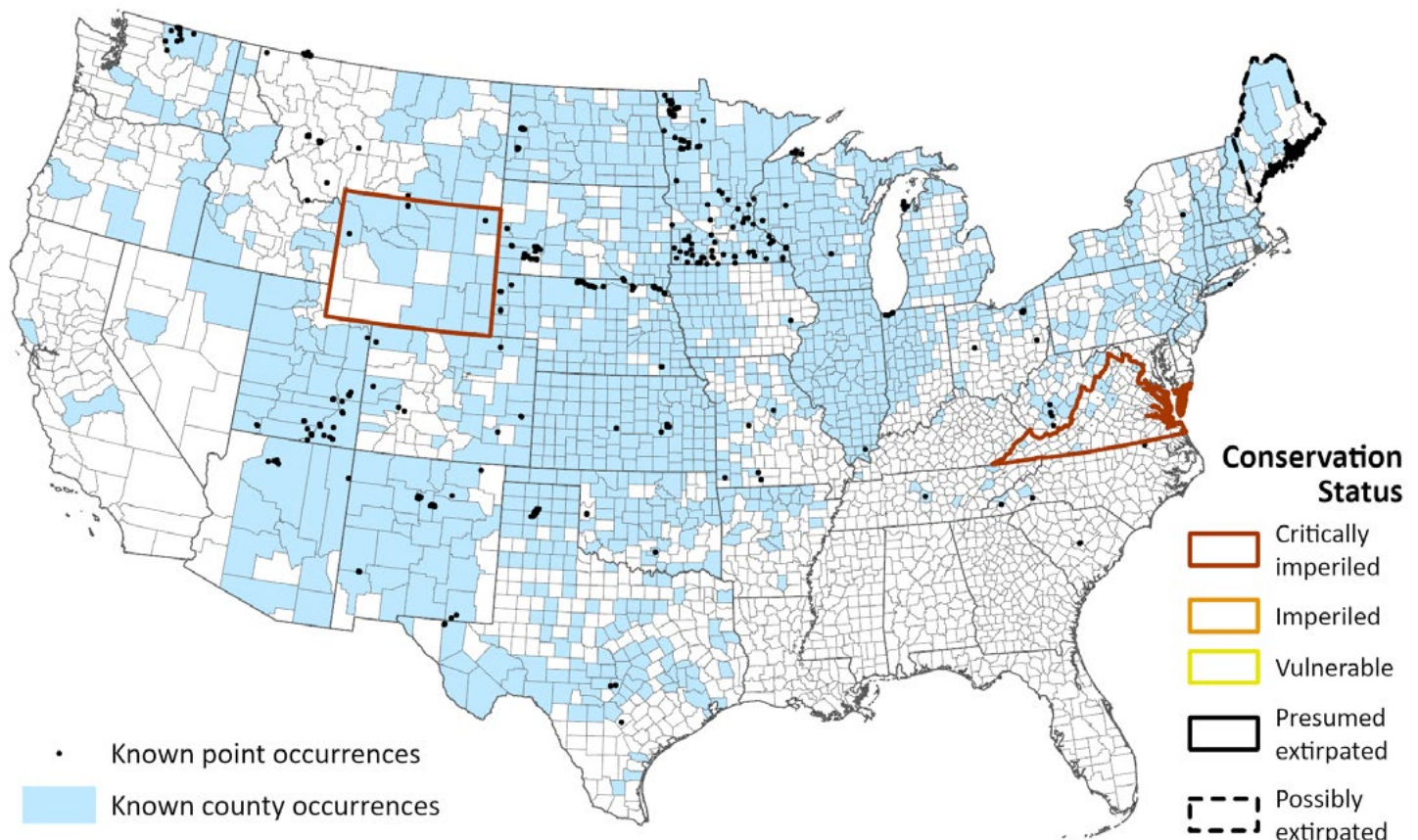


Figure 22.1. Distribution and state-level conservation status of *Elymus canadensis*. Known point occurrences were used to assess species deposition responses and critical loads.

delivering cover for nesting, brood, winter, and escape from predators. Canada wildrye is palatable to all classes of livestock when it is young but once it matures it is no longer considered good forage.

Ecosystem Services

Canada wildrye is an excellent source of hay and harvesting is recommended just as seed heads emerge. The seedlings are surprisingly robust which allows them to establish rapidly in areas prone to erosion, aiding erosion control. A traditional food source and medicine, wildrye may be consumed as a source of nutrients (seeds), used as kidney medicine (compound decoction of roots), and used ceremonially to fertilize corn seeds.



Flowers and stems of Canada wildrye.
Rob Routledge, Sault College, Bugwood.org.

Responses to Nitrogen and Sulfur

The probability of occurrence of Canada wildrye is mostly dependent on the interactive effects of N and S deposition (fig. 22.2a). At low N and S deposition, the probability of occurrence is high and decreases with increasing N deposition. At higher S deposition, the probability of occurrence is low and is largely unresponsive to N deposition. The climate effects are shown in Figure 22.2b (precipitation) and Figure 22.2c (temperature). The probability of occurrence increases with increasing precipitation and is weakly responsive to temperature, peaking broadly at 5.5 °C within the species’ sampled range. Confidence in the N and S relationships is moderate-to-high, with good model performance ($R^2 = 0.107$, AUC = 0.7; both moderate confidence), low VIFs (VIF-N = 1.7, VIF-S = 2.3; both high confidence), and a moderate N-S correlation ($r=0.65$, moderate confidence).



Flowers of Canada wildrye.
Rob Routledge, Sault College, Bugwood.org.

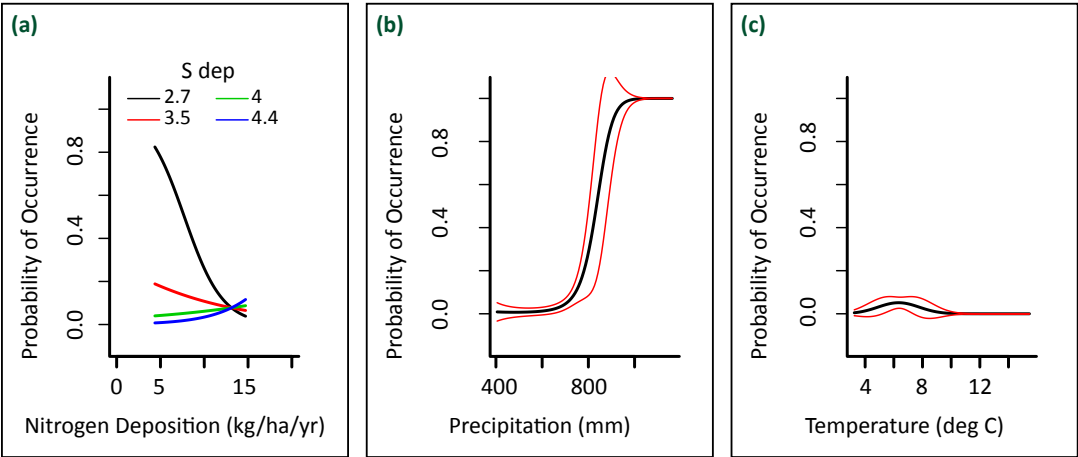


Figure 22.2. Effects of various environmental variables on the probability of occurrence of *Elymus canadensis*: a) N x S interaction, b) precipitation, c) temperature.

Critical Loads and Exceedances

The environmental hull for Canada wildrye covers the continental United States excluding the higher temperature southeastern areas and parts of the Pacific Northwest. It is sparsely present in Texas, present in the SW and largely absent from California. The N CL is 4-6 kg N/ha/yr in the West and ≥ 10 kg N/ha/yr in the East. Exceedances of N CLs based on 2019–2021 TDep total N

deposition occur at high elevations in the West, across the eastern Great Plains, and in spotted areas in the East. The S CL is 2.2 kg S/ha/yr across the entire range except near some eastern cities where the S CL is 13.3 kg S/ha/yr in midwestern and western States. The S CL is in exceedance based on 2019–2021 TDep total S deposition across most of the southeastern United States.

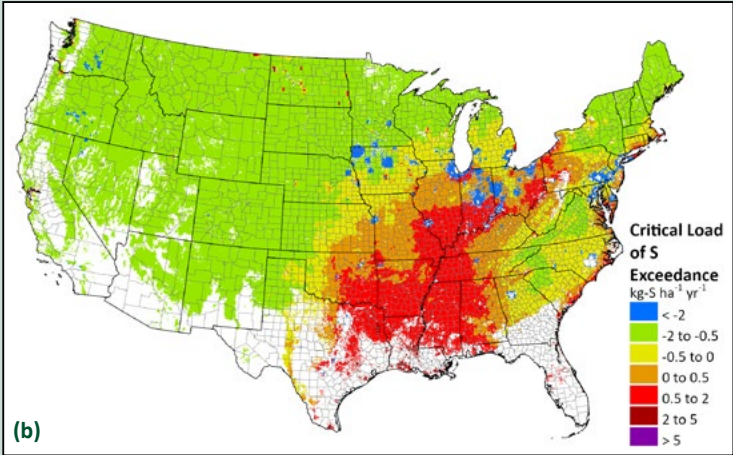
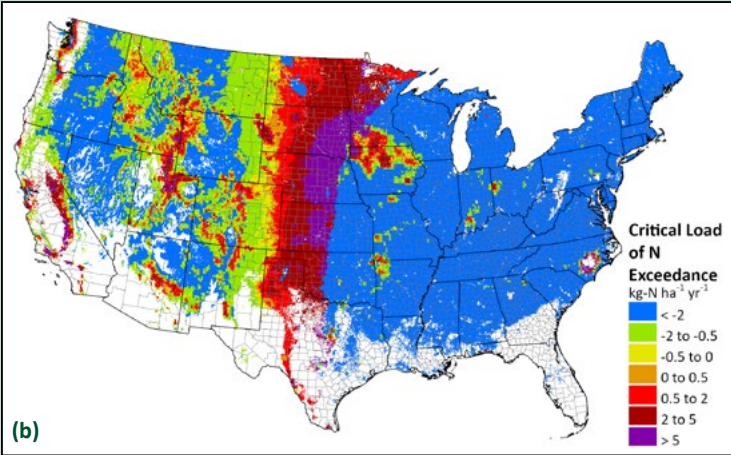
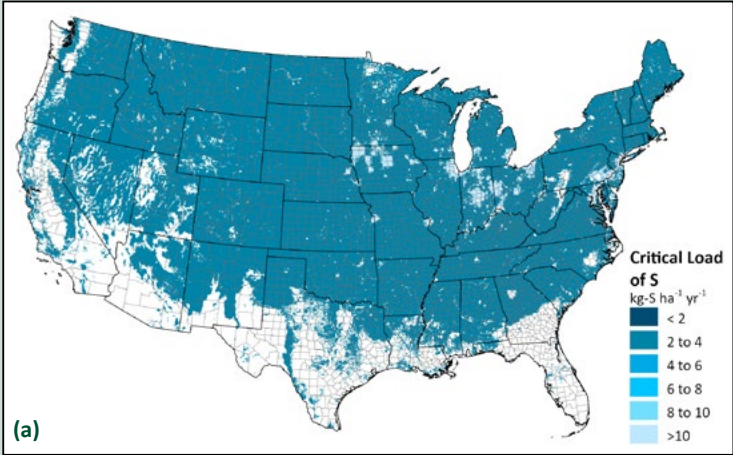
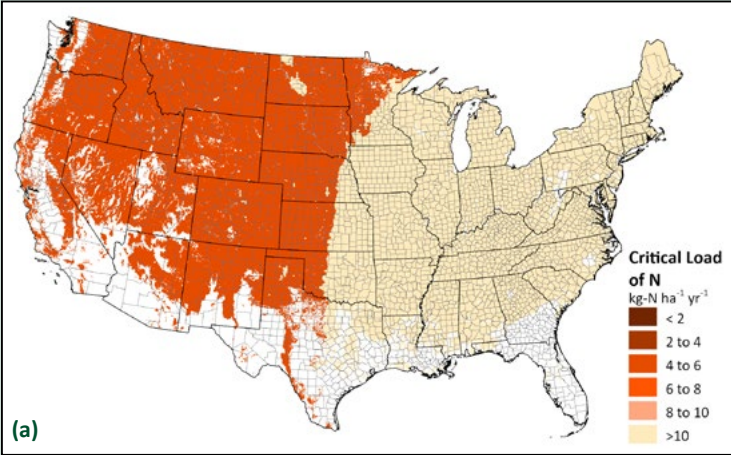


Figure 22.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Elymus canadensis* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 22.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Elymus canadensis* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

23.0 *Elymus trachycaulus* (slender wheatgrass)

Distribution and Conservation Status

Slender wheatgrass is a perennial grass native to the mountain and intermountain areas of the western United States and the northern Great Plains. It is widely distributed across North America from Alaska east to Newfoundland and south to North Carolina, Kentucky, Arkansas, Texas and western Mexico. It is critically imperiled in Illinois, North Carolina, and New Jersey, imperiled in Wyoming, Ohio, and Virginia, and vulnerable in Pennsylvania and Vermont (fig. 23.1).

Species Characteristics and Habitat

Slender wheatgrass is a short-lived, cool season, upright, tufted bunchgrass. Its rhizomes are short, and the seed-stalks and stems have a reddish-purplish tinge at the base. It has flat leaves ranging in height from 2 to 2.5 feet.

Slender wheatgrass grows best in loamy and sandy loam soils, on moist to dry sites, and is moderately tolerant of alkaline conditions and somewhat tolerant of saline

soils. It does not tolerate excessive soil moisture but does tolerate shade. Slender wheatgrass occurs at elevations ranging from 4,300 to 11,500 feet. Slender wheatgrass is a self-pollinated or wind-pollinated species with substantial seed production. Seeds are spread by attaching to animal hides. When stored in seed banks, the seeds remain viable for 3 to 6 years, with a sprouting capacity of 80 to 90 percent. Slender wheatgrass requires up to 2 months of short night/long day stratification prior to germination and is favored by summer or fall fires. Moderate-severity fire will top-kill slender wheatgrass and kill some tillers. It is most sensitive to spring fire that overlaps with its active growing period. It can be considered “weedy” because of its ability to rapidly establish in disturbed areas.

Wildlife and Livestock Uses

Game birds and small mammals use slender wheatgrass seeds as food and the vegetation for cover. Protein content averages between 22 to 25% in the spring and decreases below 10% in late summer to autumn. Typical

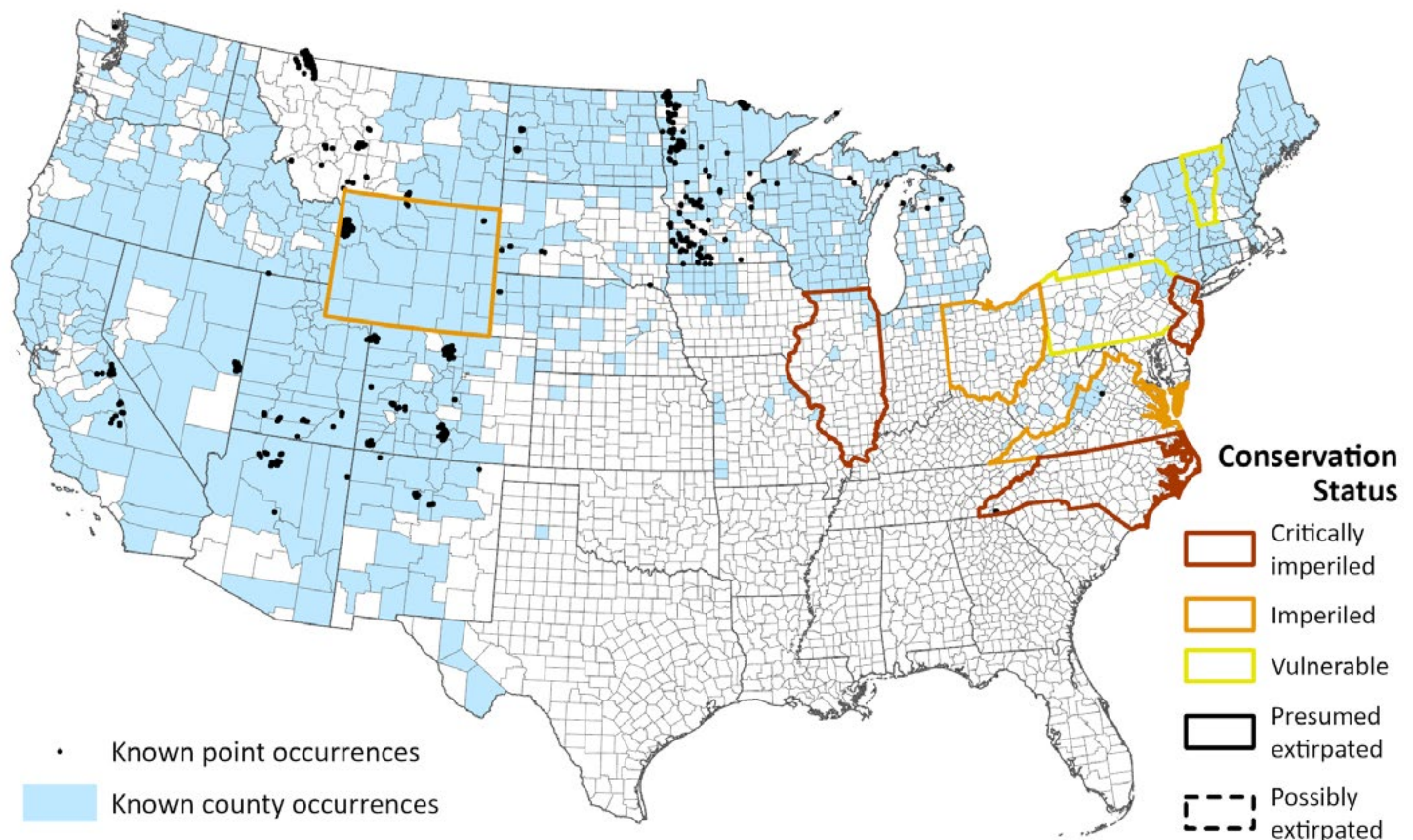


Figure 23.1. Distribution and state-level conservation status of *Elymus trachycaulus*. Known point occurrences were used to assess species deposition responses and critical loads.

dry matter yield is between 1000 and 2300 lb/acre. Sage grouse, deer, elk, moose, bighorn sheep, mountain goat, pronghorn, various rodents, and all classes of livestock graze on slender wheatgrass. It is preferred forage for Elk and bighorn sheep. Horses eat slender wheatgrass as hay.

Ecosystem Services

Slender wheatgrass produces good quality hay. Slender wheatgrass is recommended in reclamation mixes due to its vigorous seedlings and ability to establish successfully. Slender wheatgrass is used in an assortment of watershed developments, such as recovering logged-over watershed areas, upgrading of subalpine watersheds, and streambank and stream bottom improvements.



Herbarium sample of slender wheatgrass roots, stems and flowers.
Dave Powell, USDA Forest Service (retired), Bugwood.org.

Responses to Nitrogen and Sulfur

The probability of occurrence for slender wheatgrass is mostly dependent on the interactive effect of N and S deposition (fig. 23.2a). At low S deposition (≤ 2.6 kg S/ha/yr), increasing N deposition leads to a strong increase in the probability of occurrence up to roughly 10 kg N/ha/yr, after which it declines steeply with additional N deposition. At higher S deposition, slender wheatgrass is less responsive to increasing N deposition, though it still increases then decreases above roughly 13 kg N/ha/yr. Of the variables tested, the only other significant variable is pH (fig. 23.2b): the probability of occurrence increases with more alkaline soil conditions. There are no significant climate variables.

Confidence in the N and S relationships is moderate, with good model performance ($R^2 = 0.178$, $AUC = 0.78$; both moderate confidence), low VIFs ($VIF-N = 1.4$, $VIF-S = 1.9$; both high confidence), and a high N-S correlation ($r=0.73$, low confidence).



Flowers of slender wheatgrass.
Dave Powell, USDA Forest Service (retired), Bugwood.org.

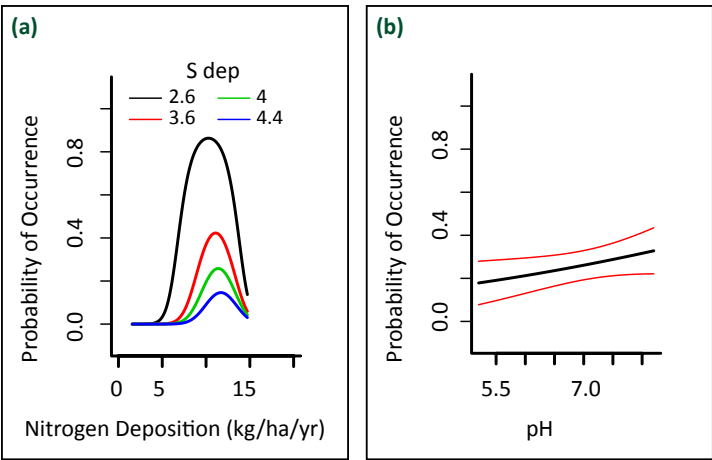


Figure 23.2. Effects of various environmental variables on the probability of occurrence of *Elymus trachycaulus*: a) N x S interaction, b) pH.

Critical Loads and Exceedances

The environmental hull for slender wheatgrass covers the northern half of the United States except west of the Pacific Coast Ranges. The N CL is >10 kg N/ha/yr across the eastern United States and between 8 and 10 kg N/ha/yr in the West. Exceedances of N CLs based on 2019–2021

TDep total N deposition exist in the central Midwest and near urban areas in the West. The S CL is 0.6 kg S/ha/yr across the entire species' range. Sulfur CLs are in exceedance based on 2019–2021 TDep total S deposition across the Midwest and eastern United States and in higher elevations in the West.

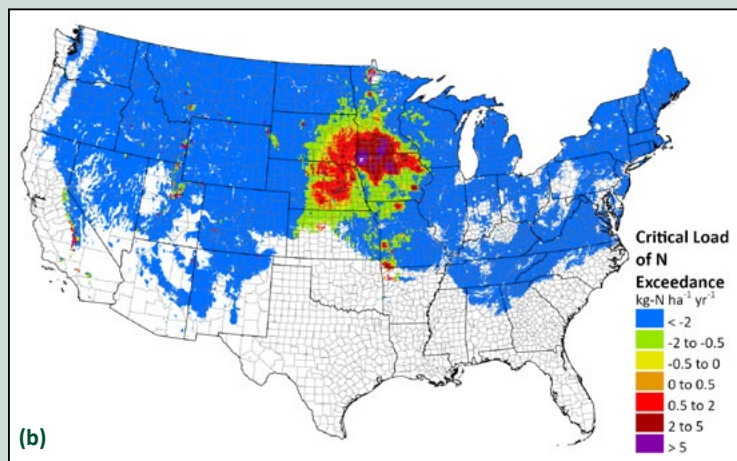
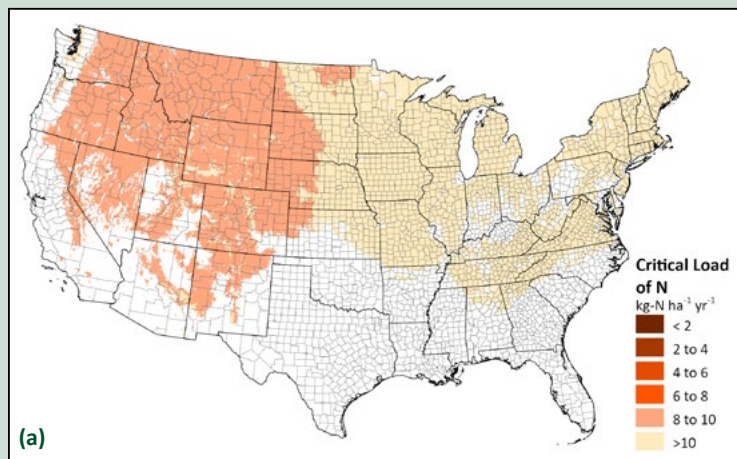


Figure 23.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Elymus trachycaulus* and (b) the exceedance of N critical loads based on TDep 2019–2021 total N deposition.

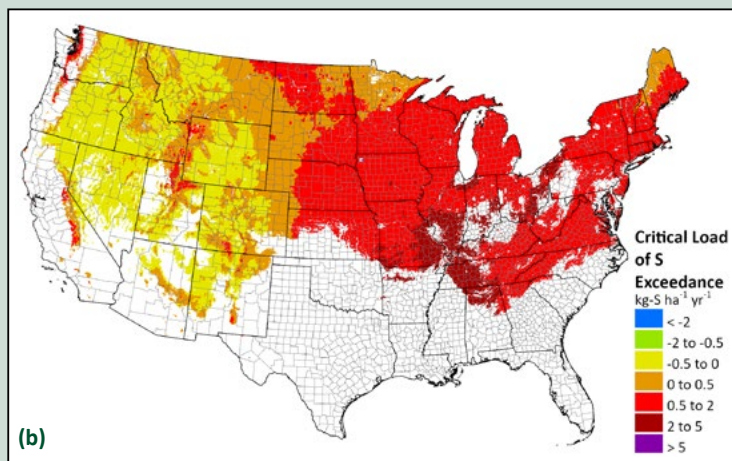
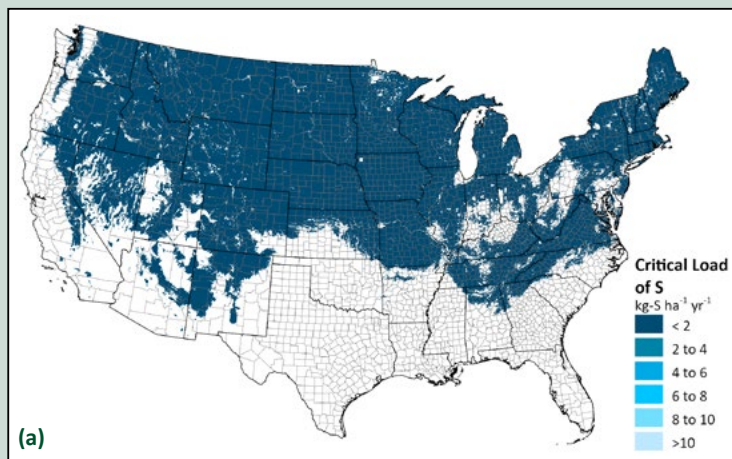


Figure 23.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Elymus trachycaulus* and (b) the exceedance of S critical loads based on TDep 2019–2021 total S deposition.

24.0 *Elymus virginicus* (Virginia wildrye)

Distribution and Conservation Status

Virginia wildrye is a native perennial grass. It grows well in open grasslands and prairies and in wooded sites throughout the United States except the Pacific Northwest, Nevada, California, Utah and Colorado (fig. 24.1).

Species Characteristics and Habitat

It is a non-rhizomatous, cool season bunchgrass growing up to 3 feet tall. The color of Virginia wildrye may vary from green to silvery blue, and foliage often has a waxy appearance. The alternately arranged leaves are roughly 12 inches in length and 2/3 inch wide. Virginia wildrye is typically hairless but can have short hairs on the leaf sheaths. Virginia wildrye blooms between March and May. Seed heads are normally upright, 3 to 6 inches in length, and contain several, coarse awns. Each densely packed spikelet has two or more florets that decrease in size as

they extend to the end of the inflorescence. The glumes bow outward at the base creating a “U” shape and are strongly nerved.

Virginia wildrye prefers soils with more moisture and fertility, but also survives in coarse sands to heavy clay. As a result, it is commonly found in moist sites such as wet prairies, margins of wetlands, ditches, and riparian areas. It does not tolerate saline sites. It is wind pollinated and reproduces by seed and tillers. Virginia wildrye self-fertilizes but can hybridize and introgress. It is shade tolerant and will adapt to disturbances and can be found in areas including forest cut overs. It has moderate drought tolerance drought but low tolerance of burning.

Wildlife and Livestock Uses

Large mammals like deer eat the foliage while small animals such as birds forage for the seeds. Birds also use the stems for nesting material. When found near riparian

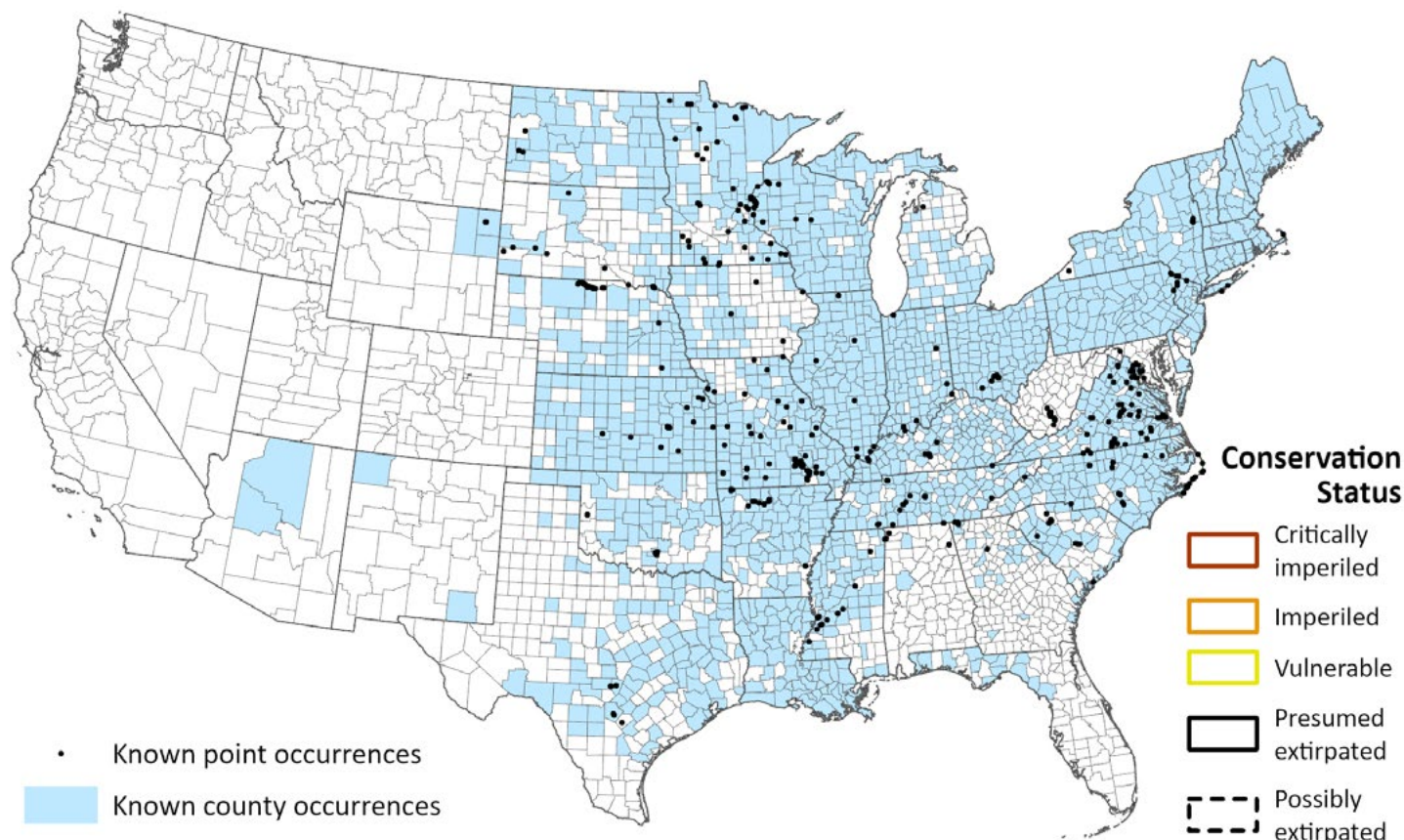


Figure 24.1. Distribution and state-level conservation status of *Elymus virginicus*. Known point occurrences were used to assess species deposition responses and critical loads.

areas, Virginia wildrye is eaten by Canada geese and used by mallards and other ducks for nesting. Virginia wildrye is highly palatable and nutritious, and thus is consumed by all types of livestock while it is green in the spring and autumn.

Ecosystem Services

Virginia wildrye can be utilized to restore range as a cool season grass. Additionally, it is an excellent cool season grass in shaded, wooded, or riparian areas. Virginia wildrye is an excellent producer of forage, producing as much as 3,300 lbs of dry weight forage per dryland acre.



Close up of the flowers of Virginia wildrye.
Larry Allain.

Responses to Nitrogen and Sulfur

Available data suggests that Virginia wildrye is not vulnerable to N or S deposition under levels of deposition assessed. Of the variables tested, the species only responds to soil pH (fig. 24.2a) with a higher probability of occurrence at intermediate soil pH. There are no significant climate variables. Confidence in the N and S relationships (or lack thereof) is moderate-to-high for N and low-to-moderate for S, with good model performance ($R^2 = 0.153$, AUC = 0.71; both moderate confidence), mixed VIFs (VIF-N = 1.9, VIF-S = 5.5; high and low confidence, respectively), and a moderate N-S correlation ($r=0.44$, moderate confidence).

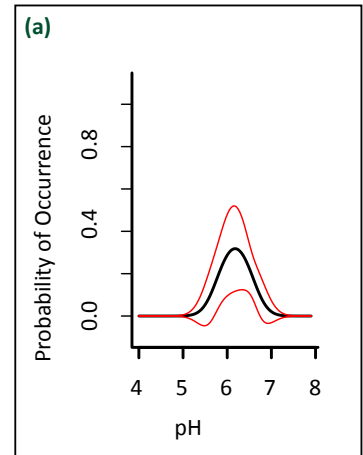


Figure 24.2. Effects of various environmental variables on the probability of occurrence of *Elymus virginicus*: a) pH.

Critical Loads and Exceedances

The environmental hull for Canada wildrye covers the entire United States except western and southwestern arid areas. There are no responses to N or S deposition.



Flowers and stem of
Virginia wildrye.
Larry Allain.

25.0 *Eryngium yuccifolium* (rattlesnake master)

Distribution and Conservation Status

Rattlesnake master is a native perennial forb normally found in wet or dry prairies and open woods in the southeastern United States, north to Virginia, and throughout the Midwest to Minnesota, Kansas and Texas. It is critically imperiled in Nebraska, imperiled in Michigan and Virginia, and vulnerable in Minnesota and Ohio (fig. 25.1).

Species Characteristics and Habitat

Rattlesnake master starts as a short, thick rootstock and grows 2 to 6 feet tall. The basal leaves are bluish green and grow up to 3 feet long. Rattlesnake master blooms in June through September and has a scent like honey. The whitish bracts stick out sharply from the flowers, giving the flower head a rough, prickly feel and appearance.

Rattlesnake master is a warm-season plant that grows best on wet or dry mesic prairie soil. It can self-pollinate but is also pollinated by insects. It is not thought of as weedy or an invasive species and does not spread to neighboring areas.

Wildlife Uses

Rattlesnake master is pollinated by wasps, bees and butterflies such as the monarch butterfly. Soldier beetles eat the pollen. A specialized insect found in prairie remnants in the Midwest, the rattlesnake insect stem-borer, is dependent on this plant to complete its life cycle. Voles and other rodents often feed on the plant's crowns during winter, causing local devastation where the plant is abundant.

Ecosystem Services

Rattlesnake master is used for roadside plantings, prairie restoration, landscaping, and wildlife cover. Due to its attractive appearance, it is often planted in wildflower gardens.

Traditional Ecological Knowledge

Traditional medicinal uses include the prevention of whooping cough, blood purification, as a kidney aid, treatment of snake bites, and as an emetic during religious ceremonies.

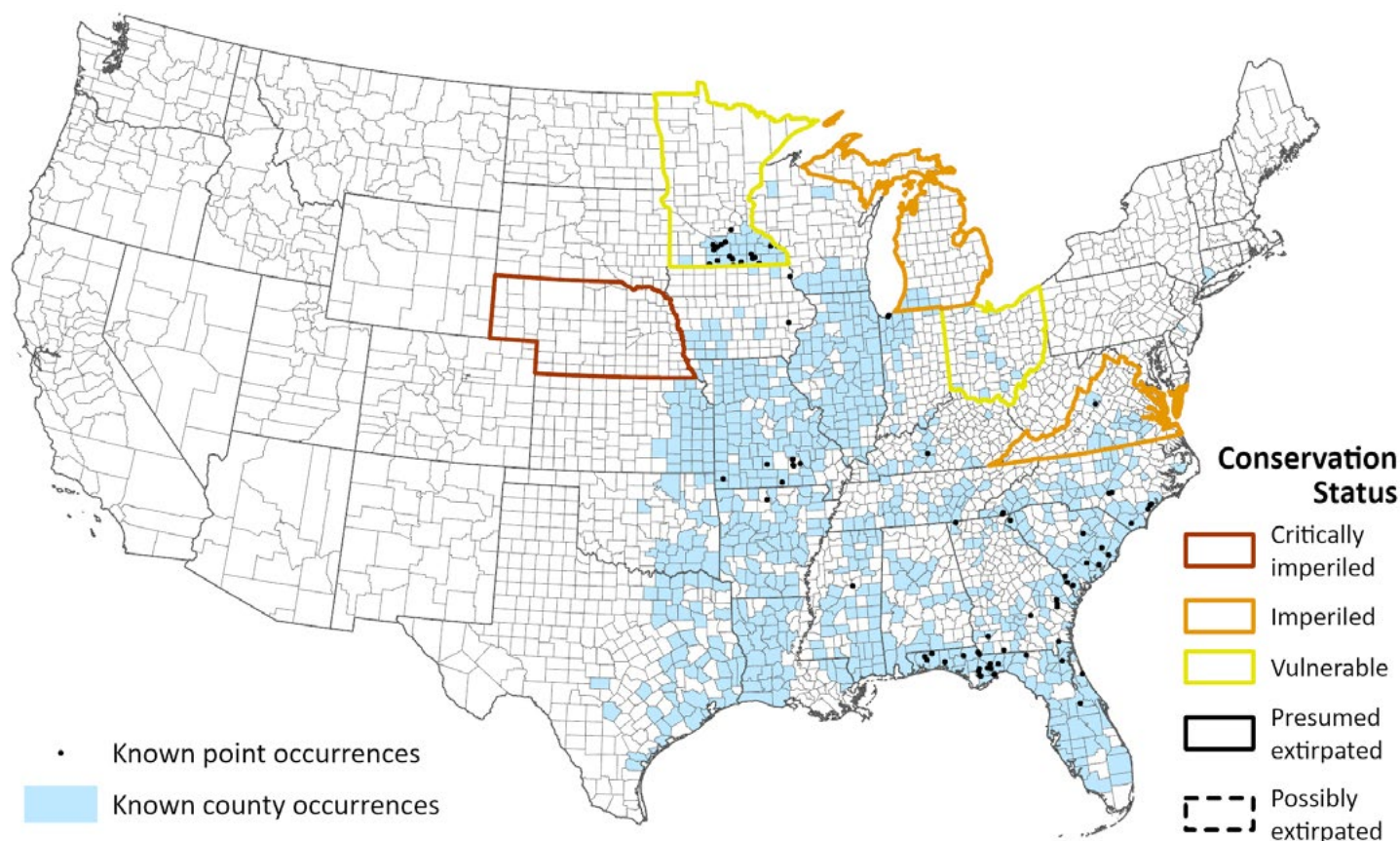


Figure 25.1. Distribution and state-level conservation status of *Eryngium yuccifolium*. Known point occurrences were used to assess species deposition responses and critical loads.

Responses to Nitrogen and Sulfur

The probability of occurrence of rattlesnake master is mostly dependent on the interactive effect between N and S deposition (fig. 25.2a). At low S deposition (≤ 2.8 kg S/ha/yr), the probability of occurrence increases with N deposition, and at higher S deposition (≥ 6.2 kg S/ha/yr) it decreases with N deposition. The climate effects are shown in Figures 25.2b (precipitation) and Figure 25.2c (temperature). The probability of occurrence increases above 900 mm precipitation and decreases above 5 °C within the species’ sampled range. Confidence in the N and S relationships is moderate-to-high, with good model performance ($R^2 = 0.215$, AUC = 0.83; moderate and high confidence, respectively), low VIFs (VIF-N = 1.1, VIF-S = 1.4; both high confidence), and a moderate N-S correlation ($r=0.48$).



Stem and flowers of rattlesnake master.
Alex Katovich, Bugwood.org.

Critical Loads and Exceedances

The environmental hull for rattlesnake master covers the Southeast and the eastern half of the midwestern United States. The N CL is 4-6 kg N/ha/yr in the Southeast and ≥ 10 kg N/ha/yr in the Midwest states. Exceedances of N CLs based on 2019–2021 TDep total N deposition exist in Southeast and in high deposition areas in Iowa and Minnesota. The S CL is 2.2 kg S/ha/yr across most of the range with S CL values of 15.0 kg S/ha/yr in Florida and southern Georgia. The S CL is in exceedance based on 2019–2021 TDep total S deposition across the southwestern part of the species’ range.



Flowers of
rattlesnake master.
Karan A. Rawlins,
University of Georgia,
Bugwood.org.

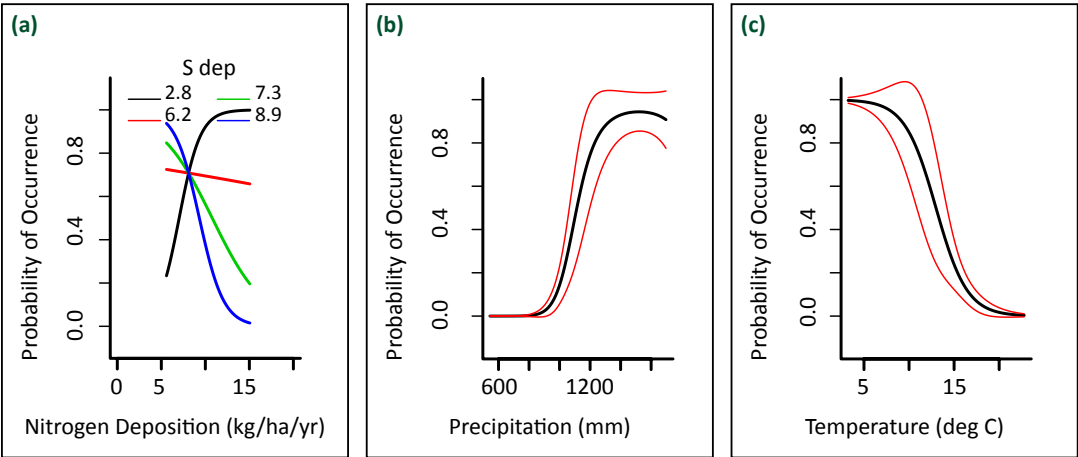


Figure 25.2. Effects of various environmental variables on the probability of occurrence of *Eryngium yuccifolium*: a) N x S interaction, b) precipitation, c) temperature.

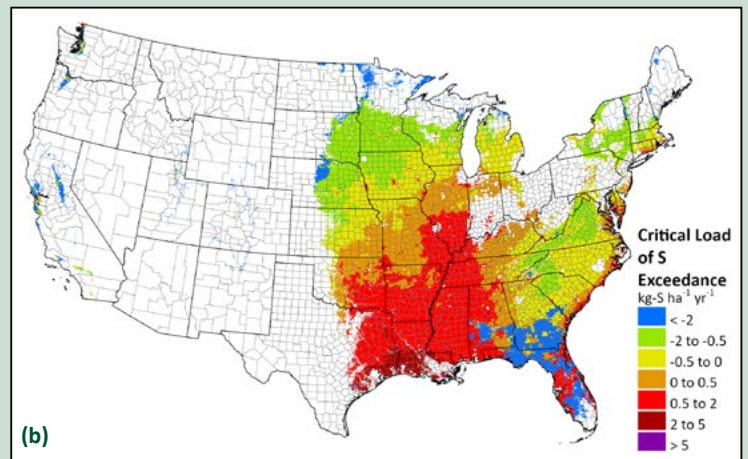
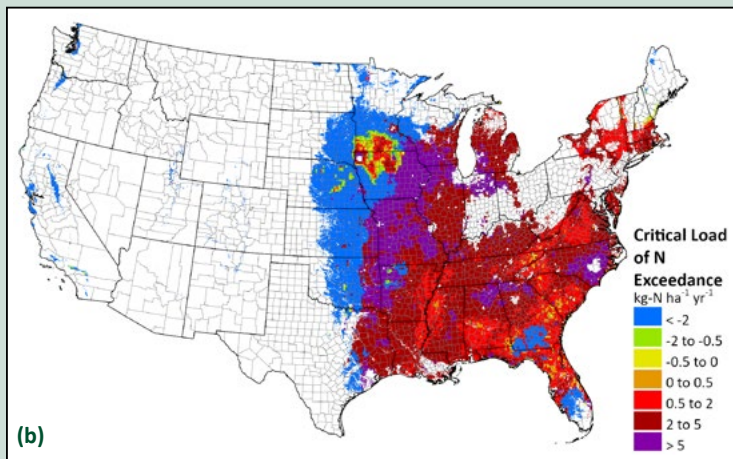
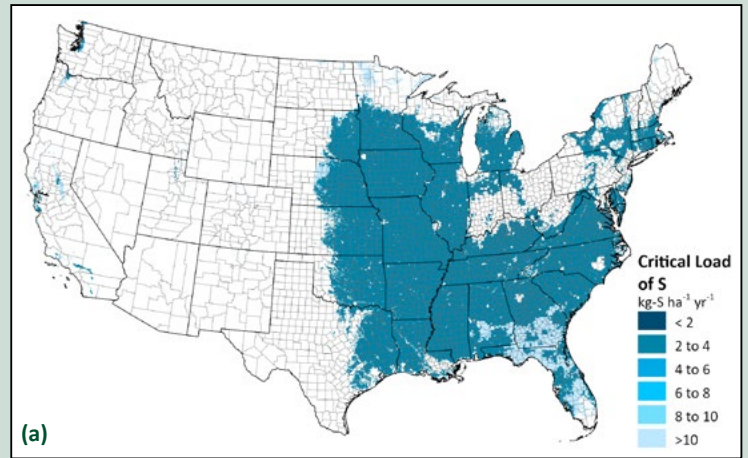
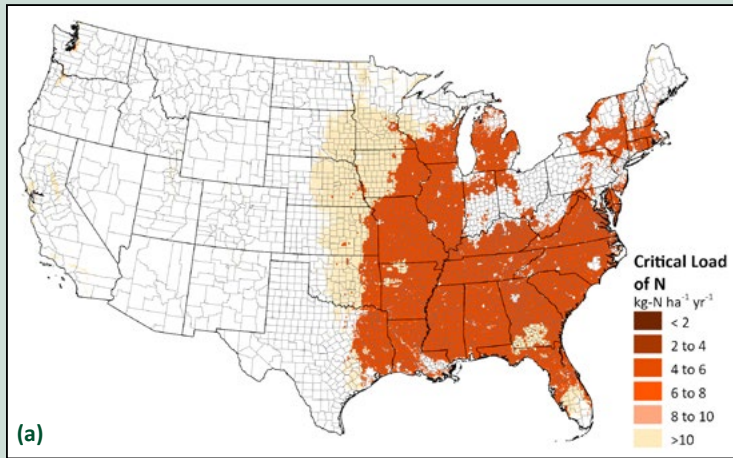


Figure 25.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Eryngium yuccifolium* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 25.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Eryngium yuccifolium* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

26.0 *Eupatorium compositifolium* (dogfennel)

Distribution and Conservation Status

Dogfennel is a native annual to perennial forb of meadows and disturbed sites. It grows in the southeastern United States from Florida west to eastern Texas, and north to Tennessee, Virginia, and New Jersey. Occasionally it is found farther north along the east coast in Massachusetts (fig. 26.1).

Species Characteristics and Habitat

Dogfennel is a common, aggressive, weedy plant that reaches an average of 5 feet tall but can grow up to 9 feet on fertile sites. It reaches peak biomass in the spring. Numerous stems grow from a stout woody caudex and sprout in distinct colonies on favorable sites. Its flowering period is particularly long because shaded plants bloom earlier than those in full sun. Dogfennel is wind pollinated and reproduces sexually. The fruit is a smooth achene.

Wildlife and Livestock Uses

Dogfennel likely has very low palatability to wildlife and livestock. Cattle seldom graze it, if at all, even when presented with few alternatives.

Ecosystem Services

Dogfennel acts as a pool for disease-causing pathogens when growing among food crops.

Responses to Nitrogen and Sulfur

The probability of occurrence of dogfennel is strongly affected by the interactive effect of N and S deposition (fig. 26.2a). At low S deposition (≤ 6.3 kg S/ha/yr), the probability of occurrence for dogfennel increases with N deposition, and at higher S deposition (≥ 7.4 kg S/ha/yr) it decreases with N deposition. Of the other variables tested, the only significant variable is temperature (fig.

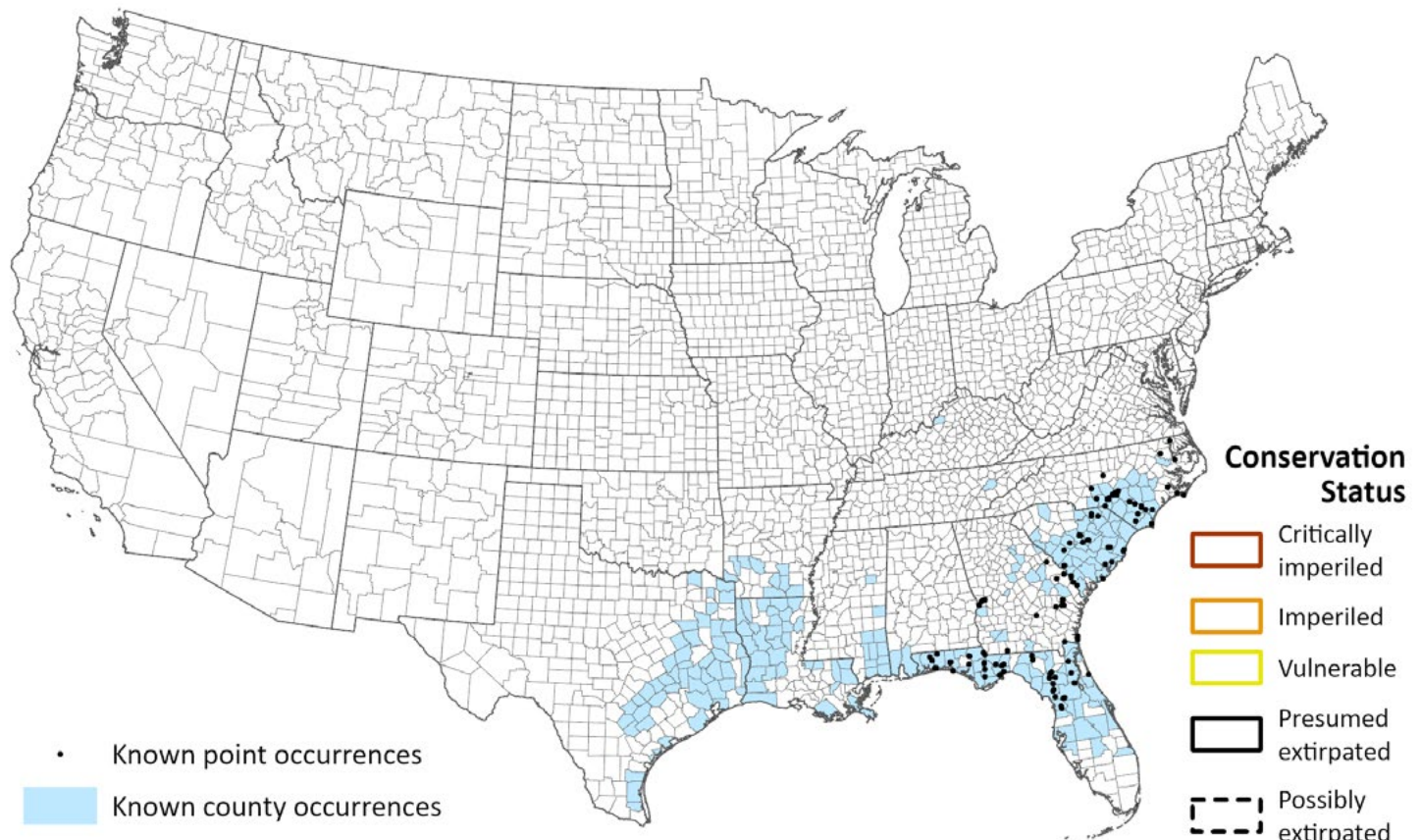


Figure 26.1. Distribution and state-level conservation status of *Eupatorium compositifolium*. Known point occurrences were used to assess species deposition responses and critical loads.

26.2b). The probability of occurrence increases with increasing temperatures within the species' sampled range. Confidence in the N and S relationships is moderate, with good model performance ($R^2 = 0.152$, $AUC = 0.75$; both moderate confidence), low VIFs ($VIF-N = 1.5$, $VIF-S = 1.4$; both high confidence), and a high N-S correlation ($r=0.78$, low confidence).

Critical Loads and Exceedances

The environmental hull for dogfennel covers the southeastern United States. The N CL is 4-6 kg N/ha/yr in the northern part of its range and ≥ 10 kg N/ha/yr in the southern part. Exceedances of N CLs based on 2019–2021 TDep total N deposition exist in all areas with the lower CLs. The S CL is 5.4 kg S/ha/yr across the northern part of the species' range with S CL values of 15.0 kg S/ha/yr in the South. The S CL is in exceedance based on 2019–2021 TDep total S deposition in a few cities along the Gulf Coast.

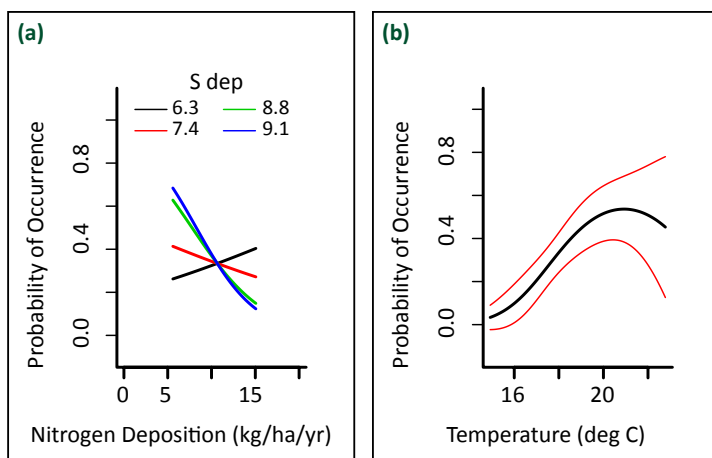


Figure 26.2. Effects of various environmental variables on the probability of occurrence of *Eupatorium compositifolium*: a) N x S interaction, b) temperature.



Foliage of dogfennel.

James H. Miller, USDA Forest Service, Bugwood.org.

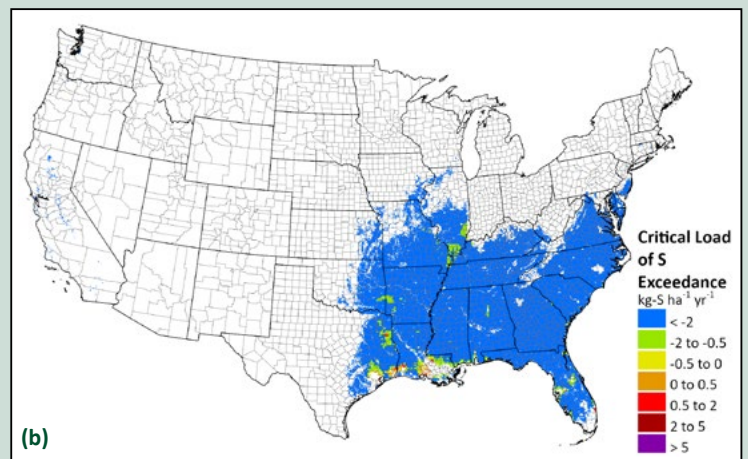
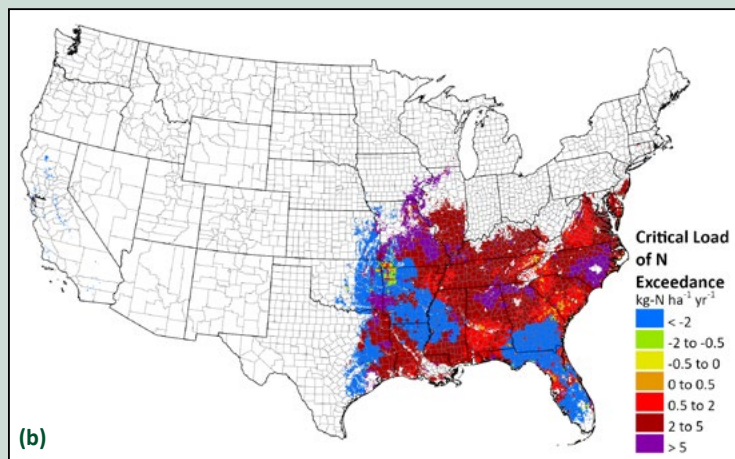
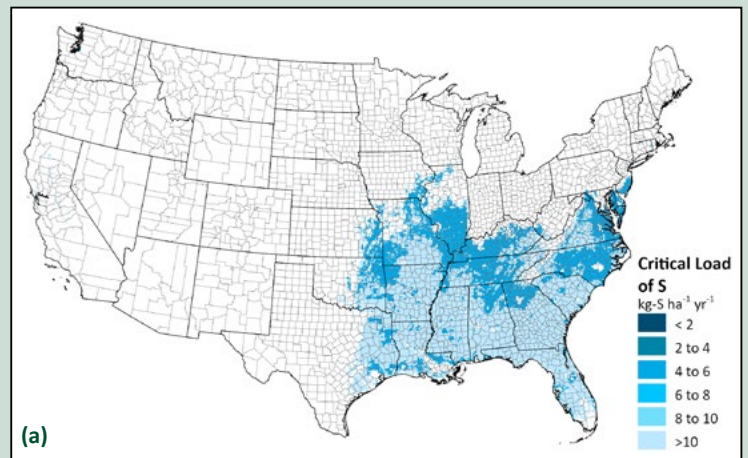
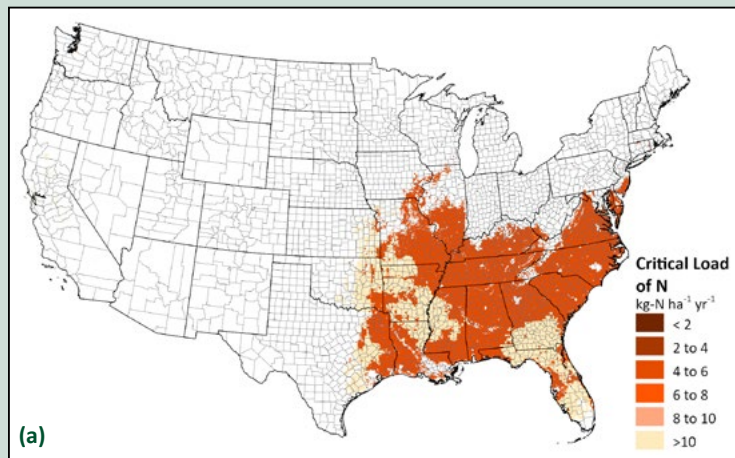


Figure 26.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Eupatorium compositifolium* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 26.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Eupatorium compositifolium* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

27.0 *Eurybia macrophylla* (bigleaf aster)

Distribution and Conservation Status

Bigleaf aster is a native perennial forb of the midwestern and northeastern regions of the United States. It is critically imperiled in Iowa, imperiled in Missouri, and possibly extirpated in Arkansas (fig. 27.1).

Species Characteristics and Habitat

Bigleaf aster has both basal and cauline leaves. The thick, sturdy, large basal leaves are borne on short, sterile shoots, and have long petioles. The cauline leaves become smaller and stalkless as they climb the inflorescence. The inflorescence, a corymb with sticky, glandular hairs, grows up to 5 feet tall. The flowers have both ray and disc florets, and the fruit is a round, ribbed, pubescent nutlet.

Although bigleaf aster is moderately to very shade tolerant, it does require a modest amount of light to flower and produce seeds, and it flourishes in high light

environments. The increase in evaporation that follows an increase in light initiates stomatal closure, avoiding excessive water loss. Bigleaf aster prefers dry to moist, nutrient poor to intermediate nutrient sites in woodlands, wooded road banks, mountains, dry open woods, shaded, well-drained sites, and elevations from 100 to 3,400 feet. Bigleaf aster reproduces by seed and vegetatively from rhizomes and root crown sprouts. Its seeds are broadly spread by small mammals and wind. It is top-killed by fire but sprouts from rhizomes and root crowns afterwards and usually increases in abundance and produces more flowers after fire. It also establishes after fire by dispersing seeds onto mineral soil from adjacent unburned areas. Bigleaf aster also responds positively to other disturbances (e.g., logging, windthrow, and road construction) that increase the availability of light, nutrients and exposed mineral soil.

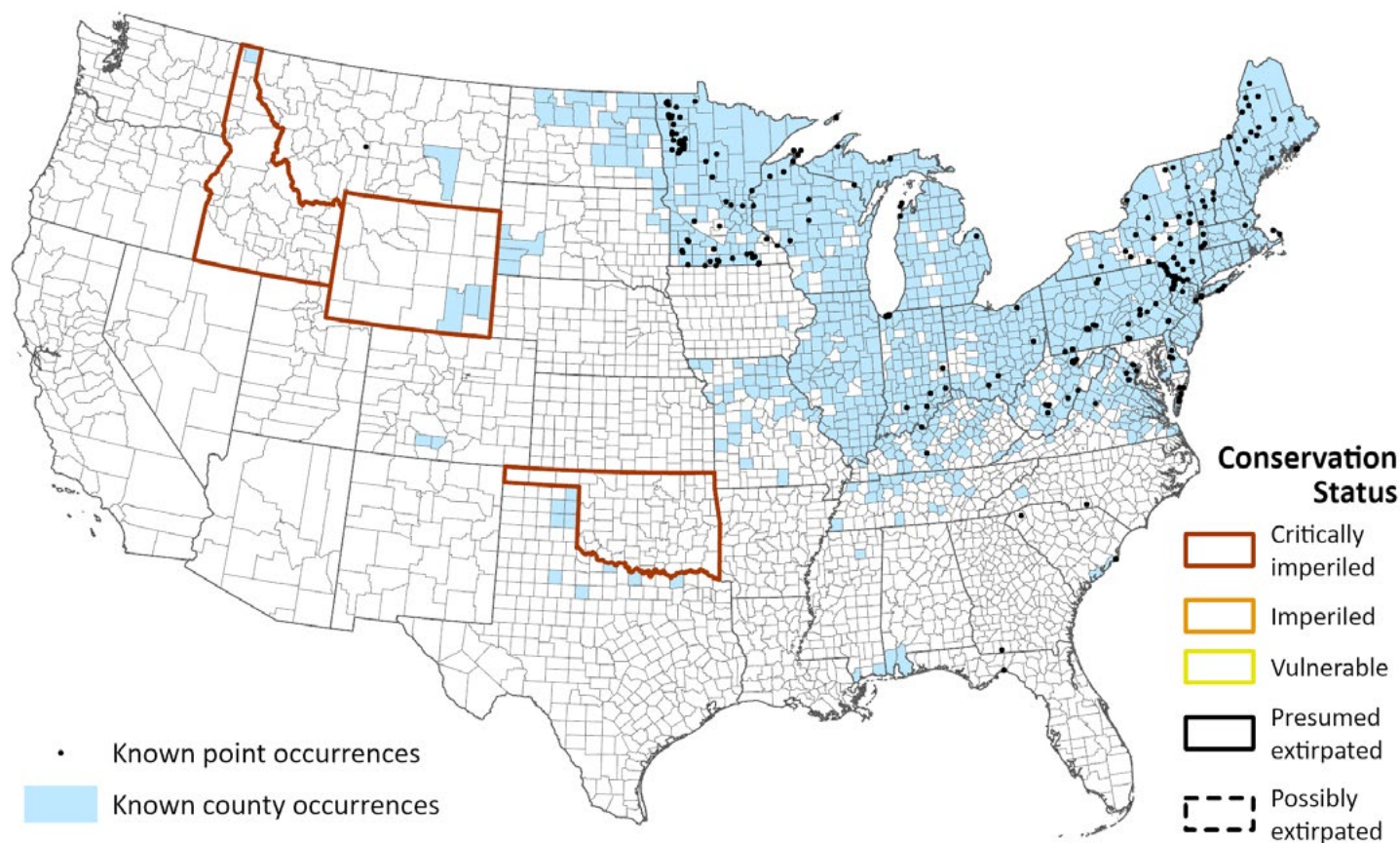


Figure 27.1. Distribution and state-level conservation status of *Eurybia macrophylla*. Known point occurrences were used to assess species deposition responses and critical loads.

Wildlife Uses

Bigleaf aster is commonly grazed in summertime by white-tailed deer and moose.

Traditional Ecological Knowledge

Traditional medicinal uses include treatments for headache (root infusion), venereal diseases (compound root decoction to relax the bowels) and other blood ailments. Smoke from the bigleaf aster is used by some hunters to attract deer.



Stem, leaves, and flowers of bigleaf aster.
Rob Routledge, Sault College, Bugwood.org.

Responses to Nitrogen and Sulfur

The probability of occurrence for bigleaf aster depends mostly on the interactive effect of N and S deposition (fig. 27.2a). At low to moderate S deposition (≤ 4.4 kg S/ha/yr), the probability of occurrence increases with N deposition up to roughly 9 kg N/ha/yr after which it decreases. At high S deposition (≥ 11.5 kg S/ha/yr) the probability of occurrence for bigleaf aster is low and not responsive to N deposition. The climate effects are shown in Figure 27.2b (precipitation) and Figure 27.2c (temperature). The probability of occurrence peaks at around 1250 mm precipitation and decreases with decreasing temperatures within the species’ sampled range. Confidence in the N and S relationships is moderate, with very good model performance ($R^2 = 0.381$, $AUC = 0.88$; both high confidence), low VIFs ($VIF-N = 1.4$, $VIF-S = 1.4$), and a high N-S correlation ($r=0.81$).



Flowers of bigleaf aster.
Elmer Verhasselt, Bugwood.org.

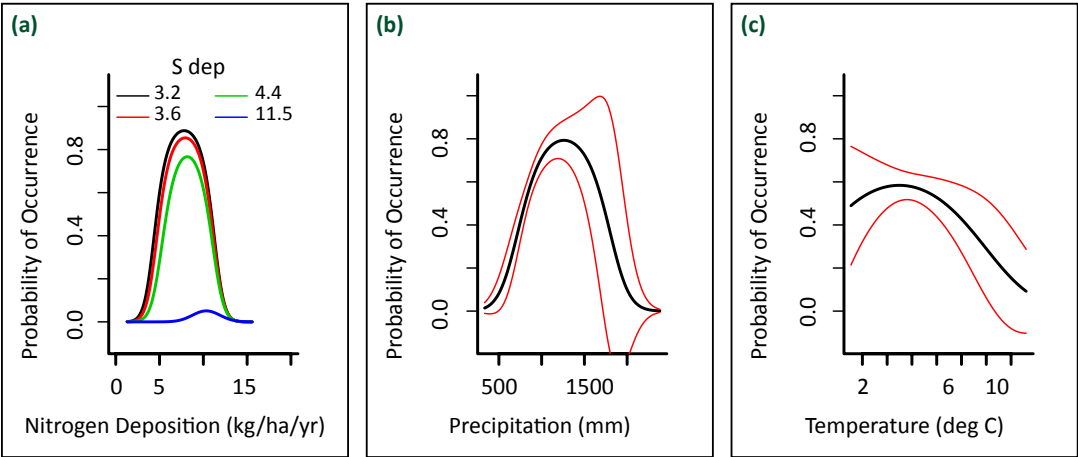


Figure 27.2. Effects of various environmental variables on the probability of occurrence of *Eurybia macrophylla*: a) N x S interaction, b) precipitation, c) temperature.

Critical Loads and Exceedances

The environmental hull for bigleaf aster covers most of the eastern United States and the mountainous areas of the West. The N CL is 8 to ≥ 10 kg N/ha/yr in the East and 6–8 kg N/ha/yr in the western range. Exceedances of N CLs based on 2019–2021 TDep total N deposition exist in the

high elevations in the West, across most of the Midwest, and near heavy agriculture in the East. The S CL is 2.2 kg S/ha/yr across the species' range. The S CL is in exceedance based on 2019–2021 TDep total S deposition in the southern States and into the Upper Midwest.

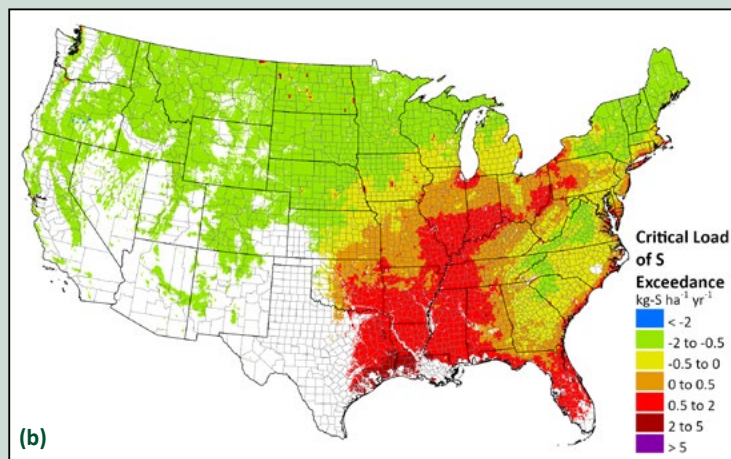
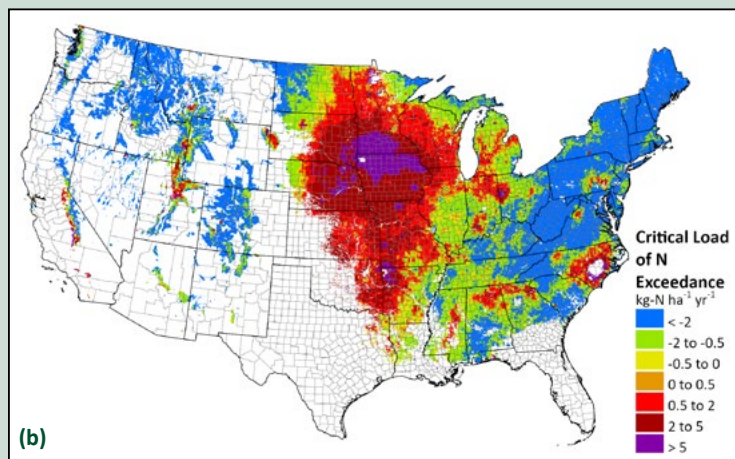
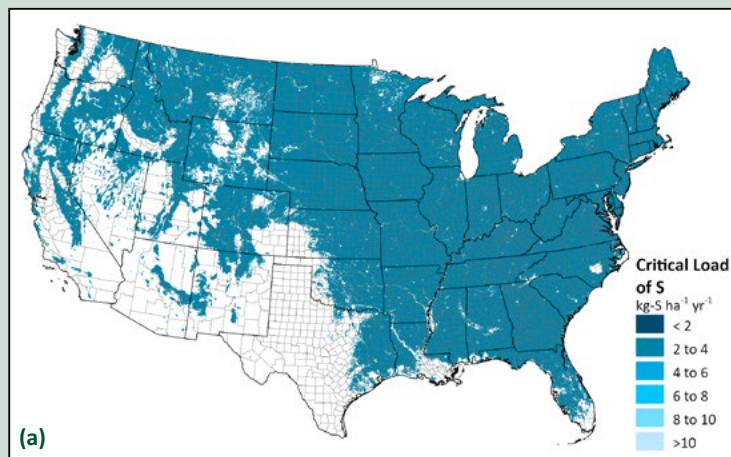
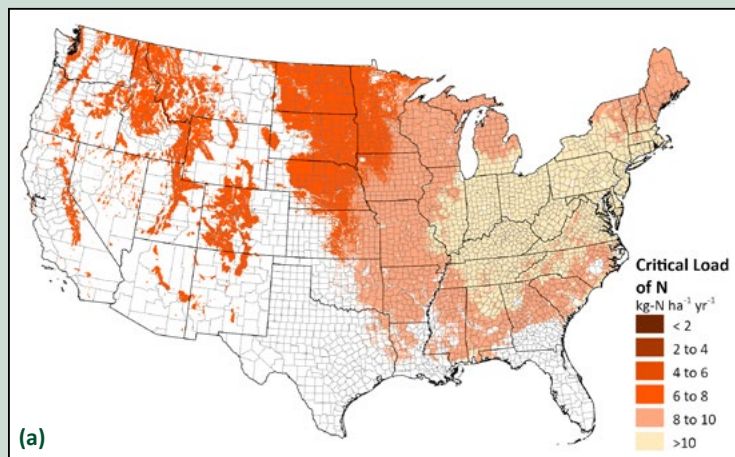


Figure 27.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Eurybia macrophylla* and (b) the exceedance of N critical loads based on TDep 2019–2021 total N deposition.

Figure 27.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Eurybia macrophylla* and (b) the exceedance of S critical loads based on TDep 2019–2021 total S deposition.

28.0 *Euthamia graminifolia* (flat-top goldentop)

Distribution and Conservation Status

Flat-top goldentop is a native perennial forb of moist, open areas including meadows and prairies, as well as along roadsides, ditches, interdunal flats, conifer swamps, lowland forests, and sandy moist shorelines. It grows throughout most of the United States except some central, western and southern states. It is critically imperiled in Idaho, Wyoming, and Oklahoma (fig. 28.1).

Species Characteristics and Habitat

Flat-top goldentop is upright and erect and grows 3 to 6 feet tall and spreads up to 2 feet. It grows from long, slender rhizomes. The leaves reach 2 to 4 inches in length and taper to a long point and narrow towards the stem. It has several branched inflorescences. The upper half of the flat-top goldentop appears bushy because of its branched stems and grass-like, narrow to linear, alternate leaves. The wide, rounded, yellow bracts around the flower

are slightly sticky. The seed is a long, firm, one-seeded, indehiscent white nutlet.

Flat-top goldentop is common in wetlands and can also occur in non-wetlands. It can withstand poor, gravelly, sandy, or dry soils and can tolerate drought conditions. The overall plant size and biomass will increase when exposed to additional nitrogen. Flat-top goldentop spreads quickly through vegetative reproduction. Flat-top goldentop can become weedy or invasive in some locations and may out-compete other native vegetation if not properly maintained.

Wildlife Uses

Flat-top goldentop is a source of nectar for pollinators and is excellent for pollinator restoration. American goldfinch, swamp sparrow, and other songbirds enjoy eating the seeds. The flower attracts the goldentop soldier beetle and black blister beetle. Deer and rabbits graze the plant.

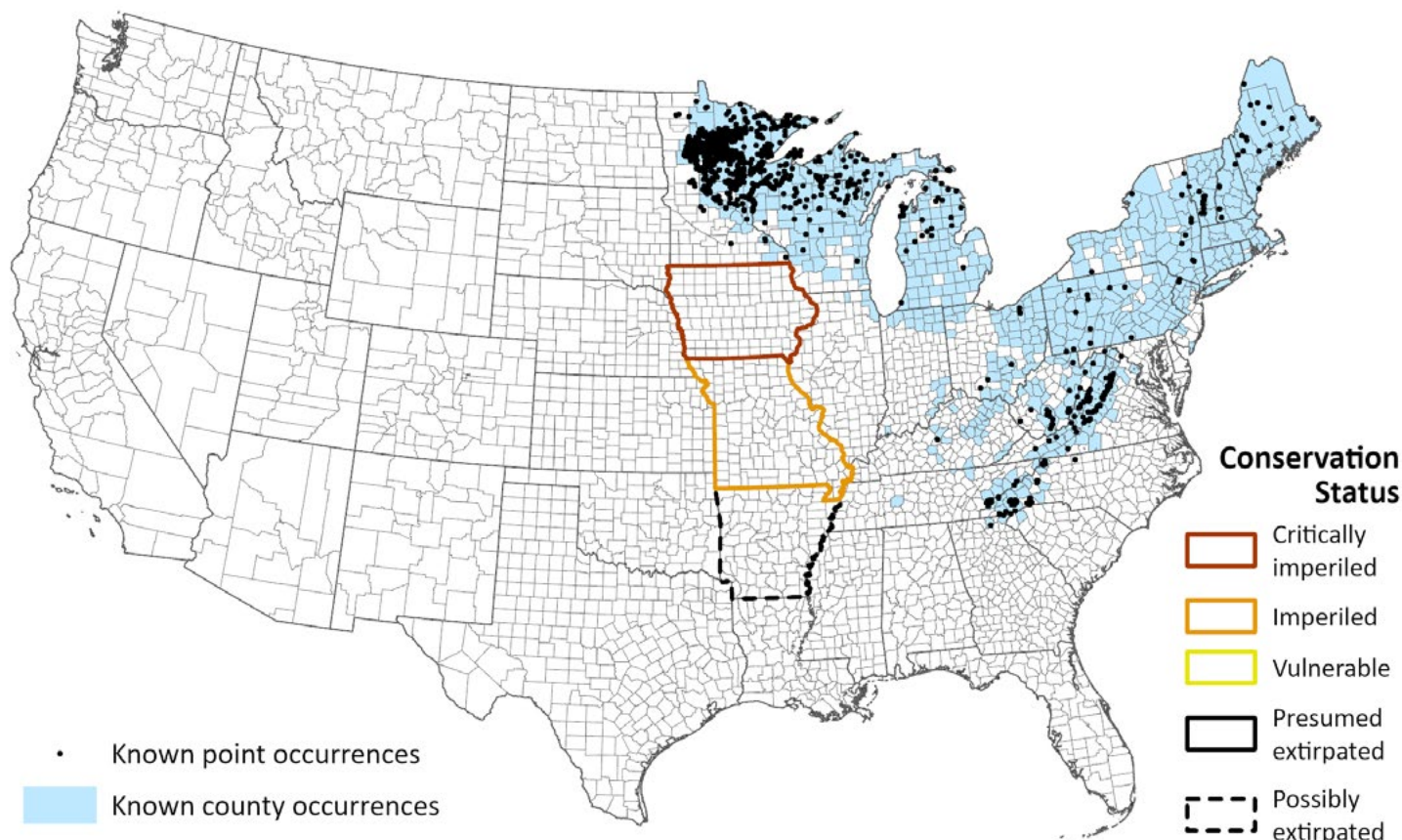


Figure 28.1. Distribution and state-level conservation status of *Euthamia graminifolia*. Known point occurrences were used to assess species deposition responses and critical loads.

Traditional Ecological Knowledge

Flat-top goldentop has been used in traditional medicine to alleviate chest pain through a decoction of roots or an infusion of blossoming flowers. The plant is also used in traditional hunting and is smoked to simulate the odor of a deer's hoof.



Stem, leaves and flowers of flat-top goldentop.
Rob Routledge, Sault College, Bugwood.org.

Responses to Nitrogen and Sulfur

The probability of occurrence for flat-top goldentop depends mostly on S deposition (fig. 28.2a) decreasing sharply as S deposition increases. The climate effects are shown in Figure 28.2b (precipitation) and Figure 28.2c (temperature). The probability of occurrence increases with increasing precipitation and peaks at temperatures around 5 °C (but note wide confidence bands) within the species' sampled range. Confidence in the N and S relationships is moderate-to-high for N and moderate for S, with good model performance ($R^2 = 0.178$, $AUC = 0.78$; both moderate confidence), mixed VIFs ($VIF-N = 1.8$, $VIF-S = 3.3$; high and moderate confidence, respectively), and a moderate N-S correlation ($r=0.68$).



Flowers of flat-top goldentop.
Rob Routledge, Sault College, Bugwood.org.

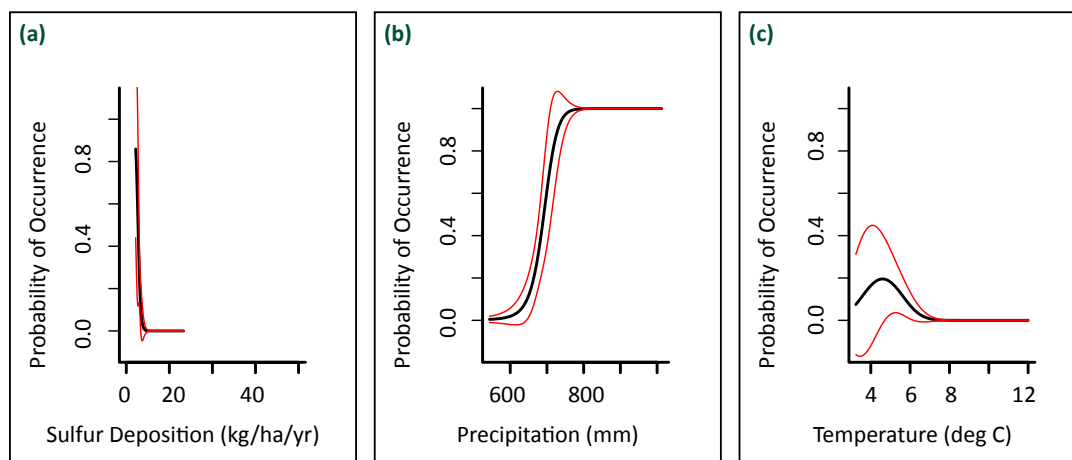


Figure 28.2. Effects of various environmental variables on the probability of occurrence of *Euthamia graminifolia*: a) S deposition, b) precipitation, c) temperature.

Critical Loads and Exceedances

The environmental hull for flat-top goldentop covers the eastern and northwestern United States. There are no calculated responses to N deposition. The S CL is 0.4 kg S/ha/yr across most of the range with S CL values of 39.4

kg S/ha/yr in a band from Iowa to Ohio. The S CL is in exceedance based on 2019–2021 TDep total S deposition in all areas in the East with the lower CL and in the higher elevations in the West.

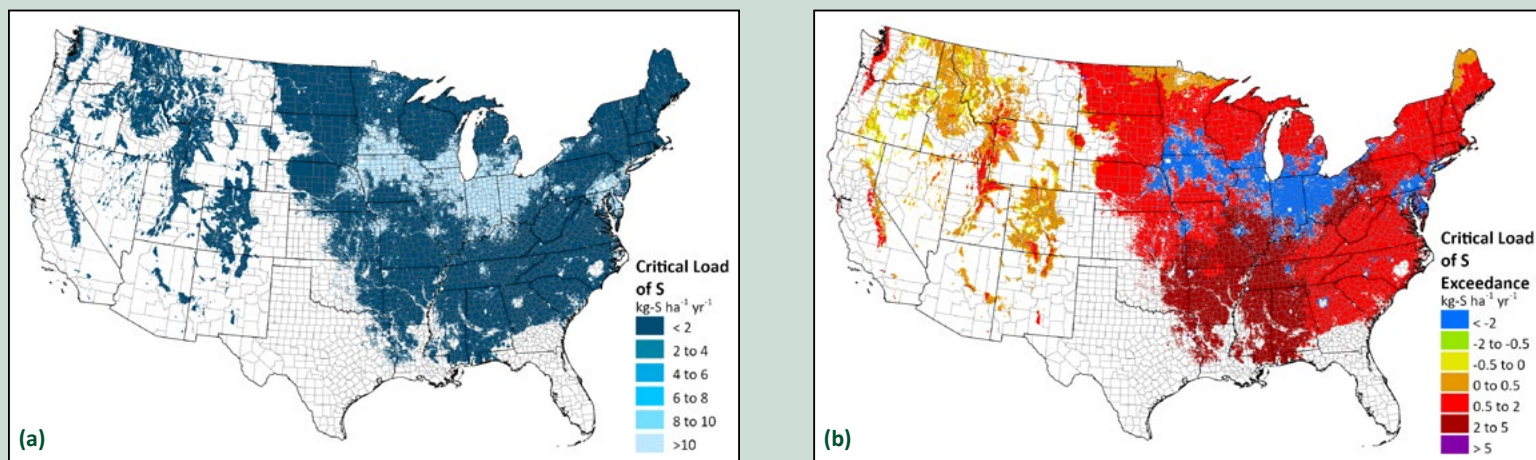


Figure 28.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Euthamia graminifolia* and (b) the exceedance of S critical loads based on TDep 2019–2021 total S deposition.

29.0 *Fragaria virginiana* (wild strawberry)

Distribution and Conservation Status

Wild strawberry is a native perennial forb that grows in most of the United States. It is critically imperiled in Louisiana (fig. 29.1).

Species Characteristics and Habitat

Wild strawberry is rhizomatous and deciduous with thin, toothed, basal leaves on petioles. The leaves grow in leaflets of three and are usually glabrous above. The flowers have five white petals with several pistils and 20–35 stamens. There are five, unlobed bracts. The fruit is a red, fleshy aggregated achene. Younger plants are more vigorous and produce more berries.

Wild strawberry establishes best at higher elevations where a good frost occurs, usually over 1,800 feet. It spreads by seed, short rhizomes, and leafless stolons. It can be invasive if the runners are not pruned back.

Wildlife Uses

Wild strawberry leaves and fruit are eaten by the Portola woodrat and the valley quail. Gophers, deer, squirrels, raccoons, and other wildlife also consume wild strawberries.

Traditional Ecological Knowledge

The savory fruit of the wild strawberry is a traditional food source for many Indigenous cultures. The leaves can be used to make tea.

Responses to Nitrogen and Sulfur

The probability of occurrence for wild strawberry depends on several variables. Increasing N deposition increases the probability of occurrence up to roughly 7 kg N/ha/yr, after which it decreases (fig. 29.2a). The effect of S deposition depends strongly on soil pH (fig. 29.2b). Under acidic soil conditions ($\text{pH} \leq 5.3$) the probability of occurrence is not

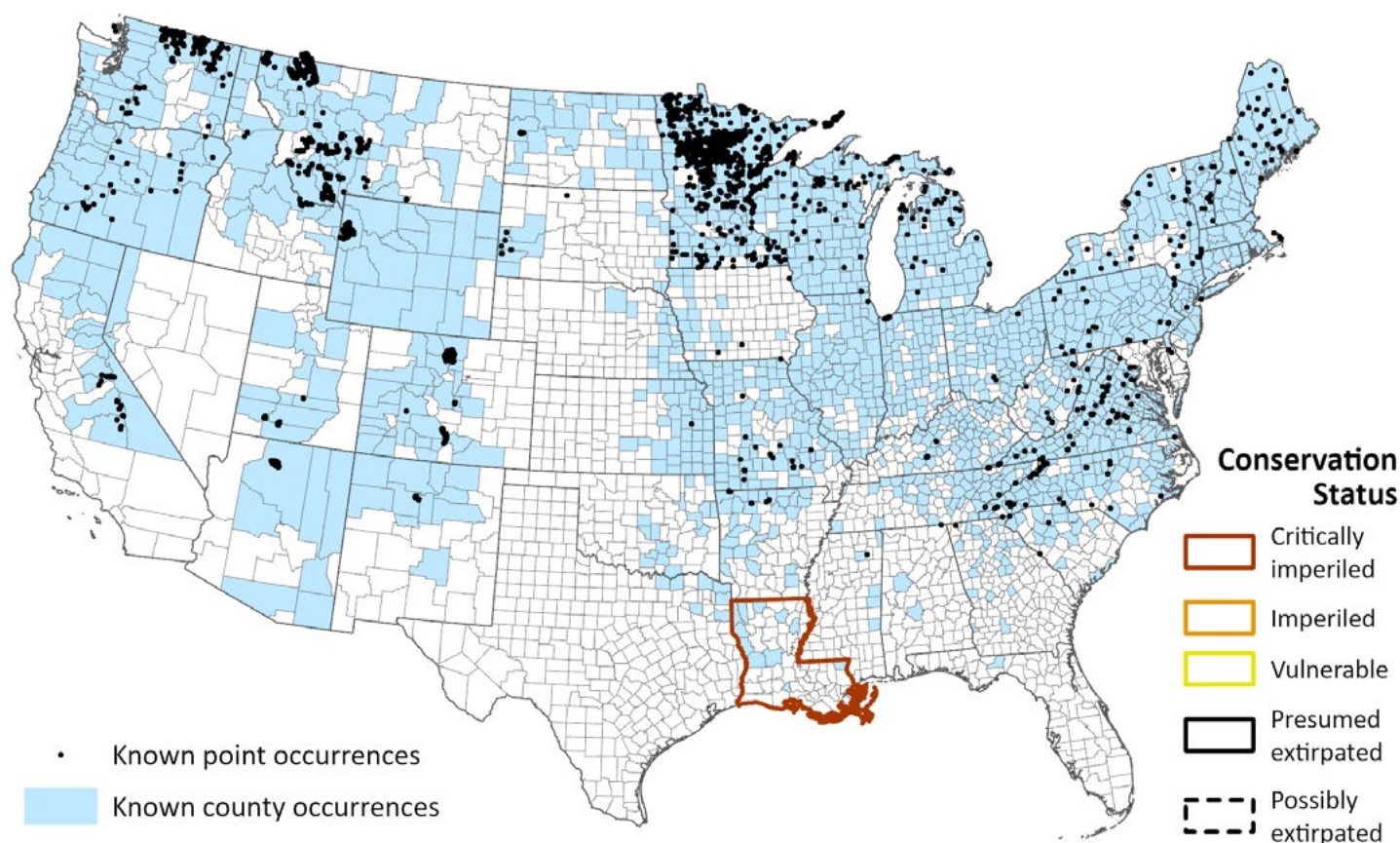


Figure 29.1. Distribution and state-level conservation status of *Fragaria virginiana*. Known point occurrences were used to assess species deposition responses and critical loads.

responsive to S deposition. At higher pH (≥ 5.8) it increases with S deposition. The climate effects are shown in Figure 29.2c (precipitation) and Figure 29.2d (temperature). The probability of occurrence decreases with decreasing precipitation and peaks at temperatures of 4 °C within the species' sampled range. Confidence in the N and S relationships is moderate, with good model performance ($R^2 = 0.134$, $AUC = 0.74$; both moderate confidence), low VIFs ($VIF-N = 1.2$, $VIF-S = 1.3$; both high confidence), and a high N-S correlation ($r=0.75$, low confidence).

Critical Loads and Exceedances

The environmental hull for wild strawberry covers most of the United States except for the Southwest and the southern half of Florida. The N CL is 6-8 kg N/ha/yr across the species' range. Exceedances of N CLs based on 2019–2021 TDep total N deposition exist across most of the East and Midwest, and in the higher elevations in the West. The S CL is 41.7 kg S/ha/yr across most of the range with S CL values of 0.4 kg S/ha/yr in the Southeast and Northeast, and some higher elevations in the West. The S CL is in exceedance based on 2019–2021 TDep total S deposition in all areas with the lower CL.



Leaves and flowers of wild strawberry.
Mary Ellen Harte, Bugwood.org.

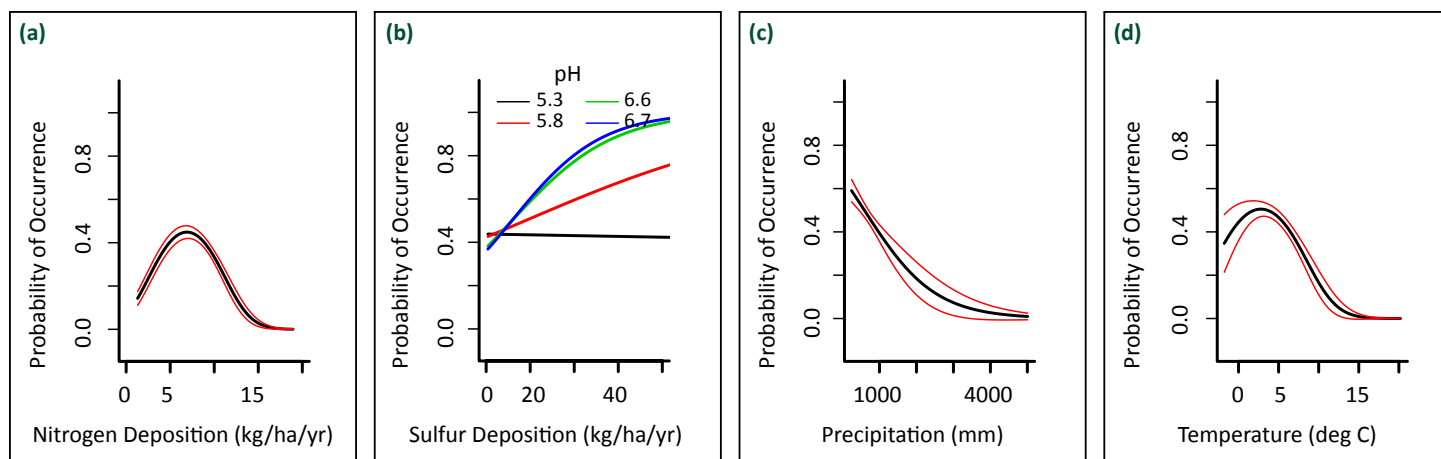


Figure 29.2. Effects of various environmental variables on the probability of occurrence of *Fragaria virginiana*: a) N deposition, b) S x pH interaction, c) precipitation, d) temperature.

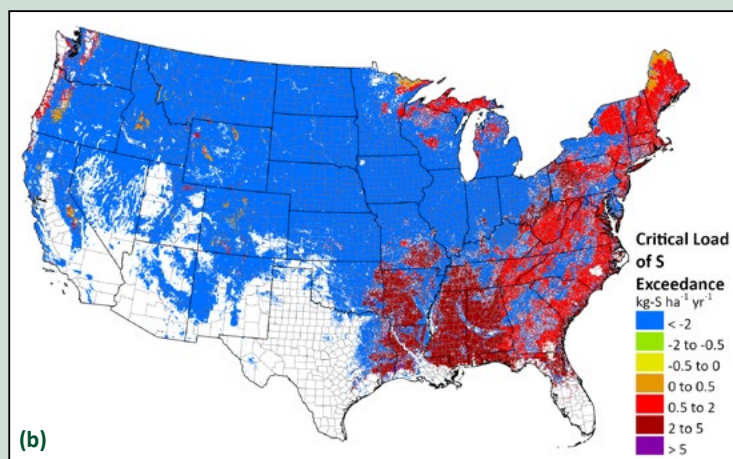
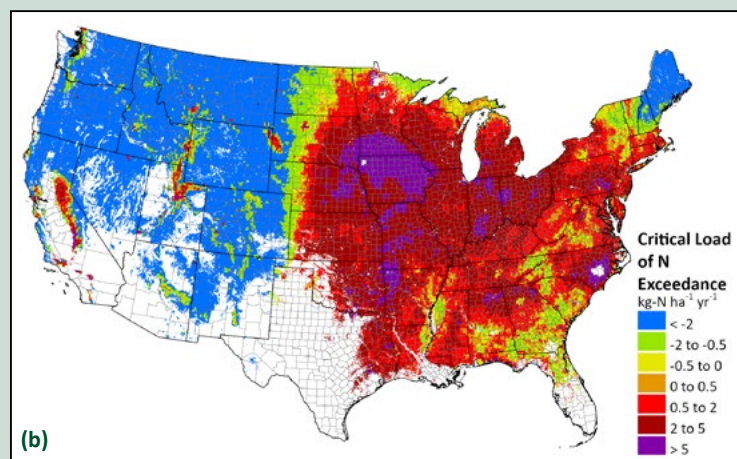
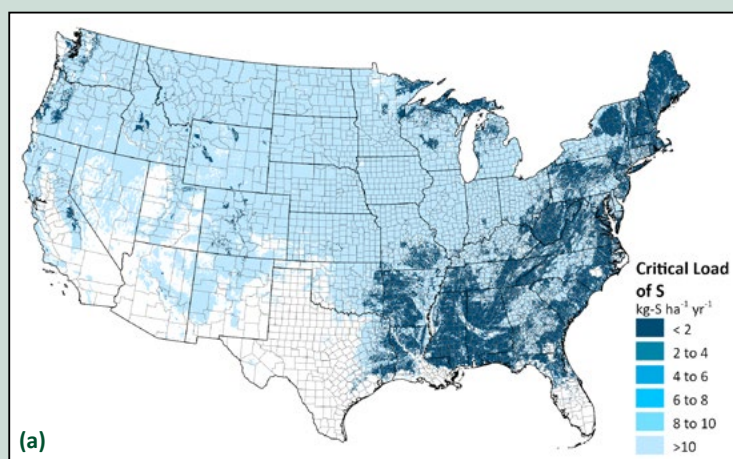
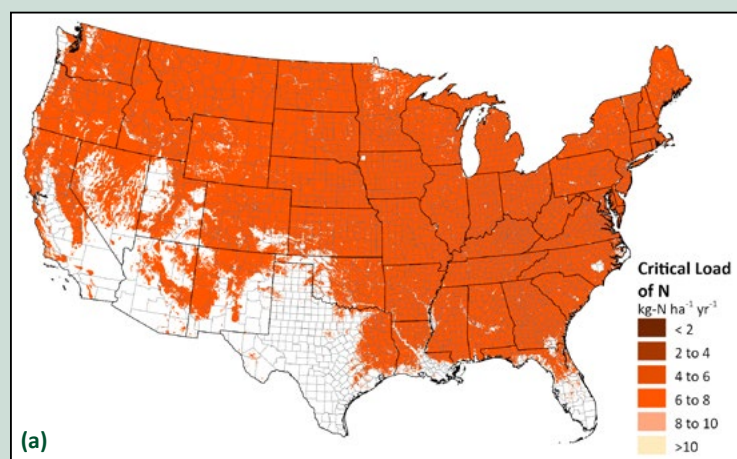


Figure 29.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Fragaria virginiana* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 29.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Fragaria virginiana* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

30.0 *Galium triflorum* (fragrant bedstraw)

Distribution and Conservation Status

Fragrant bedstraw is a native perennial forb that grows in every U.S. state except Hawaii. It is vulnerable in Wyoming (fig. 30.1).

Species Characteristics and Habitat

Fragrant bedstraw has frail branches that give rise to a scrambling or prostrate growth form. Hooked hairs concentrate at the stem angles on the lower part of the plant. It has slender rhizomes. The fragrant leaves typically grow in whorls of 5 to 6, measuring up to 2.5 inches long by 0.6 inches wide, and smell like vanilla. The seeds are coated with dense hooked hairs and usually grow up to 0.08 inches in diameter.

It can be found in a diversity of riparian habitats, grassland communities, shrublands, and coniferous and deciduous forests. In the Northwest, fragrant bedstraw is a common understory species in numerous coniferous, deciduous,

and mixed forests, often in semiarid and continental climates. In the Southwest, fragrant bedstraw inhabits shrublands and forests. Fragrant bedstraw prefers moist but well-drained soils and tolerates a range of acidities and textures but prefers acidic and nitrogen rich soils. Generally, it prefers diffuse light over full sun or full shade conditions. Fragrant bedstraw produces both slender rhizomes and seeds allowing for vegetative and sexual reproduction. It is likely that seed germination is secondary to vegetative reproduction as a way of surviving disturbances. The dense covering of hooked hairs on Fragrant bedstraw's seed is best adapted for long-distance animal dispersal. Fragrant bedstraw is frequently present in very early seral ecosystems resulting from extreme weather events or volcanic activity. It likely sprouts from rhizomes when burned in low-severity fires. However, after high-severity fires fragrant bedstraw's more delicate rhizomes are prone to damage, and recolonization of the area would likely be from on- or off-site seed sources.

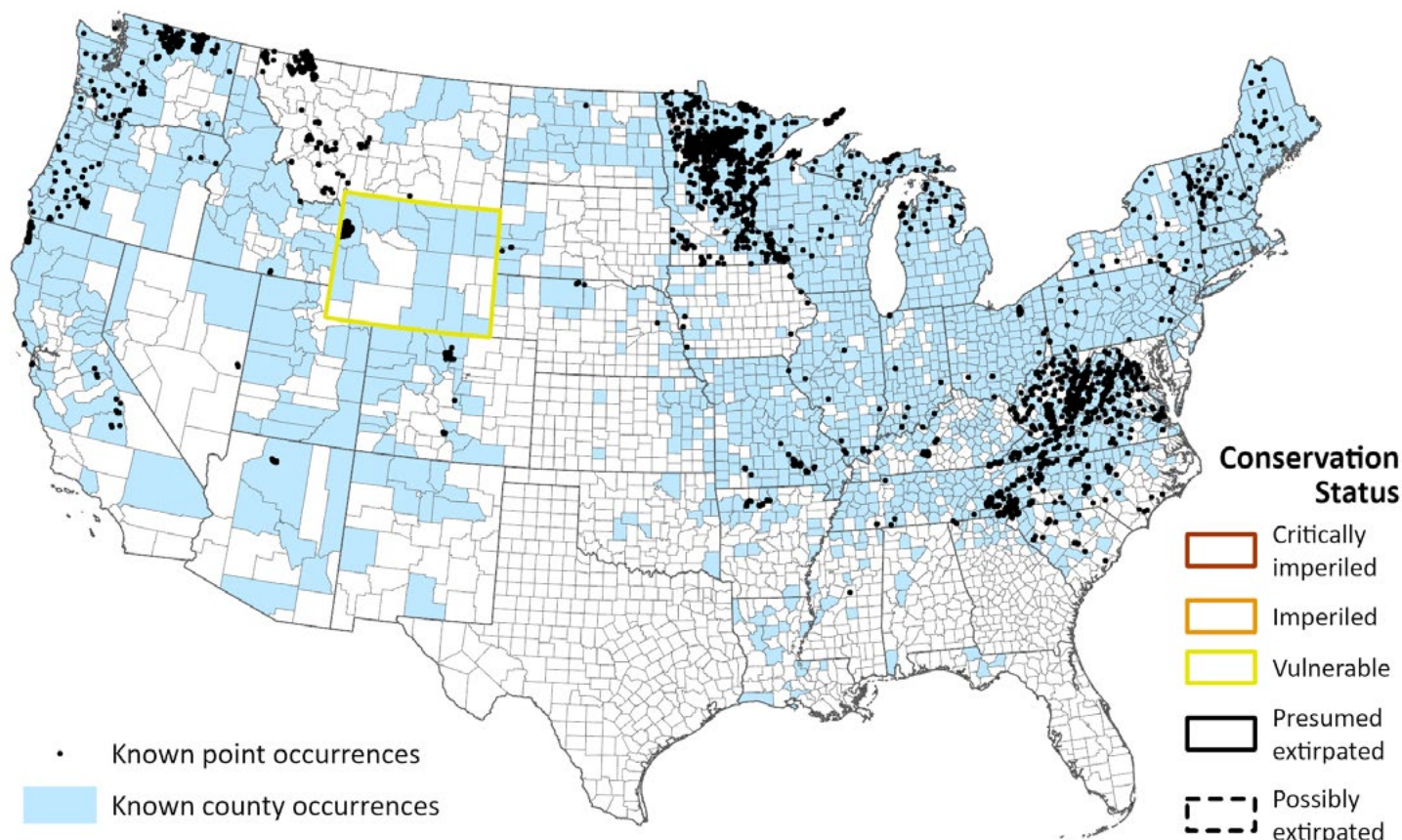


Figure 30.1. Distribution and state-level conservation status of *Galium triflorum*. Known point occurrences were used to assess species deposition responses and critical loads.

Wildlife and Livestock Uses

Early in the season, fragrant bedstraw provides a source of food for black bears. The presence of fragrant bedstraw indicates important elk, deer, and moose habitats. Fragrant bedstraw may be an important food source for rodents. Livestock and native ungulates do not find fragrant bedstraw particularly palatable, but it often makes up a minor portion of their diets.



Leaves of fragrant bedstraw.
Mary Ellen Harte, Bugwood.org.

Traditional Ecological Knowledge

Fragrant bedstraw can be used as a rinse to increase the thickness and luster of hair. Dried fragrant bedstraw flowers can also be used as a perfume.

Responses to Nitrogen and Sulfur

The probability of occurrence for fragrant bedstraw depends on several variables. The probability of occurrence increases with N deposition up to roughly 9.5 kg N/ha/yr, then decreases with further increases in N deposition (fig. 30.2a). There are other weak interactions between N and other variables that largely do not affect the N critical load (Clark et al. 2019). Increased S deposition decreases the probability of occurrence, more so under more alkaline conditions rather than acidic conditions where the occurrence is already lower (fig. 30.2b). The climate effects are shown in Figure 30.2c (precipitation) and Figure 30.2d (temperature). The probability of occurrence decreases with increasing precipitation and peaks at around 8 °C within the species' sampled ranged. Confidence in the N and S relationship is moderate, with good model performance ($R^2 = 0.102$, AUC = 0.72; both moderate confidence), low VIFs (VIF-N = 1.3, VIF-S = 1.3; both high confidence), and a high N-S correlation ($r=0.84$)

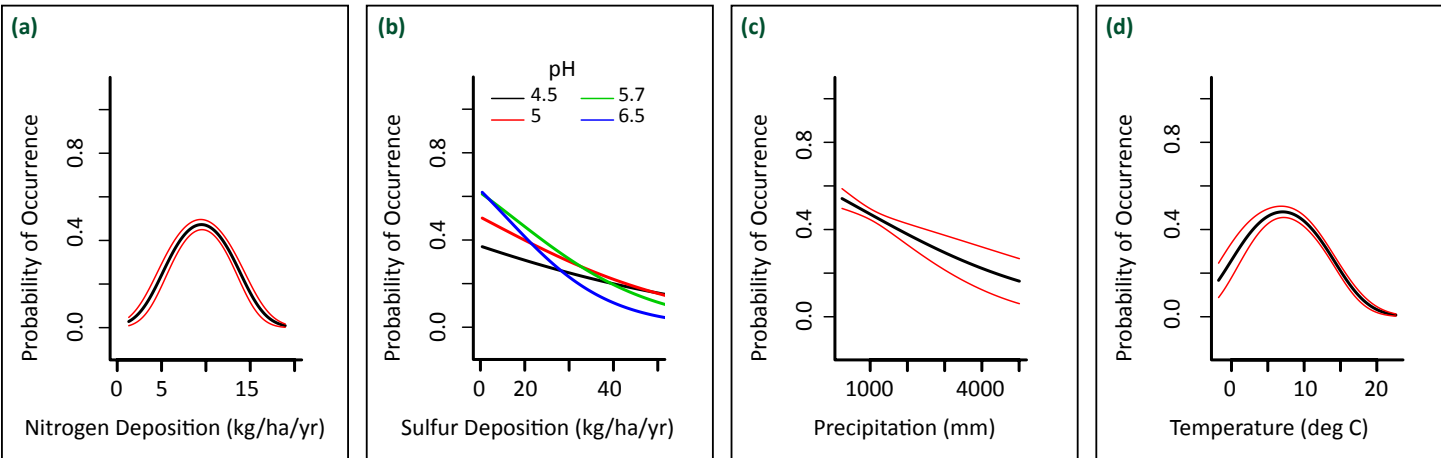


Figure 30.2. Effects of various environmental variables on the probability of occurrence of *Galium triflorum*: a) N deposition, b) S x pH interaction, c) precipitation, d) temperature.

Critical Loads and Exceedances

The environmental hull for fragrant bedstraw covers most of the United States except the Southwest and the southern half of Florida. The N CL is ≥ 10 kg N/ha/yr from Illinois to western New York and 8–10 kg N/ha/yr across the rest of the species' range. Exceedances of N CLs based on 2019–2021 TDep total N deposition exist across the Midwest, higher elevations in the West, and near agricultural areas in the East. The S CL is 0.4 kg S/ha/yr across most of the range with S CL values of 42.4 kg S/ha/yr in a band from Indiana to Pennsylvania. The S CL is in exceedance based on 2019–2021 TDep total S deposition in all areas in the East with the lower CL and most of the West.



Flowers of fragrant bedstraw.
Mary Ellen Harte,
Bugwood.org.

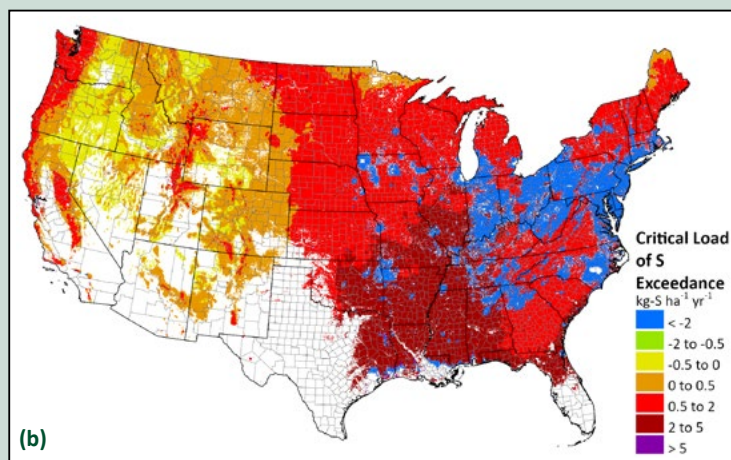
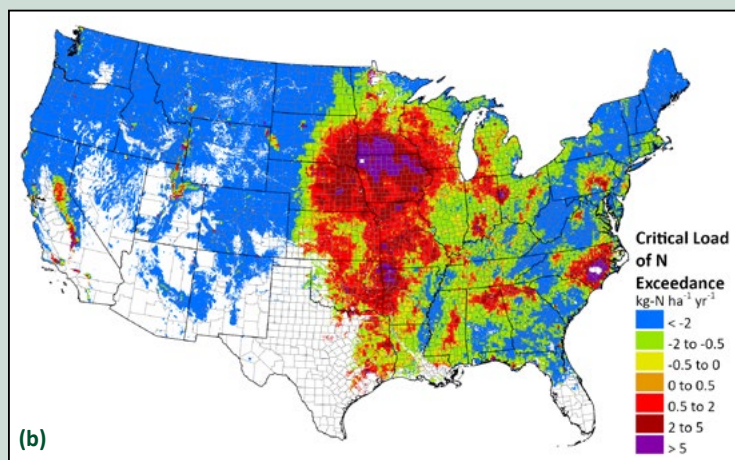
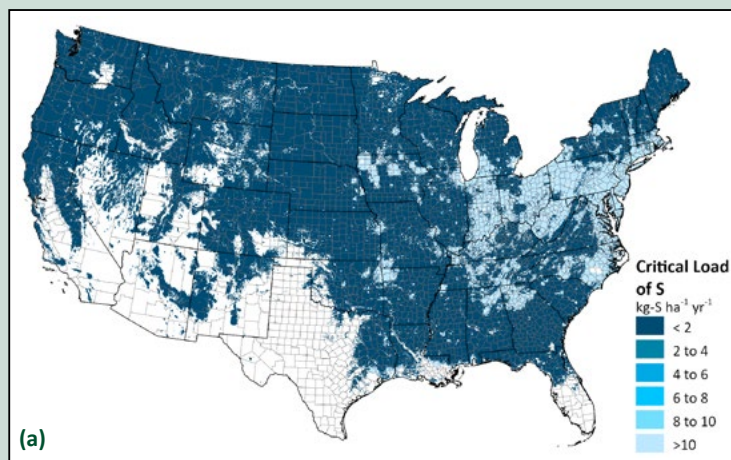
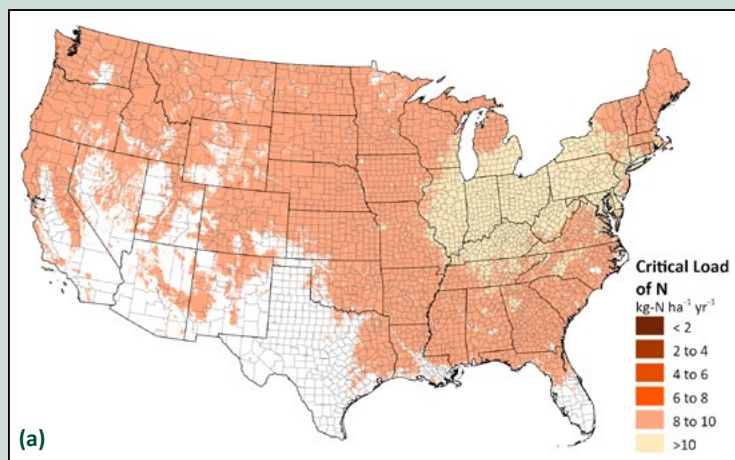


Figure 30.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Galium triflorum* and (b) the exceedance of N critical loads based on TDep 2019–2021 total N deposition.

Figure 30.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Galium triflorum* and (b) the exceedance of S critical loads based on TDep 2019–2021 total S deposition.

31.0 *Geranium maculatum* (spotted geranium)

Distribution and Conservation Status

Spotted geranium is a native perennial forb that occurs in the eastern half of the United States, from North Dakota to Florida. It is critically imperiled in South Dakota, Nebraska, and Louisiana and imperiled in Kansas (fig. 31.1).

Species Characteristics and Habitat

Spotted geranium grows 8 to 24 inches tall. It begins growing from stout, branched, underground rhizomes. The rhizomes spread horizontally up to 6 inches and produce 10 to 30 sparsely branched roots from the sides and underside. When the rhizomes are fragmented, new individuals are produced. Spotted geranium basal leaves develop early in the spring over a month, reaching 50 percent of total growth between late April and the first week of May.

Spotted geranium's preferred habitat is in woods, coves, thickets, and meadows. It prefers fertile soils of clay loam to sandy clay loam that are slightly alkaline to slightly acidic. Spotted geranium is moderately shade tolerant. Natural stands of spotted geranium are assortments of clones that appear to have grown from other, individual plants and continue to grow by exclusively vegetative means. Spotted geranium is long-lived, has a low mortality rate, and relies on pollinators for seed sets. It can grow on disturbed sites, but grows best in open, undisturbed forests. It is likely that spotted geranium is more easily killed by fire when rhizomes are closer to the surface of the soil. Spotted geranium will often increase in abundance immediately after a fire.

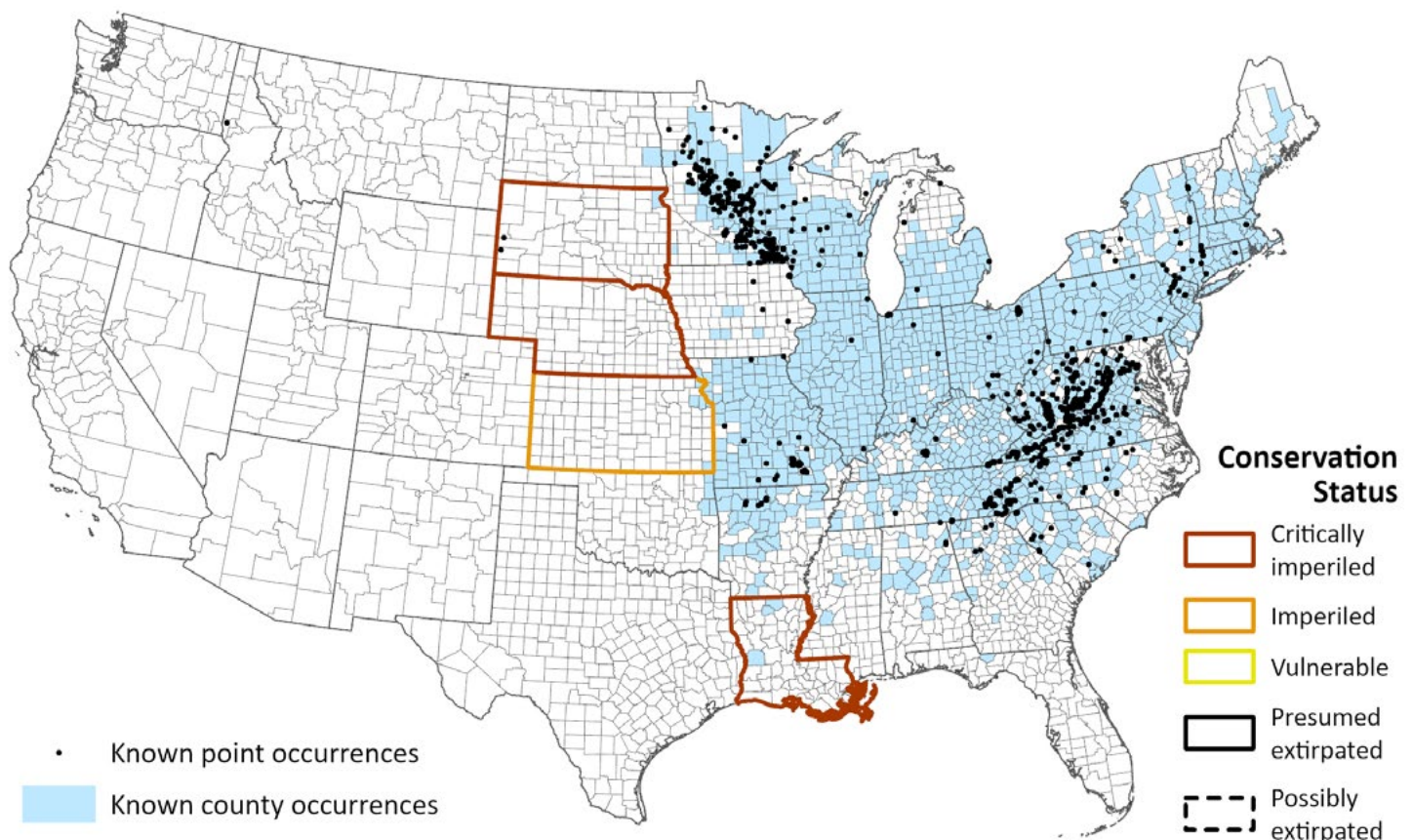


Figure 31.1. Distribution and state-level conservation status of *Geranium maculatum*. Known point occurrences were used to assess species deposition responses and critical loads.

Wildlife Uses

The flowers of spotted geranium are eaten by white-tailed deer. The maturing fruits are eaten by birds. Lepidopteran larvae are known to feed on the flowers and fruits.

Ecosystem Services

Spotted geranium is known to have an astringent quality due to tannic and gallic acids in the rhizomes; clinical trials have revealed the tannins also promote blood clotting.



Leaves and flowers of spotted geranium plant.
Katy Chayka, www.minnesotawildflowers.info, Bugwood.org.

Traditional Ecological Knowledge

Traditional medicinal practices include using an infusion of roots to cure diarrhea, and a compound decoction as a wash for thrush in a child’s mouth, or to treat open wounds and canker sores.

Responses to Nitrogen and Sulfur

The probability of occurrence for spotted geranium depends on several variables. The effect of N deposition depends on soil pH (fig. 31.2a), with larger increases and decreases with N deposition under alkaline conditions, and more muted effects under more acidic conditions. The effect of S deposition also depends on soil pH (fig. 31.2b), with large decreases in the probability of occurrence under alkaline conditions, and a lower probability of occurrence that is less responsive to S deposition under acidic conditions. The climate effects are shown in Figure 31.2c (precipitation) and Figure 31.2d (temperature). The probability of occurrence peaks broadly around 1000 mm precipitation and temperatures around 9 °C within the species’ sampled range. Confidence in the N and S relationship is moderate-to-high, with good model performance ($R^2 = 0.127$, $AUC = 0.75$; both moderate confidence), low VIFs ($VIF-N = 1.2$, $VIF-S = 1.2$; both high confidence), and a moderate N-S correlation ($r=0.699$, moderate confidence).

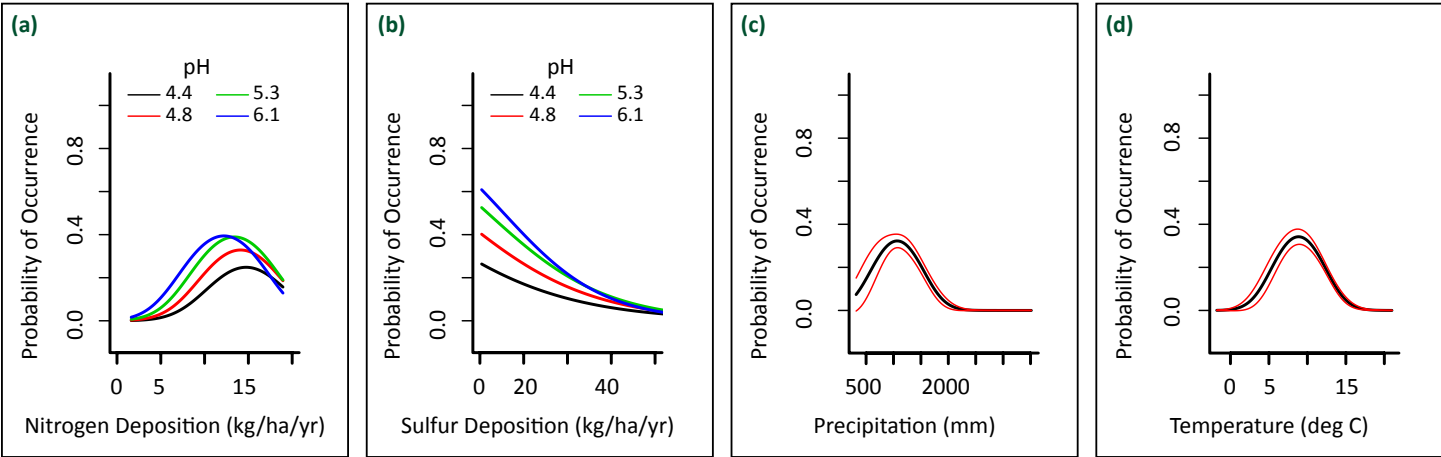


Figure 31.2. Effects of various environmental variables on the probability of occurrence of *Geranium maculatum*: a) N x pH interaction, b) S x pH interaction, c) precipitation, d) temperature.

Critical Loads and Exceedances

The environmental hull for spotted geranium covers most of the United States except the Southwest, western plains and valleys, and the southern half of Florida. The N CL is ≥ 10 kg N/ha/yr across the species' range with localized areas of 8-10 N/ha/yr at lower elevation mountainous areas. Exceedances of N CLs based on 2019–2021 TDep total N deposition are focused in the Midwest and near agricultural areas in the East. The S CL is 0.4 kg S/ha/yr across the species' range. The S CL is in exceedance based on 2019–2021 TDep total S deposition in all areas in the East with the lower CL and most of the West.



Flowers of spotted geranium.

William M. Ciesla, Forest Health Management International, Bugwood.org.

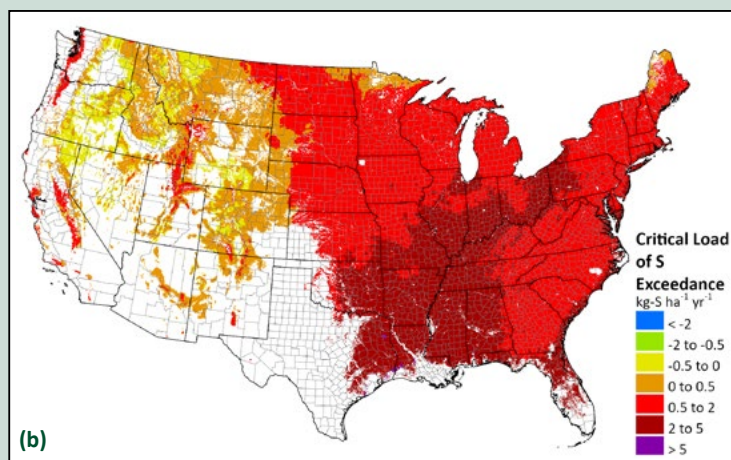
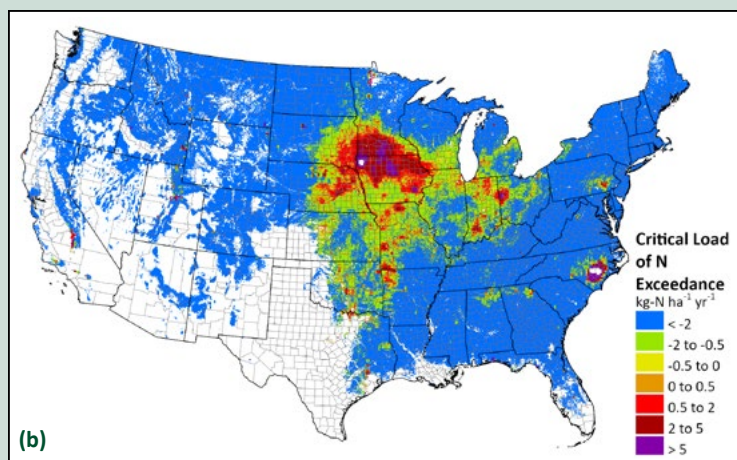
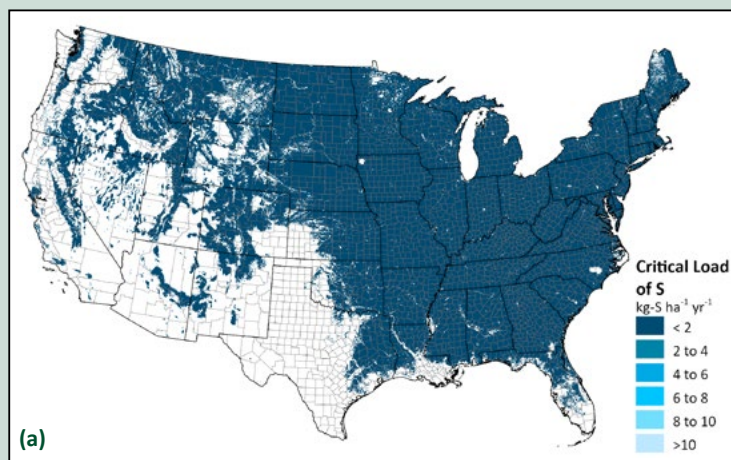
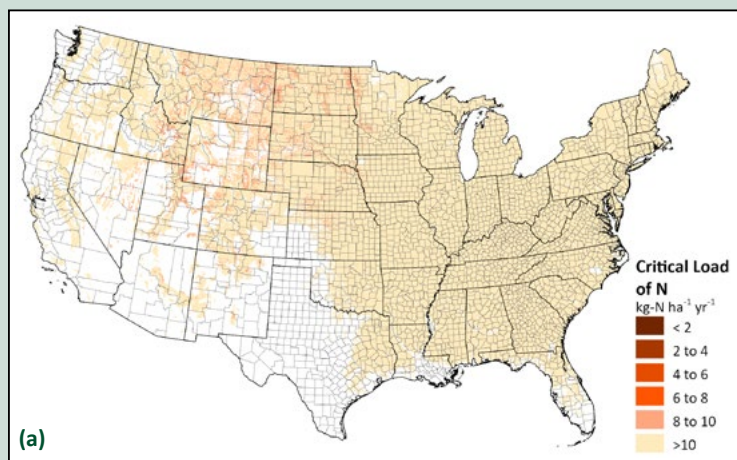


Figure 31.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Geranium maculatum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 31.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Geranium maculatum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

32.0 *Geum triflorum* (old man's whiskers)

Distribution and Conservation Status

Old man's whiskers is a native perennial forb of North America found eastward from the Pacific Coast and Rocky Mountains across the northern Great Plains and into the prairie region of the Lake States and areas in the Northeast. It is imperiled in Michigan and New York and vulnerable in Idaho (fig. 32.1).

Species Characteristics and Habitat

Old man's whiskers grows in clumps 6 to 20 inches tall. Towards the middle of the stem there are usually up to 4 small leaves. The plant's abundant leaves are predominantly basal, reaching 1 to 8 inches long, and fern-like with 7 to 19 deeply serrated, unevenly pinnate or lyrate leaflets. The leaflets are up to 2 inches long, getting gradually larger toward the top. Towards the middle of the stem there are usually up to 4 small leaves. The flower styles are 1 to 2 inches and plumose. The fruit is relatively flat. Old man's whiskers have short, thick rhizomes and the leaves grow from a thick, scaly caudex.

The presence of old man's whiskers can be indicative of a moist environment as this is where it grows best, however a wide variety of soils support the plant. Numerous studies suggest that populations of old man's whiskers may be increased by disturbance such as fire and grazing.

Wildlife and Livestock Uses

Elk will consume small amounts of old man's whiskers as winter forage on the lower slopes of the Elkhorn Range in west-central Montana. Mule deer, white-tailed deer, and domestic sheep are known to feed on it, while cattle are known to avoid it. Old man's whiskers' food value is ranked as 'poor' for elk, mule deer, pronghorn, upland game birds, waterfowl, small nongame birds, and small mammals. It is ranked as 'fair' for white-tailed deer. The palatability of old man's whiskers is considered "poor" for cattle and horses, and "fair" for domestic sheep.

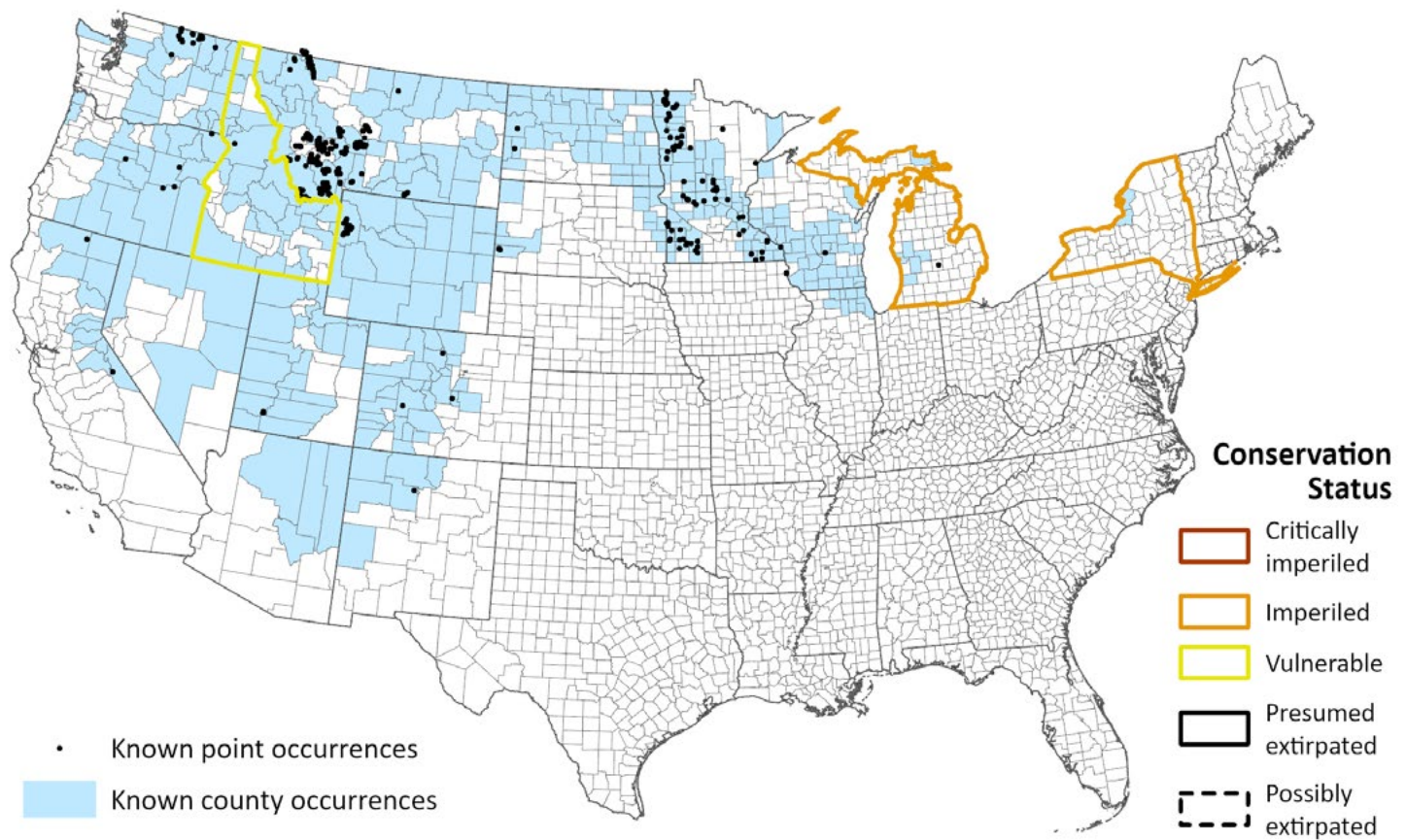


Figure 32.1. Distribution and state-level conservation status of *Geum triflorum*. Known point occurrences were used to assess species deposition responses and critical loads.

Traditional Ecological Knowledge

Traditional medicinal uses include infusions as a tonic for extreme coughs and topical applications of infusions of roots and grease to treat sores, rashes, blisters, and flesh wounds.



Flowers of old man's whiskers.

William M. Ciesla, Forest Health Management International, Bugwood.org.

Responses to Nitrogen and Sulfur

The probability of occurrence for old man's whiskers depends on several variables. The effect of N deposition depends on soil pH (fig. 32.2a) and S deposition (fig. 32.2b). Old man's whiskers increases and decreases more with N deposition under more acidic soils ($\text{pH} \leq 5.6$) than neutral to alkaline soils ($\text{pH} \geq 6.5$). Similarly, old man's whiskers increases and decreases more with N deposition when S deposition is low ($\leq 1.6 \text{ kg S/ha/yr}$) than when S deposition is higher ($\geq 4.1 \text{ kg S/ha/yr}$). The climate effects are shown in Figure 32.2c (precipitation) and Figure 32.2d (temperature). The probability of occurrence peaks weakly around 500 mm precipitation and decreases with increasing temperatures within the species' sampled range. Confidence in the N and S relationship is moderate, with good model performance ($R^2 = 0.162$, $\text{AUC} = 0.77$; both moderate confidence), low VIFs ($\text{VIF-N} = 1.2$, $\text{VIF-S} = 1.3$; both high confidence), and a high N-S correlation ($r=0.72$).

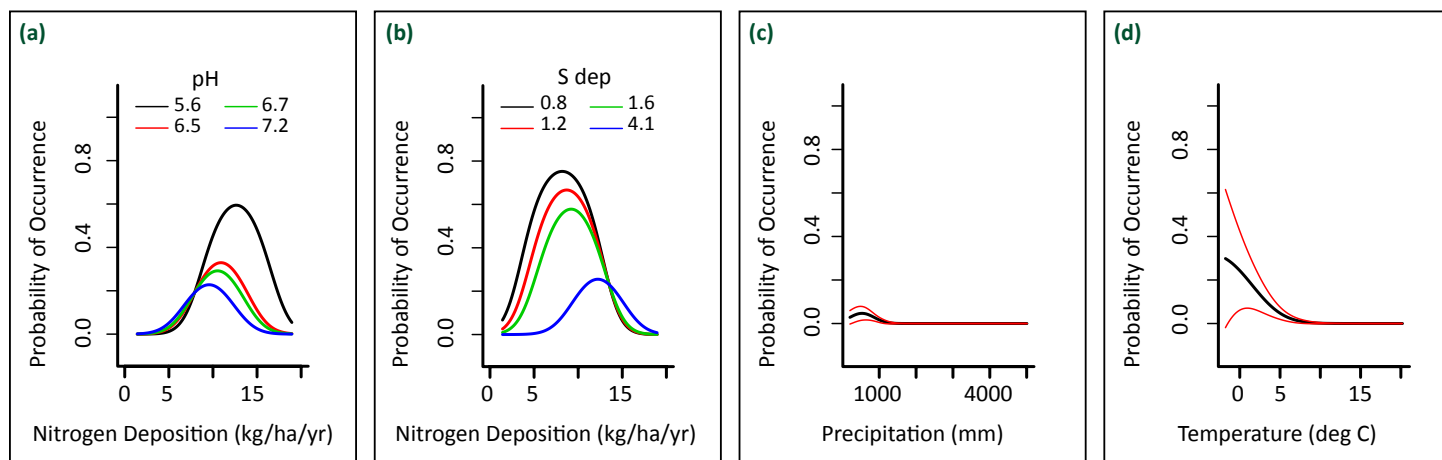


Figure 32.2. Effects of various environmental variables on the probability of occurrence of *Geum triflorum*: a) N x pH interaction, b) N x S interaction, c) precipitation, d) temperature.

Critical Loads and Exceedances

The environmental hull for old man's whiskers covers most of the northwestern and northern United States. The N CL ranges from ≤ 1 to ≥ 10 kg N/ha/yr with lower values in the West. Exceedances of N CLs based on 2019–2021 TDep total N deposition are focused in the Midwest and within the Salt Lake City airshed. The S CL is 0.4 kg S/ha/yr across most of the species' range with pockets of area in the Midwest with a S CL of 41.7 kg S/ha/yr. The S CL is in exceedance based on 2019–2021 TDep total S deposition in all areas with the lower CL in the Midwest and most of the West.



Foliage and dried flowers of old man's whiskers.
Pat Sauer, Iowa Stormwater Education Partnership, Bugwood.org.

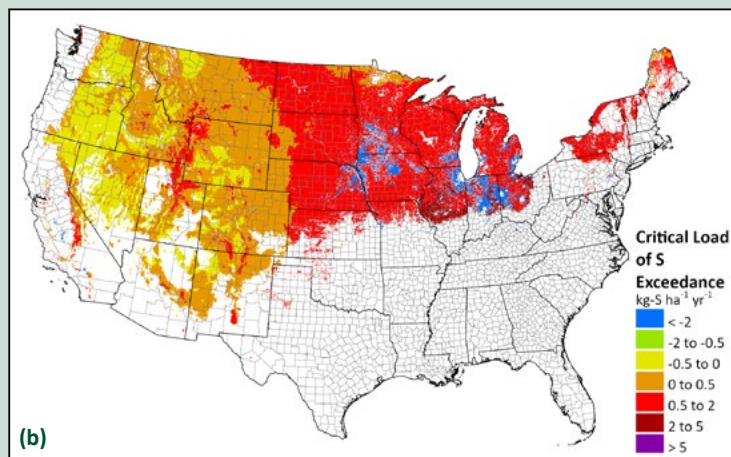
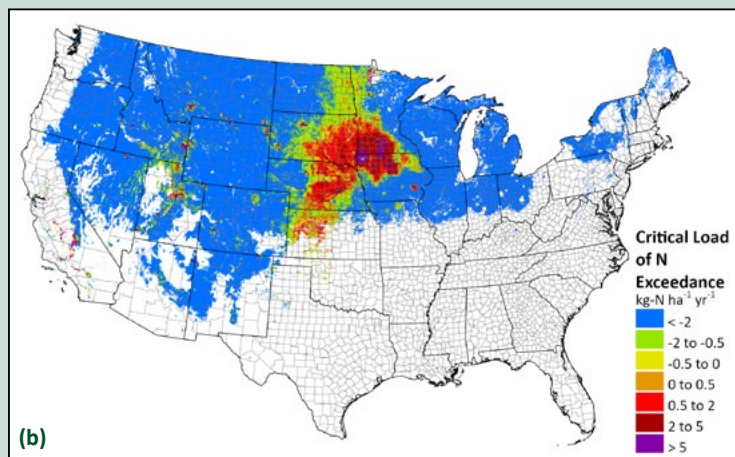
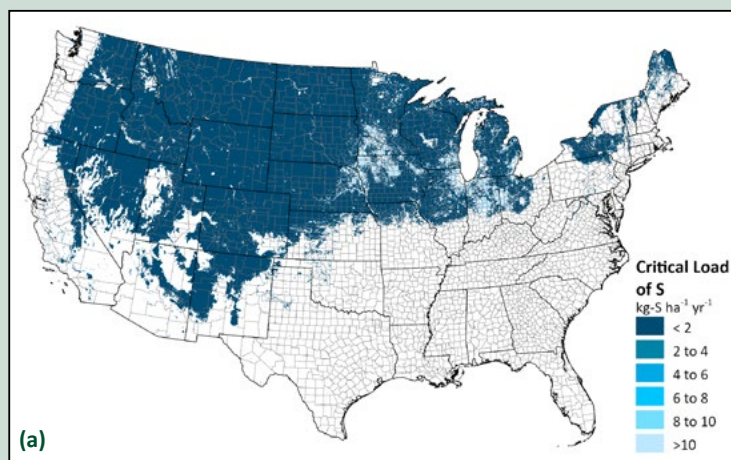
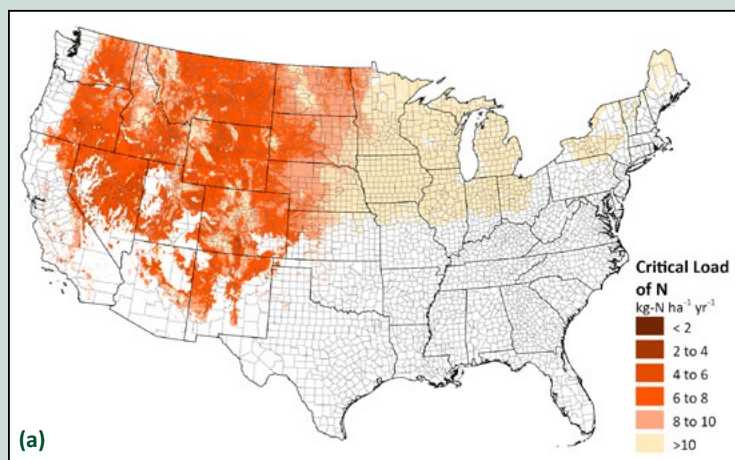


Figure 32.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Geum triflorum* and (b) the exceedance of N critical loads based on TDep 2019–2021 total N deposition.

Figure 32.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Geum triflorum* and (b) the exceedance of S critical loads based on TDep 2019–2021 total S deposition.

33.0 *Glycyrrhiza lepidota* (American licorice)

Distribution and Conservation Status

American licorice is a native perennial forb that can be found in many habitats, but is most often associated with prairies, grasslands, and riparian areas. It is common throughout the United States except some states in the Southeast and upper Midwest. It is critically imperiled in Wisconsin and presumed extirpated in New York (fig. 33.1).

Species Characteristics and Habitat

American licorice is leguminous, reaching 1.5 to 3 feet tall at maturity. It has smooth, branched stems which hold 7 to 21 smooth, alternately attached leaves. The yellowish-white flowers have short stalks and grow crowded together on terminal spikes, blooming from June through August. The seeds mature from July through October inside leathery brown seed pods.

It prefers moist to semi-wet, rich soils with pH levels ranging from 4.8 to 7.2 and can withstand mild flooding. It grows best in loam, sandy loam, and clayey loam soils. American licorice reproduces by seeds and underground stems called rhizomes. The seeds have burrs that aid plant dispersal by sticking to animal fur. American Licorice is a tolerant species able to withstand many negative environmental influences including mildly salty environments, making it a facultative wetland species. Additionally, it can survive fires by sprouting rhizomes despite it being top-killed in fires. Because it is so successful, it has become a weedy invasive in the state of Wyoming.

Wildlife and Livestock Uses

In Colorado, mule deer graze upon American licorice in the early fall. In the Great Plains, gophers eat the roots, deer and pronghorn consume the foliage, and birds

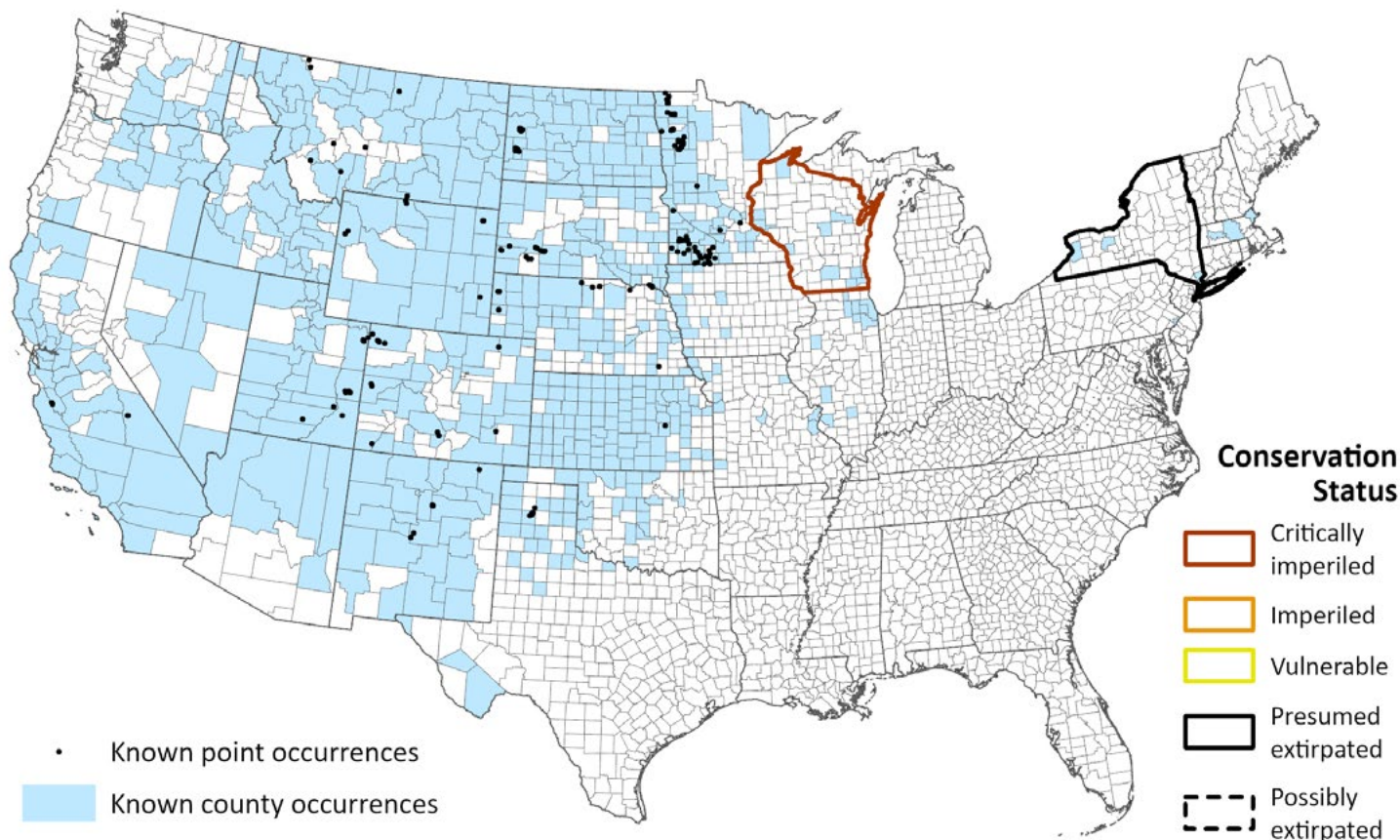


Figure 33.1. Distribution and state-level conservation status of *Glycyrrhiza lepidota*. Known point occurrences were used to assess species deposition responses and critical loads.

and rodents seek out the seeds. In Wyoming and Utah, deer, elk, pronghorn, upland game birds, passerine birds, waterfowl, and small mammals also eat American licorice. The sharp-tailed grouse uses it for shade. American licorice varies in nutritional value from as high as alfalfa to poor. It is protein limited but contains a fair energy value. Overall, it is a palatable food source for both wildlife and livestock.

Ecosystem Services

Because of its ability to proliferate via extensive underground rhizomes, one of the most important uses for American licorice is revegetating disturbed and denuded lands. The roots can extend 12 feet in prairie soil, giving it excellent soil binding abilities beneficial for erosion control. As a leguminous species, American

licorice also increases nitrogen availability in the soil by fixing atmospheric nitrogen (N_2). The roots have been used to flavor black licorice candy.

Traditional Ecological Knowledge

The roots of American licorice can be roasted in fire embers and pounded to remove the tough woody string from the center, resulting in a similar flavor to sweet potato. In traditional medicine, licorice is used to cure of a variety of ailments including fever; earaches (steeped leaves); diarrhea and upset stomach; coughs, chest pain, sore throat (drank as a tea); and toothaches and sore throat (chewed and held in the mouth).

Responses to Nitrogen and Sulfur

The probability of occurrence for American licorice mostly depends on the interactive effect of N and S deposition (fig. 33.2a). At low S deposition (≤ 2.7 kg S/ha/yr), the probability of occurrence is high and decreases sharply with N deposition, while at higher S deposition (≥ 3.8 kg S/ha/yr) the probability of occurrence is low and increases with N deposition. Of the variables tested, the only other significant variable is precipitation (fig. 33.2b). The probability of occurrence peaks weakly around 725 mm precipitation (but note wide confidence bands) within the species' sampled range. Confidence in the N and S relationship is moderate-to-high, with good model performance ($R^2 = 0.166$, $AUC = 0.76$; both moderate confidence), low VIFs ($VIF-N = 1.9$, $VIF-S = 2.6$; both high confidence), and a moderate N-S correlation ($r=0.61$, moderate confidence).



Foliage and fruits of American licorice.
Steve Dewey, Utah State University, Bugwood.org.

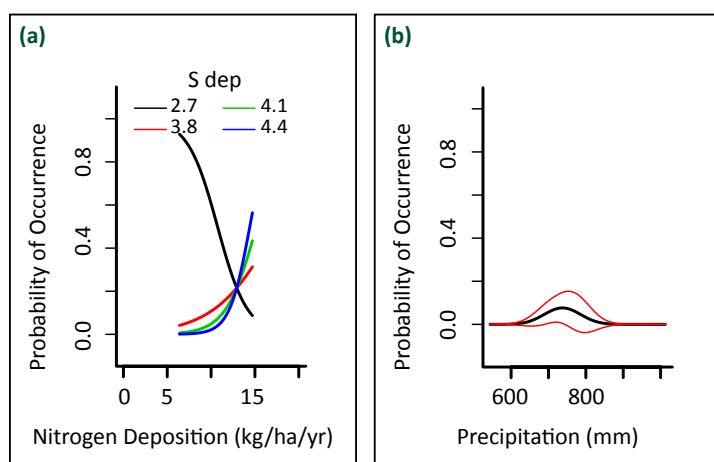


Figure 33.2. Effects of various environmental variables on the probability of occurrence of *Glycyrrhiza lepidota*: a) N x S interaction, b) precipitation.

Critical Loads and Exceedances

The environmental hull for American licorice covers most of the western, northern, and midwestern United States. The N CL is 6–8 kg N/ha/yr in the West and ≥ 10 kg N/ha/yr in the North. Exceedances of N CLs based on 2019–2021 TDep total N deposition exist in the Midwest and near some western cities. The S CL is 2.2 kg S/ha/yr across most of the species' range with pockets of area in Iowa and Illinois with a S CL of 13.3 kg S/ha/yr. The S CL is in exceedance based on 2019–2021 TDep total S deposition in small areas within the Midwest.



Fruits of American licorice.
Steve Dewey, Utah State University, Bugwood.org.

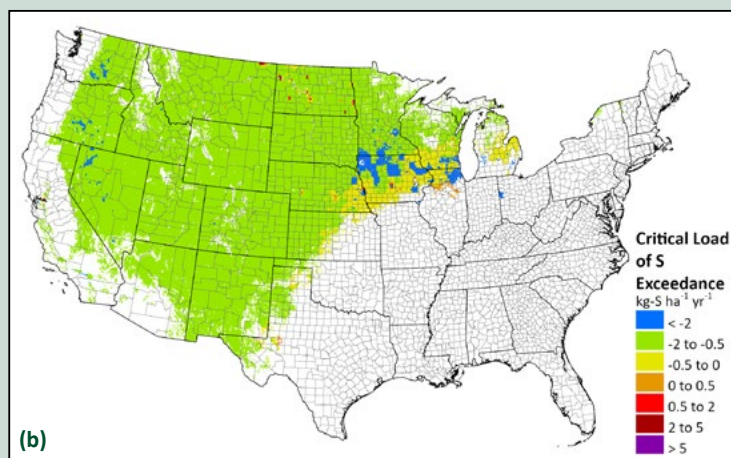
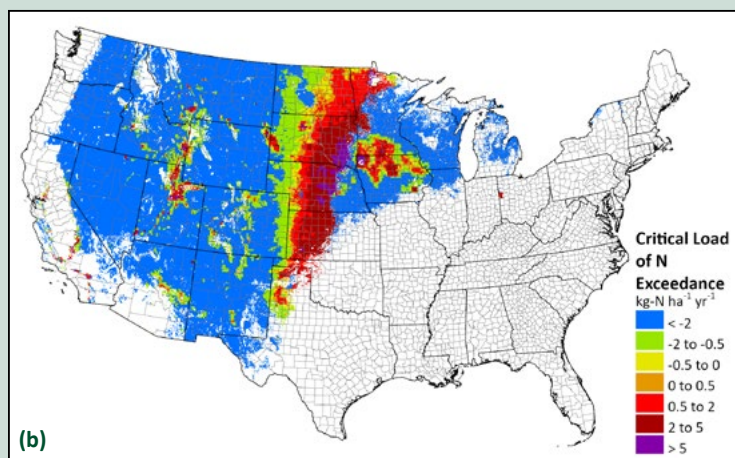
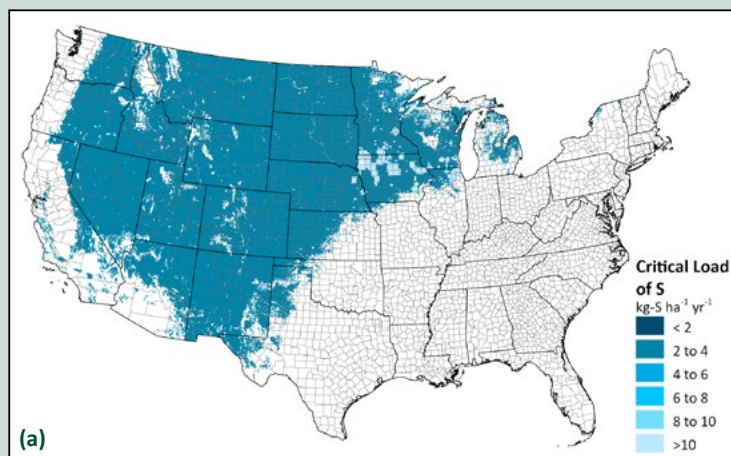
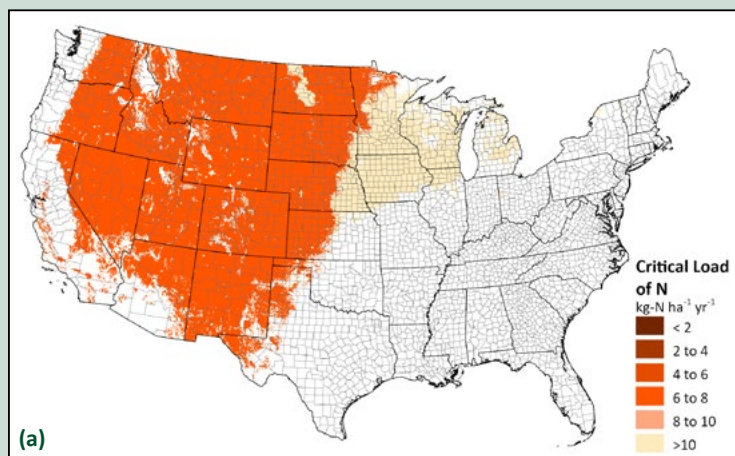


Figure 33.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Glycyrrhiza lepidota* and (b) the exceedance of N critical loads based on TDep 2019–2021 total N deposition.

Figure 33.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Glycyrrhiza lepidota* and (b) the exceedance of S critical loads based on TDep 2019–2021 total S deposition.

34.0 *Goodyera pubescens* (downy rattlesnake plantain)

Distribution and Conservation Status

Downy rattlesnake plantain is a native perennial forb that grows across the entire eastern half of the United States, from Maine south to Oklahoma, Arkansas, Mississippi and Florida. Downy rattlesnake plantains are one of the many species of orchids which are native to eastern North America. It is critically imperiled in Mississippi and Florida and vulnerable in Iowa, Illinois, and Maine (fig. 34.1).

Species Characteristics and Habitat

The prominent, evergreen leaves of downy rattlesnake live 3-4 years and are notable for displaying a web of silvery veins and a broad stripe down the center, mimicking the skin of a snake. Downy rattlesnake plantain grows low to the ground with stems that stretch across the surface of the soil, often separating from the mother plant and creating small colonies. The leaves stay close to the soil in a basal rosette around a central growing point. The entirety of the plant is coated with a very fine downy hair,

which is particularly visible on the bloom spike. Downy rattlesnake plantain flowers in late summer. The small, white flowers are closely packed on a slender cylindrical spike up to 18 inches tall.

Downy rattlesnake plantain grows best in slightly acidic, sandy to richly organic soils, such as peat or leaf mold underneath the canopy of trees and taller shrubs. It thrives in habitats with some shade and well-drained soil and is commonly found growing in dry to moist upland wooded habitats with acidic soils.

Traditional Ecological Knowledge

Downy rattlesnake plantain has been used to treat a variety of illnesses as well as injuries such as snake bites or burns. The leaves can be mashed and used to wipe out the mouths of infants to prevent soreness; they can also be used in an infusion to produce a blood tonic and treatment for colds.

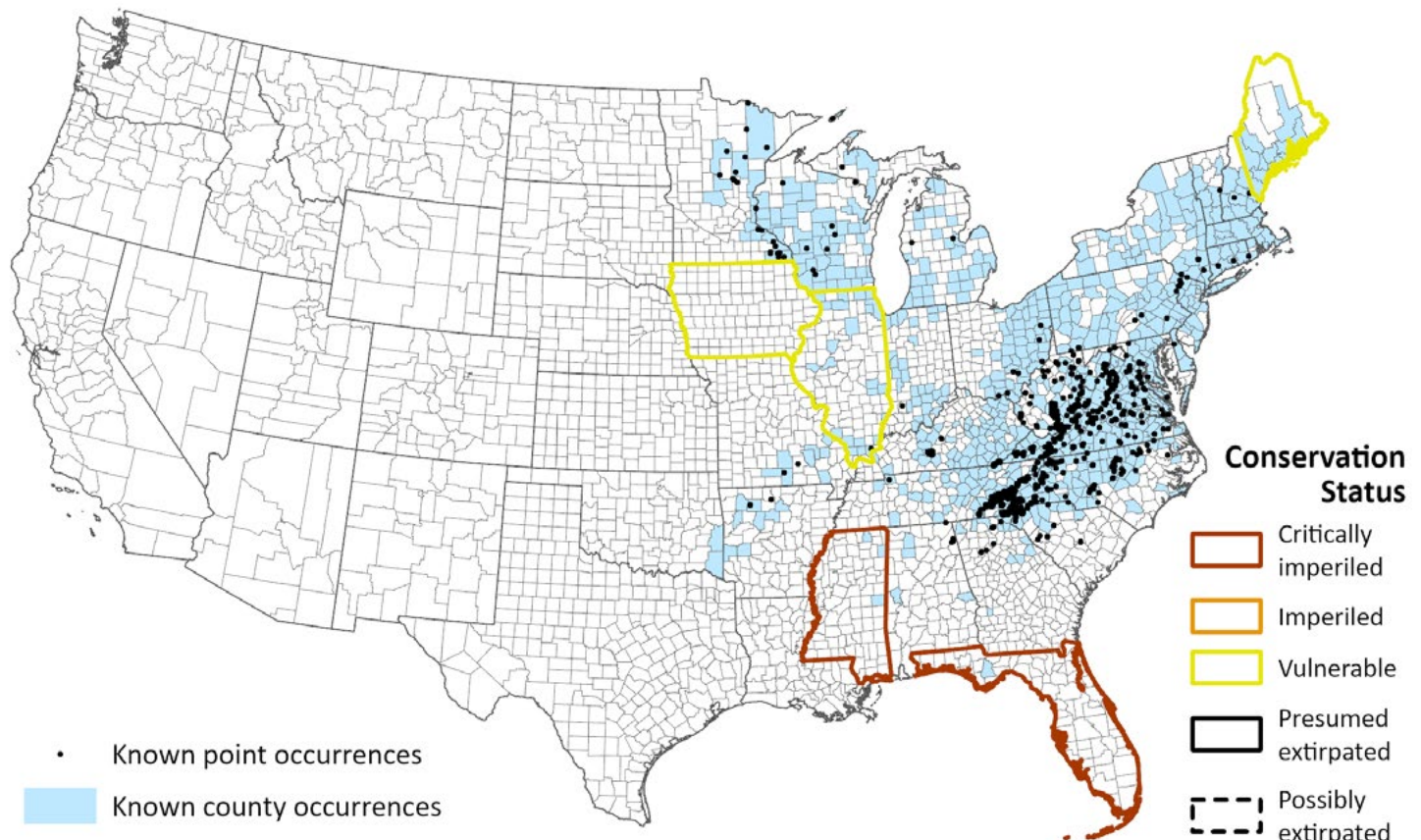


Figure 34.1. Distribution and state-level conservation status of *Goodyera pubescens*. Known point occurrences were used to assess species deposition responses and critical loads.

Responses to Nitrogen and Sulfur

The probability of occurrence for downy rattlesnake plantain is relatively simple, with a negative relationship for both N deposition (fig. 34.2a) and S deposition (fig. 34.2b). The climate effects are shown in Figure 34.2c (precipitation) and Figure 34.2d (temperature). The probability of occurrence increases with increasing temperatures and peaks at temperatures around 13 °C within the species’ sampled range. Confidence in the N and S relationships is moderate-to-high, with good model performance ($R^2 = 0.138$, $AUC = 0.76$; both moderate confidence), low VIFs ($VIF-N = 1.1$, $VIF-S = 1.1$; both high confidence), and a moderate N-S correlation ($r=0.61$, moderate confidence).



Flowers of downy rattlesnake plantain.
Chris Evans, University of Illinois, Bugwood.org.

Critical Loads and Exceedances

The environmental hull for downy rattlesnake plantain covers most of the eastern United States and the mountainous areas of the West. The N CL is 4-6 kg N/ha/yr across the entire species’ range. Exceedances of N CLs based on 2019–2021 TDep total N deposition exist across the East (except Maine) and in higher elevations in the West. The S CL is 2.5 kg S/ha/yr across the species’ range. The S CL is in exceedance based on 2019–2021 TDep total S deposition in the South and into the lower Midwest.



Whole plant of downy rattlesnake plantain.
Alex Katovich, Bugwood.org.

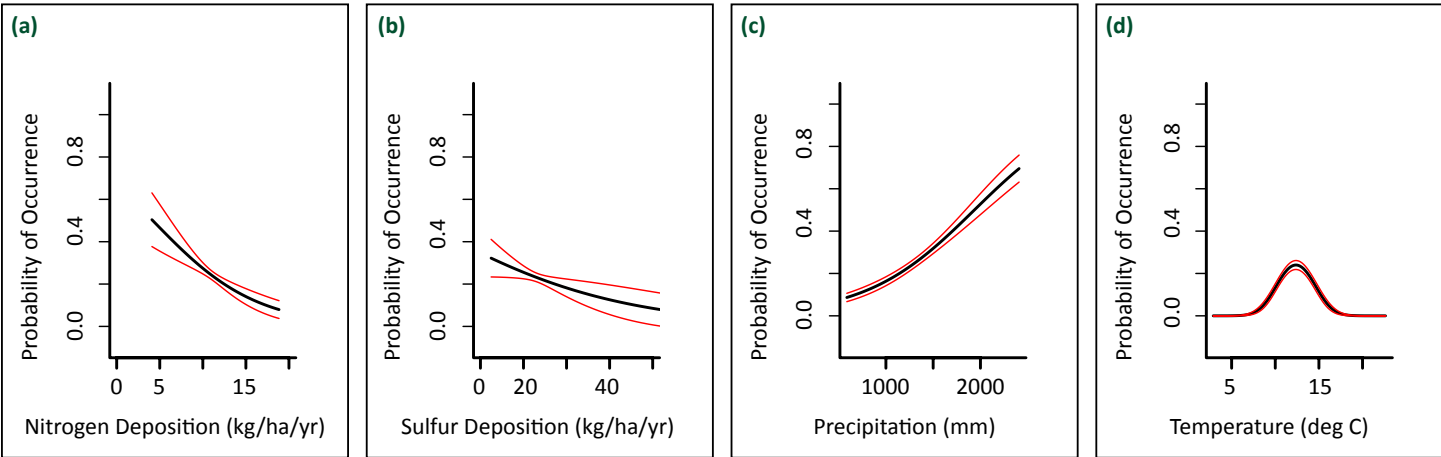


Figure 34.2. Effects of various environmental variables on the probability of occurrence of *Goodyera pubescens*: a) N deposition, b) S deposition, c) precipitation, d) temperature.

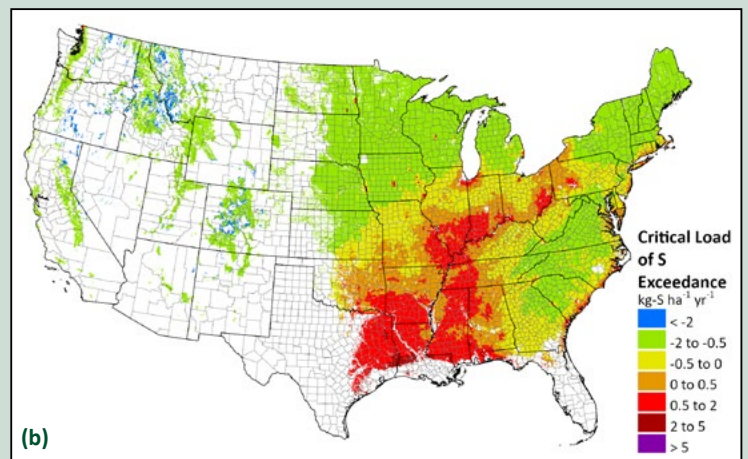
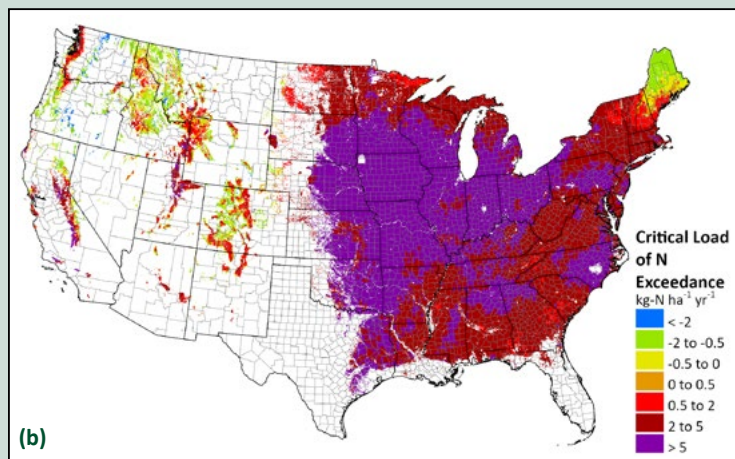
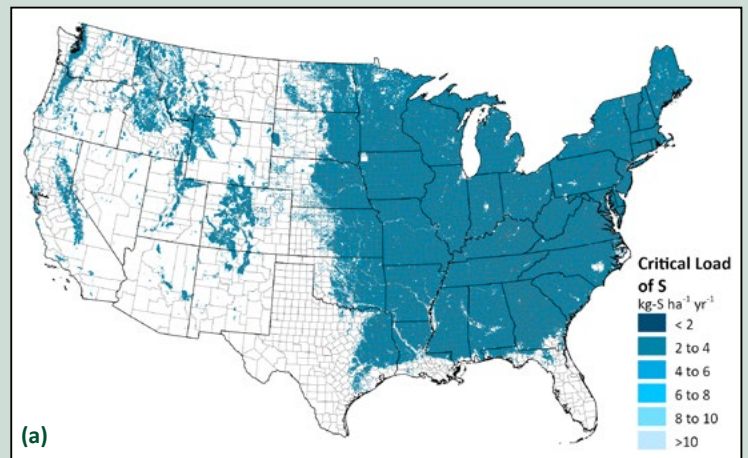
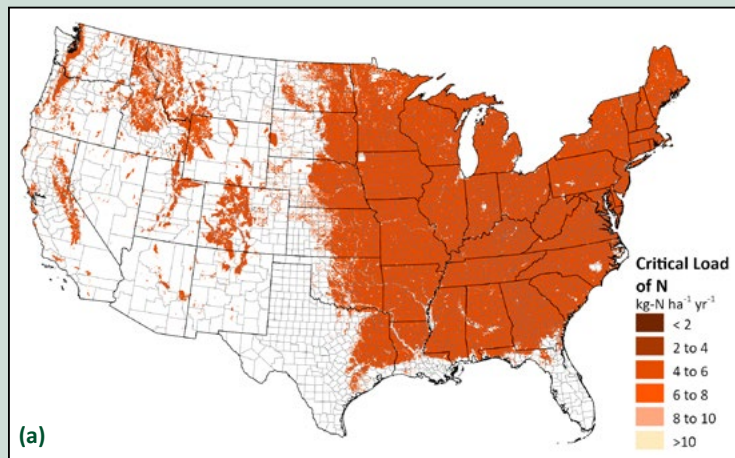


Figure 34.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Goodyera pubescens* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 34.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Goodyera pubescens* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

35.0 *Gymnocarpium dryopteris* (western oakfern)

Distribution and Conservation Status

Western oakfern is a native perennial fern that has a circumboreal distribution, growing from Alaska south to Oregon east through the Rocky Mountain states, and in New England and Virginia. Dispersed populations occur in the northern midwestern states of Wisconsin, Michigan, Minnesota, and Iowa. It is critically imperiled in New Mexico, Utah, Illinois, West Virginia, Maryland, New Jersey, and Massachusetts, imperiled in Wyoming, Nebraska, Iowa, and Ohio, and vulnerable in Colorado (fig. 35.1).

Species Characteristics and Habitat

Western oakfern grows best on mesic to wet sites in mixed conifer and northern hardwood stands. It thrives in soils that are moist and well-drained, and as a result it is often an indicator of water in forests. Western oakfern

prefers soils that are gravelly or sandy to silty clay loams, with pH ranging from 4.5 to 6.4. It favors elevations up to 1,700 feet. Western oakfern reproduces via spores and sprouts from rhizomes. The spores are adapted for high wind dispersal. It will grow on disturbed sites before canopy cover is established in the subboreal spruce. Spores are stored in the soil seedbank and as a result their populations may not be eliminated after fires that do not damage the top layers of soil. However, fire can top-kill western oakfern once it is established. Due to its ease and success at relocating, western oakfern is a desirable garden plant.

Wildlife Uses

The presence of western oakfern in mountainous areas of northwestern North America can be a sign of water.

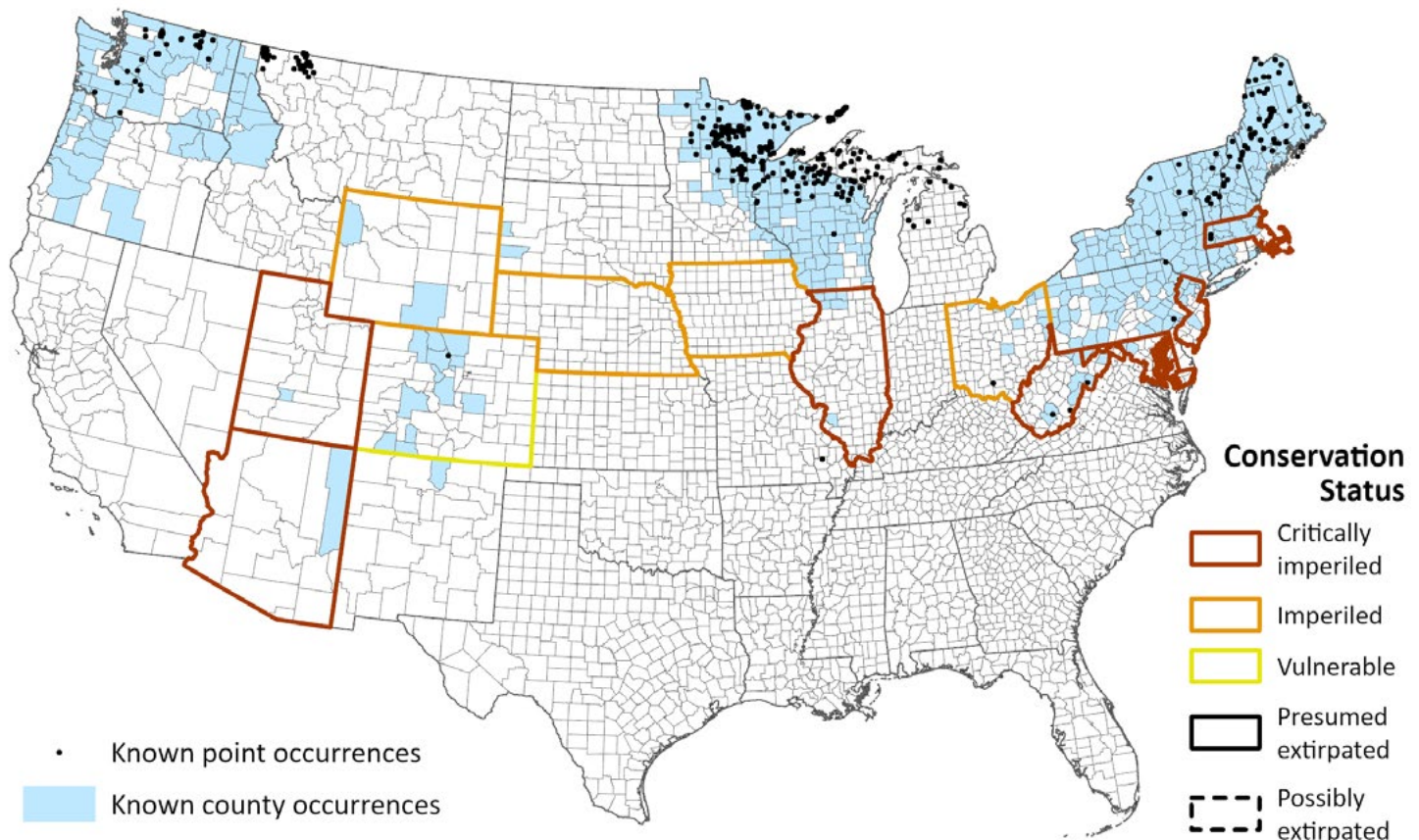


Figure 35.1. Distribution and state-level conservation status of *Gymnocarpium dryopteris*. Known point occurrences were used to assess species deposition responses and critical loads.

Responses to Nitrogen and Sulfur

The probability of occurrence for western oakfern depends on several variables. The effect of N deposition depends on soil pH (fig. 35.2a). Under less acidic conditions (pH ≥ 5.5), the probability of occurrence is high and drops sharply with N deposition, while under more acidic conditions (pH ≤ 4.8) the probability of occurrence is lower and less responsive to N deposition. There is also a spurious effect from S interacting with N and pH that was likely due to correlations with other variables (Clark et al. 2019). The climate effects are shown in Figure 35.2b (precipitation) and Figure 35.2c (temperature). The probability of occurrence increases with increasing

precipitation and peaks narrowly at temperatures around 4 °C (but note widening confidence bands with increasing precipitation) within the species' sampled range. Confidence in the N and S relationships is moderate, with good model performance ($R^2 = 0.168$, AUC = 0.8; moderate and high confidence, respectively), low VIFs (VIF-N = 1.3, VIF-S = 1.3; both high confidence), and a high N-S correlation ($r=0.8$, low confidence).



Close up of western oakfern frond.
USDA Forest Service photo by Karen Dillman.



Western oakfern fronds in a shaded forest.
USDA Forest Service photo by Karen Dillman.

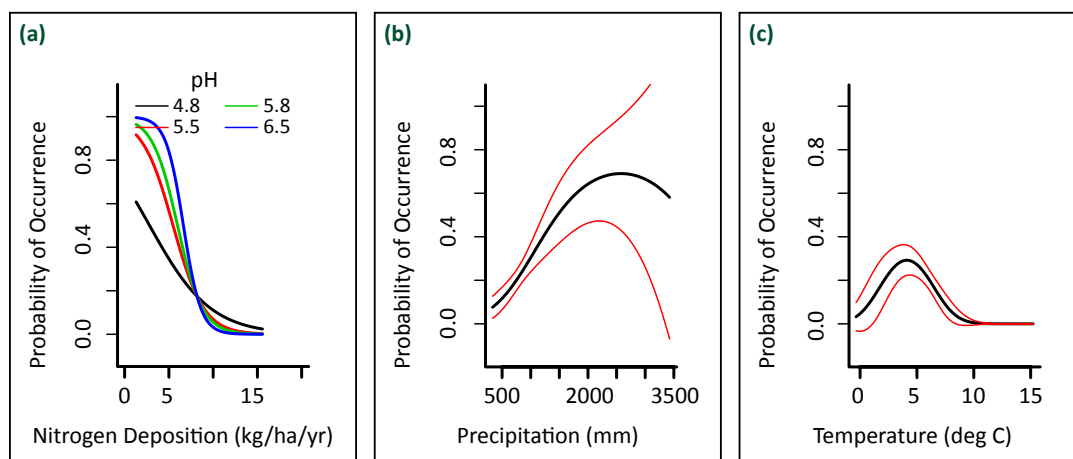


Figure 35.2. Effects of various environmental variables on the probability of occurrence of *Gymnocarpium dryopteris*: a) N x pH interaction, b) precipitation, c) temperature.

Critical Loads and Exceedances

The environmental hull for western oakfern covers most of the northern half of the United States and some mountainous areas of the Southwest. The N CL is ≤ 2 kg N/ha/yr across almost the entire range. Exceedances of N CLs based on 2019–2021 TDep total N deposition across

most of the range excluding pockets of low deposition in the West. The S CL is 39.4 kg S/ha/yr across most of the species' range with a S CL of 0.4 kg S/ha/yr in eastern States. The S CL is in exceedance based on 2019–2021 TDep total S deposition in the eastern States with the lower CL.

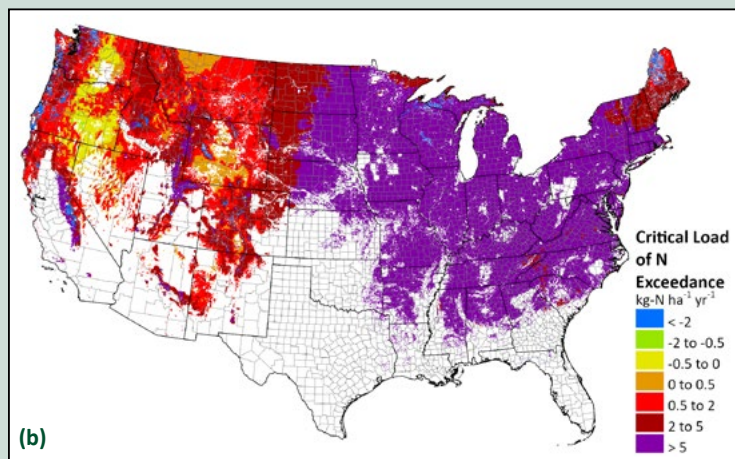
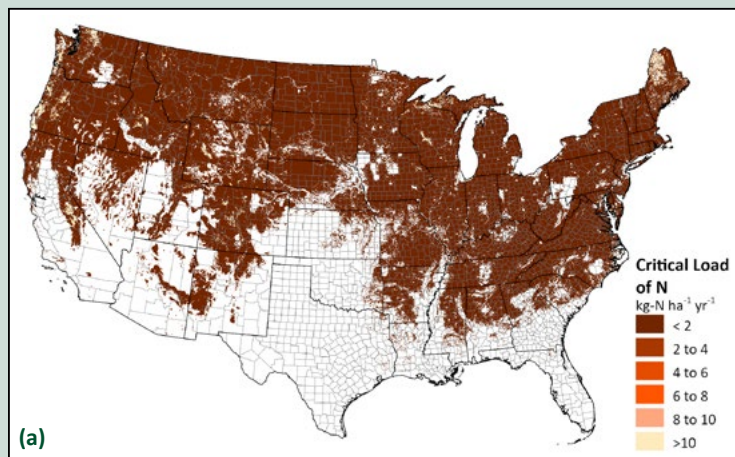


Figure 35.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Gymnocarpium dryopteris* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

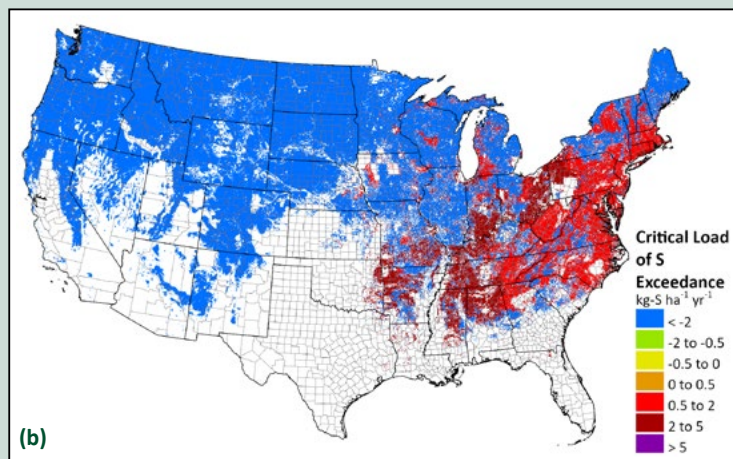
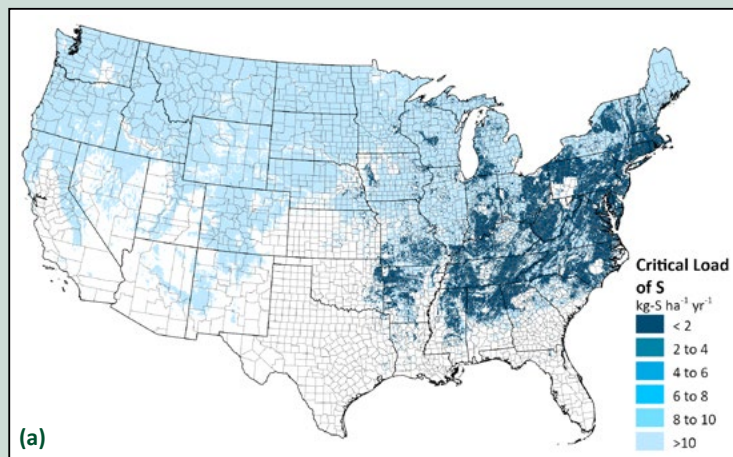


Figure 35.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Gymnocarpium dryopteris* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

36.0 *Hepatica nobilis* (sharplobe hepatica)

Distribution and Conservation Status

Sharplobe hepatica is a native perennial forb that grows from Canada south to Maine and continues south through the eastern United States to Missouri, Georgia, and Alabama. It is imperiled in Florida (fig. 36.1).

Species Characteristics and Habitat

Sharplobe hepatica is a small, rhizomatous plant in the buttercup family, 2 to 7 inches tall. It forms three simple but deeply lobed leaves from the base of the plant. The three leaves are longer than wide, with intensely pointed lobe tips and indented bases. Its thick leaves are evergreen, allowing it to begin photosynthesis early in the spring before the canopy closes. The flower stalks are long and hairy and have a single small 0.05- to 0.1-inch flower.

Sharplobe hepatica grows on topography that differs between gently rolling hills to bluffs and outcroppings. It prefers low fertility and low moisture-holding soils, such as sandy loams, to calcareous moist soils in shaded, upland woods. It sprouts from short rhizomes, growing into small

colonies. Seeds are transported away from the parent plant by ants and rodents. Sharplobe hepatica's resistance to fire depends on the protection its caudex and rhizomes receive from soil cover, however, it is probably top-killed by fire, killing the seeds but not the rhizomes.

Wildlife Uses

No food value is known for sharplobe hepatica. However, ants and rodent herbivores are known to eat the seeds.

Ecosystem Services

Sharplobe hepatica is an excellent soil stabilizer due to its rhizomes.

Traditional Ecological Knowledge

Sharplobe hepatica has a multitude of traditional medicinal uses including treating labor pain and stiff muscles, internal afflictions such as amenorrhea and dysentery (compound root decoction), and convulsions in children (root decoction).

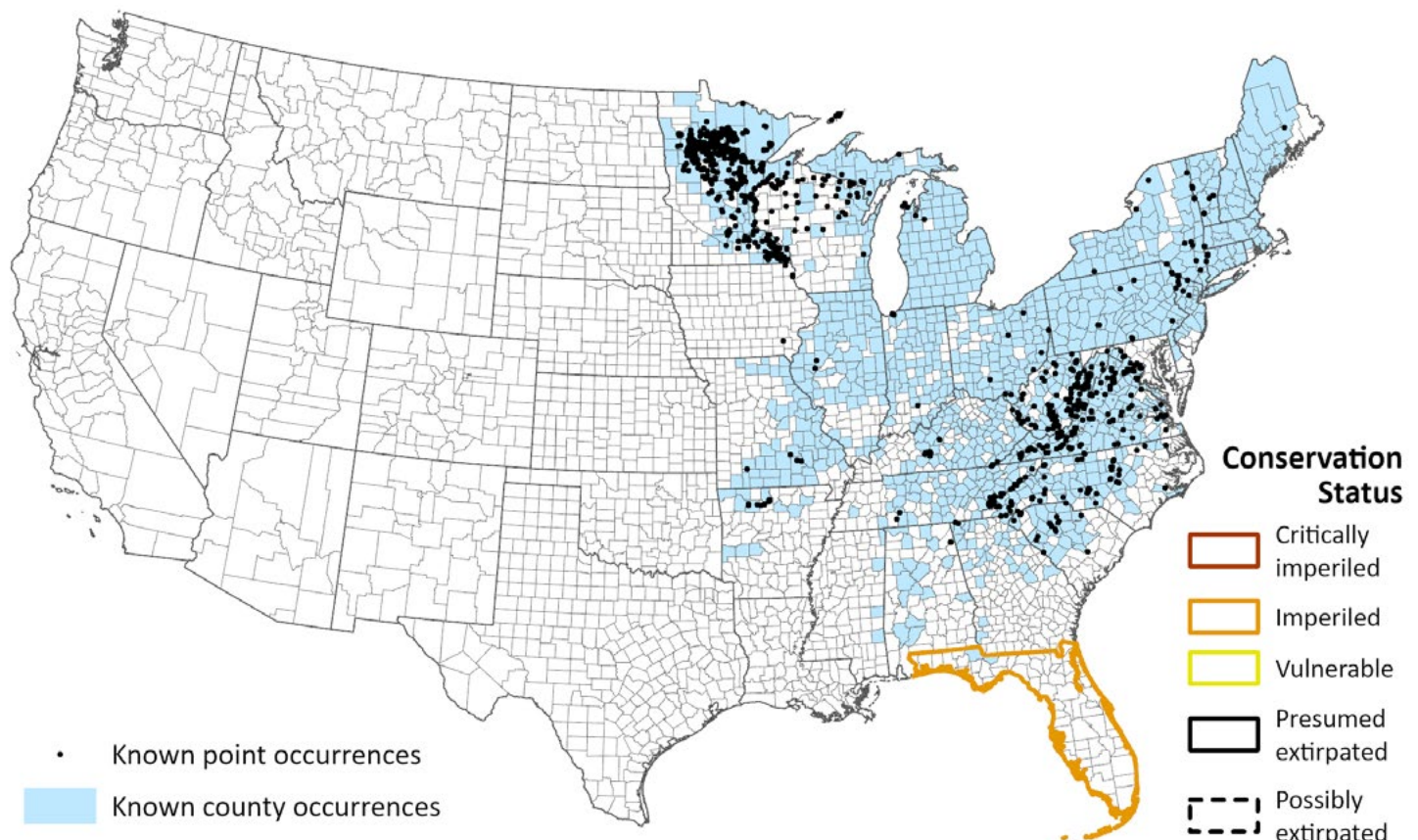


Figure 36.1. Distribution and state-level conservation status of *Hepatica nobilis*. Known point occurrences were used to assess species deposition responses and critical loads.

Responses to Nitrogen and Sulfur

The probability of occurrence for sharplobe hepatica depends on several variables. The effects for both N deposition (fig. 36.2a) and S deposition (fig. 36.2b) depend on soil pH. With increasing N deposition, under less acidic conditions ($\text{pH} \geq 5.4$), the probability of occurrence increases up to roughly 12 kg N/ha/yr and then decreases, while under more acidic conditions ($\text{pH} \leq 4.4$) sharplobe hepatica is less responsive to N deposition. With increasing S deposition, the probability of occurrence decreases under less acidic conditions ($\text{pH} \geq 5.4$) and is less responsive under more acidic conditions ($\text{pH} \leq 4.4$). The climate effects are shown in Figure 36.2c



Close up of flower for sharplobe hepatica.
David Cappaert, Bugwood.org.

(precipitation) and Figure 36.2d (temperature). The probability of occurrence decreases with increasing precipitation and weakly decreases with increasing temperatures within the species' sampled range. Confidence in the N relationship is moderate and in the S relationship is low, with moderate model performance ($R^2 = 0.189$, $\text{AUC} = 0.8$), a moderate VIF for nitrogen ($\text{VIF-N} = 3.2$), a high N-S correlation ($r=0.8$) and a very high VIF for sulfur ($\text{VIF-S} = 47$).

Critical Loads and Exceedances

The environmental hull for sharplobe hepatica covers the eastern United States and the mountainous areas of the West. The N CL ranges from 4-10 kg N/ha/yr across est and is ≥ 10 kg N/ha/yr in the East. Exceedances of N CLs based on 2019–2021 TDep total N deposition exist across the Midwest, high elevations in California and Utah, and in agricultural areas in the East. The S CL is 0.4 kg S/ha/yr across most of the species' range with a S CL of 41.7 kg S/ha/yr in a band from Iowa to Ohio. The S CL is in exceedance based on 2019–2021 TDep total S deposition in the eastern States with the lower CL and in most of the West.

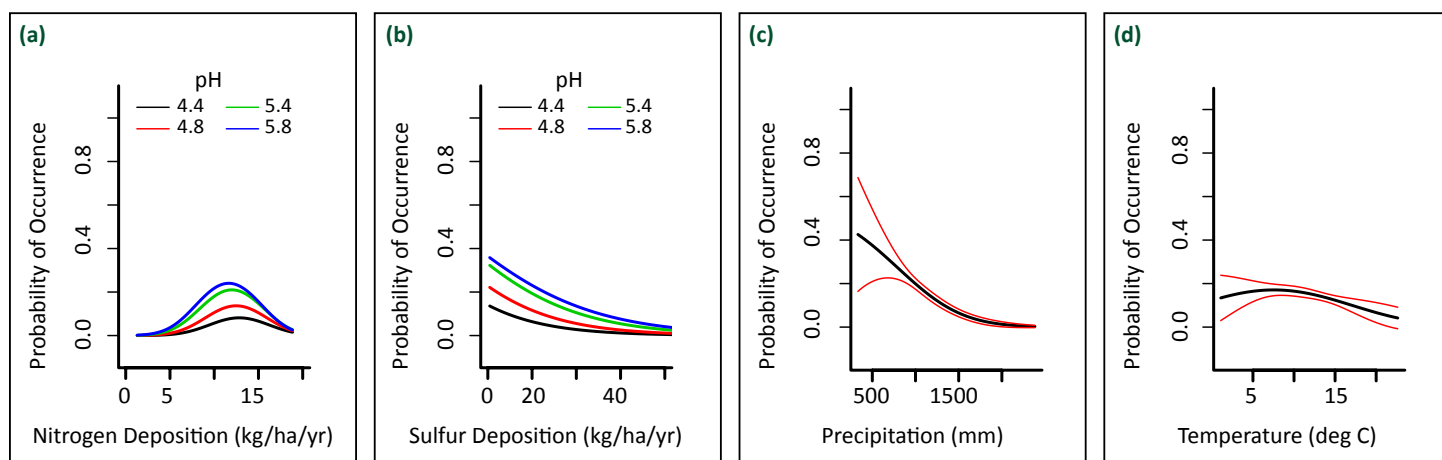


Figure 36.2. Effects of various environmental variables on the probability of occurrence of *Hepatica nobilis*: a) N x pH interaction, b) S x pH interaction, c) precipitation, d) temperature.

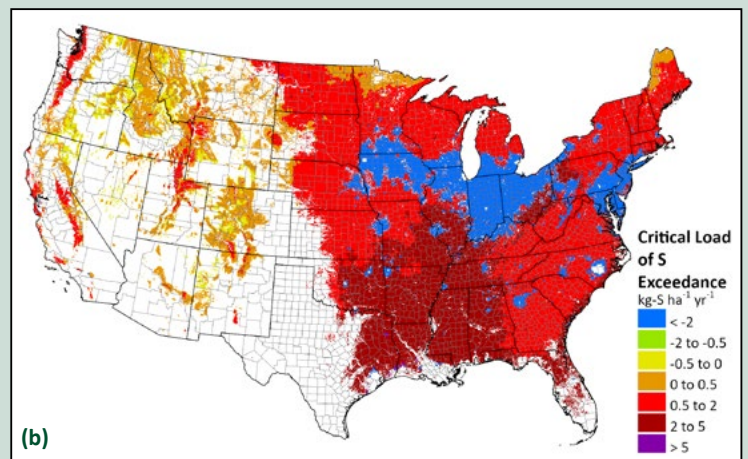
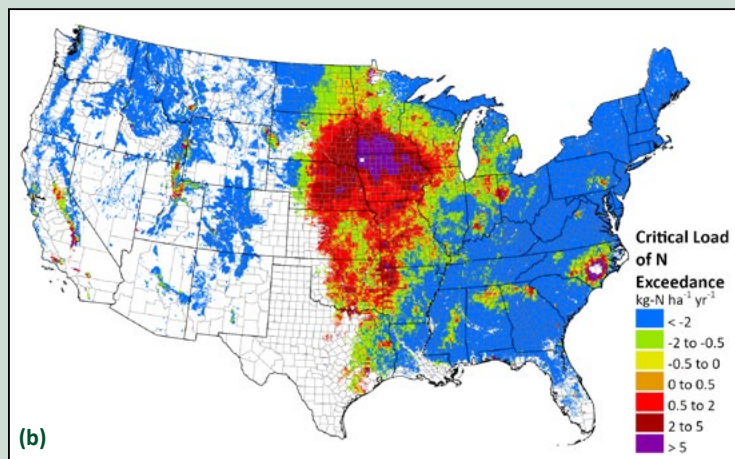
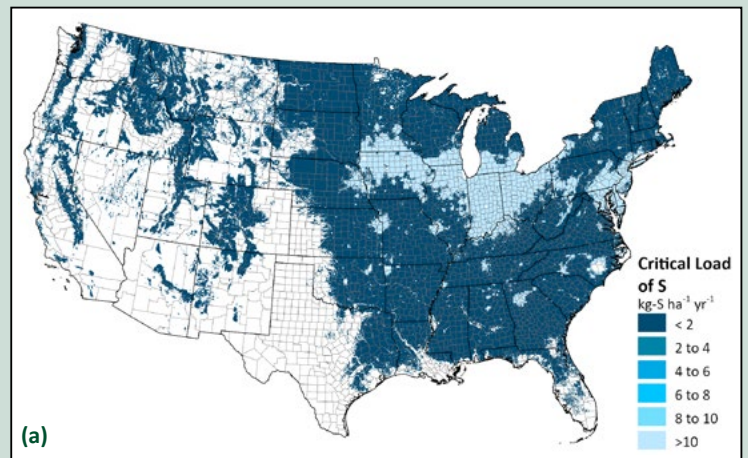
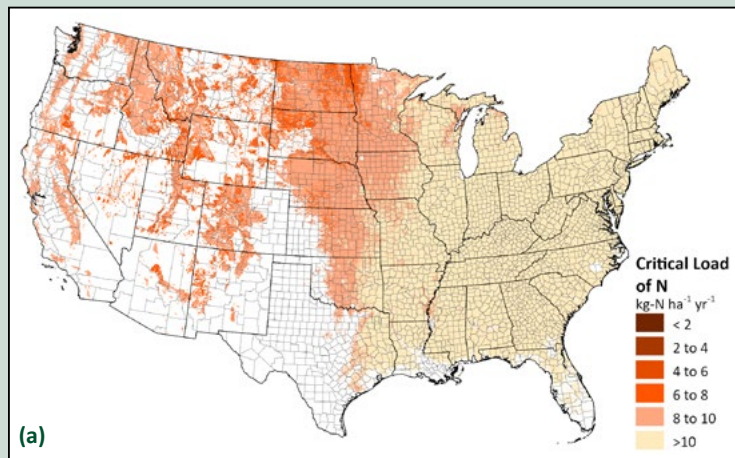


Figure 36.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Hepatica nobilis* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 36.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Hepatica nobilis* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

37.0 *Hesperostipa comata* (needle and thread)

Distribution and Conservation Status

Needle and thread is a native tufted, perennial, cool-season bunchgrass commonly found in prairies, plains and foothills of the western United States. It is critically imperiled in Iowa and Illinois, and presumed extirpated in Indiana (fig. 37.1)

Species Characteristics and Habitat

Needle and thread is a tufted, cool-season bunchgrass that grows 1 to 4 feet tall with upright, smooth culms and long, flat leaves 8 to 12 inches long. The roots grow vertically and laterally, extending more than 14 inches from the base of the plant in the first half foot of soil depth. These copiously branched roots can grow 3 to over 5 feet deep. Needle-and-thread starts to grow in the early spring, flowers in June, and produces mature seeds in July.

Needle and thread is drought tolerant and grows best on excessively drained sands, fine sandy loams or coarse gravelly loam soils, but is also found on loam to clay

loam soils in some habitats. It is one of the first types of vegetation to grow on sand dunes in the Intermountain Region. It prefers soils with slightly alkaline pH. It is mostly found at elevations between 3500 to 8500 feet. It can enter dormancy in early to mid-summer and green-up again in autumn if soil moisture is adequate. Needle and thread propagates via seed and population size increases slowly. It is not known to be “weedy” or an invasive plant, but if environmental conditions are right it is known to spread into surrounding vegetative communities. After a fire, needle-and-thread is top-killed but will sprout from the caudex, if the heat has not killed the underground parts. A full recovery after a fire generally takes 2 to 10 years.

Wildlife and Livestock Uses

Needle and thread is mildly edible to wildlife and domestic livestock in the spring before the awns develop and then later in the fall once the seeds have been released. Elk find it to be desirable forage in the winter and spring, and

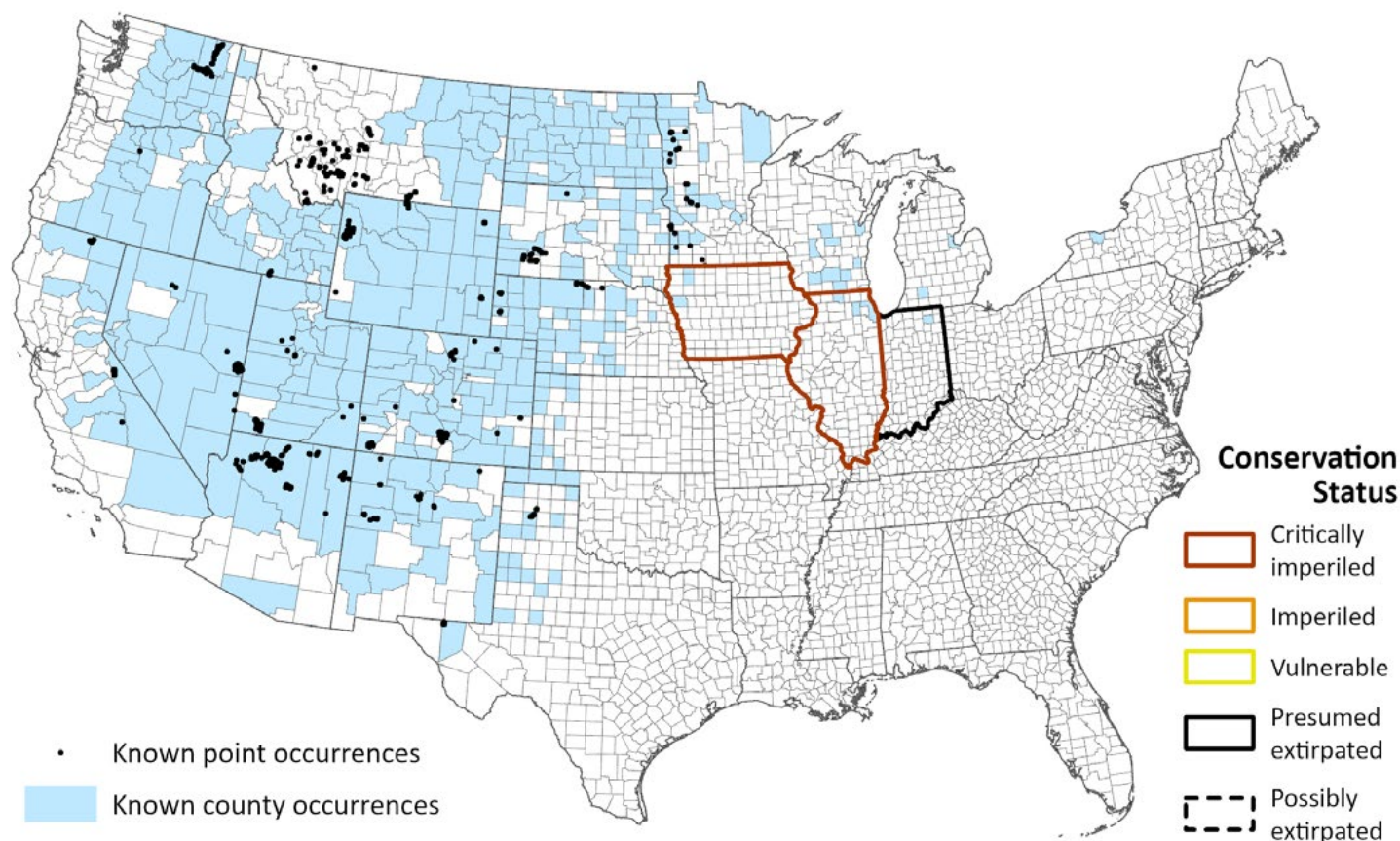


Figure 37.1. Distribution and state-level conservation status of *Hesperostipa comata*. Known point occurrences were used to assess species deposition responses and critical loads.

deer forage on it in the spring. It is almost inedible in the summer as the sharp awns on the fruit may injure grazing animals. If it is grazed by livestock, especially domestic sheep, when the seeds are present, the sharp-pointed seed may cause injury by working into the tongue, throat, eyes, ears and hide.

Ecosystem Services

Needle and thread is highly effective at preventing wind erosion especially in sandy environments. It is one of the first grasses to naturally recolonize disturbed sandy locations.



Stems of needle and thread in the field.
Bruce Bosley, Colorado State University, Bugwood.org.

Responses to Nitrogen and Sulfur

The probability of occurrence for needle and thread depends on several variables. The effect of N deposition depends on soil pH (fig. 37.2a). The species is mostly found in alkaline soils and responds less strongly to N deposition under more alkaline conditions ($\text{pH} \geq 7.5$) and more strongly under less alkaline conditions ($\text{pH} \leq 6.5$). There is also a strong decrease with S deposition (fig. 37.2b). The climate effects are shown in Figure 37.2c (precipitation) and Figure 37.2d (temperature). The probability of occurrence decreases sharply with increasing precipitation up to 1000 mm and peaks broadly at temperatures around 7 °C (but note wide confidence bands) within the species' sampled range. There were a few observations at high precipitation as well, but the high error estimates suggest these are relatively uncommon. Confidence in the N and S relationships is moderate, with good model performance ($R^2 = 0.218$, $\text{AUC} = 0.82$; moderate and high confidence, respectively), low VIFs ($\text{VIF-N} = 1.6$, $\text{VIF-S} = 2.2$; both high confidence), and a high N-S correlation ($r=0.92$, low confidence).

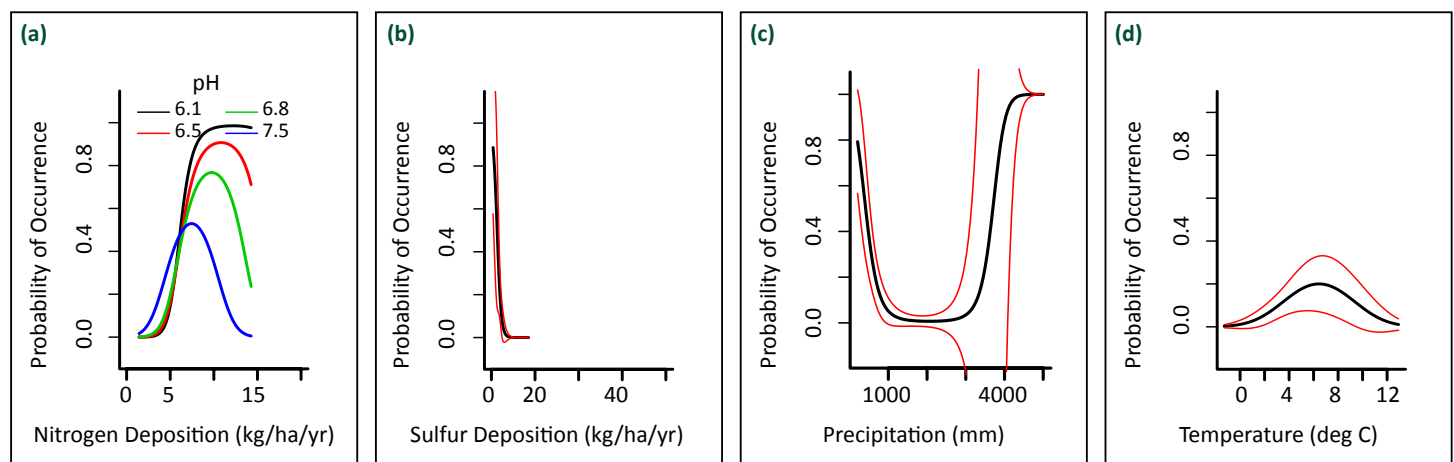


Figure 37.2. Effects of various environmental variables on the probability of occurrence of *Hesperostipa comata*: a) N x pH interaction, b) S deposition, c) precipitation, d) temperature.

Critical Loads and Exceedances

The environmental hull for needle and thread covers most of the western United States. The N CL ranges from ≤ 1 to ≥ 10 kg N/ha/yr with lowest values in arid areas. Exceedances of N CLs based on 2019–2021 TDep total N deposition exist across the Midwest, near Salt Lake City, and in California’s southern Central Valley. The S CL is 0.4 kg S/ha/yr across most of the northern and Midwest areas and 8.5 kg S/ha/yr in most of the Southwest. The S CL is in exceedance based on 2019–2021 TDep total S deposition in the midwestern and northern United States.



Close-up of flowers, stem and leaves of needle and thread.
Dave Powell, USDA Forest Service (retired), Bugwood.org.

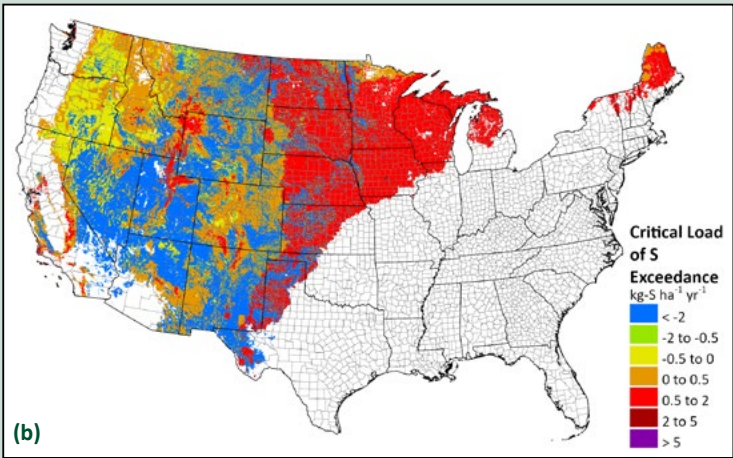
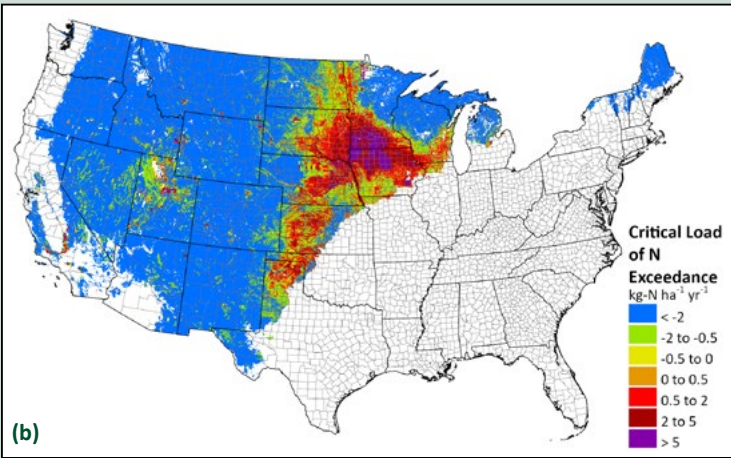
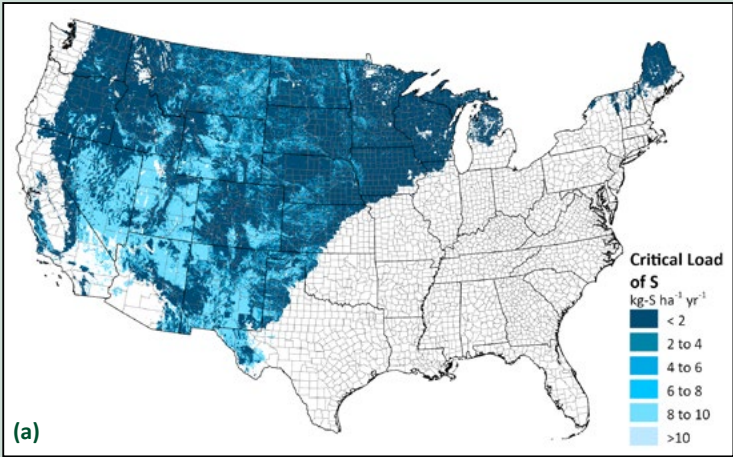
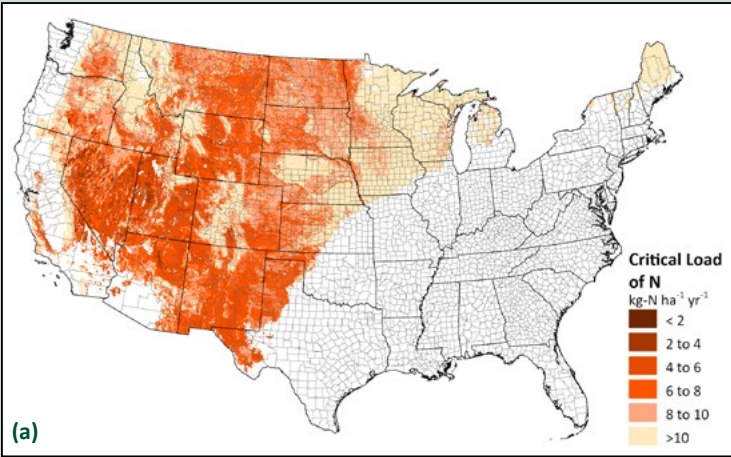


Figure 37.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Hesperostipa comata* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 37.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Hesperostipa comata* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

38.0 *Juncus arcticus ssp. littoralis* (mountain rush)

Distribution and Conservation Status

Mountain rush is a native perennial rush that occurs in wetlands throughout the United States except the Southeast. Mountain rush is considered endangered or extirpated in Maryland, threatened in Pennsylvania, and potentially threatened in Ohio (fig. 38.1).

Species Characteristics and Habitat

Mountain rush is a rhizomatous, tuft-forming plant that grows in small clusters. The green culms (jointed stems) are 1.1 to 3.6 feet tall. The leaf sheaths are clustered at the base, and are 0.75 to 6 inches long, multi-colored from red to light to dark brown, and bladeless. The inflorescence forms a loose to compact panicle of 10 to 50 flowers. Mountain rush flowers are green to brown in color, sessile to pedicellate, each subtended by a pair of hyaline-scarious bracts. The fruit is a capsule, and the seeds are brownish red.

Because mountain rush is found in wetlands, it can grow in standing water in addition to seasonally dry places, such as desert playas. It has a high shade tolerance and usually grows at elevations below 7,200 feet. Mountain rush grows well in soils with a pH of 5.0-5.9 but can also grow in anoxic soils with alkaline to calcareous properties (up to pH 9.1) and tolerate mild to moderate soil salinities. It is wind pollinated and as a result can be invasive.

Mountain rush is highly tolerant of fire when dormant and top-killed by fire during the growing season. The rhizomes and seeds are usually protected by insulating soil, allowing the plant to regrow after fires.

Wildlife and Livestock Uses

Mountain rush helps improve habitat for amphibians and spawning areas for fish in wetlands. Muskrats feed on the roots and rhizomes of mountain rush, and various wetland wading birds find shelter among the leaves. Waterfowl, songbirds, small mammals, jack rabbits, cottontail, muskrat, porcupine, quail, and gopher all eat mountain

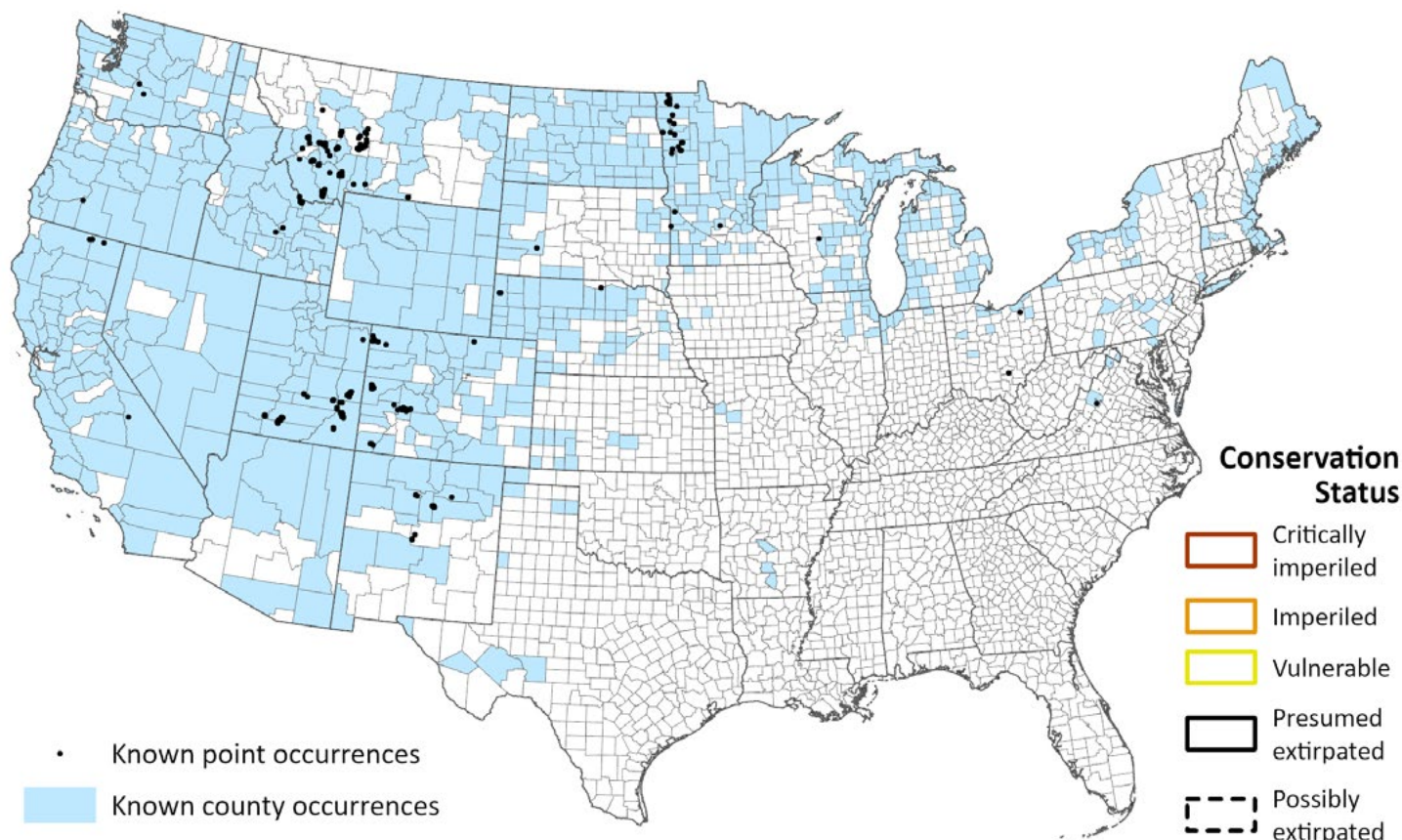


Figure 38.1. Distribution and state-level conservation status of *Juncus arcticus*. Known point occurrences were used to assess species deposition responses and critical loads.

rush. Cattle prefer not to graze mountain rush due to its low palatability but will graze it later in the season after the more palatable plants are eaten. Its unpalatability makes it more resistant to grazing pressures and, over time, the population size may increase in pastures.

Ecosystem Services

Mountain rush provides numerous ecosystem services including erosion prevention, sediment retention, basketry, wildlife food and cover, tatami mats, nitrogen-fixation, revegetation of disturbed areas, restoration and creation of wetland ecosystems, and wastewater treatment applications. The rhizomes form a matrix for many beneficial bacteria, making this plant excellent at wastewater treatment and nitrogen fixation.



Whole plant and flowers of mountain rush.
Dave Powell, USDA Forest Service (retired), Bugwood.org.

Traditional Ecological Knowledge

Various Indigenous peoples use rush stems to make traditional coiled baskets; the mature rushes can be dyed black by steeping for them hours in an infusion of horned sea-blite (*Suaeda calceoliformis*). The young shoots can be eaten raw, roasted in ashes, or boiled.

Responses to Nitrogen and Sulfur

The probability of occurrence for mountain rush is unresponsive to N deposition and mostly depends on the interaction between S deposition and soil pH (fig. 38.2a). Mountain rush is relatively uncommon overall, but the probability of occurrence decreases with S deposition when soil pH is neutral to acidic (pH ≤7) and is relatively stable under alkaline soil conditions (pH ≥7.5). The climate effects are shown in Figure 38.2b (precipitation) and Figure 38.2c (temperature). The probability of occurrence is largely unresponsive to precipitation and decreases with increasing temperatures within the species’ sampled range. The lack of a relationship with precipitation is likely because this species is found in montane wetlands, which are wet because of poor drainage rather than high precipitation. Confidence in the N and S relationship is moderate, with good model performance ($R^2 = 0.186$, AUC = 0.78; both moderate confidence), low VIFs (VIF-S = 1.4, VIF-S = 1.9; both high confidence), and a high N-S correlation ($r=0.86$, low confidence).

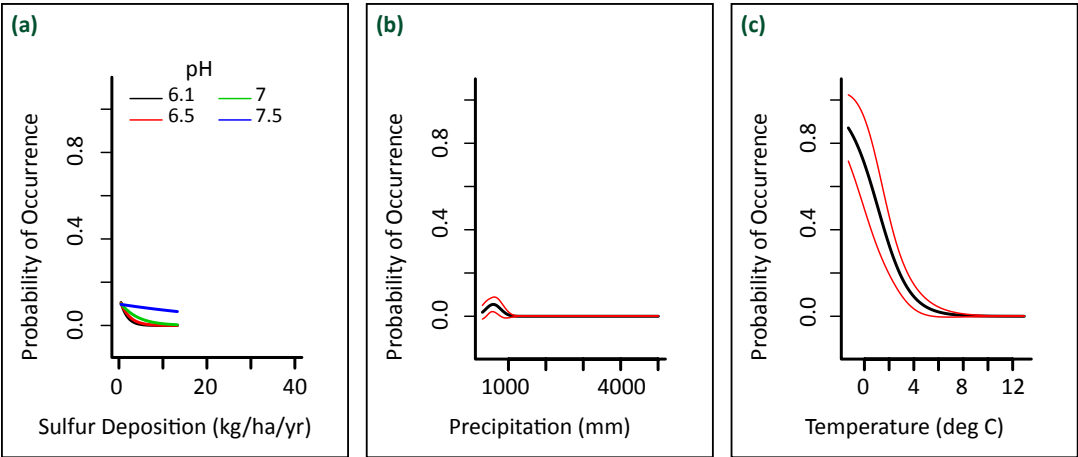


Figure 38.2. Effects of various environmental variables on the probability of occurrence of *Juncus arcticus*: a) N x pH interaction, b) precipitation, c) temperature.

Critical Loads and Exceedances

The environmental hull for mountain rush covers the northern half of the United States. There is no response to N deposition. The S CL is 0.5 kg S/ha/yr across the East and Mountain West and 13.3 kg S/ha/yr in the western plains and valleys. The S CL is in exceedance based on 2019–2021 TDep total S deposition in areas with the lower CLs except in the lower elevations of the Northwest.



Whole plant and flowers of mountain rush.

Photo courtesy of Conservation Garden Park, <https://conservationgardenpark.org/plants/1413/mountain-rush/>.

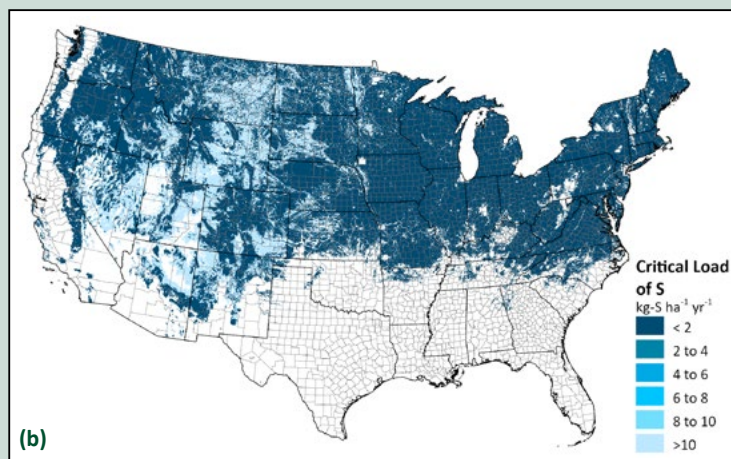
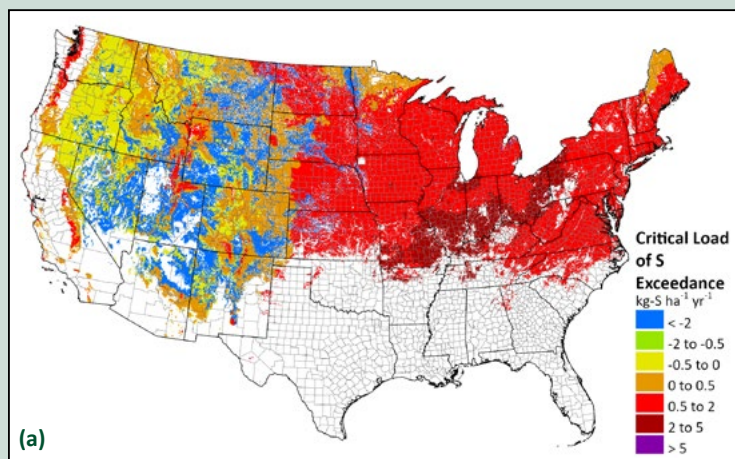


Figure 38.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Juncus arcticus* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

39.0 *Juncus effusus* (soft rush)

Distribution and Conservation Status

Soft rush is a native perennial rush that occurs across the United States excluding South Dakota, Montana and Utah. It is critically imperiled in Kansas and imperiled in Iowa (fig. 39.1).

Species Characteristics and Habitat

Soft rush is a slow spreading, clump forming, and grass-like, emerging from a stout, branching rootstock. The culms are smooth, upright, bright green and hollow. In the late summer, new shoots emerge and develop, stretching up to 4 feet tall at maturity. The rhizomes are short and finely divided, growing between 6 and 10 inches long, up to 2 inches below the soil surface. In the late summer, new shoots emerge and develop, stretching up to four feet tall at maturity. The flowers sprout and mature from March to September, blooming in July. The flowers are unremarkable in compressed bunches about four inches long. After fertilization, a three-celled, obovoid capsule develops, holding several small, straw-colored seeds.

Soft rush grows in fresh to brackish marshes, swamps, ditches, and moist seasonal wetlands and meadows. It thrives in direct sun, finely textured soils, and salinity levels under 14 ppt. It is tolerant of diverse site conditions but prefers soil pH levels from 4.0 to 6.0 and shallow water. Soft rush is wind pollinated, but sometimes it is insect pollinated. It is easily propagated from bare root stock or seedlings, from container stalks, or by direct seeding of the soil and can be invasive. Although it can tolerate periods of drought and total inundation, water management is essential during plant establishment and is also critical to proper management of wetland community composition. Soft rush tends to be resilient to insects and diseases.

Wildlife and Livestock uses

The seed and vegetative parts of soft rush are utilized by waterfowl, muskrats, non-game birds, moose and domestic livestock for food or cover.

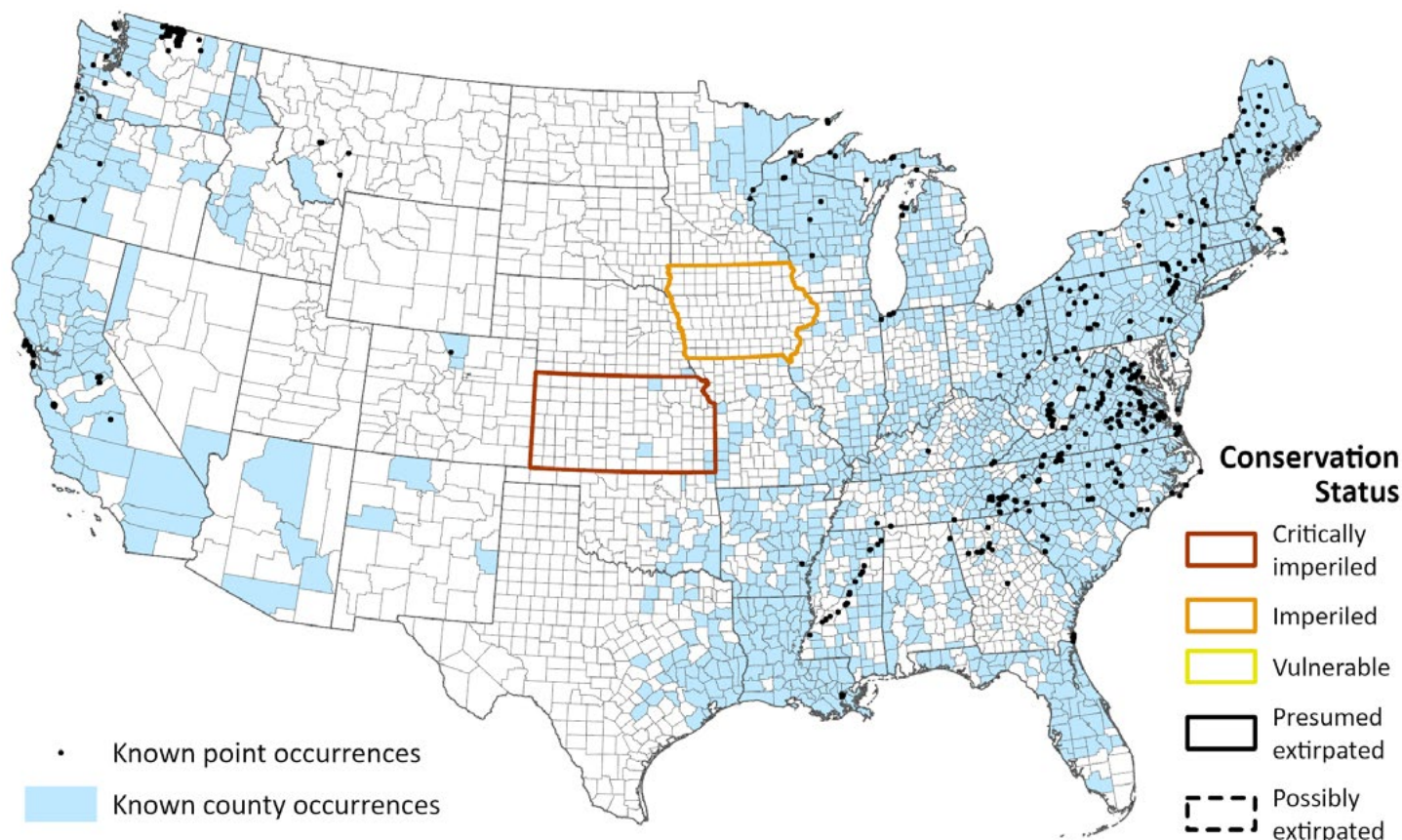


Figure 39.1. Distribution and state-level conservation status of *Juncus effusus*. Known point occurrences were used to assess species deposition responses and critical loads.

Ecosystem Services

Soft rush grows in dense stands with deep fibrous root systems that provide excellent shoreline protection, filter suspended solids, absorb nutrients, and facilitate substrate oxidation. The plant may be used to control erosion, accrete and stabilize sediments, provide food and shelter for wildlife, restore and create wetland ecosystems, and filter waste from water.

Traditional Ecological Knowledge

Traditional uses include the manufacture of floor mats, chair seats, weaving bags, and pouches; as an occasional food source (early sprouts); and as a medicinal wash for strengthening infant development (infusion).



Plants with flowers of soft rush.
Richard Gardner, Bugwood.org.

Responses to Nitrogen and Sulfur

Of the variables tested, the probability of occurrence for soft rush is only related to N deposition (fig. 39.2a) and S deposition (fig. 39.2b). Soft rush decreases with N deposition and increases with S deposition. However, the high collinearity between N and S deposition means that the data cannot be used to separate N from S effects nor to separate the effects of N and S individually from their joint effects. There are no significant climate variables. Confidence in the N and S relationships (or lack thereof) is moderate, with good model performance ($R^2 = 0.359$, AUC = 0.87; both high confidence), low VIFs (VIF-N = 2.2, VIF-S = 1.8; both high confidence), and a very high N-S correlation ($r=0.96$, low confidence).



Flowers of soft rush.
Richard Gardner, Bugwood.org.

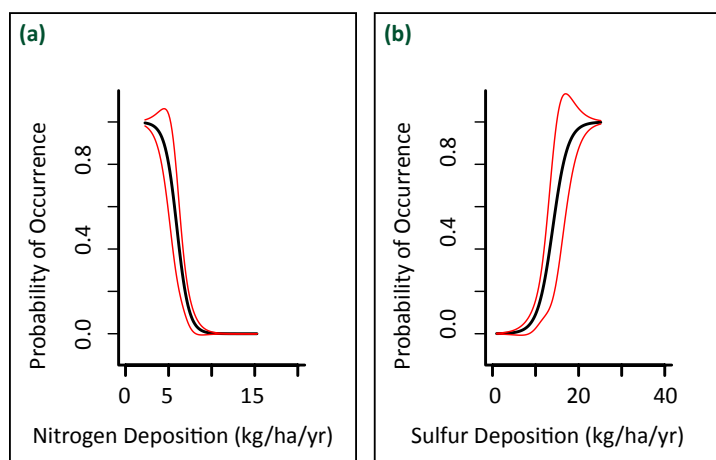


Figure 39.2. Effects of various environmental variables on the probability of occurrence of *Juncus effusus*: a) N deposition, b) S deposition.

Critical Loads and Exceedances

The environmental hull for soft rush covers the eastern United States and Mountain West. The N CL is 2 to 4 kg N/ha/yr across the entire range. The N CL is in exceedance based on 2019–2021 total N deposition across the East

and in the higher elevations in the West. The S CL is 25.1 kg S/ha/yr across the whole range. There are no exceedances of the S CL based on 2019–2021 TDep total S deposition.

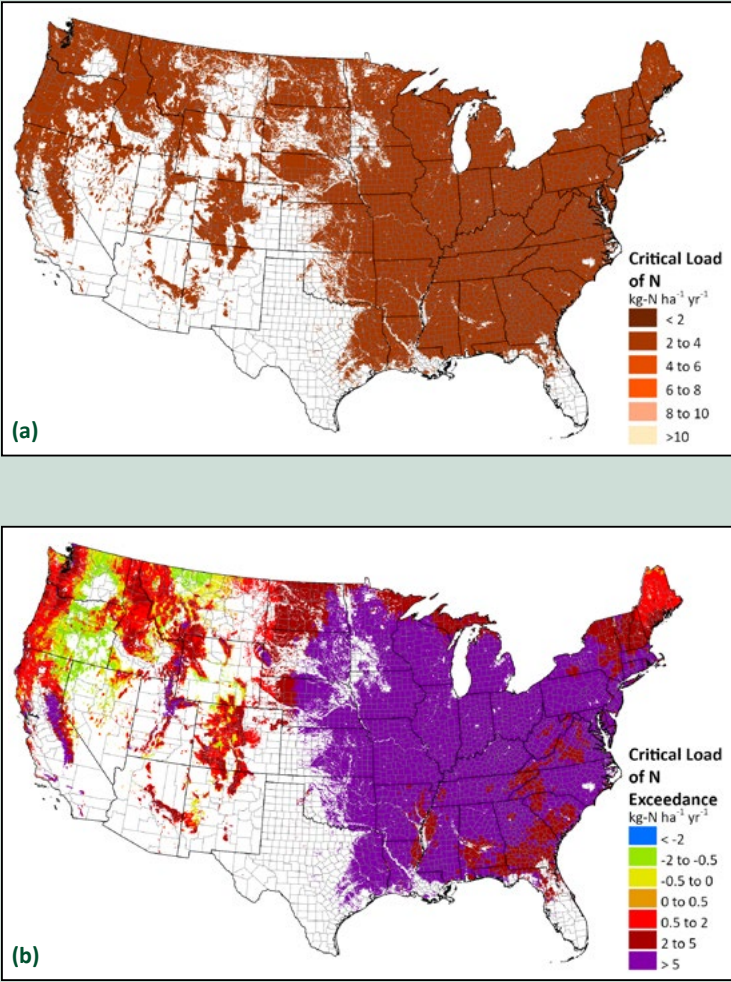


Figure 39.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Juncus effusus* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

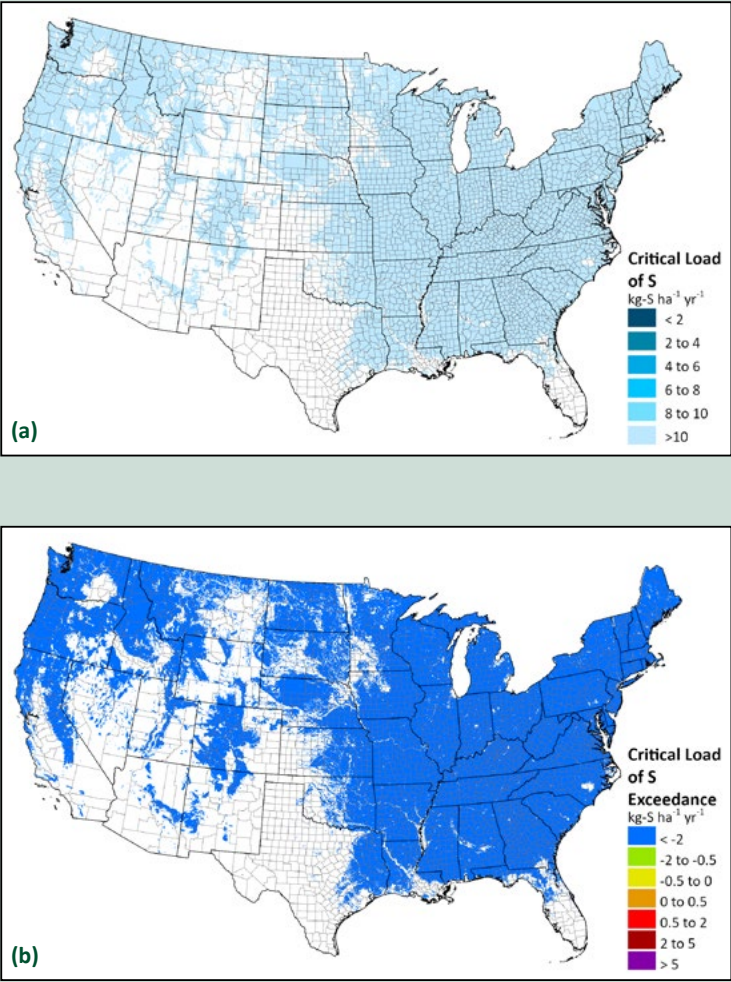


Figure 39.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Juncus effusus* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

40.0 *Koeleria macrantha* (prairie junegrass)

Distribution and Conservation Status

Prairie junegrass is a native perennial grass. The distribution of this circumpolar species ranges from eastern Alaska southeast through the continental United States, excluding the southernmost southeastern States. It is critically imperiled in Louisiana and Kentucky, imperiled in Arkansas and Ohio, and vulnerable in Indiana (fig. 40.1).

Species Characteristics and Habitat

Prairie junegrass is a cool season, tufted bunchgrass, up to 2 feet tall. It forms clusters of slender, distinctly veined, light green to bluish green leaves reaching about 7 inches tall. The leaves are flat to in-rolled with somewhat rough edges and pointed tips. Prairie junegrass flowers in April to June and the seeds mature in July or August. The glumes are sharp and shiny. The seed heads are upright and appear as dense, pale green to purplish spikes, tapering at both ends, no more than ½-foot long. The seeds often grow well above the foliage.

It is found on rangelands, plains, open forestlands, and mountain foothills where it is adapted to a wide variety of climates and soils. It usually grows on rocky to sandy loam soils of low fertility but can also grow on clay soils with adequate drainage; it prefers soil pH levels between 6.0 and 8.0. Depending on the seed source, it can tolerate cold, heat, drought, serpentine soil and fire, although it does not tolerate high soil salinity. As a result of its small stature, prairie junegrass is very resistant to fire and thus will often increase in cover after a fire or other disturbance. Occasionally, it is the target of striped flea beetles, rusts, leaf spots or blights.

Wildlife and Livestock Uses

Prairie junegrass provides good forage for deer, antelope, elk, and livestock. In rocky soils at high elevation, it may be grazed by bighorn sheep and mountain goats. It also provides food for upland game birds, small mammals, and numerous grasshoppers and leafhoppers.

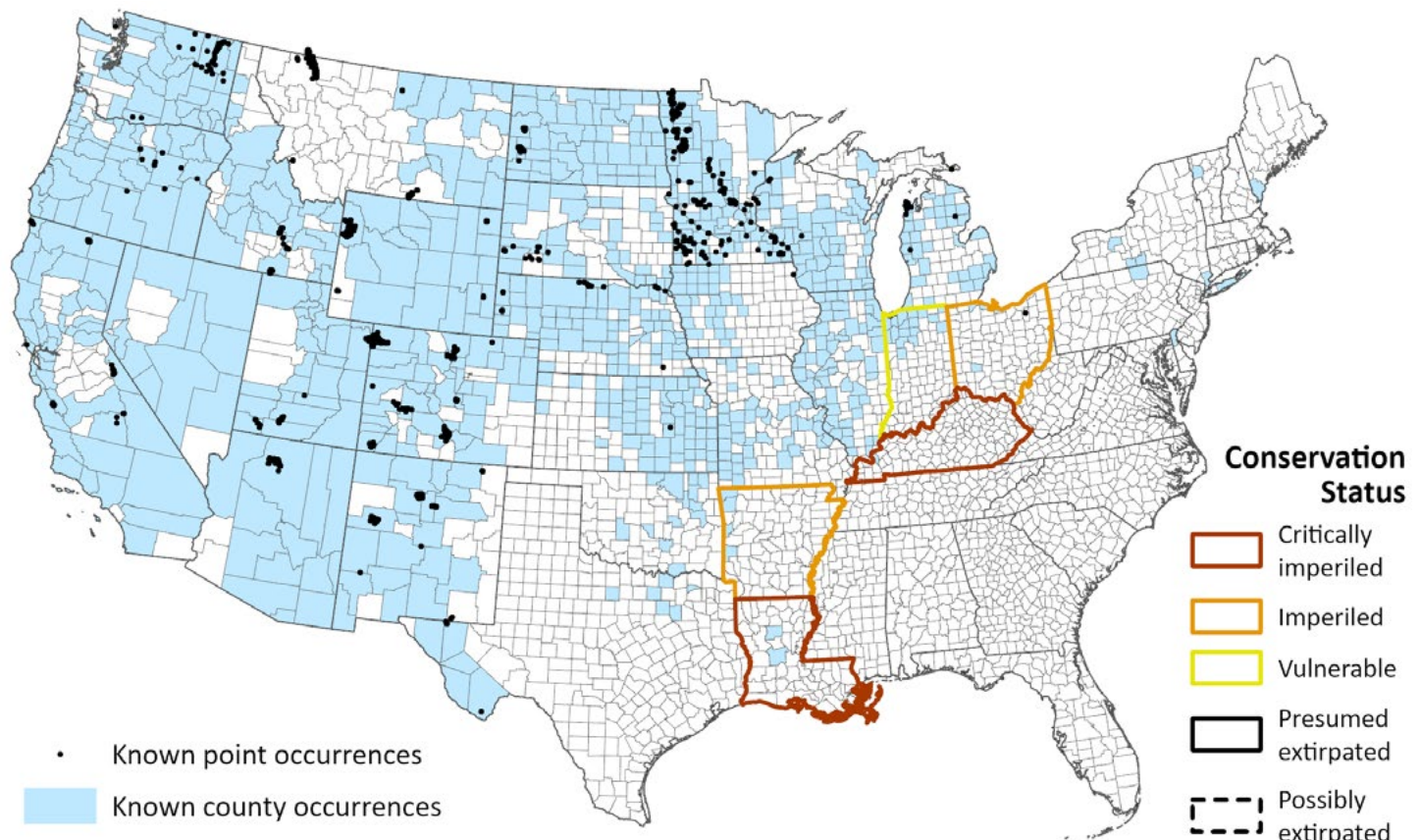


Figure 40.1. Distribution and state-level conservation status of *Koeleria macrantha*. Known point occurrences were used to assess species deposition responses and critical loads.

Ecosystem Services

Prairie junegrass is useful in seed mixes for restoration of several habitats across much of North America. It is useful for revegetation and erosion control on disturbed sites due to its ability to tolerate droughts and its fibrous roots. Prairie junegrass may also be cultivated for forage, as low input turfgrass, or as an ornamental grass.

Traditional Ecological Knowledge

Prairie junegrass seeds can be collected to make flour for bread, while the leaves may be used to shape paint brushes and brooms.



Close up of prairie junegrass.
Dave Powell, USDA Forest Service (retired), Bugwood.org.

Responses to Nitrogen and Sulfur

The probability of occurrence for prairie junegrass depends mostly on N deposition (fig. 40.2a), increasing up to roughly 9.3 kg N/ha/yr and decreasing with N deposition above that. There is a weak interaction with soil pH that does not have a large effect on the estimated critical load (fig. 40.2b) (Clark et al. 2019). Prairie junegrass has a flat or increasing relationship with S which was likely an artifact of correlated variables (fig. 40.2c). Of the variables tested, the only significant climate variable is precipitation (fig. 40.2d). The probability of occurrence decreases with increasing precipitation within the species’ sampled range. Confidence in the N and S relationships is moderate-to-high, with good model performance ($R^2 = 0.127$, $AUC = 0.74$; both moderate confidence), low VIFs (VIF-N = 1.5, VIF-S = 1.8); both high confidence), and a moderate N-S correlation ($r=0.69$, moderate confidence).



Flowers of prairie junegrass.
Dave Powell, USDA Forest Service (retired), Bugwood.org.

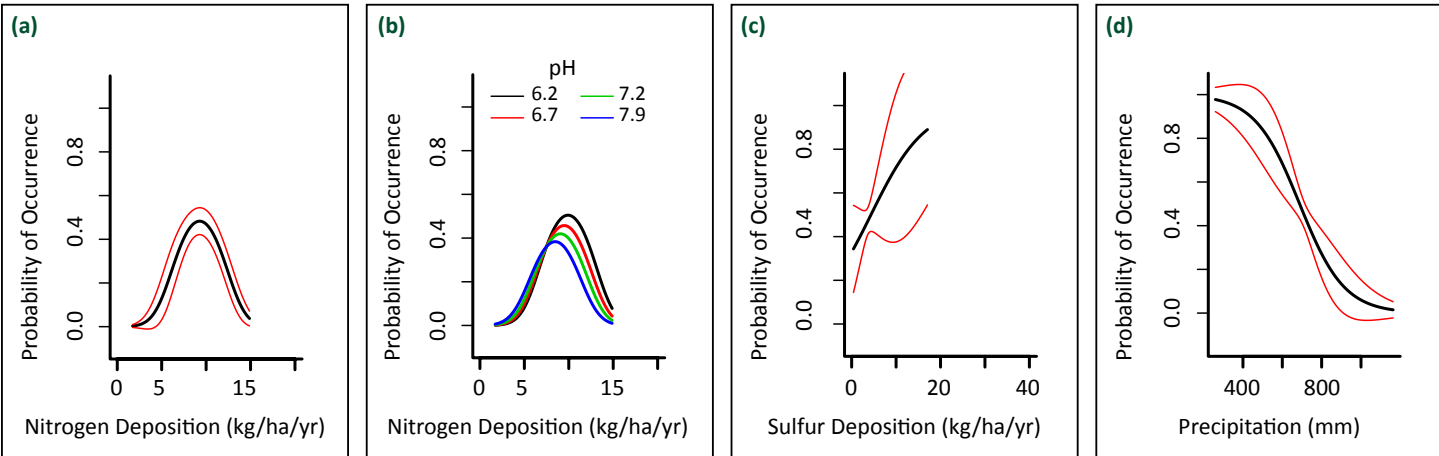


Figure 40.2. Effects of various environmental variables on the probability of occurrence of *Koeleria macrantha*: a) N deposition, b) N x pH interaction, c) S deposition, d) precipitation.

Critical Loads and Exceedances

The environmental hull for prairie junegrass covers the western United States outside of the Desert Southwest and the west coast. The N CL is 8 to 10 kg N/ha/yr across most of the West with a few areas of 6 to 8 kg N/ha/yr

and areas ≥ 10 kg N/ha/yr on the eastern edges of the range. The N CL is in exceedance based on 2019–2021 total N deposition across the Midwest. The S CL is 17.1 kg S/ha/yr across the whole range. There are no exceedances of the S CL based on 2019–2021 TDep total S deposition.

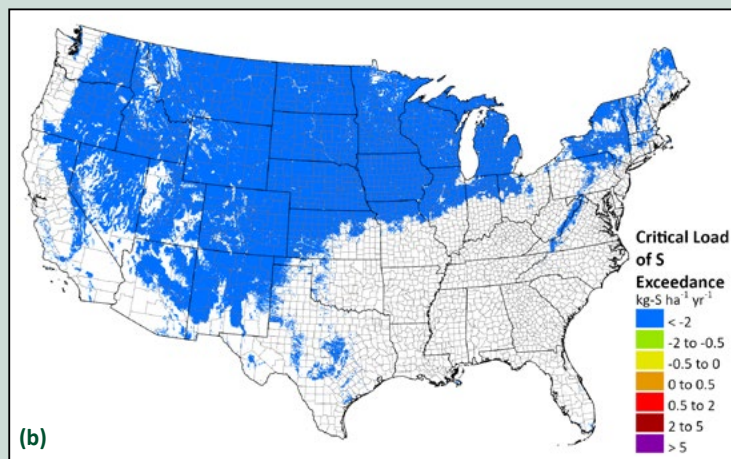
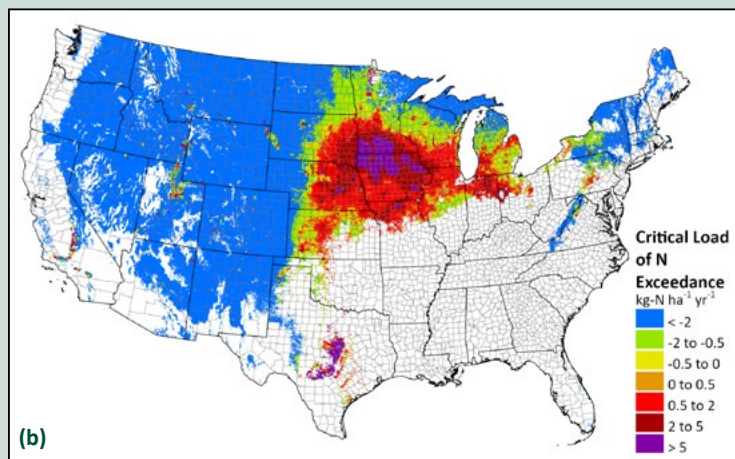
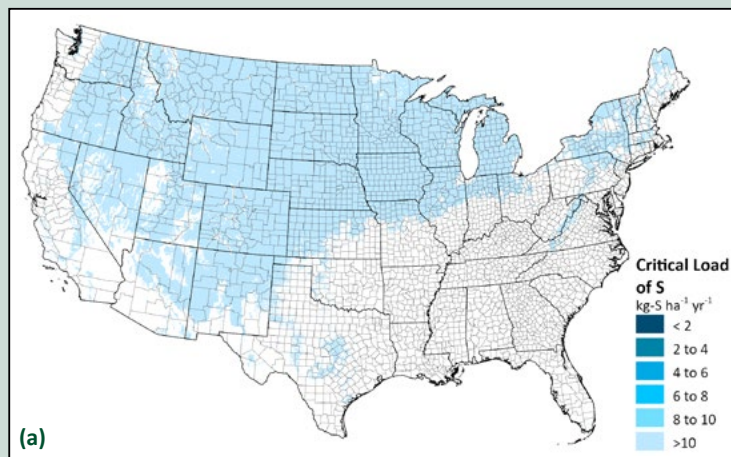
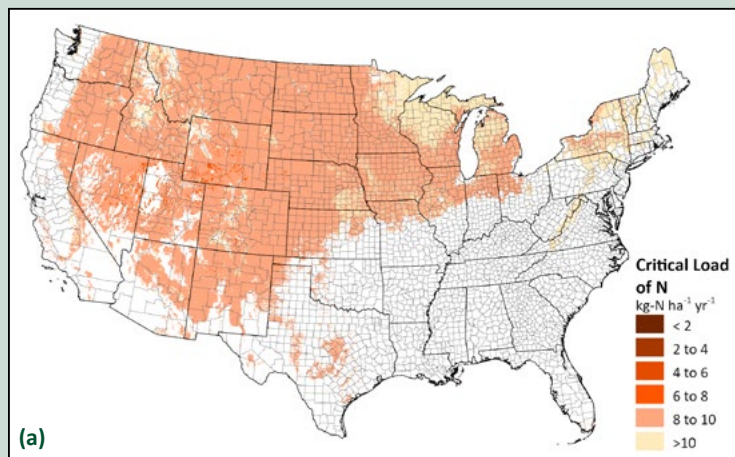


Figure 40.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Koeleria macrantha* and (b) the exceedance of N critical loads based on TDep 2019–2021 total N deposition.

Figure 40.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Koeleria macrantha* and (b) the exceedance of S critical loads based on TDep 2019–2021 total S deposition.

41.0 *Leersia oryzoides* (rice cutgrass)

Distribution and Conservation Status

Rice cutgrass is a native perennial grass that occurs in all U.S. states except Alaska and Hawaii. It is imperiled in Utah and Wyoming and vulnerable in Montana and Indiana (fig. 41.1).

Species Characteristics and Habitat

It is a cool season grass that grows and flowers comparatively late in summer. The upright to sprawling stems have smooth joints and grow up to 5 feet tall. Rice cutgrass spreads by scaly, underground rhizomes and often forms dense colonies. The leaf blades are up to 12 inches long and are yellow green. The upper surface of the leaf is rough and lined with tiny teeth along the borders. Small spikes hang in a single row creating a 1-sided appearance to each panicle branch. Rice cutgrass can be easily recognized by carefully running a hand through it. It feels coarse and sandpaper-like, and the sharp leaves can

cut flesh and tear weak clothing. The flowerhead is open, frequently drooping, reaching up to 8 inches long. Some panicles remain enclosed within the lower leaf sheaths and release seeds as the stem decays. The rice-like seeds develop in late August through early October. The seed coat is covered with miniature bristles that aid dispersal by clinging to clothing or fur.

Rice cutgrass grows in wet, sunny, and partially shaded habitats. However, it is most common near streams, ponds, or beaver areas, and in ditches, canals, or freshwater marshes. Rice cutgrass can tolerate highly acidic conditions with soils composed of sands, silts, loams, or clays and pH levels of 3. Seedlings usually cannot survive inundation for more than 2 to 3 days, while mature plants easily endure seasonal to permanent flooding. Stand maintenance or proliferation requires sufficiently fertile soil, regular flooding, and soil disturbance every two to three years to maintain open areas.

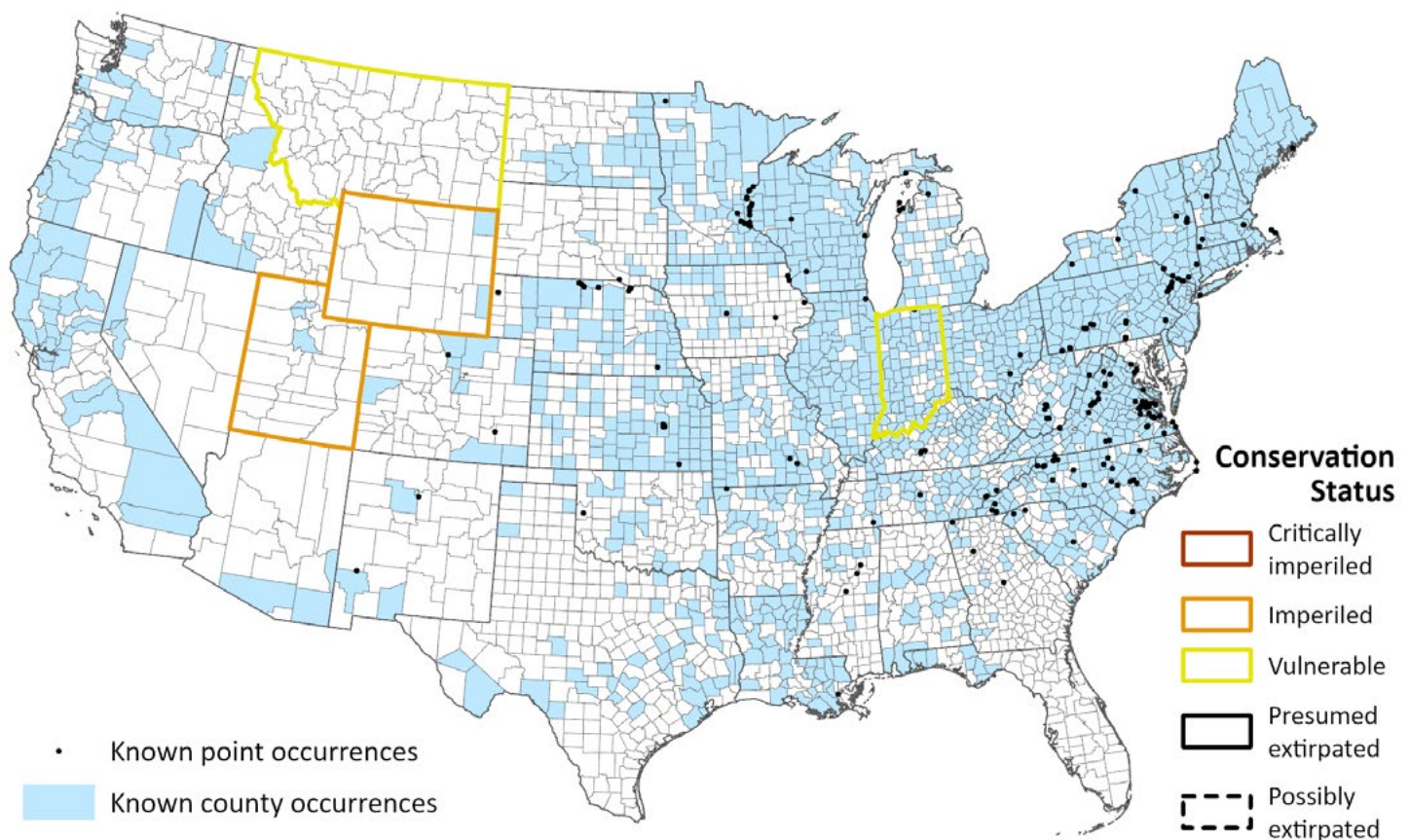


Figure 41.1. Distribution and state-level conservation status of *Leersia oryzoides*. Known point occurrences were used to assess species deposition responses and critical loads.

Wildlife Uses

The seeds of rice cutgrass provide an essential food source for waterfowl, small mammals, and shorebirds. The stems are uprooted and consumed by ducks. Dense plant growth offers cover and habitat for fish, reptiles, and amphibians. The forage produced is highly palatable.



Plant with flowers of rice cutgrass.
Robert Vidéki, Doronicum Kft. Bugwood.org.

Ecosystem Services

Rice cutgrass is useful for improving wildlife habitat, restoring wetlands, and mitigating erosion in ditches and other waterways. The extensive rhizomes and spreading habit of rice cutgrass provide excellent sediment stabilization along the immediate shorelines of streams and lakes.

Responses to Nitrogen and Sulfur

The probability of occurrence for rice cutgrass is somewhat dependent on the interactive effect of N and S deposition (fig. 41.2a). At high S deposition (≥ 12.0 kg S/ha/yr), rice cutgrass increases with N deposition up to 15 kg N/ha/yr and then decreases with higher N deposition. At lower S deposition (≤ 10.3 kg S/ha/yr), the probability of occurrence for rice cutgrass increases with N deposition. The climate effects are shown in Figure 41.2b (precipitation) and Figure 41.2c (temperature). The probability of occurrence is largely unresponsive to precipitation and increases weakly with increasing temperatures (but note widening confidence bands) within the species' sampled range. Confidence in the N and S relationships is moderate-to-high, with good model performance ($R^2 = 0.245$, $AUC = 0.86$; moderate and high confidence, respectively), low VIFs ($VIF-N = 1.1$, $VIF-S = 1.1$; both high confidence), and a moderate N-S correlation ($r=0.55$, moderate confidence).

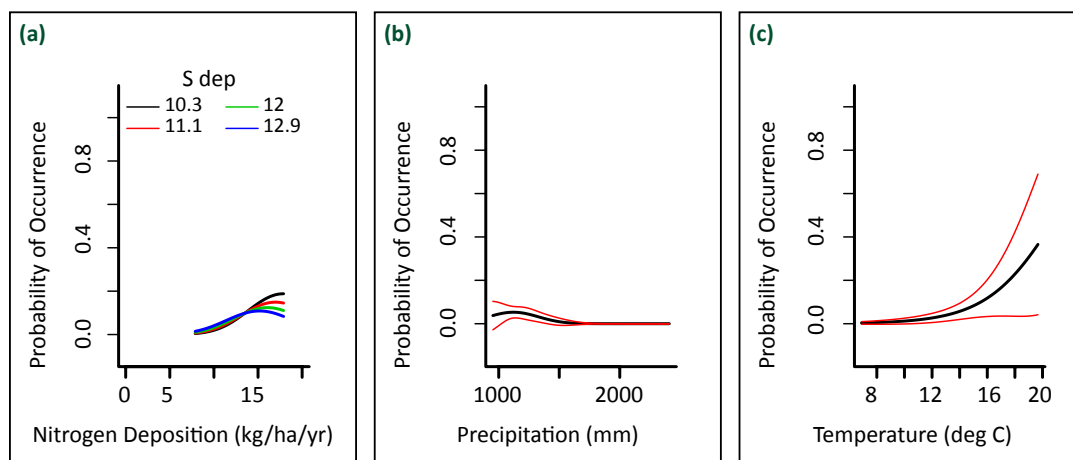


Figure 41.2. Effects of various environmental variables on the probability of occurrence of *Leersia oryzoides*:
a) N x S interaction, b) precipitation, c) temperature.

Critical Loads and Exceedances

The environmental hull for rice cutgrass covers the eastern United States and mountainous areas of the West. The N CL is ≥ 10 kg N/ha/yr across most of the range with an area in West Virginia, Ohio, and Pennsylvania that has values between 2 and 10 kg N/ha/yr. The N CL is in exceedance based on 2019–2021 total N deposition in the lower deposition areas and into southern Indiana. The S CL is 27.5 kg S/ha/yr across most of the range and 5.9 kg S/ha/yr in areas across the Midwest and east coast. There are no exceedances of the S CL based on 2019–2021 TDep total S deposition.



Flowers of rice cutgrass.
Robert Vidéki, Doronicum
Kft. Bugwood.org.

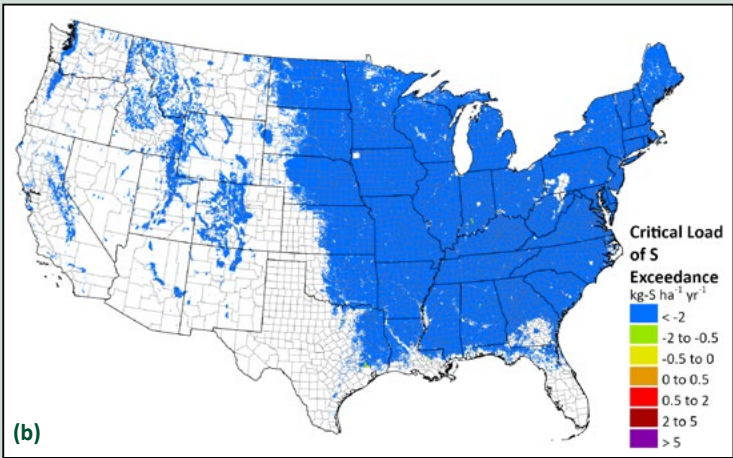
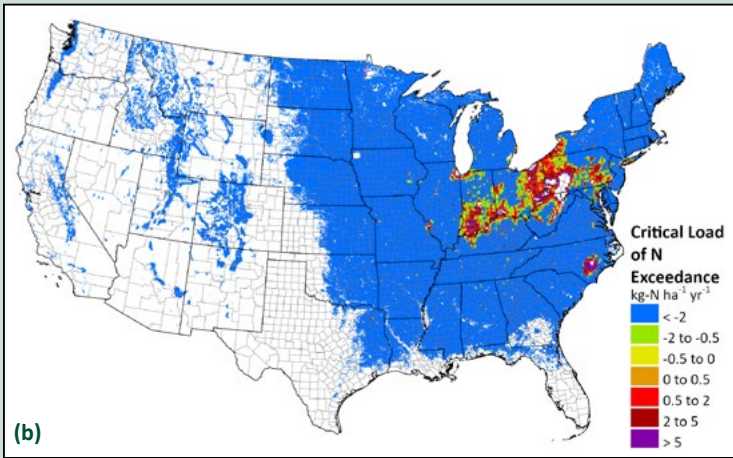
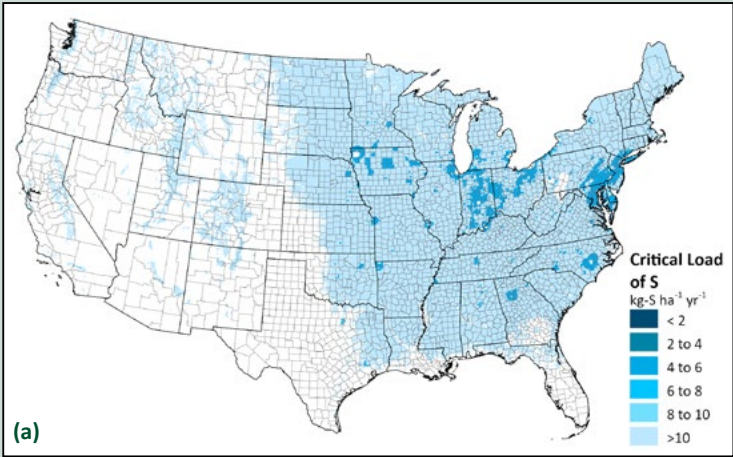
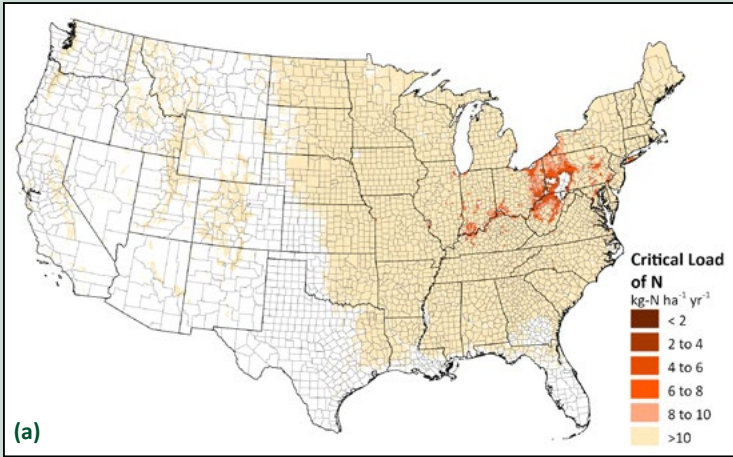


Figure 41.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Leersia oryzoides* and (b) the exceedance of N critical loads based on TDep 2019–2021 total N deposition.

Figure 41.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Leersia oryzoides* and (b) the exceedance of S critical loads based on TDep 2019–2021 total S deposition.

42.0 *Liatris pycnostachya* (prairie blazing star)

Distribution and Conservation Status

Prairie blazing star is a native perennial forb of the central and northeastern portions of the United States. It is critically imperiled in South Dakota and Kansas (fig. 42.1).

Species Characteristics and Habitat

Prairie blazing star is resilient, regrowing each year from underground rhizomes to form conspicuously tall, leafy stems up to 5 feet in height. The leaves are narrow, alternately arranged, and dark green with a light-colored mid-rib. The lowest leaves on the stems grow up to 4 inches long, decreasing in length with stem height; both the leaves and stems have short, stiff hairs. Prairie blazing star blooms in late summer and autumn. The inflorescence is a pink to purple spike with thistle-like flowers that appear fuzzy because of their extended white stamens and pistils. Flowers open first at the top of the

spike and blooming continues in a downwards direction. Each flower head along the spike consists of 5 to 12 tubular florets surrounded by a compact group of small, modified leaves along the base.

Prairie blazing star can survive in infertile soils but grows best in rich, fertile soils. A component of the tallgrass prairie biome, it can grow in thick stands on damp prairies. Multiple stems can propagate from a single bulb, forming an extensive unit of rhizomes. Prairie blazing star also grows from seeds. The flowers are cross pollinated by bumble bees and other native pollinators.

Wildlife Uses

Birds across the country enjoy consuming the seeds of prairie blazing star. Rodents and other small mammals prefer to eat the rhizomes.

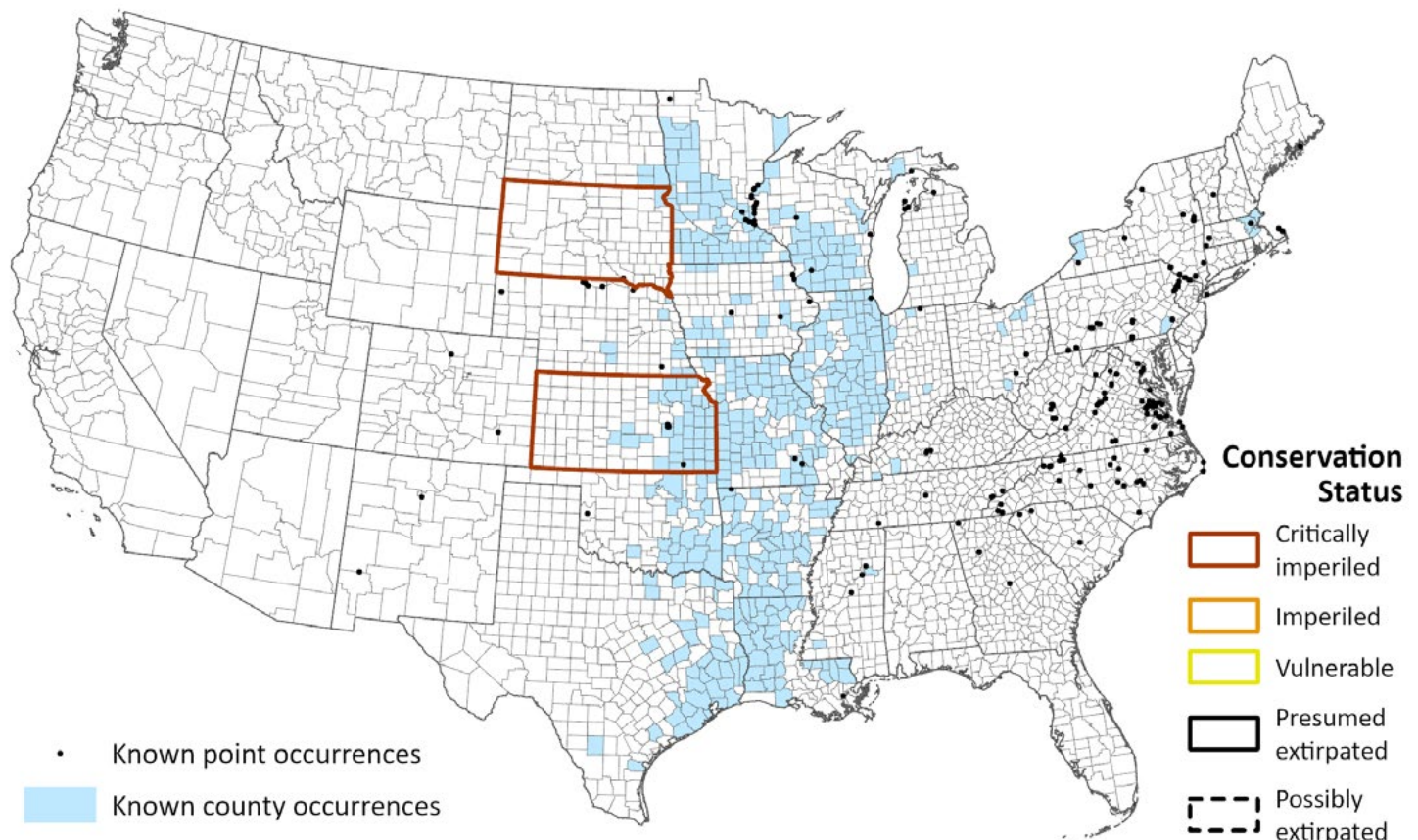


Figure 42.1. Distribution and state-level conservation status of *Liatris pycnostachya*. Known point occurrences were used to assess species deposition responses and critical loads.

Ecosystem Services

Prairie blazing star is often utilized for prairie restoration and landscaping, roadside maintenance, wildlife food and habitat, maintaining wildflower gardens, and as a minor component in seeding mixtures.

Traditional Ecological Knowledge

The rhizomes of prairie blazing star have been used to treat gonorrhea.



Plant with flowers of prairie blazing star.
William M. Ciesla, Forest Health Management International, Bugwood.org.

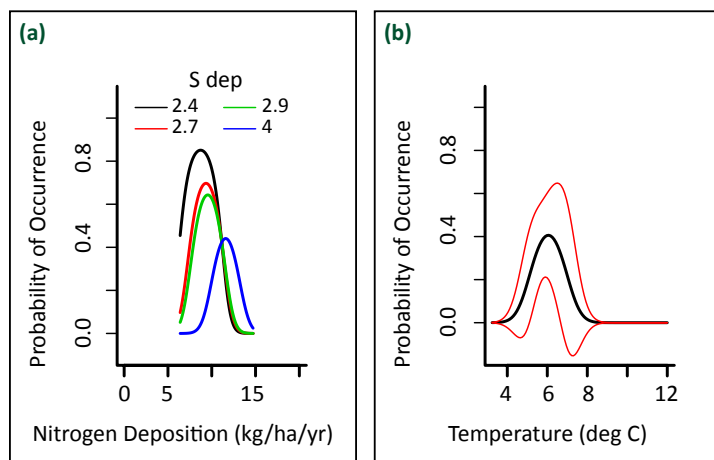


Figure 42.2. Effects of various environmental variables on the probability of occurrence of *Liatris pycnostachya*: a) N x S interaction, b) temperature.

Responses to Nitrogen and Sulfur

The probability of occurrence for prairie blazing star is dependent on the interactive effect of N and S deposition (fig. 42.2a). At lower S deposition (≤ 2.9 kg S/ha/yr), the probability of occurrence increases up to roughly 9-10 kg N/ha/yr and then decreases with higher N deposition. At higher levels of S deposition (≥ 4 kg S/ha/yr) prairie blazing star is less responsive to N deposition, though it still increases and decreases. Of the variables tested, the only significant climate variable is temperature (fig. 42.2b). The probability of occurrence peaks narrowly at temperatures around 6 °C within the species' sampled range. Confidence in the N and S relationship is moderate-to high, with very good model performance ($R^2 = 0.286$, AUC = 0.84; both high confidence), mixed VIFs (VIF-N = 1.9, VIF-S = 3.3; high and moderate confidence, respectively) and a moderate N-S correlation ($r=0.68$, moderate confidence).



Fruits of prairie blazing star.
Peter Dziuk, Minnesota Department of Agriculture, Bugwood.org.

Critical Loads and Exceedances

The environmental hull for prairie blazing star covers the northern Midwest and most of the West excluding coastal areas and the desert Southwest. The N CL is between 4 and 10 kg N/ha/yr across the West and 8 to ≥ 10 kg N/ha/yr in the Midwest. The N CL is in exceedance based on 2019–2021 total N deposition in spotted areas of the West

and in the highest deposition areas of the Midwest. The S CL is 2.2 kg S/ha/yr across most of the range and 13.3 kg S/ha/yr in the eastern part of its range. There are a few areas with an exceedance of the S CL based on 2019–2021 TDep total S deposition in North Dakota associated with oil and gas operations.

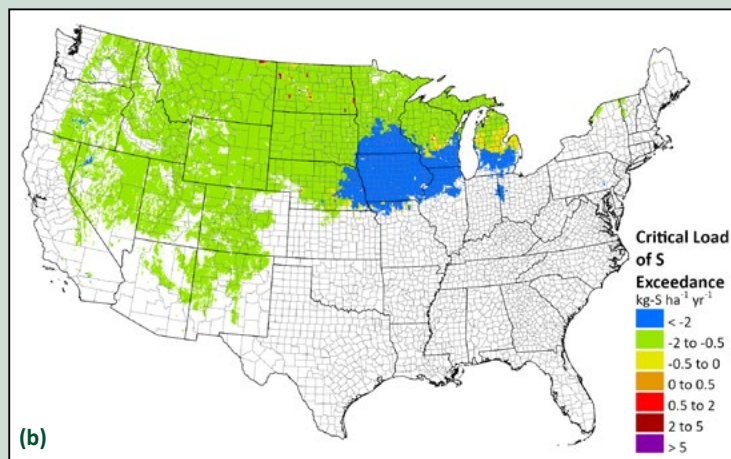
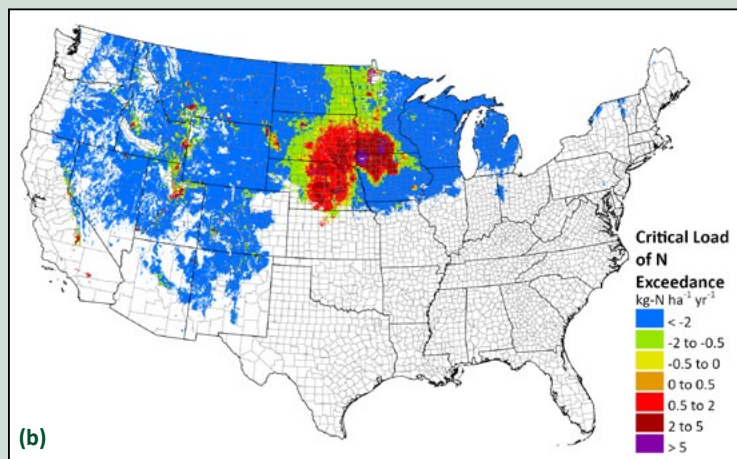
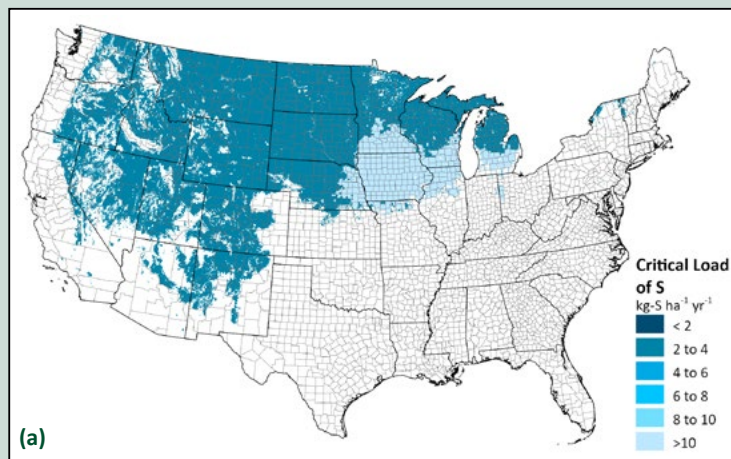
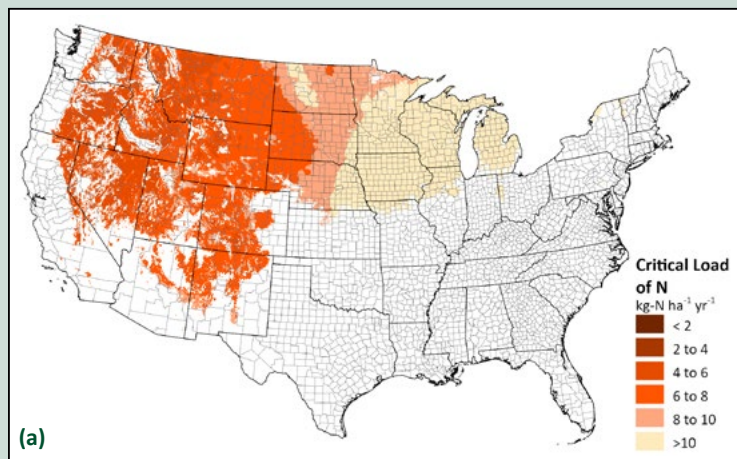


Figure 42.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Liatris pycnostachya* and (b) the exceedance of N critical loads based on TDep 2019–2021 total N deposition.

Figure 42.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Liatris pycnostachya* and (b) the exceedance of S critical loads based on TDep 2019–2021 total S deposition.

43.0 *Maianthemum canadense* (Canada mayflower)

Distribution and Conservation Status

Canada mayflower is a native perennial forb of bog forests, ecotonal swamp forests, and upland fens. It is found in the United States from Montana and Wyoming to the Atlantic Coast and south through the Appalachian Mountains into Tennessee. It is critically imperiled in Indiana, imperiled in Kentucky, and vulnerable in Iowa (fig. 43.1).

Species Characteristics and Habitat

Canada mayflower grows 3 to 8 inches tall. The leaves remain green through winter, and new leaves grow after flowering, which occurs from May through June or July. The inflorescence is a raceme with up to three leaves and 10 to 40 flowers. The berries mature within 30 days and have one to four seeds.

Canada mayflower is highly tolerant of shade and occurs in a wide range of sunlight levels. It prefers moist sites but can occur on well-drained to saturated sites; it also prefers acidic soils. It grows best in maritime to continental climates and has north to south transitions from boreal

to temperate ecoregions. Seed dispersal is dependent on insect pollinators such as bees, bee flies, and syrphids, which explains its spotty local distributions. Canada mayflower also reproduces vegetatively, forming broad patches of shoots; a single clone can stretch upwards of 20 feet in diameter. Canada mayflower is known to increase in population after fires because its meristems are low to the ground in the damp litter. The rhizomes can tolerate brief exposures to high temperatures, however fire top-kills the above ground parts.

Traditional Ecological Knowledge

A compound decoction of the roots may be used to treat kidney illnesses and to improve sore throats; an infusion of the plant can also be taken to cure headache.

Responses to Nitrogen and Sulfur

The probability of occurrence for Canada mayflower depends on many variables. The effect of N deposition depends on both S deposition (fig. 43.2a) and soil pH (fig. 43.2b). Under lower S deposition (≤ 6.7 kg S/ha/yr), Canada mayflower increases with N deposition up

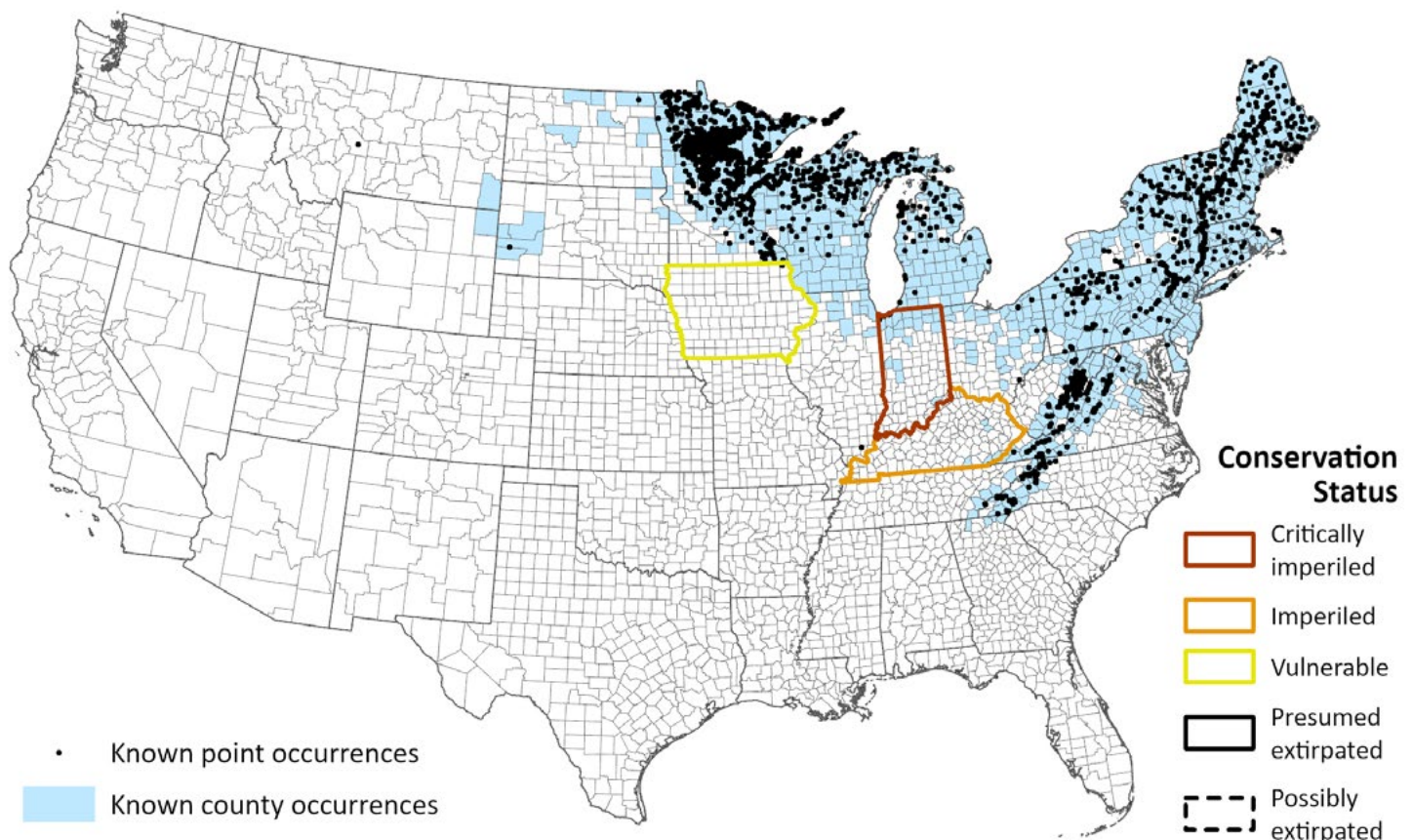


Figure 43.1. Distribution and state-level conservation status of *Maianthemum canadense*. Known point occurrences were used to assess species deposition responses and critical loads.

to approximately 9-10 kg N/ha/yr and then decreases with higher N deposition. At higher S deposition (≥ 11.7 kg S/ha/yr), Canada mayflower is less responsive to N deposition. Canada mayflower is shown to tolerate acidic soil conditions in the Simkin et al. (2016) database, with larger increases from N deposition at lower pH (fig. 43.2b). The effect of S deposition also depends on pH (fig. 43.2c). The probability of occurrence is higher at lower soil pH (≤ 6.2) and decreases more strongly as S deposition increases. The climate effects are shown in Figure 43.2d (precipitation) and Figure 43.2e (temperature). The probability of occurrence peaks broadly at 1500 mm precipitation and decreases with increasing temperatures within the species' sampled range. Confidence in the N and S relationships is moderate, with very good model performance ($R^2 = 0.487$, $AUC = 0.92$; both high confidence), low VIFs ($VIF-N = 1.3$, $VIF-S = 1.2$), and a high N-S correlation ($r=0.79$, low confidence).



Plants with flowers of Canada mayflower in its habitat.
Joy Viola, Northeastern University, Bugwood.org.

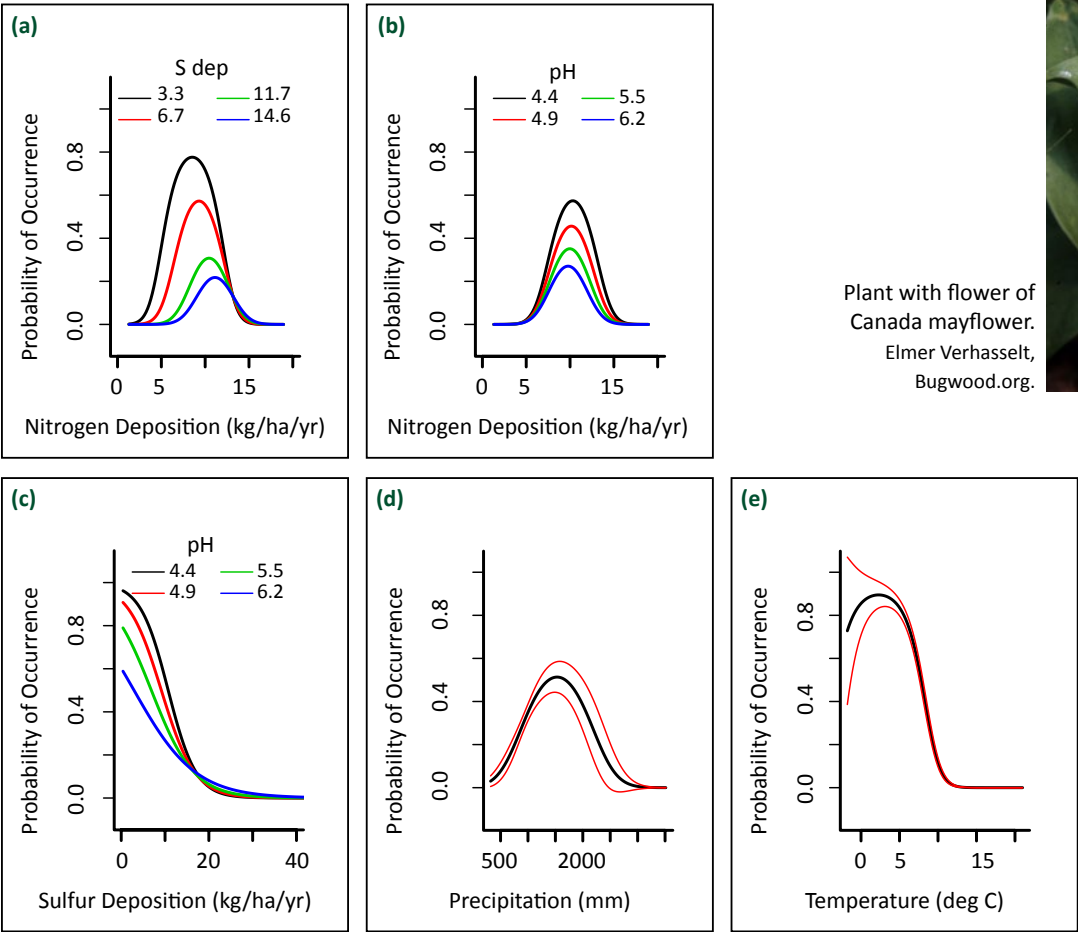


Figure 43.2. Effects of various environmental variables on the probability of occurrence of *Maianthemum canadense*: a) N x S interaction, b) N x pH interaction, c) S x pH, d) precipitation, e) temperature.



Plant with flower of
Canada mayflower.
Elmer Verhasselt,
Bugwood.org.

Critical Loads and Exceedances

The environmental hull for Canada mayflower covers most of the eastern United States and the mountainous areas in the West. The N CL is between 6 and 10 kg N/ha/yr across the West and 8 to ≥ 10 kg N/ha/yr in the East. The N CL is in exceedance based on 2019–2021 total N deposition in higher elevations in the West and in the highest

deposition areas of the Midwest and East associated with agriculture. The S CL is 0.4 kg S/ha/yr across most of the range and 41.7 kg S/ha/yr in the area from Iowa to Ohio. Most of the range has an exceedance of the S CL based on 2019–2021 TDep total S deposition except some of the lower elevations in the West.

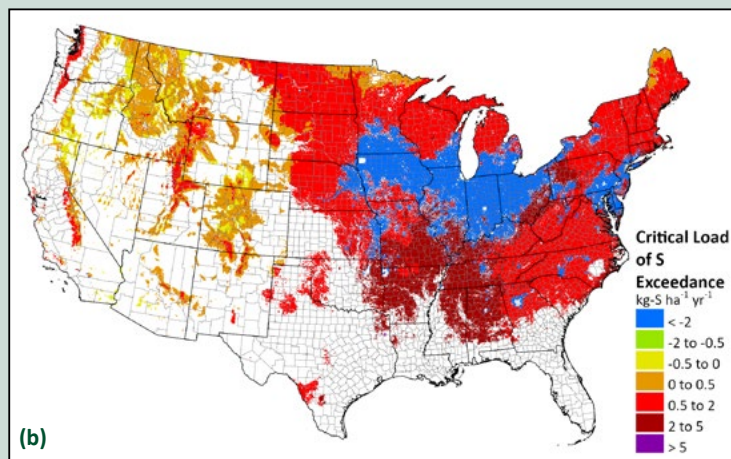
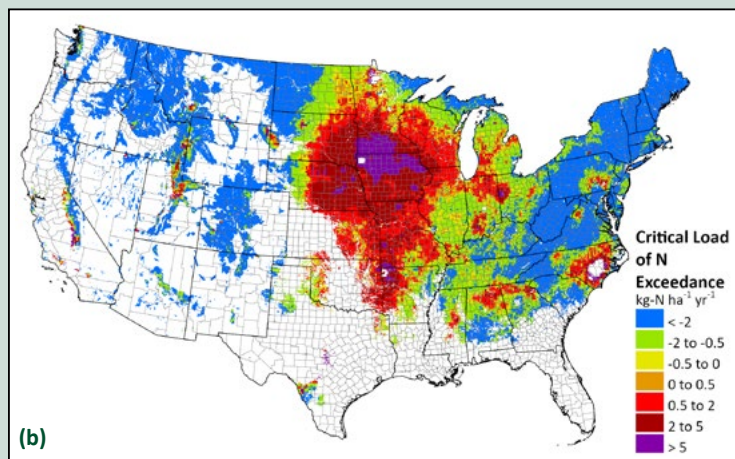
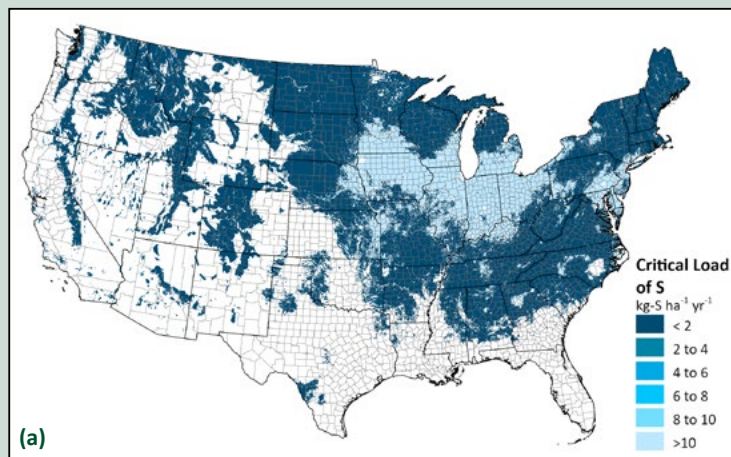
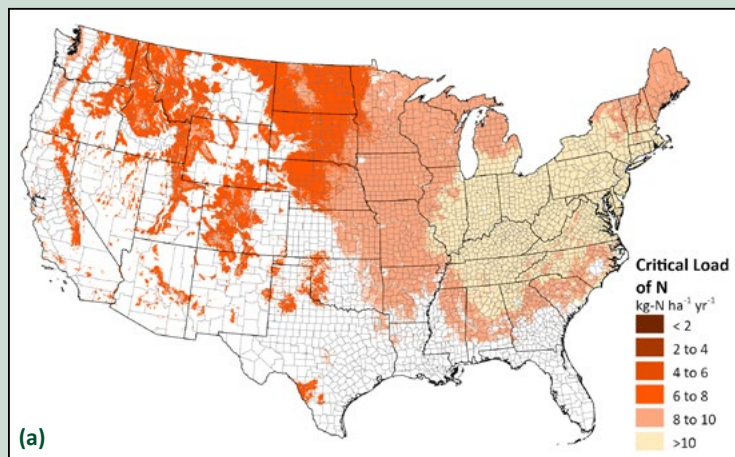


Figure 43.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Maianthemum canadense* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 43.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Maianthemum canadense* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

44.0 *Microstegium vimineum* (Nepalese browntop)

Distribution and Conservation Status

Nepalese browntop is a highly invasive annual grass native to Japan, Korea, China, Malaysia, India, and the Caucasus Mountains. In the United States, it is irregularly distributed throughout most of the East from New York south to Florida and Texas (fig. 44.1). It is a noxious weed that replaces native species in natural habitats.

Species Characteristics and Habitat

Nepalese browntop has aerial culms 3 to 5 feet tall and spreading stolons. The leaves are cauline, with 0.5-inch wide and 3- to 4-inch-long blades. Nepalese browntop blooms between August and September. The inflorescence is a raceme, up to 0.23 inches tall, bearing paired spikelets. The fruit is an ellipsoid caryopsis no more than 0.11 inches long. Compared to its aboveground biomass, the root biomass is relatively small, with 3 to 5 lateral roots per plant.

Nepalese browntop is found in forest edges, wetlands, and disturbed areas such as roadsides, shorelines, floodplains, and wastelands throughout its U.S. distribution. It prefers disturbed soils and can rapidly spread onto undisturbed soils once established nearby. It thrives at low to middle elevations and prefers moist, continental climates. Shade, low elevation, and moist to mesic soils allow successful invasion of Nepalese browntop and it is common on silty to sandy loams and on clays with a pH ranging from 4.8 to 5.8. Wind, water, animals, and humans all disperse Nepalese browntop seed. It had more biomass growth on fertilized plots compared to unfertilized control plots, but seed spikelet production was similar on both plots. Nepalese browntop is most likely killed by late-season fires. It has limited natural predators and pathogens in North America. As a result, Nepalese browntop may change ecosystem function on forest floors and in forest soils by disturbing litter layers, soil composition,

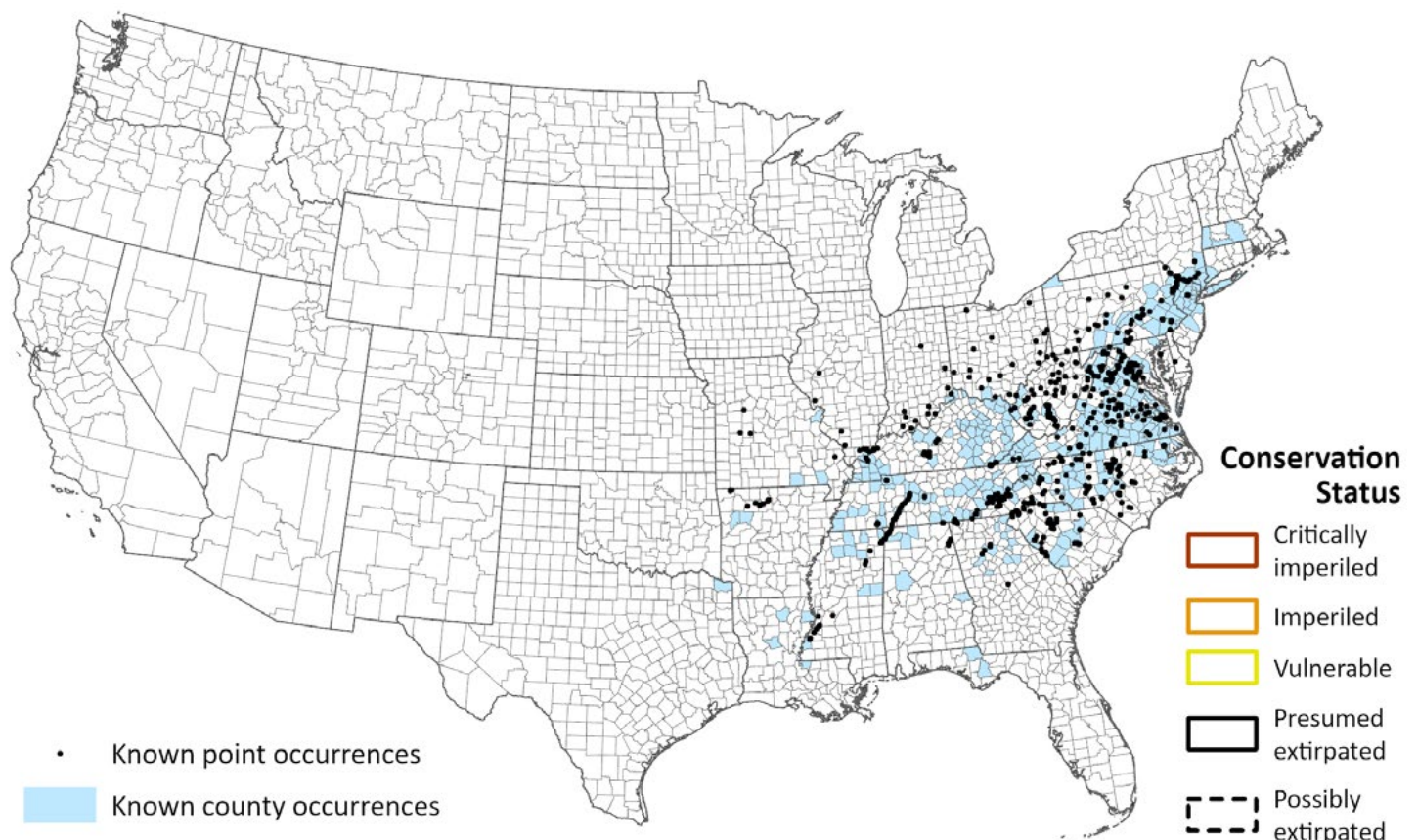


Figure 44.1. Distribution and state-level conservation status of *Microstegium vimineum*. Known point occurrences were used to assess species deposition responses and critical loads.

and species composition of soil microfauna. Locations dominated by Nepalese browntop have decreased nitrogen cycling compared to sites where it was removed.

Wildlife and Livestock Uses

Nepalese browntop is unpalatable to deer and livestock. Consequently, the lack of grazing may indirectly encourage its spreading as grazers avoid it and forage on more palatable species. Domestic goats and horses generally avoid it as well. However, some insects including grasshoppers, katydids, crickets, and bugs obtained a substantial fraction of their diet from Nepalese browntop. Further, it likely provides important cover for white-footed mice.



Infestation of Nepalese browntop.
Chuck Barger, University of Georgia, Bugwood.org.

Traditional Ecological Knowledge

Nepalese browntop has been used as packaging and basket-weaving material, possibly contributing to its spread in the United States.

Responses to Nitrogen and Sulfur

The probability of occurrence for Nepalese browntop is only related to a few variables. It increases with N deposition up to 17.2 kg N/ha/yr (fig. 44.2a) and weakly increases with S deposition (fig. 44.2b). The climate effects are shown in Figure 44.2c (precipitation) and Figure 44.2d (temperature). The probability of occurrence decreases with increasing precipitation and peaks at temperatures around 15 °C within the species’ sampled range. Confidence in the N and S relationships is moderate-to-high, with good model performance ($R^2 = 0.153$, AUC = 0.79; both moderate confidence), low VIFs (VIF-N = 1.1, VIF-S = 1.1; both high confidence), and a moderate N-S correlation ($r=0.57$, moderate confidence).



Leaves and stems of Nepalese browntop.
Chris Evans, University of Illinois, Bugwood.org.

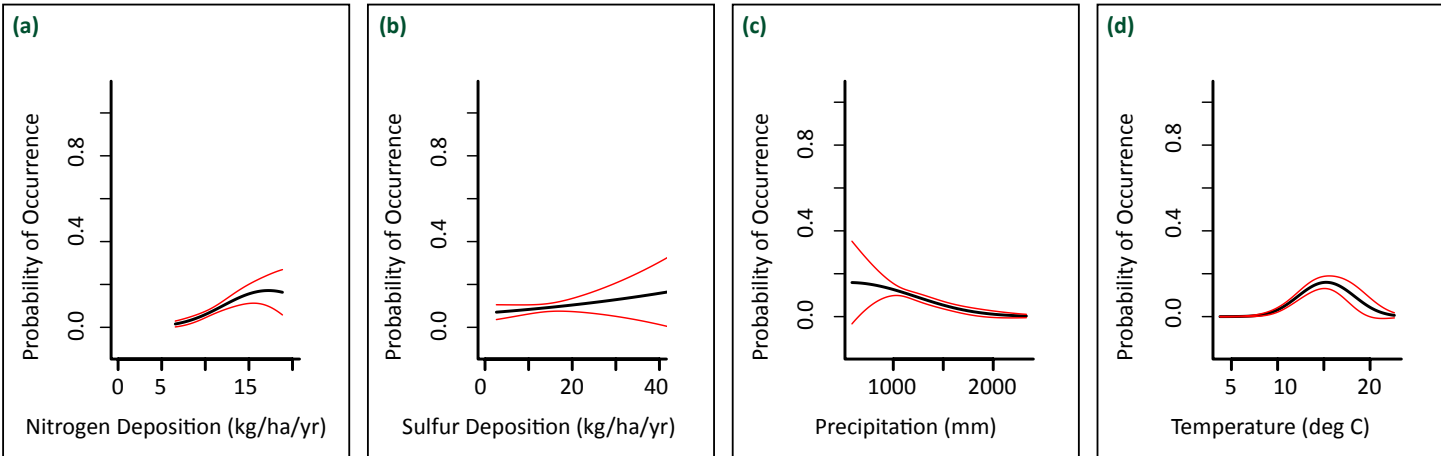


Figure 44.2. Effects of various environmental variables on the probability of occurrence of *Microstegium vimineum*: a) N deposition, b) S deposition, c) precipitation, d) temperature.

Critical Loads and Exceedances

The environmental hull for Nepalese browntop covers most of the eastern United States and the lower elevation mountains in California. The N CL is ≥ 10 kg N/ha/yr across the range. The N CL is in exceedance based on 2019–2021

total N deposition in high agricultural areas of North Carolina. The S CL is 42.5 kg S/ha/yr across the entire species' range. There are no exceedances of the S CL based on 2019–2021 TDep total S deposition.

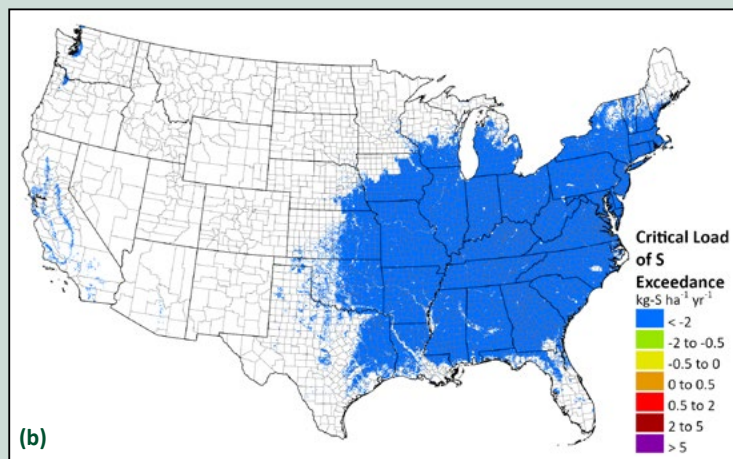
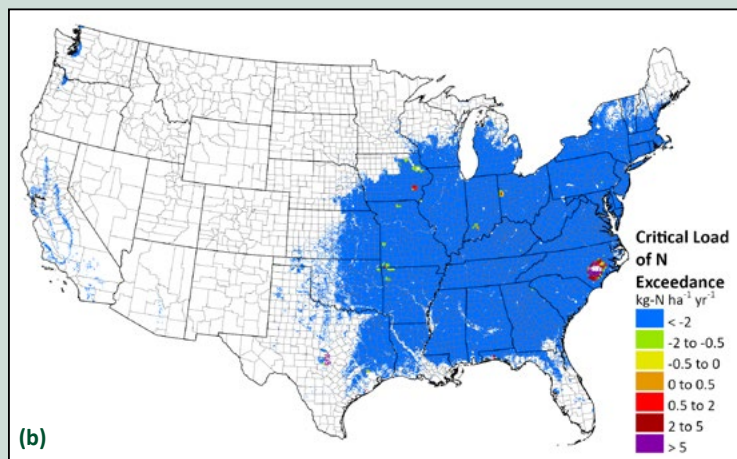
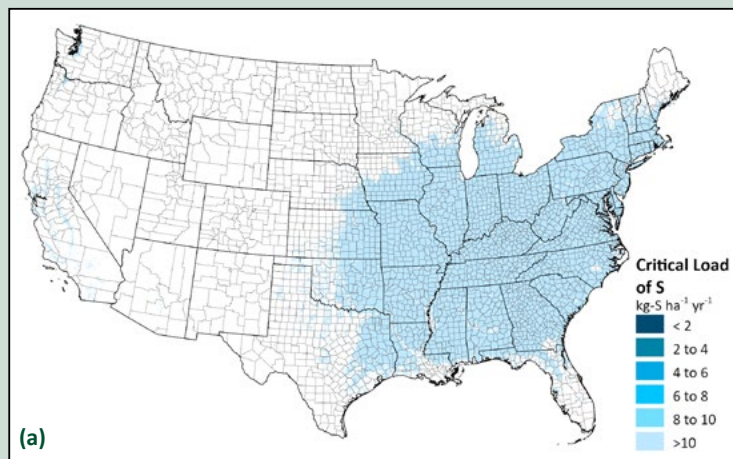
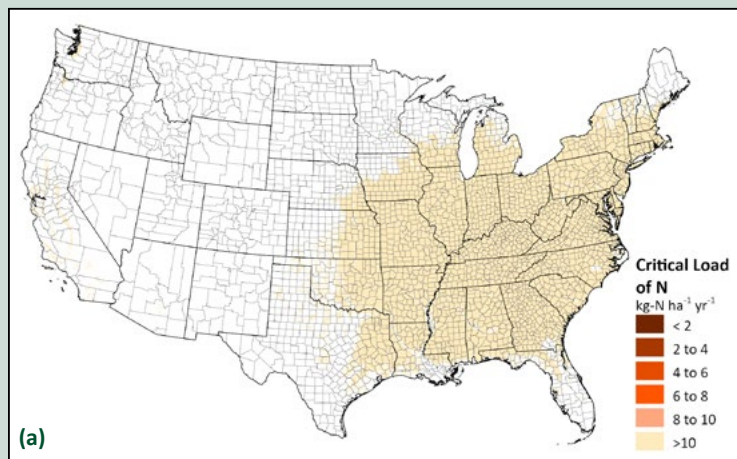


Figure 44.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Microstegium vimineum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 44.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Microstegium vimineum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

45.0 *Muhlenbergia cuspidata* (plains muhly)

Distribution and Conservation Status

Plains muhly is a native perennial grass of North America. Its U.S. distribution encompasses grasslands, shrublands, and woodlands of the northern and central states west to the Rocky Mountains. It is critically imperiled in Indiana, Ohio, and Tennessee, imperiled in Illinois, Kentucky, and Virginia, and vulnerable in Wyoming and Iowa (fig. 45.1).

Species Characteristics and Habitat

Plains muhly is a densely tufted bunchgrass of medium height, it has coarse culms (8 to 20 inches tall and 0.03 to 0.08 inches thick) and a bulbous, thick, scaly base with short, fibrous roots. The leaves are narrow and folded. Plains muhly flowers from June to October across its habitat. The inflorescence is a narrow, uneven, spikelike panicle 2 to 5 inches long. Flower spikelets are 0.09 to 0.11 inches long.

Plains muhly generally establishes on dry, coarse, cobbly, gravely, and sandy soils with dissected topography, and is often observed on eroded soils. It is a warm-season, dry climate grass and as a result is fairly drought tolerant.

Plains muhly is most common on hillslopes, ridges, and other upland sites which are known to experience erosion. Occasionally sites disturbed by erosion or by animals favor plains muhly growth and abundance. Plains muhly dominates plant communities with limited species richness and nutrients. In these situations, it can make up the majority of an ecosystem's biomass. It produces seeds which allows it to reproduce sexually while also propagating vegetatively from lateral tillers. Fire usually kills plains muhly as a result of its moderate size and density. After fire, plains muhly likely sprouts from tillers and re-establishes from seed. Generally, plains muhly populations show little change or increase after a fire.

Wildlife and Livestock Uses

Plains muhly provides seasonal forage for elk, white-tailed deer, mule deer, and livestock. In the fall and winter wild turkeys feed on plains muhly seeds. Several species of insects that are prevalent in tallgrass prairies eat almost exclusively on plains muhly. Ground-nesting birds rely on it for cover.

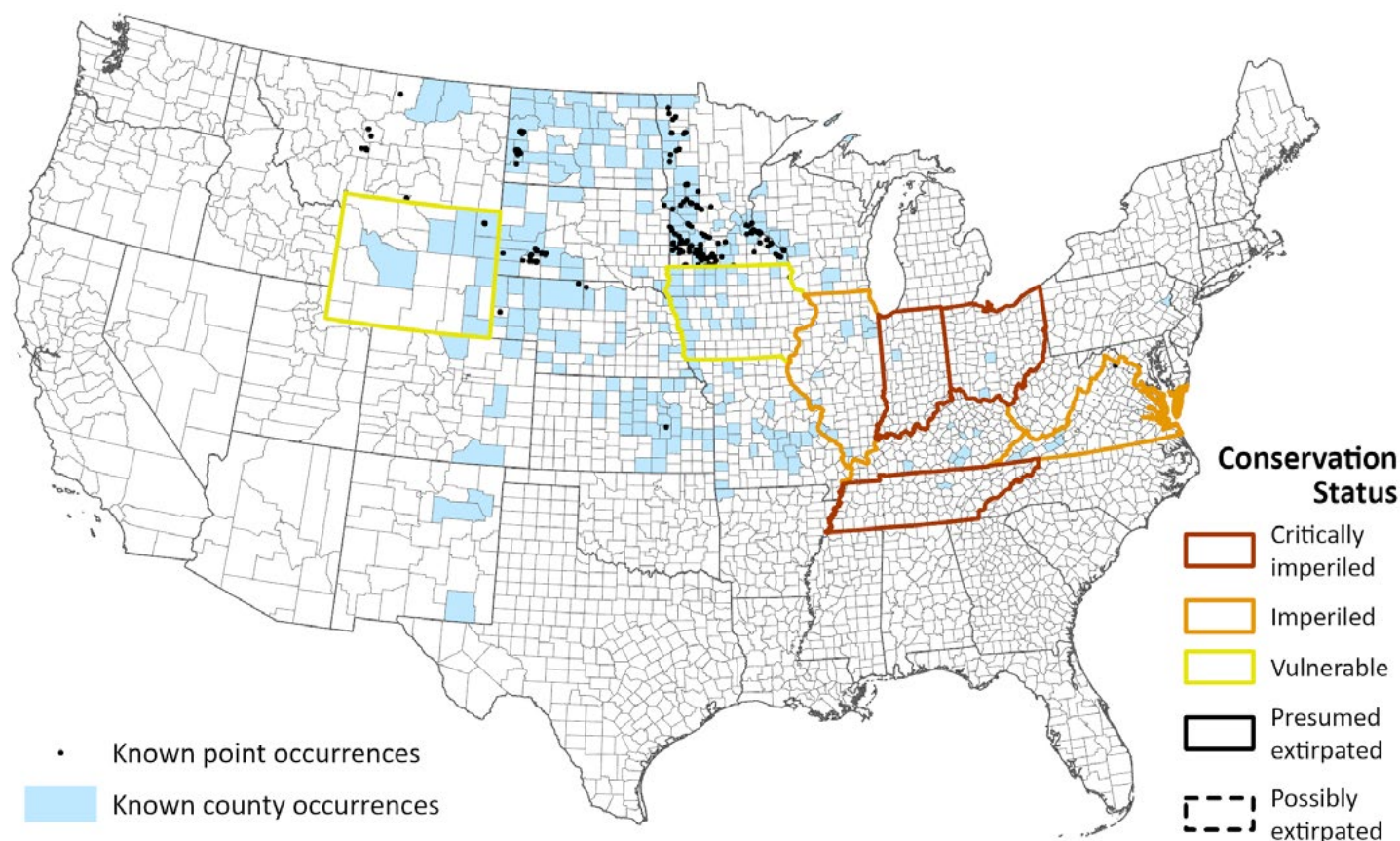


Figure 45.1. Distribution and state-level conservation status of *Muhlenbergia cuspidata*. Known point occurrences were used to assess species deposition responses and critical loads.

Ecosystem Services

The roots of plains muhly stabilize steep, eroded landscapes.

Traditional Ecological Knowledge

The fibrous grasses of plains muhly can be used to create brushes, brooms, and hairbrushes.

Responses to Nitrogen and Sulfur

The probability of occurrence for plains muhly depends on N deposition, with a decreasing association (fig. 45.2a) and is not related to S deposition. The climate effects are shown in Figure 45.2b (precipitation) and Figure 45.2c (temperature). The probability of occurrence peaks broadly at 750 mm precipitation and increases with increasing temperatures within the species' sampled range. Confidence in the N and S relationships

is moderate-to-high, with good model performance ($R^2 = 0.106$, $AUC = 0.71$; both moderate confidence), low VIFs ($VIF-N = 1.9$, $VIF-S = 2.6$; both high confidence), and a moderate N-S correlation ($r=0.61$, moderate confidence).

Critical Loads and Exceedances

The environmental hull for plains muhly covers most of the northern half of the United States. The N CL is 6 to 8 kg N/ha/yr across the species' range. The N CL is in exceedance based on 2019–2021 total N deposition across the Midwest and eastern United States as well as the Salt Lake City air basin. There is no response to S deposition.



Flowers of plains muhly.

Peter Dziuk, <https://www.minnesotawildflowers.info>.



Plant of plains muhly.

Peter Dziuk, <https://www.minnesotawildflowers.info>.

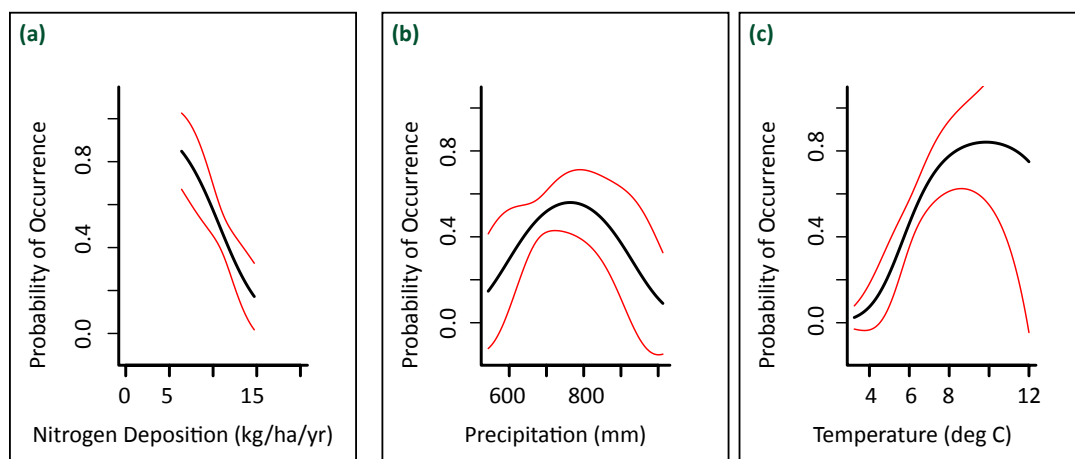


Figure 45.2. Effects of various environmental variables on the probability of occurrence of *Muhlenbergia cuspidata*: a) N deposition, b) precipitation, c) temperature.

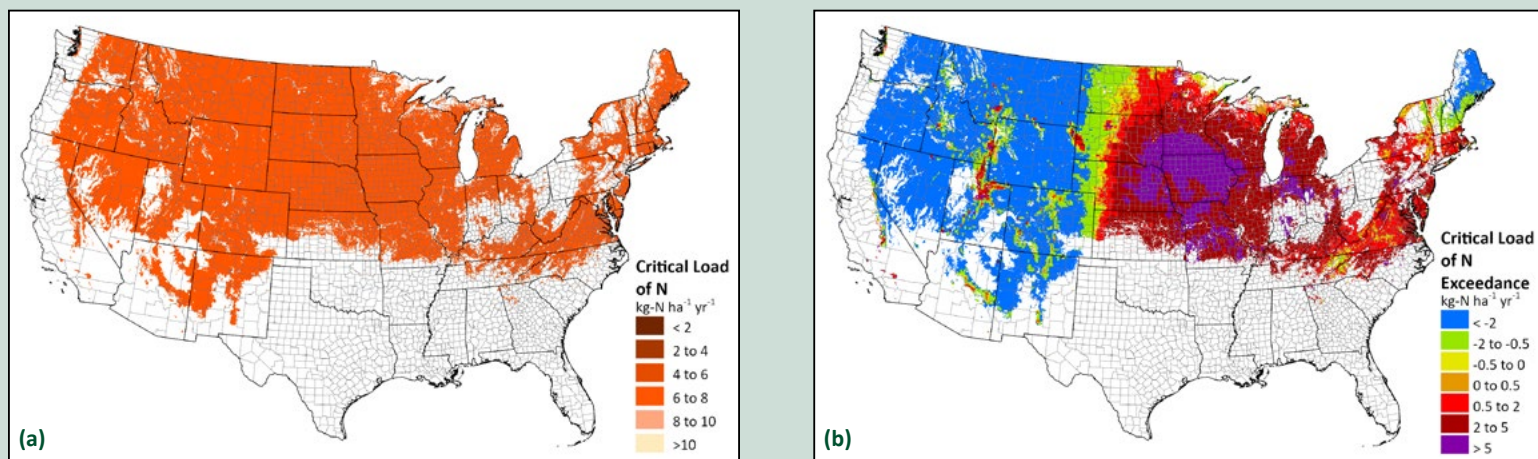


Figure 45.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Muhlenbergia cuspidata* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

46.0 *Muhlenbergia glomerata* (spiked muhly)

Distribution and Conservation Status

Spiked muhly is a native perennial grass common in and native to the northeastern United States and also found across the northern 2/3 of the continental United States. It is critically imperiled in Idaho and North Carolina, imperiled in Washington, Wyoming, Nebraska, Illinois, and New Jersey, and vulnerable in Iowa (fig. 46.1).

Species Characteristics and Habitat

Spiked muhly is a warm-season plant with slim, upright culms reaching up to 50 inches tall with some upright branches at the base. Its many rhizomes are described as scaly, abundant, and slender to stout. The leaf blades are flat, up to 6 inches long, and 0.23 inches wide. Its flowering period ranges from the end of July to October. The inflorescence is a narrow, compact panicle, and is 6 inches long. The fruit of spiked muhly is a caryopsis.

Spiked muhly prefers moist to wet, open ground on sites that are seasonally flooded. It grows best in soils with high organic matter content in the surface layers and thus is most commonly found in open marshes, gravelly shores, peaty meadows, moist ditches, sphagnum bogs, alkaline fens, swamps, shorelines, streambanks, hot springs, and wet deciduous woods. It occasionally grows in relatively dry sites such as upland forests. Spiked muhly is known to grow in partial shade to full sun. In some locations, it occurs in communities that may be influenced by periodic fire although it usually prefers relatively undisturbed sites. In the absence of occasional fire, shrub density increases and herbaceous cover decreases. Spiked muhly regenerates by rhizomes and by seeds. It is likely to survive and sprout from extensive underground rhizomes following low-severity fire, depending on how deep the rhizomes are located in the soil. As it typically occurs in open plant communities and

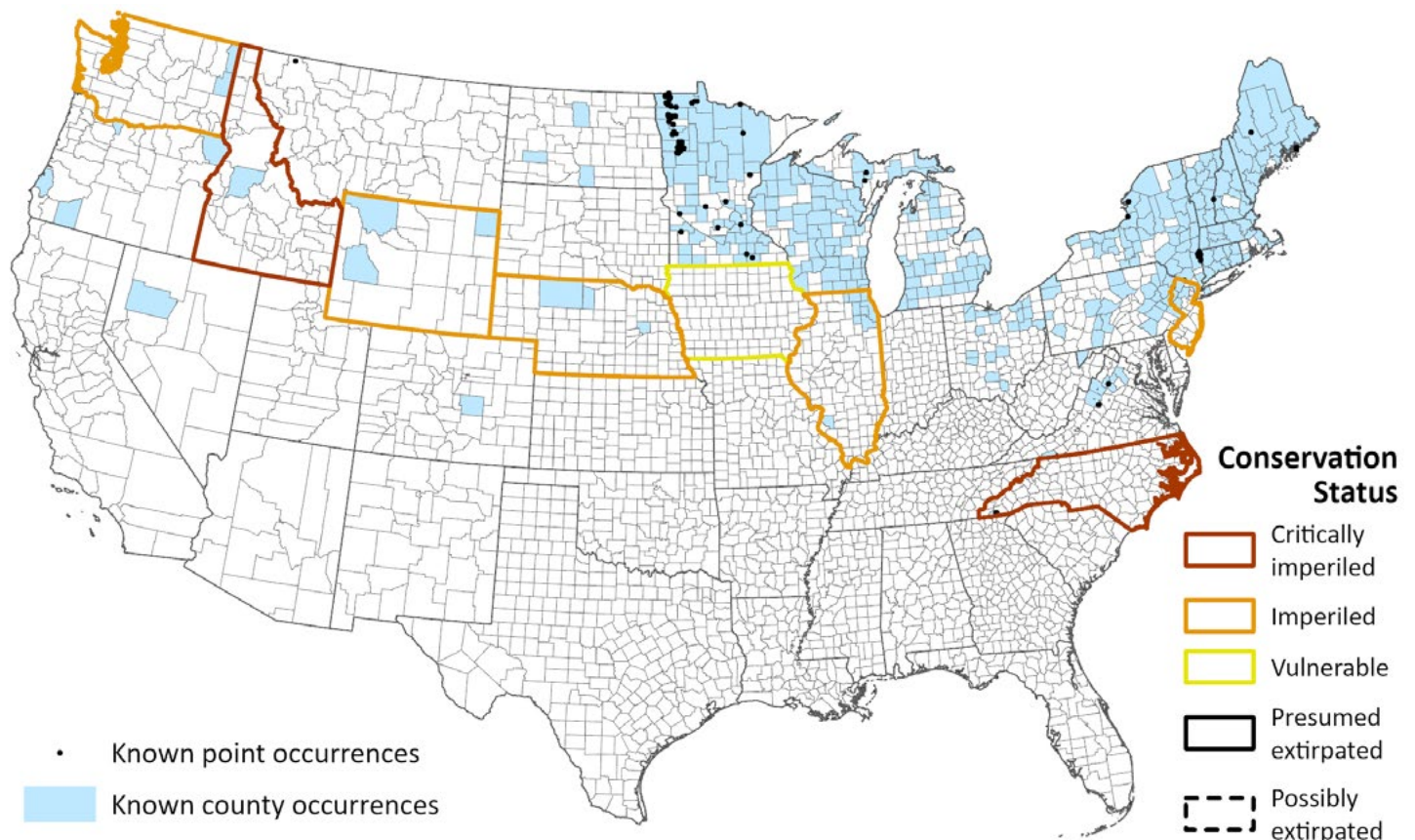


Figure 46.1. Distribution and state-level conservation status of *Muhlenbergia glomerata*. Known point occurrences were used to assess species deposition responses and critical loads.

microsites, it would likely tolerate relatively short fire-return intervals in some plant communities.

Wildlife and Livestock Uses

There is limited information about spiked muhly's importance to wildlife and livestock. It occurs in some areas on sites disturbed by wildlife and livestock, indicating that it may be less palatable than similar species to grazing animals in these communities.



Plant of spiked muhly.

Howard F. Schwartz, Colorado State University, Bugwood.org.

Responses to Nitrogen and Sulfur

The probability of occurrence of spiked muhly is related to the interactive effect of N and S deposition (fig. 46.2a). Under lower S deposition (≤ 2.8 kg S/ha/yr), spiked muhly increases with N deposition up to approximately 7-8 kg N/ha/yr and then decreases with higher N deposition. At higher S deposition (≥ 3.1 kg S/ha/yr), spiked muhly is rare and relatively unresponsive to N deposition. Of the other variables tested, the only significant variable is precipitation (fig. 46.2b). The probability of occurrence increases with increasing precipitation within the species' sampled range. Confidence in the N and S relationships is moderate-to-high, with good model performance ($R^2 = 0.205$, $AUC = 0.8$; moderate and high confidence, respectively), low VIFs ($VIF-N = 1.6$, $VIF-S = 1.6$; both high confidence), and a moderate N-S correlation ($r=0.6$, moderate confidence).

Critical Loads and Exceedances

The environmental hull for spiked muhly covers most of the northeastern United States and the mountains of the West. The N CL is 6 to 8 kg N/ha/yr across most of the West and ≥ 10 kg N/ha/yr in the East. The N CL is in exceedance based on 2019–2021 total N deposition in the higher elevations of the West and in the high deposition agricultural areas of the Midwest. The S CL is 2.2 kg S/ha/yr across most of the species' range with small areas in Indiana and Iowa with a S CL of 17.1 kg S/ha/yr. There are exceedances of the S CL based on 2019–2021 TDep total S deposition in the southern part of the species' range.

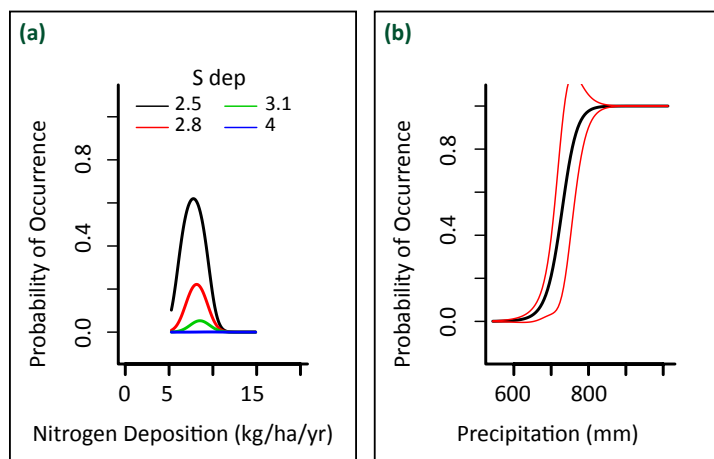


Figure 46.2. Effects of various environmental variables on the probability of occurrence of *Muhlenbergia glomerata*: a) N x S interaction, b) precipitation.



Flowers of spiked muhly plant.

Rob Routledge, Sault College, Bugwood.org.

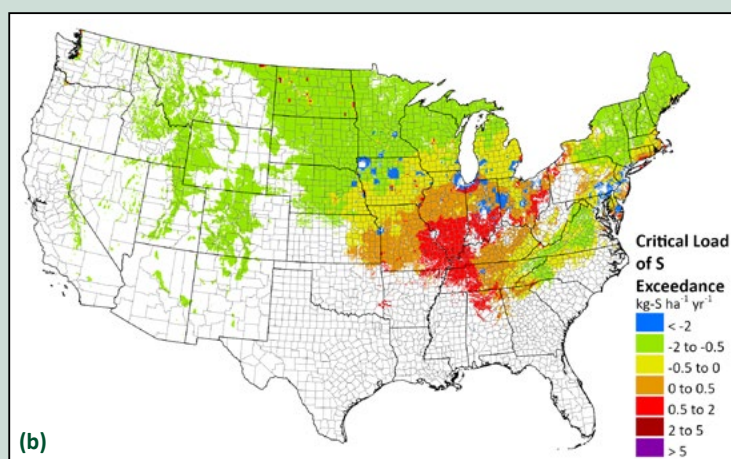
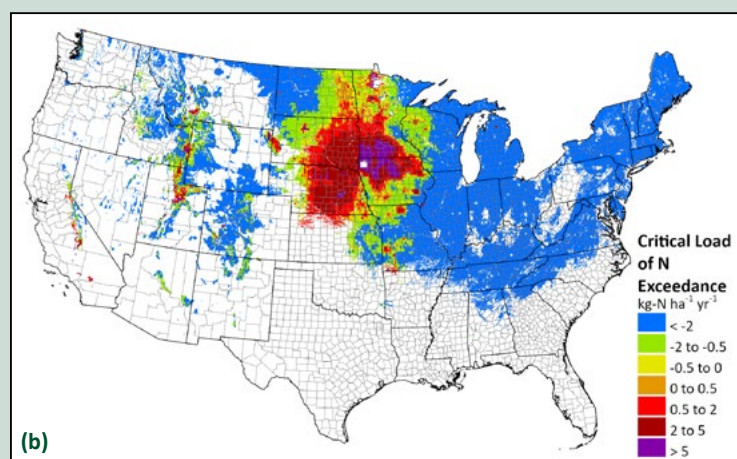
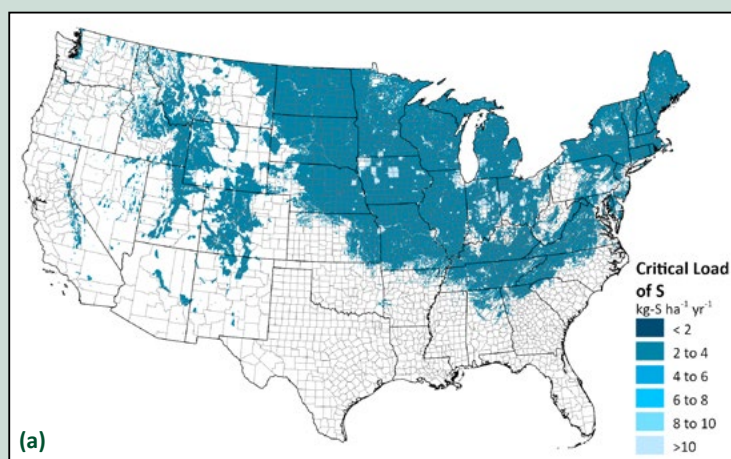
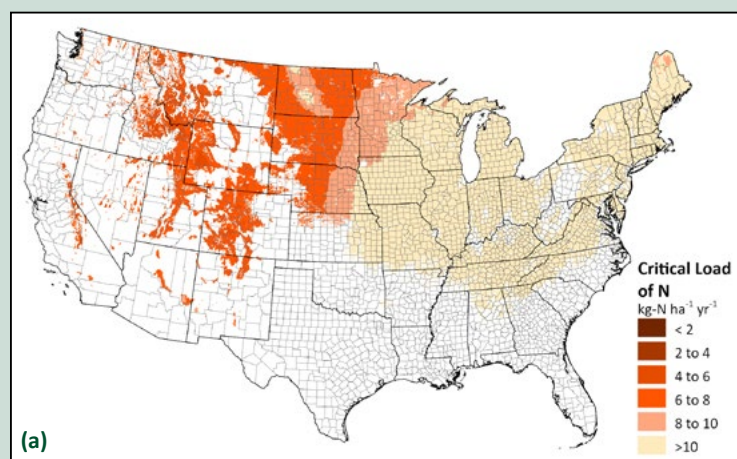


Figure 46.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Muhlenbergia glomerata* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 46.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Muhlenbergia glomerata* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

47.0 *Oligoneuron rigidum* (stiff goldenrod)

Distribution and Conservation Status

Stiff goldenrod is a native perennial forb. Its distribution encompasses prairies and dry woodlands from Massachusetts south to Texas and Georgia. It can also be found sporadically in the understory of U.S. northern hardwood and eastern deciduous forests. It is critically imperiled in South Carolina, West Virginia, Maryland, and Massachusetts, imperiled in Ohio, Virginia, and North Carolina, and vulnerable in Montana, Wyoming, and Georgia (fig. 47.1).

Species Characteristics and Habitat

The plant can grow over 3 feet in height. The leaves are stiff, rough textured, and are alternately arranged on the stems. The leaves on the lower stem are oblong and have short petioles; those on the upper stem are lance-shaped and stalkless. Blooming in the fall, it forms an inflorescence about 6 inches across and flat across the top of yellow flowers. It can be invasive in prairies, rapidly establishing itself after a grassland has been over-grazed.

Ecosystem Services

Stiff goldenrod is often used for roadside plantings as well as wildlife food and habitat.

Traditional Ecological Knowledge

Traditional medicinal uses include regulating urine flow (root decoction) or reducing swelling from stings (drug made from the flowers).

Responses to Nitrogen and Sulfur

The probability of occurrence for stiff goldenrod is related to N deposition (fig. 47.2a) and S deposition (fig. 47.2b). Stiff goldenrod increases with N deposition up to roughly 14.2 kg N/ha/yr and then decreases with higher N deposition. It decreases sharply with S deposition. There are interactions with pH and between N and S deposition, but these do not greatly affect the critical loads (Clark et al. 2019). The only significant climate variable is temperature (fig. 47.2c). The probability of occurrence decreases with increasing temperatures (but note widening confidence bands) within the species'

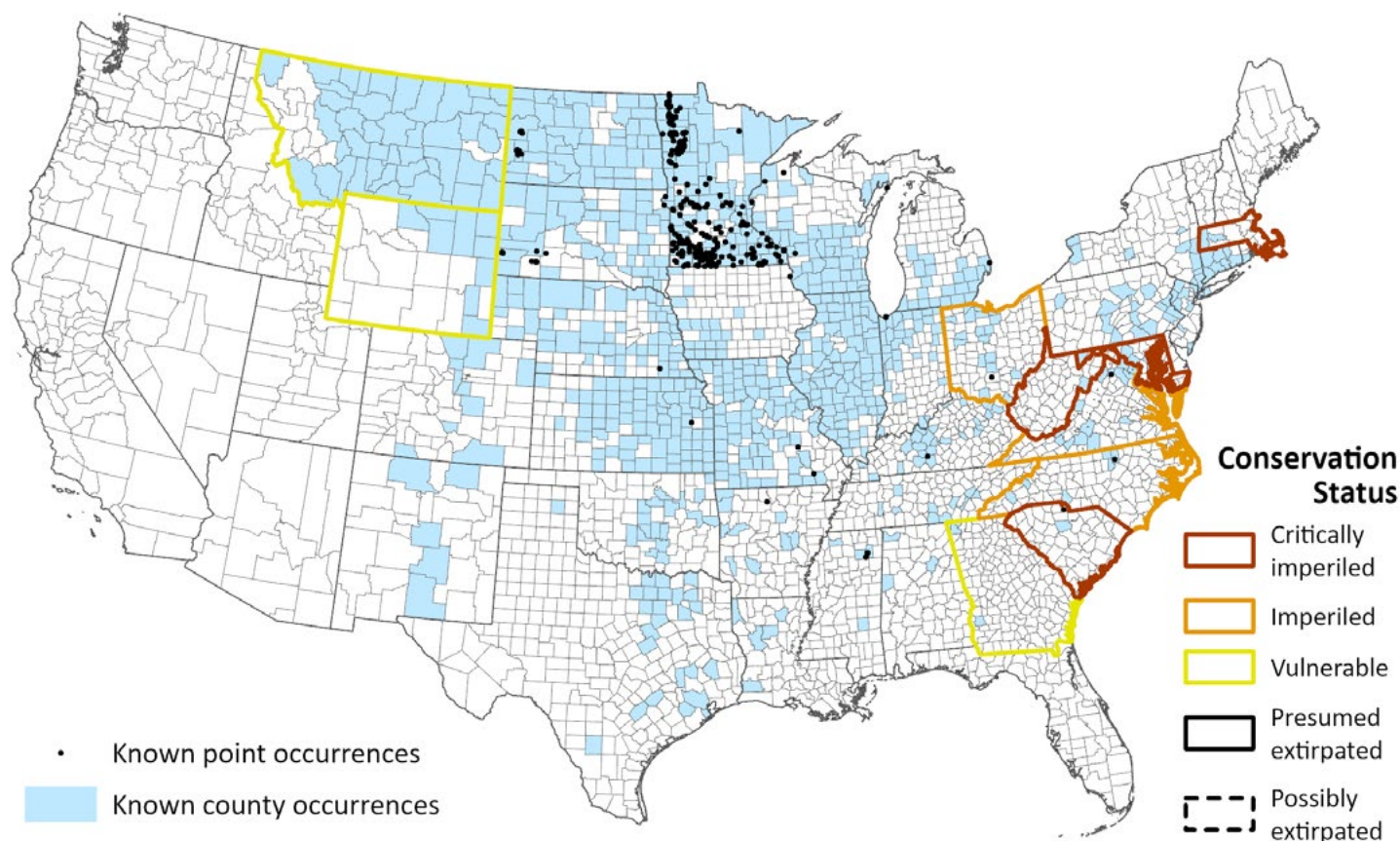
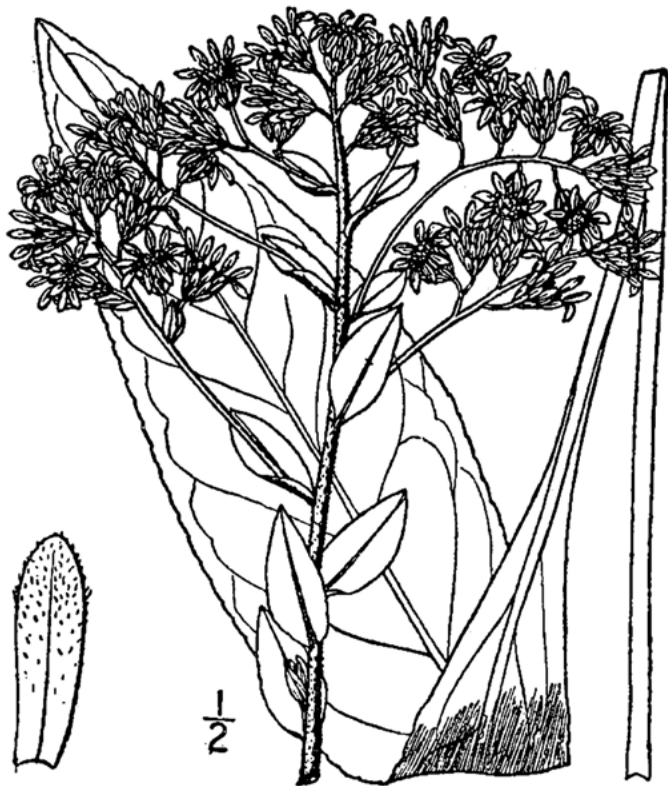


Figure 47.1. Distribution and state-level conservation status of *Oligoneuron rigidum*. Known point occurrences were used to assess species deposition responses and critical loads.

sampled range. Confidence in the N and S relationships is moderate-to-high, with good model performance ($R^2 = 0.415$, AUC = 0.89; both high confidence), low VIFs (VIF-N = 1.1, VIF-S = 1.2; both high confidence), and a moderate N-S correlation ($r=0.55$, moderate confidence).



Sketch of stiff goldenrod flowers and leaves.
Britton, N.L., and A. Brown, 1913, An illustrated flora of the northern United States, Canada and the British Possessions. 3 vols. Provided by Kentucky Native Plant Society, New York. Scanned By Omnitek Inc.

Critical Loads and Exceedances

The environmental hull for stiff goldenrod covers most of the eastern United States and the mountains of the West. The N CL is ≥ 10 kg N/ha/yr across most of the range and 8 to 10 kg N/ha/yr in small pockets in the West. The N CL is in exceedance based on 2019–2021 total N deposition in high deposition agricultural areas of the Midwest. The S CL is 0.4 kg S/ha/yr across most of the species' range with small areas with a S CL of 41.7 kg S/ha/yr in midwestern urban areas. There are exceedances of the S CL based on 2019–2021 TDep total S deposition across almost all areas with the lower CL.



Flowers of stiff goldenrod.
Courtesy of Thomas Barnes and the Department of Forestry and Natural Resources - Extension, University of Kentucky.

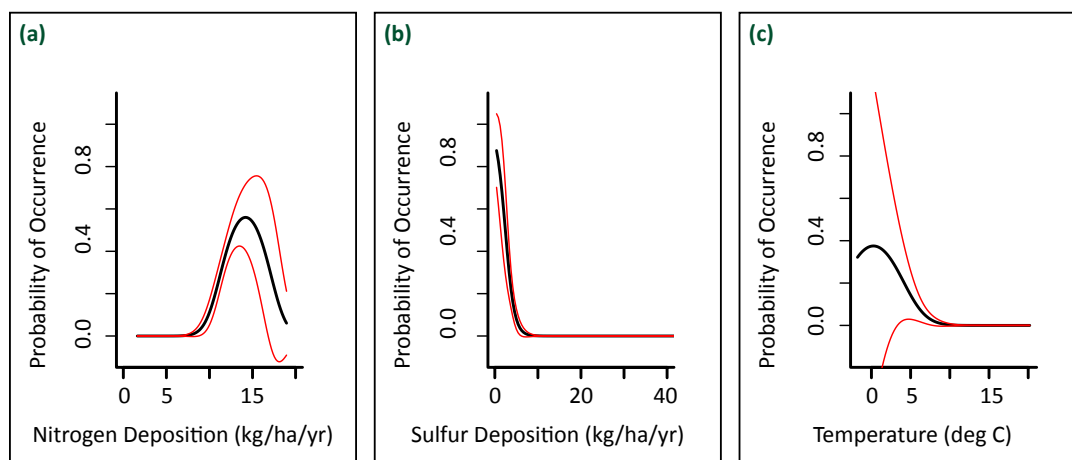


Figure 47.2. Effects of various environmental variables on the probability of occurrence of *Oligoneuron rigidum*: a) N deposition, b) S deposition, c) temperature.

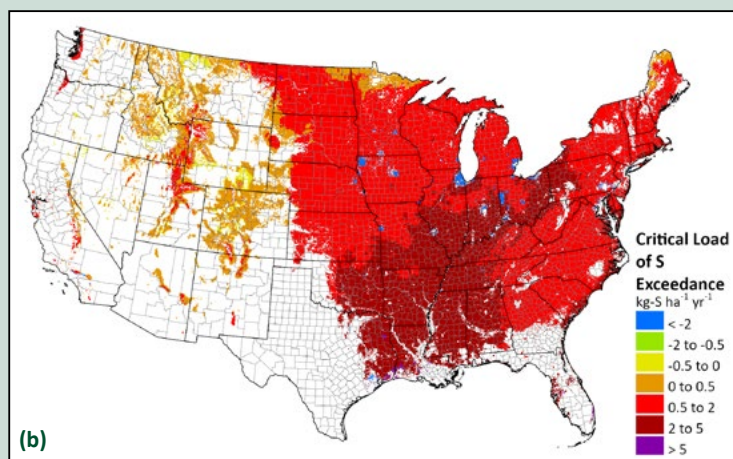
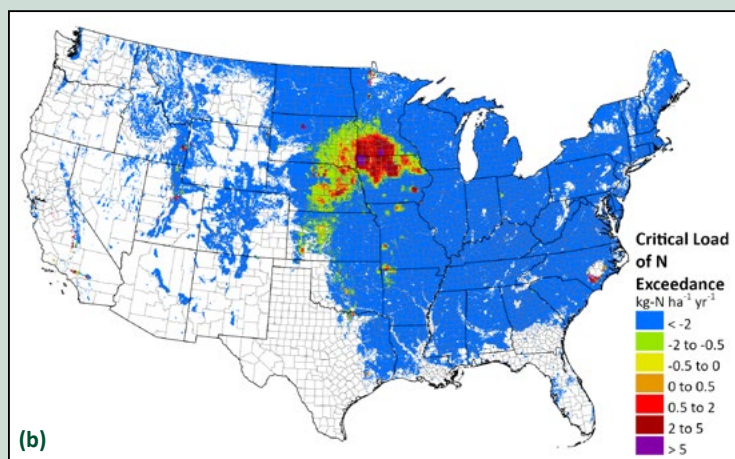
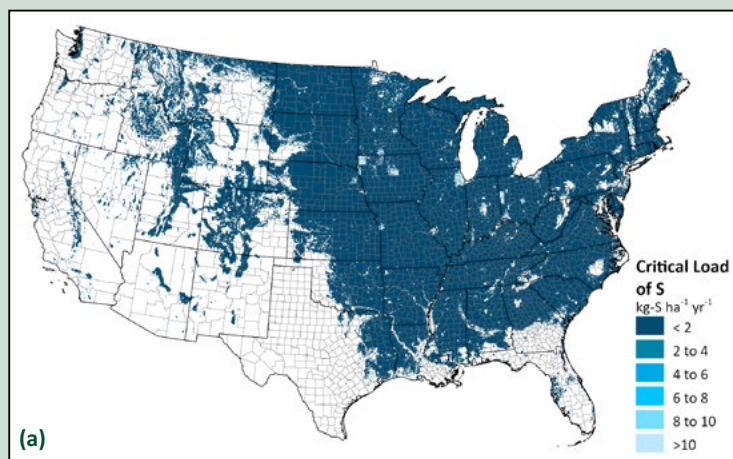
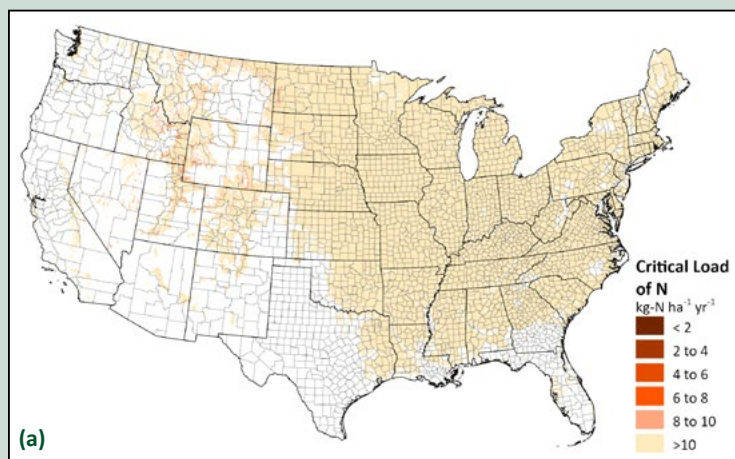


Figure 47.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Oligoneuron rigidum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 47.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Oligoneuron rigidum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

48.0 *Osmorhiza claytonii* (Clayton's sweetroot)

Distribution and Conservation Status

Clayton's sweetroot is a native perennial forb. It grows in the understory in rich, mesic, mixed- hardwood forests, wet prairies, and meadows and has an uneven distribution across the northern hardwood and eastern deciduous forests of the continental United States. It is critically imperiled in Kansas, imperiled in Arkansas and South Carolina, and vulnerable in North Dakota (fig. 48.1).

Species Characteristics and Habitat

Clayton's sweetroot has thickened, fibrous roots extending from a caudex. The solitary stem grows 12 to 35 inches tall and produces compound leaves. It grows new foliage in the fall and flowers annually in the spring, regenerating from the root stock. The flower stalks have tiny umbels which produce thin black seeds with stiff, hairy ribs.

Clayton's sweetroot's soil preferences are for well-drained sandy loams to poorly drained clay loams with acidic to strongly acidic pH levels, and limited calcium and magnesium availability. It grows on level ground to very steep slopes at elevations from 600 to 2,200 feet. It prefers short, mild summers and long, cold winter climates and is relatively shade tolerant. The seeds are spread by dropping from the plant or by snagging in animal fur, hair, or clothing. Fire is known to top-kill its foliage. The root stock may survive if it is covered in soil. If the conditions are dry and duff layers are well-developed, the fire may consume the caudex and kill the plant and seed bank. Its fire recovery is influenced by the severity of the fire and the rooting depth of the caudex. If the fire occurs at the end of summer or early autumn, the surviving root stocks should sprout, since its sprouting season is in the fall.

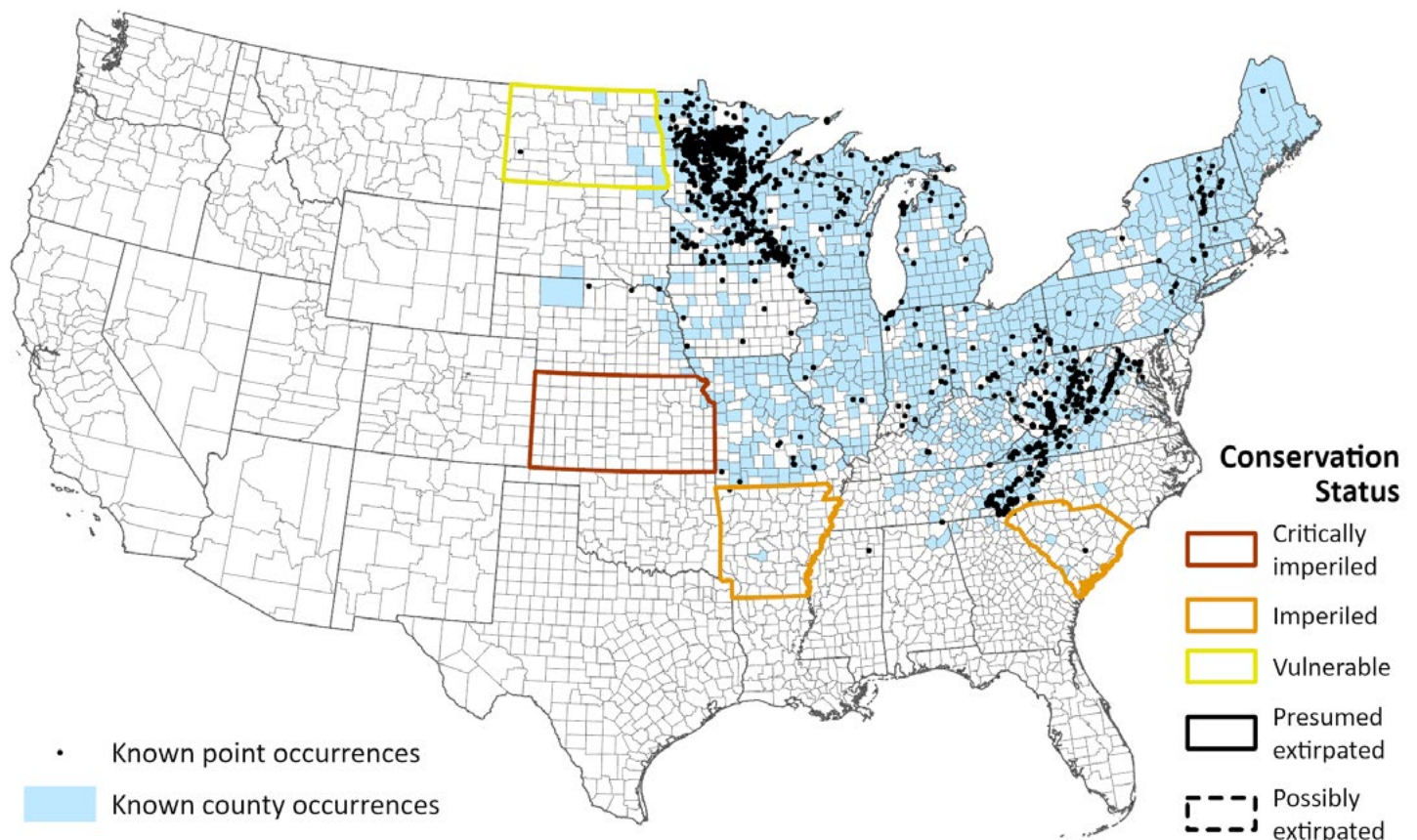


Figure 48.1. Distribution and state-level conservation status of *Osmorhiza claytonii*. Known point occurrences were used to assess species deposition responses and critical loads.

Traditional Ecological Knowledge

Clayton's sweetroot has been utilized in a variety of traditional medicines. In decoctions, it can be gargled and chewed to treat sore throats or used as an eyewash to treat sore eyes. Pieces of the root can be used as a dietary supplement to gain weight or as a dermatological aid to treat sores.



Flowers of Clayton's sweetroot.
Vern Wilkins, Indiana University, Bugwood.org.

Responses to Nitrogen and Sulfur

The probability of occurrence for Clayton's sweetroot is related to several variables. The effect of N deposition depends on S deposition (fig. 48.2a). At low S deposition (≤ 3.4 kg S/ha/yr), Clayton's sweetroot increases strongly with N deposition up to approximately 10 kg N/ha/yr and decreases with higher N deposition. At higher S deposition

(≥ 9.8 kg S/ha/yr), the probability of occurrence increases less with N deposition. The effect of N deposition also depends on soil pH (fig. 48.2b). The species increases and decreases more with N deposition under alkaline soils compared to acidic soils. The climate effects are shown in Figure 48.2c (precipitation) and Figure 48.2d (temperature). The probability of occurrence decreases with increasing precipitation and peaks broadly at temperatures around 7 °C within the species' sampled range. Confidence in the N and S relationships is moderate, with good model performance ($R^2 = 0.218$, AUC = 0.81; moderate and high confidence, respectively), low VIFs (VIF-N = 1.3, VIF-S = 1.2; both high confidence) and a high N-S correlation ($r=0.78$, low confidence).



Foliage of Clayton's sweetroot.
Vern Wilkins, Indiana University, Bugwood.org.

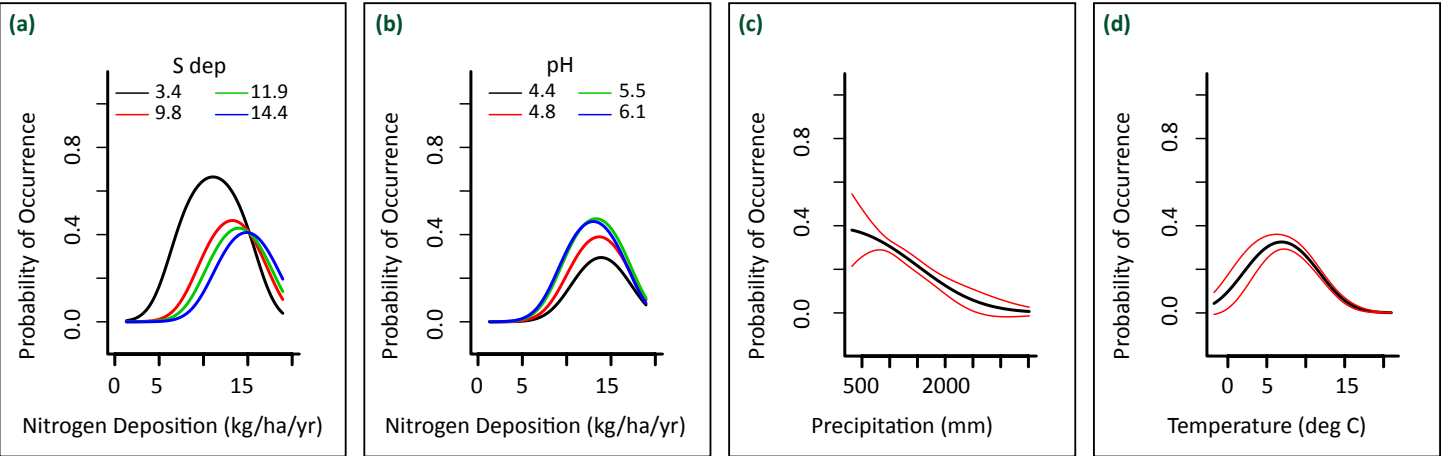


Figure 48.2. Effects of various environmental variables on the probability of occurrence of *Osmorhiza claytonii*: a) N x S interaction, b) N x pH interaction, c) precipitation, d) temperature.

Critical Loads and Exceedances

The environmental hull for Clayton's sweetroot covers most of the eastern United States and the mountains of the West. The N CL is ≥ 10 kg N/ha/yr across the East and 8 to 10 kg N/ha/yr in most of the West. The N CL is in exceedance based on 2019–2021 total N deposition in high deposition agricultural areas of the Midwest and

some of the higher elevations of the West. The S CL is 0.4 kg S/ha/yr across most of the species' range with small areas with a S CL of 42.5 kg S/ha/yr in midwestern urban areas. There are exceedances of the S CL based on 2019–2021 TDep total S deposition across almost all areas with the lower CL.

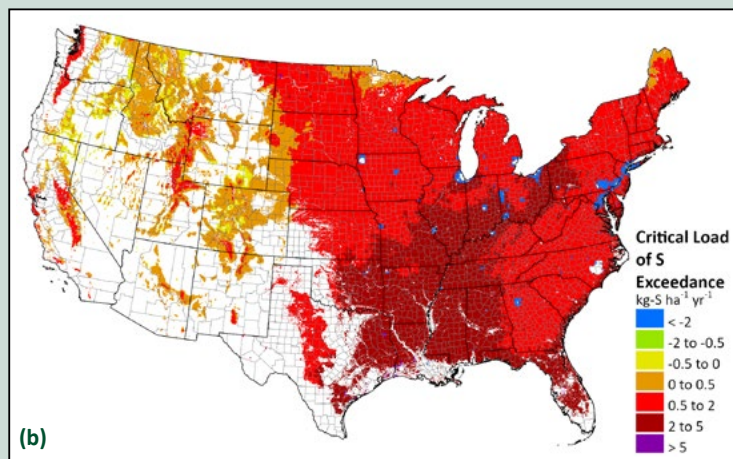
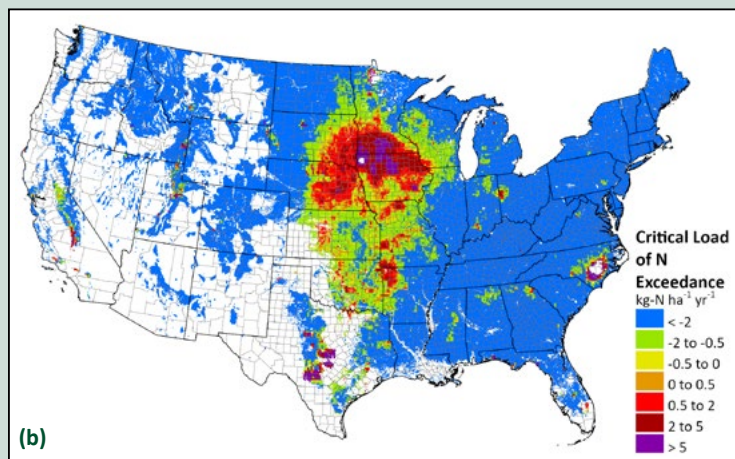
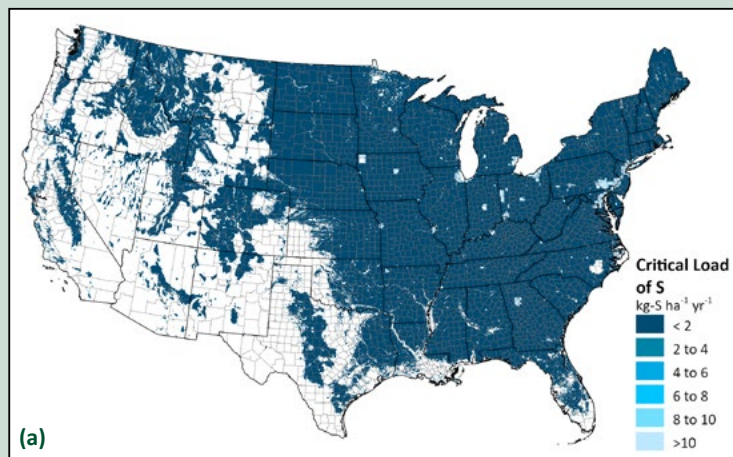
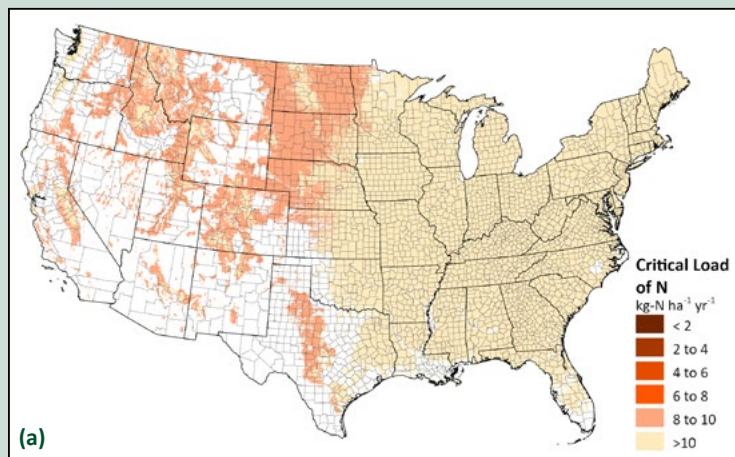


Figure 48.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Osmorhiza claytonii* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 48.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Osmorhiza claytonii* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

49.0 *Peltandra virginica* (arrow arum)

Distribution and Conservation Status

The native range of arrow arum is from Maine to Michigan, south to Florida, Louisiana, and Missouri, as well as the west coast in California and Oregon where it has naturalized. It is critically imperiled in Oklahoma and Iowa, imperiled in West Virginia and Vermont, and vulnerable in Illinois and Maine (fig. 49.1).

Species Characteristics and Habitat

The leaves of arrow arum are a vibrant green and smooth, succulent, arrow-to heart-shaped. Its leaves emerge annually from perennial bulbs. The ascending leaves grow from 4 to 30 inches long, 3 to 8 inches wide, and have three prominent veins with an abrupt, sharp tip. The bulbs are surrounded with thick fibrous roots. Arrow arum blooms from May to July. It is monoecious, with both male and female parts contained in a partially closed 4 to 8 inch green spathe. As the fruit matures, the entire flowering stem curves downward. The green berry-like fruit grows up to 1/2 inch long, and typically holds one seed.

Extensive stands of arrow arum frequently sprout in riparian habitats. It grows in shallow water areas of marshes, bogs, swamps, stream and river bottoms, lakes, ponds, and ditches. Arrow arum grows best in open, loose silty or organic soils that are saturated or inundated up to 1 foot. It can withstand a pH range from 3.0 to 9.5, and up to 2 ppt salinity. Seed production is the predominant means arrow arum uses for re-establishment and population distribution, but it can be propagated vegetatively. A pound of arrow arum yields an average of 500 cleaned seeds. The fruit coating swells and ruptures when the fruit falls into or is stored in water and the floating fruit turns black when it separates from the flowering stem. If the site conditions are right, the seed separates, sinks, then begins to germinate. Vegetative propagation occurs by root bulb divisions. Sustainable, strong plant growth continues when soil is deep and maintained at the saturation point, or inundated to a depth shallower than the leaves.

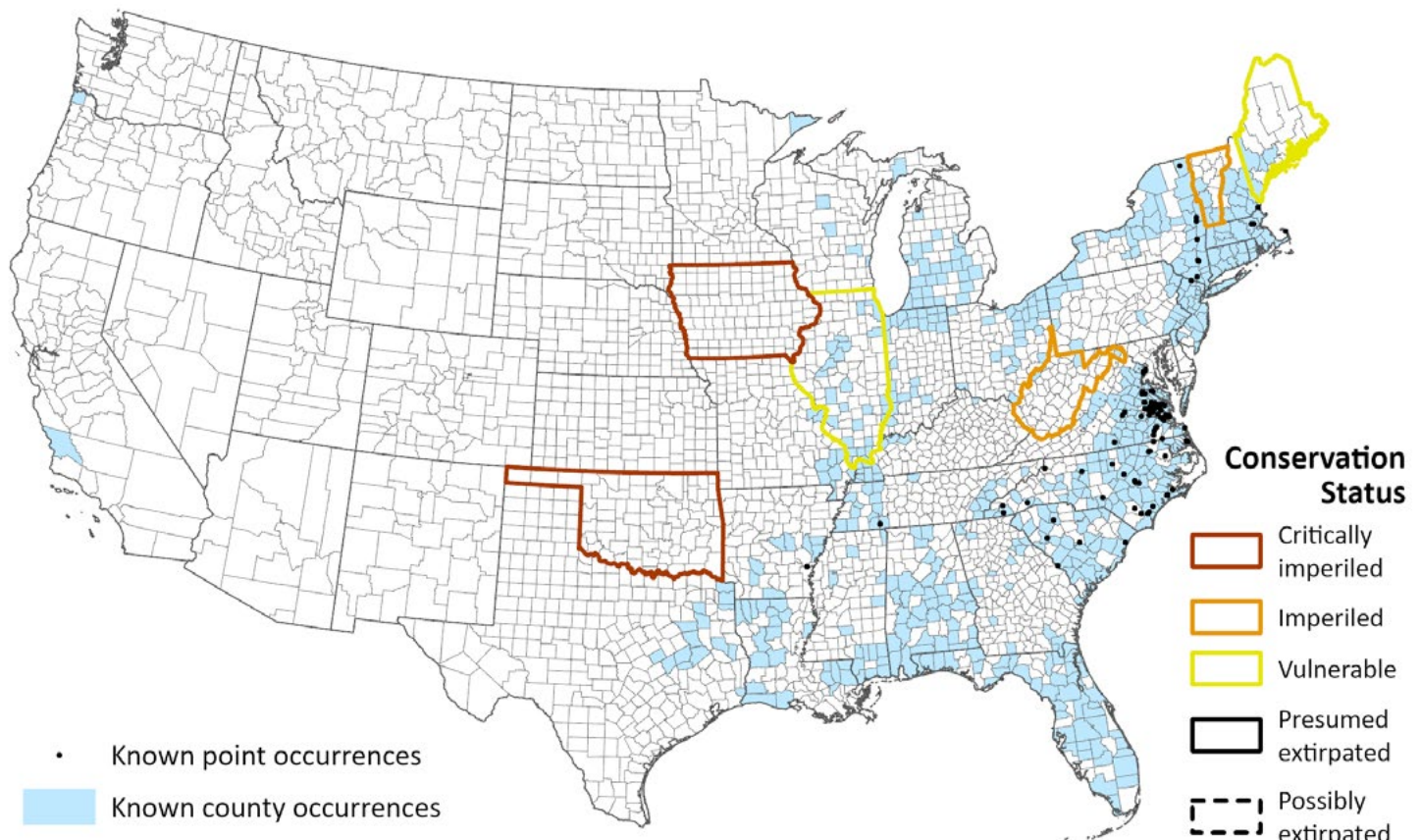


Figure 49.1. Distribution and state-level conservation status of *Peltandra virginica*. Known point occurrences were used to assess species deposition responses and critical loads.

Wildlife Uses

The fruit of arrow arum is a favorite food of wood ducks. Muskrats and rails also enjoy eating arrow arum. The sturdy foliage acts as a cover for waterfowl, wading birds, insects, and aquatic mammals.

Ecosystem Services

The large foliage and stems in these stands work as a wave buffer and barrier zone, while the large network of roots knitted together stabilize submerged sediments. The roots and shoots are excellent translocators of methane from the substrate.

Traditional Ecological Knowledge

Arrow arum is a traditional food source. The grated root can be used to produce a pediatric aid for infants.



Foliage of arrow-arum.
Graves Lovell, Alabama Department of Conservation and Natural Resources, Bugwood.org.

Responses to Nitrogen and Sulfur

The probability of occurrence for arrow arum depends on several variables. The probability of occurrence is not strongly related to N deposition, though it peaks weakly at roughly 12.3 kg N/ha/yr (fig. 49.2a). The effect of S deposition depends on soil pH (fig. 49.2b): the probability of occurrence increases more strongly under more basic conditions. This is likely an effect from soil pH rather than from S deposition. The climate effects are shown in Figure 49.2c (precipitation) and Figure 49.2d (temperature). The probability of occurrence is largely unresponsive to precipitation and peaks narrowly at temperatures around 16 °C within the species’ sampled range. Confidence in the N ad S relationships is moderate-to-high, with good model performance ($R^2 = 0.358$, $AUC = 0.91$; both high confidence), low VIFs ($VIF-N = 1.2$, $VIF-S = 1.2$; both high confidence), and a moderate N-S correlation ($r=0.63$, moderate confidence).



Patch of arrow-arum.
Graves Lovell, Alabama Department of Conservation and Natural Resources, Bugwood.org.

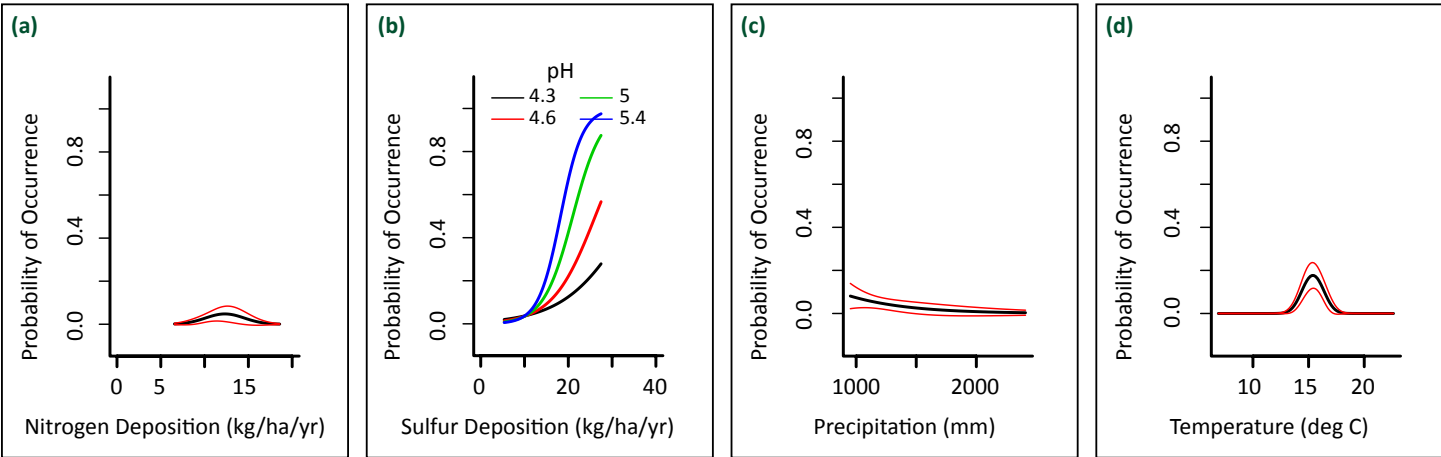


Figure 49.2. Effects of various environmental variables on the probability of occurrence of *Peltandra virginica*: a) N deposition, b) S x pH interaction, c) precipitation, d) temperature.

Critical Loads and Exceedances

The environmental hull for arrow arum covers most of the eastern United States. The N CL is ≥ 10 kg N/ha/yr across most of the East and 6 to 10 kg N/ha/yr in the Midwest. The N CL is in exceedance based on 2019–2021 total N deposition across the Midwest and some agricultural

areas in the South. The S CL is 27.5 kg S/ha/yr across most of the species’ range except a small area in eastern North Carolina with a S CL of 5.4 kg S/ha/yr. There are no exceedances of the S CL based on 2019–2021 TDep total S deposition.

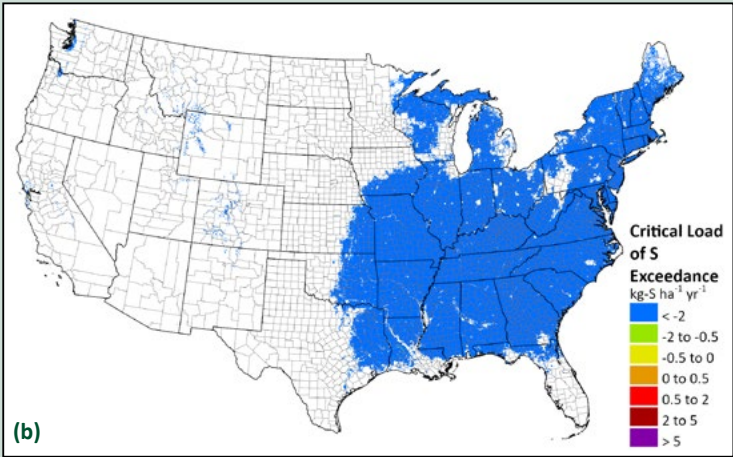
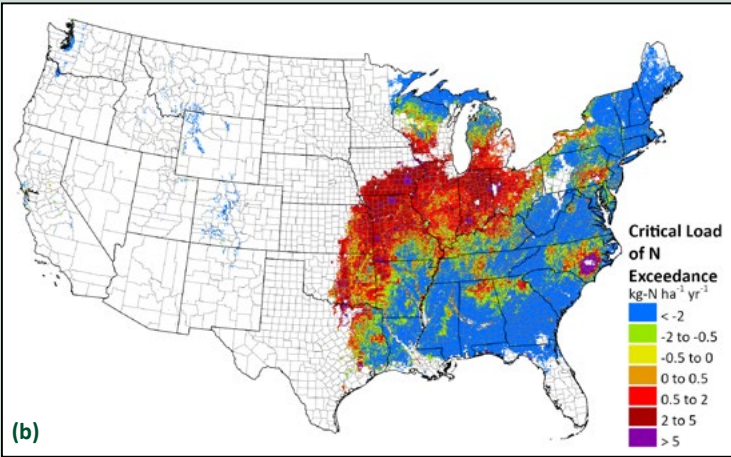
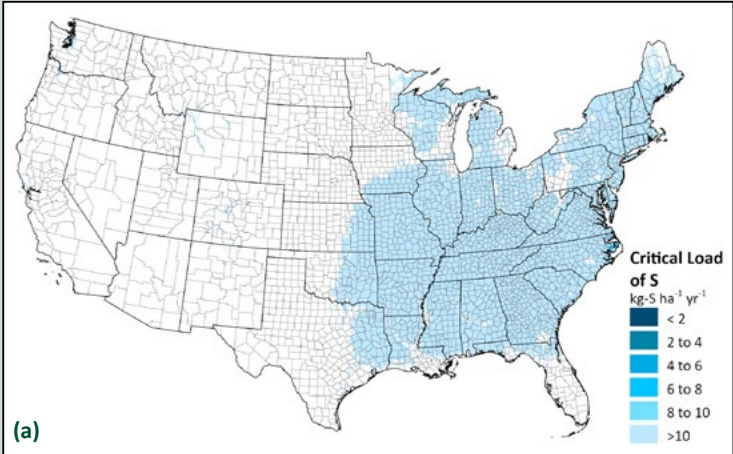
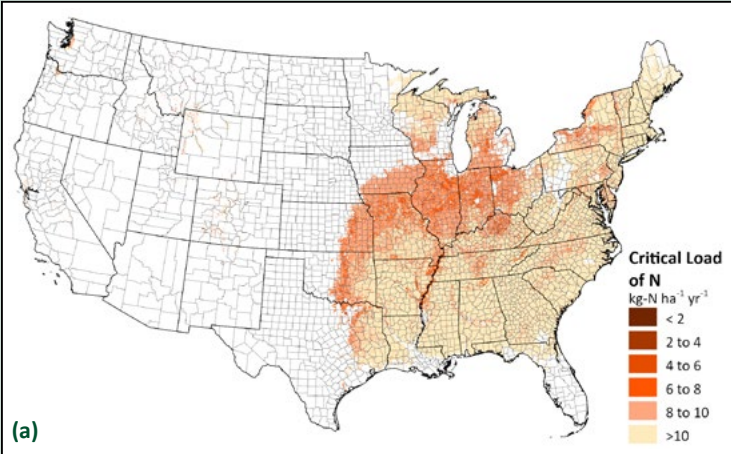


Figure 49.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Peltandra virginica* and (b) the exceedance of N critical loads based on TDep 2019–2021 total N deposition.

Figure 49.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Peltandra virginica* and (b) the exceedance of S critical loads based on TDep 2019–2021 total S deposition.

50.0 *Poa compressa* (Canada bluegrass)

Distribution and Conservation Status

Canada bluegrass is an introduced species, native to Europe, found throughout North America except Florida (fig. 50.1). It is listed as potentially invasive and banned in Connecticut.

Species Characteristics and Habitat

Canada bluegrass is a perennial, cool-season, upright, rhizomatous, sod-forming grass. Culms are solitary or loosely tufted, flattened, and 10 to 24 inches tall. Sheaths are open, glabrous, smooth or faintly and minutely scabrous, flattened, and keeled. Leaves are long, flat, folded or loosely involute, boat tipped, glabrous to scabrous and have two grooves down the middle of the upper blade surface. The inflorescence is a narrow panicle. Spikelets are 3 to 8 flowered and crowded at the end of the branches.

It is found on wet sites, open meadows, and in open deciduous and coniferous forests as well as waste areas. Canada bluegrass is adapted to wet sites but thrives on moderately acidic, and droughty soils with poor fertility. Because it is so successful on infertile soil, it is unable to compete with other grasses on productive soils. It grows best in clay soils. It has slight drought and salinity tolerances, but it cannot tolerate shade. Canada bluegrass spreads primarily by rhizomes and is apomictic. If not properly managed it can be weedy or invasive in some habitats and displace desirable vegetation. Oat necrotic mottle virus is the only documented disease found in Canada bluegrass. It is a mild or symptomless disease in Canada bluegrass and other grasses which is usually transmitted by a mite. Annual late spring burning can be used to control Canada bluegrass and promote the growth of warm-season grasses.

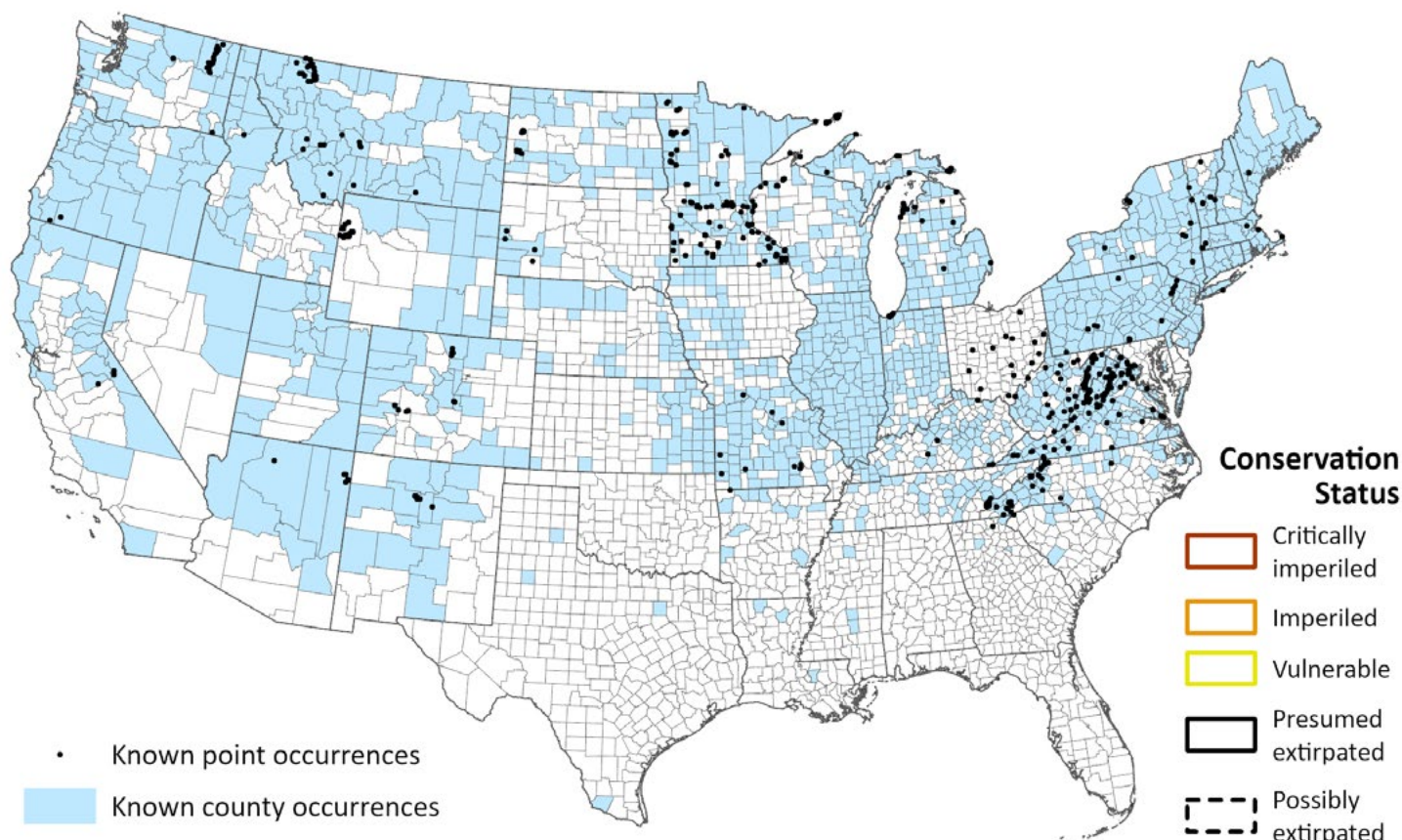


Figure 50.1. Distribution and state-level conservation status of *Poa compressa*. Known point occurrences were used to assess species deposition responses and critical loads.

Wildlife and Livestock Uses

Although Canada bluegrass does not produce abundant forage, the leaves and seeds are consumed by small mammals such as rabbits, and songbirds including prairie chickens and wild turkeys. In the winter, mule deer graze Canada bluegrass. Upland game birds, waterfowl, nongame birds, and small mammals all used Canada bluegrass for cover. Grasshoppers, plant bugs, stink bugs, skipper caterpillars, moth caterpillars, beetles, and bluegrass billbugs feed on Canada bluegrass. It is palatable to livestock and big game.

Ecosystem Services

Canada bluegrass is primarily used for erosion control on disturbed sites such as roadsides, mine reclamation sites, heavy use recreation areas, and for low maintenance landscaping.



Plants of Canada bluegrass.

Joseph M. DiTomaso, University of California - Davis, Bugwood.org.

Responses to Nitrogen and Sulfur

The probability of occurrence for Canada bluegrass depends on several variables. The effect of N deposition depends on soil pH (fig. 50.2a). The probability of occurrence is highest at high pH (pH ≥ 7.2) and low N deposition (≤ 7 kg N/ha/yr) but decreases as N deposition increases above that level. The probability of occurrence is low at lower pH (≤ 6.2) and low N deposition, but increases with N deposition peaking between 10-15 kg N/ha/yr. The effect of S deposition also depends on soil pH (fig. 50.2b), although this relationship is more likely a nitrogen effect given the moderate collinearity of S and N. Under more acidic conditions (pH ≤ 5.5), Canada bluegrass decreases with increasing S deposition, while under less acidic conditions (pH ≥ 6.2), Canada bluegrass is either unaffected or increases with S deposition. The effects of these high pH levels are more uncertain as there are fewer observations. The climate effects are shown in Figure 50.2c (precipitation) and Figure 50.2d (temperature). The probability of occurrence peaks broadly at about 900 mm precipitation and temperatures around 10 °C within the species' sampled range. Confidence in the N relationship is moderate-to-high, with good model performance ($R^2 = 0.193$, AUC = 0.81; moderate and high confidence, respectively), low VIFs (VIF-N = 1.2, VIF-S = 1.3; both high confidence), and a moderate N-S correlation ($r=0.62$, moderate confidence).

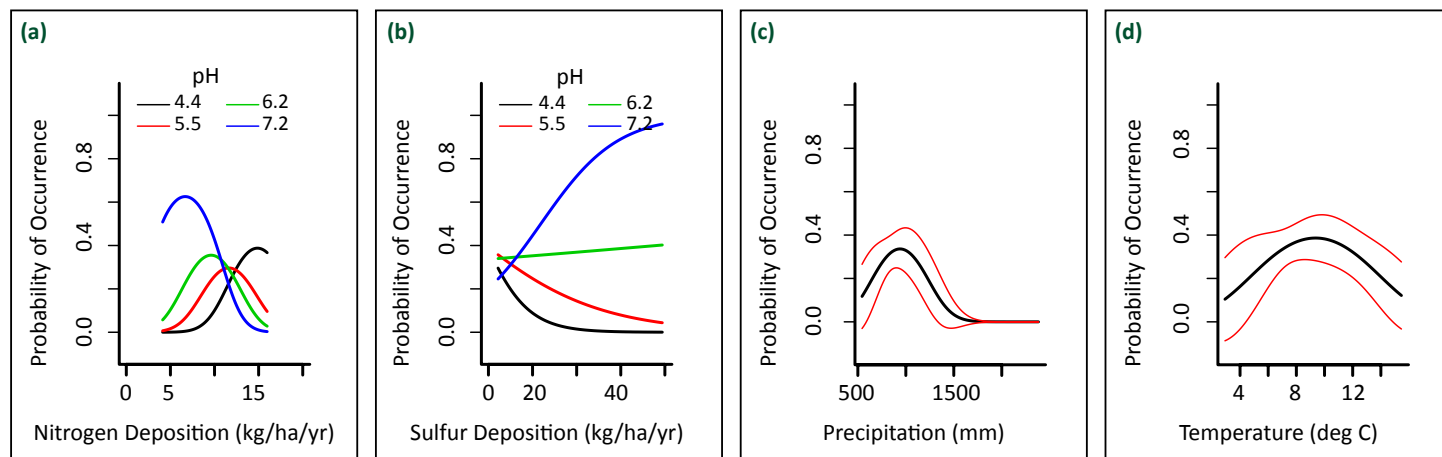


Figure 50.2. Effects of various environmental variables on the probability of occurrence of *Poa compressa*: a) N x pH interaction, b) S x pH interaction, c) precipitation, d) temperature.

Critical Loads and Exceedances

The environmental hull for Canada bluegrass covers most of the eastern United States and the non-arid western United States. The N CL is ≥ 10 kg N/ha/yr across most of the East, 6 to 10 kg N/ha/yr in the Midwest, and between 4 and 10 in the West. The N CL is in exceedance based on 2019–2021 total N deposition across most of the Midwest and in higher elevations in the West. The S CL is 2.2 kg S/ha/yr across most of the East and higher elevation in the West and 39.4 kg S/ha/yr in the Midwest and the rest of the West. There are exceedances of the S CL based on 2019–2021 TDep total S deposition in the South and along the east coast.



Flowers of Canada bluegrass.
Joseph M. DiTomaso,
University of California -
Davis, Bugwood.org.

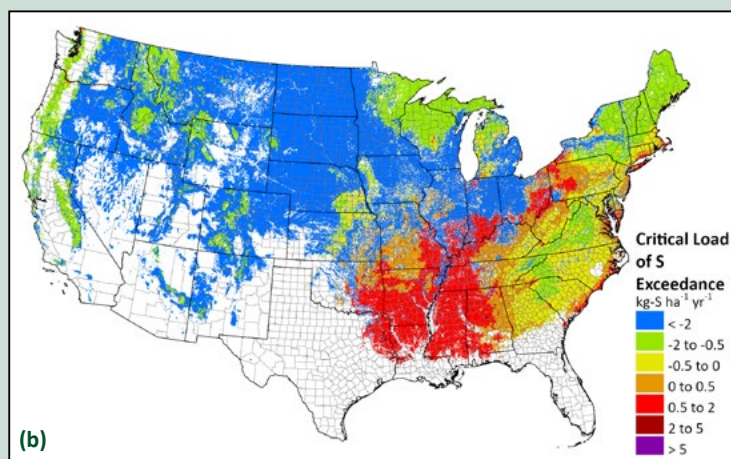
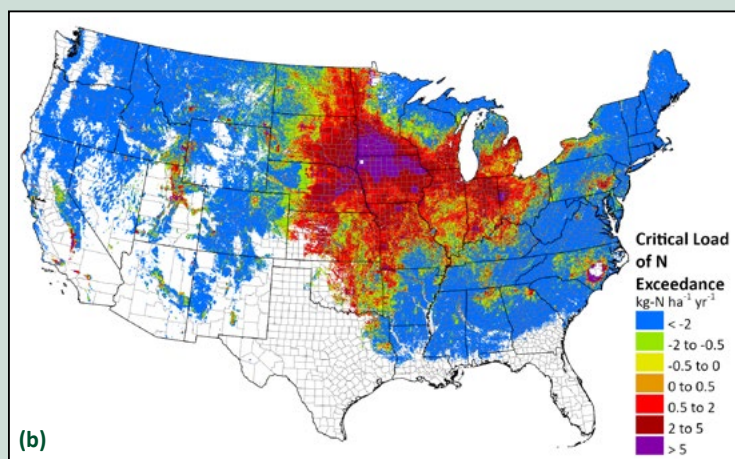
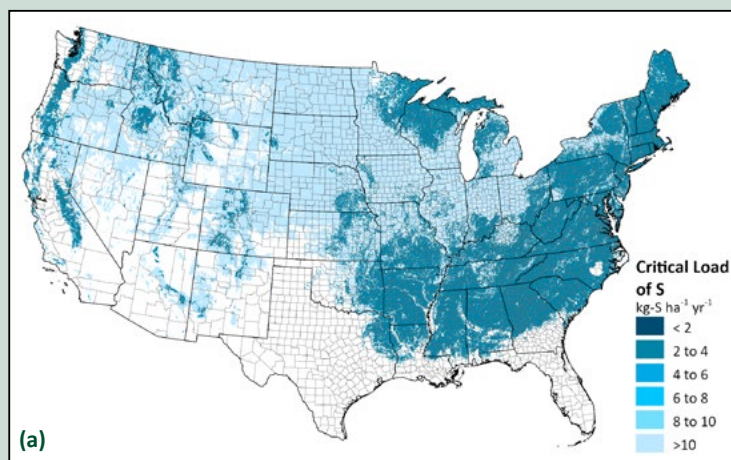
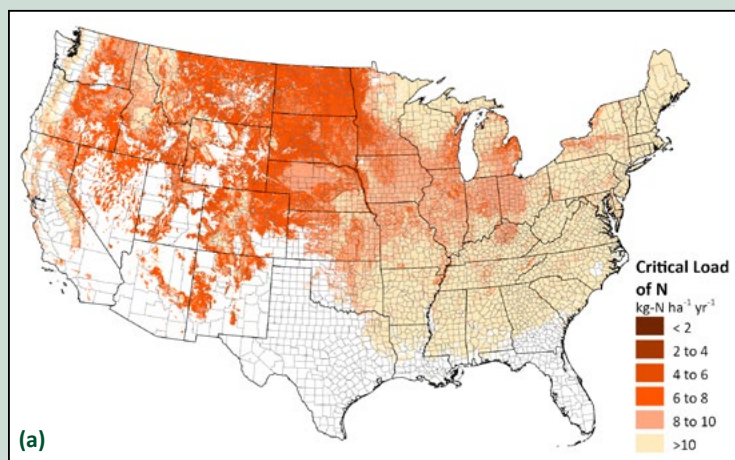


Figure 50.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Poa compressa* and (b) the exceedance of N critical loads based on TDep 2019–2021 total N deposition.

Figure 50.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Poa compressa* and (b) the exceedance of S critical loads based on TDep 2019–2021 total S deposition.

51.0 *Poa pratensis* (Kentucky bluegrass)

Distribution and Conservation Status

Kentucky bluegrass is a perennial, cool-season, sod-forming grass native to Europe. It grows throughout the United States but is most prevalent in the northern half (fig. 51.1). It is frequently found dominating midwestern prairies where it may become weedy or invasive and displace local vegetation if not properly maintained.

Species Characteristics and Habitat

The stems and rhizomes of Kentucky bluegrass develop from tiller buds, and nodes of older rhizomes can also produce new rhizomes. The smooth, soft leaves reach 6 to 12 inches long with boat-shaped tips. Flowering begins in May and the fruit is mature by mid-June. The inflorescence is an open panicle composed of two to six flowers, and the lemmas have a tuft of cobweb-like hairs. The seed head stems grow 18 to 24 inches tall and the seed head has an open, pyramid-like shape and produces many small seeds. Kentucky bluegrass begins growing early in the spring, and becomes dormant during the summer heat, yet regains or maintains its green color in fall.

Kentucky bluegrass is best adapted to well-drained, fertile, loamy or clay loam soils rich with limestone and pH levels ranging from 6.0 to 7.5. Kentucky bluegrass grows best in humid areas with ample sunlight, although it can survive in shaded areas if sufficient moisture and nutrients are available. As a result of these requirements, Kentucky bluegrass is intolerant of drought and excessive flooding. Additionally, it requires significant amounts of nitrogen during active growth stages. Kentucky bluegrass populations can be destroyed by pests such as white grubs, billbugs and sod webworms. Because the rhizomes typically grow 2 to 4 inches beneath the soil surface, it is likely to survive grassland fires which pass quickly and don't not raise soil temperatures significantly.

Wildlife and Livestock Uses

Kentucky bluegrass seeds are eaten by several kinds of songbirds and rodents. Animals enjoy consuming it as soon as growth begins. Leaves are eaten by rabbits and turkey. In the West, it provides important winter forage grass for animals such as cottontail rabbits, wild turkeys, and prairie chickens. In the mountains of the

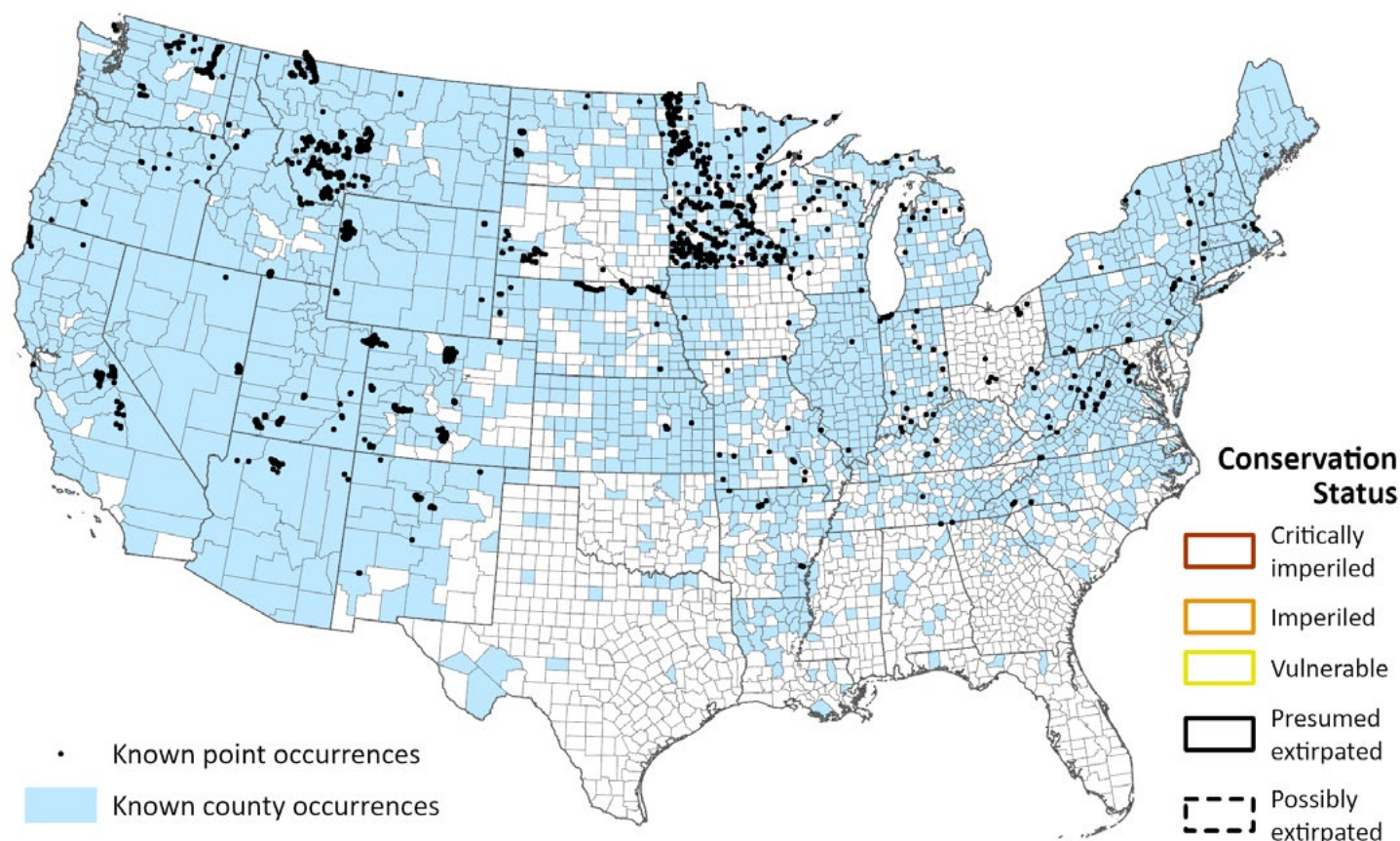


Figure 51.1. Distribution and state-level conservation status of *Poa pratensis*. Known point occurrences were used to assess species deposition responses and critical loads.

Pacific Northwest, the northern pocket gopher, mice, and Columbian ground squirrel feed off it where it is abundant. Kentucky bluegrass provides shelter for small mammals and nongame birds. It is highly palatable to horses, cattle, sheep, elk, bighorn sheep, and deer.

Ecosystem Services

Kentucky bluegrass can be used as a dense green sod for parks and home lawns. Its denseness also allows it to work as an excellent erosion control plant. The seeds of Kentucky bluegrass are included in seed mixes used for revegetating road banks. In eastern North America, Kentucky bluegrass is considered one of the best pasture grasses.



Plant of Kentucky bluegrass.
Steve Dewey, Utah State University, Bugwood.org.

Responses to Nitrogen and Sulfur

The probability of occurrence for Kentucky bluegrass depends on several variables. The effect of N deposition depends on S deposition (fig. 51.2a) and to a lesser extent on soil pH (fig. 51.2b). At lower S deposition, Kentucky bluegrass is more responsive to N deposition, increasing and decreasing at lower levels of N deposition such that the N critical load is lower (10 kg N/ha/yr) when S deposition is low (≤ 1.2 kg S/ha/yr) and the N critical load is higher (12-15 kg N/ha/yr) when S deposition is higher (≥ 2.9 kg S/ha/yr). The N critical load is not affected by soil pH, but the magnitude of increase and decrease is larger with N deposition under more alkaline conditions. The climate effects are shown in Figure 51.2c (precipitation) and Figure 51.2d (temperature). The probability of occurrence decreases sharply with increasing precipitation up to 1100 mm precipitation and decreases with increasing temperatures within the species' sampled range. Confidence in the N and S relationships is moderate, with good model performance ($R^2 = 0.144$, AUC = 0.76; both moderate confidence), low VIFs (VIF-N = 1.2, VIF-S = 1.3; both high confidence), and a high N-S correlation ($r=0.72$, low confidence).

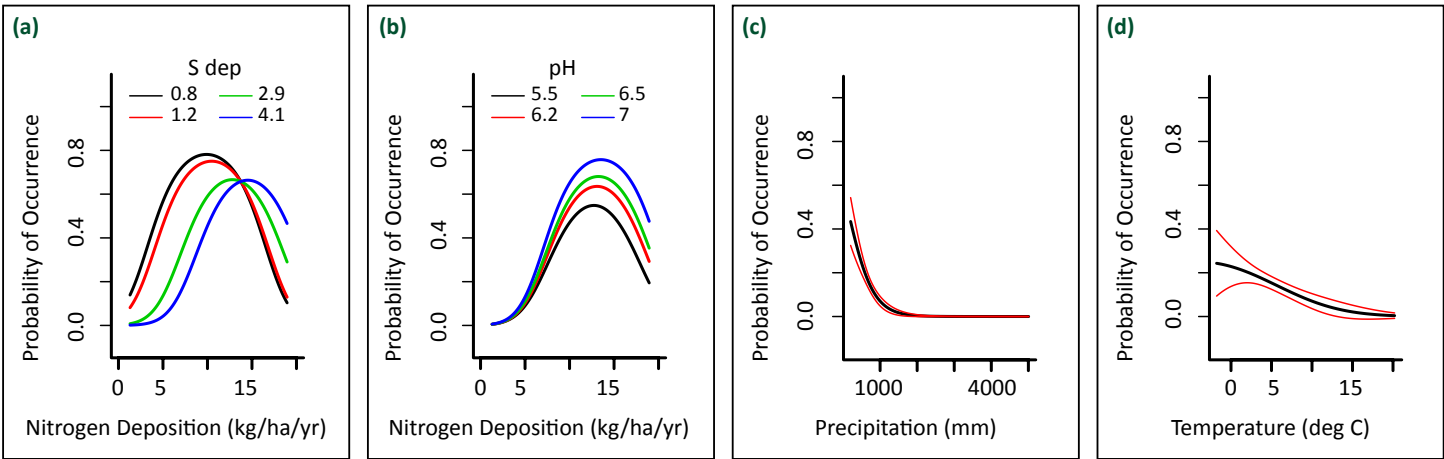


Figure 51.2. Effects of various environmental variables on the probability of occurrence of *Poa pratensis*: a) N x S interaction, b) N x pH interaction, c) precipitation, d) temperature.

Critical Loads and Exceedances

The environmental hull for Kentucky bluegrass covers most of the eastern United States and the non-arid western United States. The N CL is ≥ 10 kg N/ha/yr across most of the range, with the plains of the northwest having a N CL between 8-10 kg N/ha/yr. The N CL is in exceedance based on 2019–2021 total N deposition in high deposition areas of the Midwest, in California's Central Valley, and in some western urban areas. The S CL is < 2 kg S/ha/yr across most of the range and > 10 kg S/ha/yr around most urban areas. There are exceedances of the S CL based on 2019–2021 TDep total S deposition in all areas with the lower CL.

Flowers of Kentucky bluegrass.
Joseph M. DiTomaso,
University of California -
Davis, Bugwood.org.

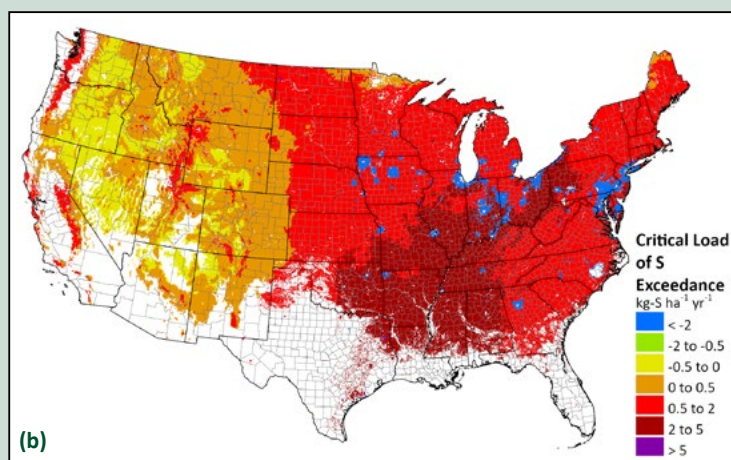
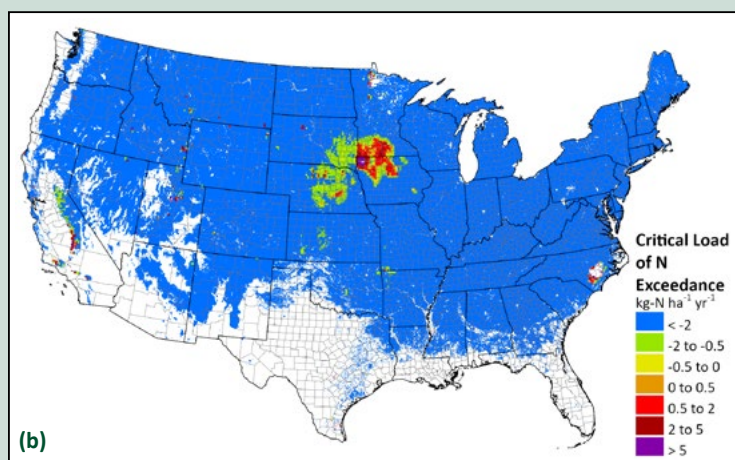
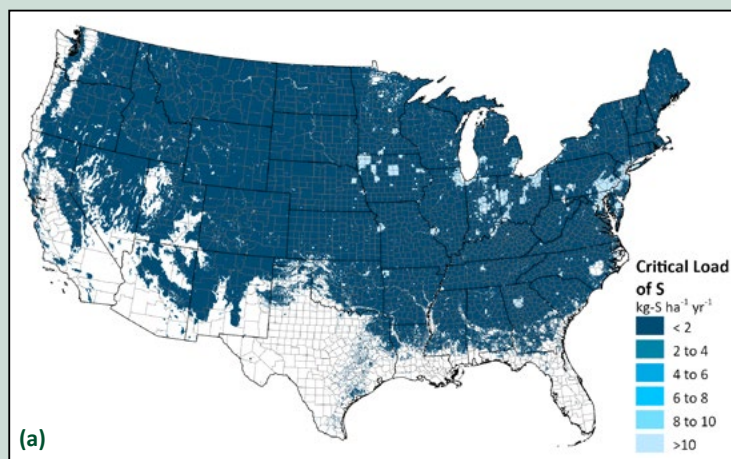
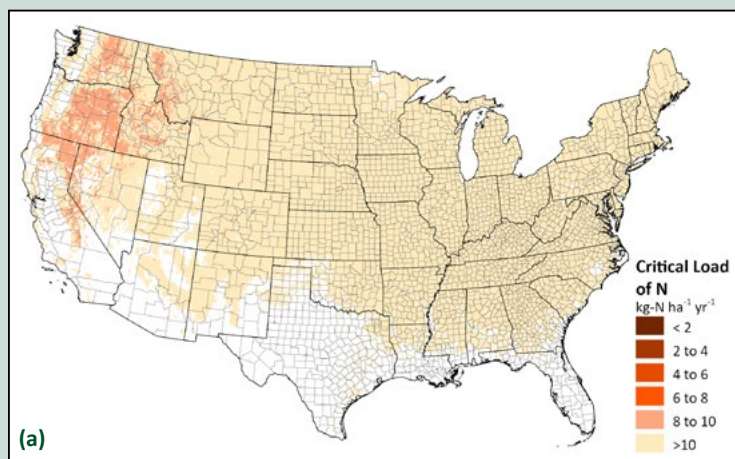


Figure 51.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Poa pratensis* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 51.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Poa pratensis* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

52.0 *Polygonum cespitosum* (Oriental lady's thumb)

Distribution and Conservation Status

This species of lady's thumb is native to Asia. It was introduced in the United States and now grows from the East Coast west to Minnesota and south to Louisiana. Populations have also been reported in Nebraska, Kansas, Texas, and New Mexico (fig. 52.1). It grows best in wetland areas, such as wet meadows, pond margins, seeps, and mudflats, and is also known to grow on disturbed sites.

Species Characteristics and Habitat

Oriental lady's thumb plant is upright, reaching 3 feet in height and has fibrous roots. Its leaves are alternate, thin, and elliptic in shape and 3 inches long. It flowers from May to October; the flowers are small, dark pink, and arranged in thin spikes. The seeds are small, smooth, trigonous achenes.

This plant reproduces by seed and does not regenerate vegetatively. The seeds can germinate from animal fecal pellets. It prefers soils with a broad range of macronutrient availability and soil pH from 4.8 to 8. Germination rates improve with cooler, fluctuating temperatures and increased light, although it can germinate in darker conditions. High summer temperatures can induce dormancy. It is likely that fire would kill entire plants.

Responses to Nitrogen and Sulfur

The probability of occurrence for long-bristled smartweed increases with N deposition (fig. 52.2a) and with S deposition (fig. 52.2b), though the uncertainty at higher deposition levels is higher. Of the other variables tested, the only significant variable is temperature (fig. 52.2c). The probability of occurrence decreases with increasing

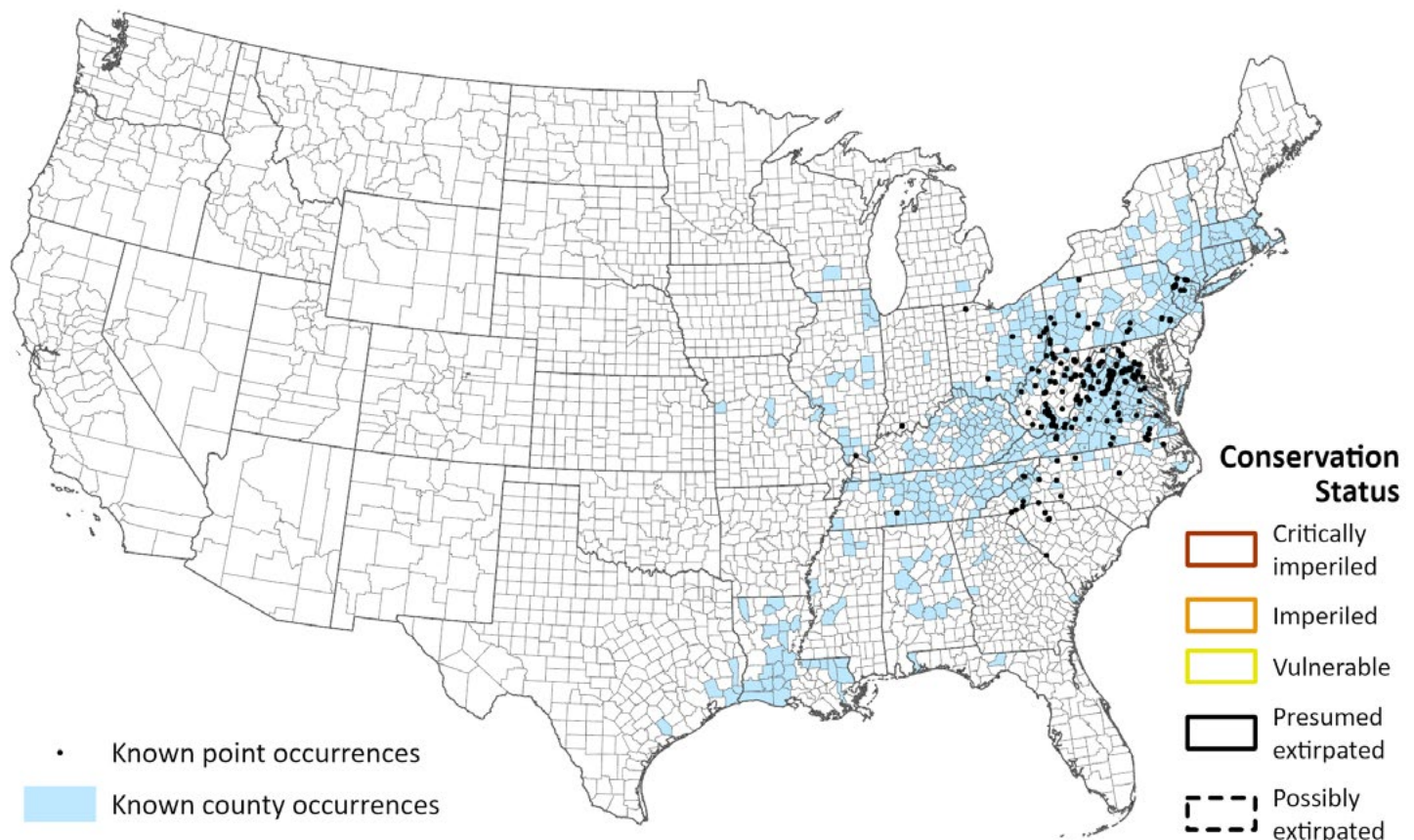


Figure 52.1. Distribution and state-level conservation status of *Polygonum cespitosum*. Known point occurrences were used to assess species deposition responses and critical loads.

temperatures within the species' sampled range. Confidence in the N and S relationships is moderate, with good model performance ($R^2 = 0.111$, AUC = 0.7; both moderate confidence), low VIFs (VIF-N = 1.3, VIF-S = 1.2; both high confidence), and a high N-S correlation ($r=0.73$, low confidence).



Sketch of Oriental lady's thumb plant, leaves, and flower.
USDA NRCS, Wetland flora: Field office illustrated guide to plant species.
Provided by NRCS National Wetland Team.

Critical Loads and Exceedances

The environmental hull for long-bristled smartweed covers the eastern United States outside of Florida and Maine. The N CL is ≥ 10 kg N/ha/yr across most of the range, 6 to 8 kg N/ha/yr in West Virginia and eastern Pennsylvania and on the southern borders of Indiana and Ohio. The N CL is in exceedance based on 2019–2021 total N deposition in the areas with lower CLs and in eastern North Carolina. The S CL is 26.6 kg S/ha/yr across most of the range and 9.3 kg S/ha/yr around most urban areas. There are almost no exceedances of the S CL based on 2019–2021 TDep total S deposition except a small area in South Carolina.



Flower buds of
Oriental lady's thumb.
Robert H. Mohlenbrock. USDA SCS,
1989, Midwest wetland flora: Field
office illustrated guide to plant
species. Provided by USDA NRCS
Wetland Science Institute (WSI),
Lincoln., <https://plants.usda.gov/home/plantProfile?symbol=POCE4>.

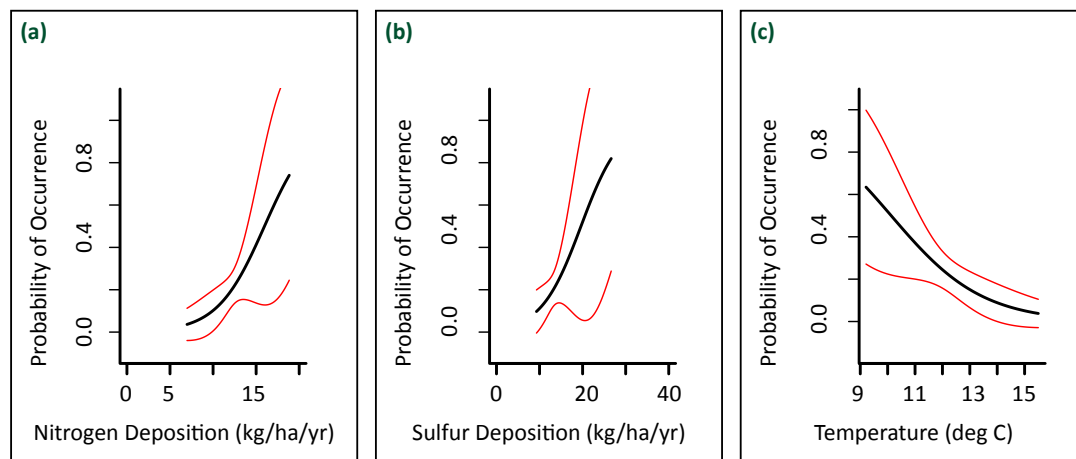


Figure 52.2. Effects of various environmental variables on the probability of occurrence of *Polygonum cespitosum*: a) N deposition, b) S deposition, c) temperature.

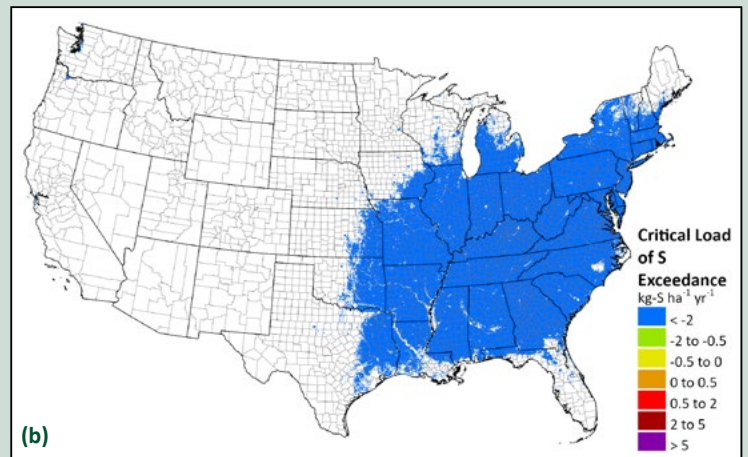
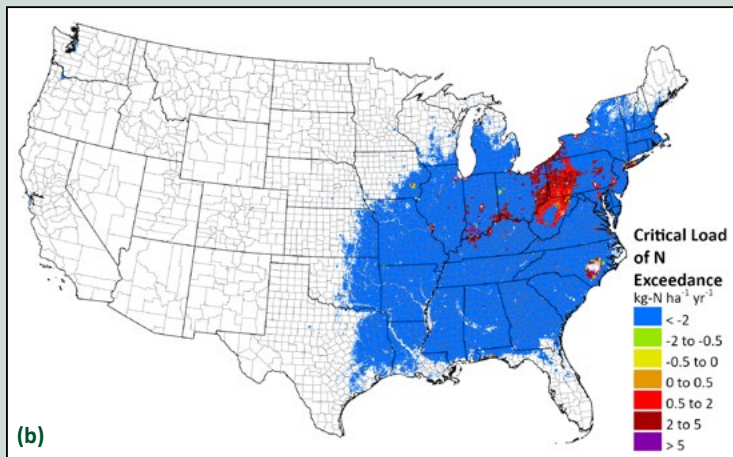
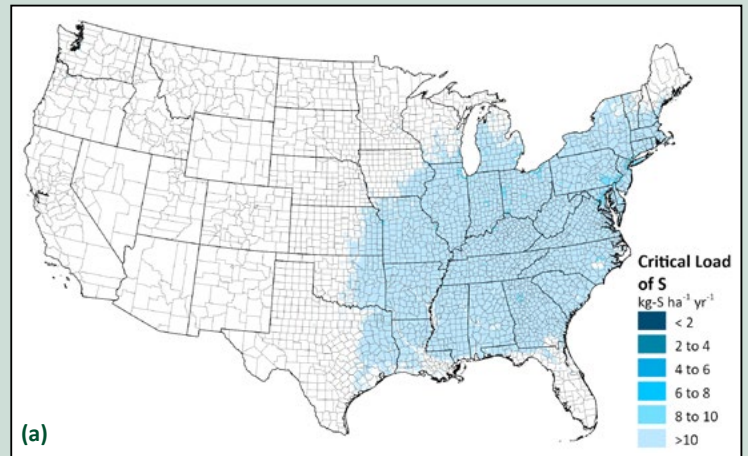
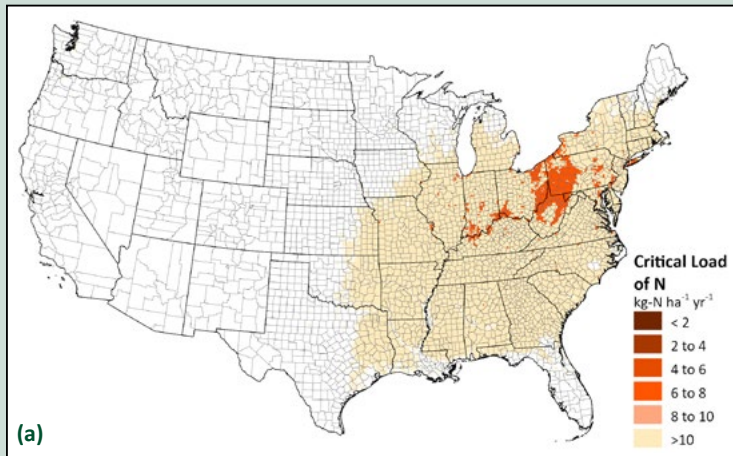


Figure 52.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Polygonum cespitosum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 52.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Polygonum cespitosum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

53.0 *Pteridium aquilinum* (western brackenfern)

Distribution and Conservation Status

Western brackenfern is found throughout the continental U.S. and Alaska. It is imperiled in Wyoming (fig. 53.1).

Species Characteristics and Habitat

The fronds of western brackenfern can be 1 to 10 feet long, including the leaf-stalk that may be as long as 40 to 60 inches. The blades of the fronds are divided into pinnae. Each pinna is in turn divided into pinnules. On fertile fronds the spores are produced beneath the outer margins of the pinnules. Nectaries are found at the base of the pinnae during spring and early summer. The largest nectaries grow at the base of the frond and they get progressively smaller up the rachis. Young western brackenfern plants can produce spores by the end of the second growing season in cultivation. A single, fertile frond can produce 300,000,000 spores annually.

Western brackenfern needs very moist conditions to survive. It can grow in a variety of soils apart from heavily waterlogged soils. Optimal germination pH ranges from

5.5 to 7.5. western brackenfern thrives in warm climates and the fronds are killed by frost. In northern climates the fronds are killed each winter and new fronds grow in spring. In milder habitats, individual fronds persist for 2 to 3 years before being replaced. Fossil evidence indicates that western brackenfern has had at least 55 million years to evolve and has perfect anti disease and antiherbivore chemicals. It is common following fire. Western brackenfern is considered a fire-adapted species throughout the world. In fact, it is well-known as a postfire colonizer in western coniferous forests and eastern pine and oak forests.

Wildlife and Livestock Uses

Elk eat western brackenfern in June when new fronds are developing, and white-tailed deer in New Jersey also eat it in the spring. Rabbits are known to eat the fronds and rhizomes. Western brackenfern's palatability to livestock is usually poor, although sometimes it is consumed after autumn frosts. Goats are the only livestock that normally eat western brackenfern. The fronds are known to release

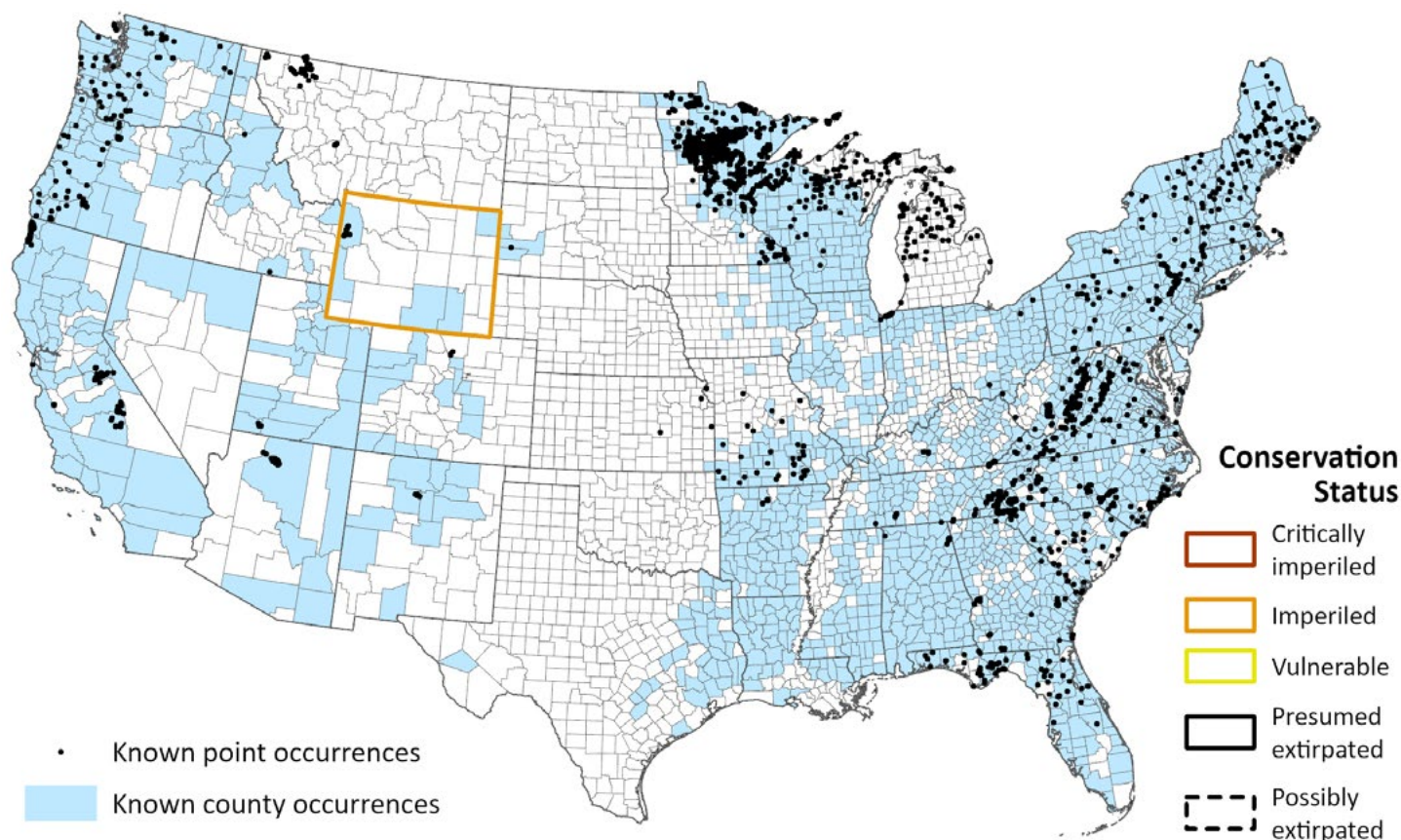


Figure 53.1. Distribution and state-level conservation status of *Pteridium aquilinum*. Known point occurrences were used to assess species deposition responses and critical loads.

hydrogen cyanide when damaged, especially the younger fronds and as a result, it can be poisonous to livestock. Acute bracken poisoning affects the bones of both cattle and sheep, and can cause anemia and hemorrhaging which is often fatal.

Traditional Ecological Knowledge

Western brackenfern shoots are a common traditional food source. The rhizomes can be broken down into a flour or peeled and boiled. The rhizomes also have medicinal uses as an antiseptic and to alleviate menstrual cramps.



Plant of western brackenfern.

Chris Evans, University of Illinois, Bugwood.org.

Responses to Nitrogen and Sulfur

The probability of occurrence for western brackenfern is related to the interaction between N and S (fig. 53.2a). At lower S deposition (≤ 3.3 kg S/ha/yr), western brackenfern is highly responsive to N deposition: the probability of occurrence increases up to 7-8 kg N/ha/yr and then decreases with higher levels of N deposition. At higher S deposition (≥ 8.8 kg S/ha/yr), the probability of occurrence of western brackenfern is lower and less responsive to N deposition. The effect of N deposition also depends on soil pH, but this effect is relatively weak and does not affect the critical load (Clark et al. 2019). The climate effects are shown in Figure 53.2b (precipitation) and Figure 53.2c (temperature). The probability of occurrence increases with increasing precipitation (but note widening confidence bands) and is relatively unresponsive to temperature within the species' sampled range. Confidence in the N and S relationships is moderate, with good model performance ($R^2 = 0.194$, AUC = 0.8; moderate and high confidence, respectively), low VIFs (VIF-N = 1.3, VIF-S = 1.2; both high confidence), and a high N-S correlation ($r=0.8$, low confidence).

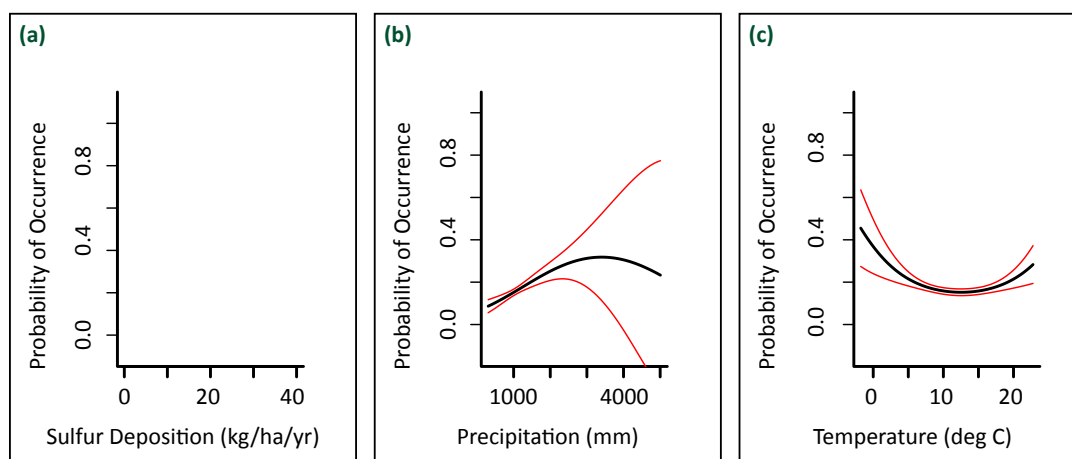


Figure 53.2. Effects of various environmental variables on the probability of occurrence of *Pteridium aquilinum*: a) S x pH interaction, b) precipitation, c) temperature.

Critical Loads and Exceedances

The environmental hull for western brackenfern covers the entire United States except the Desert Southwest. The N CL is generally 6 to 8 kg N/ha/yr across the West, 8 to 10 kg N/ha/yr across the Midwest, South, and Northeast, and ≥ 10 kg N/ha/yr in the rest of the East. The N CL is in exceedance based on 2019–2021 total N deposition in higher elevations in the West, across most of the Midwest, and in high deposition agricultural areas in the East. The S CL is 0.4 kg S/ha/yr across most of the range and 41.7 kg S/ha/yr in half of Iowa, a band from Indiana to New Jersey, and small areas in the South. There are exceedances of the S CL based on 2019–2021 TDep total S deposition across areas with the lower CL the lower elevation plains of the West.



Foliage of western brackenfern.
Chris Evans, University of Illinois, Bugwood.org.

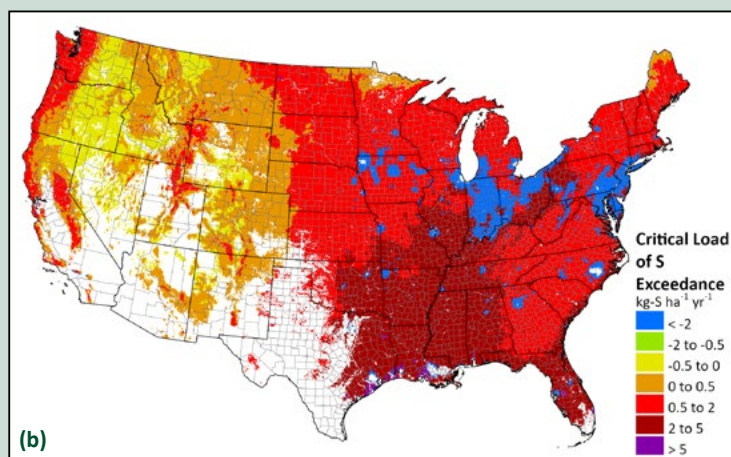
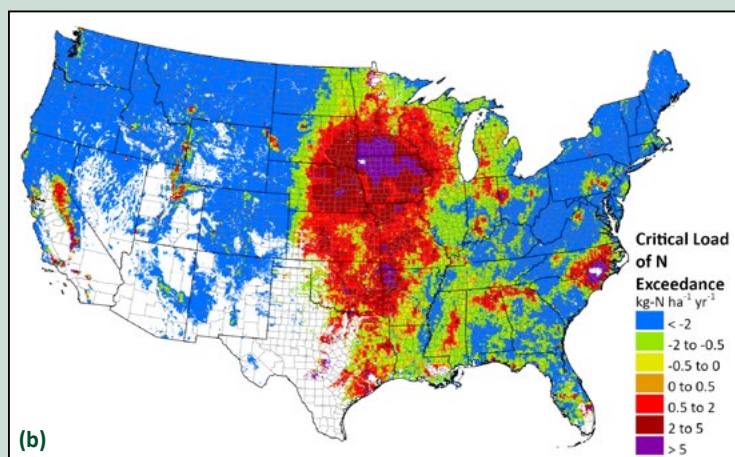
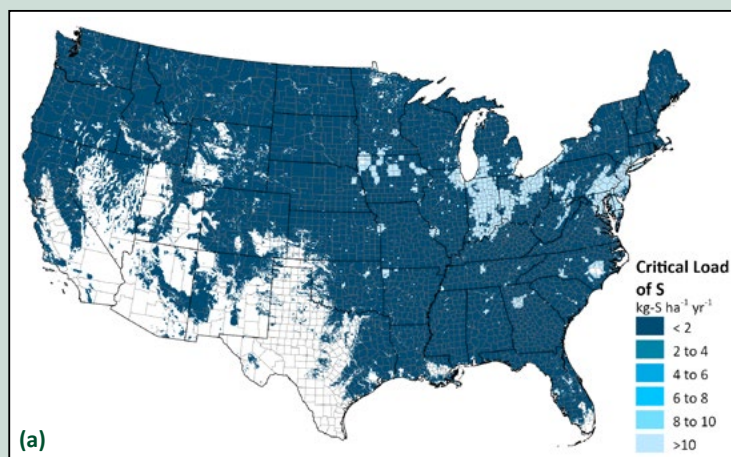
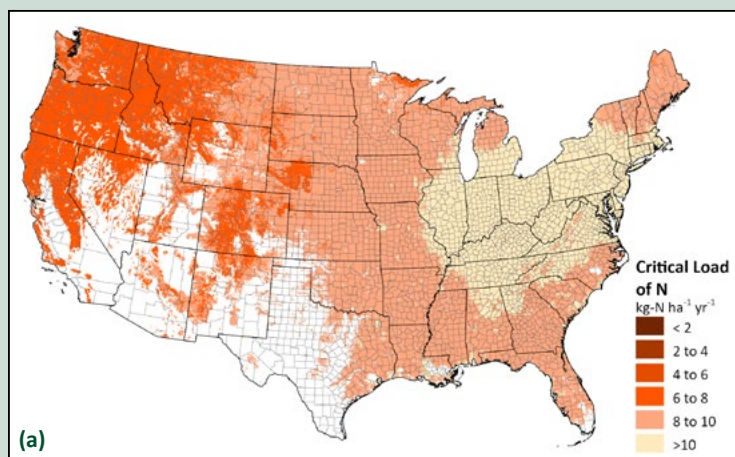


Figure 53.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Pteridium aquilinum* and (b) the exceedance of N critical loads based on TDep 2019–2021 total N deposition.

Figure 53.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Pteridium aquilinum* and (b) the exceedance of S critical loads based on TDep 2019–2021 total S deposition.

54.0 *Rudbeckia hirta* (black-eyed Susan)

Distribution and Conservation Status

Black-eyed Susan is a native, biennial, warm season forb in the sunflower family. It is found throughout the United States, excluding Nevada and Arizona. Black-eyed Susan grows in fields, pastures, prairies, open woodlands, along railroad tracks, roadsides, and abandoned areas. It is vulnerable in Wyoming (fig. 54.1).

Species Characteristics and Habitat

After germination, the black-eyed Susan seedling grows into a rosette with oblong leaves. As the taproot grows it produces many firm, rough, upright pubescent stems 1 to 3 feet tall. The basal leaves are alternately arranged and grow up to 3 inches wide and 4 inches long with toothed margins. Each stem produces a solitary bloom with 8-20 yellow ray flowers around a flat, dark brown cone. Black-eyed Susan usually blooms from June to September of the second year, and then dies after flowering and seed maturation. The seed is tiny and black, about 0.7 inches long and 0.02 inches in diameter.

Black-eyed Susan is an early successional species adapted to clay, loam, and sandy soils with pH levels around 6.8. It grows best on well-drained to poorly-drained soils in full sunlight. This plant may become weedy or invasive in some habitats and may displace wanted vegetation if not effectively managed. Pests include aphids which suck plant sap and produce a sticky honeydew. Diseases include downy mildew which attacks seedlings and produces light yellow spots on foliage, powdery mildew that produces a white growth on leaves, and white smut that causes light spots on leaves. Black-eyed Susan is fire tolerant when dormant since it reproduces vegetatively from the root crown. It can establish on burned sites as a result of its seeds. In fact, black-eyed Susan thrives in the open, sunny conditions created by fire allowing it to be an initial on-site colonizer. However, it is probably top-killed by fire during the growing season.

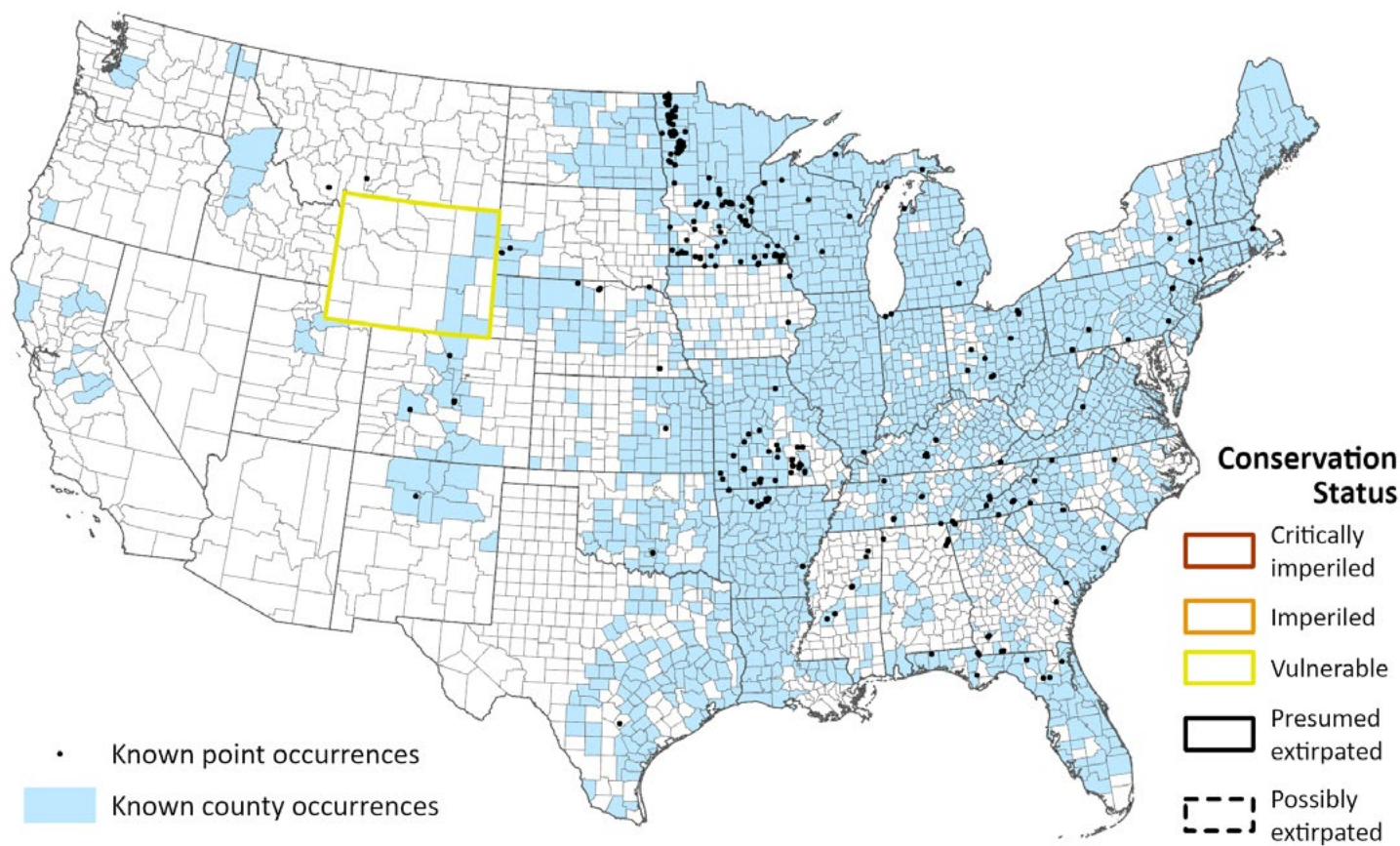


Figure 54.1. Distribution and state-level conservation status of *Rudbeckia hirta*. Known point occurrences were used to assess species deposition responses and critical loads.

Wildlife and Livestock Uses

Black-eyed Susan as a larval host for silvery checkerspot and bordered patch butterfly caterpillars. Carpenter bees, leaf cutting bees, and green metallic bees collect pollen and nectar from the flower. Bobwhite quail, wild turkey, and songbirds eat its seeds. White-tailed deer graze on the basal leaves in winter. Black-eyed Susan has poor nutritional value for livestock although cattle are known to graze on it lightly in the spring.

Ecosystem Services

Black-eyed Susan is used for landscaping and in wildflower gardens. it can be a significant factor in maintaining areas subject to erosion such as road cuts and hillsides.



Flower of black-eyed Susan.
David Cappaert, Bugwood.org.

Traditional Ecological Knowledge

Black-eyed Susan is used in many traditional medicinal practices to reduce swelling and heal sores and to remedy common colds. The blooms of the plant can be used to make green and yellow dyes.

Responses to Nitrogen and Sulfur

The probability of occurrence for black-eyed Susan is related to the interaction between N deposition and soil pH (fig. 54.2a). Under more alkaline conditions (pH ≥ 7.5), black-eyed Susan is more common and decreases more strongly with N deposition, while under more acidic conditions (pH ≤ 6.7), the species is less common and decreases less strongly with N deposition. Black-eyed Susan also decreases sharply with increasing S deposition (fig. 54.2b). The climate effects are shown in Figure 54.2c (precipitation) and Figure 54.2d (temperature). The probability of occurrence increases with increasing precipitation and decreases with increasing temperatures within the species' sampled range. Confidence in the N and S relationships is moderate-to-high, with good model performance ($R^2 = 0.228$, AUC = 0.81; moderate and high confidence, respectively), low VIFs (VIF-N = 1.7, VIF-S = 2.4; both high confidence), and a moderate N-S correlation ($r=0.62$).

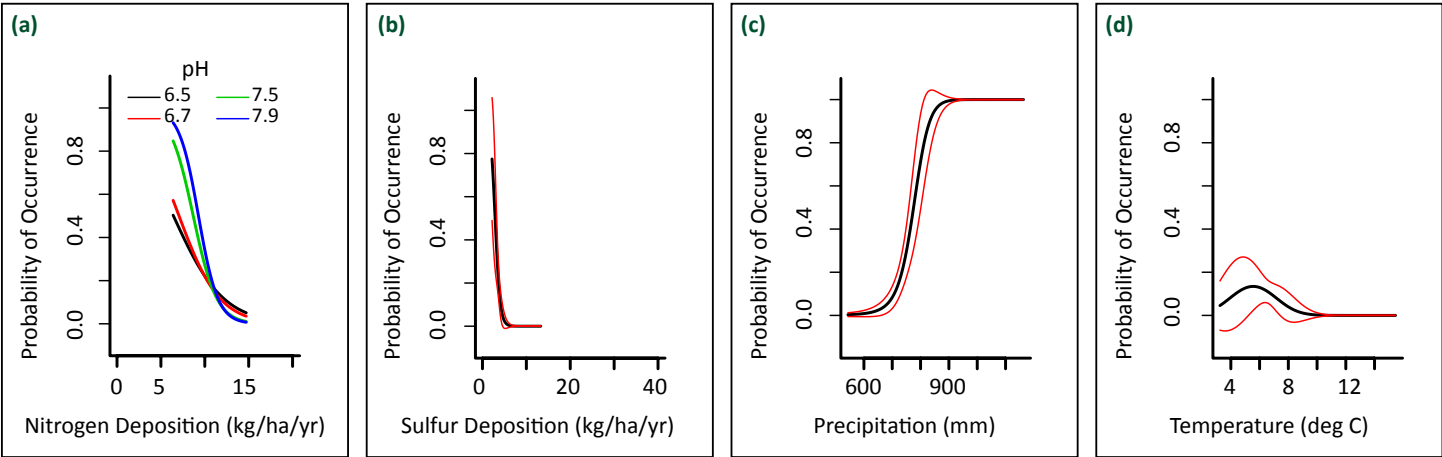


Figure 54.2. Effects of various environmental variables on the probability of occurrence of *Rudbeckia hirta*: a) N x pH interaction, b) S deposition, c) precipitation, d) temperature.

Critical Loads and Exceedances

The environmental hull for black-eyed Susan covers the eastern United States and the higher elevations of the West. The N CL is generally 6 to 8 kg N/ha/yr across most of the West and Midwest, and >10 kg N/ha/yr across the South and East. The N CL is in exceedance based on 2019–2021 total N deposition in higher elevations in the West, across most of the Midwest, and in areas with the lower CL in the South and East. The S CL is 2.2 kg S/ha/yr across the entire species’ range. There are exceedances of the S CL based on 2019–2021 TDep total S deposition across the South and into southern Illinois and Indiana.



Foliage of black-eyed Susan.
Katy Chayka, www.minnesotawildflowers.info,
Bugwood.org.

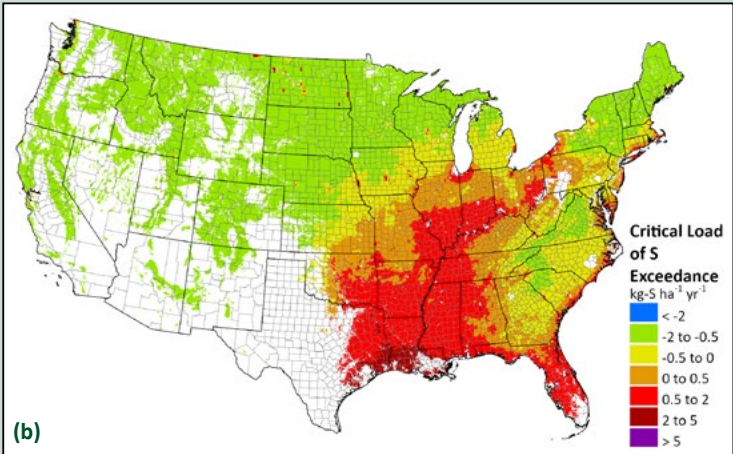
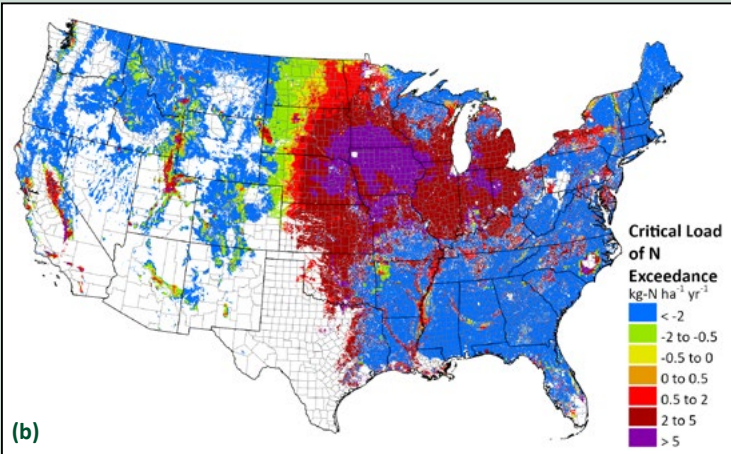
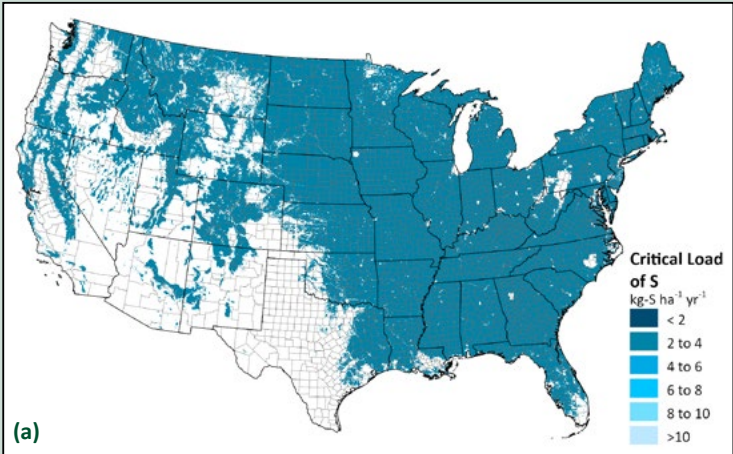
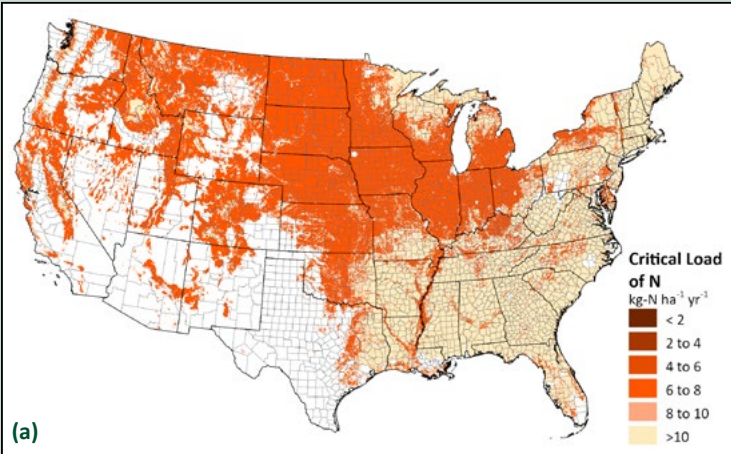


Figure 54.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Rudbeckia hirta* and (b) the exceedance of N critical loads based on TDep 2019–2021 total N deposition.

Figure 54.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Rudbeckia hirta* and (b) the exceedance of S critical loads based on TDep 2019–2021 total S deposition.

55.0 *Salvia lyrata* (lyreleaf sage)

Distribution and Conservation Status

Lyreleaf sage is a perennial herb distributed primarily throughout the eastern and lower midwestern United States. It is critically imperiled in Kansas (fig. 55.1).

Species Characteristics and Habitat

Lyreleaf sage has quadrangular flowering stems extending upright from a basal rosette of leaves. The basal leaves are long, elliptical, dark green to somewhat purple, and are often lobed or dissected. Flowering begins in April and continues through June. The flowers are violet and clustered at the top of the stem. Lyreleaf sage produces seeds that are round, dark brown, and held loosely in a cup-like structure.

It thrives in many soil types, and in full sun or a light to medium shade. Native stands grow on roadsides, and in fields and open woodlands. Lyreleaf sage can become weedy or invasive in some ecosystems and may displace wanted vegetation if poorly managed.

Ecosystem Services

Lyreleaf sage is used for landscape enhancement. It is sometimes used in gardens, and around naturalized prairie or meadow plantings, and along roadsides.

Traditional Ecological Knowledge

Traditional Indigenous medicinal uses of lyreleaf sage include external (salve from the root applied to sores) and internal (antidiarrheal infusion, cough syrup for asthma) applications.

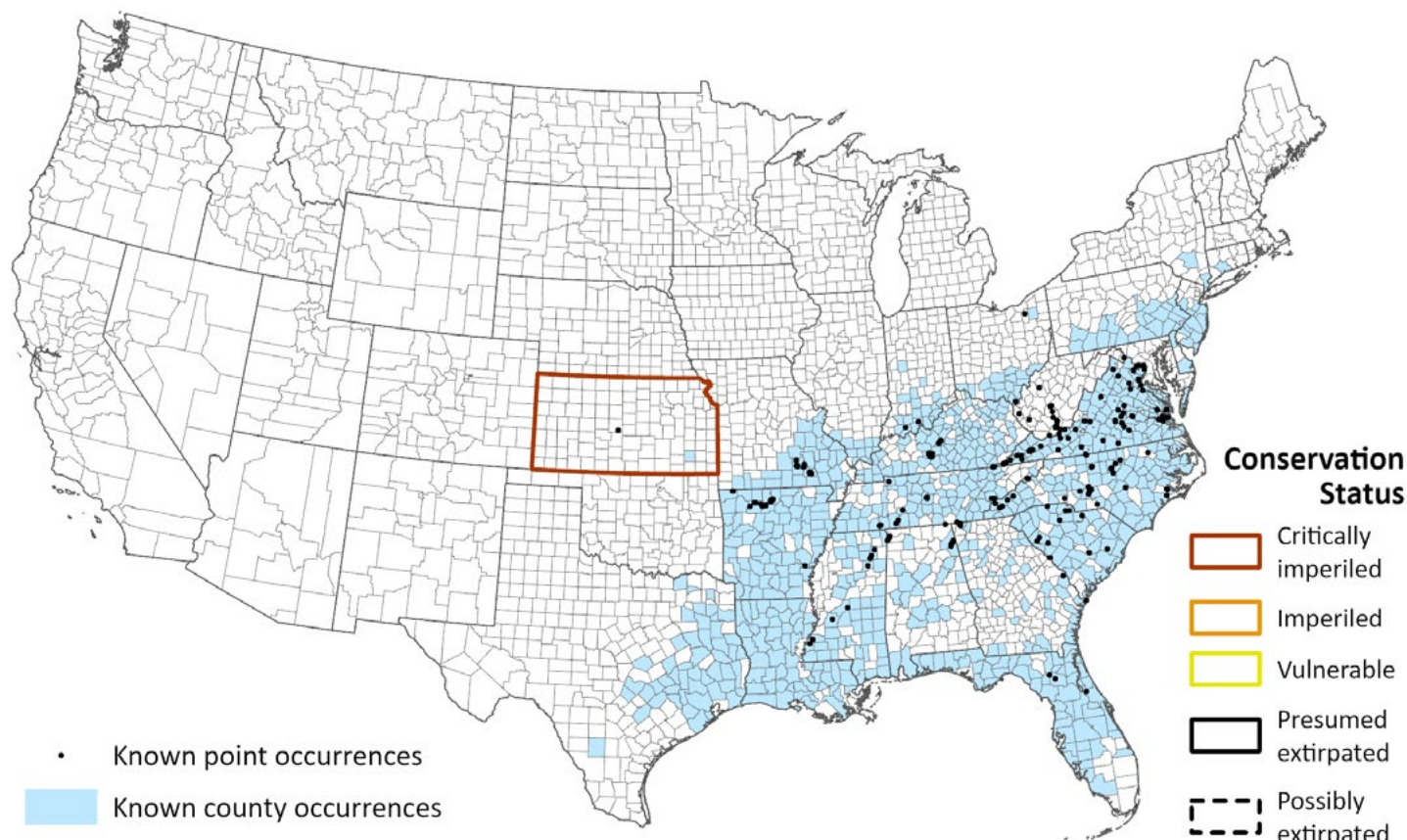


Figure 55.1. Distribution and state-level conservation status of *Salvia lyrata*. Known point occurrences were used to assess species deposition responses and critical loads.

Responses to Nitrogen and Sulfur

Available information suggests that lyreleaf sage is unresponsive to N deposition and S deposition under the range of deposition assessed. Of the other variables tested, the only significant variable is precipitation (fig. 55.2a). The probability of occurrence increases with increasing precipitation within the species' sampled range. Confidence in the N and S relationships (or lack thereof) is moderate-to-high, with good model performance ($R^2 = 0.196$, AUC = 0.79; both moderate confidence), low VIFs (VIF-N = 1.1, VIF-S = 1.1; both high confidence), and a moderate N-S correlation ($r=0.53$, moderate confidence).

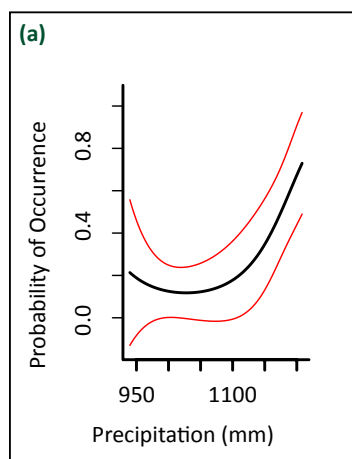


Figure 55.2. Effects of various environmental variables on the probability of occurrence of *Salvia lyrata*: a) precipitation.



Flowers of lyreleaf sage.
Rebekah D. Wallace, University of Georgia, Bugwood.org.

Critical Loads and Exceedances

The environmental hull for lyreleaf sage covers the eastern United States, the southern Midwest and high elevations on the west coast. There are no responses to N or S.



Foliage of lyreleaf sage.
John D. Byrd, Mississippi State University, Bugwood.org.

56.0 *Schizachyrium scoparium* (little bluestem)

Distribution and Conservation Status

Little bluestem is a native perennial grass found across the contiguous United States, from Maine south to Florida, west to Arizona, and north to Montana (fig. 56.1).

Species Characteristics and Habitat

Little bluestem is an up-right, warm-season, frost-sensitive plant commonly found in the understory of pine tree stands, and in tallgrass and coastal prairies. Little bluestem's roots are fibrous and grow deep stretching downwards over 5 feet. It does not usually form rhizomes, but on wet sites it may form a sod with short rhizomes. In dry conditions, little bluestem will grow up-right in pure stands less than a foot wide. The stems are solid and up to 6.5 feet tall. The leaves are flat and slender, stretching up to 14 inches long when mature. In the spring and summer, the leaves are light green, but at maturity both leaves and

stems turn a purplish-reddish-brown. The leaves are red and brown at maturity and red in fall and winter. Little bluestem often produces flowers; however it is dependent on growing conditions and tall grass competition. Seed production is usually consistent except during droughts. The seeds are mostly wind-dispersed over short distances up to 6 feet away from the parent plant. Occasionally, animals will carry the seeds farther.

Little bluestem thrives on coarse, well-drained, disturbed, and nutrient deficient soils and sapric peat. It can grow well with low levels of available nitrogen and low soil fertility. It is found in dune habitats, prairies, savannas, and forests. Fire can increase the growth rate of little bluestem by removing litter and standing dead plant materials, thus increasing soil temperature and light penetration. Hotter fires can top-kill or completely kill little bluestem.

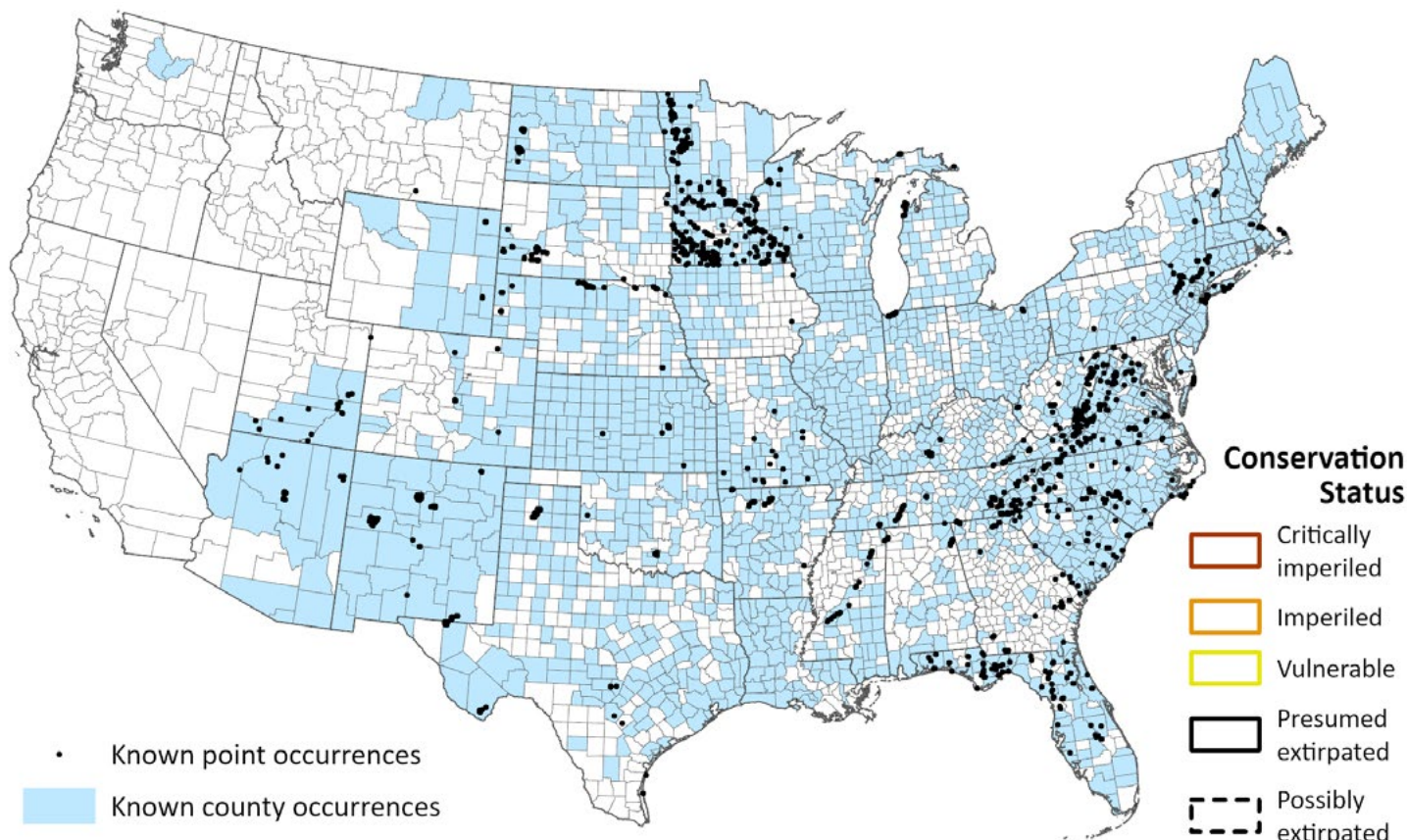
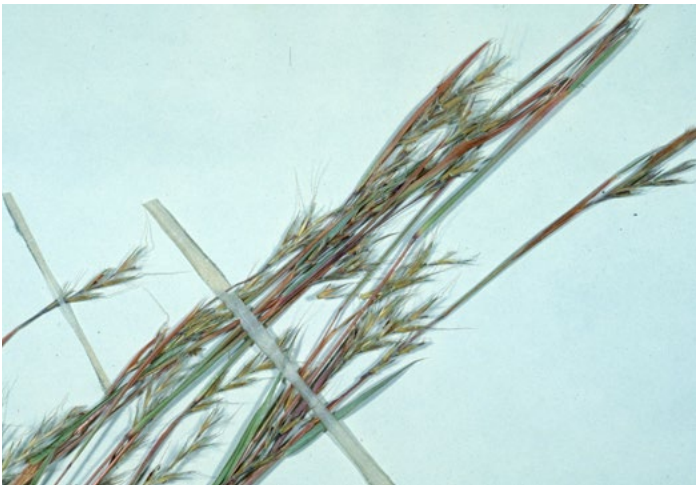


Figure 56.1. Distribution and state-level conservation status of *Schizachyrium scoparium*. Known point occurrences were used to assess species deposition responses and critical loads.

Wildlife and Livestock Uses

Little bluestem provides food and shelter for many important upland game bird species. Songbirds and sharp-tailed grouse enjoy the seeds. Northern bobwhites, ring-necked pheasants, and scaled quail also feed on it. In the Great Plains, little bluestem offers cover to the red-headed woodpecker, Baltimore oriole, eastern kingbird, vesper sparrow, field sparrow, lark sparrow, brown thrasher, American goldfinch, and brown-headed cowbird. The bobwhite quail, northern bobwhites, lesser prairie chickens, Montezuma quail, sharp-tailed grouse, and other upland game birds use little bluestem for nesting habitat and cover. Bison eat little bluestem in the Great Plains. Young little bluestem is highly palatable to most livestock, especially cattle and horses.



Flowers of little bluestem.
Howard F. Schwartz, Colorado State University, Bugwood.org.

Ecosystem Services

Little bluestem is used extensively in prairie restoration projects, to restore disturbed areas along highways, and to reclaim mine spoils. It is becoming a popular landscaping plant for homes due to its colorful and easy-care nature.

Traditional Ecological Knowledge

Little bluestem has a variety of traditional uses in medicine (ashes to treat syphilitic sores), textiles (clothing and moccasin insulation), and ceremonies (stems as sweat lodge switches).

Responses to Nitrogen and Sulfur

The probability of occurrence of little bluestem has relatively simple relationships with the variables tested. It increases with N deposition up to roughly 11.2 kg N/ha/yr and then decreases with higher N deposition (fig. 56.2a). It decreases with S deposition (fig. 56.2b). There are interactions with pH for both N and S deposition, but these do not much affect the probability of occurrence (Clark et al. 2019). The only significant climate variable is temperature (fig. 56.2c). The probability of occurrence increases below around 8 °C and above 13 °C within the species’ sampled range. Confidence in the N and S relationships is moderate-to-high, with good model performance ($R^2 = 0.206$, AUC = 0.8; moderate and high confidence, respectively), low VIFs (VIF-N = 1.1, VIF-S = 1.2; both high confidence), and a moderate N-S correlation ($r=0.64$, moderate confidence).

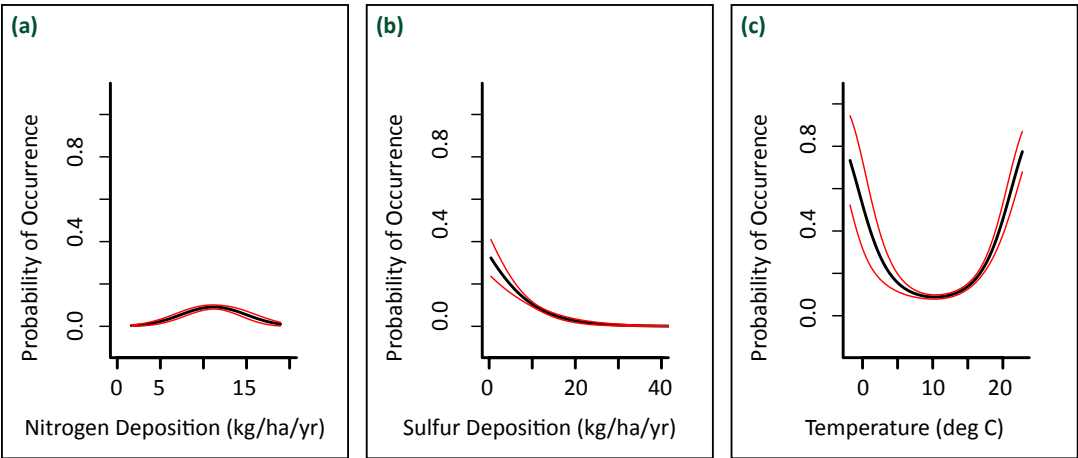


Figure 56.2. Effects of various environmental variables on the probability of occurrence of *Schizachyrium scoparium*: a) N deposition, b) S deposition, c) temperature.

Critical Loads and Exceedances

The environmental hull for little bluestem covers the United States excluding the Desert Southwest. The N CL is >10 kg N/ha/yr across most of the range with small areas between 8 and 10 kg N/ha/yr in Florida and Georgia. The N CL is in exceedance based on 2019–2021 total N deposition in the higher deposition areas associated with agriculture in the Midwest, South, and East. The S CL is 0.4 kg S/ha/yr across the entire species' range. There are exceedances of the S CL based on 2019–2021 TDep total S deposition across all areas except the lower elevation plains of the West.

Little bluestem grass growing on a field in Colorado.
Dave Powell, USDA Forest Service (retired), Bugwood.org.

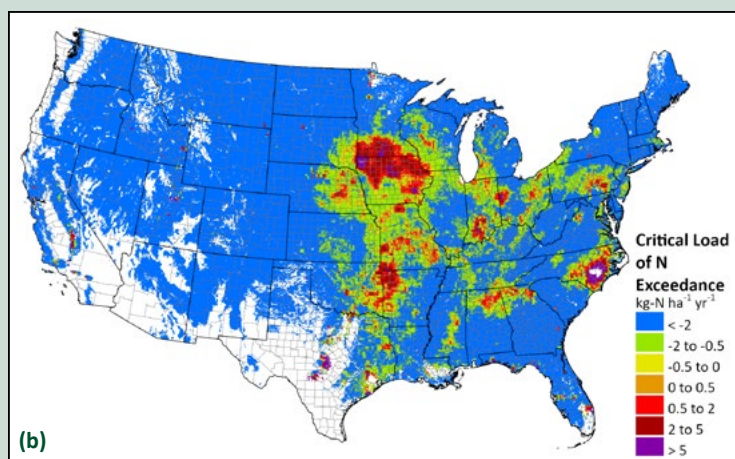
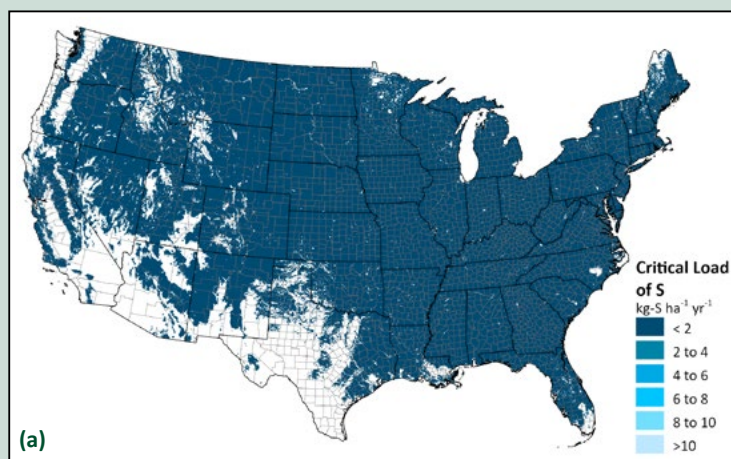
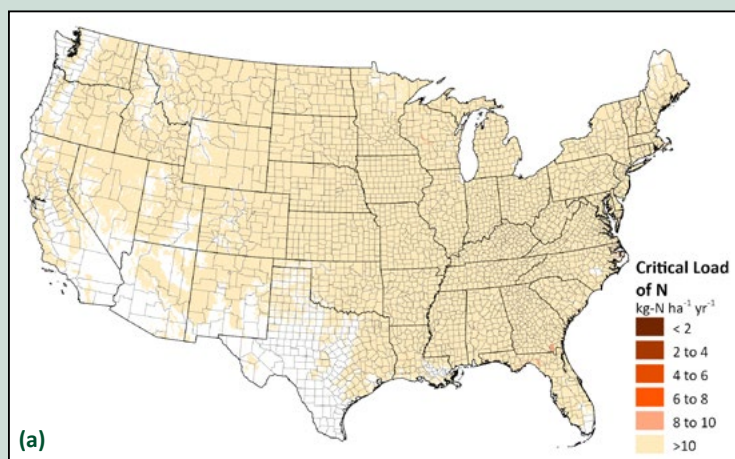


Figure 56.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Schizachyrium scoparium* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

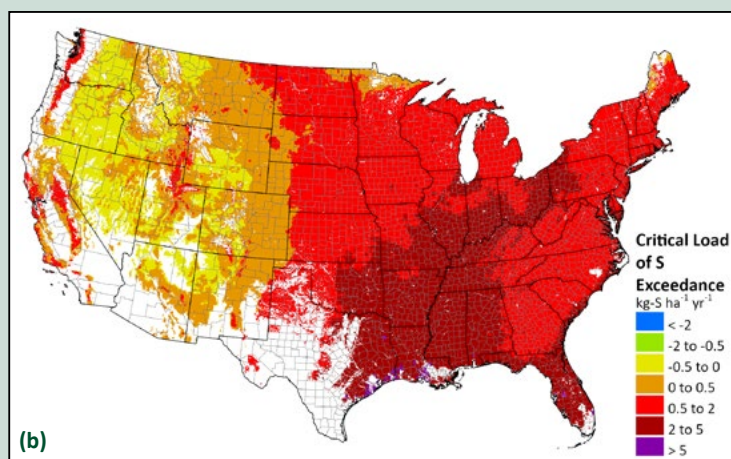


Figure 56.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Schizachyrium scoparium* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

57.0 *Solidago canadensis* (Canada goldenrod)

Distribution and Conservation Status

Canada goldenrod is a native perennial grass that grows throughout the United States excluding Hawaii, Louisiana, Alabama, Georgia, South Carolina, and Florida (fig. 57.1).

Species Characteristics and Habitat

Canada goldenrod is a warm-season, long-lived plant that spreads by rhizomes and seeds. The rhizomes grow from the base of the aerial stems and are usually 2 to 5 inches long. The smooth stems grow up to 7 feet tall and are covered with fine hairs at the top. Leaves alternate around each central stem with larger leaves growing lower on the stem. The leaves are sharply toothed, lance-shaped, triple-nerved, covered with fine hairs, and 2 to 5 inches long. Canada goldenrod blooms in late summer, usually from July through October. The 10-inch wide inflorescence grows mostly on one side of long, drooping panicle branches and produces between 10 to 17 flowers. The fruit is an achene. Canada goldenrod seeds are small and sparsely covered with hairs and many pale bristles at the

tip. The seed is spread by wind with most seeds falling within 6.5 feet of the parent plant.

Canada goldenrod can thrive in full sun or part shade. It prefers moist soil and moderate levels of organic matter. Canada goldenrod is found in damp meadows, waterways, roadside ditches and railroads. It is occasionally found growing in dry, upland prairies, and deciduous and evergreen forests. It can withstand intense cutting and can regrow if cut during the optimal growing season. Canada goldenrod is susceptible to many pathogens and insect pests, including powdery mildew, root rot and needle blister rust which is known to reduce seed production. Canada goldenrod commonly establishes on abandoned farmland, infrequently grazed pastures, waste areas and tall-grass prairies. In areas disturbed by fire, Canada goldenrod is one of the first species to establish. Fire will top-kill all above ground parts of Canada goldenrod. In low or moderate severity fires, Canada goldenrod is known to respond positively and regrow.

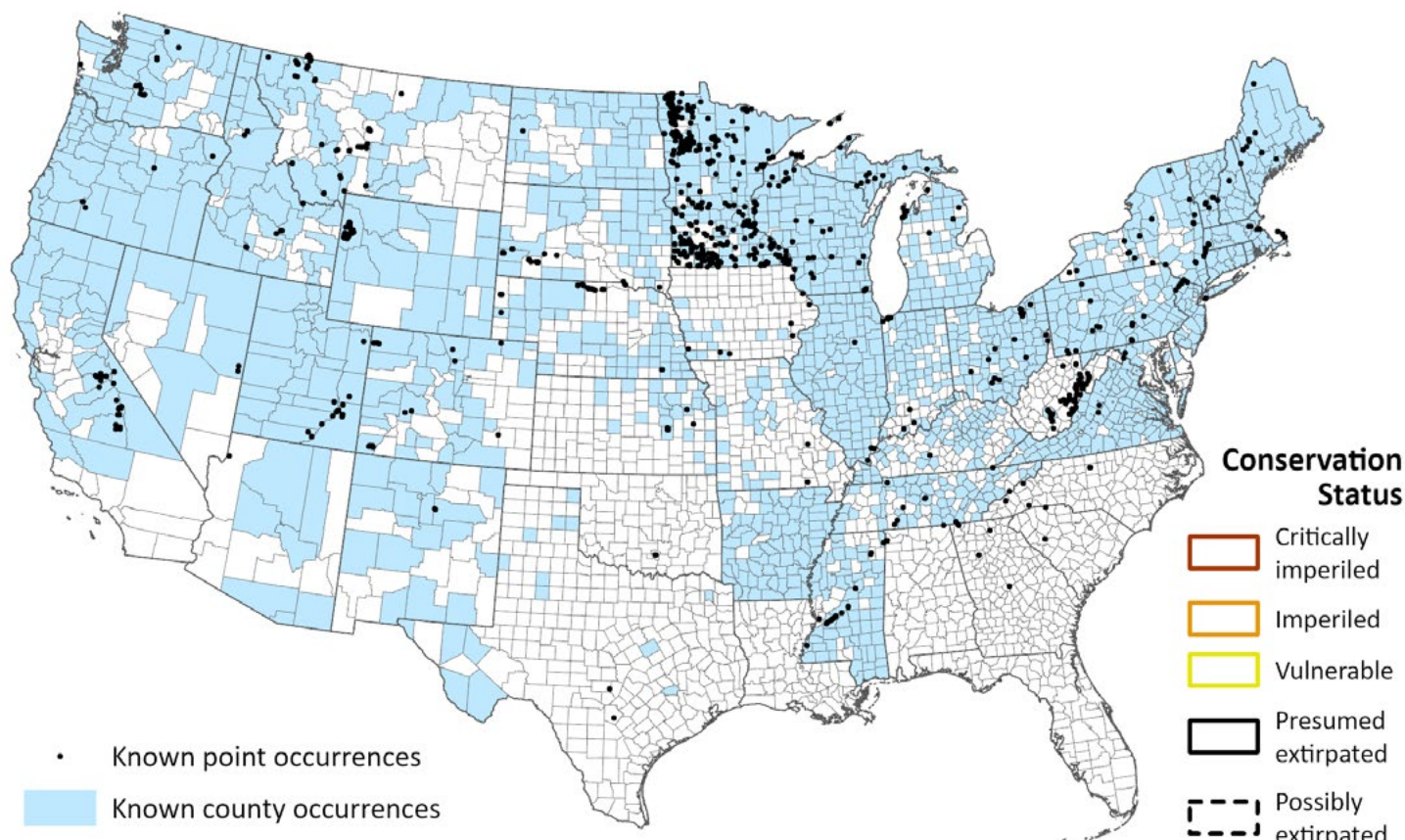


Figure 57.1. Distribution and state-level conservation status of *Solidago canadensis*. Known point occurrences were used to assess species deposition responses and critical loads.

Wildlife and Livestock Uses

Canada goldenrod serves as a vital source of pollen and nectar for bees and other insects such as solitary wasps and pollen-eating beetles like the soldier beetle and the black blister beetle. It provides poor cover for elk, deer, pronghorn, and upland game birds. Canada goldenrod is considered to have fair palatability for cattle, sheep and horses. It is grazed by cattle, sheep, horses, and whitetail deer.



Foliage of Canada goldenrod.
Bonsak Hammaras, NIBIO - The Norwegian Institute of Bioeconomy Research, Bugwood.org.

Ecosystem Services

Canada goldenrod is often used in revegetation of disturbed areas, reclaiming mine spoils, and stabilizing soil.

Traditional Ecological Knowledge

Canada goldenrod has a variety of traditional uses from nutritional (seeds, roots) to medicinal. It can be used as a pain reliever (root/flower infusions), pediatric sedative (tuber infusion, decoction), fever reducer (shoot infusion, flower infusion), emetic (root infusion), and diarrheal aid (flower infusion, plant-top decoction).

Responses to Nitrogen and Sulfur

The probability of occurrence for Canada goldenrod has relatively simple relationships with the variables tested. It increases with N deposition up to roughly 15-17 kg N/ha/yr (fig. 57.2a) and is unresponsive to S deposition (fig. 57.2b). There is a weak interaction between N deposition and soil pH, but this does not largely affect the probability of occurrence (Clark et al. 2019). The climate effects are shown in Figure 57.2c (precipitation) and Figure 57.2d (temperature). The probability of occurrence decreases with increasing precipitation (there were few observations at higher precipitation levels) and decreases with increasing temperatures within the species' sampled range. Confidence in the N and S relationships is moderate-to-high, with good model performance ($R^2 = 0.264$, AUC = 0.84; both high confidence), low VIFs (VIF-N = 1.2, VIF-S = 1.3; both high confidence), and a moderate N-S correlation ($r=0.68$, moderate confidence).

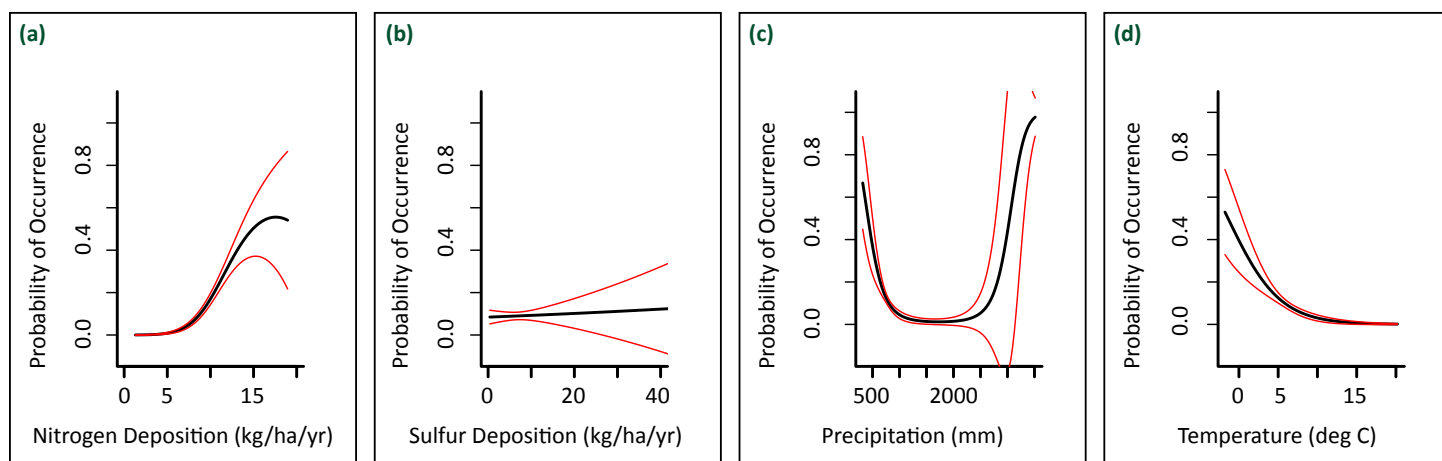


Figure 57.2. Effects of various environmental variables on the probability of occurrence of *Solidago canadensis*: a) N deposition, b) S deposition, c) precipitation, d) temperature.

Critical Loads and Exceedances

The environmental hull for Canada goldenrod covers the upper two-thirds of the United States. The N CL is >10 kg N/ha/yr across the entire range. The N CL is in exceedance based on 2019–2021 total N deposition only in the highest deposition areas associated with agriculture in the Midwest and East. The S CL is 41.7 kg S/ha/yr across the entire species' range. There are no exceedances of the S CL based on 2019–2021 TDep total S deposition.



Plant of Canada goldenrod.
Theodore Webster, USDA Agricultural Research Service, Bugwood.org.

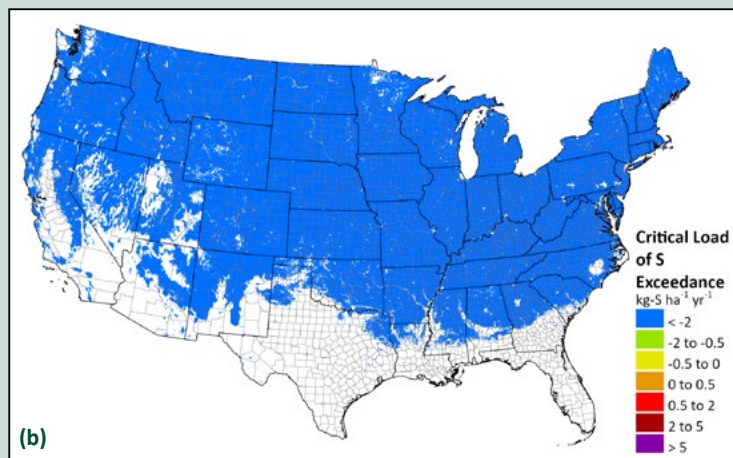
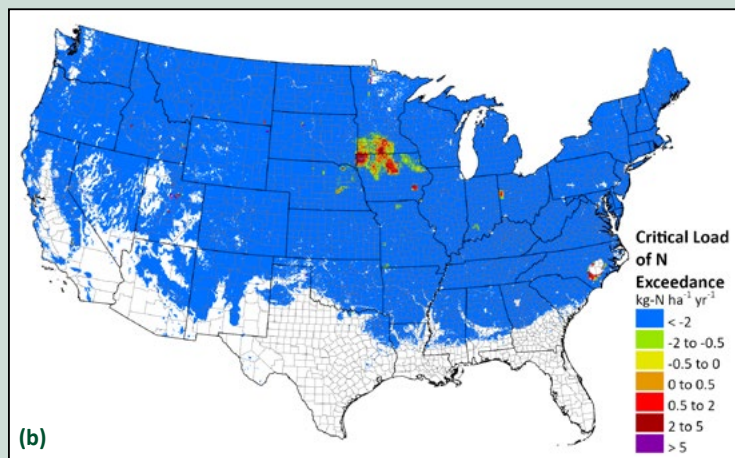
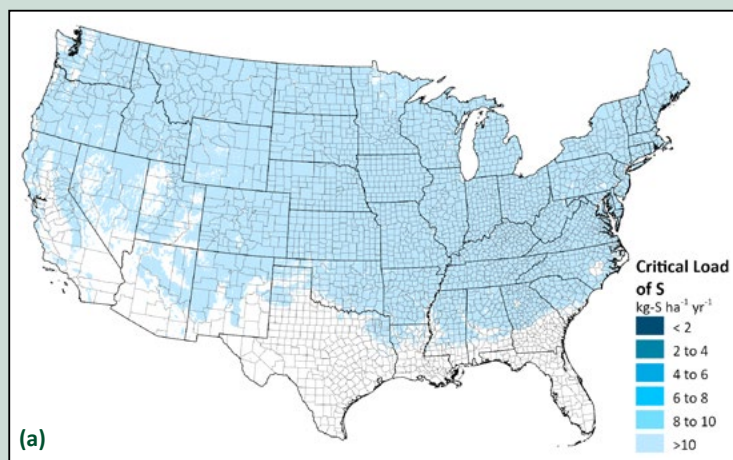
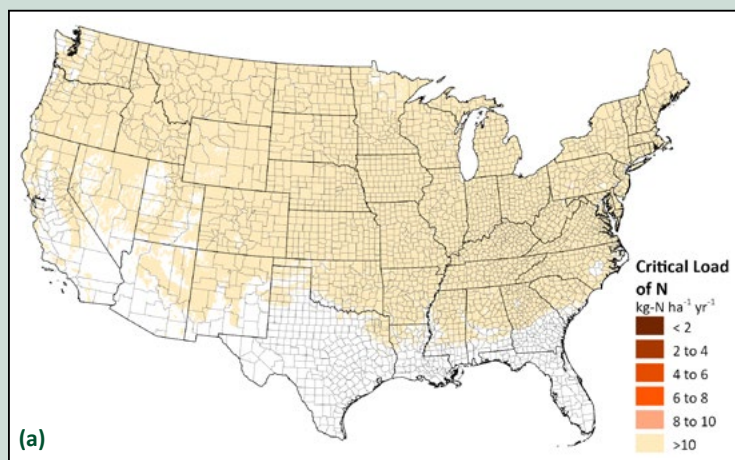


Figure 57.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Solidago canadensis* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 57.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Solidago canadensis* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

58.0 *Solidago missouriensis* (Missouri goldenrod)

Distribution and Conservation Status

Missouri goldenrod is a native perennial forb found in most midwestern and western parts of the United States. Missouri goldenrod is a warm-season, short-lived plant of dry, open slopes in upland prairies, plains, meadows, deciduous and evergreen forests, deserts, and along roadsides, railroads, and ditches. It is vulnerable in Kentucky (fig. 58.1).

Species Characteristics and Habitat

The stems grow singularly or in a stand from a woody base or from extensive rhizomes. They are reddish-green, smooth, lean, upright and up to 3 feet tall. The leaves are alternate, triple-nerved, and have sparsely serrated edges. Missouri goldenrod's basal leaves grow up to 1 foot long and have short petioles, while the upper leaves

are smaller and sessile. Numerous inflorescences form on curved panicle branches. The inflorescences have 7 to 13 yellow disc flowers and 8 to 13 yellow ray flowers, all blooming in July. The seeds are smooth, brown cylinders, with or without hairs, and have a white bristly pappus.

Missouri goldenrod thrives in sandy loam to clay loam soils. It is tolerant of weakly acidic to moderately basic and weakly saline conditions. Missouri goldenrod may form thick stands in its habitats, particularly where ground is open and disturbed. It is established by seed or by its expansive rhizomes. The native leaf feeding beetle *Trirhabda canadensis* is known to damage Missouri goldenrod. When Missouri goldenrod is in a dormant state it can survive fires. It has been reported that fire has no effect or a minimal negative effect on Missouri goldenrod.

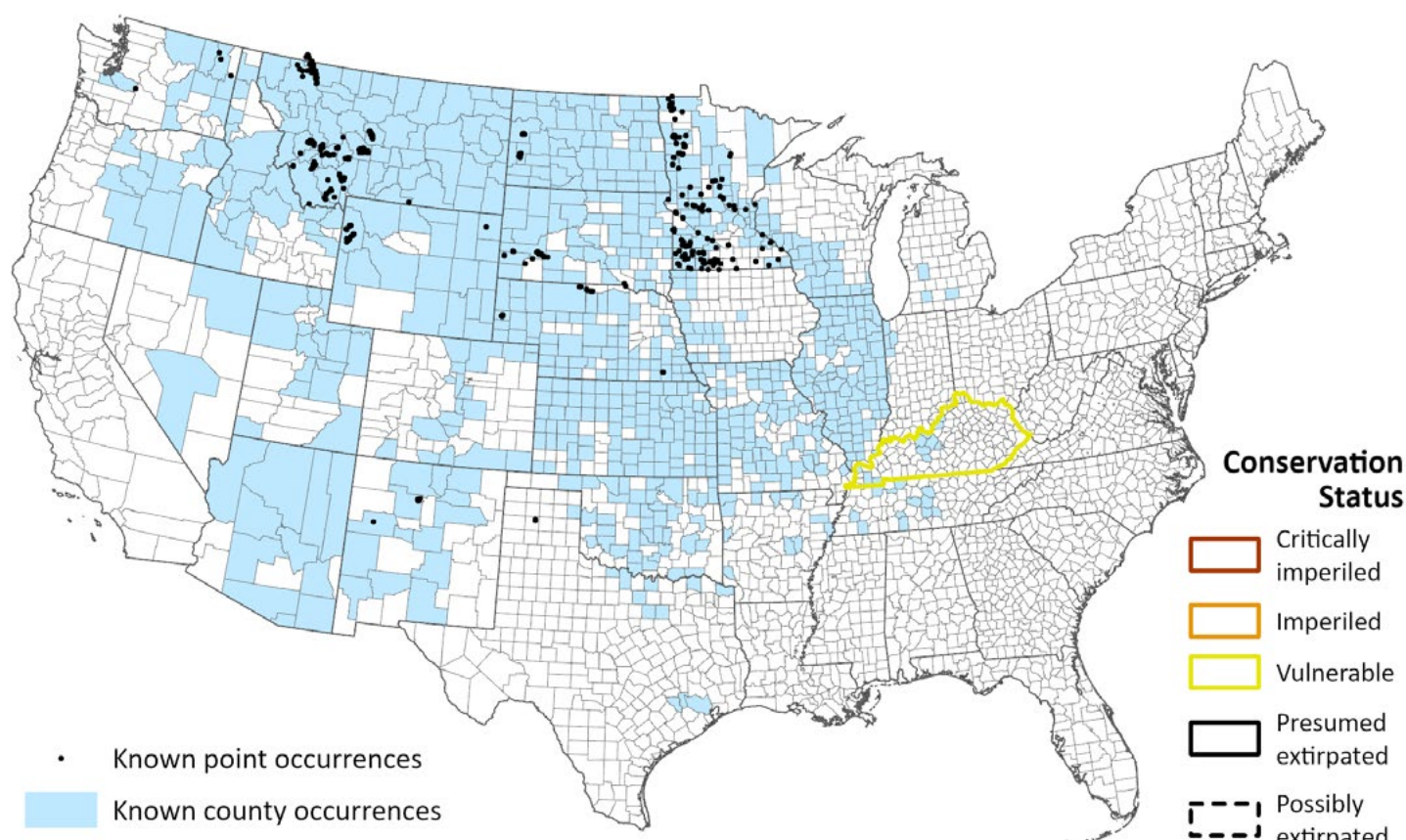


Figure 58.1. Distribution and state-level conservation status of *Solidago missouriensis*. Known point occurrences were used to assess species deposition responses and critical loads.

Wildlife and Livestock Uses

Missouri goldenrod provides vital sources of pollen and nectar for bees, wasps, and pollen-eating beetles such as the soldier beetle and the black blister beetle. It is grazed by sheep, cattle, deer, and antelope but has poor forage value. The plant may be toxic to sheep and is slightly poisonous to other livestock.

Ecosystem Services

Missouri goldenrod is used for revegetating disturbed areas, for reclaiming mine spoils, and stabilizing soil.



Foliage of Missouri goldenrod.
Mary Ellen (Mel) Harte, Bugwood.org.

Traditional Ecological Knowledge

Chewed leaves and flowers of this plant relieve sore throats and chewed roots relieve toothache.

Responses to Nitrogen and Sulfur

The probability of occurrence for Missouri goldenrod is related to the interaction between N and S deposition (fig. 58.2a). At lower S deposition (≤ 1.2 kg S/ha/yr), Missouri goldenrod increases with N deposition up to approximately 9-10 kg N/ha/yr and then decreases, while at higher S deposition (≥ 2.5 kg S/ha/yr) the maximum probability of occurrence is lower and increases and decreases at higher levels of N deposition. The climate effects are shown in Figure 58.2b (precipitation) and Figure 58.2c (temperature). The probability of occurrence peaks weakly around 500 mm precipitation (there were few observations at the higher precipitation levels) and 5 °C within the species’ sampled range. Confidence in the N and S relationships is moderate-to-high, with good model performance ($R^2 = 0.118$, AUC = 0.73; both moderate confidence), low VIFs (VIF-N = 1.2, VIF-S = 1.3, both high confidence), and a moderate N-S correlation ($r=0.71$, moderate confidence).

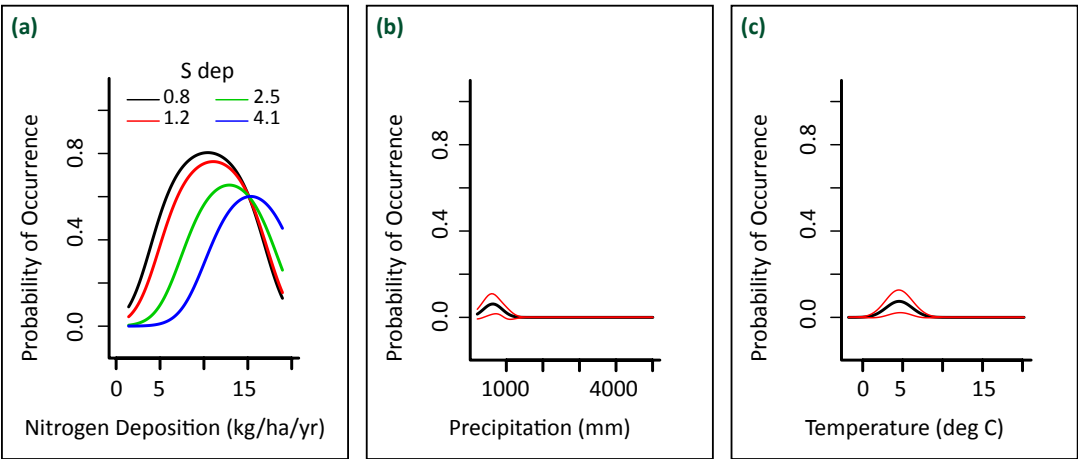


Figure 58.2. Effects of various environmental variables on the probability of occurrence of *Solidago missouriensis*: a) N x S interaction, b) precipitation, c) temperature.

Critical Loads and Exceedances

The environmental hull for Missouri goldenrod covers the northern Midwest, Interior West, and northern New England states. The N CL is 8 to 10 kg N/ha/yr in the lower elevation plains of the West and >10 kg N/ha/yr across the rest of the range. The N CL is in exceedance based on 2019–2021 total N deposition only in the highest deposition areas associated with agriculture in the Midwest. The S CL is 0.4 kg S/ha/yr across most of the species' range with small areas with a S CL of 41.7 kg S/ha/yr in the eastern Midwest. There are exceedances of the S CL based on 2019–2021 TDep total S deposition in all areas except the lower elevation plains of the West.



Flowers of Missouri goldenrod.
Mary Ellen (Mel) Harte, Bugwood.org.

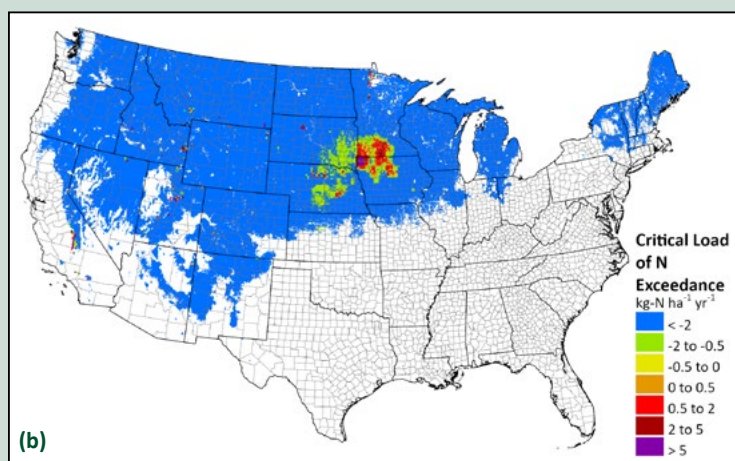
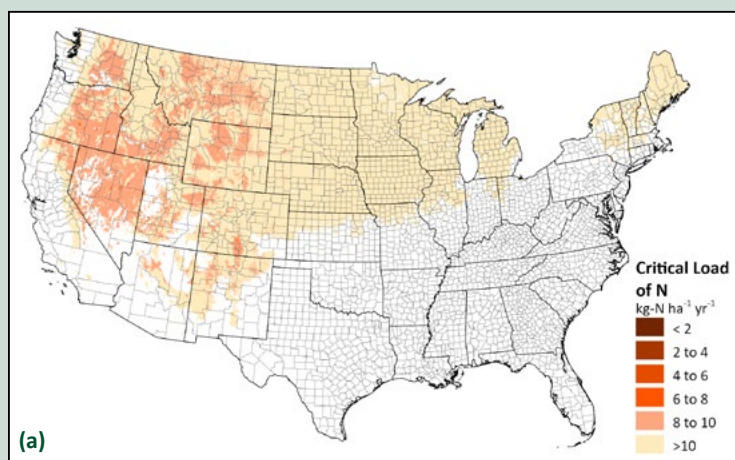


Figure 58.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Solidago missouriensis* and (b) the exceedance of N critical loads based on TDep 2019–2021 total N deposition.

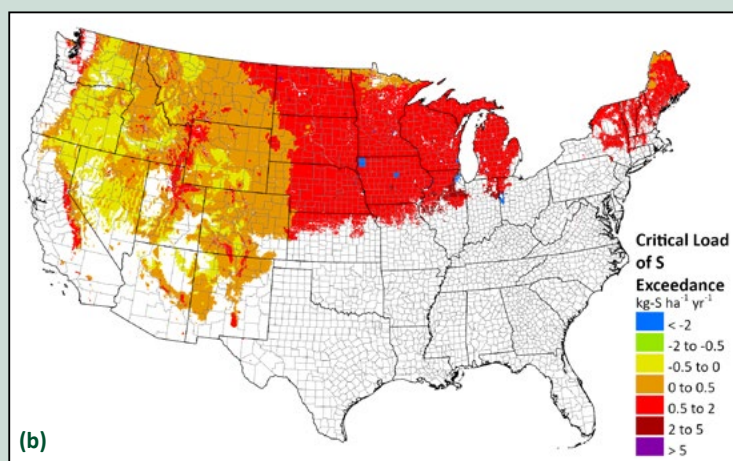
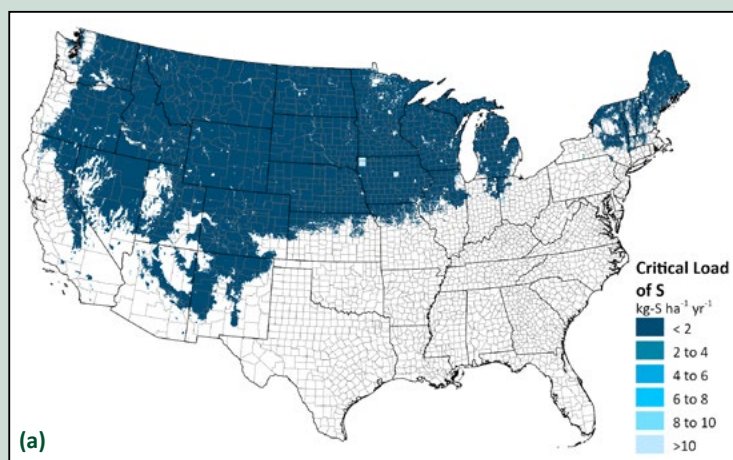


Figure 58.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Solidago missouriensis* and (b) the exceedance of S critical loads based on TDep 2019–2021 total S deposition.

59.0 *Solidago nemoralis* (gray goldenrod)

Distribution and Conservation Status

Gray goldenrod is a native perennial forb that is well-distributed from Georgia to Texas, north to Canada and west to the Rocky Mountains. It thrives in meadows, dry open woods, upland prairies, pastures, savannas, fallow fields, thickets, roadsides, railroads, eroded slopes, and sand dunes. It is vulnerable in Wyoming (fig. 59.1).

Species Characteristics and Habitat

Gray goldenrod grows from 6 inches and seldom reaches 2.5 feet tall. The thick root system consists of a branching caudex and a structure that serves as water storage for the plant and rhizomes. The central stem is either reddish or gray-green and covered with short white hairs, usually in lines, with winged leaflets at the axils of the upper leaves. The alternating leaves are up to 4 inches long, covered with fine short hairs, decreasing in length with height on the stem. The leaf margins are smooth or slightly serrate. Gray goldenrod blooms later than most other goldenrods, blooming during the fall and continuing for about a month. The narrow flowerhead is wider in

the middle with numerous yellow compound flowers about ¼-inch across. The flowers occasionally have a light fragrance. The small, dry seeds develop tufts of white hair-like pappi that aid wind dispersal.

Gray goldenrod is a resilient, pioneer plant. It prefers growing in full sun and dry soil in sand, clay or gravel. It will grow in fertile soils however it can be short-lived if the site is too rich. Gray goldenrod is easy to maintain in environments with low to moderate levels of nitrogen.

Wildlife Uses

A variety of insects, including long-tongued and short-tongued bees, sphecids and vespids wasps, flies, butterflies, moths and beetles, use the flowers for pollen and nectar. Bee pollinators include honey bees, little carpenter bees, halictid bees and plasterer bees. Fly pollinators include syrphid flies, tachinid flies, flesh flies, blow flies and muscid flies. The caterpillars of many moths, including the goldenrod scarlet plant bug, net-veined beetle and leaf-footed bug, feed on the foliage and other parts of this

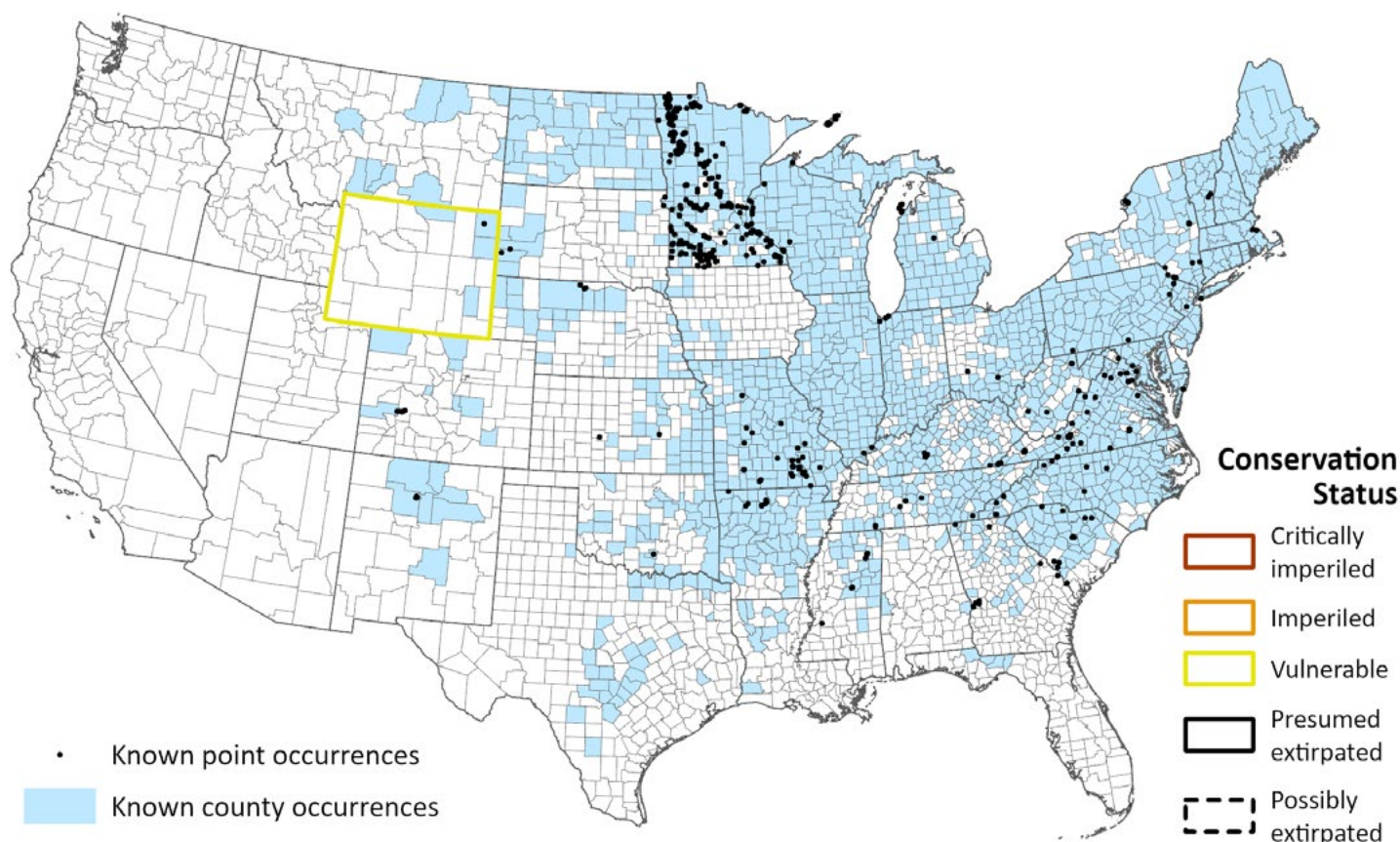


Figure 59.1. Distribution and state-level conservation status of *Solidago nemoralis*. Known point occurrences were used to assess species deposition responses and critical loads.

plant. The seeds are occasionally eaten by the eastern goldfinch.

Ecosystem Services

Gray goldenrod produces visually appealing flowers and is an effective groundcover in dry, harsh, sunny conditions. It is often used in native plant landscaping, rock gardens, butterfly gardens and meadow plantings. Gray goldenrod seed is occasionally included in conservation mixes.

Traditional Ecological Knowledge

Traditional uses of gray goldenrod include a variety of medicinal applications to treat skin ulcers (leaves), yellow jaundice (boiled roots), and kidney afflictions (roots). The plant can also be burned for incense. The seeds may be consumed as a food source.



Flowers of gray goldenrod.
Rob Routledge, Sault College, Bugwood.org.

Responses to Nitrogen and Sulfur

The probability of occurrence for gray goldenrod is related to the interaction between N and soil pH (fig. 59.2a). The maximum probability of occurrence is highest under more alkaline conditions ($\text{pH} \geq 7.9$), peaking at approximately 7 kg N/ha/yr. The maximum probability of occurrence is lower under more acidic conditions ($\text{pH} \leq 7$), increasing up to 10-12 kg N/ha/yr and then decreasing above that. There is also an interaction between S deposition and soil pH (fig. 59.2b), but this relationship is uncertain given the high VIF for sulfur (Clark et al. 2019). The only significant climate variable is precipitation (fig. 59.2c). The probability of occurrence decreases with increasing precipitation within the species' sampled range. Confidence in the N relationship is moderate-to-high, with good model performance ($R^2 = 0.125$, $\text{AUC} = 0.72$; both moderate confidence), low VIFs ($\text{VIF-N} = 1.1$, $\text{VIF-S} = 1.3$; both high confidence), and a low N-S correlation ($r=0.33$, high confidence).



Plant of Gray goldenrod.
Rob Routledge, Sault College, Bugwood.org.

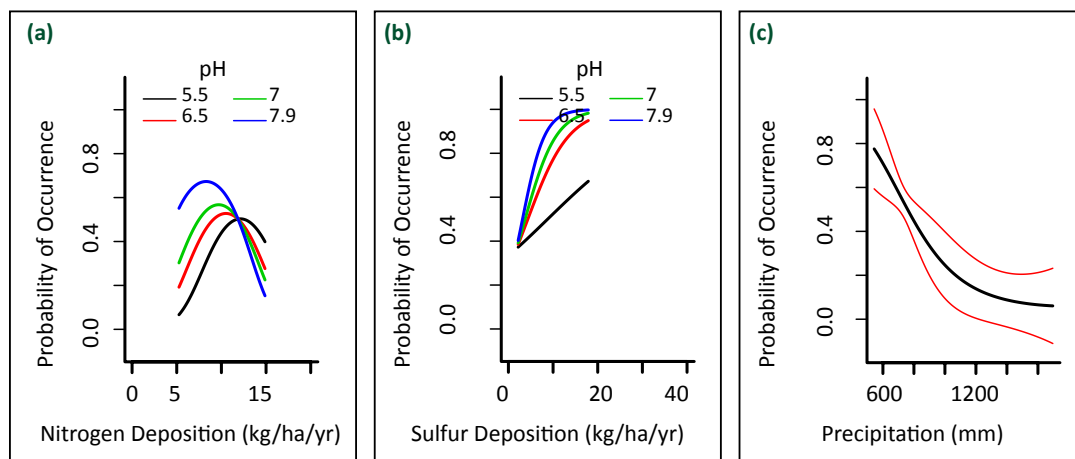


Figure 59.2. Effects of various environmental variables on the probability of occurrence of *Solidago nemoralis*: a) N x pH interaction, b) S x pH interaction, c) precipitation.

Critical Loads and Exceedances

The environmental hull for gray goldenrod covers the eastern United States and higher elevations of the West. The N CL is >10 kg N/ha/yr in most of the range with areas in the western Midwest and Rocky Mountains with a N CL of 8 to 10 kg N/ha/yr. The N CL is in exceedance based on 2019–2021 total N deposition only in the

highest deposition areas associated with agriculture in the Midwest and East. The S CL is 17.9 kg S/ha/yr across most of the species’ range with small areas with a S CL of 2.2 kg S/ha/yr along the east coast and Appalachian mountains. There are exceedances of the S CL based on 2019–2021 TDep total S deposition in the areas south of New York with the lower CL.

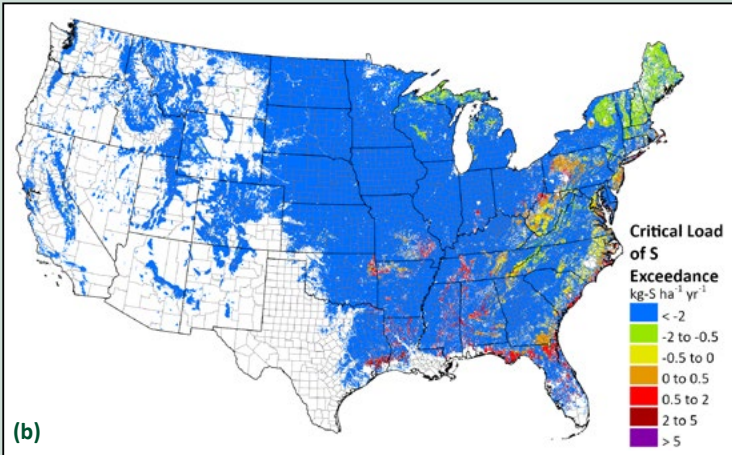
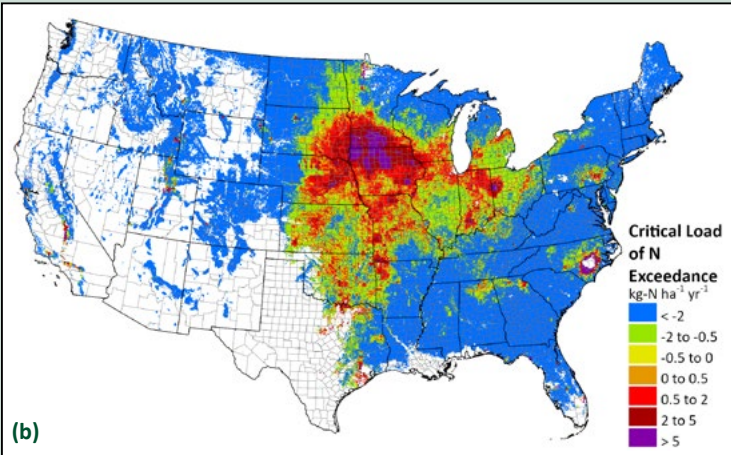
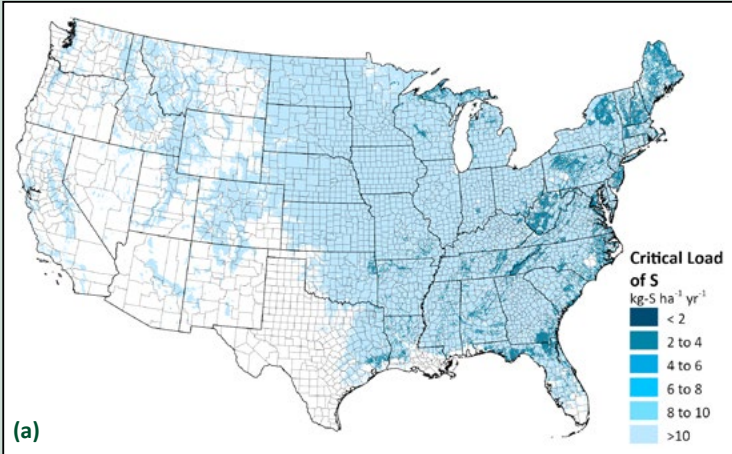
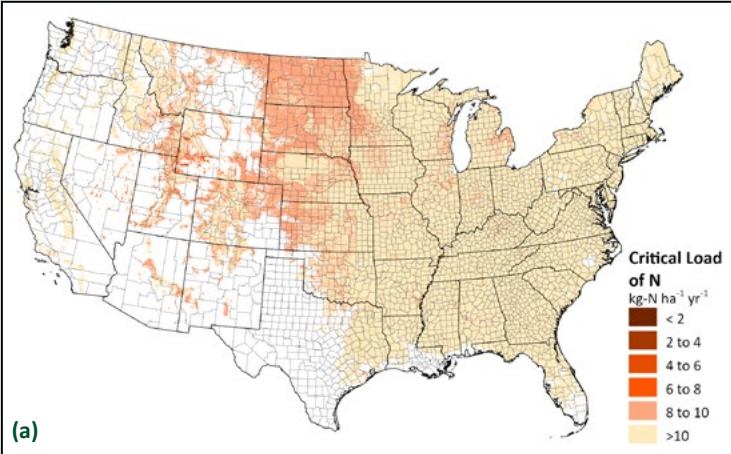


Figure 59.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Solidago nemoralis* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 59.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Solidago nemoralis* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

60.0 *Sorghastrum nutans* (yellow prairie grass)

Distribution and Conservation Status

Yellow prairie grass is a native perennial grass found throughout the eastern and central United States and as far west as Arizona, Wyoming, and Utah. It is a warm-season plant of prairies, bottomlands, open woods, and meadows. It is critically imperiled in Maine and Rhode Island, and imperiled in Utah (fig. 60.1).

Species Characteristics and Habitat

The glabrous culms (hollow stems) have hairy nodes and grow 3 to 5 feet tall. The root system extends from short, scaly rhizomes. The leaf blades are flat and between 10 and 20 inches long, narrowing at the point of attachment. The foliage color varies from glaucous blue-green to green. A notable characteristic is the inflorescence, a dense golden-bronze to yellow, plume-like panicle.

Yellow prairie grass thrives on deep, moist, well-drained soils varying from heavy clays to coarse sands. It is highly tolerant of poorly to excessively well-drained soils, and acidic to alkaline conditions. It has a medium tolerance to salinity and drought. Yellow prairie grass needs a soil temperature above 50 °F in a firm, moist seedbed for satisfactory germination, making early May to late June the optimal time for planting. Perennial or noxious weeds make germination challenging. When fertilizing, moderate levels of phosphorus and potassium are recommended for establishment. Nitrogen applications are not recommended until the grass is well established. This plant can become weedy or invasive in some regions or habitats and may displace desirable vegetation if not properly managed. Yellow prairie grass is tolerant to fire. It is adapted to periodic burning and survives by

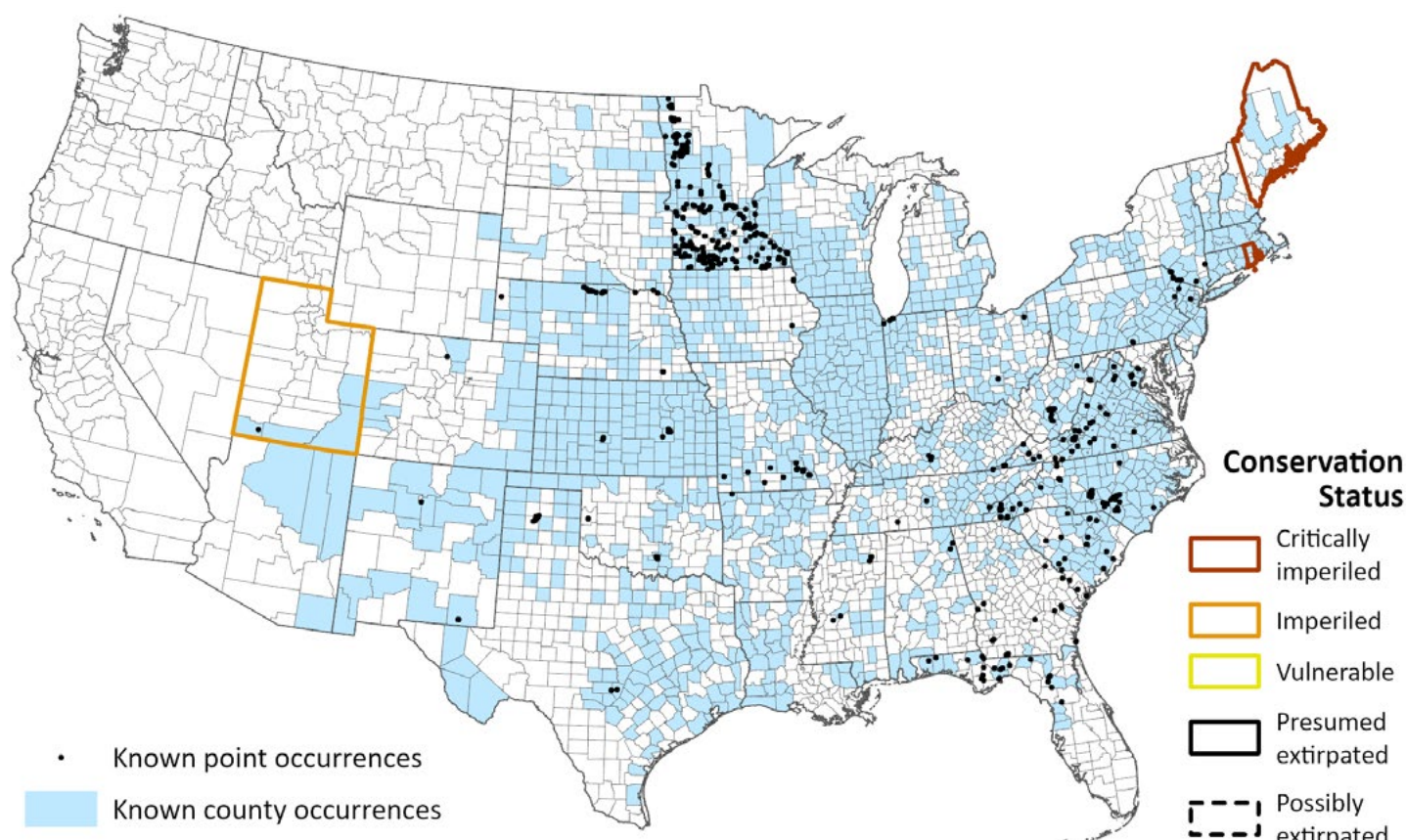


Figure 60.1. Distribution and state-level conservation status of *Sorghastrum nutans*. Known point occurrences were used to assess species deposition responses and critical loads.

sprouting from underground rhizomes. The occurrence of fire usually regulated the presence of the yellow prairie grass before European settlement. In the absence of fire, invasion by woody species is common in its habitats.

Wildlife and Livestock Uses

Yellow prairie grass offers habitat and food for wildlife. White-tailed deer use it for cover. The bunch growth and leaves around the base provides ground cover and nesting



Flowers of yellow prairie grass.
Amy Kay, City of Cedar Falls, Bugwood.org.

areas for numerous types of birds including pheasants, northern bobwhite, mourning doves, prairie chickens, and several songbirds. Yellow prairie grass is a larval host and food source for the adult pepper-and-salt skipper butterfly. Native bees collect nesting materials from yellow prairie grass. It provides good forage for livestock on range, pasture, and hay lands. It is highly palatable for livestock and is excellent for grazing.

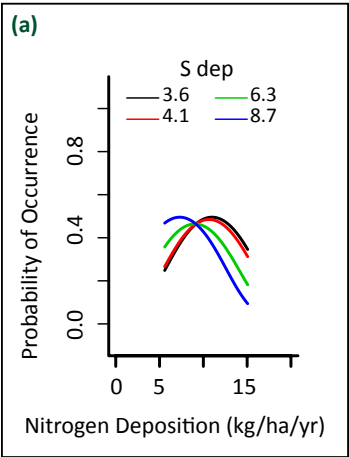


Figure 60.2. Effects of various environmental variables on the probability of occurrence of *Sorghastrum nutans*: a) N x S interaction.

Ecosystem Services

Yellow prairie grass is seeded on critical areas, is used for roadside cover, and provides soil stability to areas subject to wind erosion.

Traditional Ecological Knowledge

Yellow prairie grass is traditionally used for weaving baskets and mats. It can also be used decoratively, dyed and threaded with beads, bark, and quills.

Responses to Nitrogen and Sulfur

The probability of occurrence for yellow prairie grass is mostly related to the interaction between N and S dep (fig. 60.2a). At lower S deposition (≤ 4.1 kg S/ha/yr), Yellow prairie grass increases up to approximately 10-11 kg N/ha/yr and then decreases with higher levels of N deposition. At high levels of S deposition (≥ 8.7 kg S/ha/yr), the species mostly decreases with increasing N deposition. There are no significant pH or climate variables. Confidence in the N and S relationships is moderate-to-high, with good model performance ($R^2 = 0.127$, AUC = 0.73; both moderate confidence), low VIFs (VIF-N = 1.1, VIF-S = 1.3; both high confidence), and a low N-S correlation ($r=0.17$, high confidence).



Plant of yellow prairie grass.
Karan A. Rawlins, University of Georgia, Bugwood.org.

Critical Loads and Exceedances

The environmental hull for yellow prairie grass covers the eastern United States and higher elevations of the West. The N CL is >10 kg N/ha/yr in the West and ranges from 2 to 10 kg N/ha/yr in the East with the most sensitive areas in a band between Indiana and Pennsylvania. The N CL is in exceedance based on 2019–2021 total N deposition

across most of the eastern half of the range with the exception of the Southeast and Northeast. The S CL is 2.2 kg S/ha/yr across most of the East but has a S CL of 17.9 kg S/ha/yr in the Southeast, Northeast, and West. There are exceedances of the S CL based on 2019–2021 TDep total S deposition in the areas in states adjacent to the Mississippi River from Louisiana into southern Indiana.

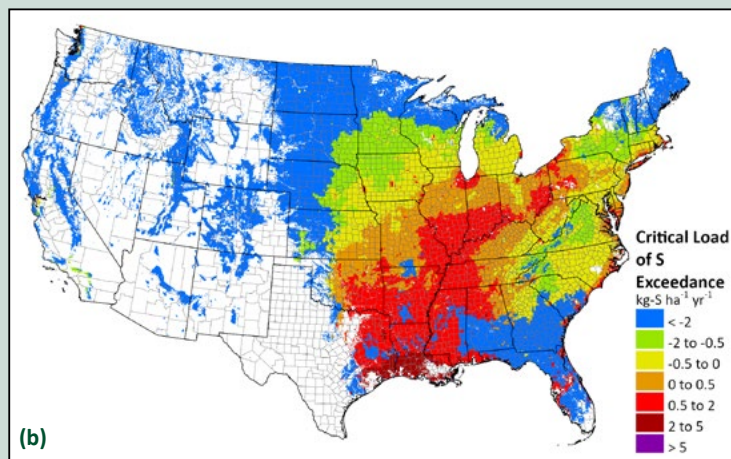
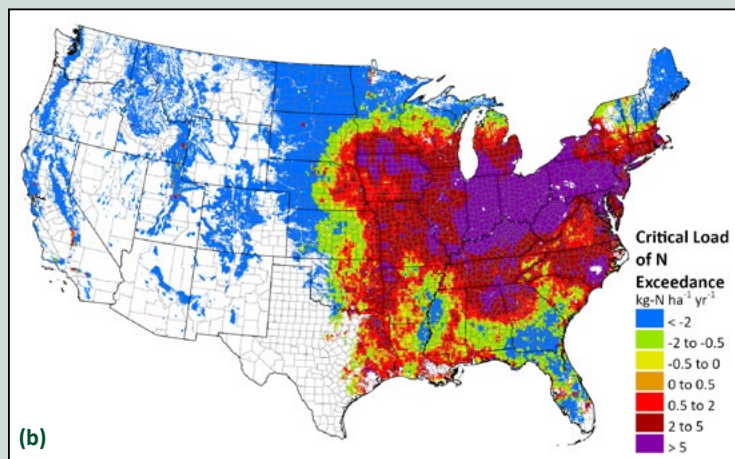
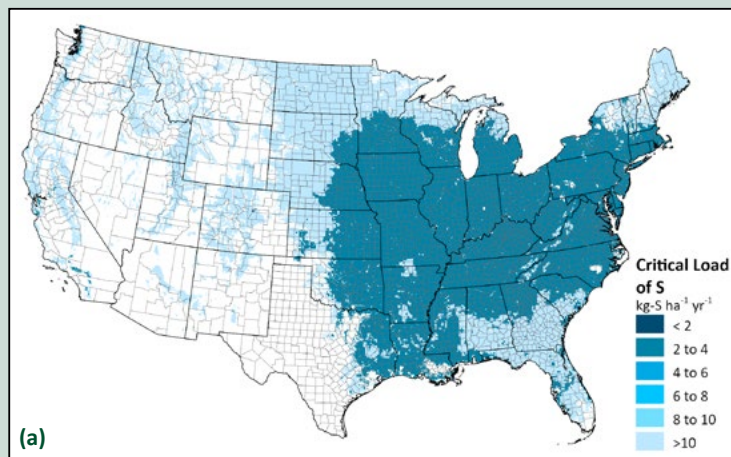
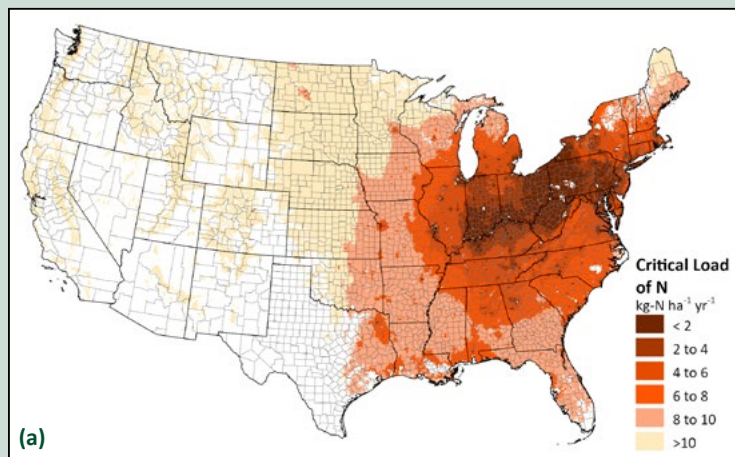


Figure 60.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Sorghastrum nutans* and (b) the exceedance of N critical loads based on TDep 2019–2021 total N deposition.

Figure 60.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Sorghastrum nutans* and (b) the exceedance of S critical loads based on TDep 2019–2021 total S deposition.

61.0 *Spartina pectinata* (prairie cordgrass)

Distribution and Conservation Status

Prairie cordgrass is a native, warm-season, perennial grass. It is found in most of the continental United States except for the extreme southeastern states, California, Nevada and Arizona. It is critically imperiled in Iowa, Virginia, and Delaware, imperiled in Washington, Oregon, Virginia, and Louisiana, and vulnerable in Wyoming and Kentucky (fig. 61.1).

Species Characteristics and Habitat

It grows between 3 and 8 feet tall and has extensive, scaly, tough rhizomes that grow 5-10 feet per year laterally. The stems are stiff and the leaf blades are coarse, tough, and thick, from 0.1 to 0.5 inches wide and up to 30 inches long. The leaf edges are serrated and sharp. The seed heads consist of 10 to 20 spikes attached to the main stem, with each spike growing up to 40 spikelets in two rows on the side of the spike away from the stem. The seeds of prairie cordgrass are flat, paper-like with barbed awns that attach securely to fur or fabric.

Prairie cordgrass is often found in poorly drained soils along roadsides, ditches, streams, marshes, and potholes. It grows best in floodplains, wet meadows and back dune areas. Although it grows well in wet habitats, it is intolerable of prolonged flooding. As a result, prairie cordgrass thrives in seasonally dry sites, tolerates alkaline conditions and seasonally high water tables. The seeds of prairie cordgrass are not shade tolerant. Prairie cordgrass seeds develop rapidly which allows it to avoid frost conditions which occur around wet soils. No nitrogen fertilizer should be applied during the seeding year. Phosphorus and potassium should be at medium levels, and the pH should remain around 6.0. Prairie cordgrass's success will be reduced if it is cut more than once per season. It may become weedy or invasive in some habitats and out compete other local plants if not properly managed. Prairie cordgrass can survive fires due to its expansive rhizomes. Survival is more likely if a fire occurs during the wet seasons. However, all the above ground portions of prairie cordgrass will be killed by fire.

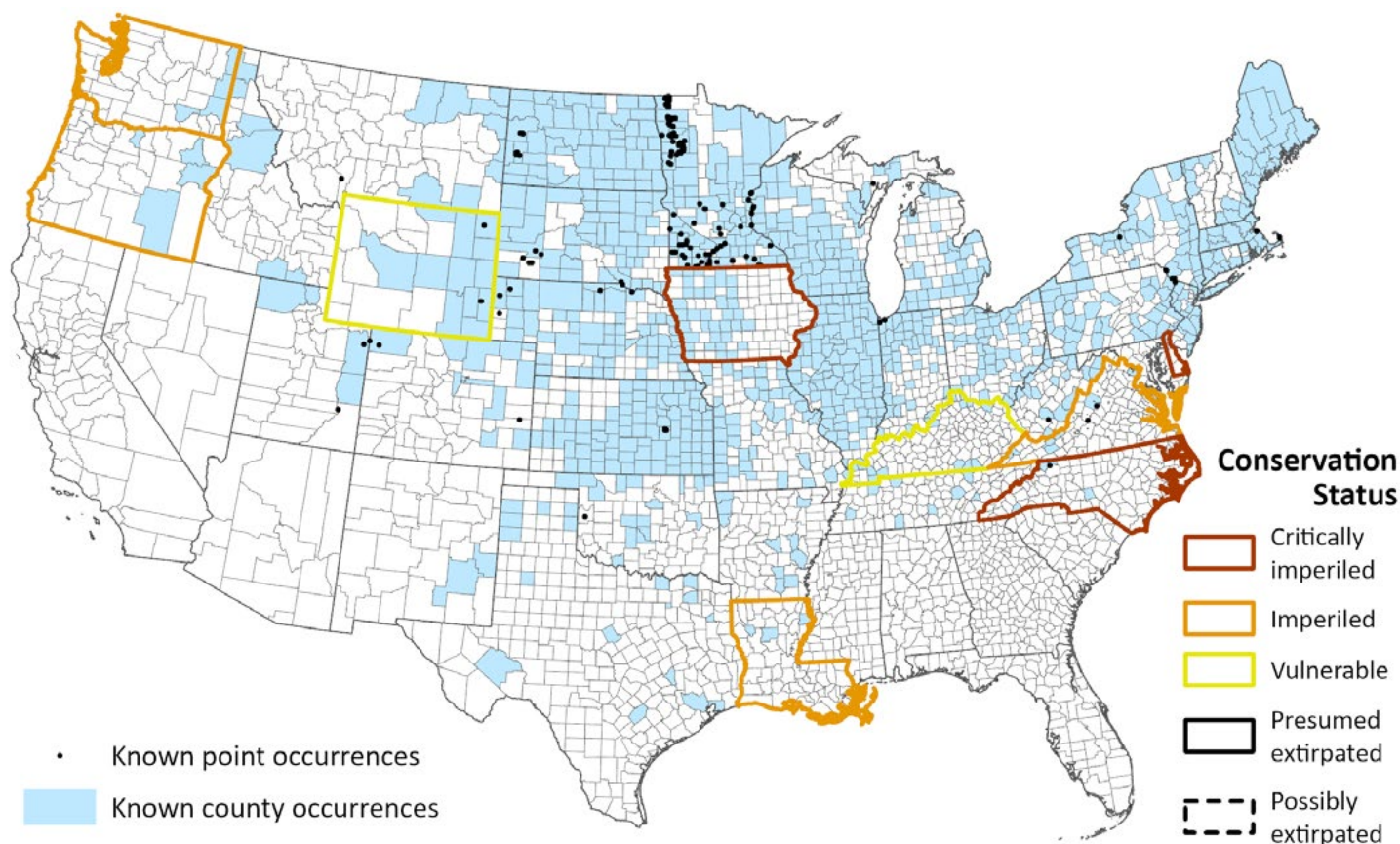


Figure 61.1. Distribution and state-level conservation status of *Spartina pectinata*. Known point occurrences were used to assess species deposition responses and critical loads.

Wildlife and Livestock Uses

Prairie cordgrass forms thick stands around marshes, providing good cover for game birds, songbirds and small mammals. It also provides shade and hiding cover for larger wildlife. Prairie cordgrass provides fair forage for wildlife and livestock and is usually grazed in the spring before the stems become too coarse. Prairie cordgrass is low in nutritive value, providing fair energy but poor protein for wildlife and livestock. However, it is seldom grazed due to its association with marsh areas.

Ecosystem Services

Prairie cordgrass is useful in preventing erosion near dams, spillways and drainage channels. It is often used to restore or reconstruct wetlands where continuous flooding does not occur.

Indigenous Knowledge

Traditional uses include building material to support covers of village lodges.

Responses to Nitrogen and Sulfur

The probability of occurrence for depends on several variables. The effect of N deposition depends on S deposition (fig. 61.2a): under lower S deposition (≤ 2.9 kg S/ha/yr) prairie cordgrass is common and decreases with N deposition, while under higher S deposition (≥ 4 kg S/ha/yr) the species is uncommon and not responsive to N deposition. The effect of N deposition also depends on soil pH (fig. 61.2b: under neutral to acidic conditions ($\text{pH} \leq 7$) prairie cordgrass is uncommon and not responsive to N while under alkaline conditions ($\text{pH} \geq 7.5$) the species is more common and decreases with N deposition. Prairie cordgrass also decreases strongly with S deposition (fig. 61.2c). The climate effects are shown in Figure 61.2d (precipitation) and Figure 61.2e (temperature). The probability of occurrence increases with increasing precipitation and temperature within the species' sampled range. Confidence in the N and S relationships is moderate-to-high for N and moderate for S, with good model performance ($R^2 = 0.127$, $\text{AUC} = 0.73$; both moderate confidence), mixed VIFs ($\text{VIF-N} = 1.9$, $\text{VIF-S} = 3.3$; high and moderate confidence, respectively), and a moderate N-S correlation ($r=0.68$, moderate confidence).



Foliage of prairie cordgrass. Jennifer Anderson. United States, Iowa, Scott Co., Davenport, Nahant Marsh. 2002, <https://plants.usda.gov/home/plantProfile?symbol=SPPE>.

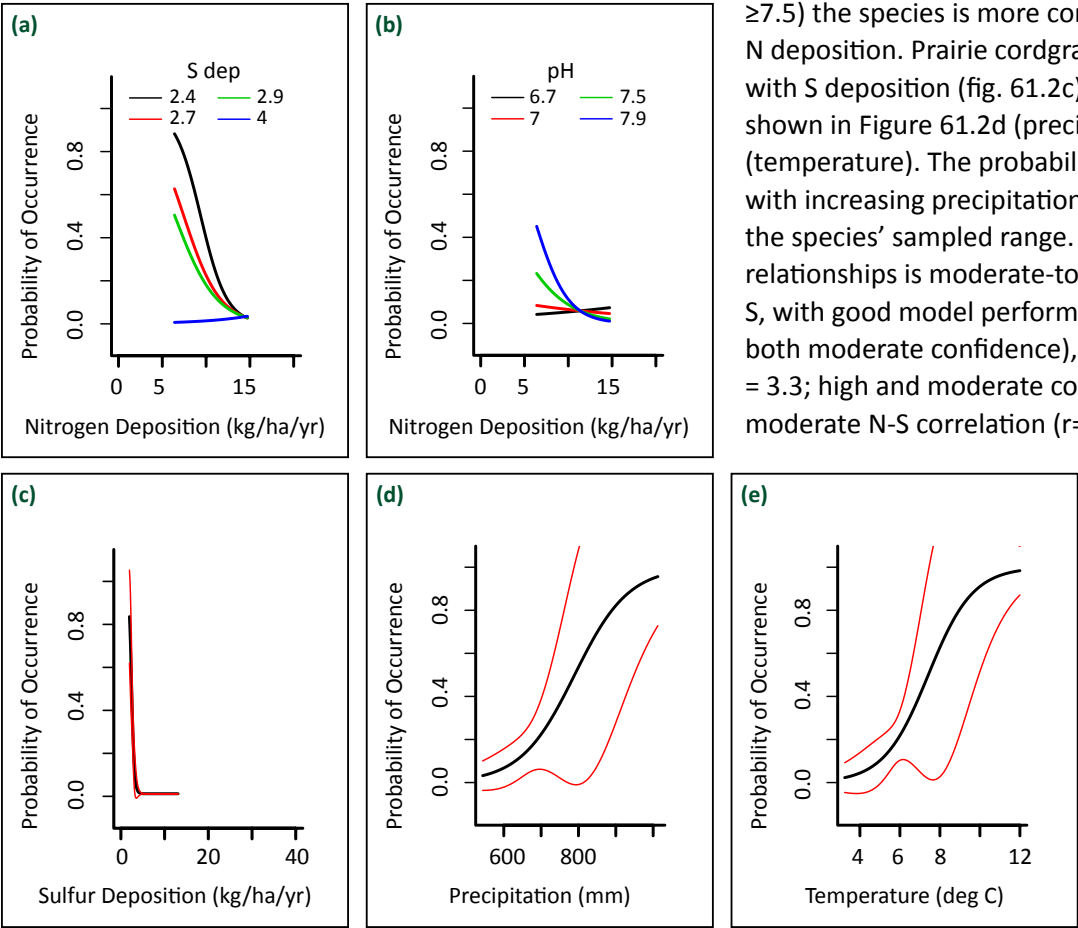


Figure 61.2. Effects of various environmental variables on the probability of occurrence of *Spartina pectinata*: a) N x S interaction, b) N x pH interaction, c) S deposition, d) precipitation, e) temperature.

Critical Loads and Exceedances

The environmental hull for prairie cordgrass covers most of the western and eastern United States excluding much of the west coast, a band between Indiana and Pennsylvania, and the Gulf Coast. The N CL is 2 to 4 kg N/ha/yr in the East and high elevations of the West, and >10 kg N/ha/yr in the rest of the range. The S CL is 9.7 kg S/ha/yr across most of the range except the Southwest and lower elevation plains of the West that have a S CL of 0.8 kg S/ha/yr. There are exceedances of the S CL based on 2019–2021 TDep total S deposition in the areas in west Texas and areas with lower CLs in the western Midwest.



Flower/seed of prairie cordgrass.
Larry Allain. Provided by
USGS National Wetlands
Research Center (NWRC).

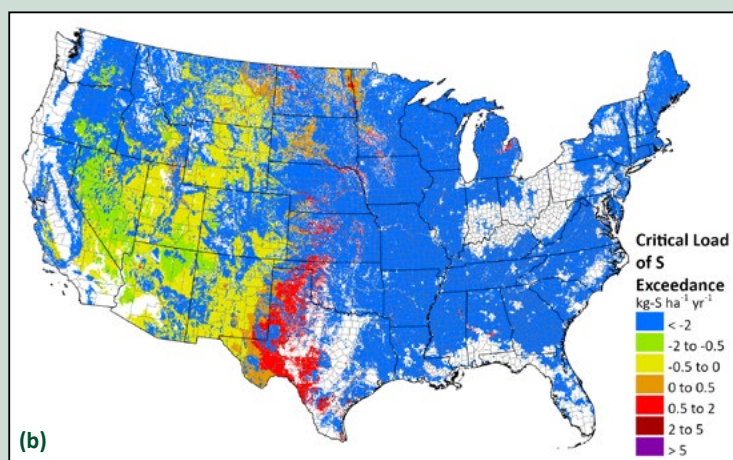
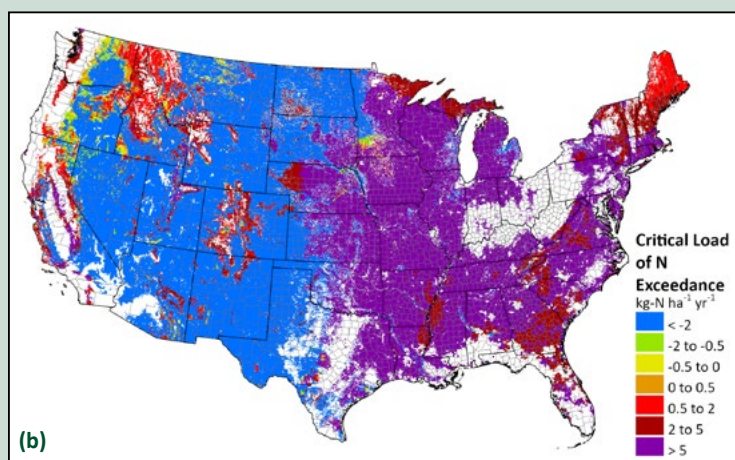
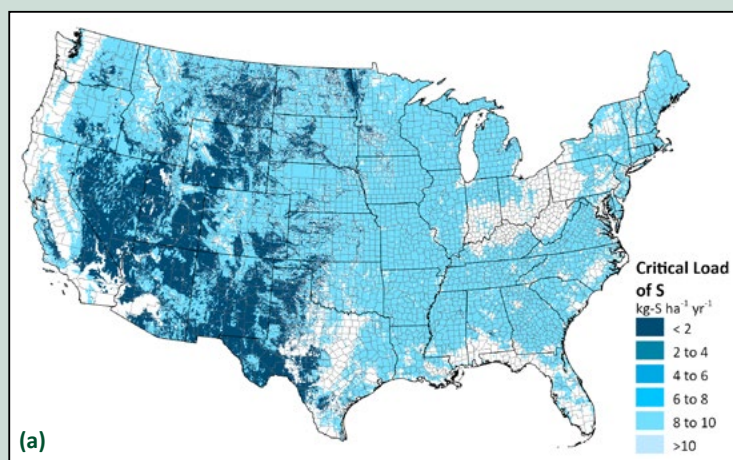
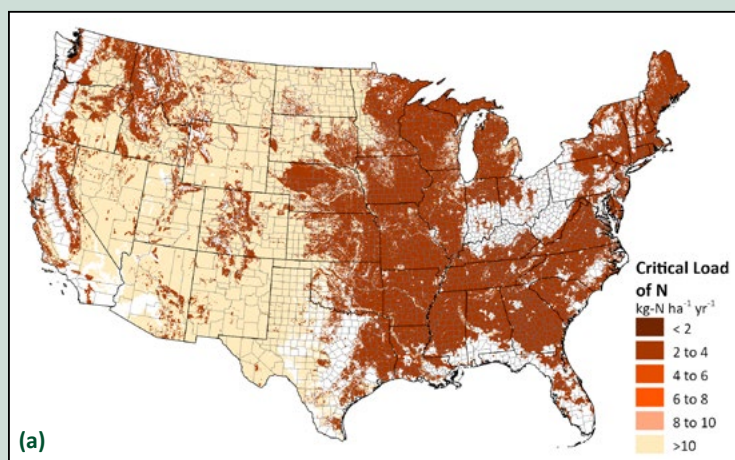


Figure 61.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Spartina pectinata* and (b) the exceedance of N critical loads based on TDep 2019–2021 total N deposition.

Figure 61.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Spartina pectinata* and (b) the exceedance of S critical loads based on TDep 2019–2021 total S deposition.

62.0 *Sporobolus cryptandrus* (sand dropseed)

Distribution and Conservation Status

Sand dropseed is native perennial bunchgrass found throughout North America except Alaska and the extreme southeastern United States. It is critically imperiled in New Hampshire and Connecticut, imperiled in Massachusetts, and vulnerable in Illinois, Ohio, and Pennsylvania (fig. 62.1).

Species Characteristics and Habitat

Sand dropseed is a warm-season, shallow-rooted, drought resistant plant that grows 2 to 3 feet tall. It forms a dense network of sand-binding roots that spread up to 2 feet laterally and over 8 feet deep. The leaf blade is flat, less than an inch wide, and 3 to 10 inches long with a tapering tip and rolling inward. The inflorescence, a panicle, is purplish, ranging between 6 and 16 inches long, and 1 to 6 inches wide.

Sand dropseed grows best in sandy soils, but can survive in coarse gravelly soils. Sand dropseed prefers well-drained soils, adapts to slightly acidic and slightly basic soils, and can survive in moist soils. It grows best around other grasses but is also successful growing in pure stands. Sand dropseed produces an abundant seed crop, with most held between the stem and sheath until the plant deteriorates. The seeds remain viable for many years which allows it to easily reestablish on ranges following overgrazing or drought. It is also a successful colonizer of drought disturbed ranges. By rolling up its leaves to reduce surface area and evapotranspiration it can survive summer drought, making it one of the most drought resistant prairie grasses. Sand dropseed can become weedy or invasive if not properly managed. It is typically killed or top-killed by fire. However, since it produces abundant, resilient seeds, it has potential for postfire regeneration and seedling establishment within the burned areas.

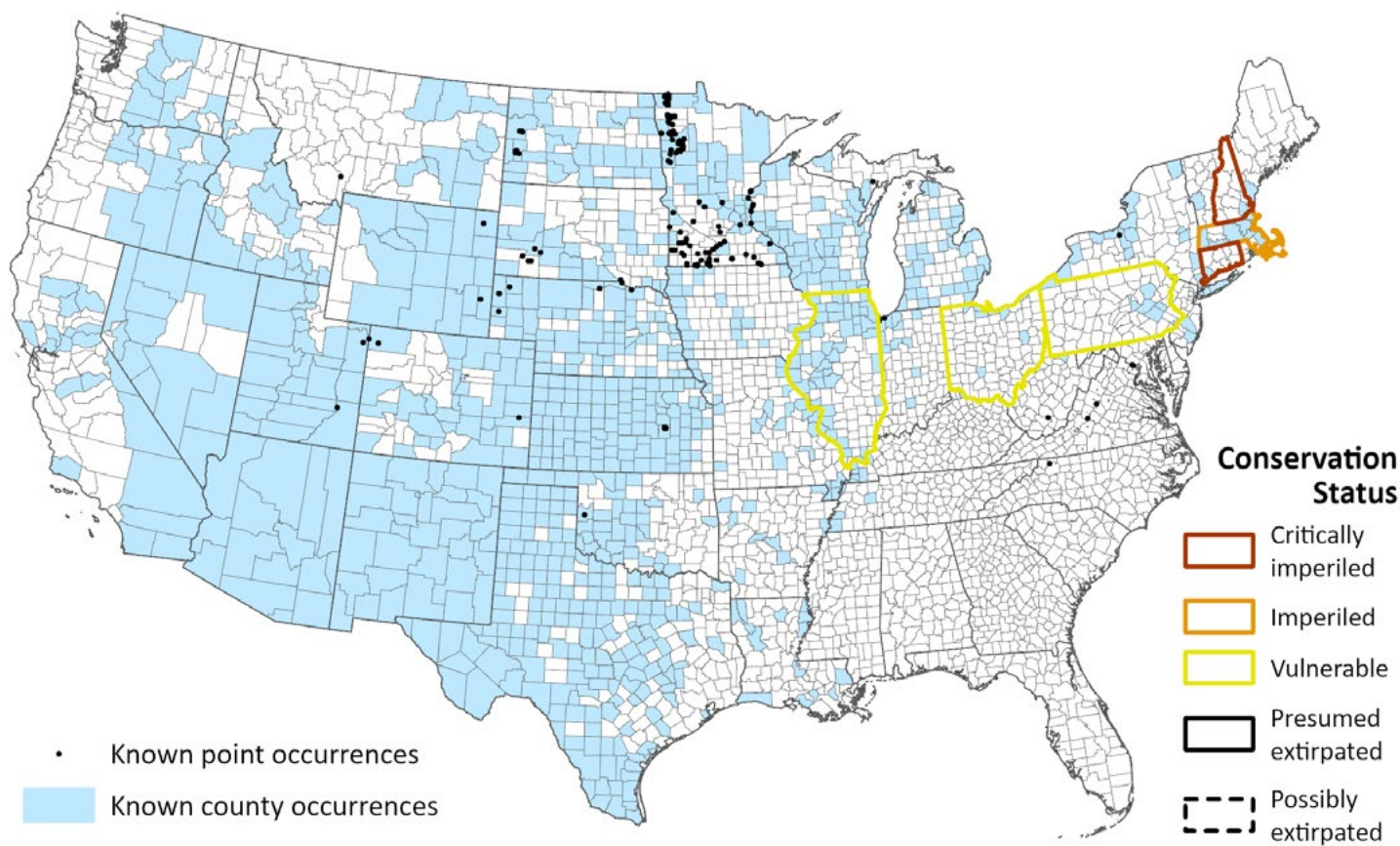


Figure 62.1. Distribution and state-level conservation status of *Sporobolus cryptandrus*. Known point occurrences were used to assess species deposition responses and critical loads.

Wildlife and Livestock Uses

Sand dropseed can offer good forage during winter, spring and summer months in the Southwest and other desert areas. Scaled quail, rodents, jackrabbits, prairie dogs all use it for forage. Small mammals and birds prefer sand dropseed more than large mammals. It produces palatable forage for all livestock.



Plant of sand dropseed.

Robert Soreng. Provided by Smithsonian Institution, Department of Botany.
<https://plants.usda.gov/home/plantProfile?symbol=SPCR>.

Ecosystem Services

Sand dropseed's fibrous root system successfully stabilizes sand dunes and hills. Its prolific seed production makes it an excellent pioneer plant in disturbed and sandy areas.

Traditional Ecological Knowledge

Sand dropseed is a traditional food and a common ingredient in flour used to bake bread as well as dumplings, griddle cakes, and tortillas. An infusion of the plant can be used as a veterinary aid for sores or bruising on horse legs.

Responses to Nitrogen and Sulfur

The probability of occurrence of sand dropseed is related to the interaction between N deposition and soil pH (fig. 62.2a). Under less acidic conditions ($\text{pH} \geq 6.7$), sand dropseed is uncommon and unresponsive to N deposition, while under more acidic conditions ($\text{pH} \leq 6.2$) the species is more common and decreases with N deposition. There is also an (uncertain) association between S deposition and soil pH (fig. 62.2b) (Clark et al. 2019). The only significant climate variable is precipitation (fig. 62.2c). The probability of occurrence decreases with increasing precipitation within the species' sampled range. Confidence in the N and S relationships is moderate-to-high, with good model performance ($R^2 = 0.296$, $\text{AUC} = 0.84$; both high confidence), low VIFs ($\text{VIF-N} = 1.4$, $\text{VIF-S} = 2.1$; both high confidence), and a moderate N-S correlation ($r=0.45$, moderate confidence).

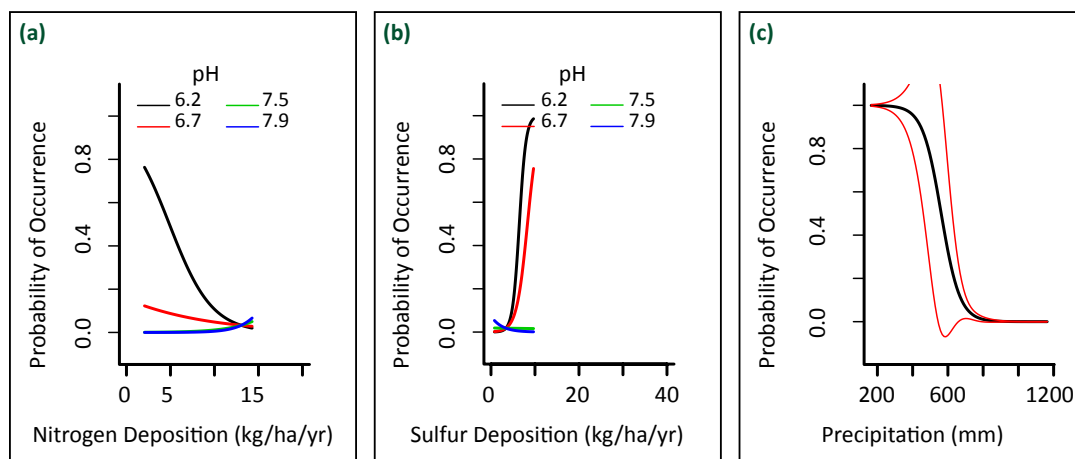


Figure 62.2. Effects of various environmental variables on the probability of occurrence of *Sporobolus cryptandrus*: a) N x pH interaction, b) S x pH interaction, c) precipitation.

Critical Loads and Exceedances

The environmental hull for sand dropseed covers most of the northern half of the United States excluding the west coast and areas in the Northeast. The N CL is >10 kg N/ha/yr in the East and 6 to 8 kg N/ha/yr in the West. The N CL is in exceedance based on 2019–2021 total N deposition in higher elevations in the West and across most of the western Midwest. The S CL is 2.2 kg S/ha/yr across most of the range except in some eastern urban areas that have a S CL of 13.3 kg S/ha/yr. There are exceedances of the S CL based on 2019–2021 TDep total S deposition in the areas surrounding the Mississippi and Ohio Rivers.



Flower/fruit of sand dropseed.
Patrick Alexander, <https://plants.usda.gov/home/plantProfile?symbol=SPCR>.

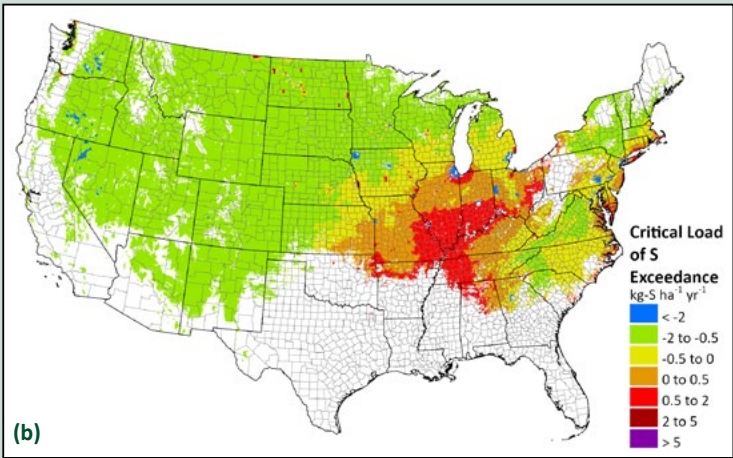
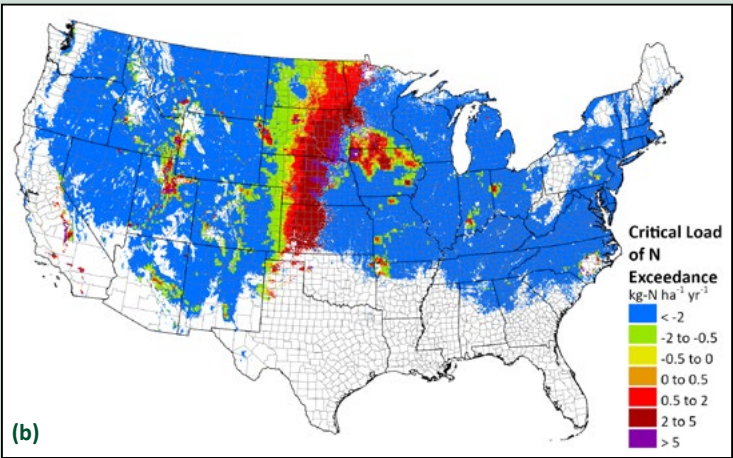
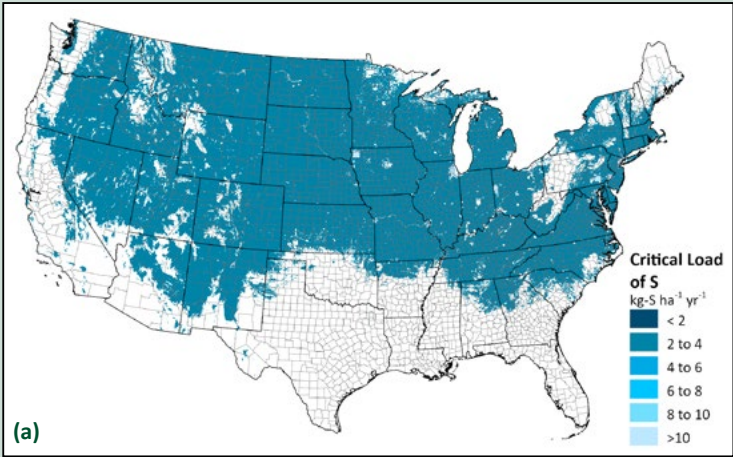
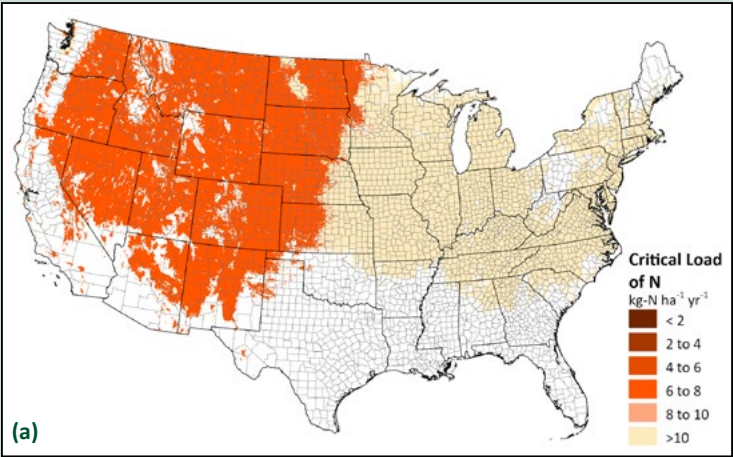


Figure 62.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Sporobolus cryptandrus* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 62.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Sporobolus cryptandrus* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

63.0 *Symphyotrichum ericoides* (white heath aster)

Distribution and Conservation Status

White heath aster is a native perennial forb that is widely distributed across most of the central continental US. It is not known from Nevada or California and is sparsely distributed in the southeastern US. White heath aster grows in dry-mesic prairies, open oak or pine woods, sand dunes and savanna ecosystems. It can also grow as a weed in disturbed areas like roadsides, railroads, sandy fields, gravel pits and quarries, and occasionally riverbanks and lakeshores. It is critically imperiled in Georgia, imperiled in Mississippi, and vulnerable in Pennsylvania, New Jersey, and Virginia (fig. 63.1).

Species Characteristics and Habitat

White heath aster is a bushy plant, up to 3 ft tall and 12 inches in circumference. It has an extensive root system of rhizomes and stolons. The leaves are narrow, no more than 0.40 inches wide and 2.7 inches long, resembling the leaves of heather. Flowering occurs in August through November. When white heath aster flowers, most leaves drop except for those directly beneath the flower

head. The remaining leaves are reduced to bracts. The blunt point of the bracts beneath the flower head are a defining characteristic of this species. One plant can produce up to 100 flower heads. White heath aster ray flowers are white-to-pink; the center disc flowers are yellowish-to-purple. The seeds of white heath aster are achenes that have tufts of white bristles to help them disperse with the wind.

White heath aster is a hardy plant, best adapted to dry and medium wet, well-drained soils found in open areas with sandy, gravelly, or rocky substrates. It is resistant to drought and does well in full sun. The rhizomatous roots allow it to resprout after a fire and respond to fire with vigorous growth the following growing season. As part of prairie restoration, prescribed burns should take place annually for the first 5 to 6 years, and biannually after the initial phase.

Ecosystem Services

White heath aster is a valuable ornamental plant.

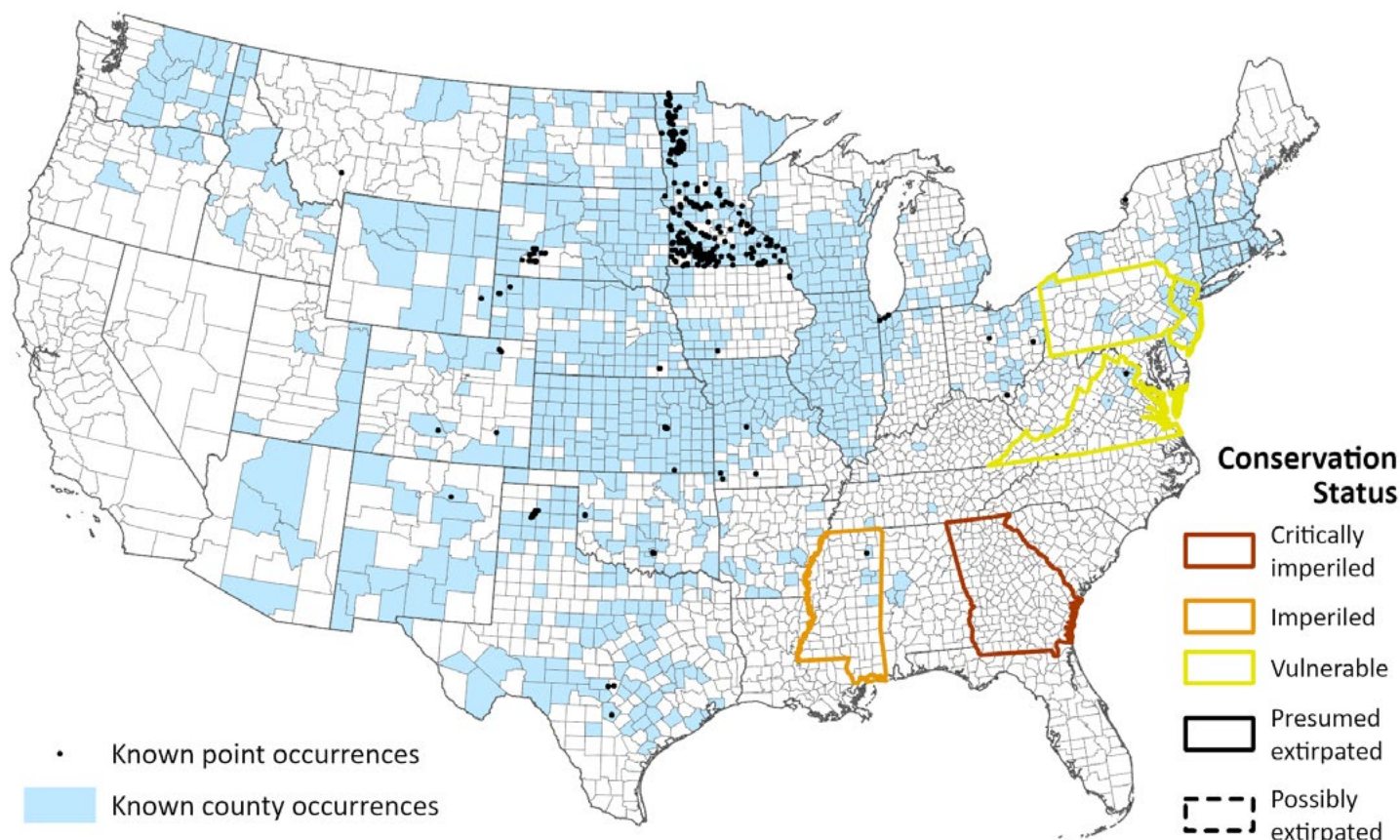


Figure 63.1. Distribution and state-level conservation status of *Symphyotrichum ericoides*. Known point occurrences were used to assess species deposition responses and critical loads.

Traditional Ecological Knowledge

The flowering parts can be used to binding sweat lodge structures and added to hot rocks to produce herbal steam. A traditional medicinal practice utilizes the plant as a stimulant to revive consciousness.

Responses to Nitrogen and Sulfur

The probability of occurrence for white heath aster depends on several variables. The effect of N deposition depends on S deposition (fig. 63.2a): under lower S deposition (≤ 4.2 kg S/ha/yr) the probability of occurrence increases with N deposition up to 10-12 kg N/ha/yr and then decreases with higher N deposition. Under high S deposition (≥ 9.6 kg S/ha/yr) the species is less responsive to N deposition. The effect of N deposition also depends on soil pH (fig. 63.2b): under alkaline to slightly acidic conditions ($\text{pH} \geq 6.5$) white heath aster responds strongly to N deposition, while under acidic

conditions ($\text{pH} \leq 5.5$) it is much less responsive. Likewise, the effect of S deposition depends on soil pH (fig. 63.2c): under higher pH (≥ 6.5) white heath aster is relatively common and decreases sharply with S deposition while under lower pH (≤ 5.5) the species is less common and less responsive to S deposition. The only significant climate variable is temperature (fig. 63.2d). The probability of occurrence increases with decreasing temperatures (but note the widening confidence bands) within the species' sampled range. Confidence in the N and S relationships is moderate-to-high, with good model performance ($R^2 = 0.417$, $\text{AUC} = 0.89$; both high confidence), low VIFs ($\text{VIF-N} = 1.1$, $\text{VIF-S} = 1.2$; both high confidence), and a moderate N-S correlation ($r=0.55$, moderate confidence).

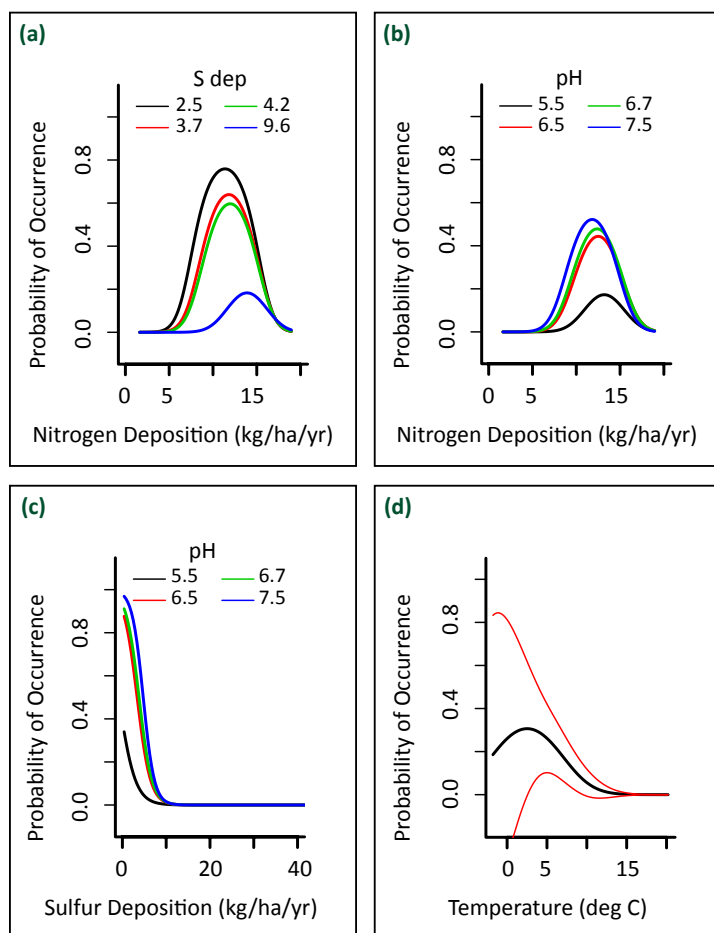


Figure 63.2. Effects of various environmental variables on the probability of occurrence of *Symphyotrichum ericoides*: a) N x S interaction, b) N x pH interaction, c) S x pH, d) temperature.



Plant of white heath aster.
Catherine Herms, The Ohio State University, Bugwood.org.

Critical Loads and Exceedances

The environmental hull for white heath aster covers most of the upper two-thirds of the United States excluding much of the west coast and the Northeast. The N CL is >10 kg N/ha/yr across most of the range and 8 to 10 kg N/ha/yr in western arid lowlands. The N CL is in exceedance based on 2019–2021 total N deposition in high agricultural areas in the Midwest and East and in a few deposition hot spots in the West. The S CL is 0.4 kg S/ha/yr across most of the range excluding a few spots in the Midwest and East that have a S CL of 41.7 kg S/ha/yr. There are exceedances of the S CL based on 2019–2021 TDep total S deposition in all areas excluding the lower elevation plains of the West.



Flowers of white heath aster.
Ohio State Weed Lab, The Ohio State University, Bugwood.org.

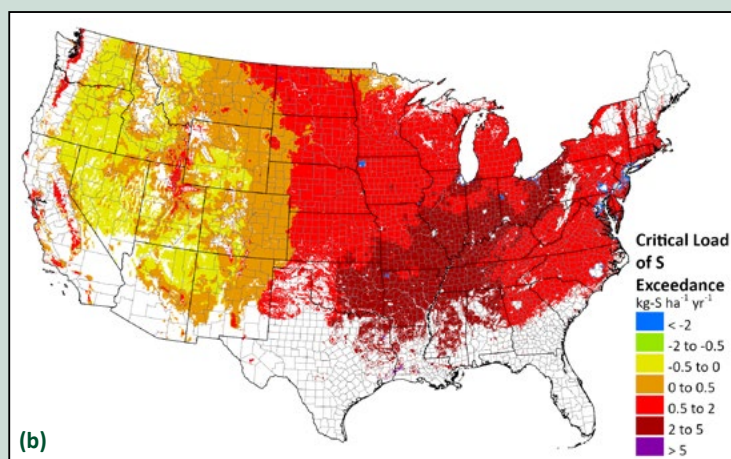
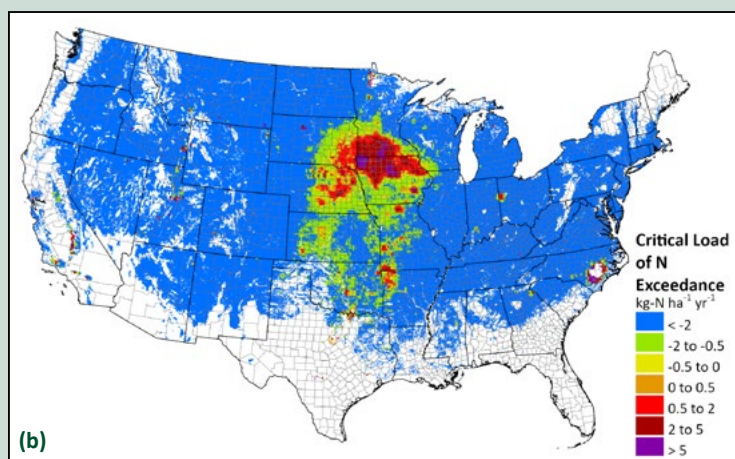
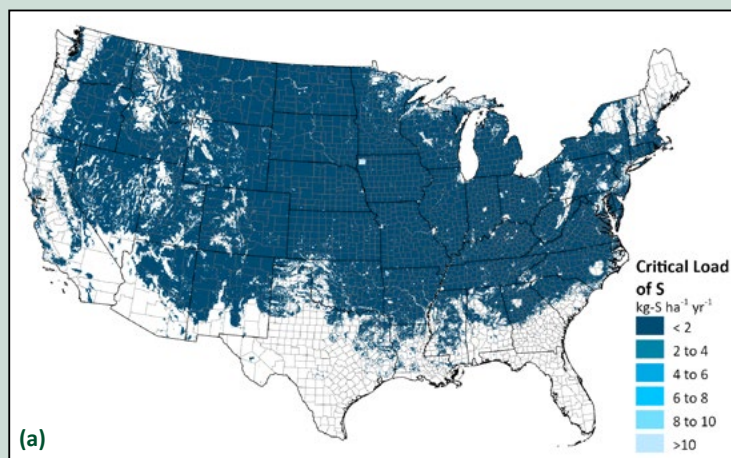
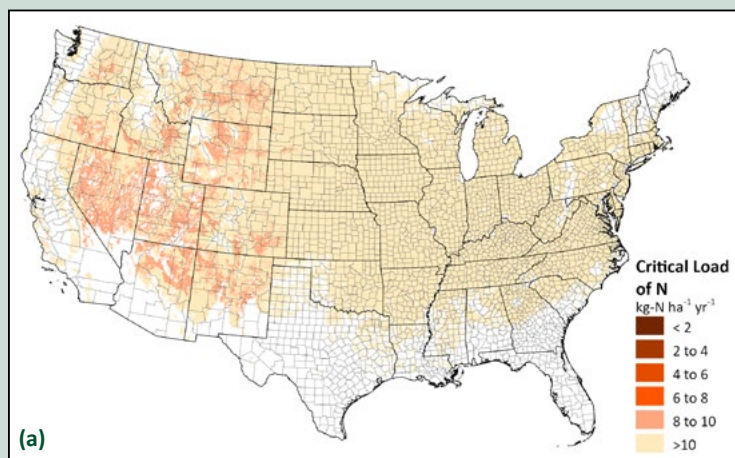


Figure 63.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Symphyotrichum ericoides* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 63.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Symphyotrichum ericoides* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

64.0 *Symphyotrichum laeve* (smooth blue aster)

Distribution and Conservation Status

Smooth blue aster is a native perennial forb of the United States and Canada. It is found from the Atlantic Coast to the eastern slopes of the Cascade Range, south to New Mexico, Texas, and Florida. It grows in a wide variety of ecosystems, including moist, sandy soil in woods, dry woods, and open areas, and prairies. It is critically imperiled in Utah, Maine, New Jersey, and Virginia, imperiled in Kentucky, Vermont, and South Carolina, and vulnerable in Wyoming, West Virginia, and Georgia (fig. 64.1).

Species Characteristics and Habitat

Smooth blue aster grows between 1 to 4 feet tall and has numerous upright stems, a branching caudex, and stout rhizomes. The lowermost leaves are early deciduous, and the remaining leaves are dropped after frost top-kills the plant. Smooth blue aster blooms in August to October. The fruit of smooth blue aster is a one-seeded achene.

The amount of cover and frequency of occurrence of smooth blue aster is highest on sites with high light intensities though it occurs on more shaded sites as well. Smooth blue aster cannot tolerate intense shade but can tolerate moderate shade. It often grows more abundantly on wetter, more poorly drained glacial till soils. Although smooth blue aster is not an initial colonizer, it is often found on roadsides and other previously disturbed areas. Smooth blue aster is top-killed by fire but will regrow and sprout from the rhizome. Generally, smooth blue aster is more adversely affected by fires that occur later in the spring.

Wildlife and Livestock Uses

White-tailed deer prefer to graze on smooth blue aster over other forbs. Smooth blue aster has high nutritional value for wildlife although this value decreases as the plant matures. It is palatable to wildlife and livestock.

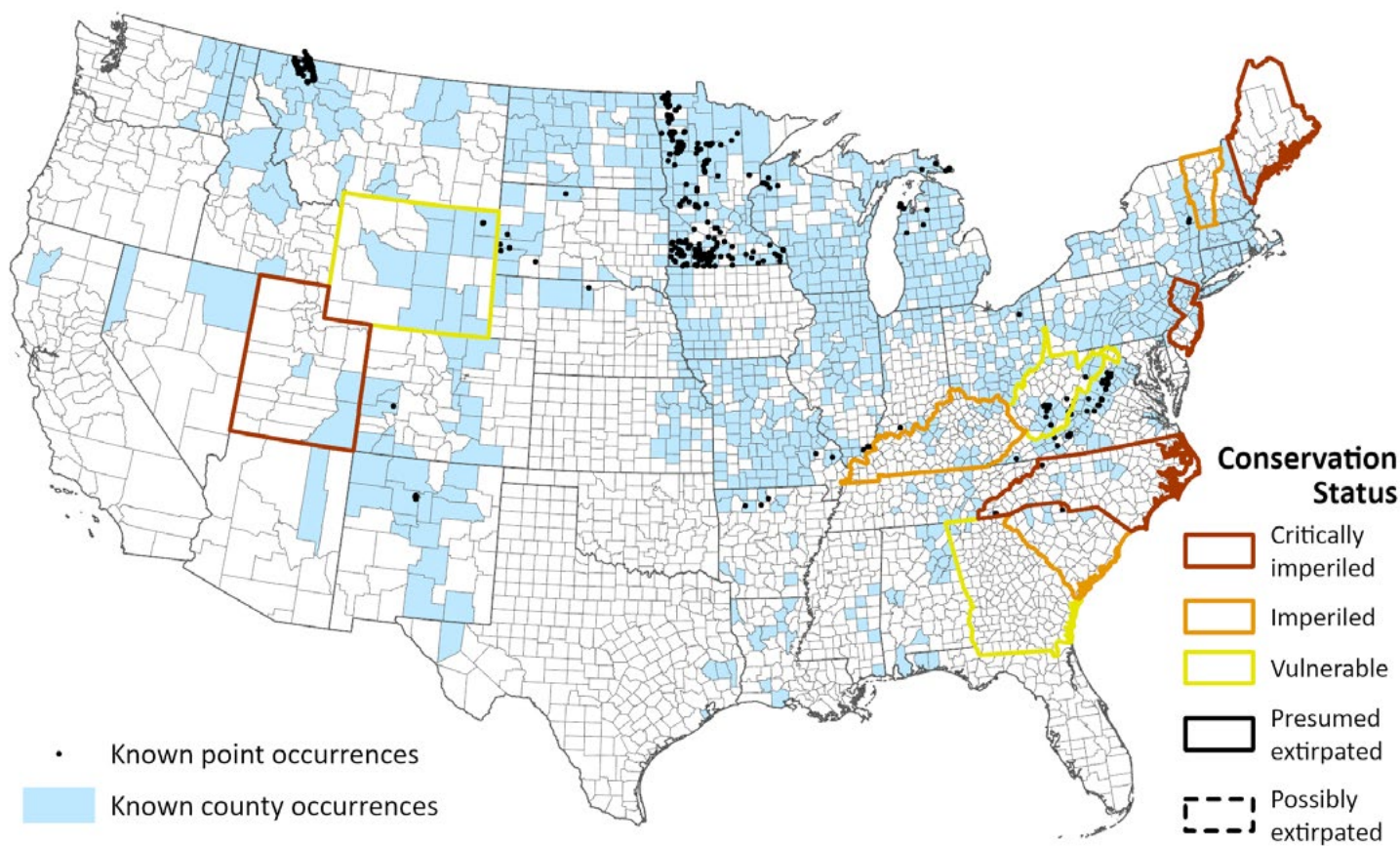


Figure 64.1. Distribution and state-level conservation status of *Symphyotrichum laeve*. Known point occurrences were used to assess species deposition responses and critical loads.

Ecosystem Services

Smooth blue aster is frequently used for rehabilitation or restoration of native mixed-grass and tallgrass prairies. Direct seeding of smooth blue aster is usually successful in establishing plants along highway margins.

Traditional Ecological Knowledge

Smooth blue aster has traditional uses as a stimulant (smoke forced into nostrils to revive unconscious patients), a blue dye (flowers mixed with white clay), and as food (eaten with corn and eggs).

Responses to Nitrogen and Sulfur

The probability of occurrence of smooth blue aster increases with N deposition (fig. 64.2a) and decreases sharply with S deposition (fig. 64.2b). There are interactions with soil pH (fig. 64.2c and fig. 64.2d), but these do not greatly affect the probability of occurrence

(Clark et al. 2019). The climate effects are shown in Figure 64.2e (precipitation) and Figure 64.2f (temperature). The probability of occurrence increases with increasing precipitation and decreases with decreasing temperatures (but note wide confidence bands) within the species’ sampled range. Confidence in the N and S relationships is moderate-to-high, with good model performance ($R^2 = 0.157$, $AUC = 0.76$; both moderate confidence), low VIFs ($VIF-N = 1.7$, $VIF-S = 1.8$; both high confidence), and a moderate N-S correlation ($r=0.61$, moderate confidence).



Flowers of smooth blue aster.
Katy Chayka, www.minnesotawildflowers.info, Bugwood.org.

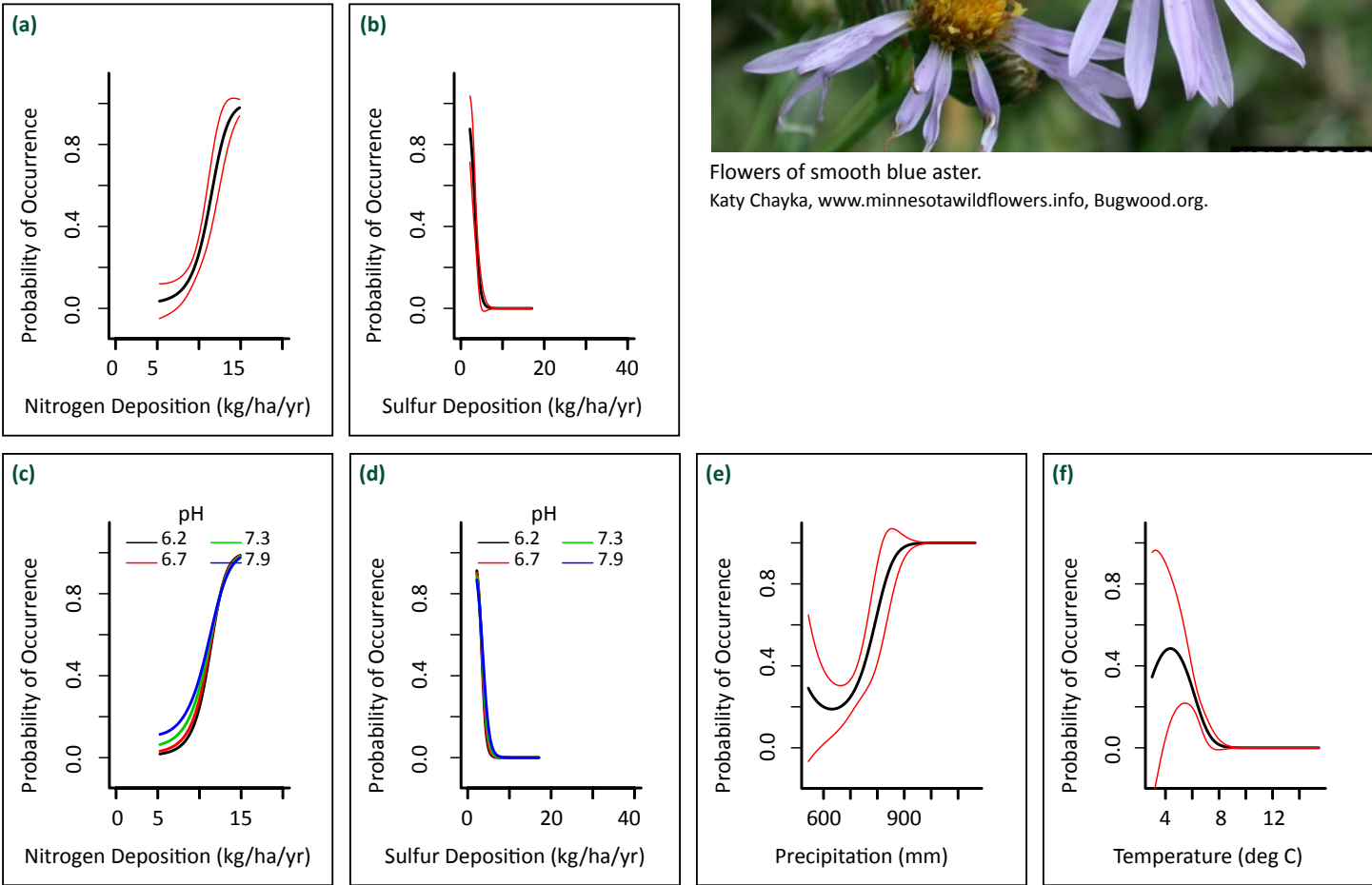


Figure 64.2. Effects of various environmental variables on the probability of occurrence of *Symphyotrichum laeve*: a) N deposition, b) S deposition, c) N x pH, d) S x pH, e) precipitation, f) temperature.

Critical Loads and Exceedances

The environmental hull for smooth blue aster covers most of the upper two-thirds of the United States excluding much of the west coast and the Northeast. The N CL is <2 kg N/ha/yr across most of the East and 2-6 kg N/ha/yr in the West. The N CL is in exceedance based on 2019–2021 total N deposition across the East and Midwest, and in high elevation areas of the West. The S CL is 2.2 kg S/ha/yr across the entire species’ range. There are exceedances of the S CL based on 2019–2021 TDep total S deposition in the areas surrounding the Mississippi and Ohio Rivers.

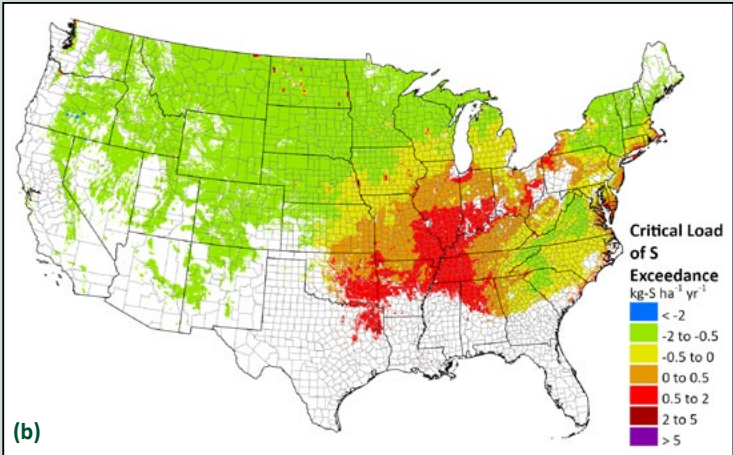
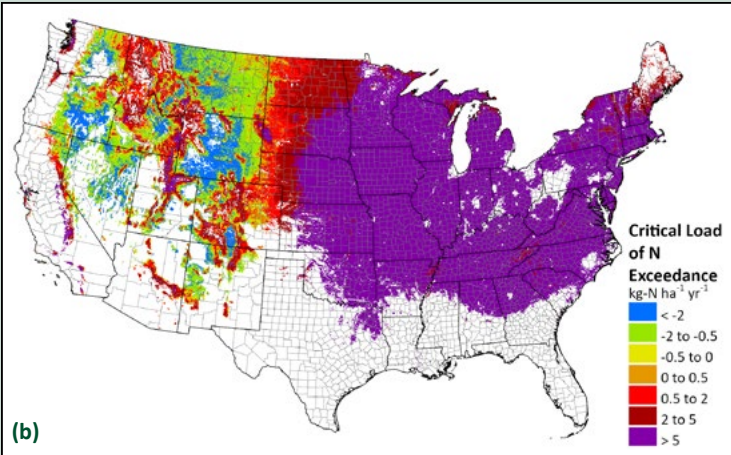
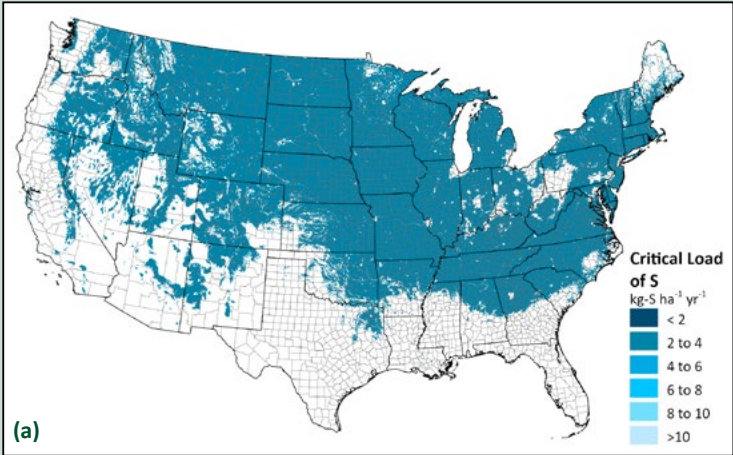
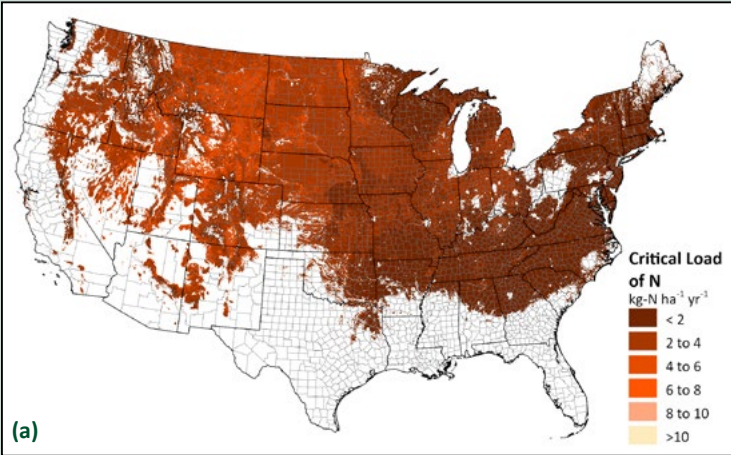


Figure 64.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Symphyotrichum laeve* and (b) the exceedance of N critical loads based on TDep 2019–2021 total N deposition.

Figure 64.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Symphyotrichum laeve* and (b) the exceedance of S critical loads based on TDep 2019–2021 total S deposition.

65.0 *Symphyotrichum lanceolatum* (white panicle aster)

Distribution and Conservation Status

White panicle aster is a perennial forb of tallgrass regions such as wet prairies, low wet depressions and along streams from Maine south to South Carolina, west Texas and North Dakota. It is imperiled in North Carolina and vulnerable in Iowa (fig. 65.1).

Species Characteristics and Habitat

White panicle aster grows up to 2 feet tall. Its leaves grow up to 6 inches and are long, narrow, alternate, are widest near the middle, and sometimes irregularly toothed along the edges. White panicle aster has open, leafy, conical clusters of flower heads at the top of the plant. The flowers of white panicle aster are hermaphrodite, meaning they have both male and female organs.

It grows best in well-drained soil and prefers sandy, loamy and clay soils. White panicle aster can grow on nutritionally poor soil, but it thrives in rich soil. It grows best in sunny locations but can succeed in partial shade.

Wildlife Uses

White panicle aster flowers are pollinated by bees, butterflies, flies, beetles and moths and these are attracted to areas where white panicle aster is flowering. The flowers provide nectar for bees in the autumn. Rabbits graze on white panicle aster.

Traditional Ecological Knowledge

Traditional medicinal uses of white panicle aster include treating arrow or bullet wounds (decoction), staunching nosebleeds (smoke from burning blossoms), treating abrasions from ceremonial masks (dried, ground blossoms), and as a febrifuge (infusion).

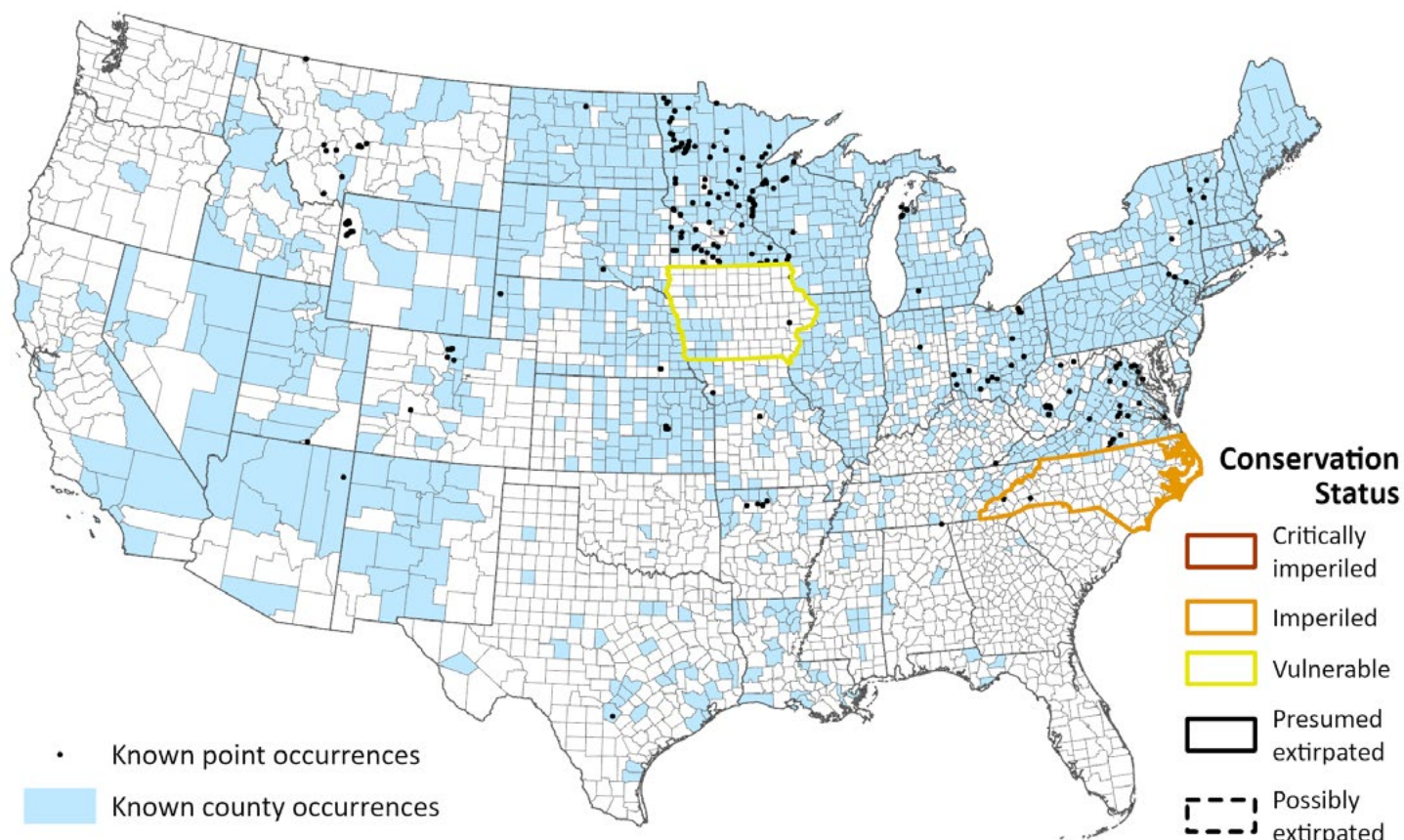


Figure 65.1. Distribution and state-level conservation status of *Symphyotrichum lanceolatum*. Known point occurrences were used to assess species deposition responses and critical loads.

Responses to Nitrogen and Sulfur

Available information suggests that white panicle aster is not responsive to N or S deposition under the levels of deposition assessed. The climate effects are shown in Figure 65.2a (precipitation) and Figure 65.2b (temperature). The probability of occurrence decreases sharply with increasing precipitation and increases with increasing temperatures (but note wide confidence bands) within the species' sampled range. Confidence in the N and S relationships (or lack thereof) is moderate-to-high for N and moderate for S, with good model performance ($R^2 = 0.174$, $AUC = 0.78$; both moderate confidence), mixed VIFs ($VIF-N = 1.9$, $VIF-S = 3.3$; high and moderate confidence, respectively), and a moderate N-S correlation ($r=0.68$, moderate confidence).



Flowers of white panicle aster.

Katy Chayka, www.minnesotawildflowers.info, Bugwood.org.



Foliage of white panicle aster.

Mary Ellen (Mel) Harte, Bugwood.org.

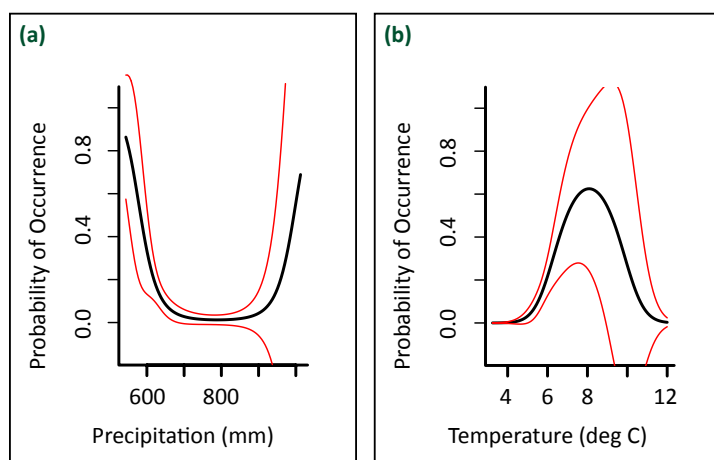


Figure 65.2. Effects of various environmental variables on the probability of occurrence of *Symphyotrichum lanceolatum*: a) precipitation, b) temperature.

66.0 *Thalictrum dioicum* (early meadow-rue)

Distribution and Conservation Status

Early meadow-rue is a dioecious perennial forb of moist open woods, north-facing slopes, ledges, rocky areas, ravines, and limestone outcrops. It is found in Canada south to the Mississippi River region, east to the Atlantic Coast and south to Georgia and Alabama. It is critically imperiled in Kansas, Arkansas, and Delaware and vulnerable in Illinois and North Carolina (fig. 66.1).

Species Characteristics and Habitat

Early meadow-rue has hollow stems which grow from 8 to 28 inches from a caudex and is known to grow in colonies. It has been observed that only the male plants grow stolons, and as a result, the colonies are unisexual. The male plants reproduce asexually by stolons, which helps it stabilize shaded, moist disturbed habitats. The alternate, compound leaves have long stalks. Early meadow-rue blooms early in spring, around April or May. Its flowers have no petals and are in loose, open panicles. Early meadow-rue is also wind pollinated. Both the male and

female flowers have four purple to greenish white sepals that drop off before fruits are produced. The fruits of early meadow-rue are achenes with no special dispersal mechanisms. Unless eaten by animals, the dry fruits drop near the parent plants. The foliage dies back to caudex rootstock each winter and resprouts in spring.

Early meadow-rue usually grows on alluvial soils ranging from well-drained sandy loams to poorly drained clays; however, it usually is found on well-drained soils. It can persist through dry summers and autumns. It offers good ground cover for shaded wildflower gardens, and it itself is very shade tolerant. As a result of its shallowly rooted caudex, its ability to resist fire damage depends on protection obtained from soil cover. Like other stolon-producing species, early meadow-rue is most likely to survive cool fires that do not consume duff. However, it is usually top-killed by fire, killing any aboveground stolons as well. Fires occurring in the spring have the worst impact of early meadow-rue, since this would kill the seeds that mature in June.

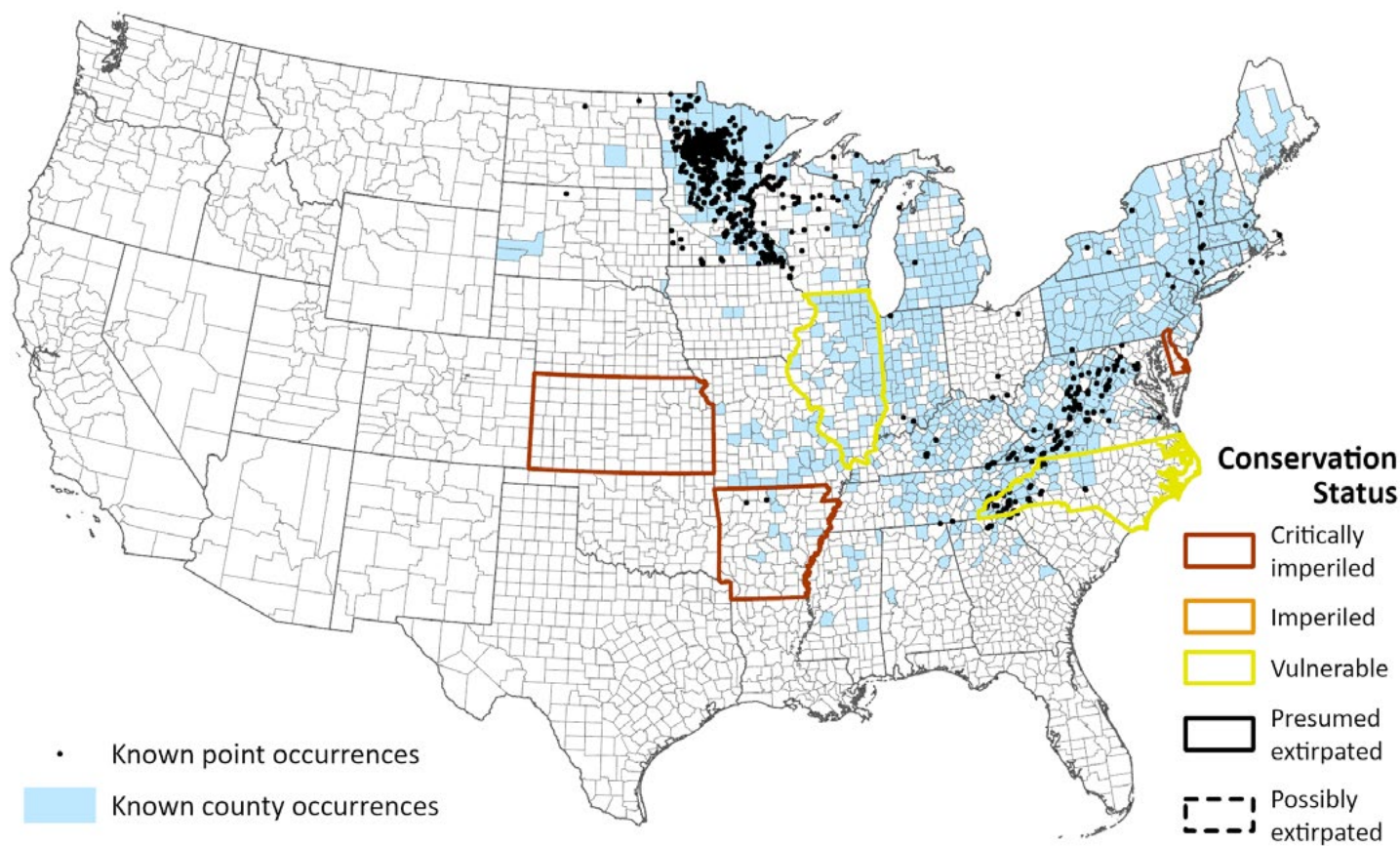


Figure 66.1. Distribution and state-level conservation status of *Thalictrum dioicum*. Known point occurrences were used to assess species deposition responses and critical loads.

Wildlife Uses

Many birds and small mammals eat the seeds of early meadow-rue although their food value is poorly understood.

Ecosystem Services

Early meadow-rue is used as a decorative plant.



Plant of early meadow-rue.
Alex Katovich, Bugwood.org.

Traditional Ecological Knowledge

Traditional medicinal uses include antidiarrheal and anti nausea treatments (root infusion), eye wash (roots) and treatments for heart palpitations (root decoction).

Responses to Nitrogen and Sulfur

The probability of occurrence of early meadow-rue is related to the interaction between N and S deposition (fig. 66.2a). Under lower S deposition (≤ 4.6 kg S/ha/yr), early meadow-rue increases with N deposition up to approximately 8-10 kg N/ha/yr and then decreases at higher N deposition levels. Under higher S deposition (≥ 12.1 kg S/ha/yr), early meadow-rue is uncommon and relatively unresponsive to N deposition. The probability of occurrence decreases sharply with S deposition (fig. 66.2b) (Clark et al. 2019). The climate effects are shown in Figure 66.2c (precipitation) and Figure 66.2d (temperature). The probability of occurrence increases with increasing precipitation (but note widening confidence bands) and peaks at temperatures around 8 °C within the species' sampled range. Confidence in the N and S relationships is moderate-to-high, with good model performance ($R^2 = 0.299$, $AUC = 0.85$; both high confidence), low VIFs ($VIF-N = 1.3$, $VIF-S = 1.3$; both high confidence), and a high N-S correlation ($r=0.76$, low confidence).

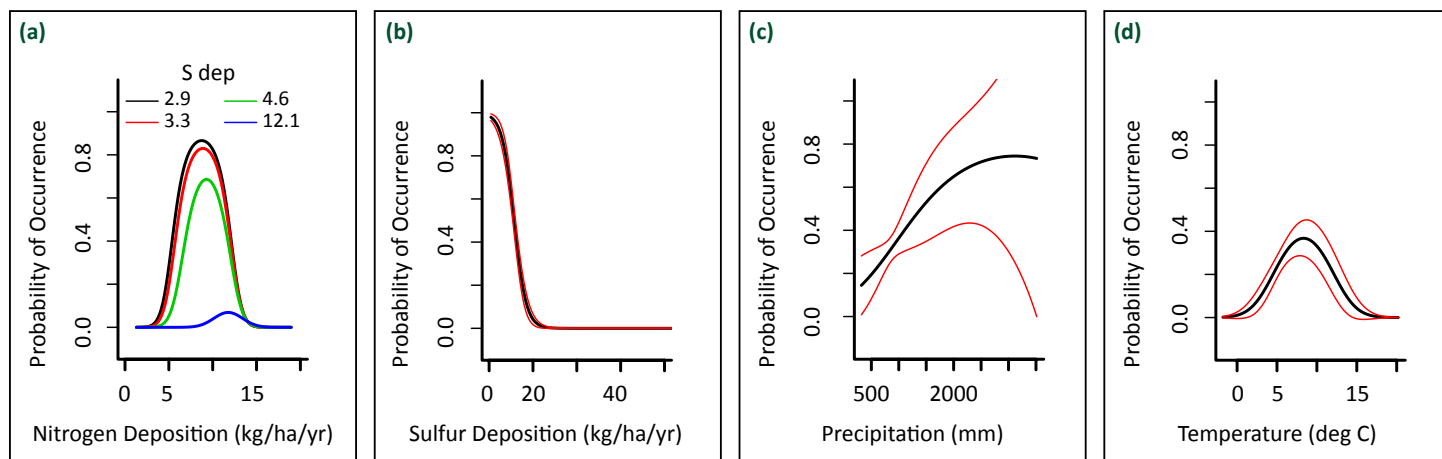


Figure 66.2. Effects of various environmental variables on the probability of occurrence of *Thalictrum dioicum*: a) N x S interaction, b) S deposition, c) precipitation, d) temperature.

Critical Loads and Exceedances

The environmental hull for early meadow-rue covers most of the eastern United States and the higher elevations of the West. The N CL is >10 kg N/ha/yr across most of the East and 6 to 10 kg N/ha/yr in the West, western Midwest, and Maine. The N CL is in exceedance based on 2019–2021 total N deposition in high agricultural areas of the Midwest and East and in the edge of California’s Central Valley and the Salt Lake Air Basin. The S CL is 0.4 kg S/ha/yr across most of the species’ range and 41.7 kg S/ha/yr in eastern urban areas. There are exceedances of the S CL based on 2019–2021 TDep total S deposition in the areas with the lower CL excluding the lower elevation plains in the West.



Flowers of early meadow-rue.
Alex Katovich,
Bugwood.org.

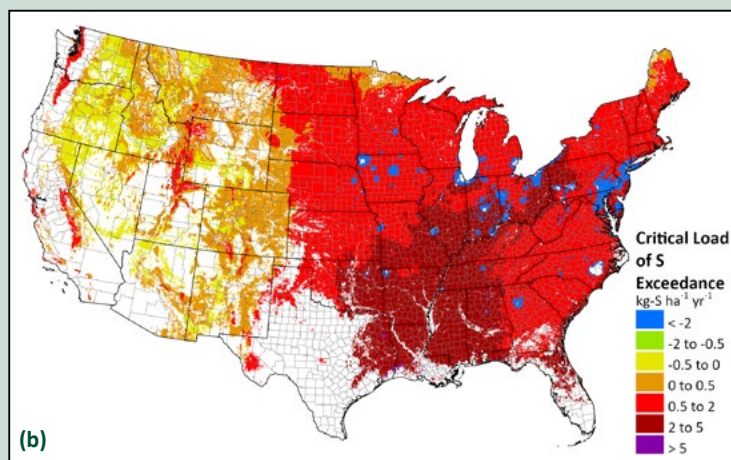
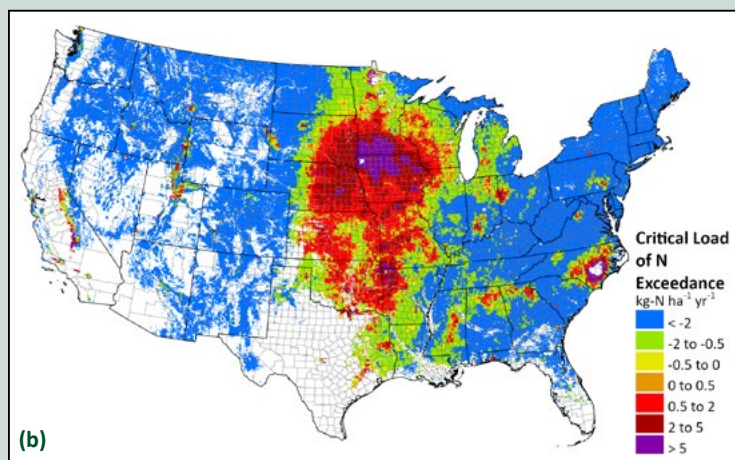
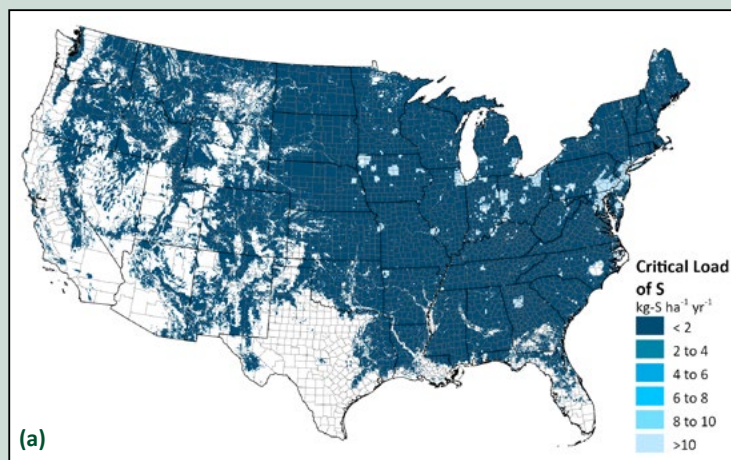
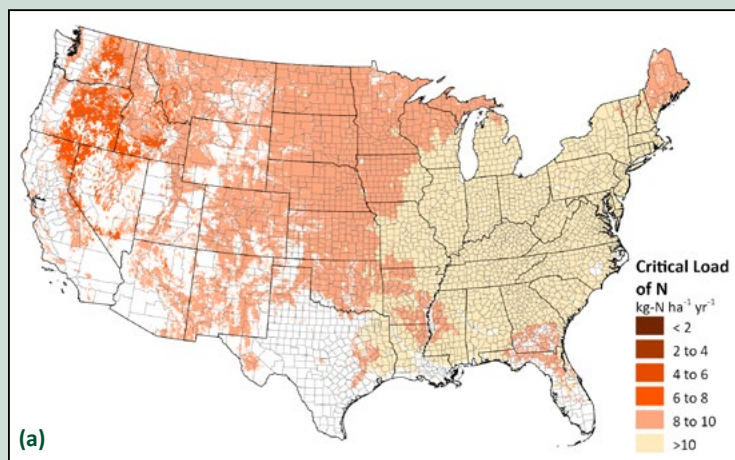


Figure 66.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Thalictrum dioicum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 66.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Thalictrum dioicum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

67.0 *Urtica dioica* (American stinging nettle)

Distribution and Conservation Status

American stinging nettle is a native forb that is a common understory component of riparian communities, marshes and meadows of the United States (fig. 67.1). It has several varieties including one introduced from Europe that occurs in the Atlantic States region.

Species Characteristics and Habitat

Stinging nettle is an upright, perennial, rhizomatous plant that forms dense clonal patches. It has stout stems which grow 3 to 6 feet tall. The leaves, stems, and flowers of stinging nettle are sparsely to moderately covered with stinging hairs. The fruit of stinging nettle is an achene. Stinging nettle produces abundant seed. Seeds remain on the plant until frost when they fall to the ground.

American stinging nettle commonly sprouts in deep, rich soils, and as a result it is used by foresters as an indicator of high soil fertility. It is often found in the sedge-dominated zone between an emergent marsh and

upland meadow making it a facultative wetland species. However, it cannot withstand persistent flooding. It is also found growing in moist forest communities in the southern Appalachian Mountains. American stinging nettle occurs from sea level to subalpine elevations. American stinging nettle has both epigeal and shallow subterranean rhizomes and reproduces vegetatively by these rhizomes and by seeds. It is intermediate in shade tolerance and survives fire by sprouting from its rhizomes, although it is top-killed by fire. As fire removes litter, it encourages stinging nettle growth and provides a suitable germination site for seed, yet, frequent fire may actually decrease stinging nettle growth. Although repeated plowing will eliminate stinging nettle, moderate soil disturbance allows stinging nettle rhizomes to establish dense new colonies. Stinging nettle responds to mowing by sending up multiple bushy shoots. Stinging nettle hairs irritate human skin, and its pollen is a major contributor to summer hay fever.

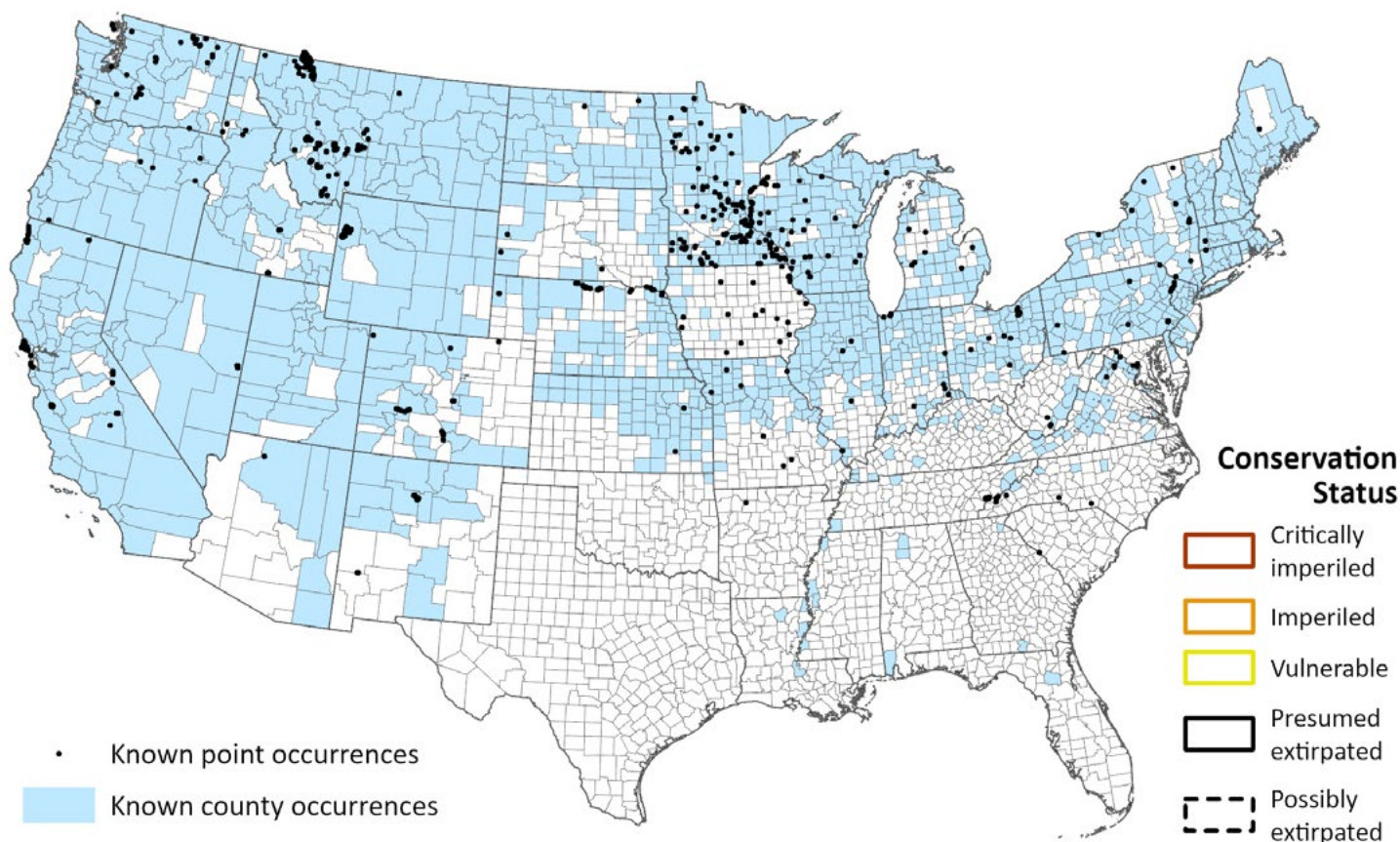


Figure 67.1. Distribution and state-level conservation status of *Urtica dioica*. Known point occurrences were used to assess species deposition responses and critical loads.

Wildlife Uses

Stinging nettle provides tall, dense, nesting cover for mallards, gadwalls, and sharp-tailed grouse. In Utah, it is known to be fair cover for small nongame birds and mammals.

Traditional Ecological Knowledge

Stinging nettle leaves are edible and have a high nutritional value. The many traditional medicinal uses include treatment for upset stomachs and gastrointestinal discomfort, to keep blood flowing after childbirth, to induce labor (juice) and reduce aches, pains, and backaches (leaves rubbed on body, sore area cauterized with bark). The fibers can be used to make bow strings for hunting and fishing line, twine, fishing net, rope, clothing, and baskets.



Fruits/flowers of American stinging nettle.
Richard Gardner, Bugwood.org.

Responses to Nitrogen and Sulfur

The probability of occurrence of American stinging nettle increases with N deposition (fig. 67.2a) but the effect of S deposition depends on soil pH (fig. 67.2b). Under more acidic conditions ($\text{pH} \leq 6.5$), the probability of occurrence decreases with S deposition, while under neutral to alkaline conditions ($\text{pH} \geq 7$) the species is relatively unaffected by S deposition. The climate effects are shown in Figure 67.2c (precipitation) and Figure 67.2d (temperature). The probability of occurrence decreases weakly with increasing precipitation and peaks weakly at temperatures around 8 °C within the species' sampled range. Confidence in the N and S relationships is moderate-to-high, with good model performance ($R^2 = 0.108$, $\text{AUC} = 0.74$), low VIFs ($\text{VIF-N} = 1.2$, $\text{VIF-S} = 1.2$; both high confidence), and a high N-S correlation ($r=0.71$, low confidence).



Foliage of American stinging nettle.
Ohio State Weed Lab, The Ohio State University, Bugwood.org.

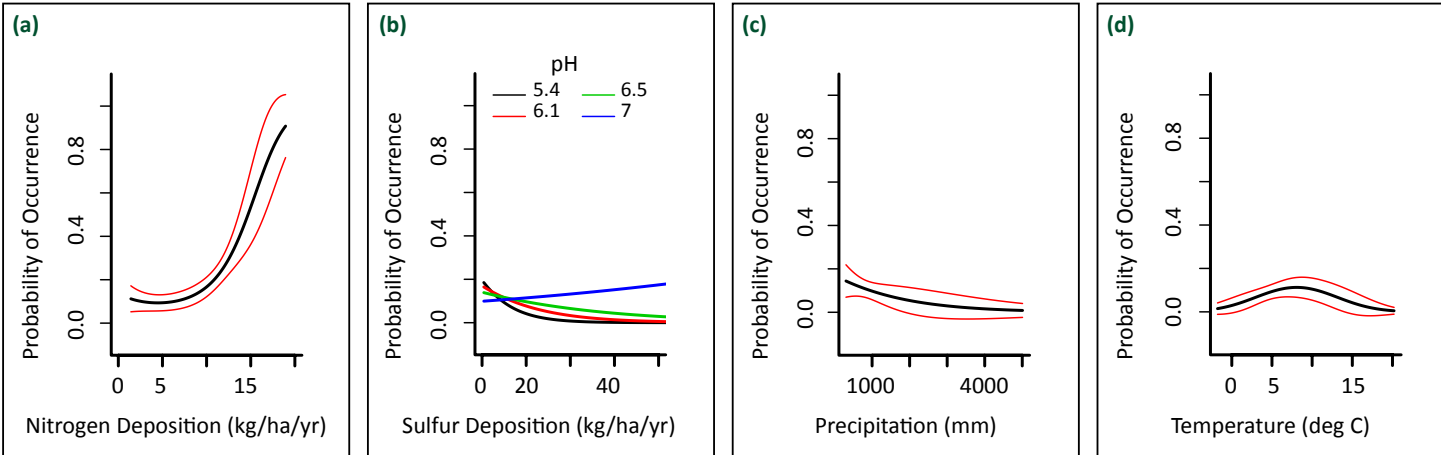


Figure 67.2. Effects of various environmental variables on the probability of occurrence of *Urtica dioica*: a) N deposition, b) S x pH interaction, c) precipitation, d) temperature.

Critical Loads and Exceedances

The environmental hull for American stinging nettle covers most of the United States except the arid Southwest and the Gulf Coast. The N CL is 4 to 6 kg N/ha/yr across the species’ range. The N CL is in exceedance based on 2019–2021 total N deposition across the East and in

higher elevations in the West. The S CL is 0.4 kg S/ha/yr across the East and in higher elevations in the West, and 43.0 kg S/ha/yr in the western Midwest and the lower elevation plains of the West. There are exceedances of the S CL based on 2019–2021 TDep total S deposition in the areas with the lower CL.

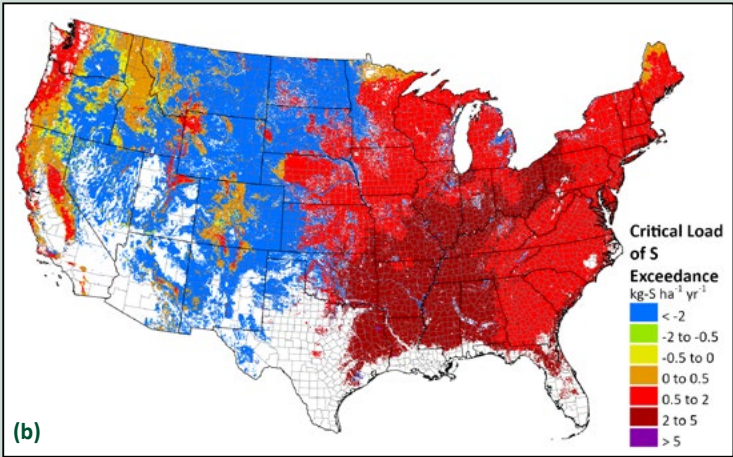
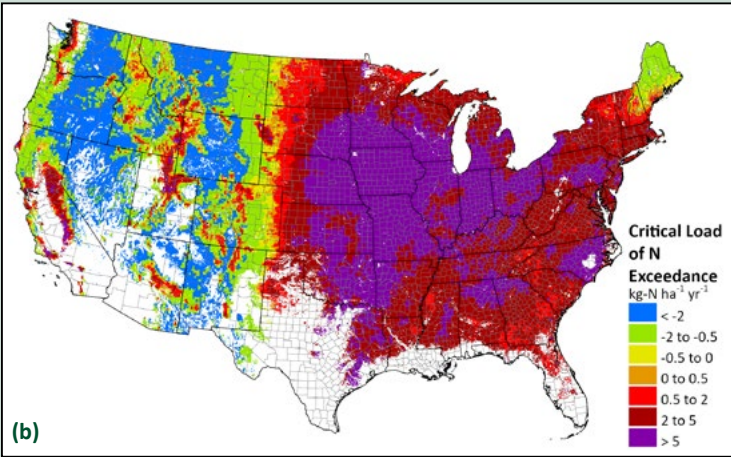
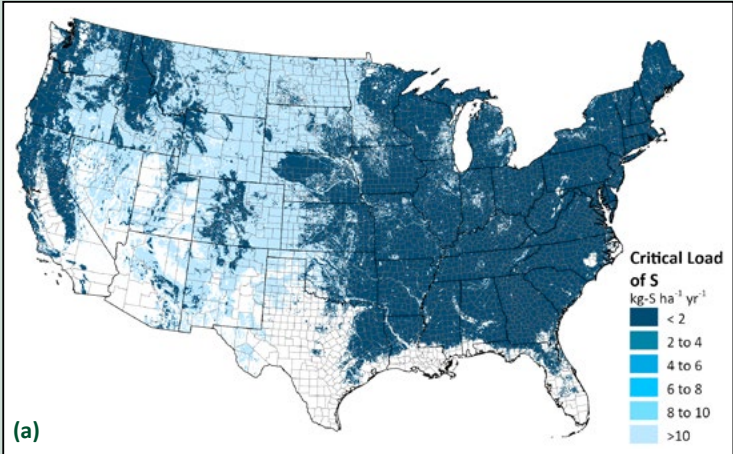
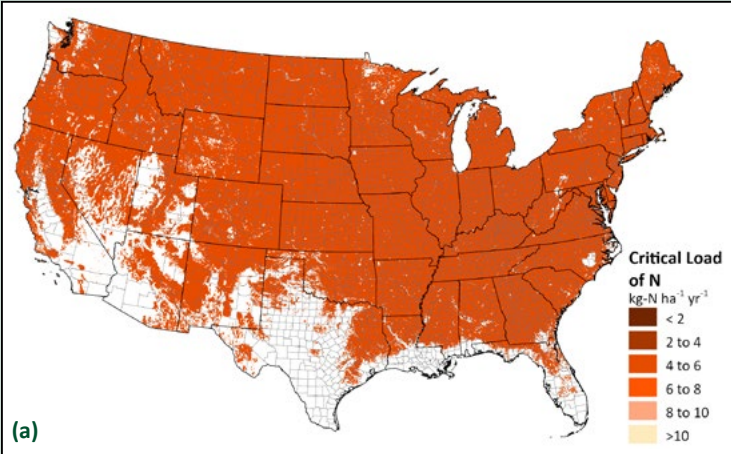


Figure 67.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Urtica dioica* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 67.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Urtica dioica* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

68.0 *Verbascum thapsus* (common mullein)

Distribution and Conservation Status

Common mullein is a non-native, ephemeral, biennial forb of meadows, prairies, desert shrublands, chaparral, deciduous woodlands, coniferous forests, and disturbed areas. Introduced in the mid 1700s, it has naturalized throughout most of North America (fig. 68.1).

Species Characteristics and Habitat

Common mullein is a densely woolly, sturdy plant with thick, deep taproots and fibrous lateral roots which grow in the first year of rosette growth. A rosette of large, hairy leaves at the base of the plant and an extensive crown are produced in the first year. The basal leaves are simple, persistent, and grow between 3 to 20 inches long. In the second year, the flowering year, common mullein sprouts a single, stout, upright, flowering stem out of the basal leaves that can grow over 7 feet tall. The leaves on the stem are alternate with their size reducing up the stem. The thick layer of hairs on the stems and leaves breaks the impact of winds, thus preventing water loss to evaporation. Common mullein flowers are closely arranged on a spike-like, terminal inflorescence. Flowers

are short-lived, open only 1 day for pollination from just before dawn to midafternoon. Common mullein has hairy, egg-shaped, two-celled capsules, no more than 0.4 inches long that split at maturity, and contain numerous seeds. Seeds do not travel far from the parent plant. Common mullein reproduces entirely by seed and has no means of vegetative regeneration. Self and cross pollination of common mullein flowers are both possible. By the end of the day, if an open flower has not been visited by a pollinator, it self-pollinates. Common mullein produces ample seed and branching of the flower stalk can lead to even greater seed production. The rod-like spike of fruits often survives through the winter.

Common mullein thrives in bright and warm conditions with dry, infertile, highly calcareous soils. It is frequently observed on bulldozed, burned, or other disturbed locations. As a result, common mullein is typical in early postfire habitats. Fire kills common mullein plants; however, populations are known to persist in locations burned in high-severity fires. Common mullein is regarded as disruptive to the growth of native plants in Hawaii.

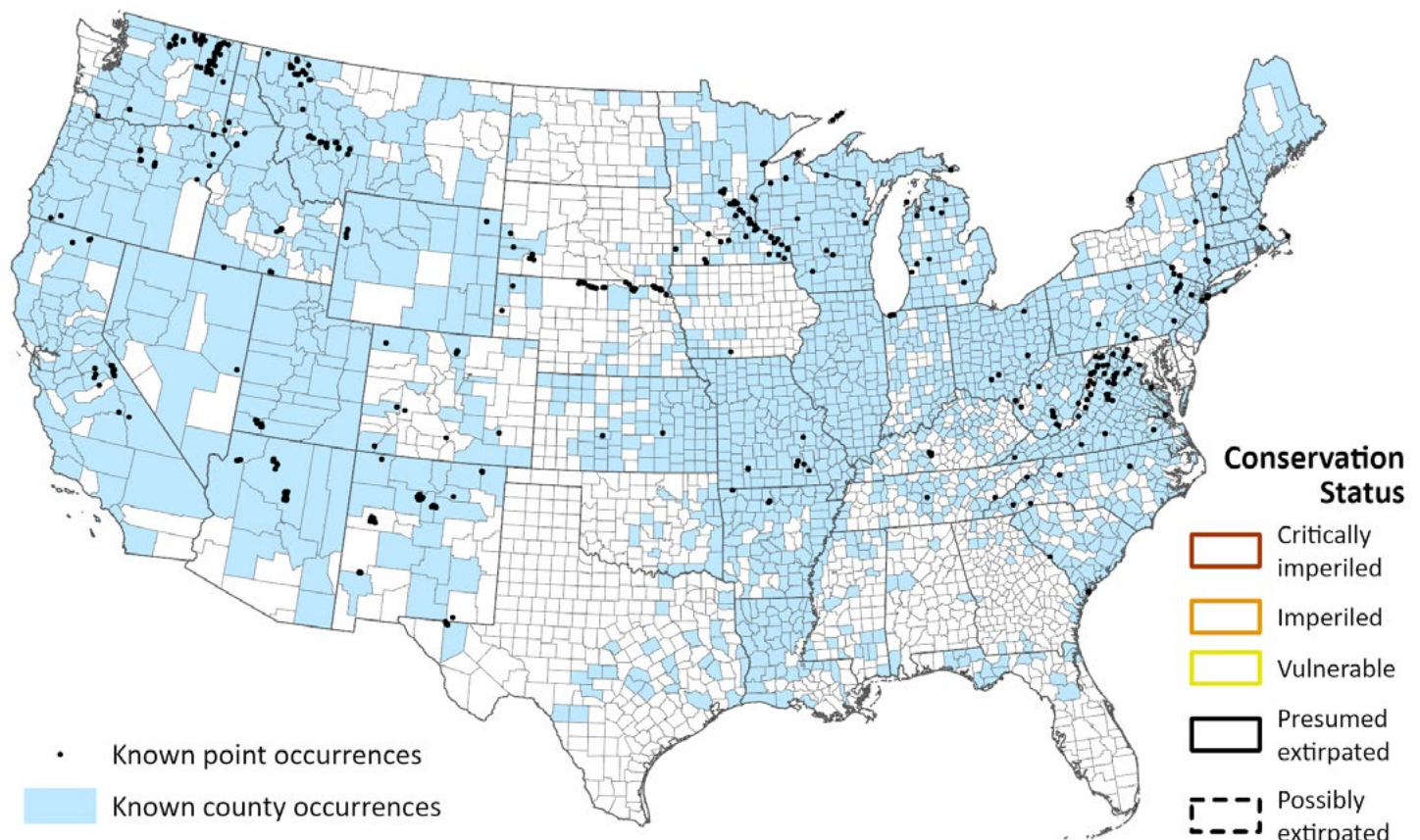


Figure 68.1. Distribution and state-level conservation status of *Verbascum thapsus*. Known point occurrences were used to assess species deposition responses and critical loads.

Minimizing disturbances may be the most effective and economical method of common mullein control due to its ability to establish in disturbed sites. First year rosettes are easily killed by herbicide but second-year plants are more resilient.

Wildlife and Livestock Uses

Common mullein is frequently found on sites grazed by animals. Deer, elk, mountain goats, and small mammals consume common mullein, especially in the winter. Small mammals such as chipmunks and prairie dogs are known to eat the seeds and fruits of common mullein. Domestic



Flowers of common mullein.
Steve Dewey, Utah State University, Bugwood.org.

grazing animals usually do not prefer to consume common mullein unless other forage is unavailable. The young and immature leaves with the densest and longest hairs are fed on significantly less than mature leaves.

Ecosystem Services

Extracts of oil from common mullein leaves and flowers have demonstrated antibacterial and antitumor properties and common mullein is one of several plants used commercially in herbal ear drops to treat earaches in children.

Traditional Ecological Knowledge

Common mullein has been used in a wide variety of traditional medicines. These include teething necklaces (roots) and treatments for colds (leaf decoction), bruises and wounds (smashed leaf compress), mental illness (smoked dried leaves and flowers), colds, bronchitis, asthma (smoked leaves), and coughs (boiled root syrup).

Responses to Nitrogen and Sulfur

The probability of occurrence of common mullein decreases with increasing N deposition (fig. 68.2a) and is unresponsive to S deposition (Clark et al. 2019). The climate effects are shown in Figure 68.2b (precipitation) and Figure 68.2c (temperature). The probability of occurrence increases with increasing precipitation and with temperatures above 6 °C within the species' sampled range. Confidence in the N and S relationships is moderate-to-high, with good model performance ($R^2 = 0.206$, AUC = 0.85; moderate and high confidence, respectively), low VIFs (VIF-N = 1.3, VIF-S = 1.4; both high confidence), and a moderate N-S correlation ($r=0.66$, moderate confidence).

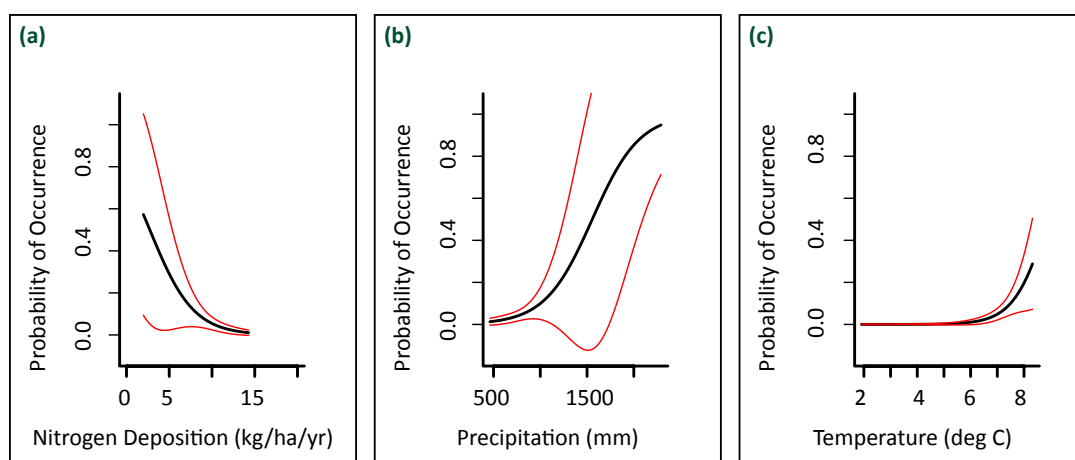


Figure 68.2. Effects of various environmental variables on the probability of occurrence of *Verbascum thapsus*: a) N deposition, b) precipitation, c) temperature.

Critical Loads and Exceedances

The environmental hull for common mullein covers most of the United States except the arid Southwest, Pacific Northwest, and the Gulf Coast. The N CL is <2 kg N/ha/yr across the species' range. The N CL is in exceedance based on 2019–2021 total N deposition across the East and in higher elevations in the West. There is no response to S deposition.



Foliage of common mullein.
John Cardina, The Ohio State University, Bugwood.org.

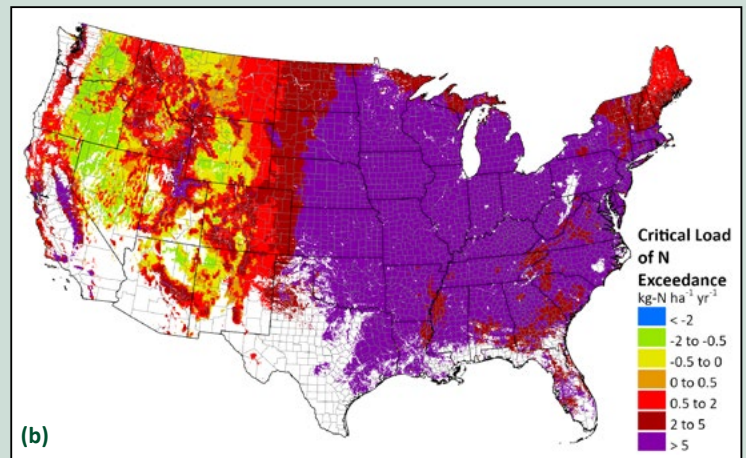
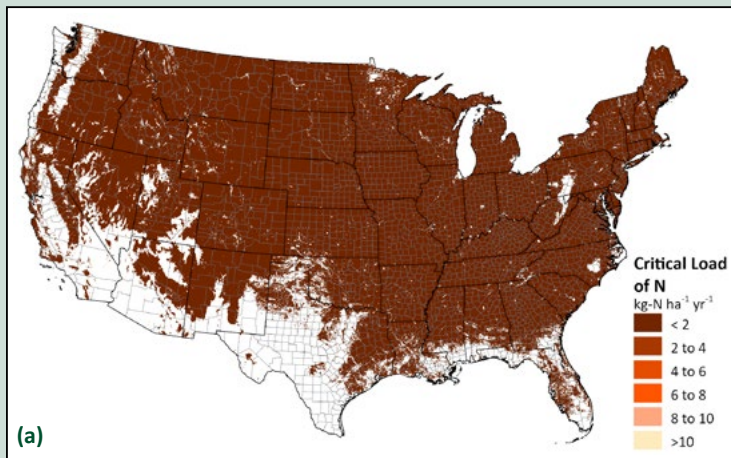


Figure 68.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Verbascum thapsus* and (b) the exceedance of N critical loads based on TDep 2019–2021 total N deposition.

69.0 *Veronicastrum virginicum* (Culver's root)

Distribution and Conservation Status

Culver's root is a native, clumping, perennial forb growing well along the East Coast and continues west to Texas, Kansas, and North Dakota. Culver's root thrives in moist to wet meadows and prairies but cannot handle overwatering. Culver's root grows best in sunny habitats and combines well with wildflowers. It is critically imperiled in South Dakota, Nebraska, Oklahoma, Alabama, South Carolina, Delaware, and Vermont, imperiled in New York, Massachusetts, and North Carolina, and vulnerable in Mississippi, Georgia, and New Jersey (fig. 69.1).

Species Characteristics and Habitat

It is a tall, durable wildflower that blooms in late summer, around July to September when most other plants are not flowering. Culver's root grows 3 to 6 feet tall with a round and smooth central stem. There are 3 to 7 leaves arranged along the stems and attached at the same point and wrap around the stem. The leaves are no longer than 6 inches and have finely toothed, serrated edges. At the top of the stem are slender spikes of white, pink or blue flowers no longer than 8 inches. The flowers bloom from the top to

the bottom for about a month and do not have a scent. Culver's root has a central taproot in addition to rhizomes. The seeds of Culver's root are abundant and occur in a small woody capsule. The seeds are small and can be carried by the wind several feet from the mother plant. Culver's root is most easily propagated by divisions in the late fall or early spring.

Wildlife Uses

Short tongued bees are the most common pollinator that uses Culver's root for pollen and nectar. Honeybees, bumblebees, mason bees, green metallic bees and masked bees are other pollinators and users of Culver's root. Sphecid wasps, butterflies, moths, and syrphid flies also use Culver's root.

Traditional Ecological Knowledge

Although Culver's root is considered poisonous, there are a variety of traditional medicinal uses for the root as an analgesic to treat back aches, as a purgative, and to make a diaphoretic (sweat inducing drug) to treat typhus or fevers associated with nausea or vomiting. It has also been

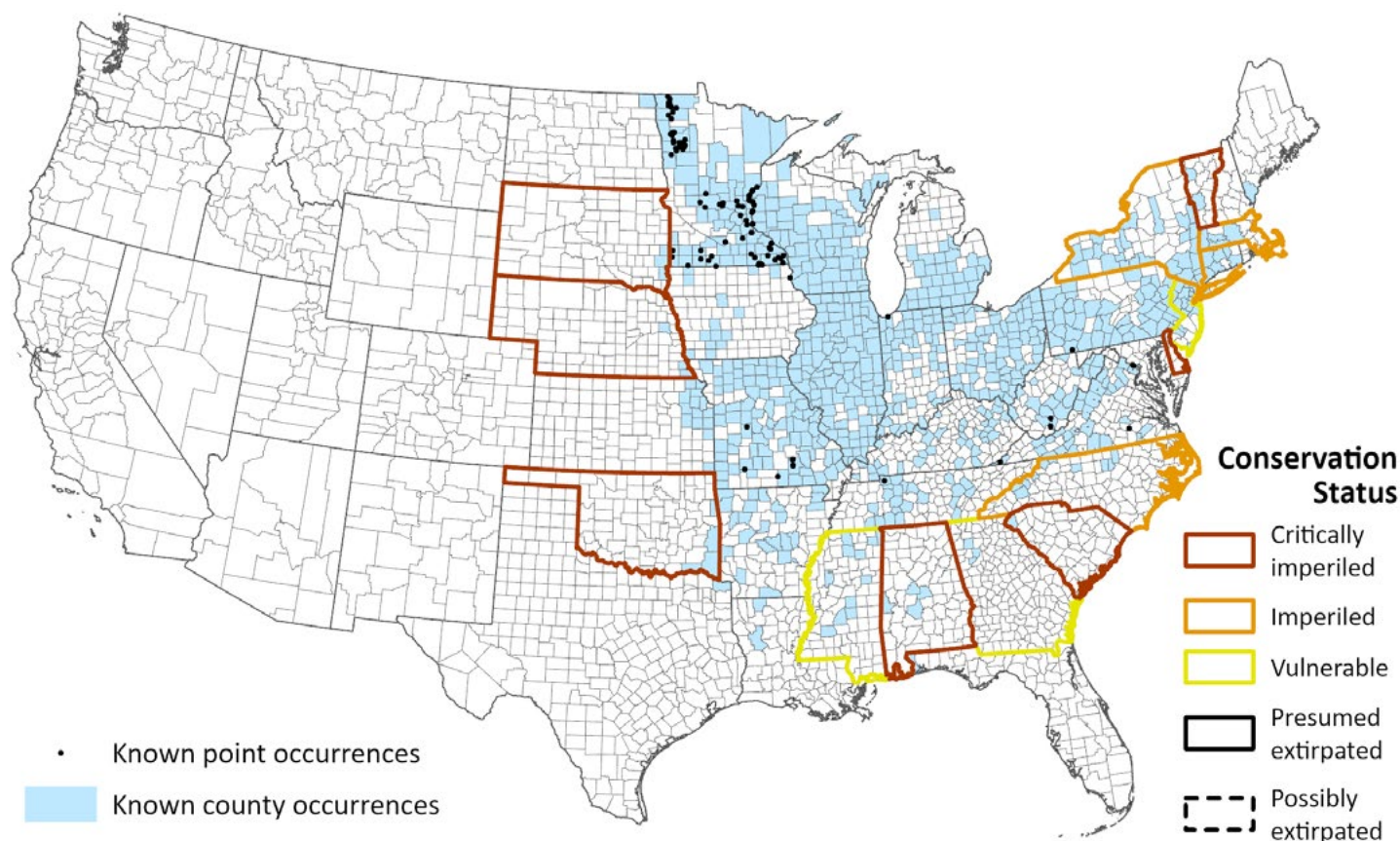


Figure 69.1. Distribution and state-level conservation status of *Veronicastrum virginicum*. Known point occurrences were used to assess species deposition responses and critical loads.

used to treat tuberculosis (decoction), diarrhea (infusion), as well as chills and fevers, and as a gynecological aid for women in labor.

Responses to Nitrogen and Sulfur

The probability of occurrence of Culver's root is related to the interaction between N deposition and soil pH (fig. 69.2a). Under more alkaline conditions (pH ≥ 7.2),



Flowers of Culver's root.
David Cappaert, Bugwood.org.

Culver's root is more common and decreases with N deposition, while under more acidic conditions (pH ≤ 6.7) the species is less common and relatively unaffected by N deposition. The climate effects are shown in Figure 69.2b (precipitation) and Figure 69.2c (temperature). The probability of occurrence increases with increasing precipitation and peaks broadly around 5 °C within the species' sampled range. Confidence in the N and S relationships is moderate-to-high, with good model performance ($R^2 = 0.129$, AUC = 0.75; both moderate confidence), low VIFs (VIF-N = 1.7, VIF-S = 2.5), and a moderate N-S correlation ($r=0.69$, moderate confidence).



Foliage of Culver's root.
Chris Evans, University of Illinois, Bugwood.org.

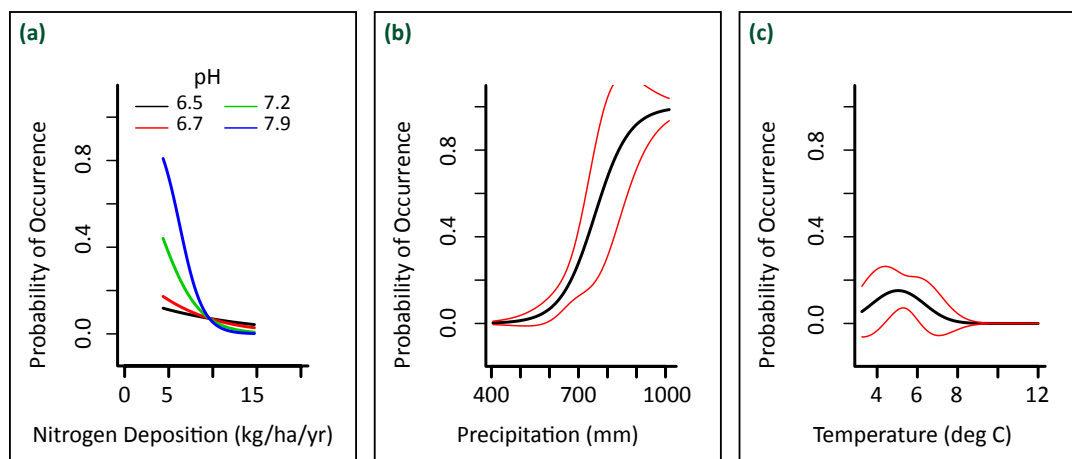


Figure 69.2. Effects of various environmental variables on the probability of occurrence of *Veronicastrum virginicum*: a) N x pH interaction, b) precipitation, c) temperature.

Critical Loads and Exceedances

The environmental hull for Culver's root covers most of the eastern United States excluding the Northeast, and the higher elevations in the West. The N CL is >10 kg N/ha/yr across most of the East and 4 to 6 kg N/ha/yr in the

western Midwest and western mountains. The N CL is in exceedance based on 2019–2021 total N deposition in most of the Midwest and in higher elevations in the West. There is no response to S deposition.

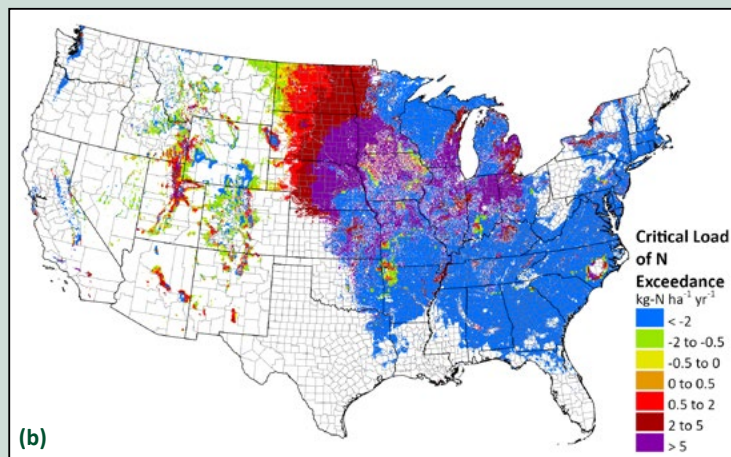
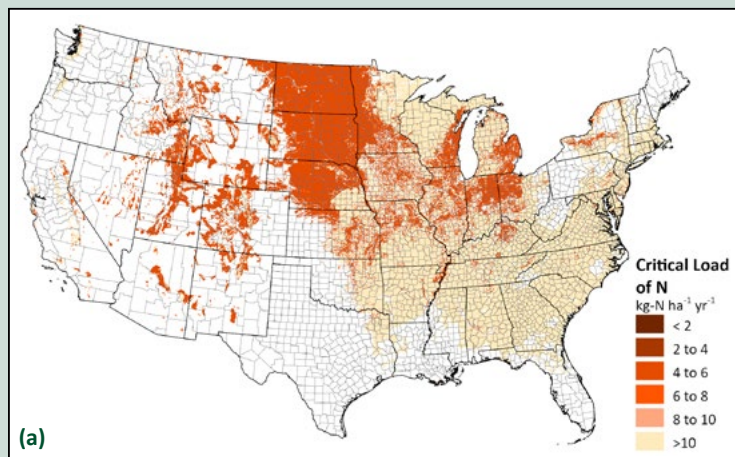


Figure 69.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Veronicastrum virginicum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

70.0 *Woodwardia virginica* (Virginia chainfern)

Distribution and Conservation Status

Virginia chainfern is a native perennial fern of swamps, cypress ponds, marshes, low prairies, and adjacent hammocks. It is found throughout the eastern United States stretching from Maine south to Florida and Louisiana and as far west as Michigan and Texas. It is critically imperiled in Vermont and Kentucky, imperiled in Rhode Island and Tennessee, and vulnerable in Ohio (fig. 70.1).

Species Characteristics and Habitat

Virginia chainfern is a tall, upright, deciduous, dark-colored fern with brown stalks and an average leaf length growing up to 5 feet. The fronds begin growing at the end of February and continue throughout October, when leaf drop occurs. The leaves of Virginia chainfern grow close together to form groups of wide spreading and deep-growing rhizomes. There are only a few roots compared

to the number of rhizomes and they are elongate, slender fibers. Virginia chainfern has dark brown spores on the underside of its leaves, which first go through an asexual stage, followed by a sexual stage, maturing in summer and fall.

Virginia chainfern grows best in low, moist areas in soils that are generally acidic sands, clays, and peat. It is able to grow in open areas; however, it thrives in partial shade around the bases of trees. Its abundance decreases as flooding depth increases. Virginia chainfern often stays sterile until a disturbance such as fire or animal activity activates fertility, however the specific factors which activate fertility are unclear. It is best collected for propagation when the spores are mature, i.e., from May to September. Virginia chainfern is top-killed by fire, however, it can survive fires by sprouting from rhizomes.

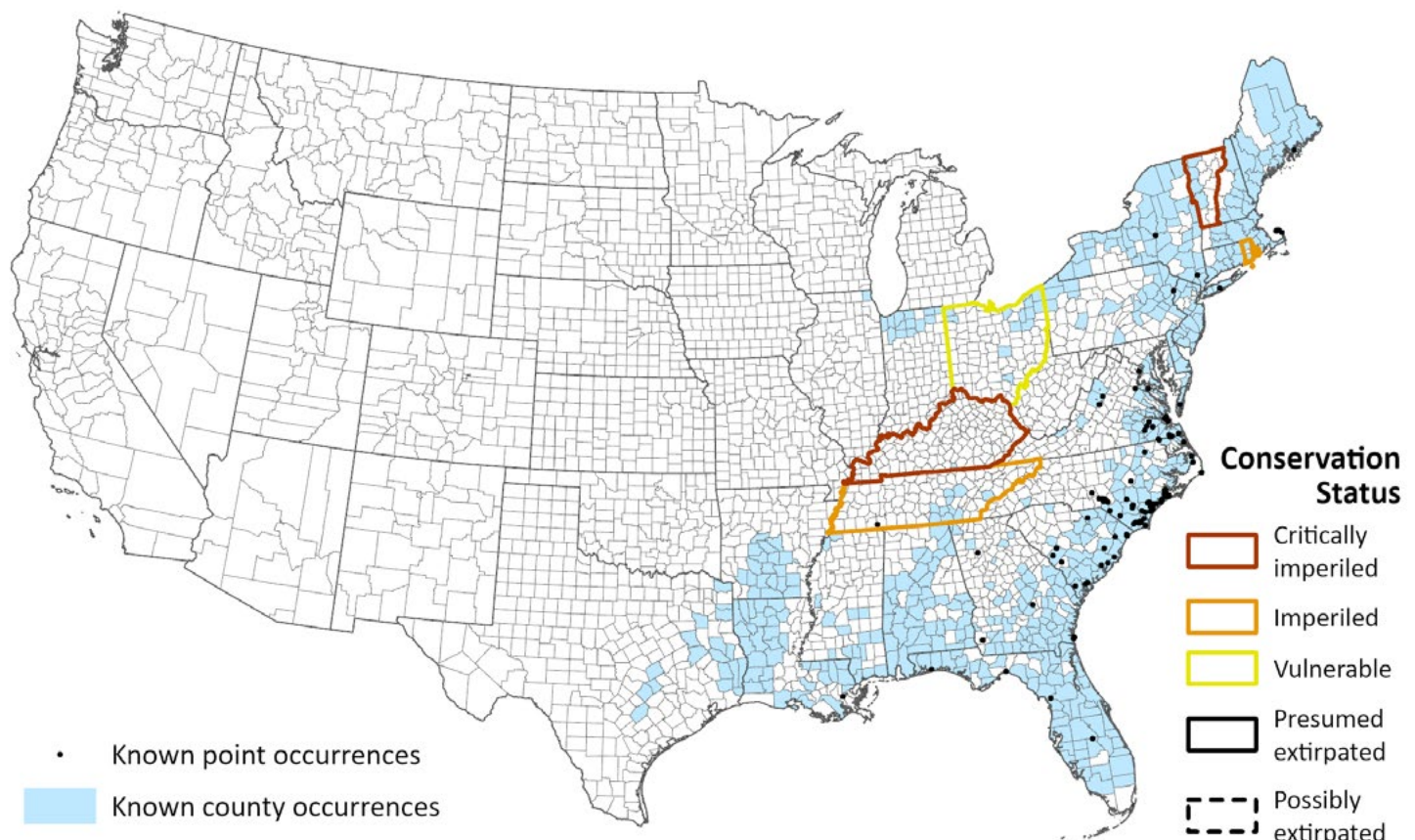


Figure 70.1. Distribution and state-level conservation status of *Woodwardia virginica*. Known point occurrences were used to assess species deposition responses and critical loads.

Responses to Nitrogen and Sulfur

The probability of occurrence for Virginia chainfern depends mostly on the interaction between N deposition and soil pH (fig. 70.2a). Under more acidic conditions (pH ≤4.3) the species is more common and increases with N deposition up to approximately 14-15 kg N/ha/yr and then decreases with higher levels of N deposition. Under less acidic conditions (pH ≥4.7) Virginia chainfern is less common and less responsive to N deposition. The climate effects are shown in Figure 70.2b (precipitation) and Figure 70.2c (temperature). The probability of occurrence peaks narrowly around 1300 mm precipitation and at temperatures around 17 °C within the species’ sampled



Patch of Virginia chainfern.
Chris Evans, University of Illinois, Bugwood.org.

range. Confidence in the N and S relationship is moderate, with good model performance ($R^2 = 0.36$, $AUC = 0.89$; both high confidence), low VIFs ($VIF-N = 1.4$, $VIF-S = 1.4$; both high confidence), and a high N-S correlation ($r=0.82$, low confidence).

Critical Loads and Exceedances

The environmental hull for Virginia chainfern covers the eastern United States except the Northeast. The N CL ranges from <2 to >10 kg N/ha/yr across with the lowest values in Indiana and Ohio and the highest values along the Appalachian Mountains. The N CL is in exceedance based on 2019–2021 total N deposition along the western edge of the range as well as scattered areas along the eastern States. There is no response to S deposition.



Plant of Virginia chainfern.
Chris Evans, University of Illinois, Bugwood.org.

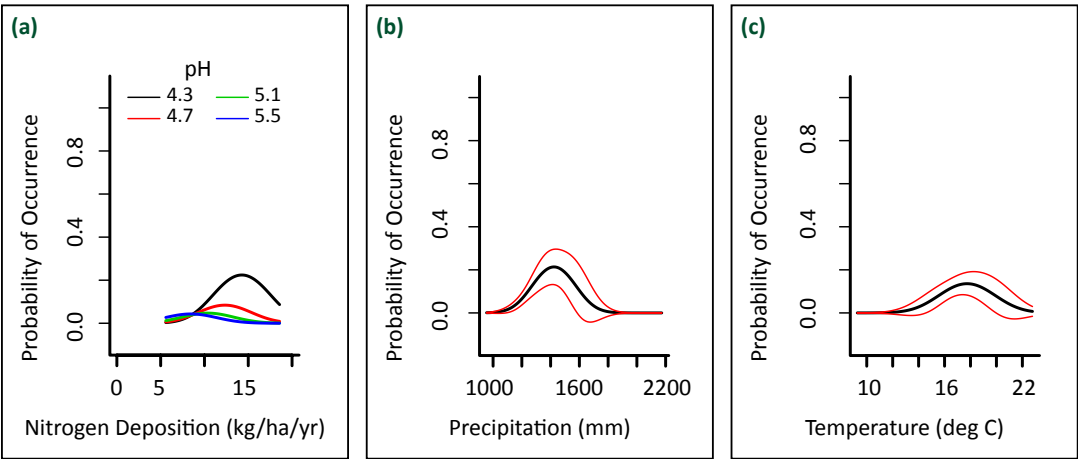


Figure 70.2. Effects of various environmental variables on the probability of occurrence of *Woodwardia virginica*: a) N x pH interaction, b) precipitation, c) temperature.

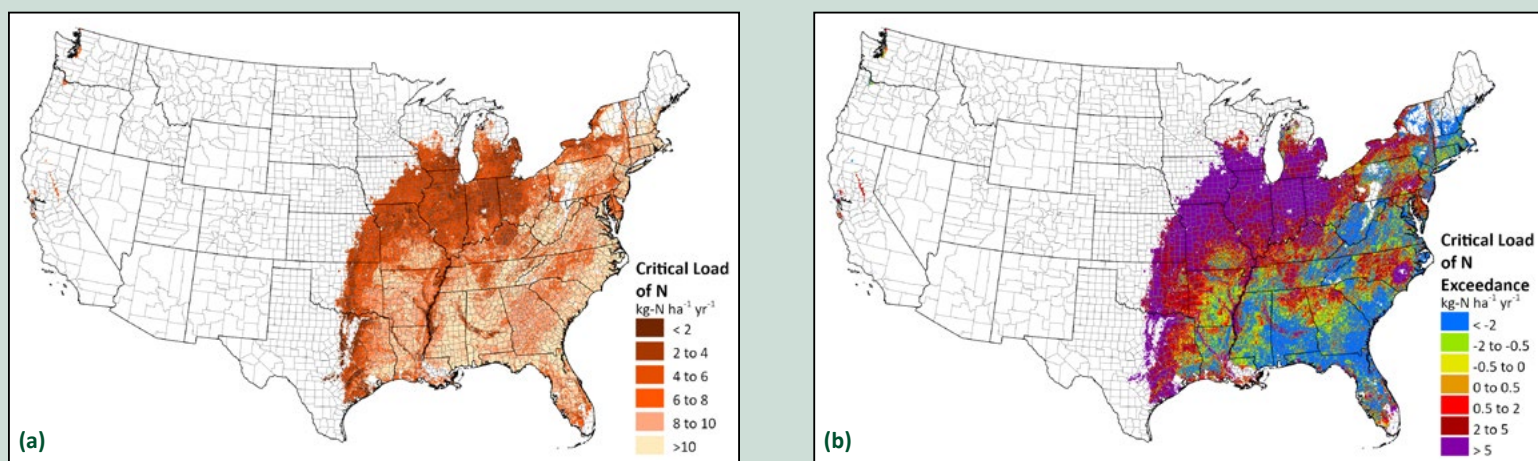


Figure 70.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Woodwardia virginica* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

71.0 *Zizia aurea* (Golden alexanders)

Distribution and Conservation Status

Golden alexanders is a native perennial forb of wet, sunny meadows, open woodlands savannas, thickets, limestone glades and bluffs, power line clearings in woodland areas, and abandoned fields. It is widely distributed across the East Coast, Southeast and Midwest regions of the United States. It is imperiled in Rhode Island, Maryland, and Delaware (fig. 71.1).

Species Characteristics and Habitat

Golden alexanders grows 1 to 2 feet tall, with ovate leaves up to 3 inches long with finely serrated margins. The leaves by the base of the stem are twice compound with long petioles, while the upper leaves are once compound with short petioles. Golden alexanders is known for its bright yellow flowers which bloom in late spring, from May through June. The yellow flowers are less than 0.4 inches long, with 5 sepals, 5 petals, and 5 stamens. Groups of flowers grow into a flat-topped flower head. The fruits of golden alexanders are large, round, capsules which slowly ripen in flattened heads. The flowers eventually

fall to reveal the green fruit. They are green for most of the summer then slowly change to a burgundy and then brown, when they are ready to be crushed to release the dark brown seeds. The leaf color changes to a light purple in autumn.

Golden alexanders grows freely in small colonies in wet soils. Although it prefers wet soil, it is tolerant of dry conditions in the summer. It thrives in full sun but can tolerate partial shade. Golden alexanders is a sturdy, resilient plant with relatively few threats. It grows easily and is maintained with moderate levels of N, P and K.

Wildlife Uses

A wide variety of butterflies and insects use the flower of golden alexanders. Golden alexanders also provides an abundant source of pollen and nectar to many insects.

Ecosystem Services

Golden alexanders is primarily used as a component of conservation mixes and wildflower gardens.

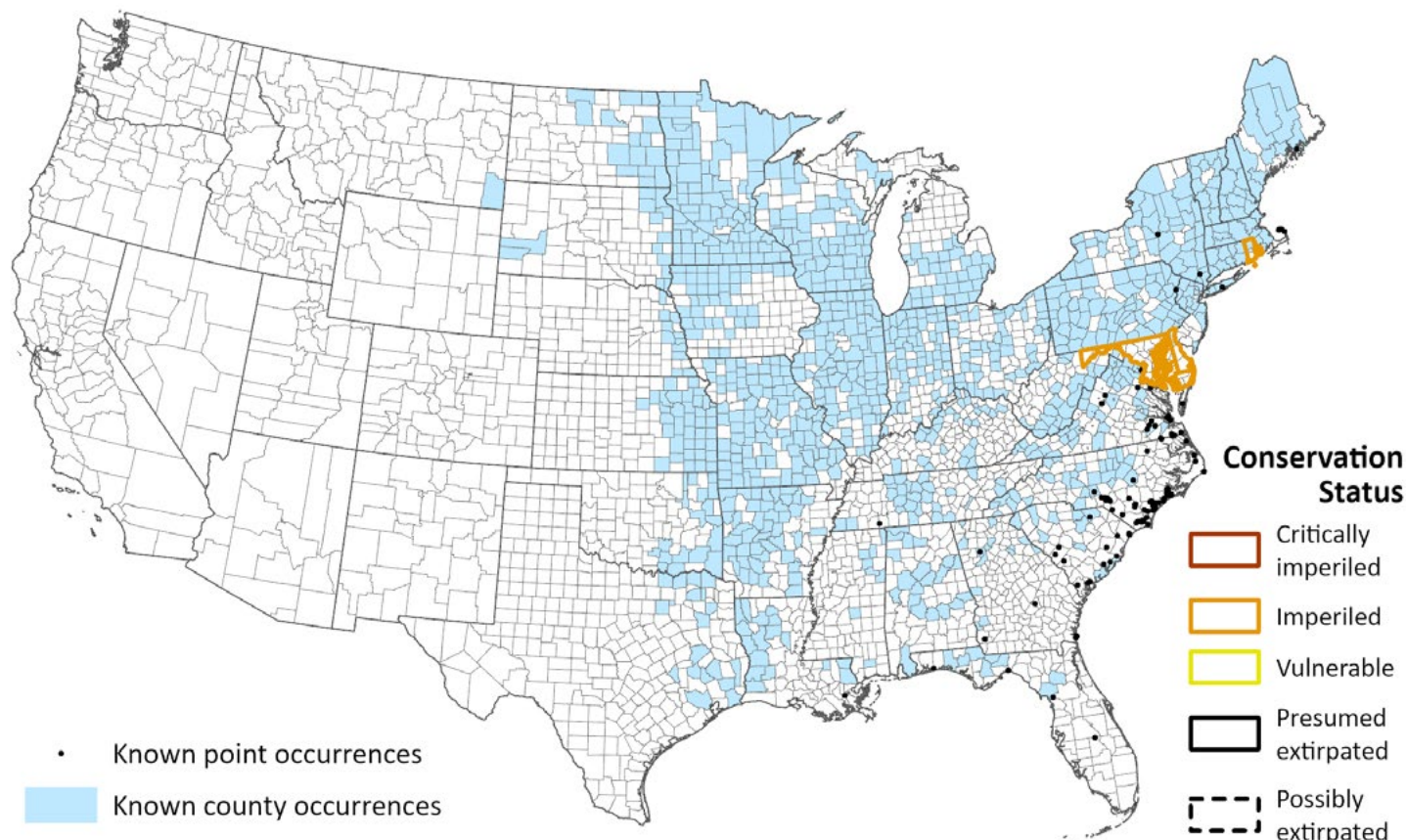


Figure 71.1. Distribution and state-level conservation status of *Zizia aurea*. Known point occurrences were used to assess species deposition responses and critical loads.

Traditional Ecological Knowledge

Golden alexanders is used in traditional medicine to relieve headache pain (flowering stalks) and treat fevers (roots).

Responses to Nitrogen and Sulfur

The probability of occurrence of golden alexanders increases with N deposition (fig. 71.2a) and decreases with S deposition (fig. 71.2b). There are interactions (Clark et al. 2019), but these do not greatly affect the probability of occurrence or the critical loads. The only significant climate variable is temperature (fig. 71.2c). The probability of occurrence is largely unresponsive to temperature (but note wide confidence bands at lower temperatures) within the species’ sampled range. Confidence in the N and S relationship is moderate-to-high, with good model performance ($R^2 = 0.426$, AUC = 0.92; both high

confidence), low VIFs (VIF-N = 1.3, VIF-S = 1.4; both high confidence), and a moderate N-S correlation ($r=0.58$, moderate confidence).

Critical Loads and Exceedances

The environmental hull for golden alexanders covers the eastern United States and the higher elevations in the West. The N CL is >10 kg N/ha/yr across the East and 8 to 10 kg N/ha/yr in the West. The N CL is in exceedance based on 2019–2021 total N deposition in the highest deposition areas in the Midwest and some areas impacted by the Los Angeles and Salt Lake City air basins. The S CL is 0.43 across most of the species’ range and 27.6 kg S/ha/yr in a band from Iowa to Ohio. The S CL is in exceedance based on 2019–2021 total S deposition in areas with the lower CL.



Flowers of golden alexanders.
David Cappaert, Bugwood.org.



Foliage of golden alexanders.
Katy Chayka, www.minnesotawildflowers.info, Bugwood.org.

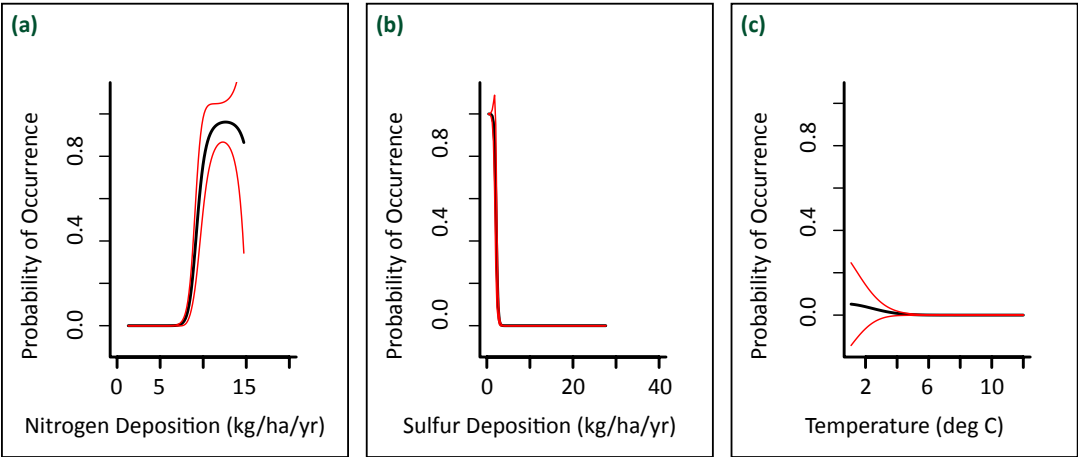


Figure 71.2. Effects of various environmental variables on the probability of occurrence of *Zizia aurea*: a) N deposition, b) S deposition, c) temperature.

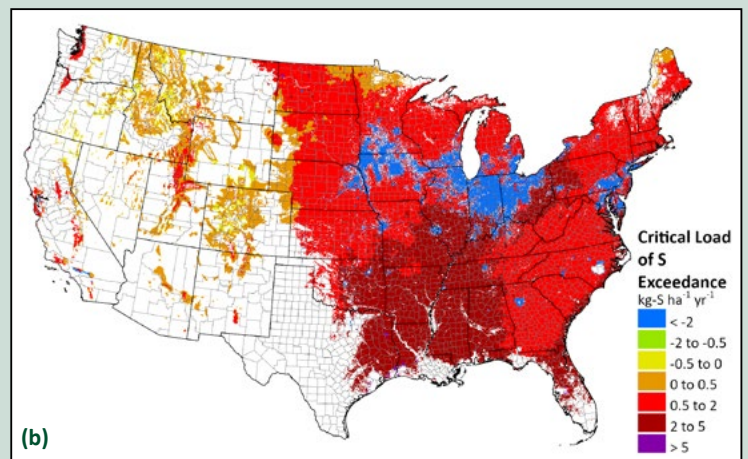
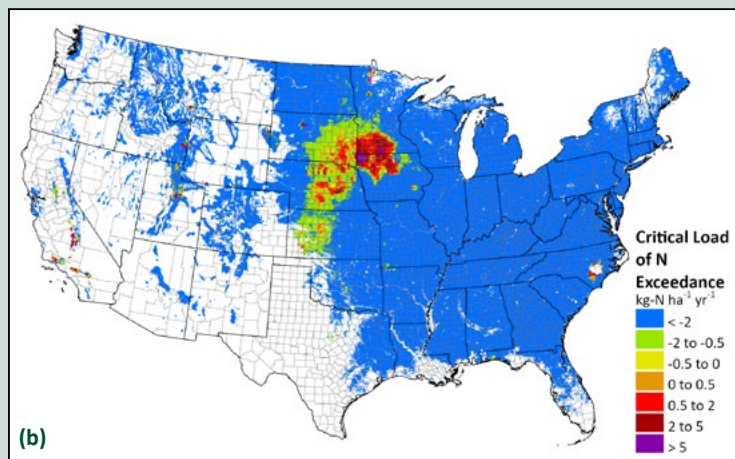
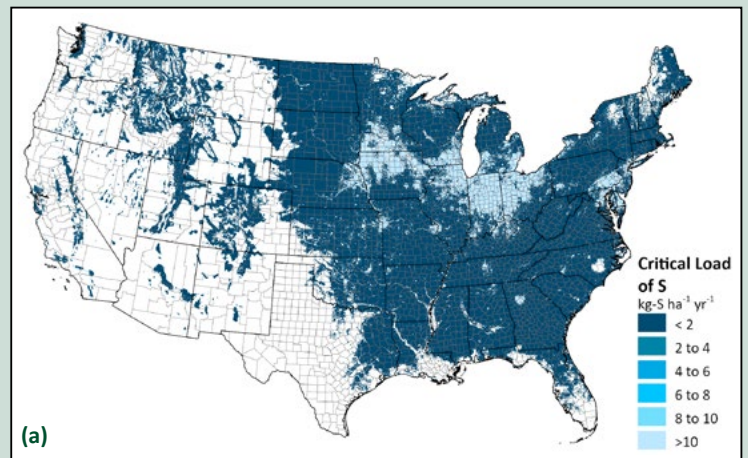
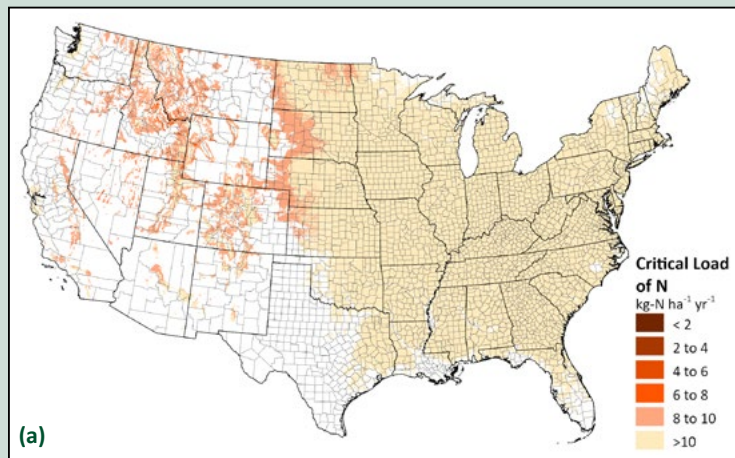


Figure 71.3. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Zizia aurea* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

Figure 71.4. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Zizia aurea* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A1. *Agoseris glauca* (pale agoseris)

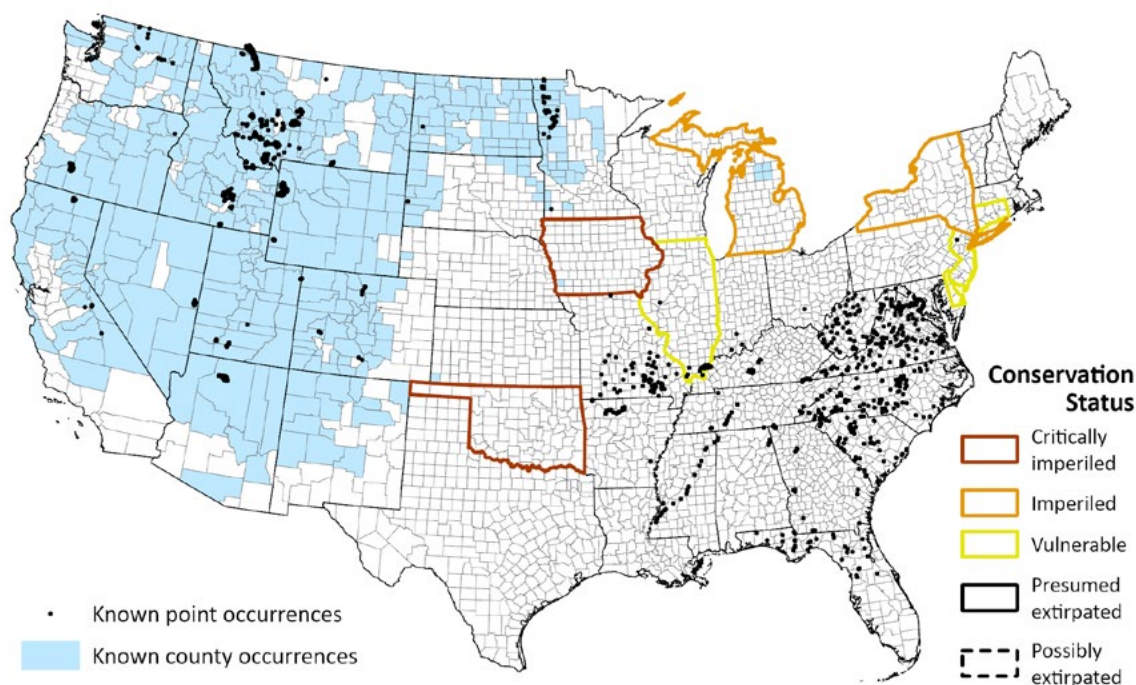


Figure A1.1. Distribution and state-level conservation status of *Agoseris glauca*. Known point occurrences were used to assess species deposition responses and critical loads.

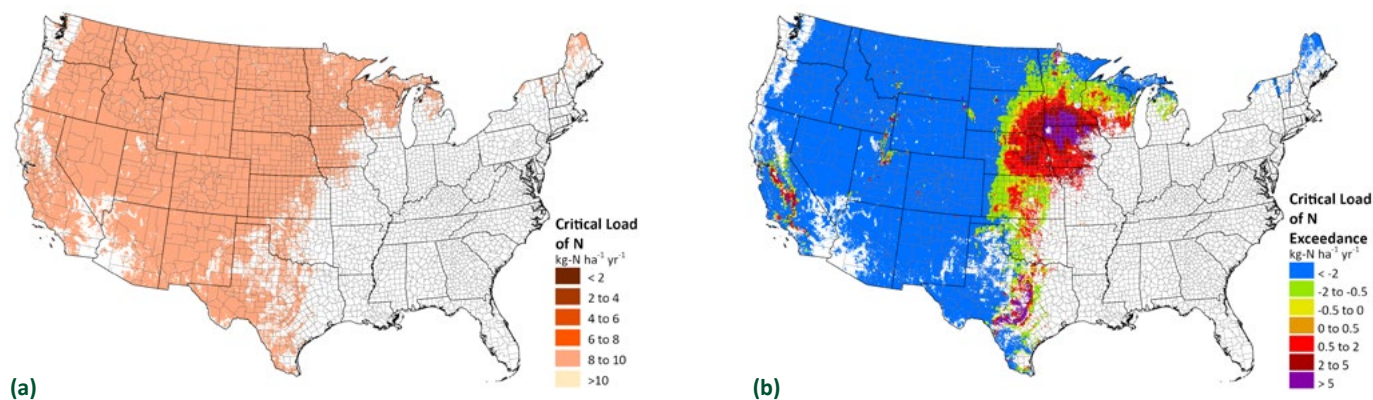


Figure A1.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Agoseris glauca* and (b) the exceedance of N critical loads based on TDep 2019–2021 total N deposition.

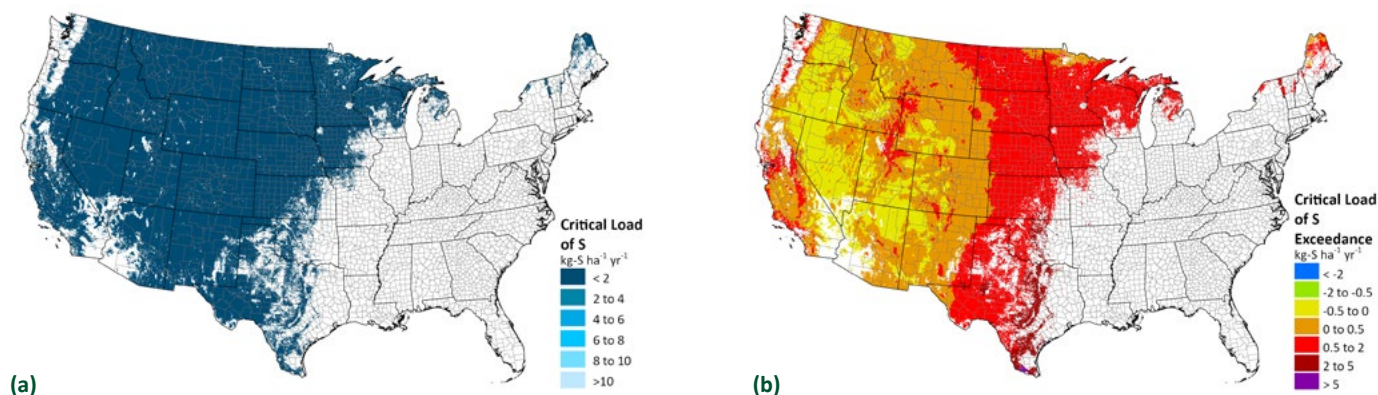


Figure A1.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Agoseris glauca* and (b) the exceedance of S critical loads based on TDep 2019–2021 total S deposition.

A2. *Agrimonia rostellata* (beaked agrimony)

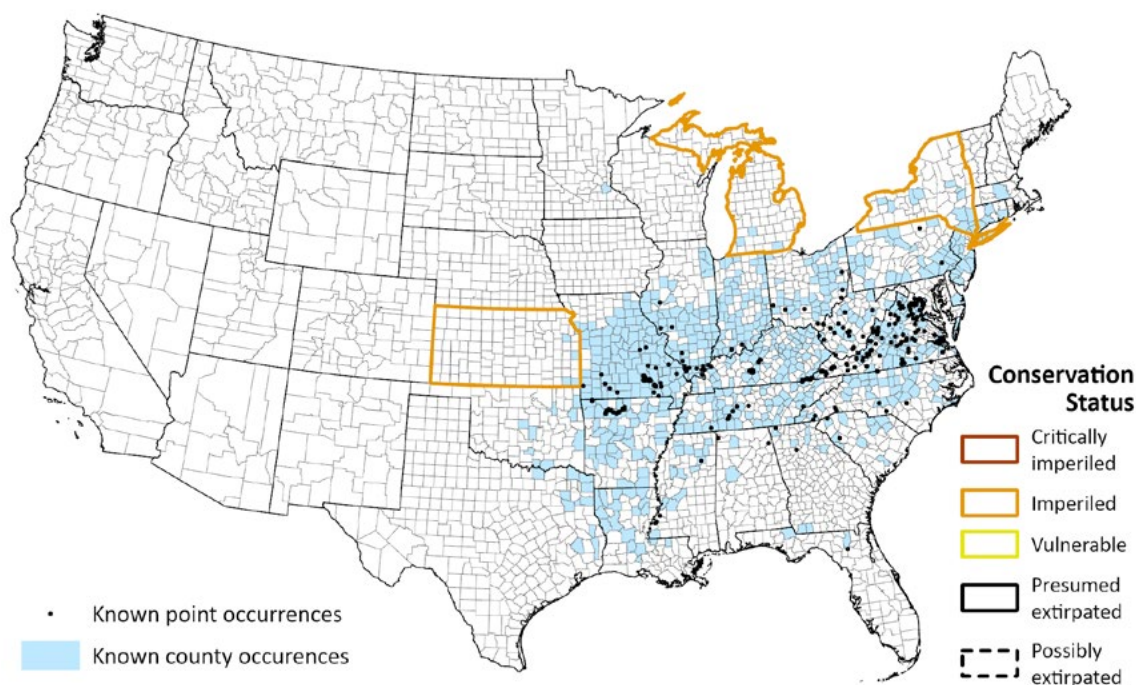


Figure A2.1. Distribution and state-level conservation status of *Agrimonia rostellata*. Known point occurrences were used to assess species deposition responses and critical loads.

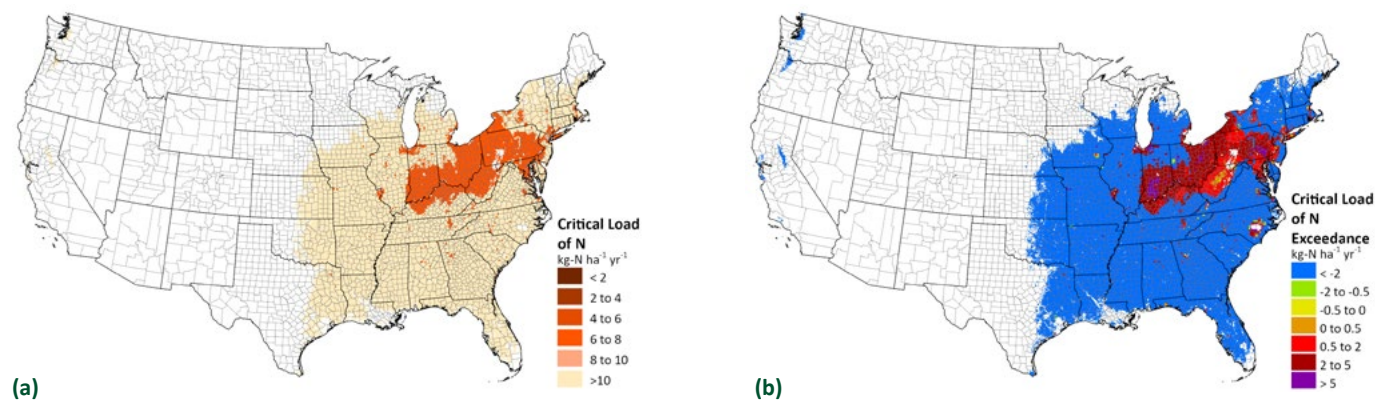


Figure A2.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Agrimonia rostellata* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

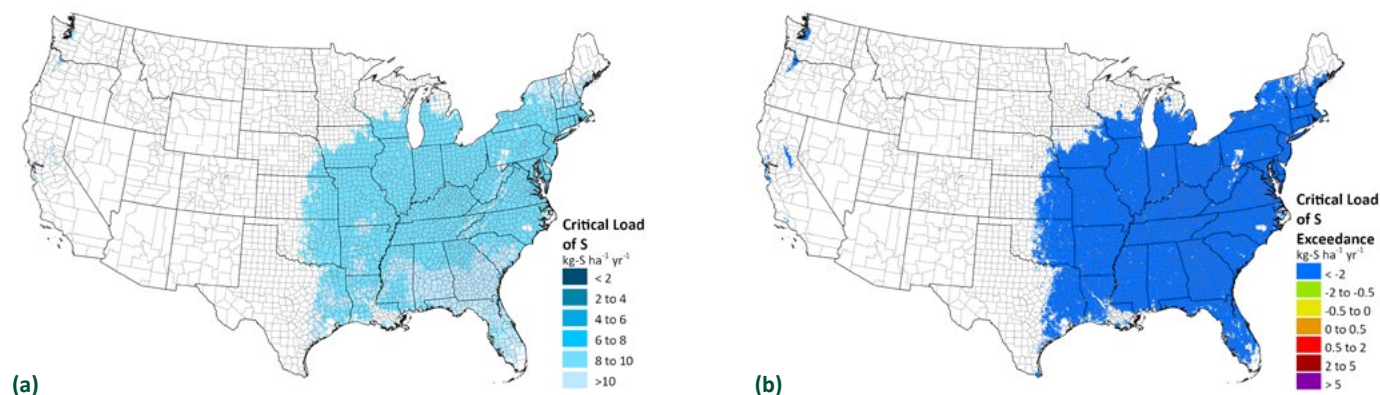


Figure A2.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Agrimonia rostellata* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A3. *Allium cernuum* (nodding onion)

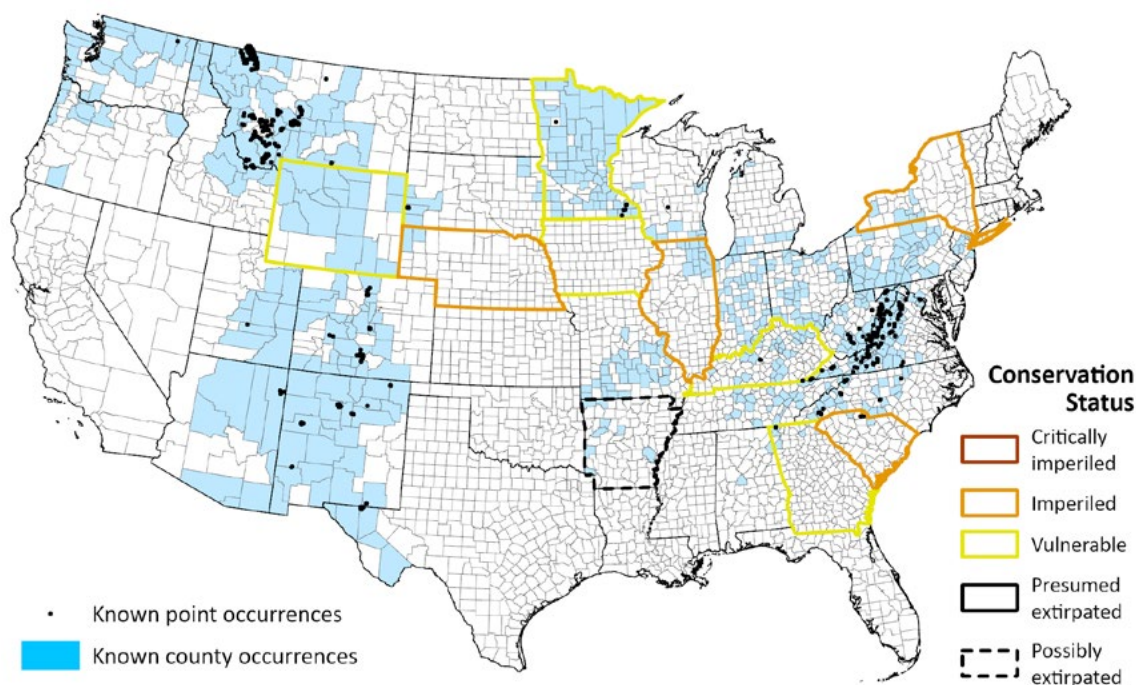


Figure A3.1. Distribution and state-level conservation status of *Allium cernuum*. Known point occurrences were used to assess species deposition responses and critical loads.

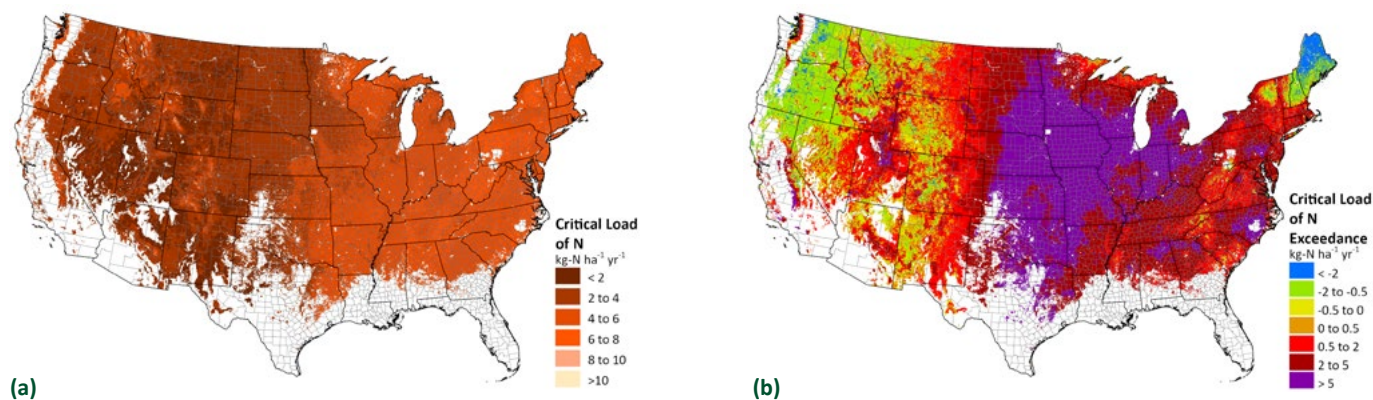


Figure A3.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Allium cernuum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

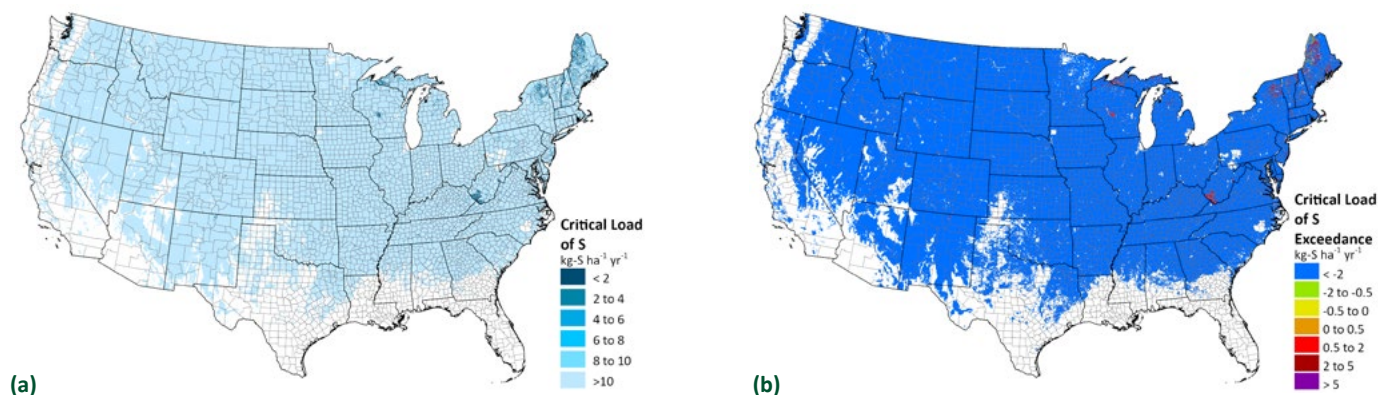


Figure A3.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Allium cernuum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A4. *Allium stellatum* (autumn onion)

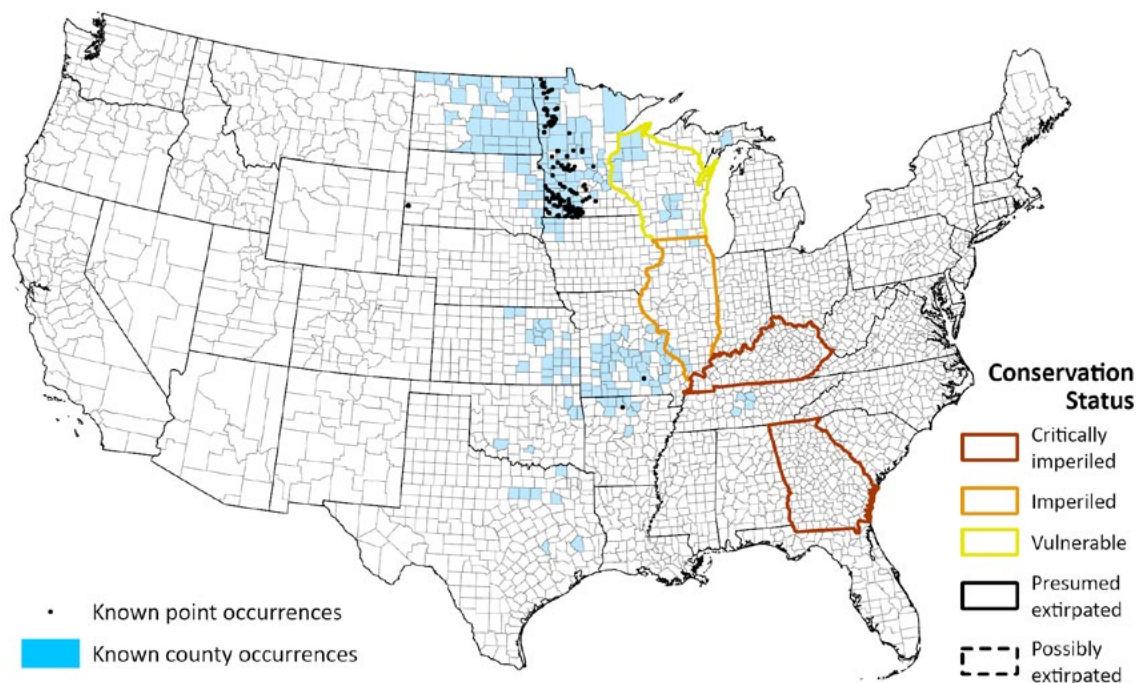


Figure A4.1. Distribution and state-level conservation status of *Allium stellatum*. Known point occurrences were used to assess species deposition responses and critical loads.

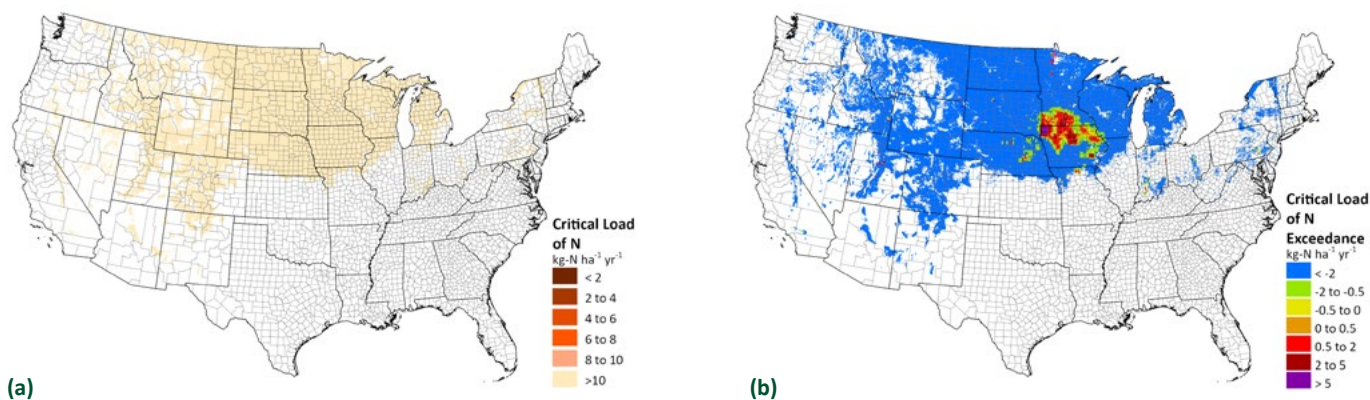


Figure A4.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Allium stellatum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

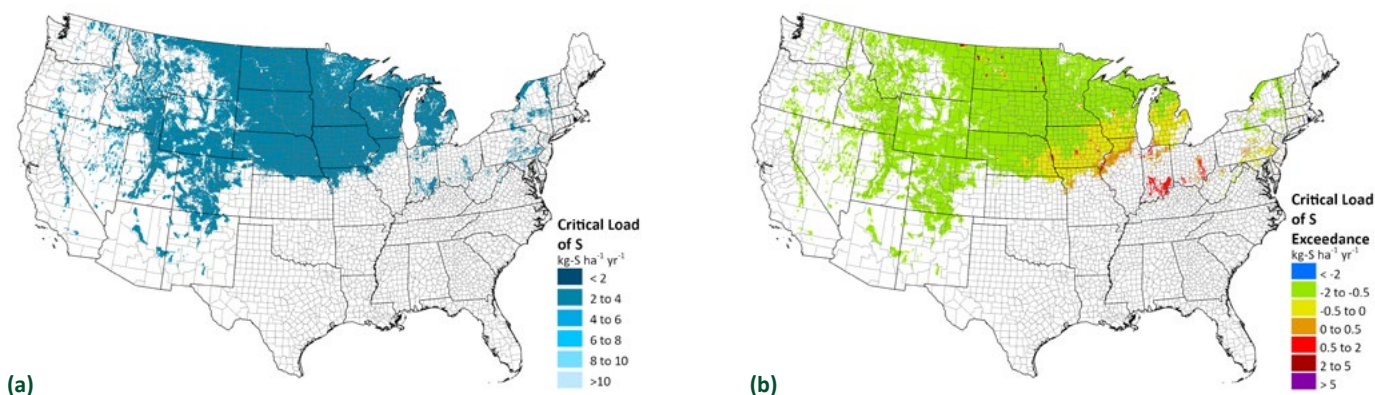


Figure A4.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Allium stellatum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A5. *Allium tricoccum* (ramp)

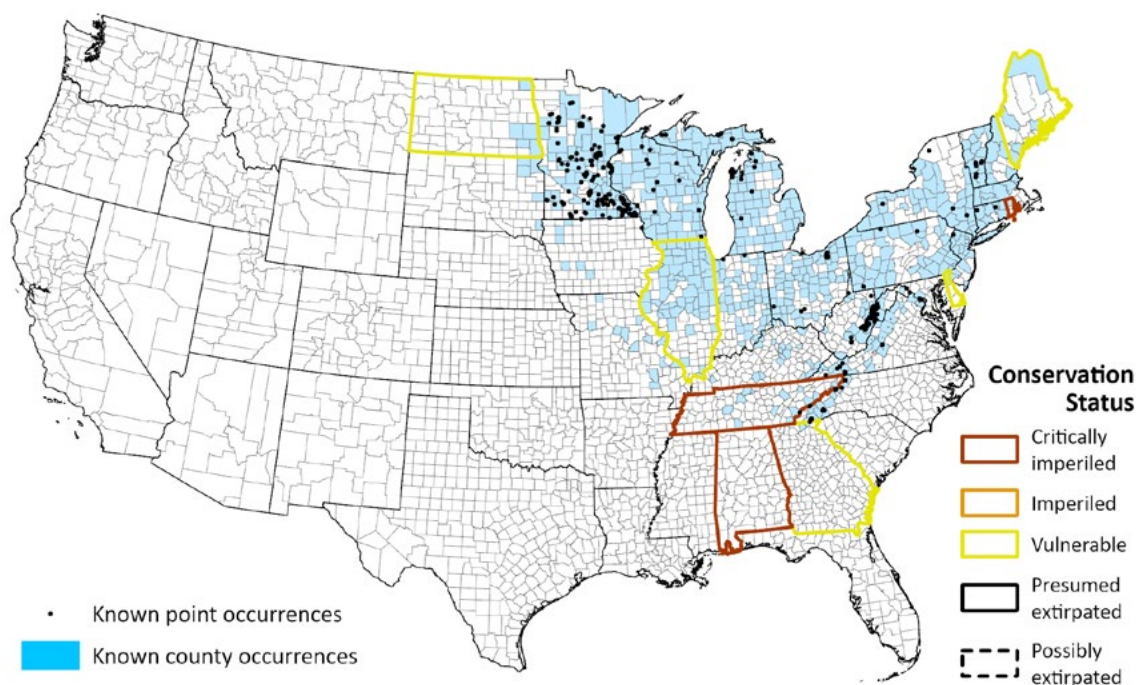


Figure A5.1. Distribution and state-level conservation status of *Allium tricoccum*. Known point occurrences were used to assess species deposition responses and critical loads.

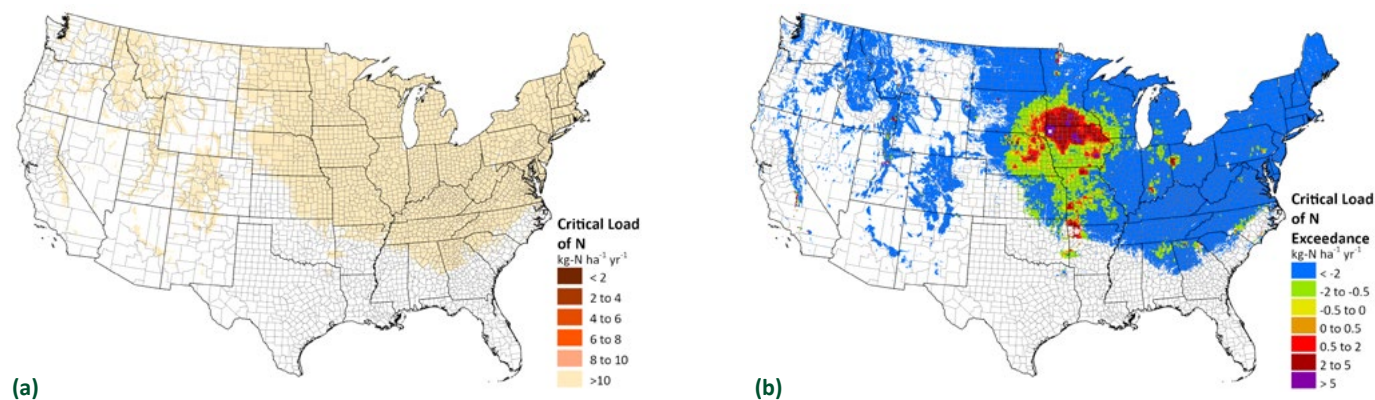


Figure A5.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Allium tricoccum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

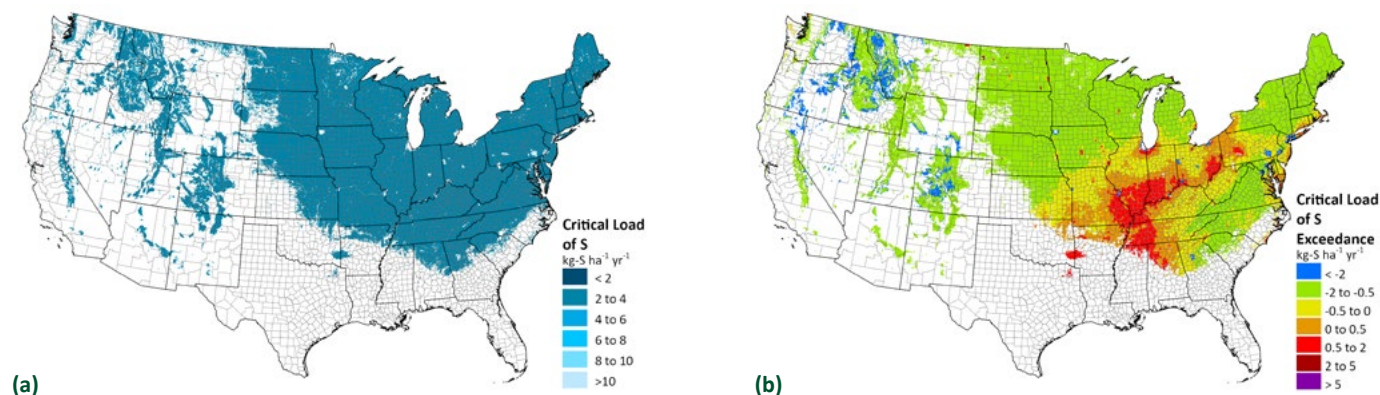


Figure A5.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Allium tricoccum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A6. *Anemone quinquefolia* (wood anemone)

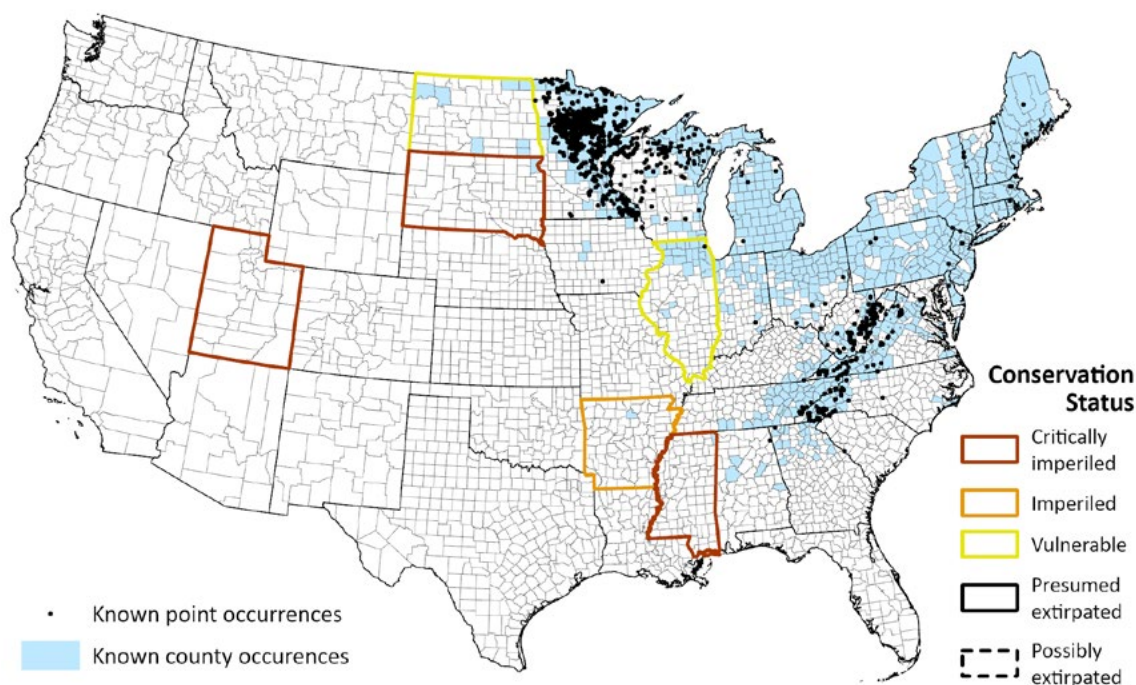


Figure A6.1. Distribution and state-level conservation status of *Anemone quinquefolia*. Known point occurrences were used to assess species deposition responses and critical loads.

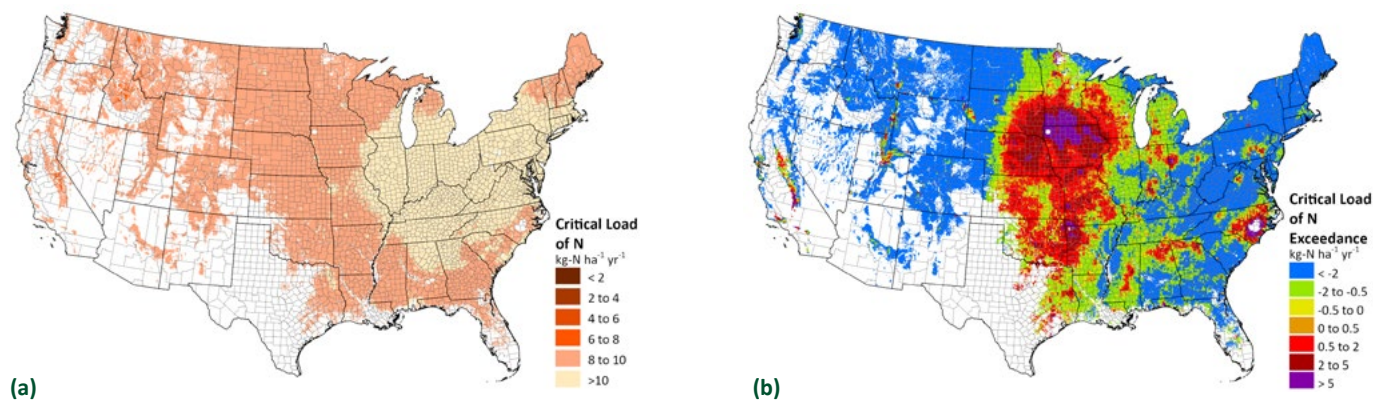


Figure A6.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Anemone quinquefolia* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

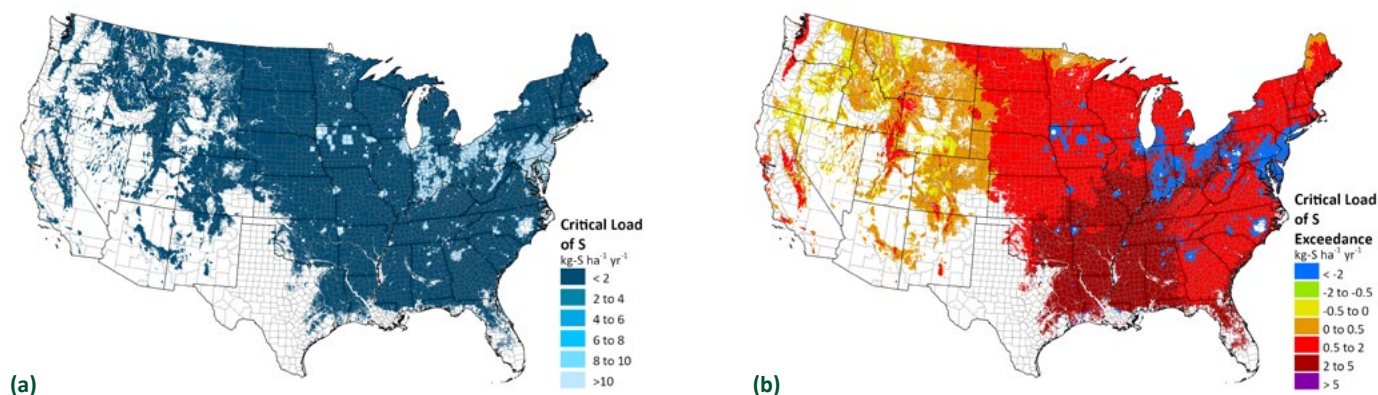


Figure A6.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Anemone quinquefolia* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A7. *Antennaria neglecta* (field pussytoes)

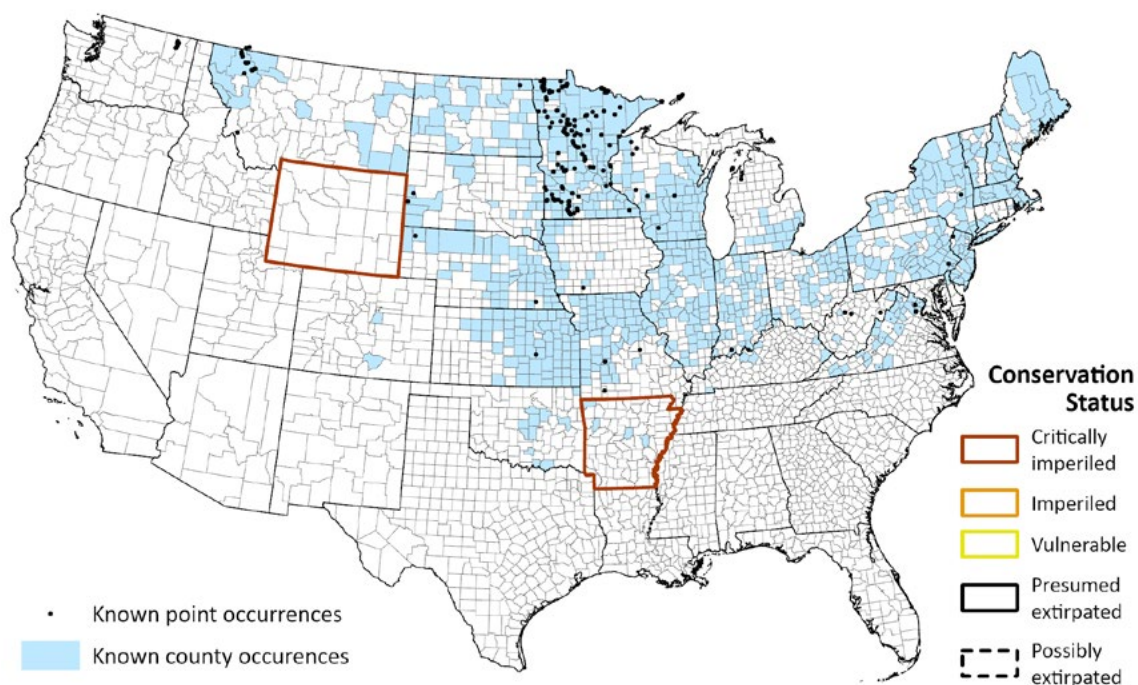


Figure A7.1. Distribution and state-level conservation status of *Antennaria neglecta*. Known point occurrences were used to assess species deposition responses and critical loads.

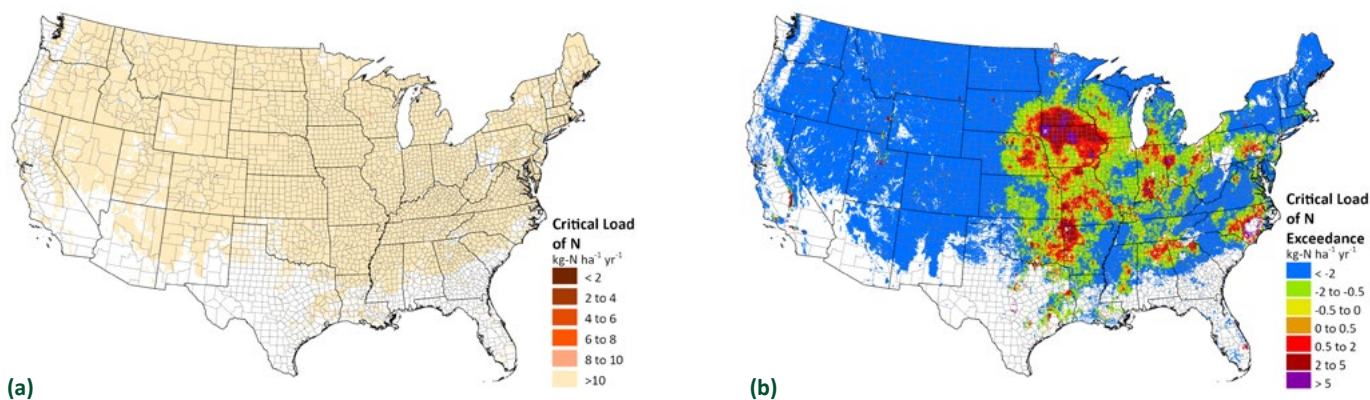


Figure A7.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Antennaria neglecta* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

A8. *Antennaria plantaginifolia* (woman's tobacco)

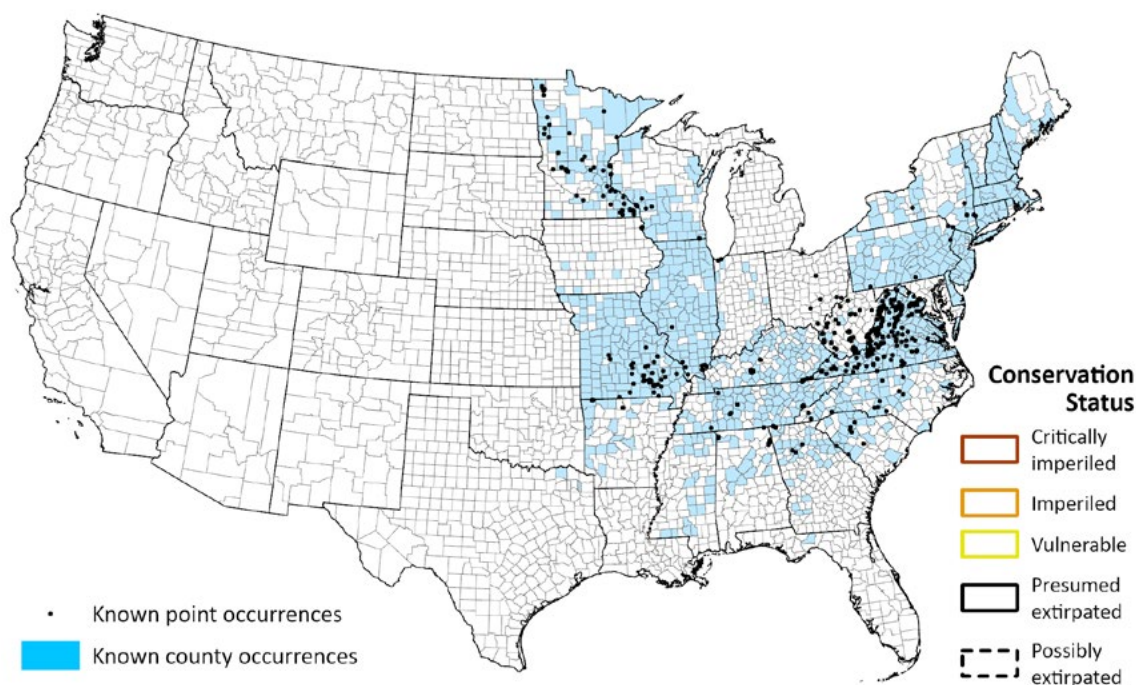


Figure A8.1. Distribution and state-level conservation status of *Antennaria plantaginifolia*. Known point occurrences were used to assess species deposition responses and critical loads.

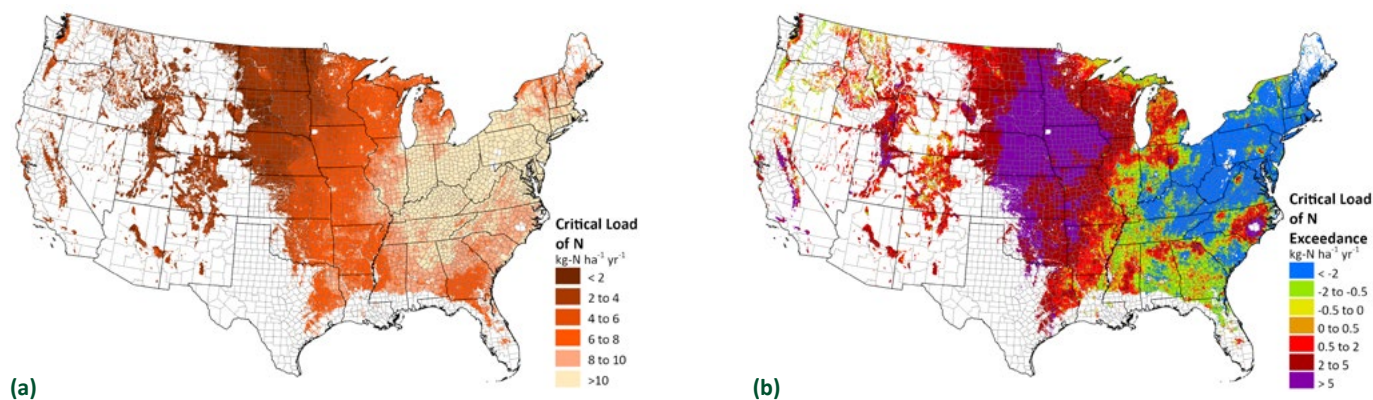


Figure A8.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Antennaria plantaginifolia* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

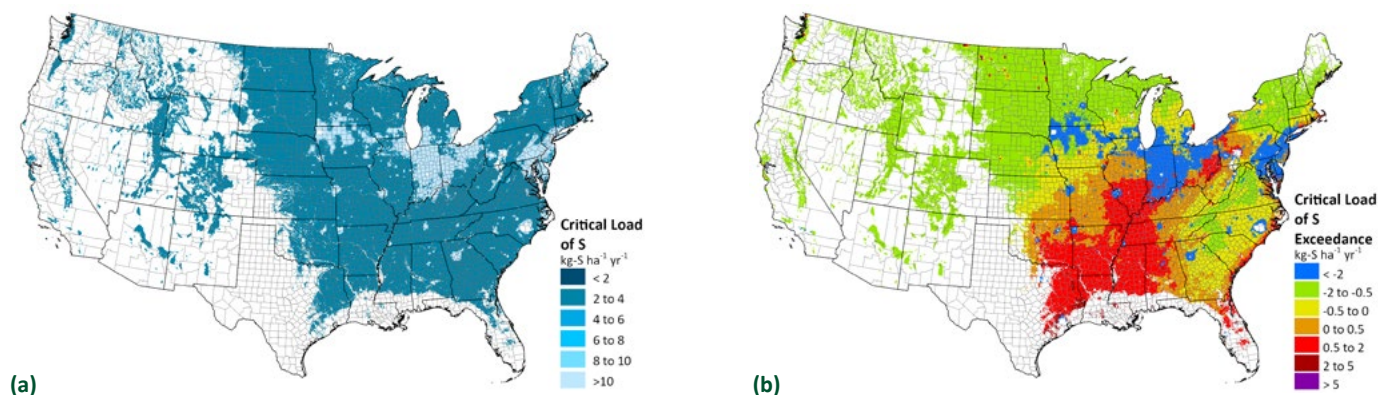


Figure A8.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Antennaria plantaginifolia* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A9. *Arctium minus* (lesser burdock)

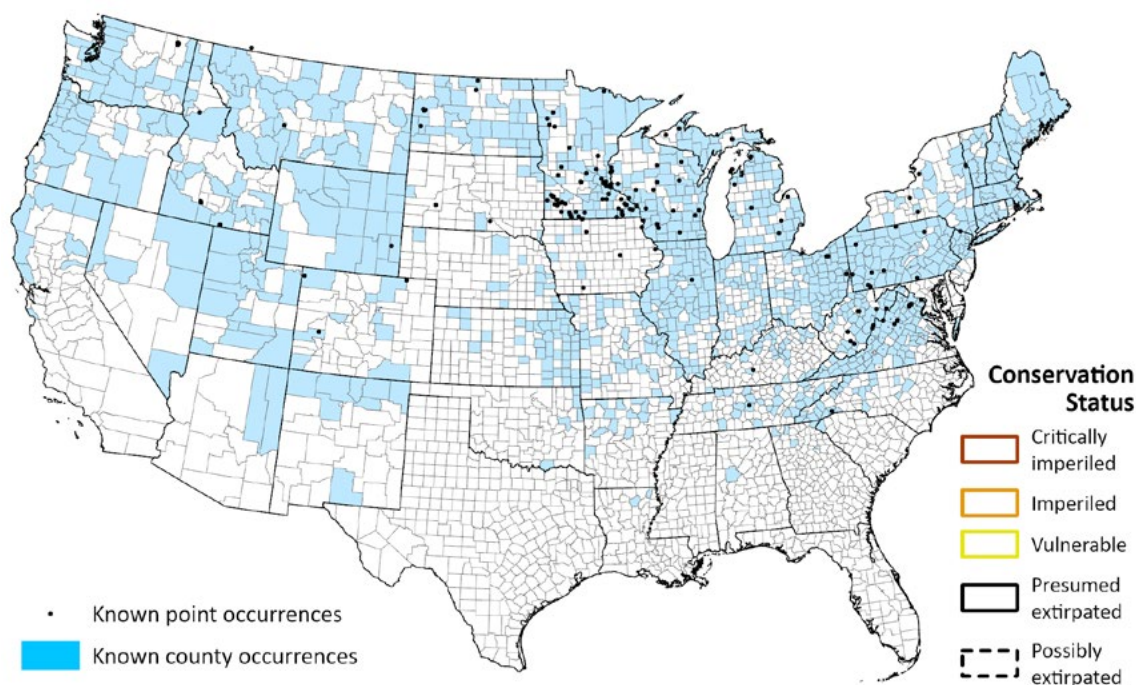


Figure A9.1. Distribution and state-level conservation status of *Arctium minus*. Known point occurrences were used to assess species deposition responses and critical loads.

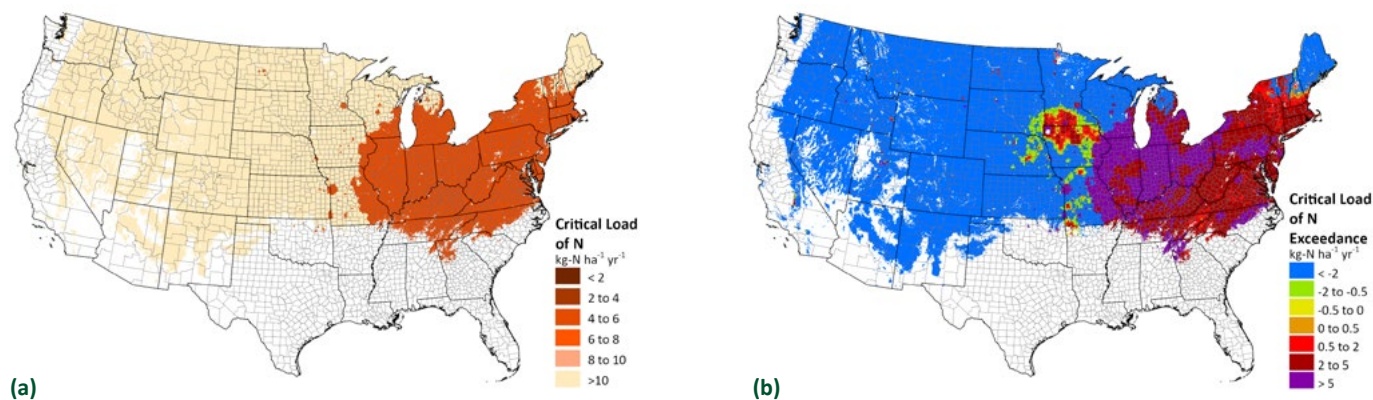


Figure A9.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Arctium minus* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

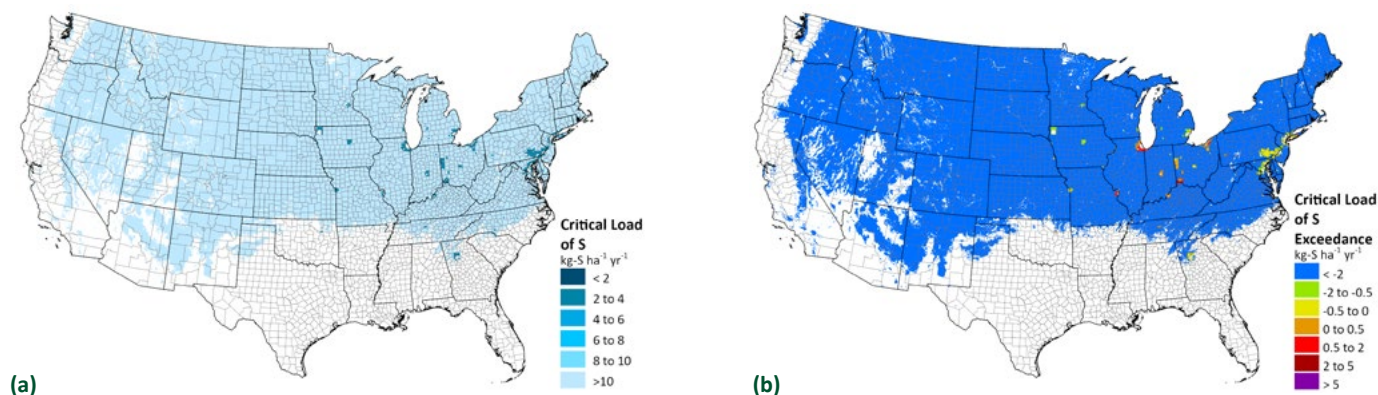


Figure A9.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Arctium minus* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A10. *Aristolochia serpentaria* (Virginia snakeroot)

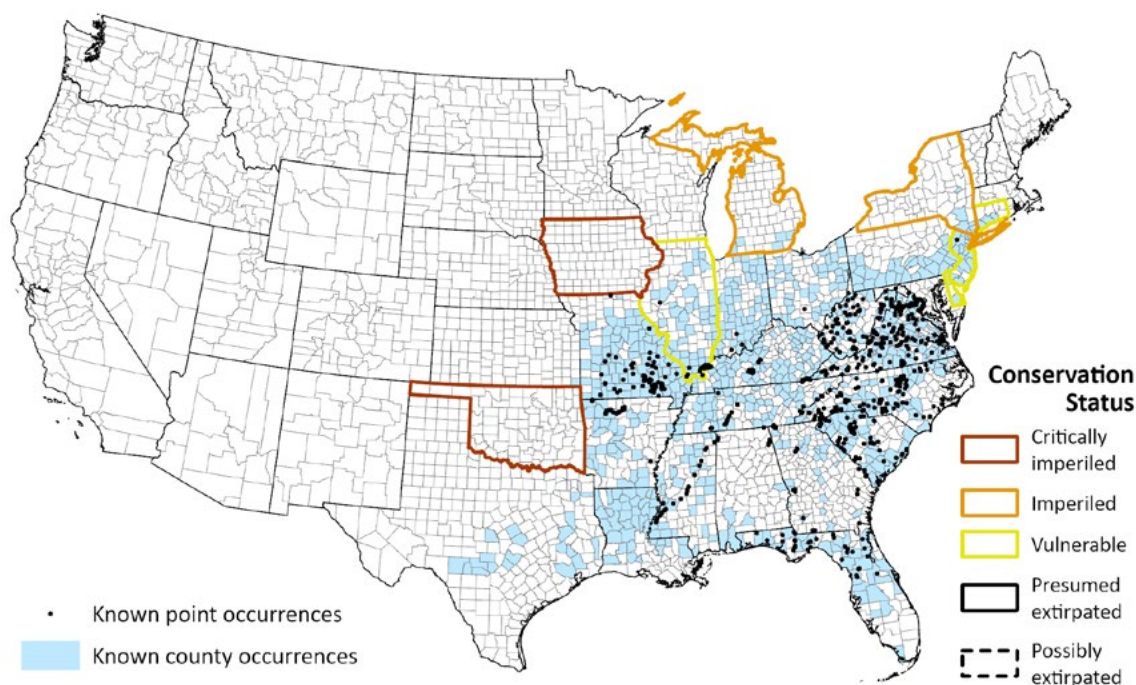


Figure A10.1. Distribution and state-level conservation status of *Aristolochia serpentaria*. Known point occurrences were used to assess species deposition responses and critical loads.

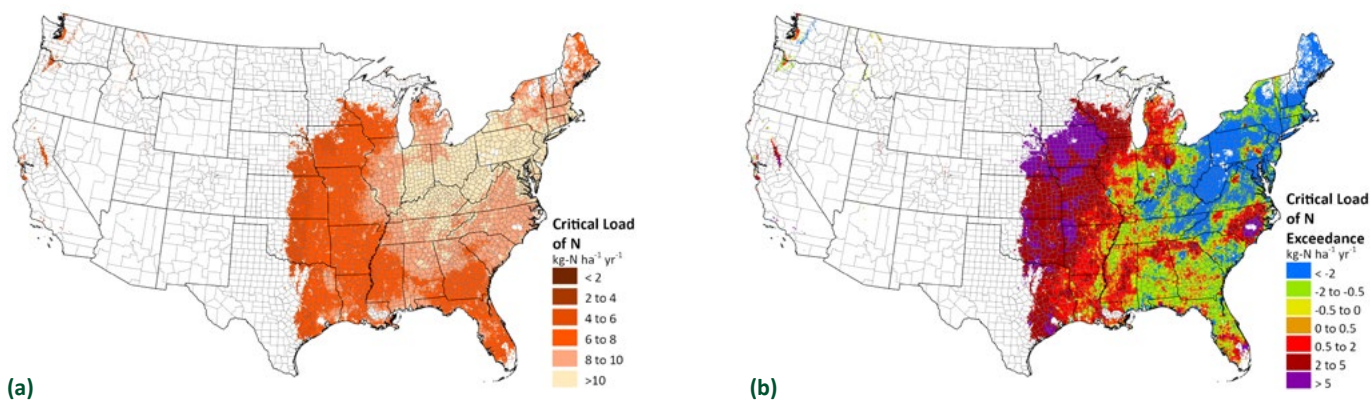


Figure A10.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Aristolochia serpentaria* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

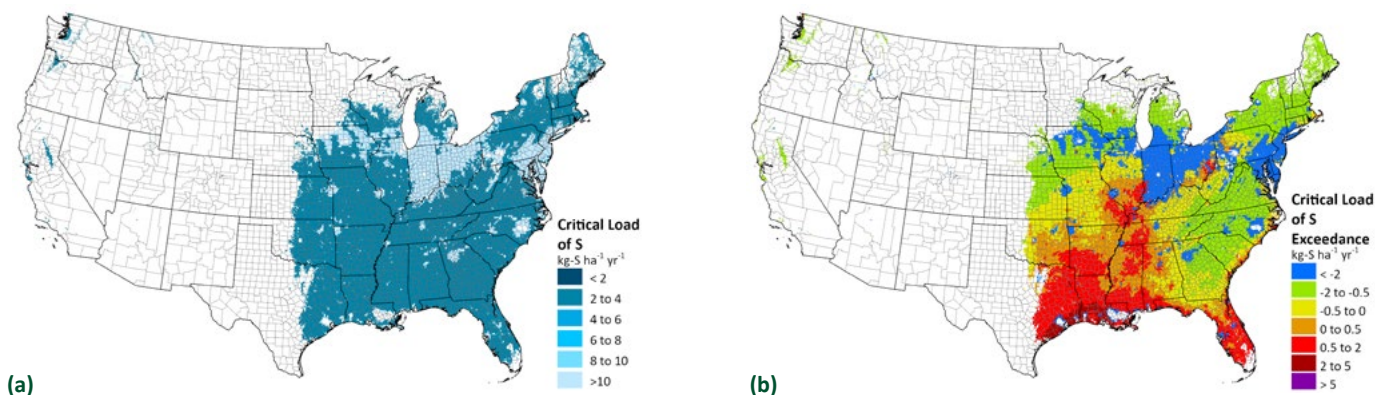


Figure A10.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Aristolochia serpentaria* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A11. *Asplenium platyneuron* (ebony spleenwort)

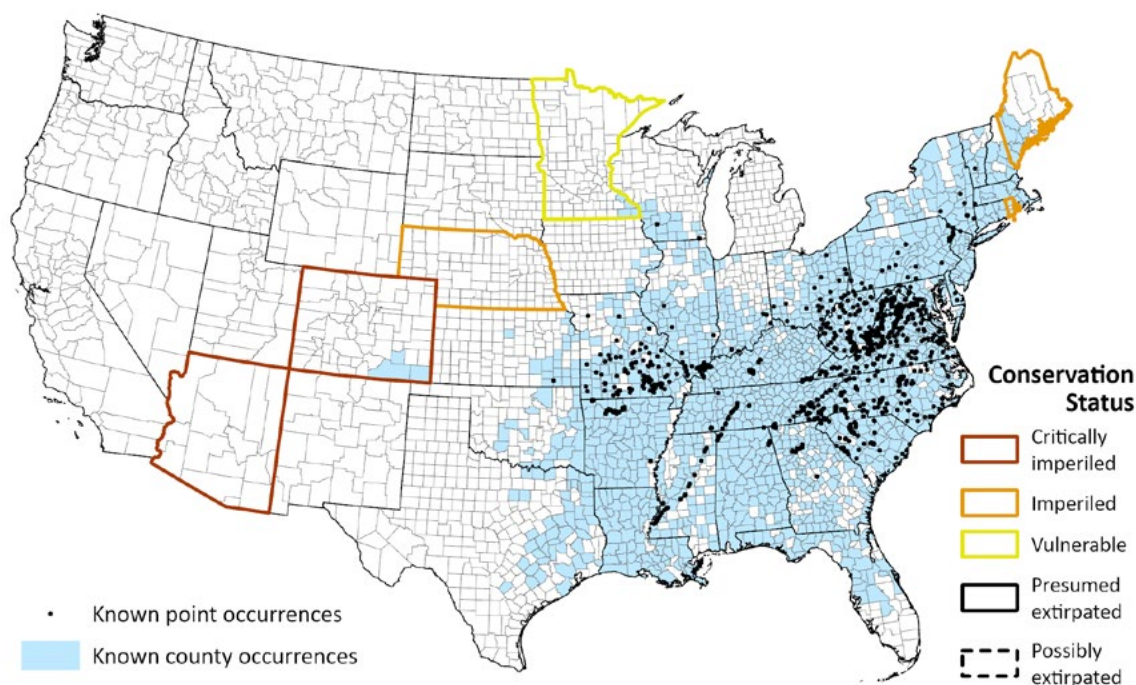


Figure A11.1. Distribution and state-level conservation status of *Asplenium platyneuron*. Known point occurrences were used to assess species deposition responses and critical loads.

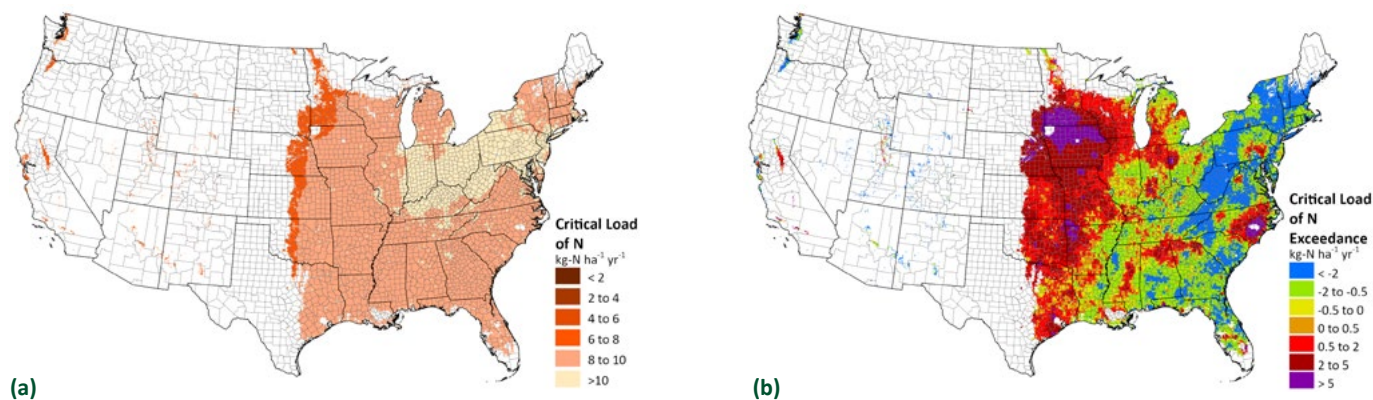


Figure A11.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Asplenium platyneuron* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

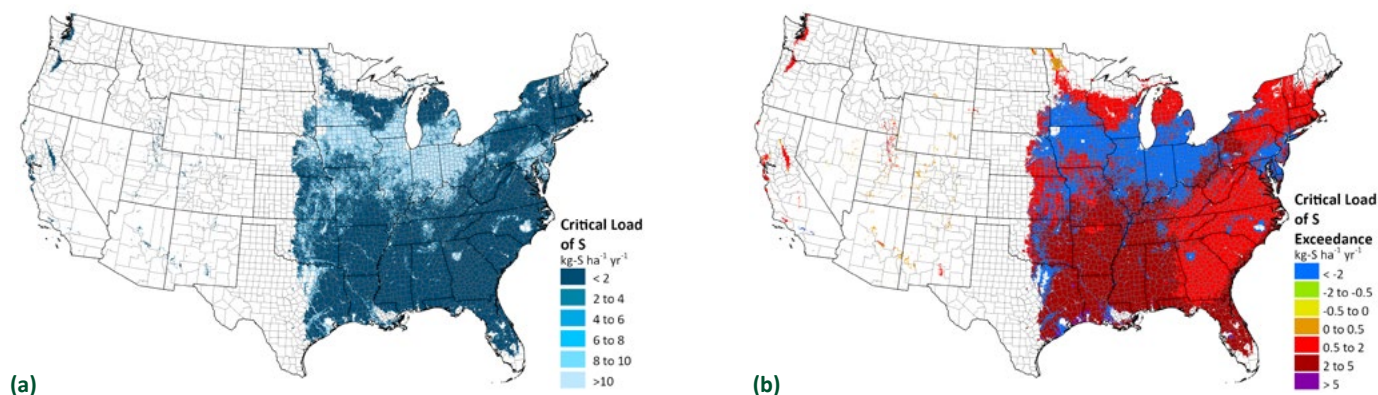


Figure A11.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Asplenium platyneuron* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A12. *Boehmeria cylindrica* (smallspike false nettle)

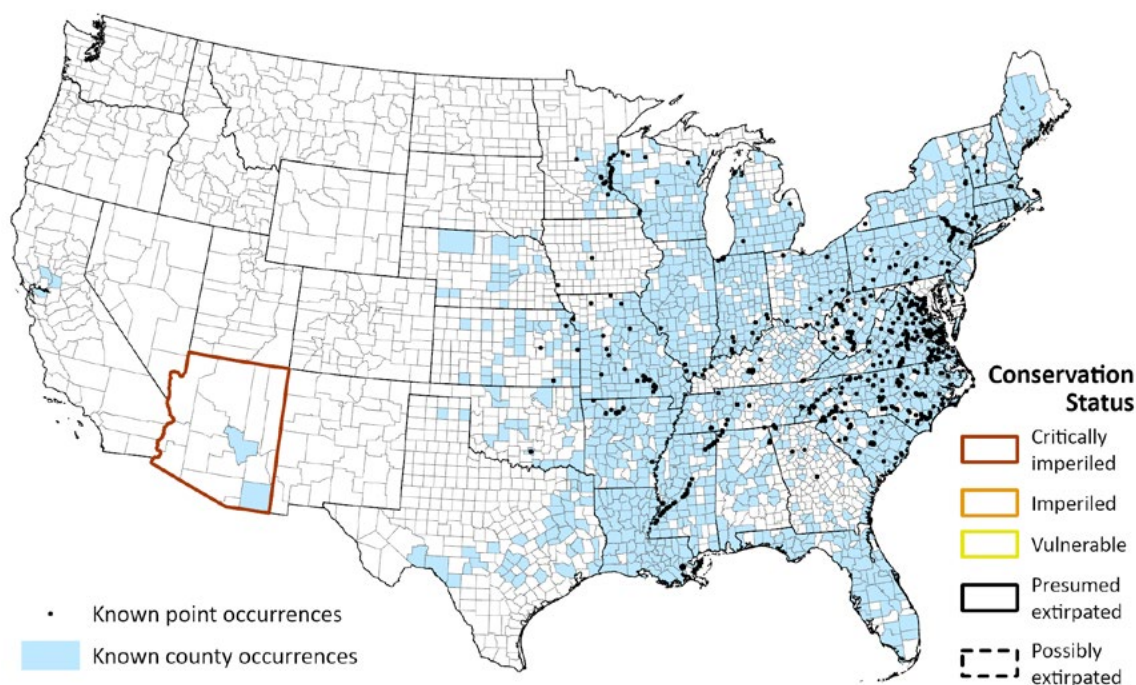


Figure A12.1. Distribution and state-level conservation status of *Boehmeria cylindrica*. Known point occurrences were used to assess species deposition responses and critical loads.

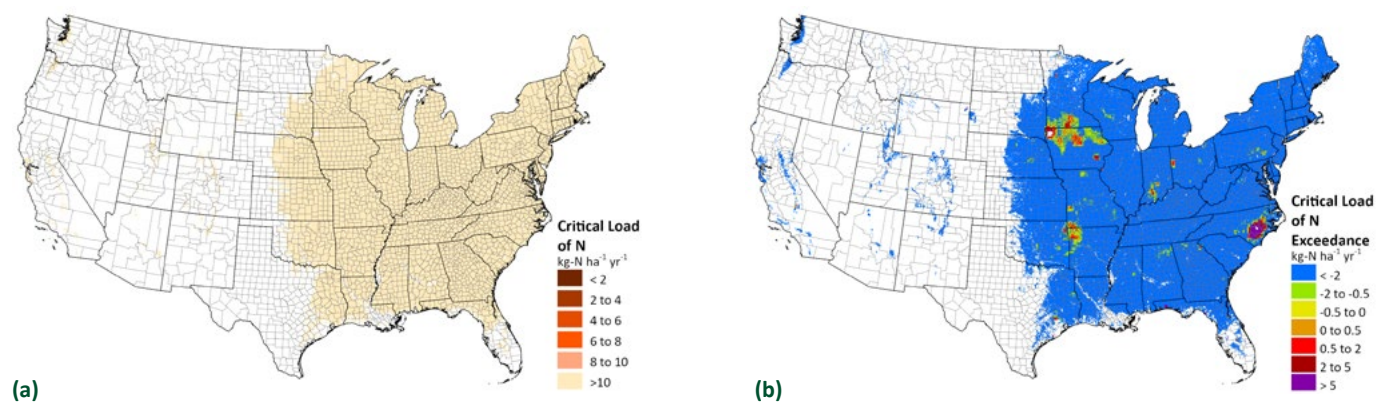


Figure A12.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Boehmeria cylindrica* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

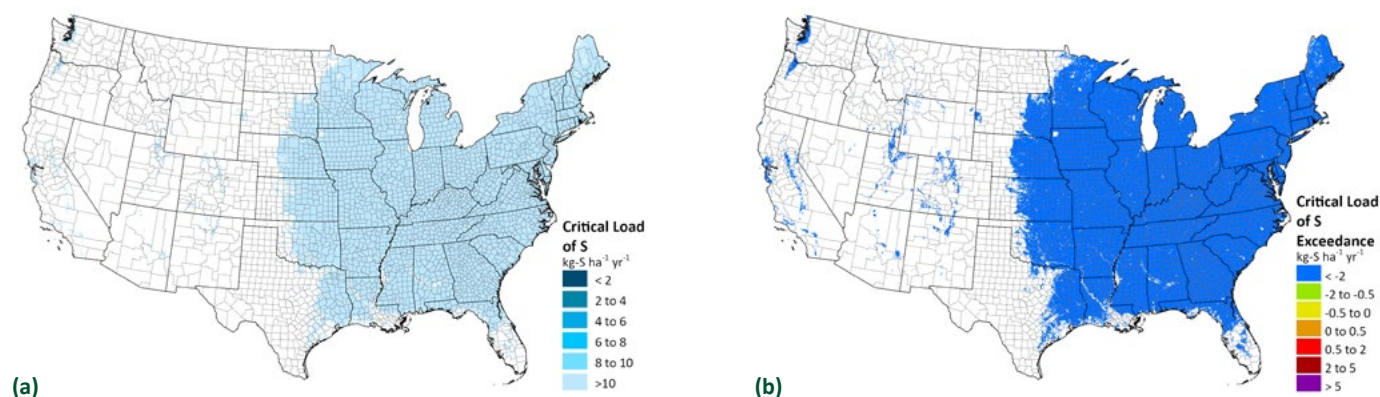


Figure A12.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Boehmeria cylindrica* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A13. *Calamagrostis stricta* (slimstem reedgrass)

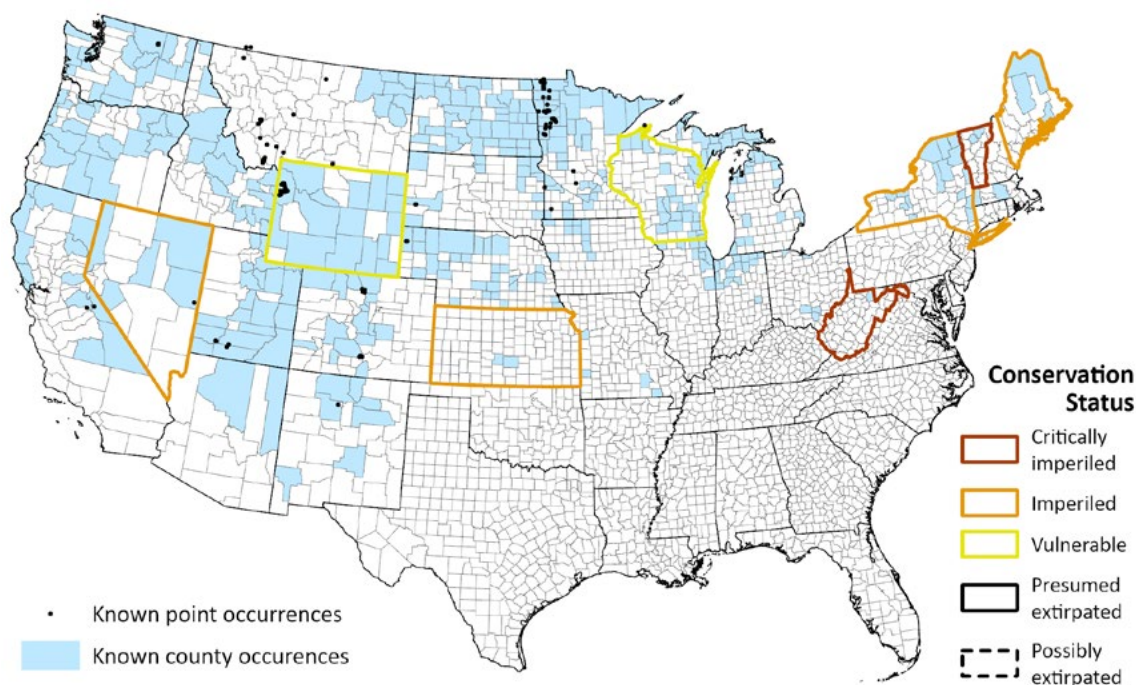


Figure A13.1. Distribution and state-level conservation status of *Calamagrostis stricta*. Known point occurrences were used to assess species deposition responses and critical loads.

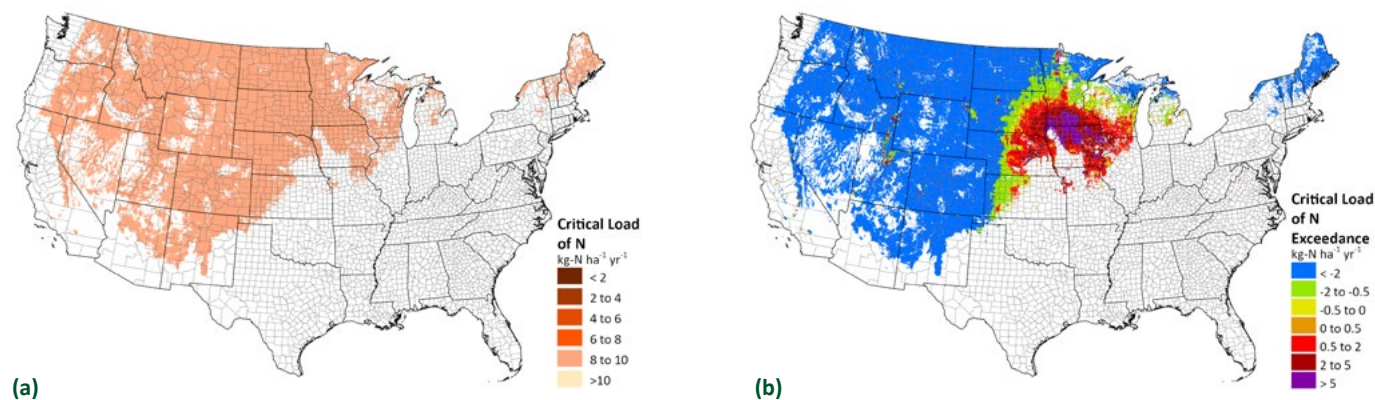


Figure A13.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Calamagrostis stricta* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

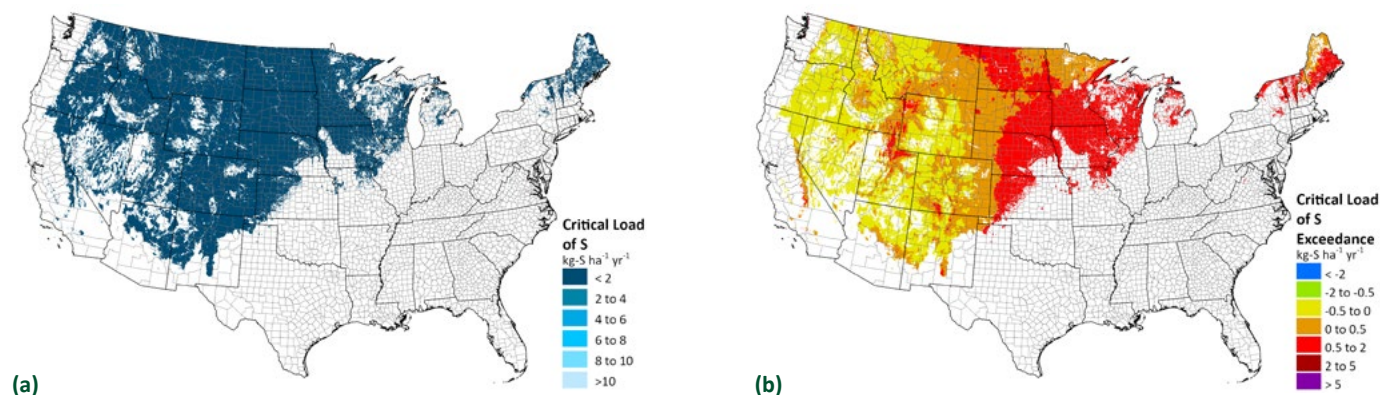


Figure A13.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Calamagrostis stricta* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A14. *Campanula rotundifolia* (bluebell bellflower)

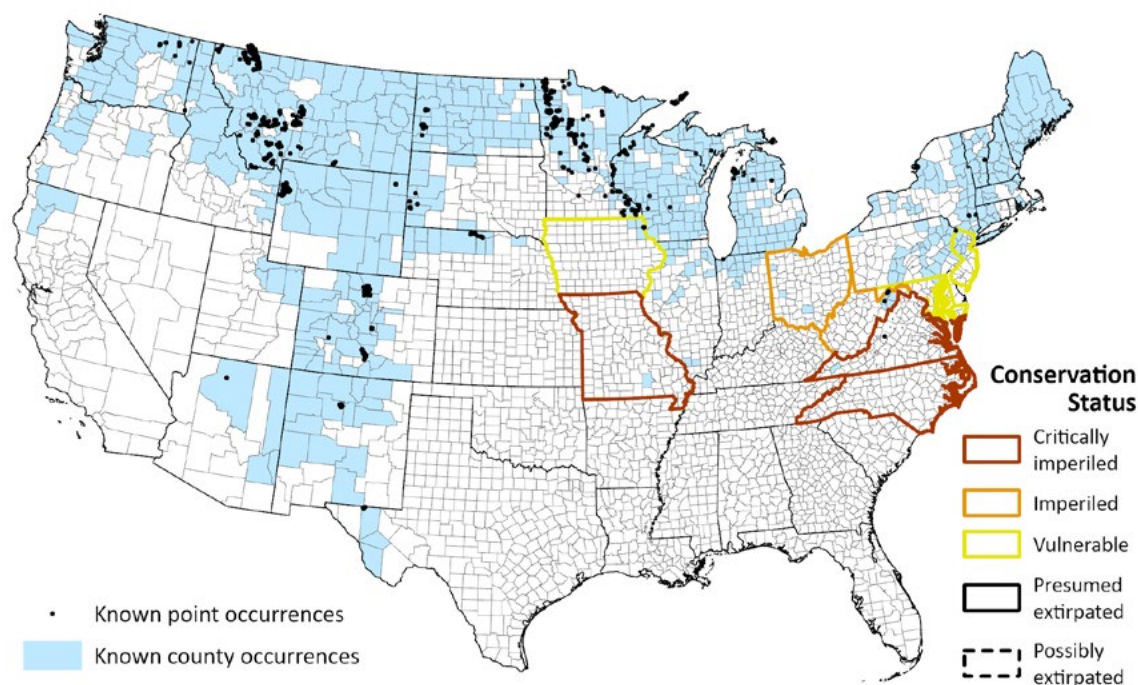


Figure A14.1. Distribution and state-level conservation status of *Campanula rotundifolia*. Known point occurrences were used to assess species deposition responses and critical loads.

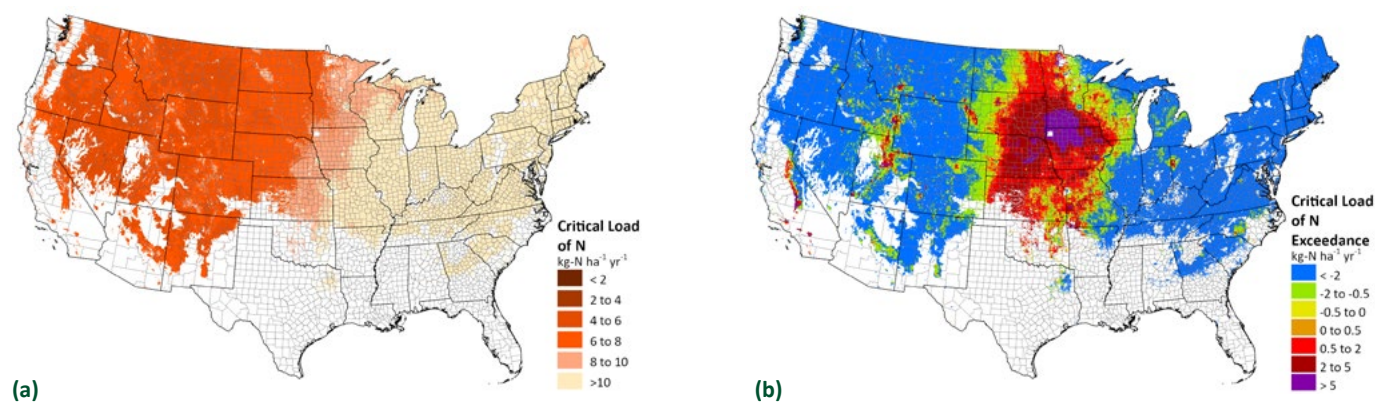


Figure A14.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Campanula rotundifolia* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

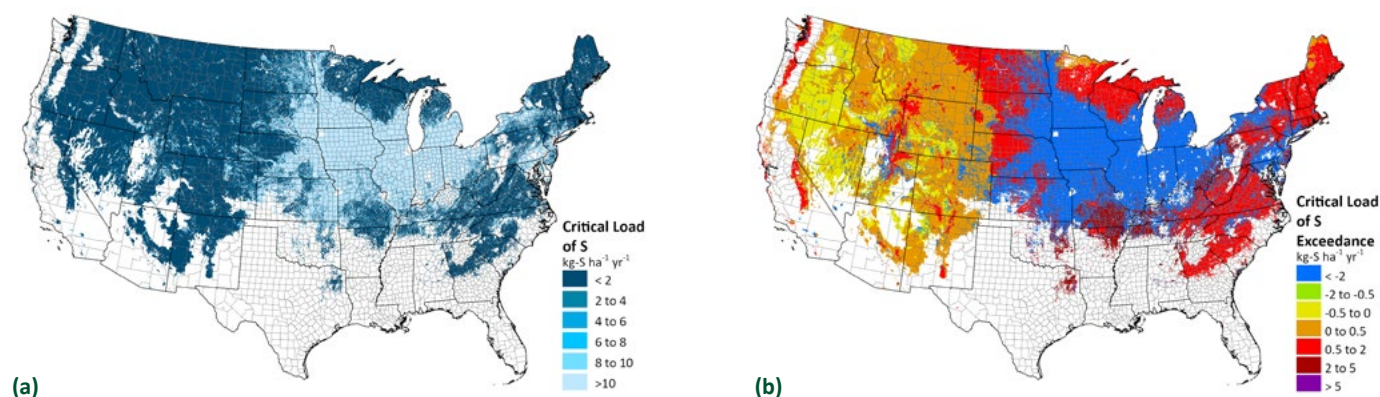


Figure A14.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Campanula rotundifolia* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A15. *Carex albicans* (whitewing sedge)

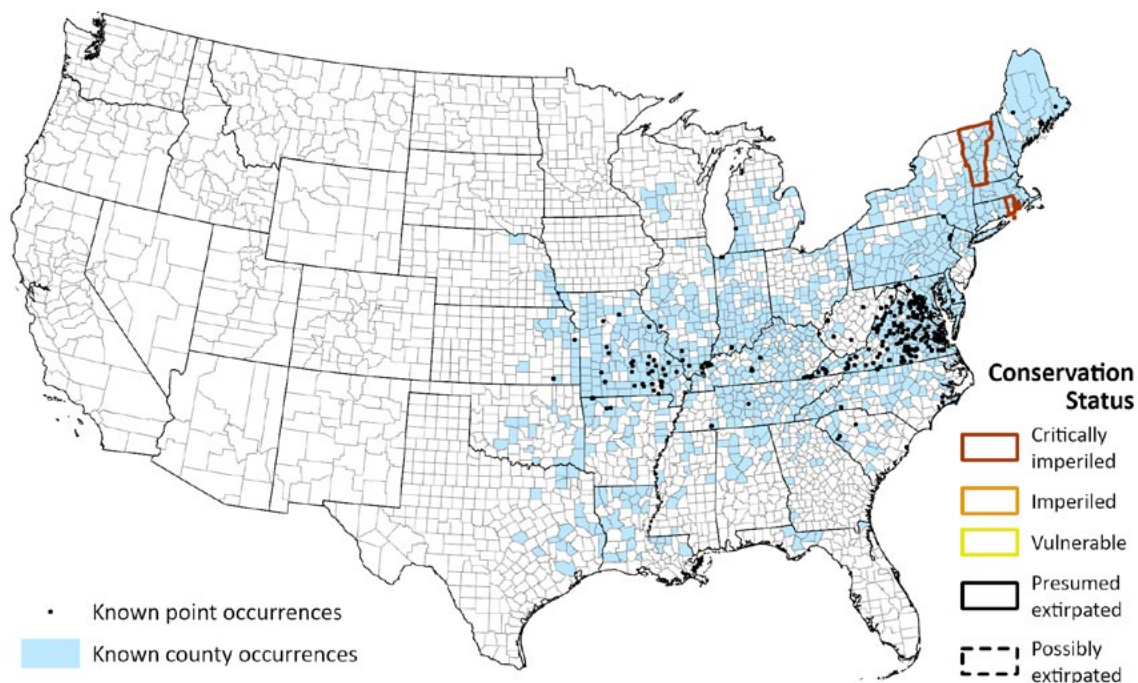


Figure A15.1. Distribution and state-level conservation status of *Carex albicans*. Known point occurrences were used to assess species deposition responses and critical loads.

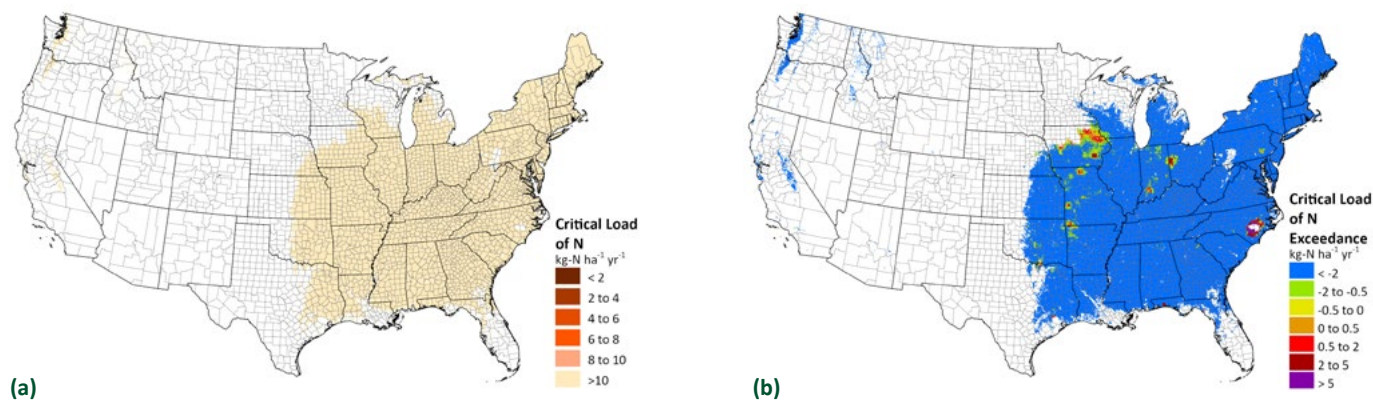


Figure A15.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Carex albicans* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

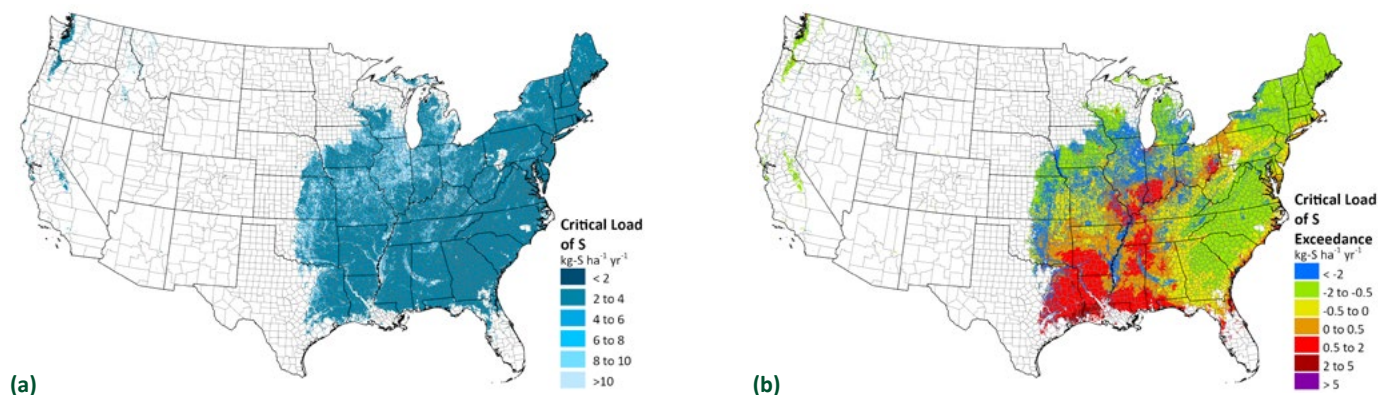


Figure A15.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Carex albicans* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A16. *Carex albursina* (white bear sedge)

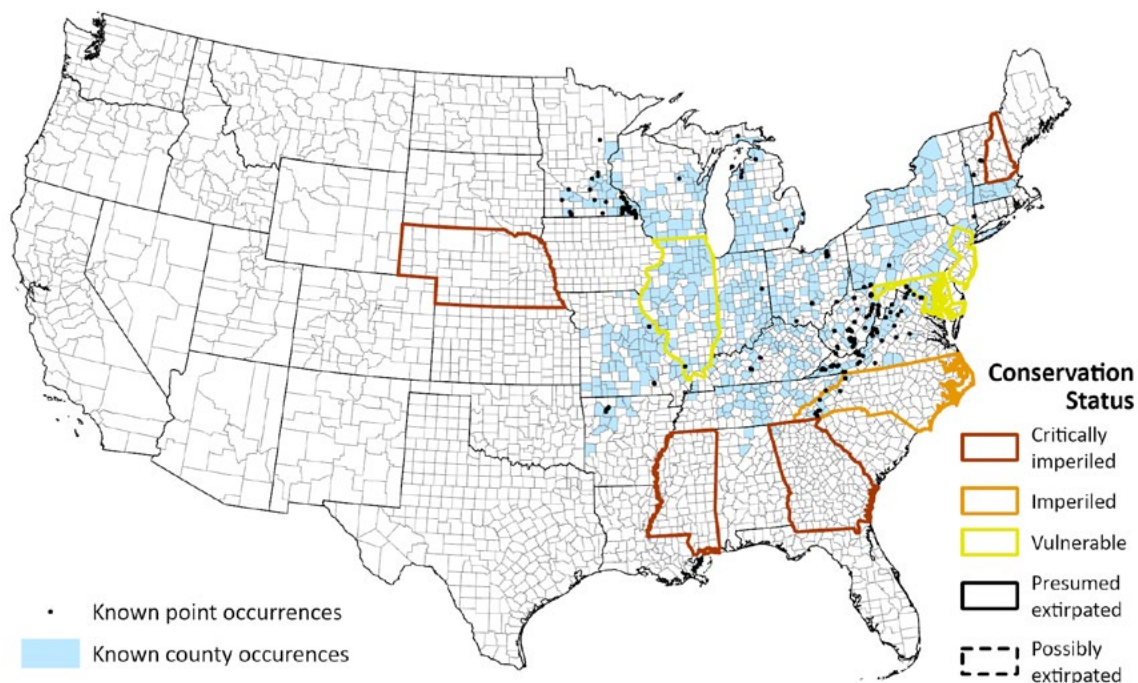


Figure A16.1. Distribution and state-level conservation status of *Carex albursina*. Known point occurrences were used to assess species deposition responses and critical loads.

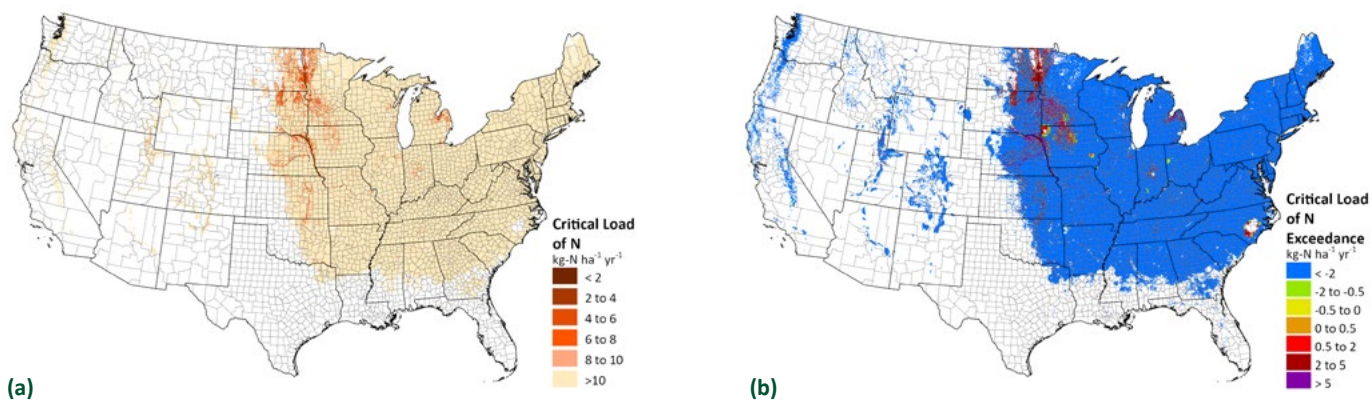


Figure A16.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Carex albursina* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

A17. *Carex arctata* (drooping woodland sedge)

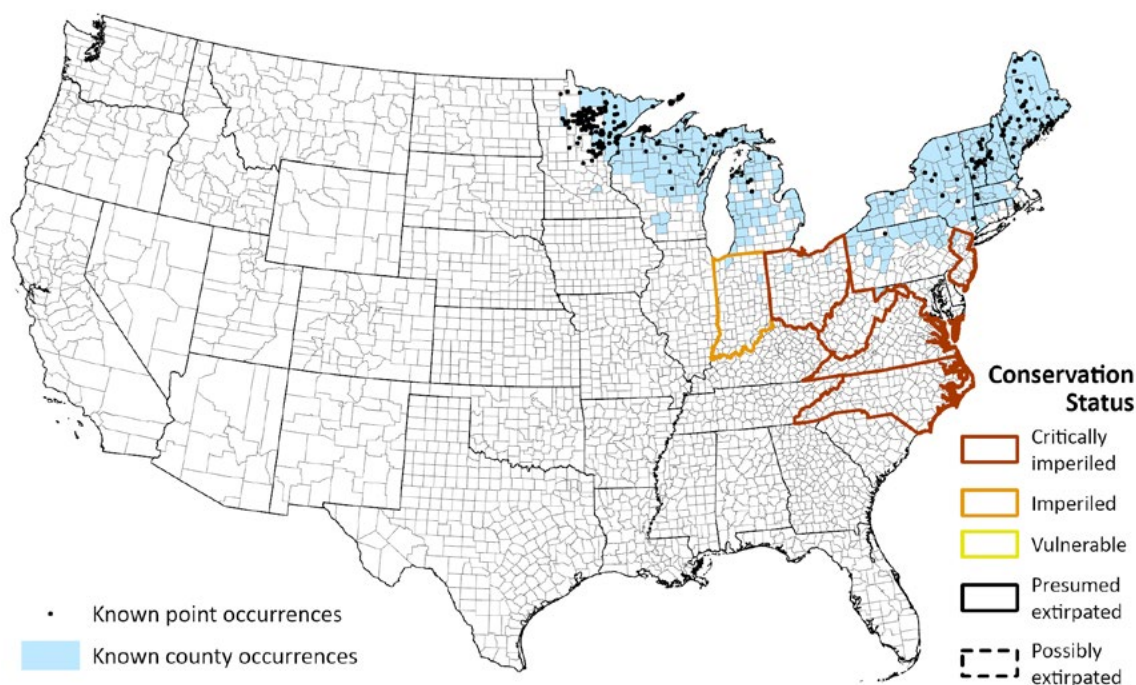


Figure A17.1. Distribution and state-level conservation status of *Carex arctata*. Known point occurrences were used to assess species deposition responses and critical loads.

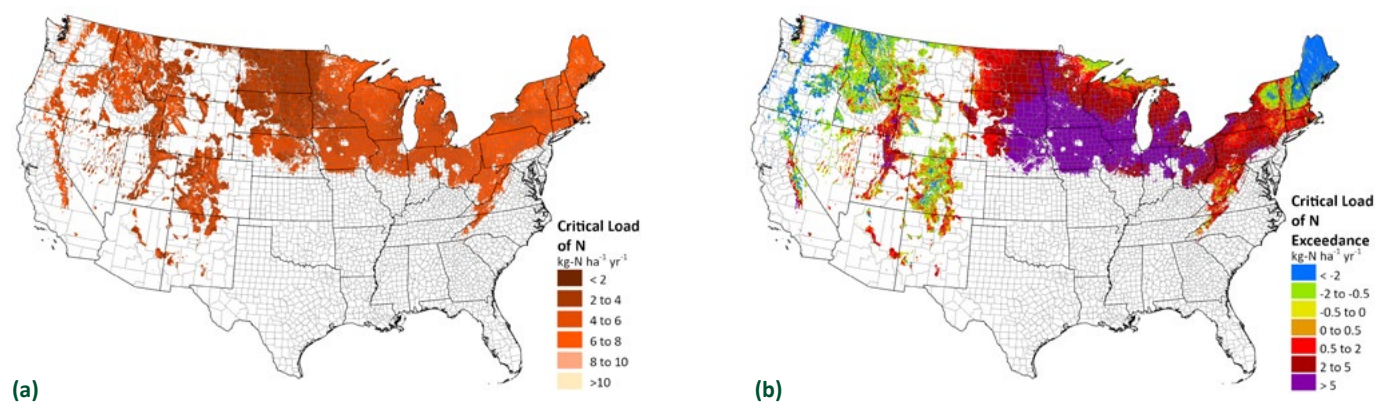


Figure A17.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Carex arctata* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

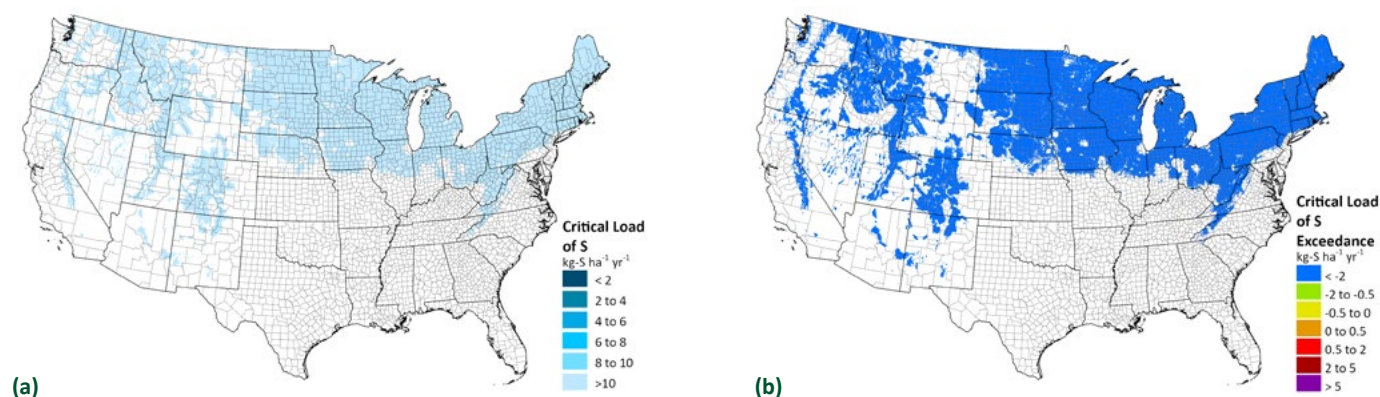


Figure A17.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Carex arctata* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A18. *Carex blanda* (eastern woodland sedge)

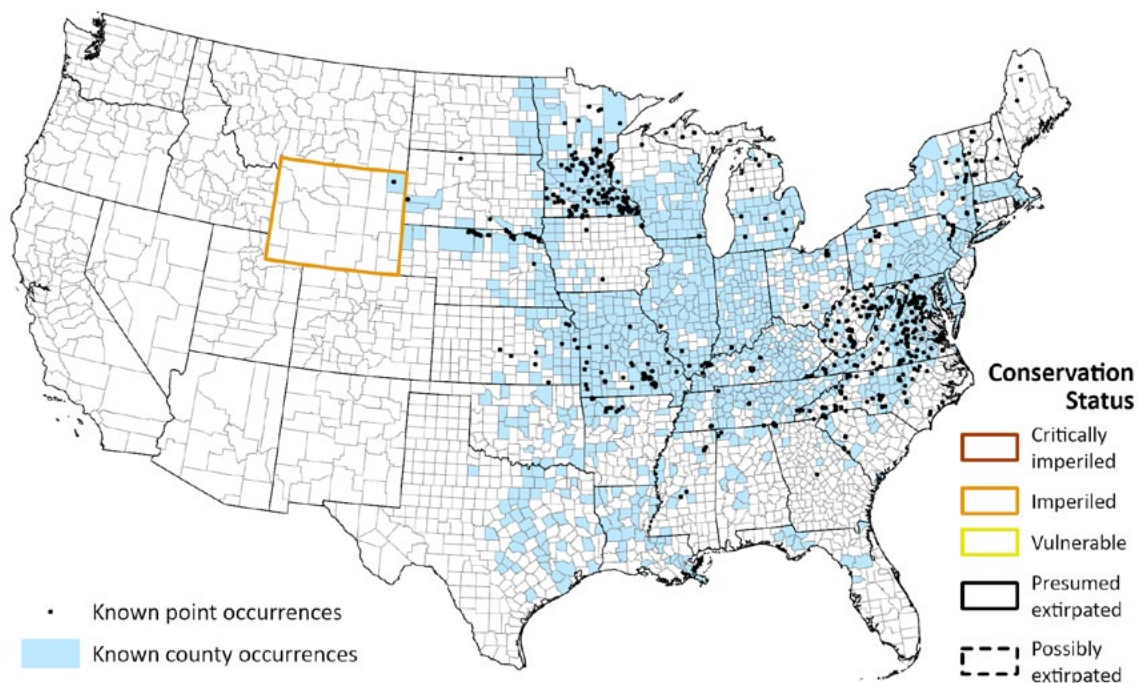


Figure A18.1. Distribution and state-level conservation status of *Carex blanda*. Known point occurrences were used to assess species deposition responses and critical loads.

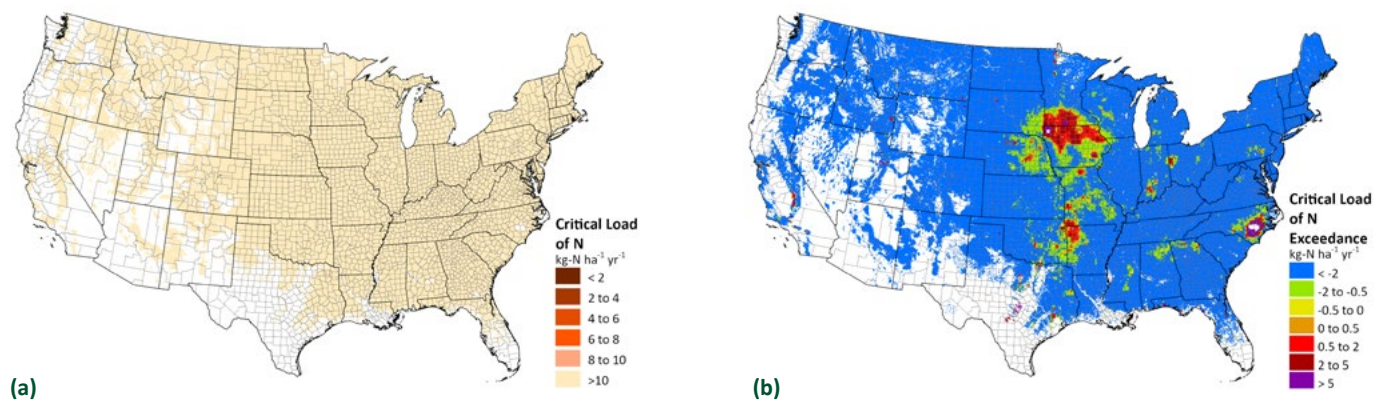


Figure A18.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Carex blanda* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

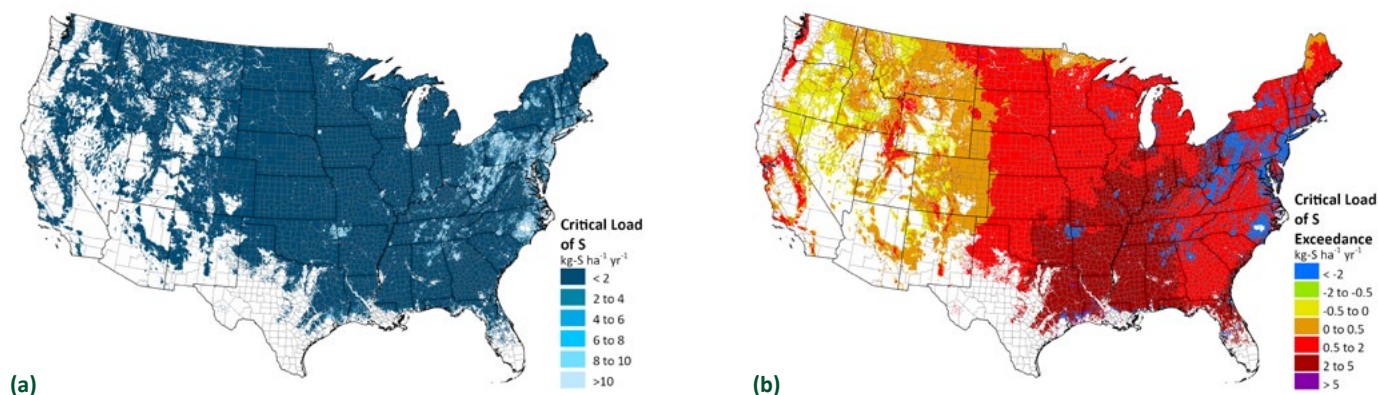


Figure A18.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Carex blanda* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A19. *Carex brunnescens* (brownish sedge)

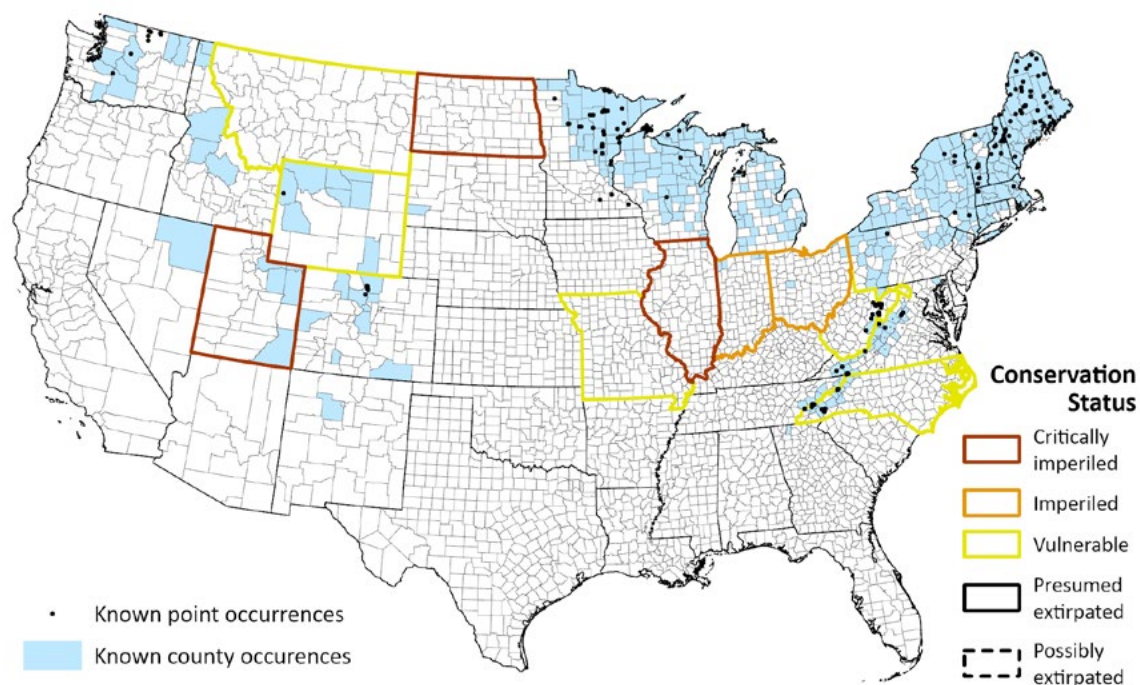


Figure A19.1. Distribution and state-level conservation status of *Carex brunnescens*. Known point occurrences were used to assess species deposition responses and critical loads.

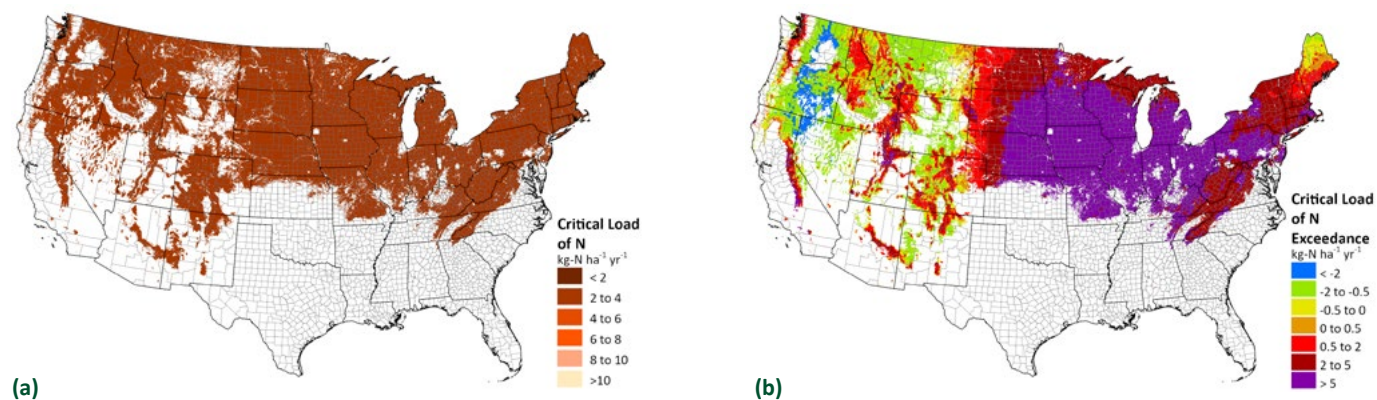


Figure A19.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Carex brunnescens* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

A20. *Carex communis* (fibrousroot sedge)

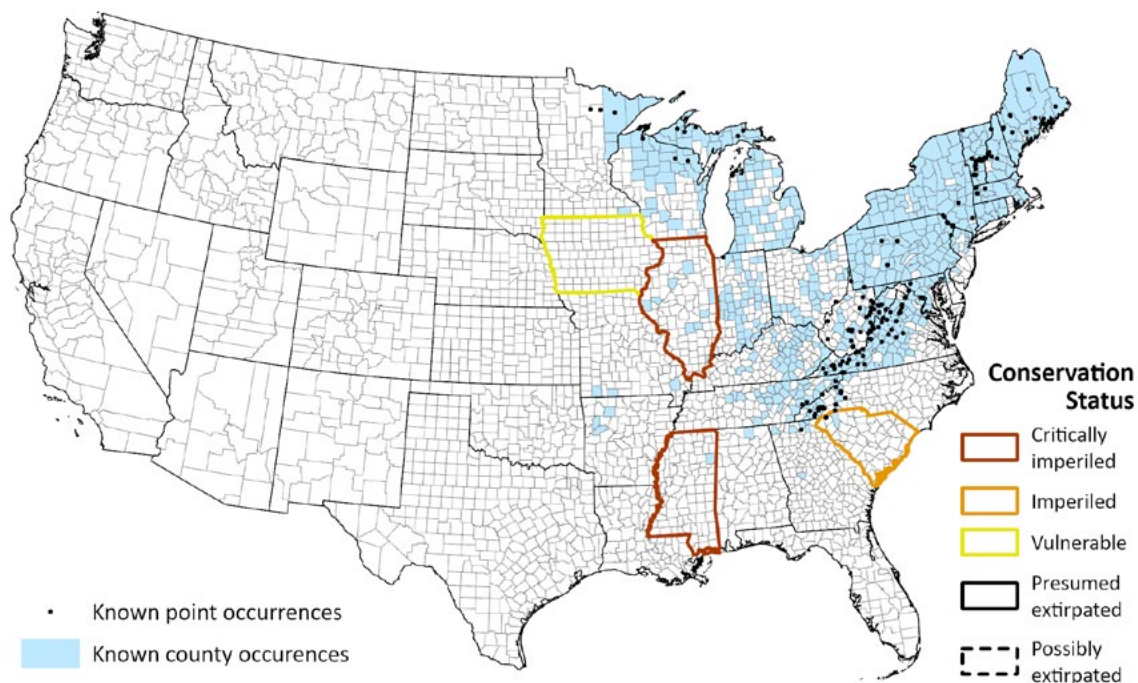


Figure A20.1. Distribution and state-level conservation status of *Carex communis*. Known point occurrences were used to assess species deposition responses and critical loads.

A21. *Carex debilis* (white edge sedge)

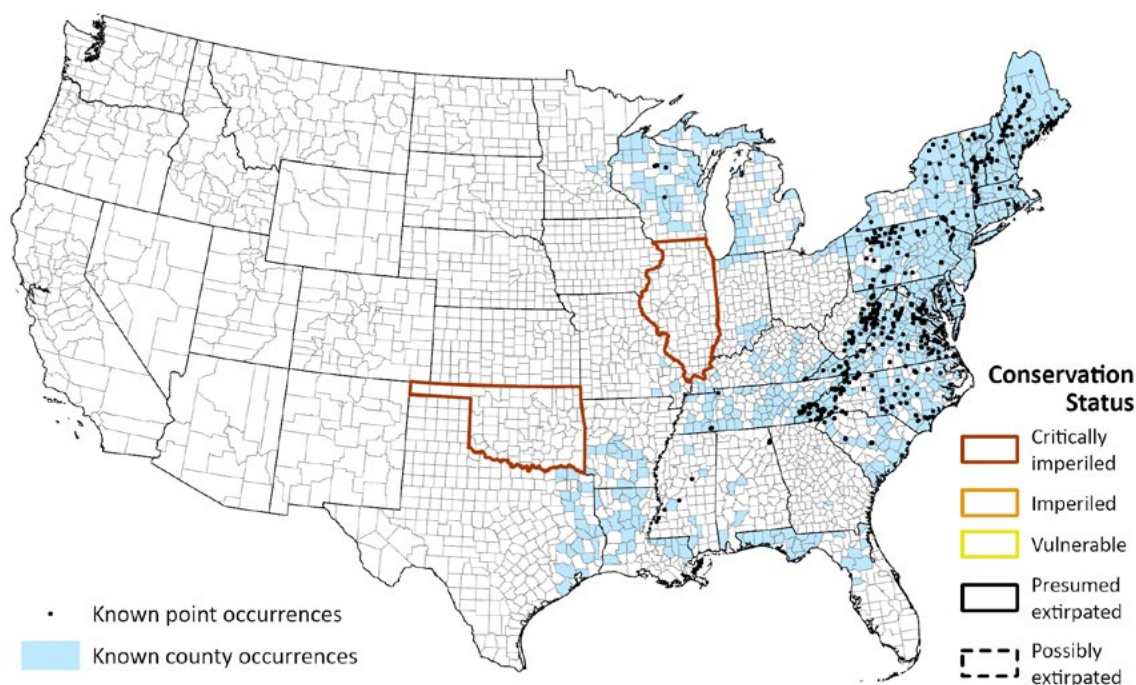


Figure A21.1. Distribution and state-level conservation status of *Carex debilis*. Known point occurrences were used to assess species deposition responses and critical loads.

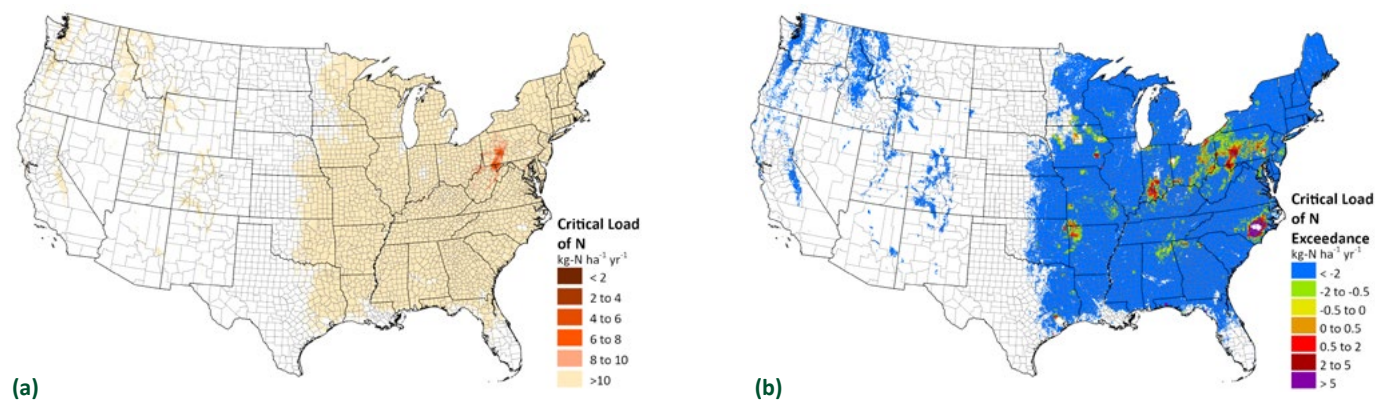


Figure A21.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Carex debilis* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

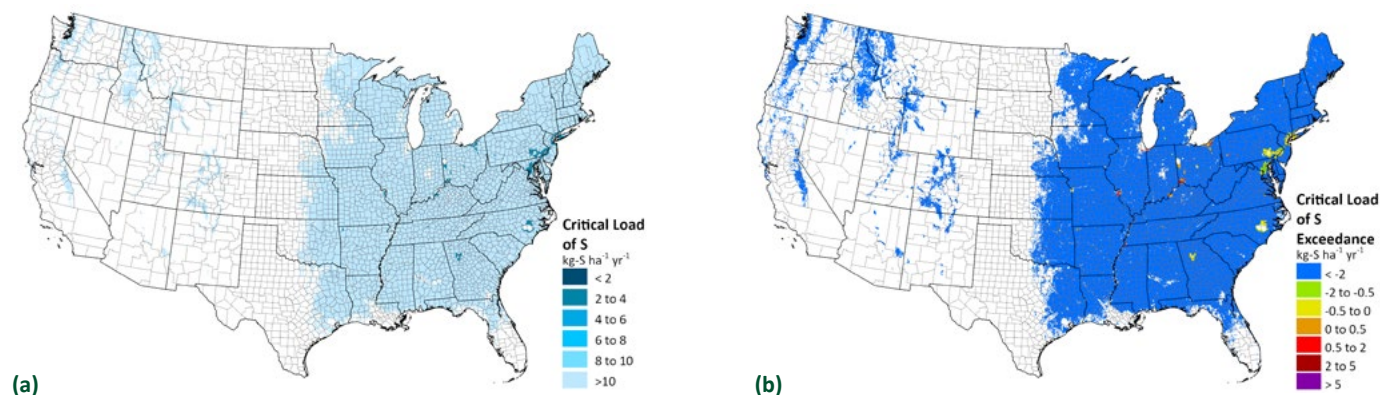


Figure A21.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Carex debilis* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A22. *Carex disperma* (softleaf sedge)

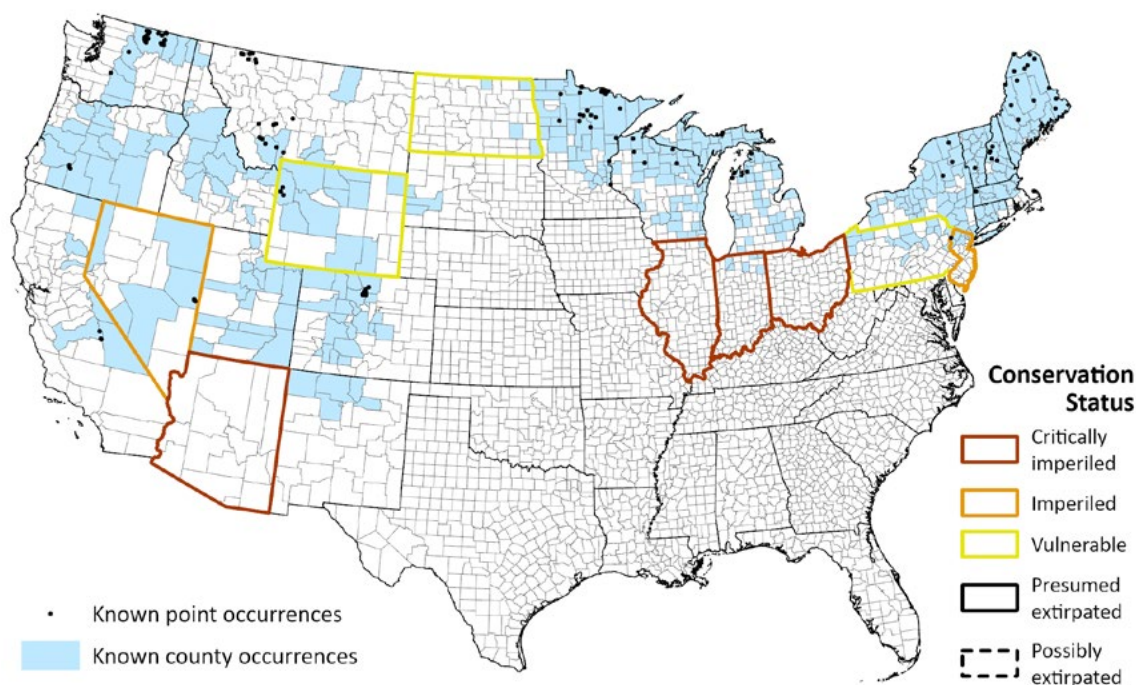


Figure A22.1. Distribution and state-level conservation status of *Carex disperma*. Known point occurrences were used to assess species deposition responses and critical loads.

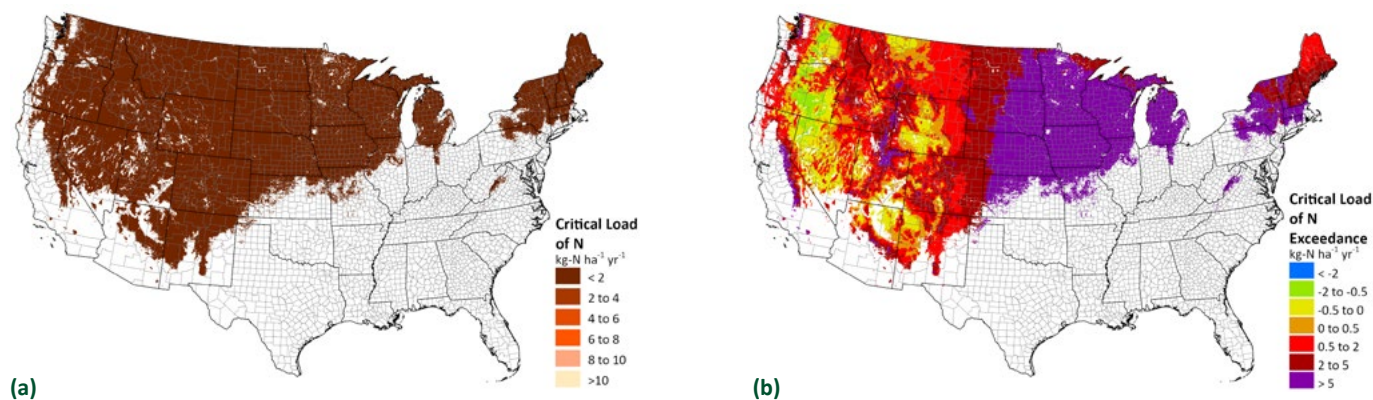


Figure A22.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Carex disperma* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

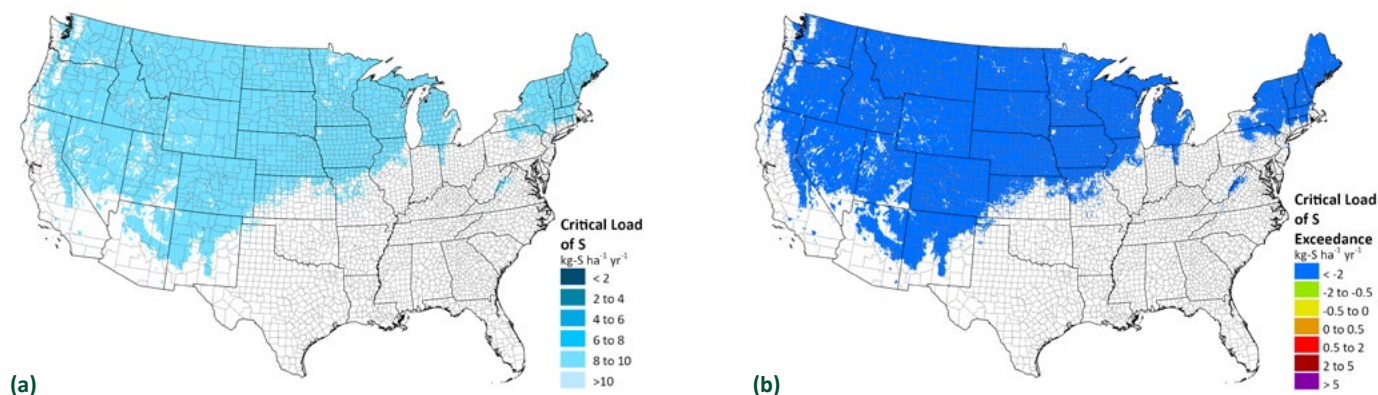


Figure A22.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Carex disperma* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A23. *Carex gracillima* (graceful sedge)

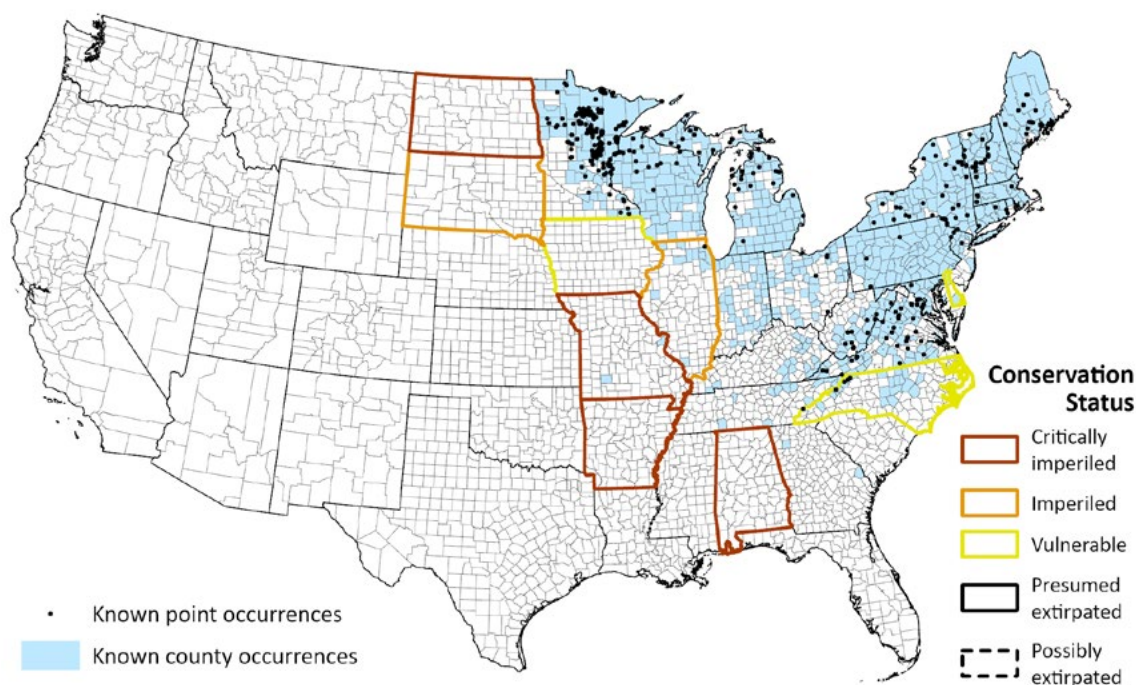


Figure A23.1. Distribution and state-level conservation status of *Carex gracillima*. Known point occurrences were used to assess species deposition responses and critical loads.

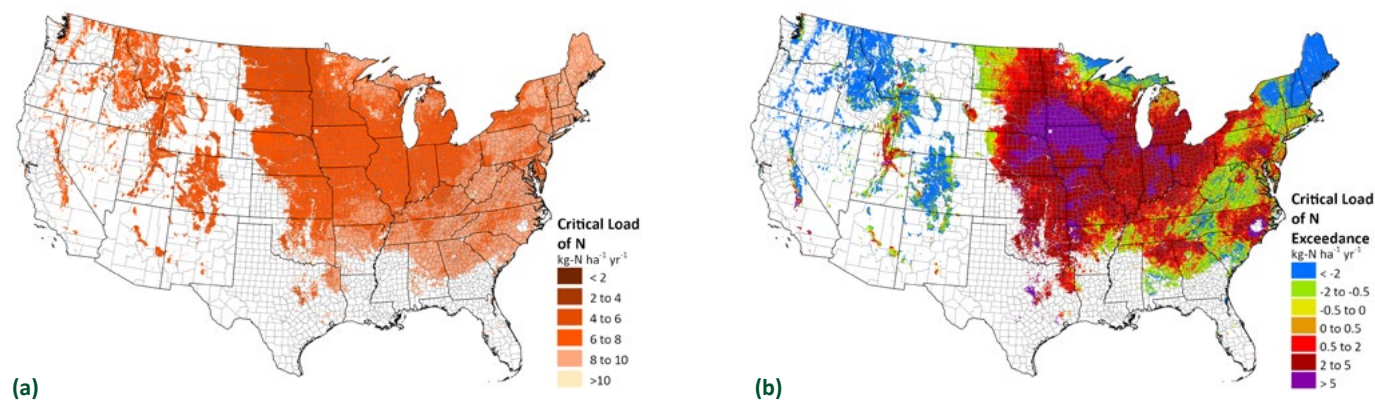


Figure A23.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Carex gracillima* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

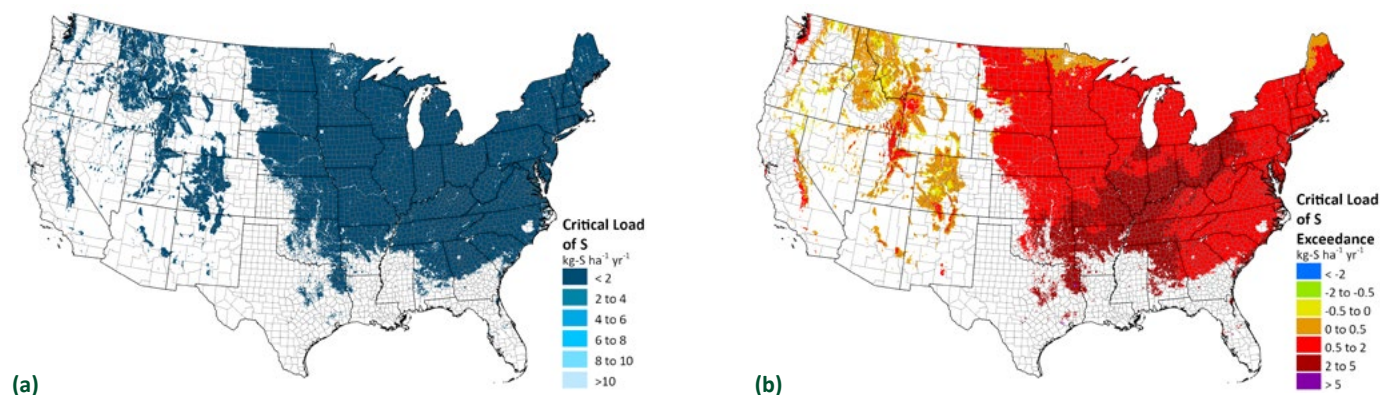


Figure A23.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Carex gracillima* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A24. *Carex hirsutella* (fuzzy wuzzy sedge)

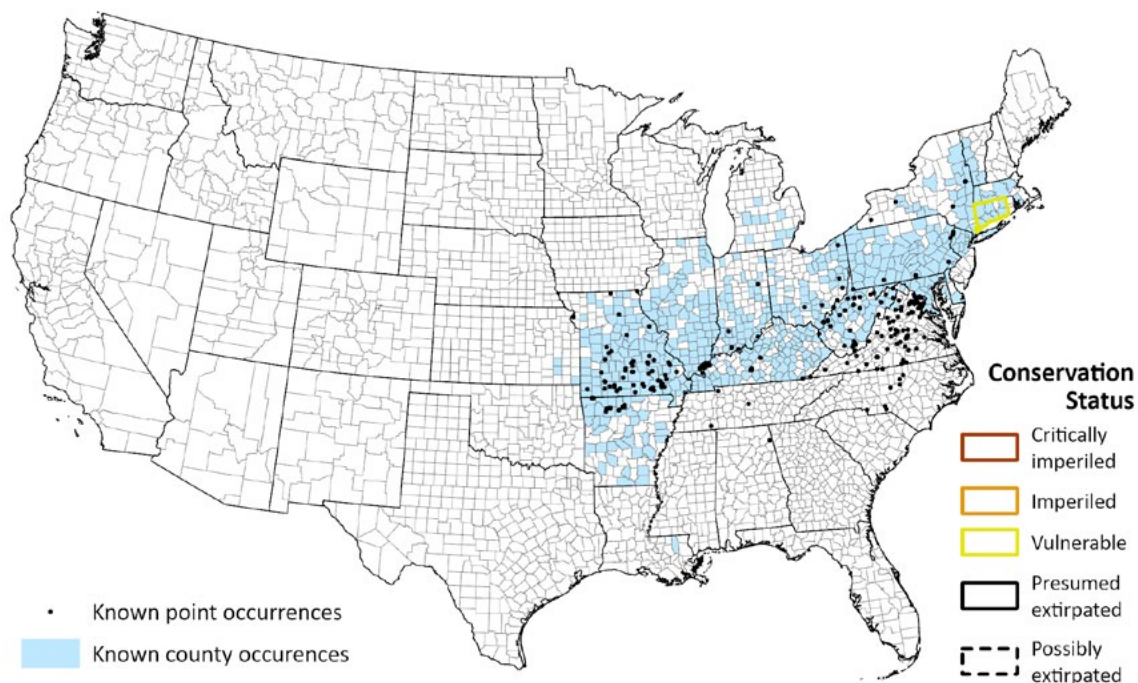


Figure A24.1. Distribution and state-level conservation status of *Carex hirsutella*. Known point occurrences were used to assess species deposition responses and critical loads.

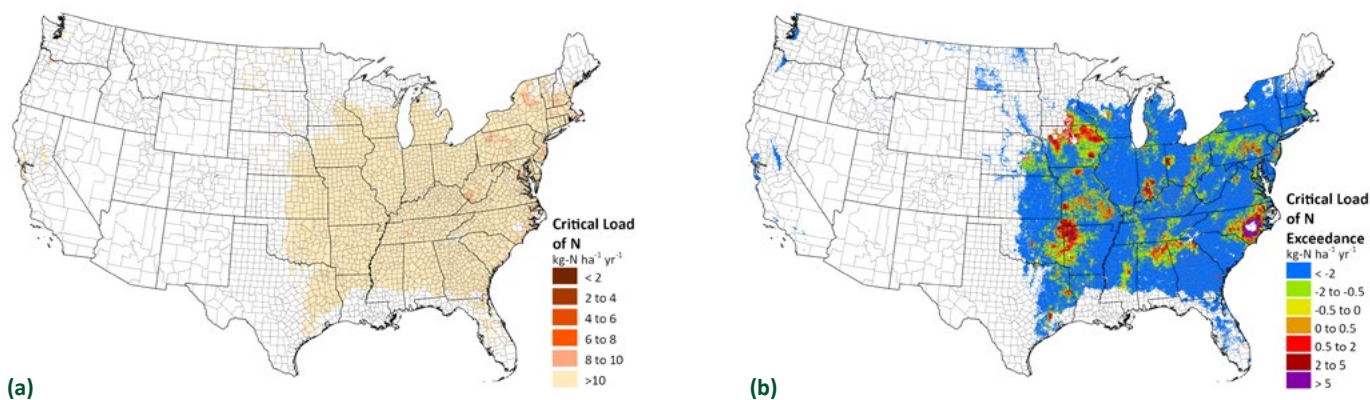


Figure A24.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Carex hirsutella* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

A25. *Carex laxiculmis* (spreading sedge)

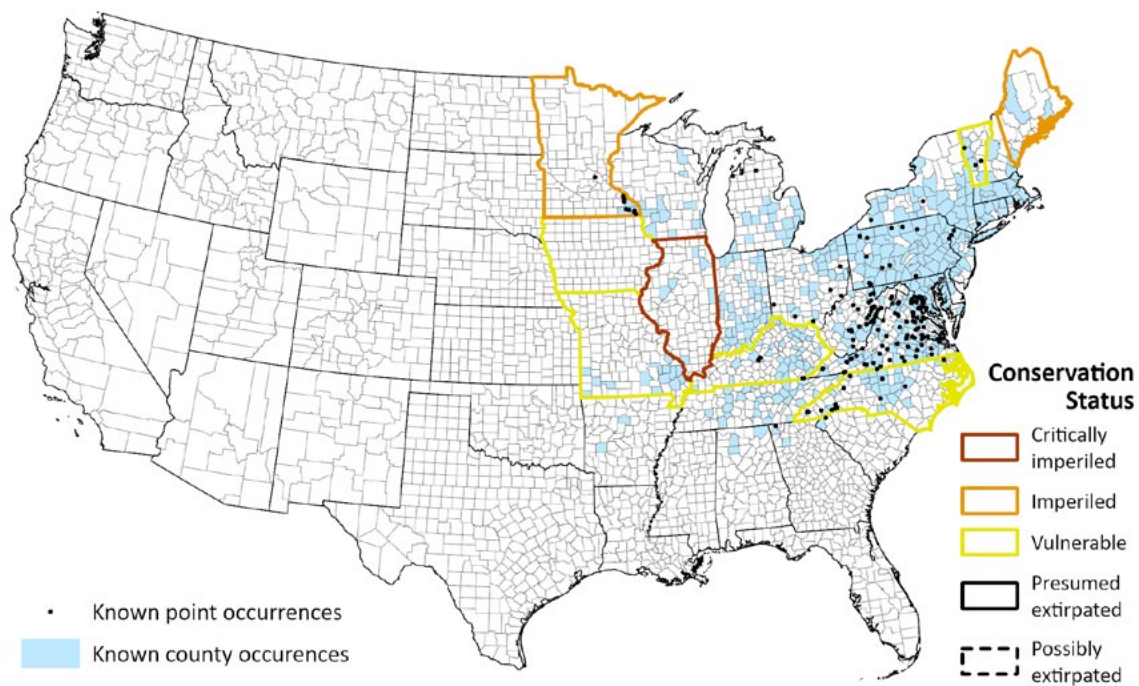


Figure A25.1. Distribution and state-level conservation status of *Carex laxiculmis*. Known point occurrences were used to assess species deposition responses and critical loads.

A26. *Carex pedunculata* (longstalk sedge)

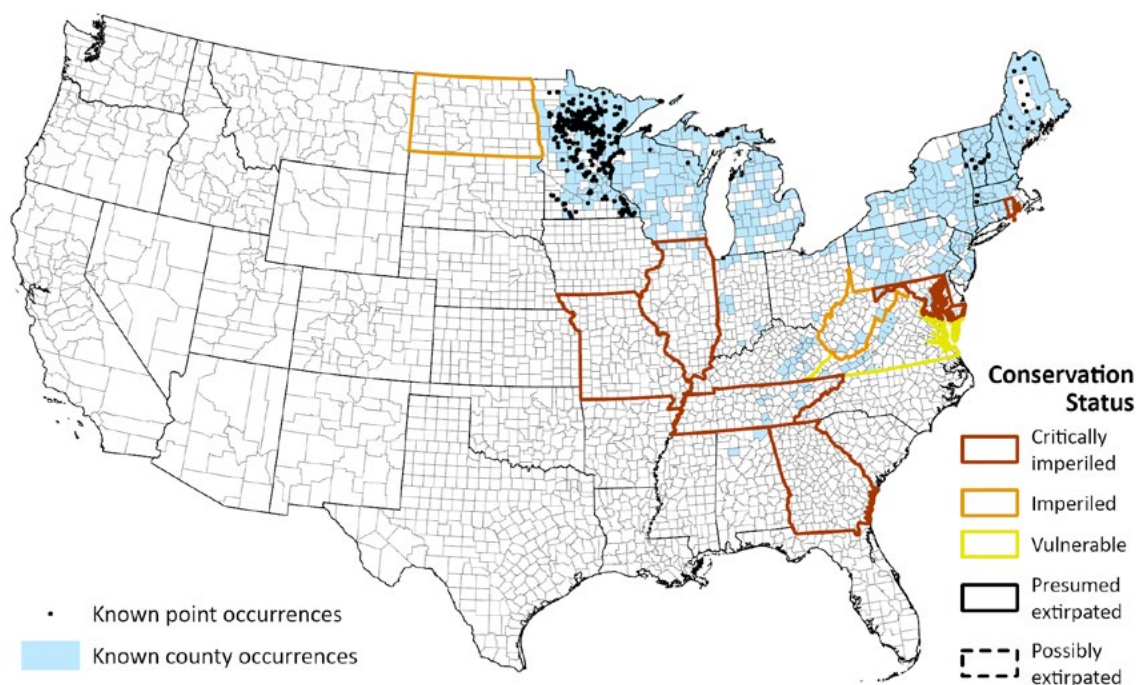


Figure A26.1. Distribution and state-level conservation status of *Carex pedunculata*. Known point occurrences were used to assess species deposition responses and critical loads.

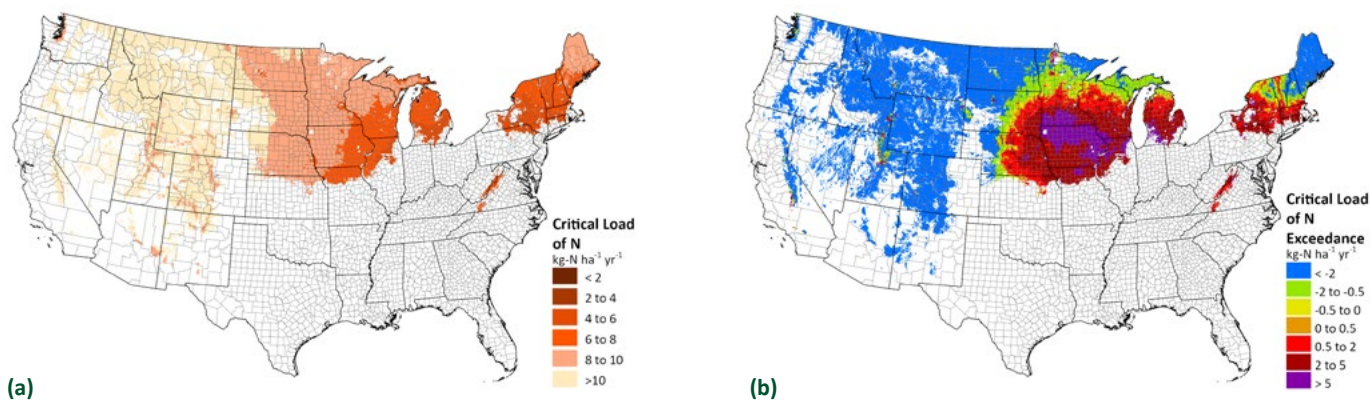


Figure A26.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Carex pedunculata* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

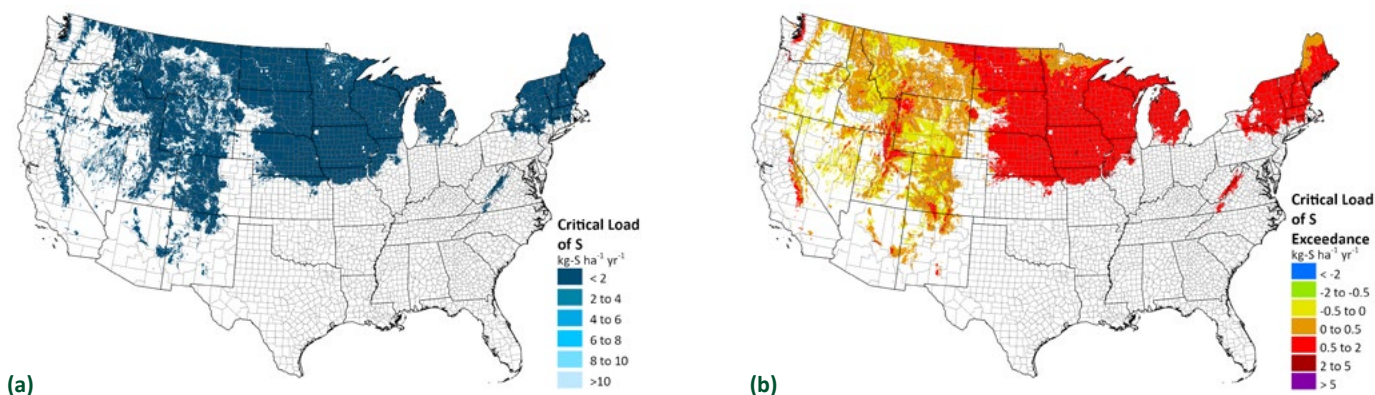


Figure A26.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Carex pedunculata* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A27. *Carex radiata* (eastern star sedge)

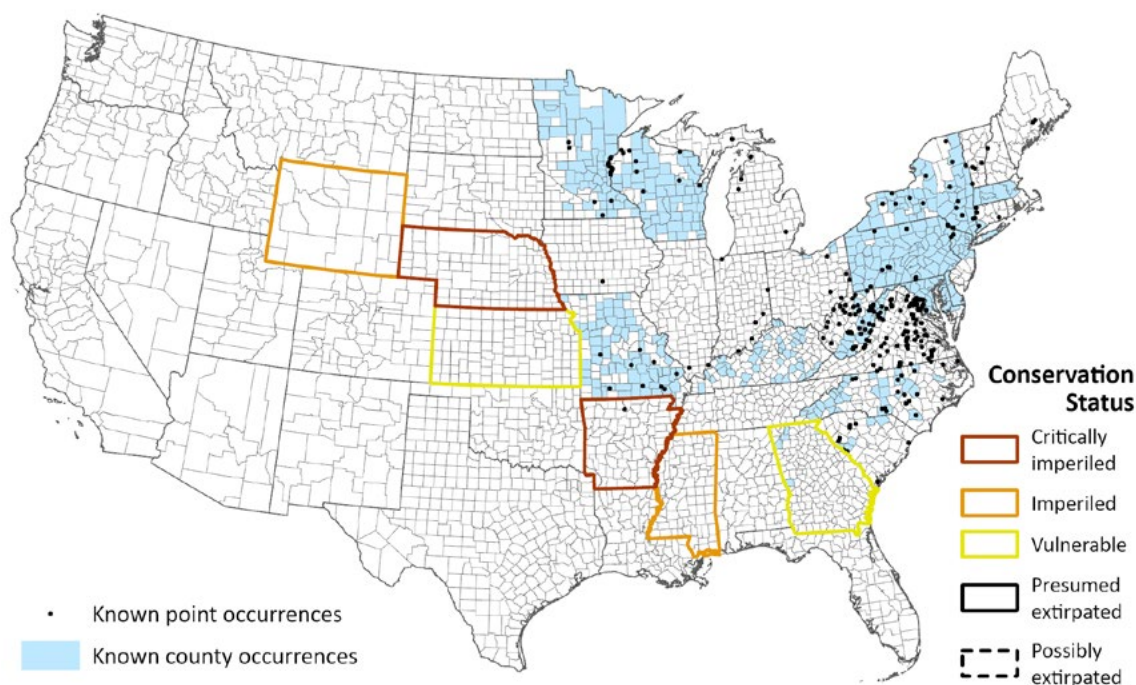


Figure A27.1. Distribution and state-level conservation status of *Carex radiata*. Known point occurrences were used to assess species deposition responses and critical loads.

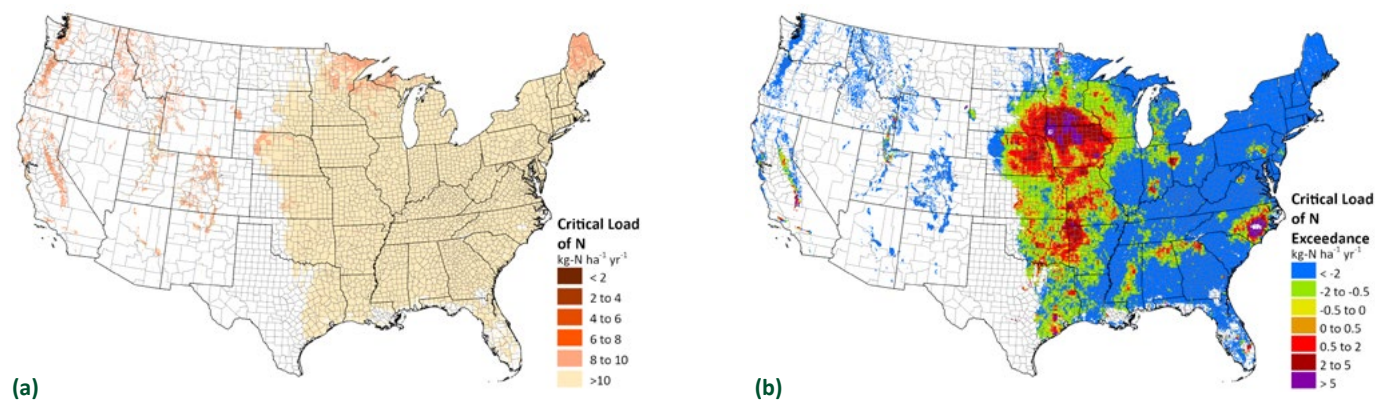


Figure A27.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Carex radiata* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

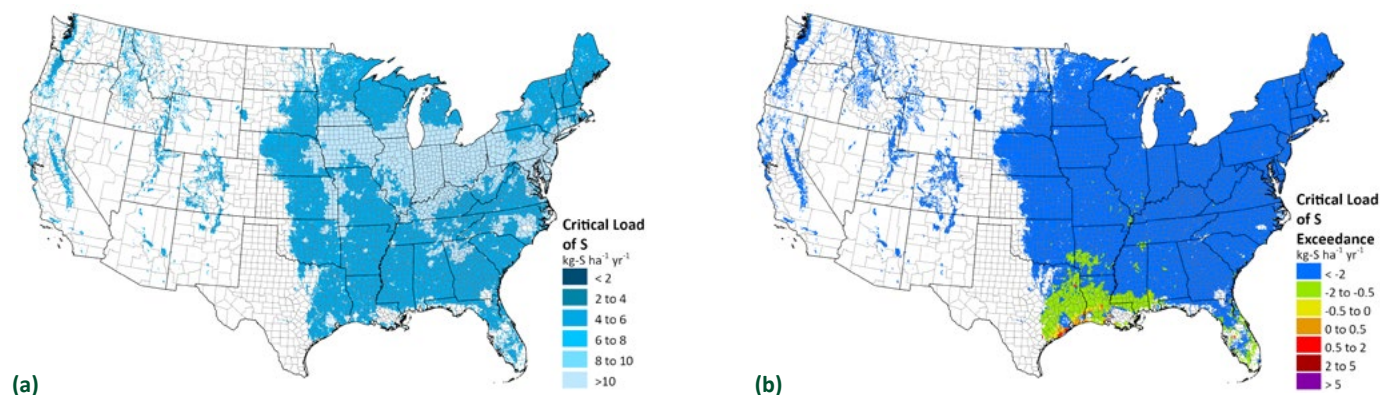


Figure A27.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Carex radiata* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A28. *Carex rosea* (rosy sedge)

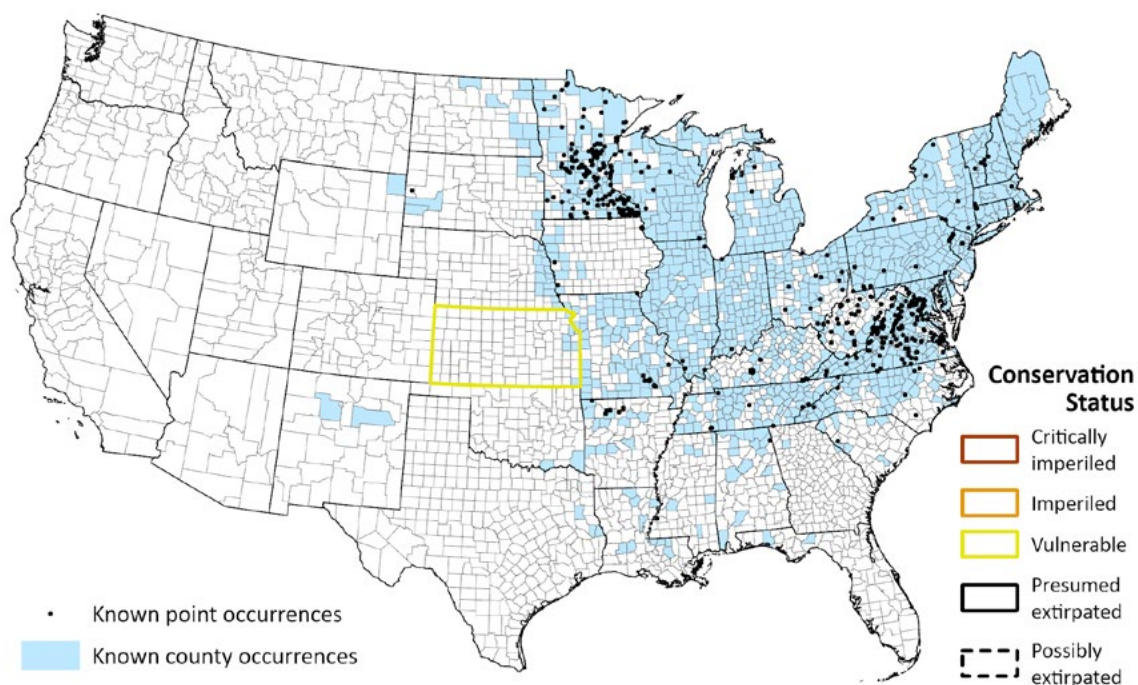


Figure A28.1. Distribution and state-level conservation status of *Carex rosea*. Known point occurrences were used to assess species deposition responses and critical loads.

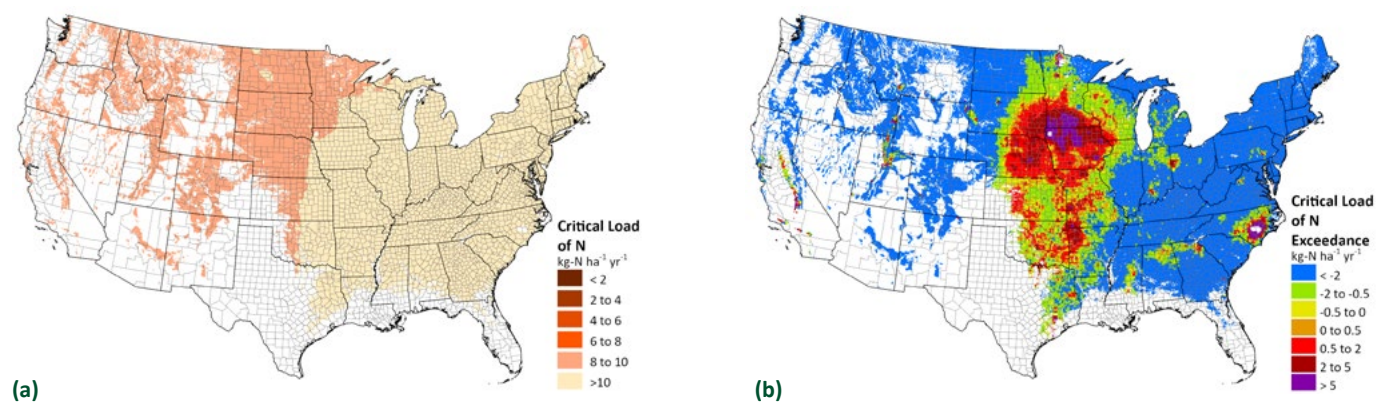


Figure A28.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Carex rosea* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

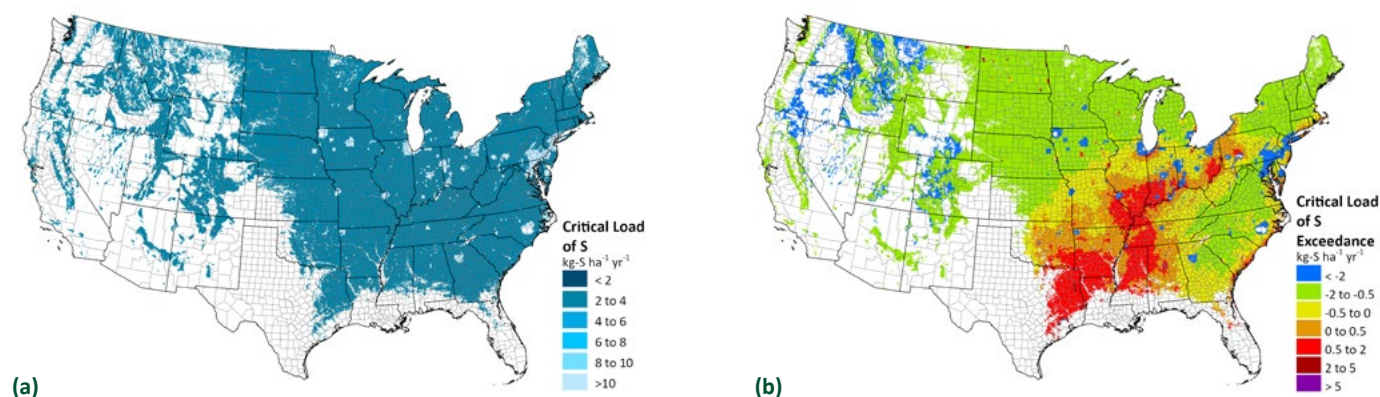


Figure A28.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Carex rosea* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A29. *Carex swanii* (Swan's sedge)

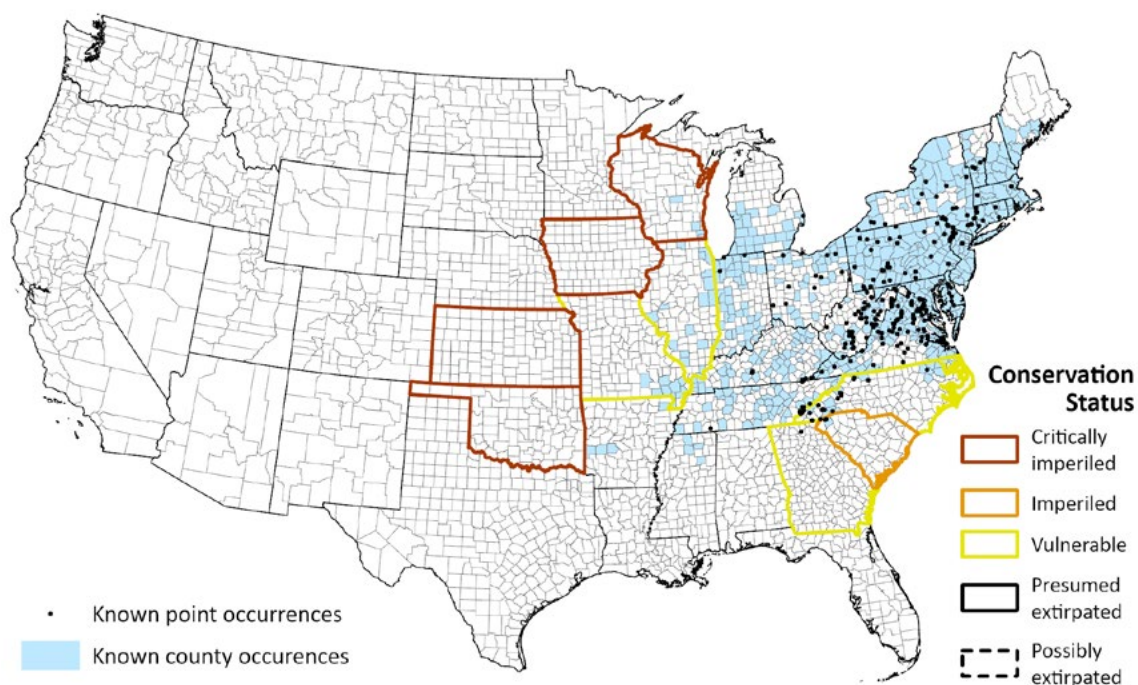


Figure A29.1. Distribution and state-level conservation status of *Carex swanii*. Known point occurrences were used to assess species deposition responses and critical loads.

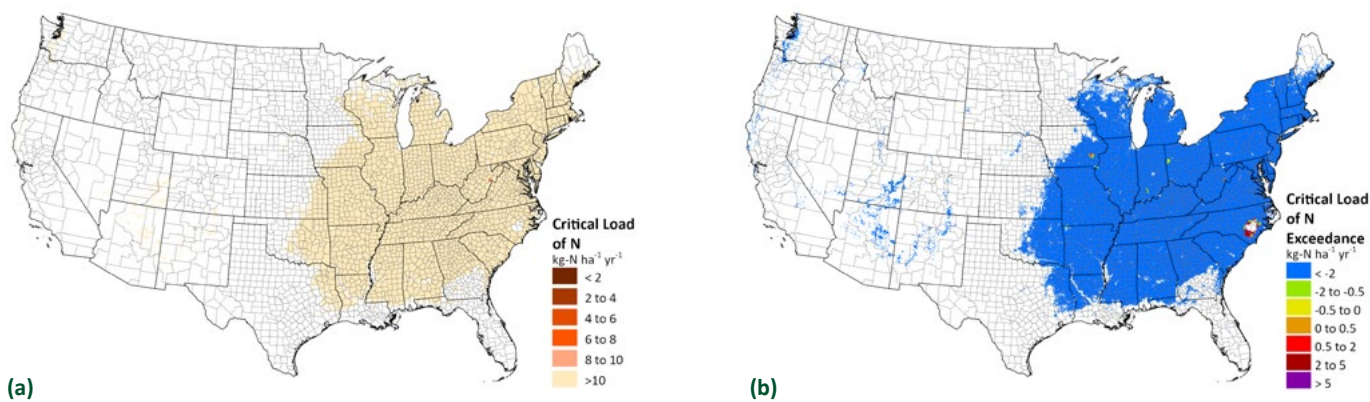


Figure A29.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Carex swanii* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

A30. *Carex tetanica* (rigid sedge)

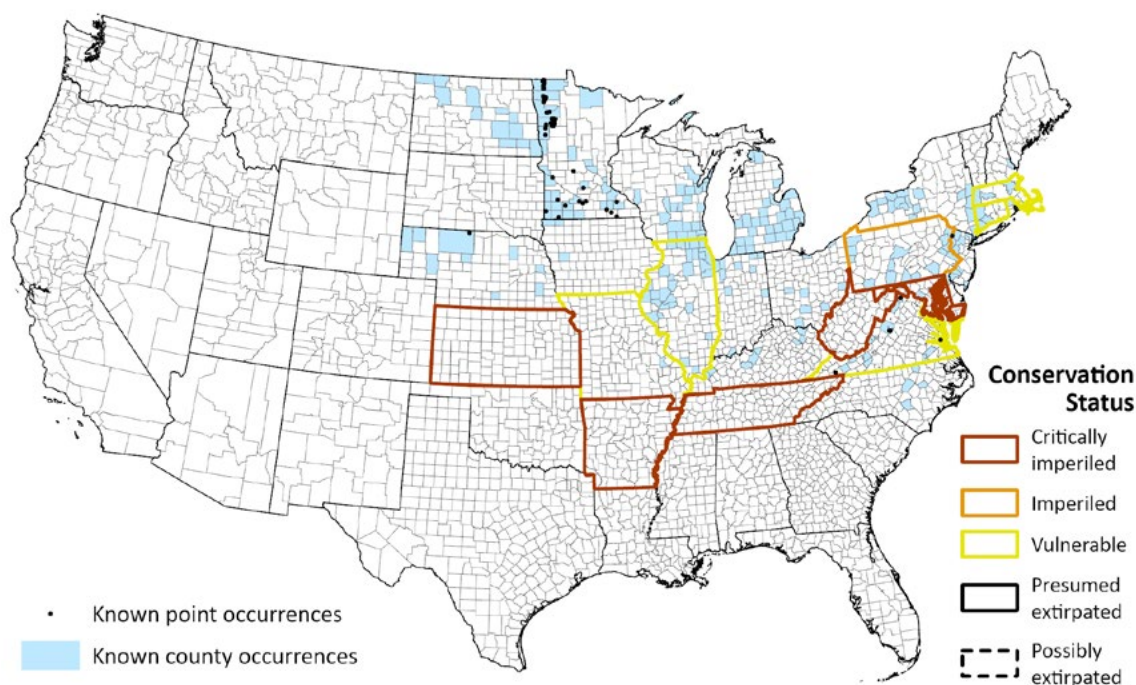


Figure A30.1. Distribution and state-level conservation status of *Carex tetanica*. Known point occurrences were used to assess species deposition responses and critical loads.

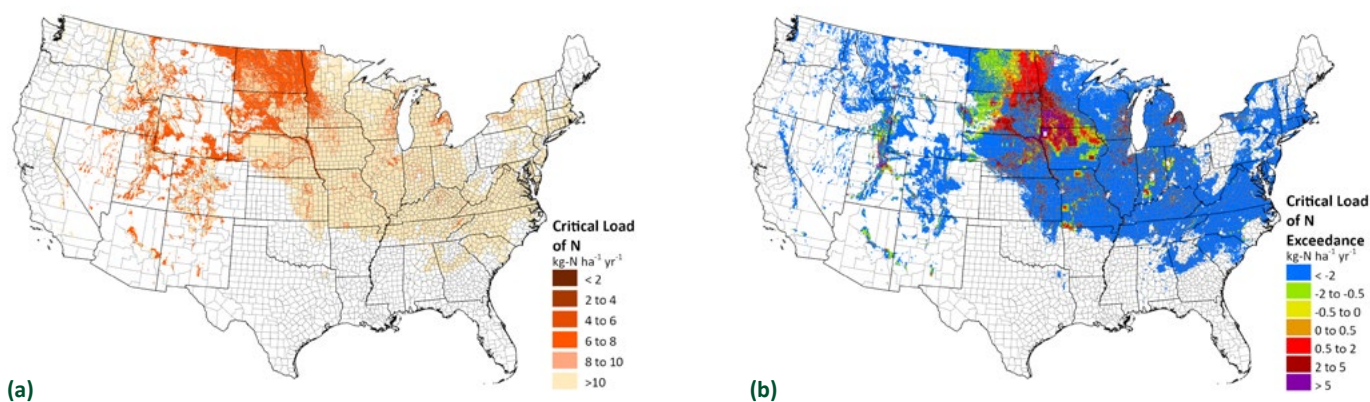


Figure A30.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Carex tetanica* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

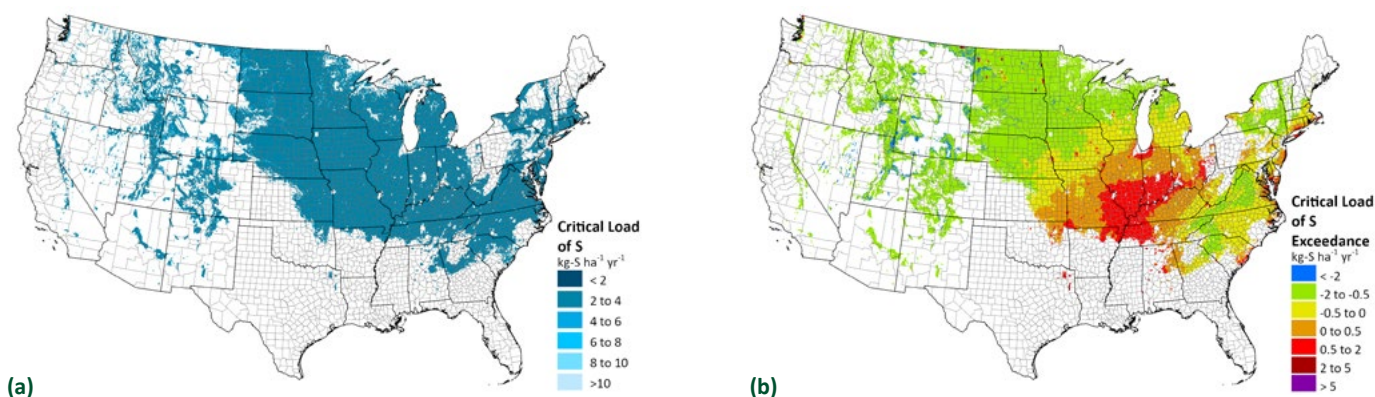


Figure A30.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Carex tetanica* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A31. *Carex virescens* (ribbed sedge)

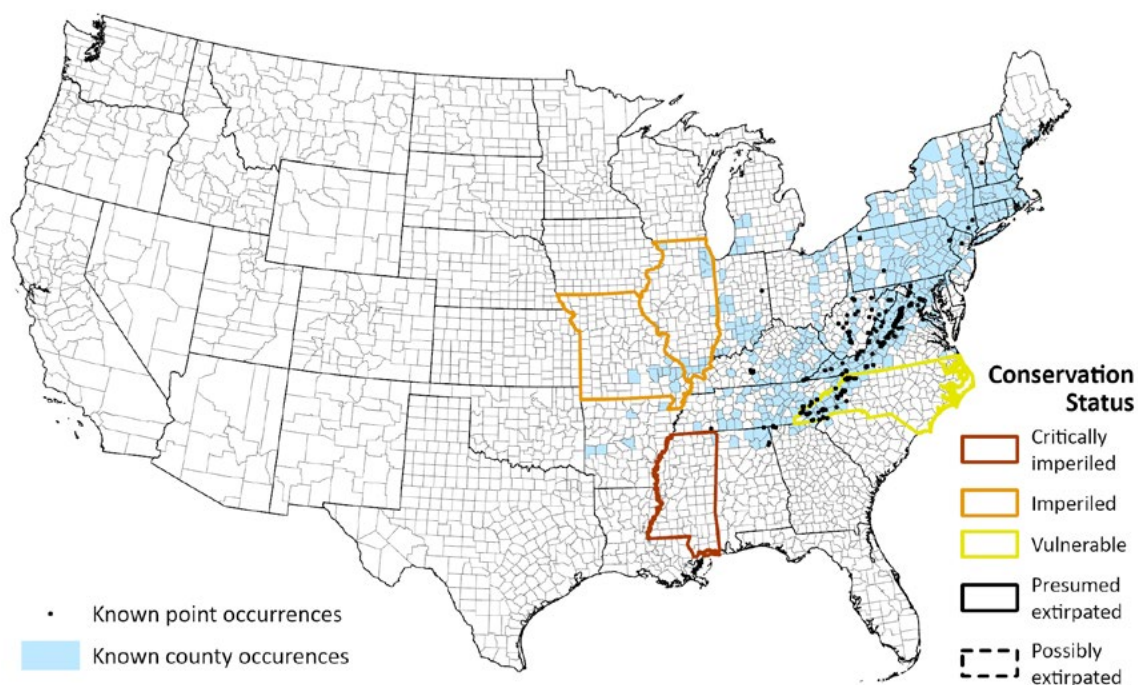


Figure A31.1. Distribution and state-level conservation status of *Carex virescens*. Known point occurrences were used to assess species deposition responses and critical loads.

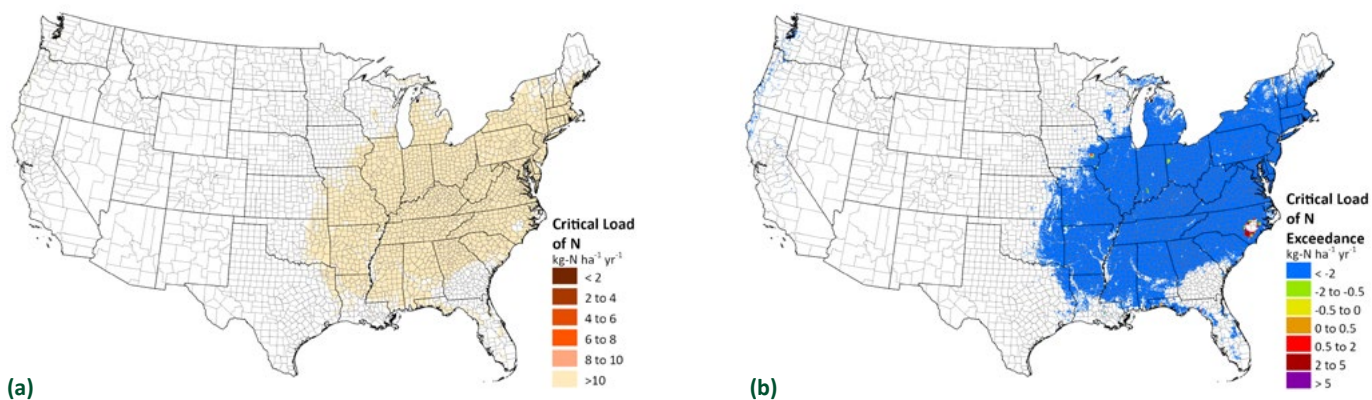


Figure A31.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Carex virescens* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

A32. *Cerastium arvense* (field chickweed)

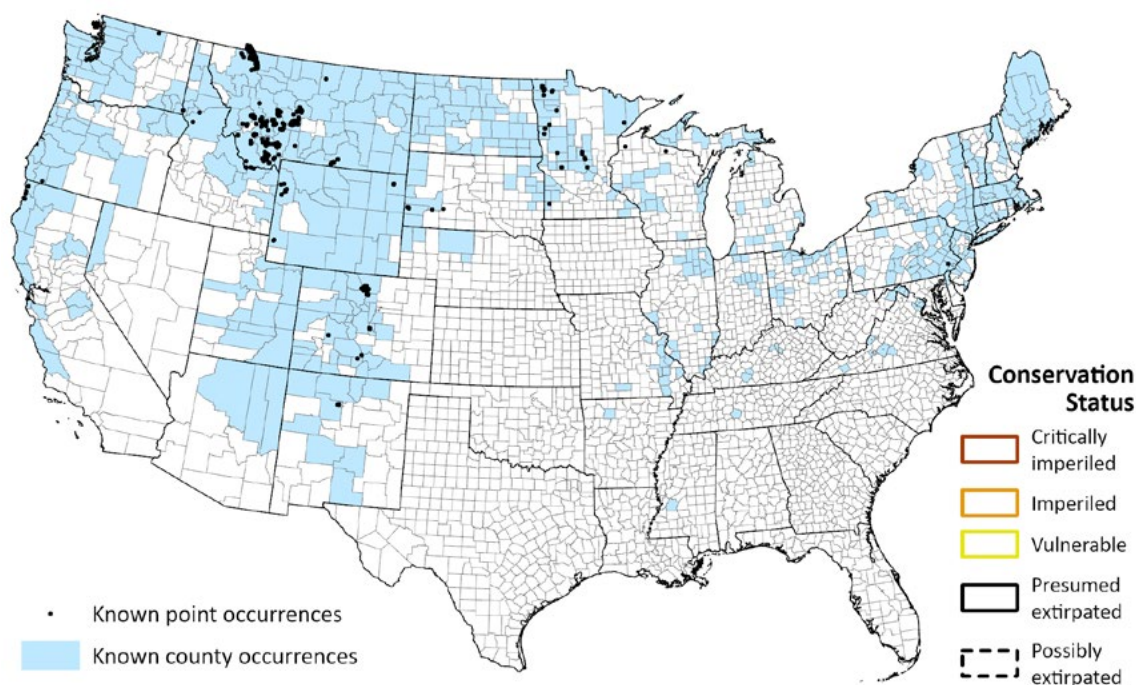


Figure A32.1. Distribution and state-level conservation status of *Cerastium arvense*. Known point occurrences were used to assess species deposition responses and critical loads.

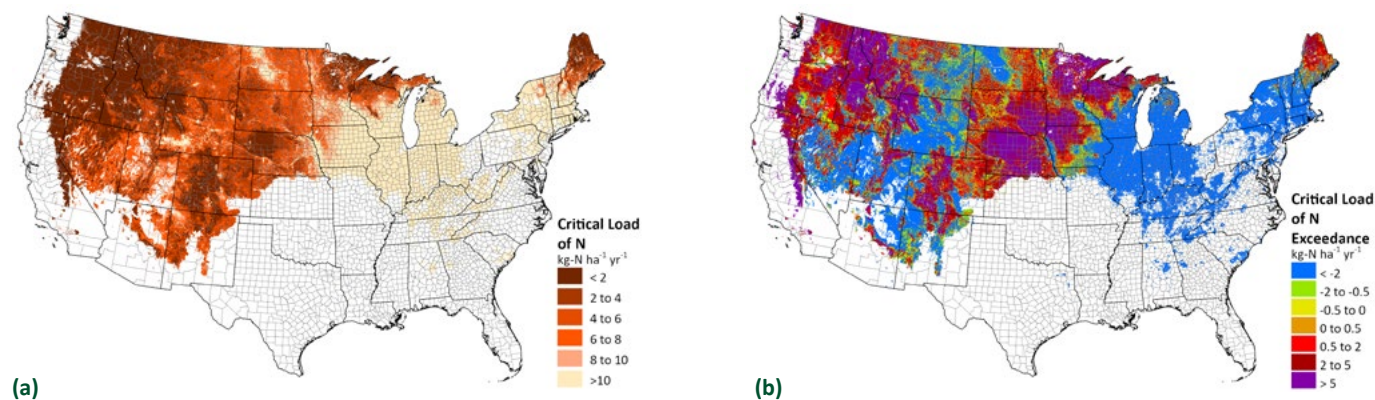


Figure A32.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Cerastium arvense* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

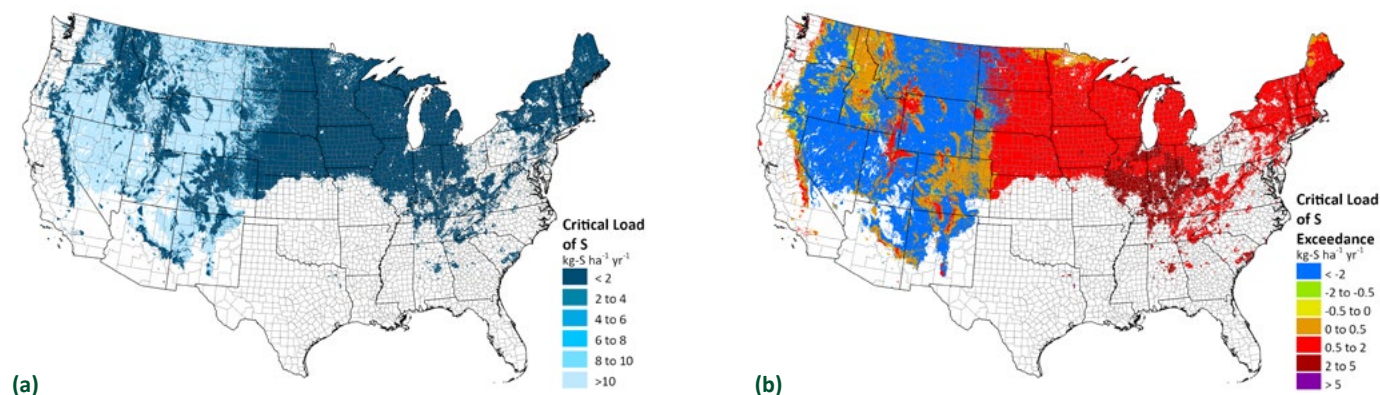


Figure A32.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Cerastium arvense* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A33. *Chenopodium album* (lambsquarters)

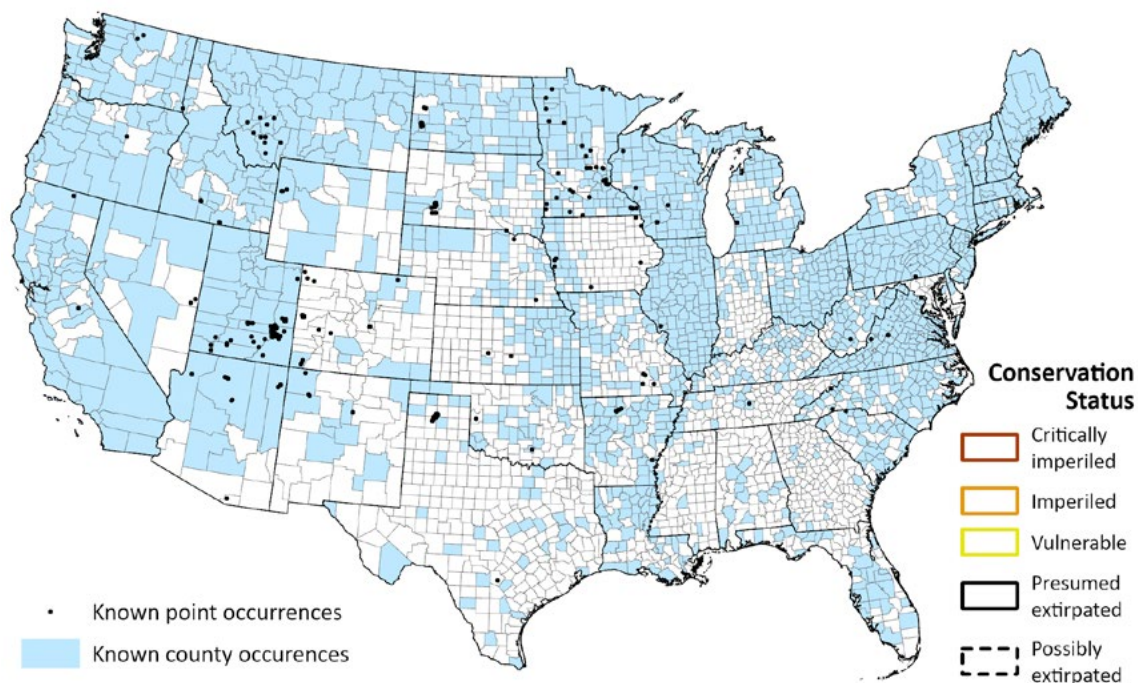


Figure A33.1. Distribution and state-level conservation status of *Chenopodium album*. Known point occurrences were used to assess species deposition responses and critical loads.

A34. *Cinna latifolia* (drooping woodreed)

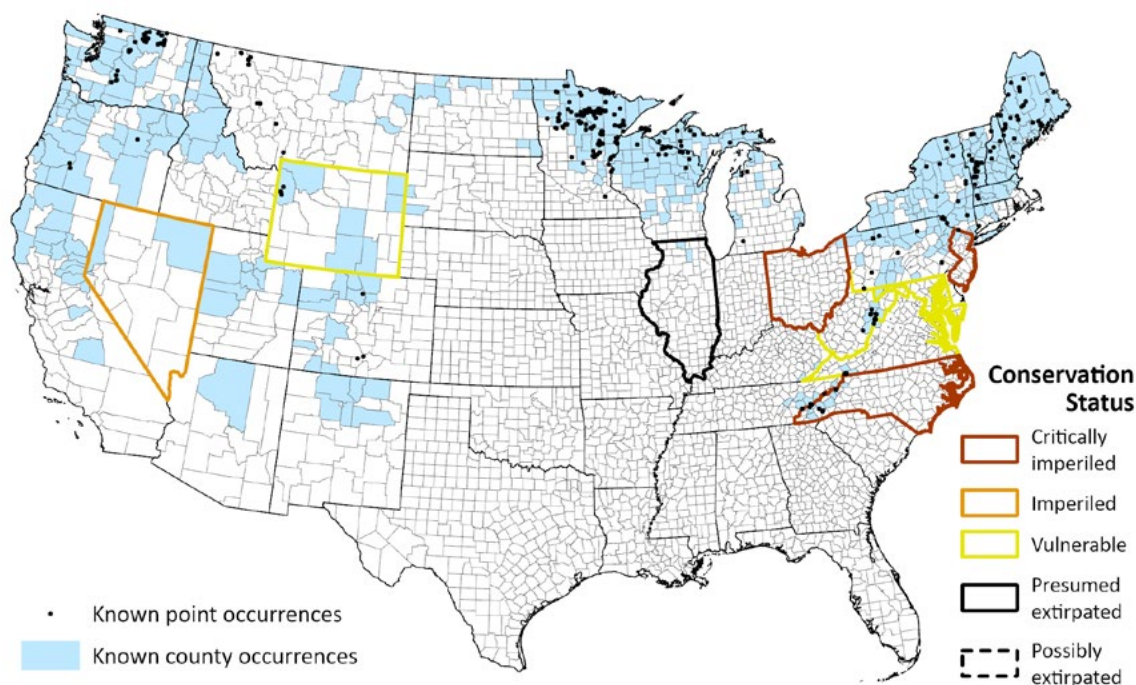


Figure A34.1. Distribution and state-level conservation status of *Cinna latifolia*. Known point occurrences were used to assess species deposition responses and critical loads.

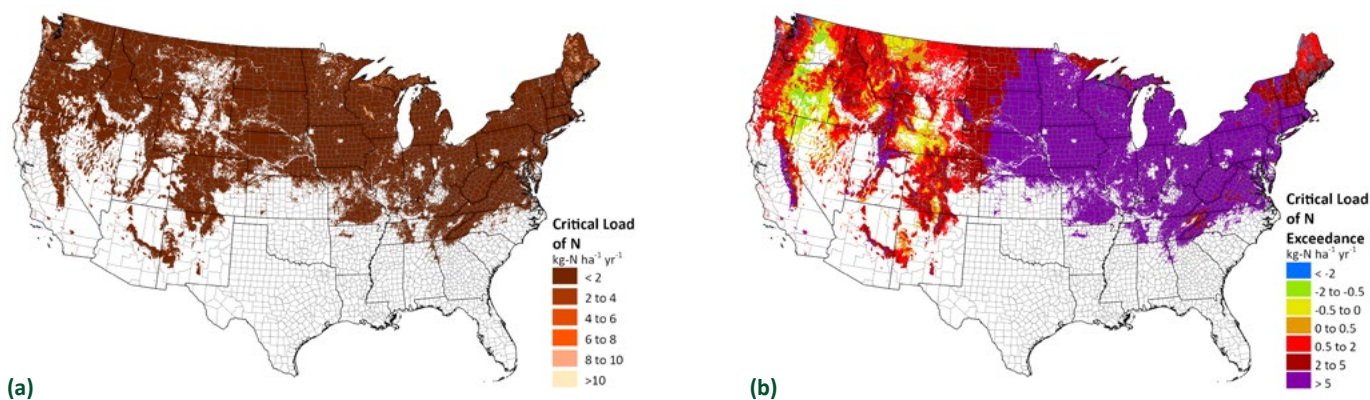


Figure A34.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Cinna latifolia* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

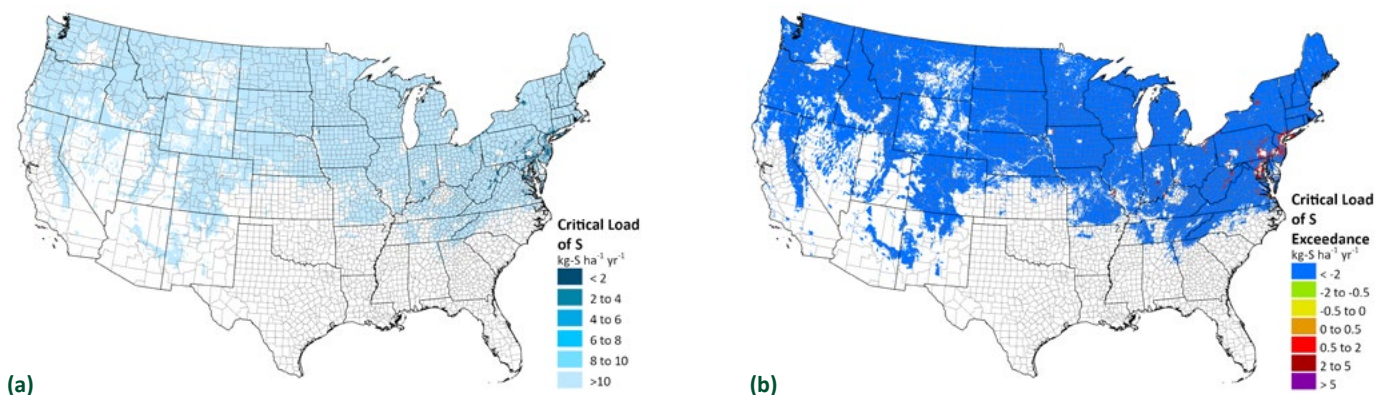


Figure A34.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Cinna latifolia* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A35. *Circaea canadensis* (enchanter's nightshade)

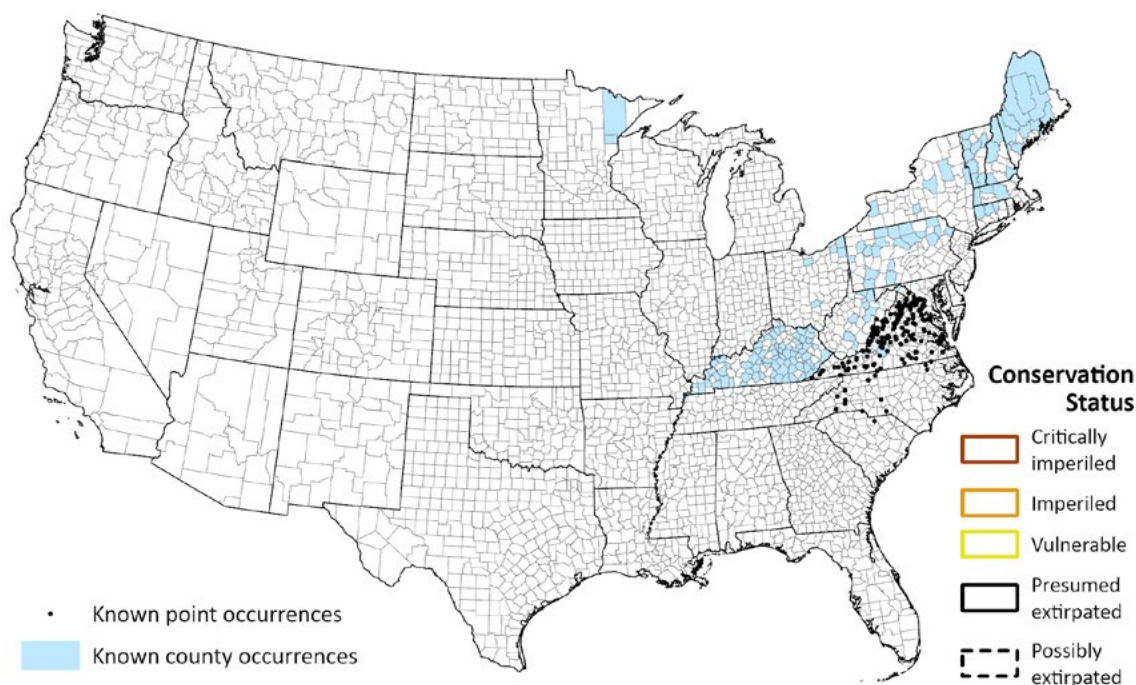


Figure A35.1. Distribution and state-level conservation status of *Circaea canadensis*. Known point occurrences were used to assess species deposition responses and critical loads.

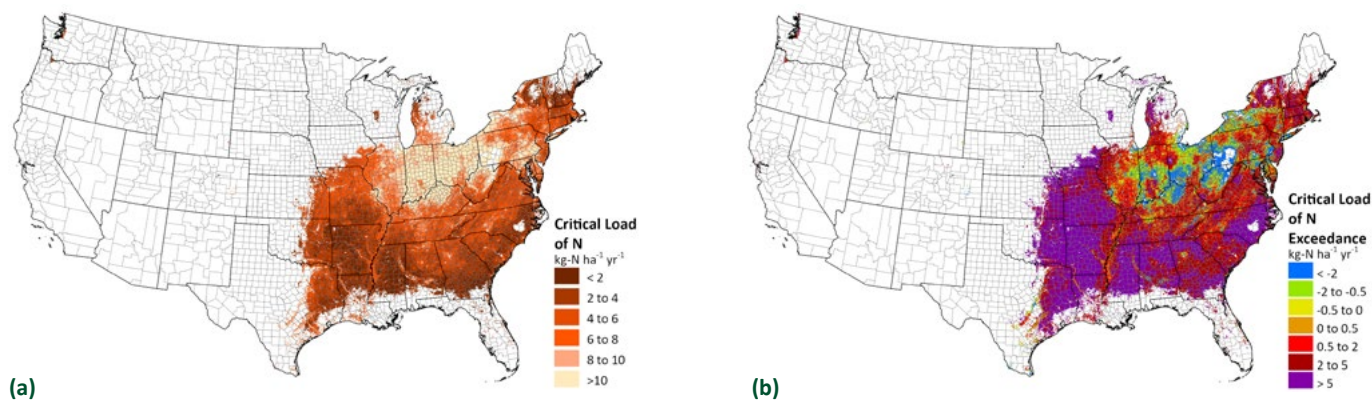


Figure A35.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Circaea canadensis* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

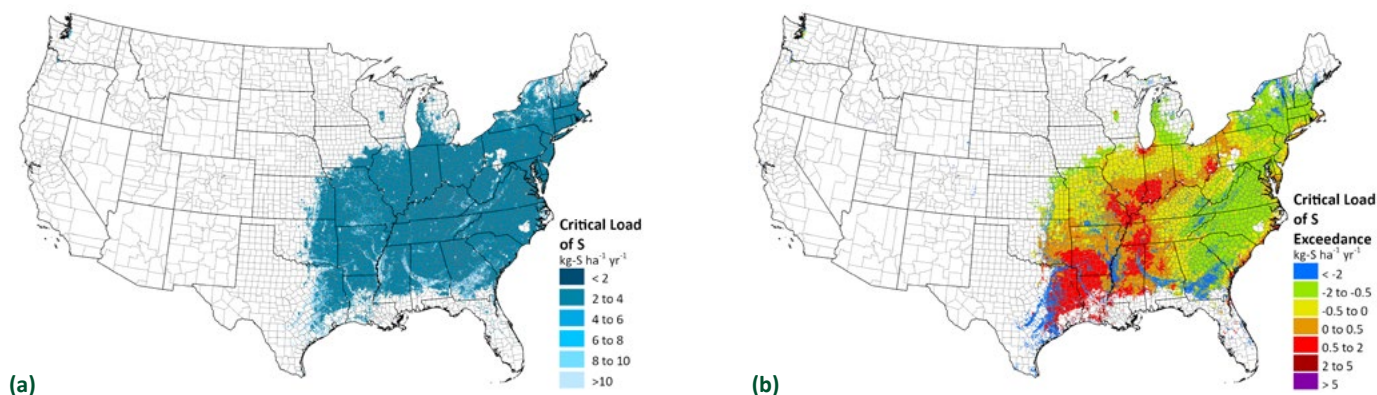


Figure A35.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Circaea canadensis* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A36. *Circaea lutetiana* (broadleaf enchanter's nightshade)

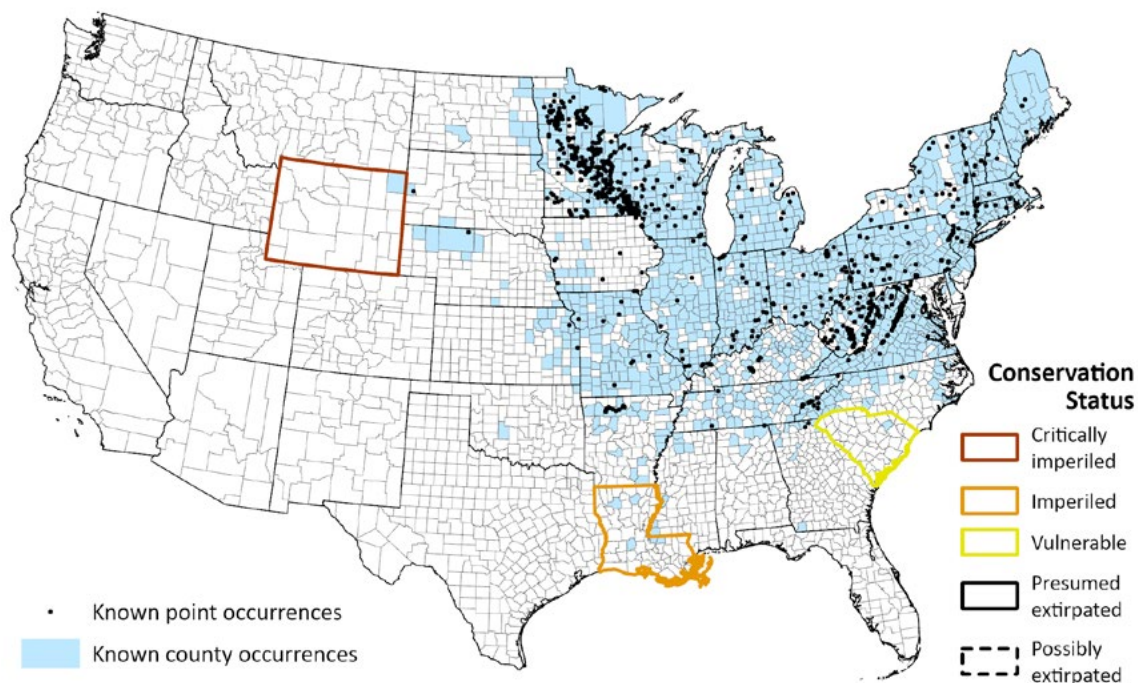


Figure A36.1. Distribution and state-level conservation status of *Circaea lutetiana*. Known point occurrences were used to assess species deposition responses and critical loads.

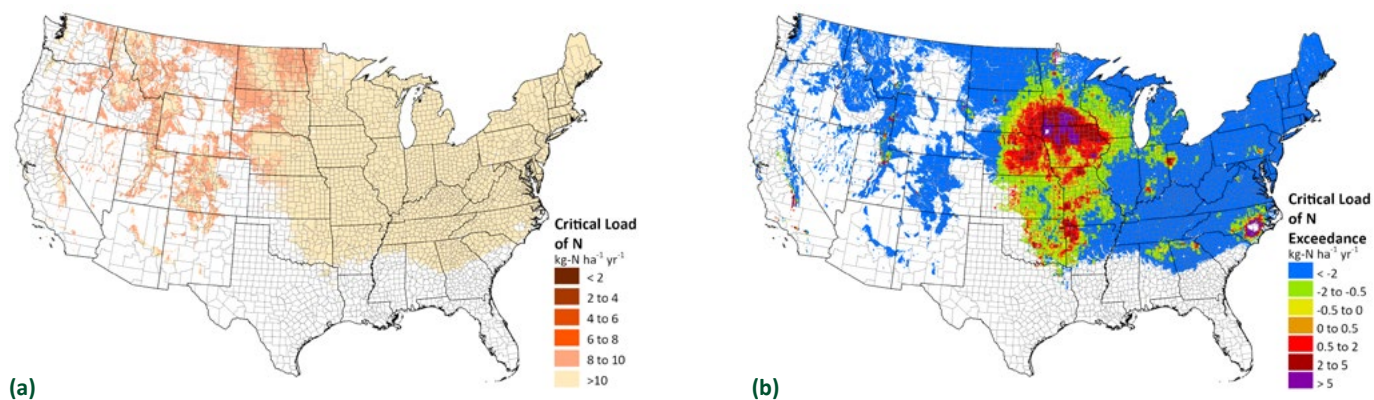


Figure A36.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Circaea lutetiana* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

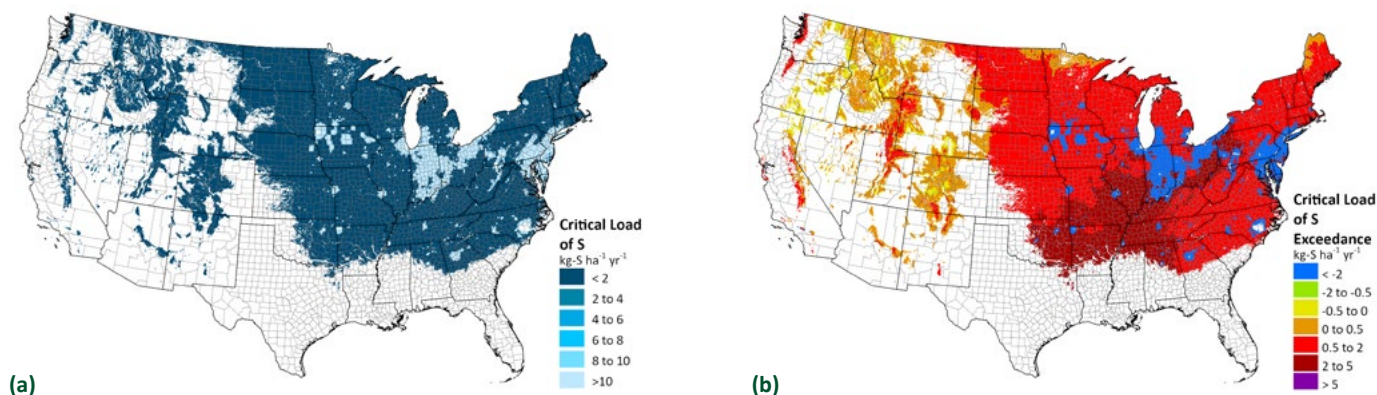


Figure A36.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Circaea lutetiana* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A37. *Clintonia borealis* (bluebead)

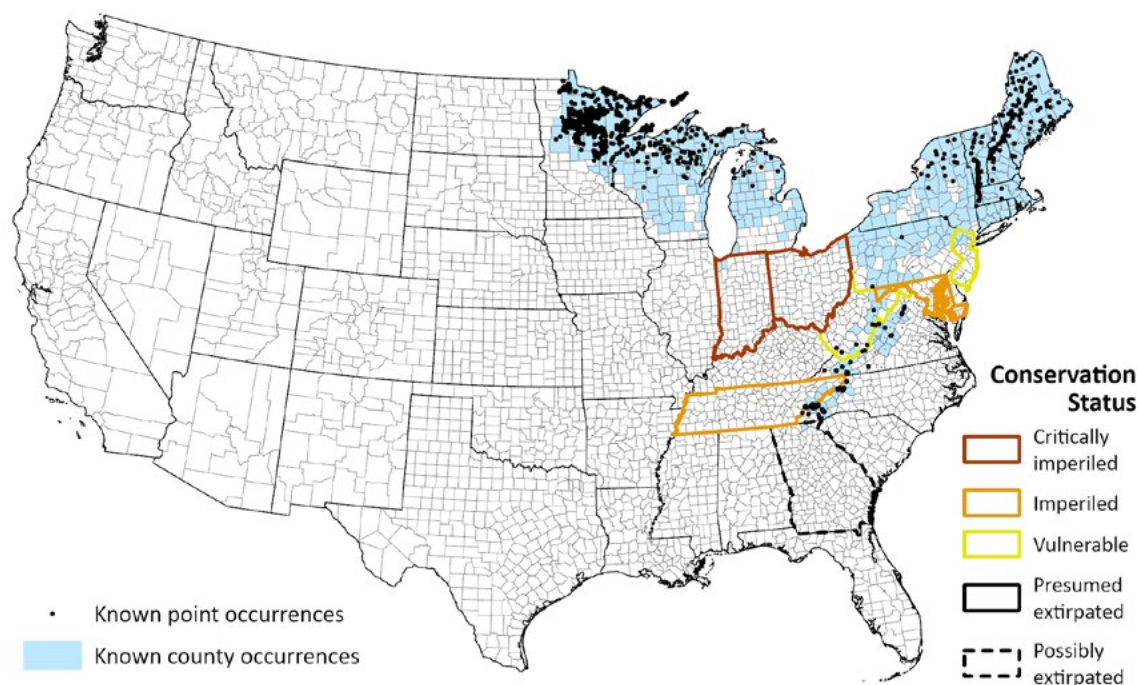


Figure A37.1. Distribution and state-level conservation status of *Clintonia borealis*. Known point occurrences were used to assess species deposition responses and critical loads.

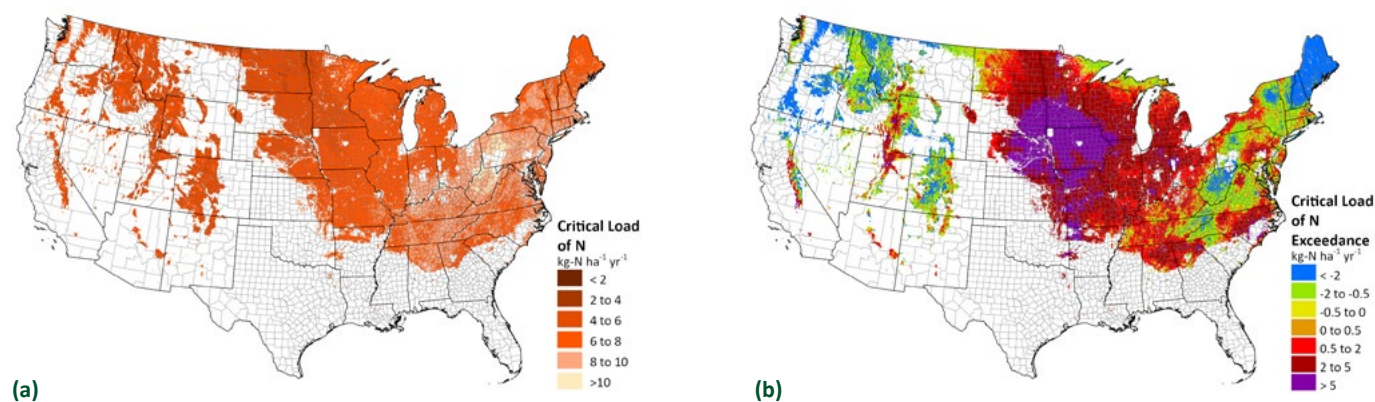


Figure A37.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Clintonia borealis* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

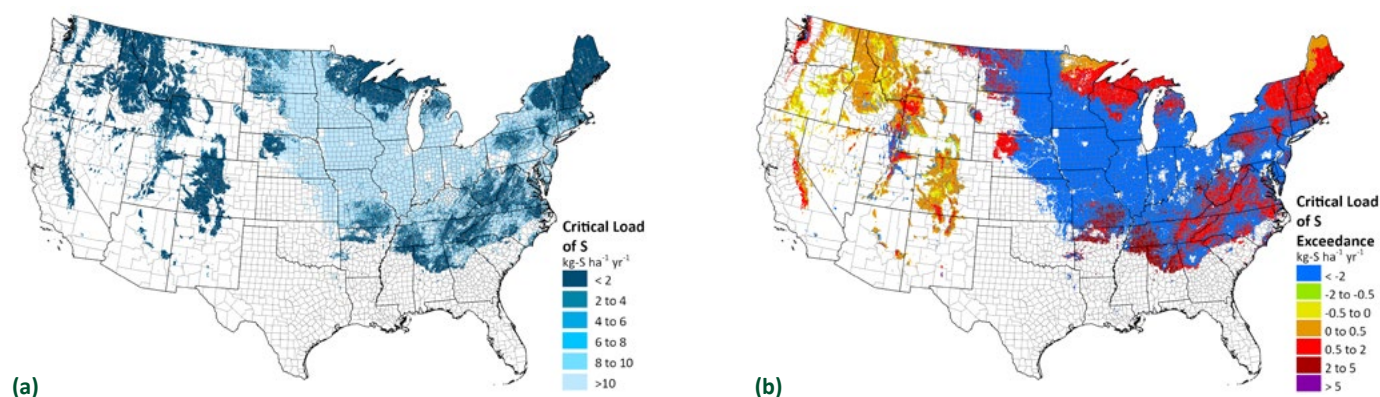


Figure A37.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Clintonia borealis* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A38. *Cryptotaenia canadensis* (Canadian honewort)

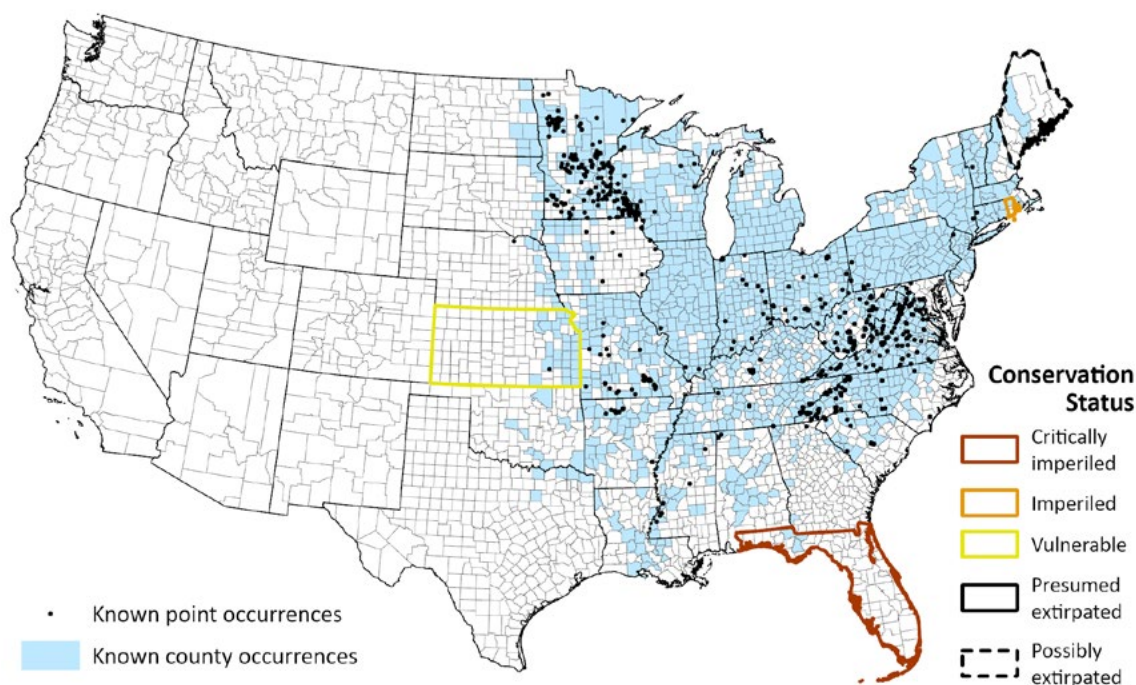


Figure A38.1. Distribution and state-level conservation status of *Cryptotaenia canadensis*. Known point occurrences were used to assess species deposition responses and critical loads.

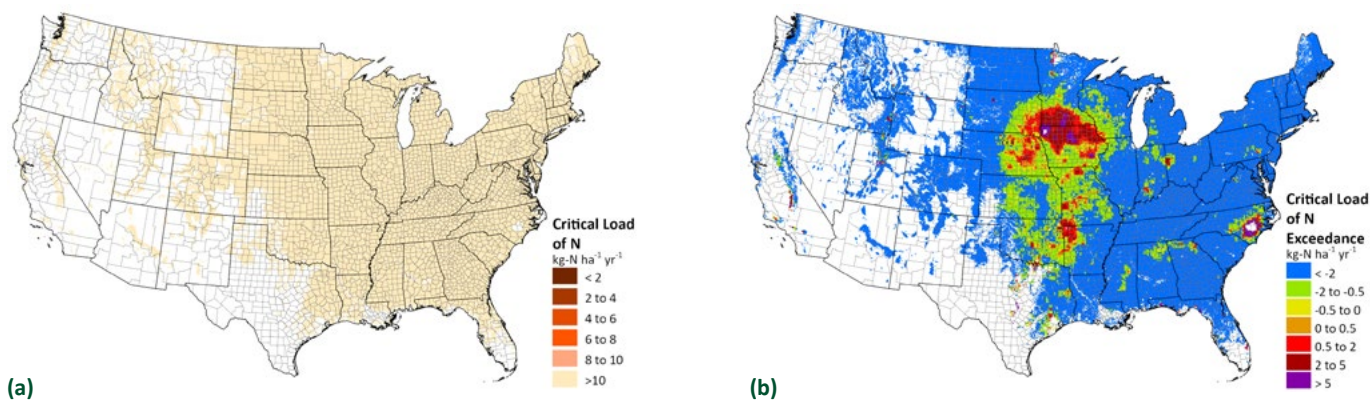


Figure A38.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Cryptotaenia canadensis* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

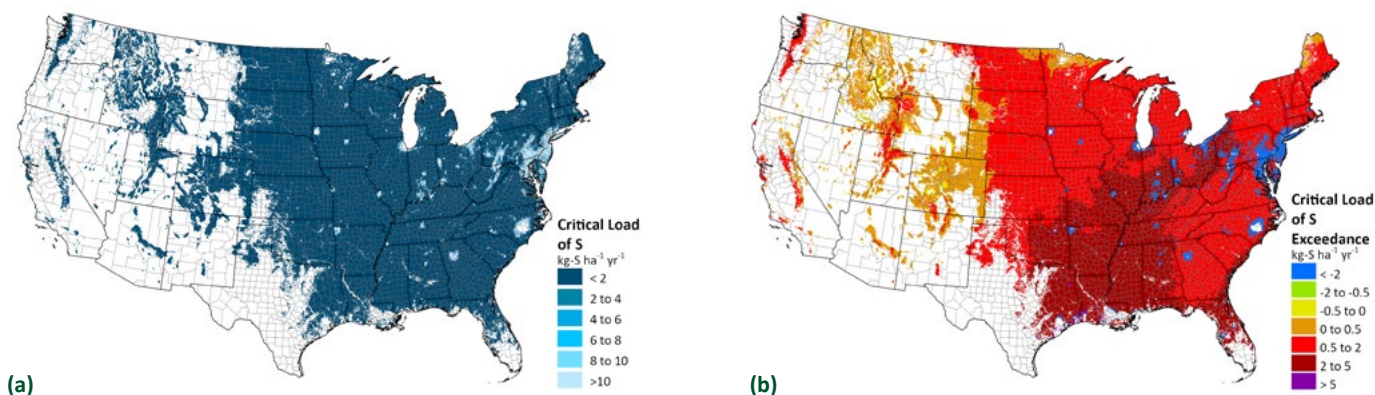


Figure A38.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Cryptotaenia canadensis* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A39. *Deparia acrostichoides* (silver false spleenwort)

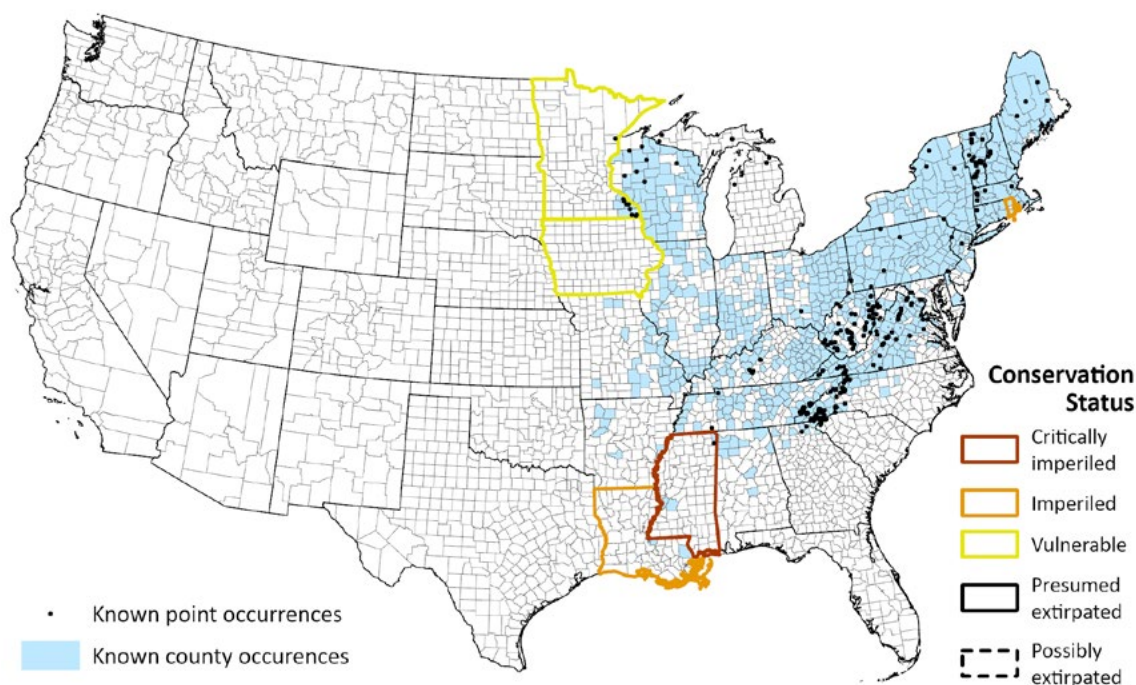


Figure A39.1. Distribution and state-level conservation status of *Deparia acrostichoides*. Known point occurrences were used to assess species deposition responses and critical loads.

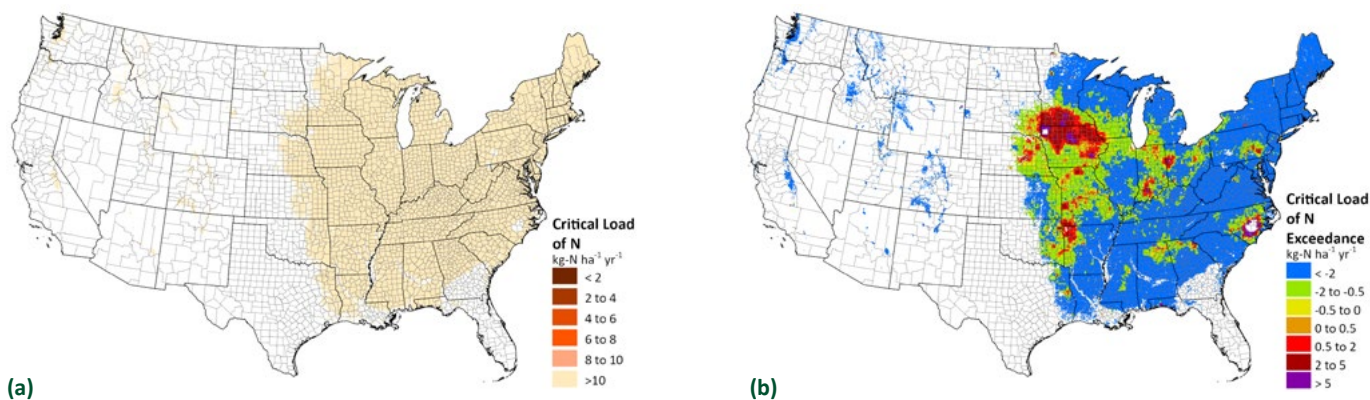


Figure A39.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Deparia acrostichoides* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

A40. *Desmodium canadense* (showy ticktrefoil)

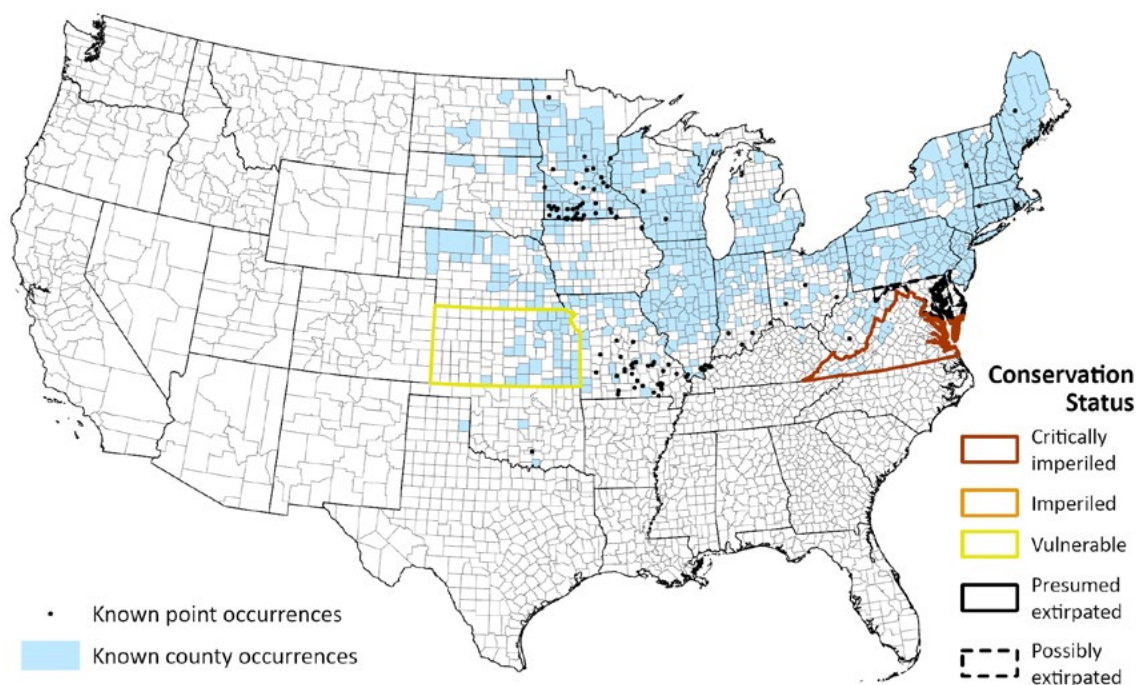


Figure A40.1. Distribution and state-level conservation status of *Desmodium canadense*. Known point occurrences were used to assess species deposition responses and critical loads.

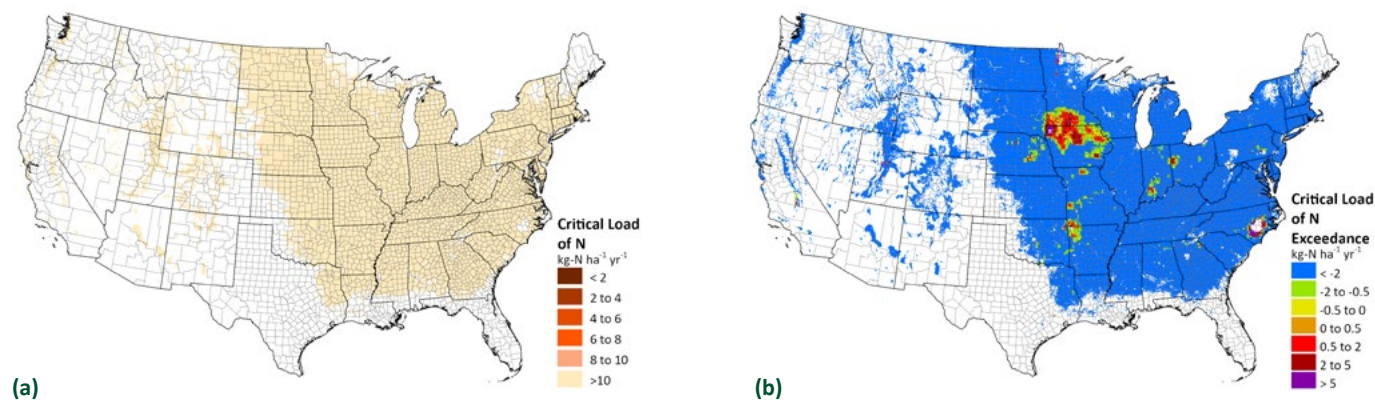


Figure A40.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Desmodium canadense* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

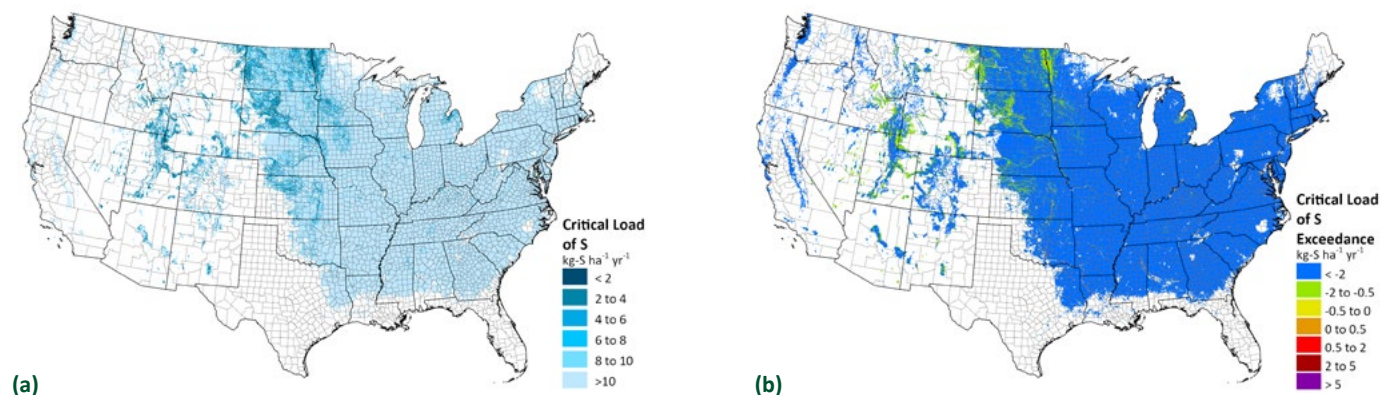


Figure A40.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Desmodium canadense* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A41. *Desmodium nudiflorum* (nakedflower ticktrefoil)

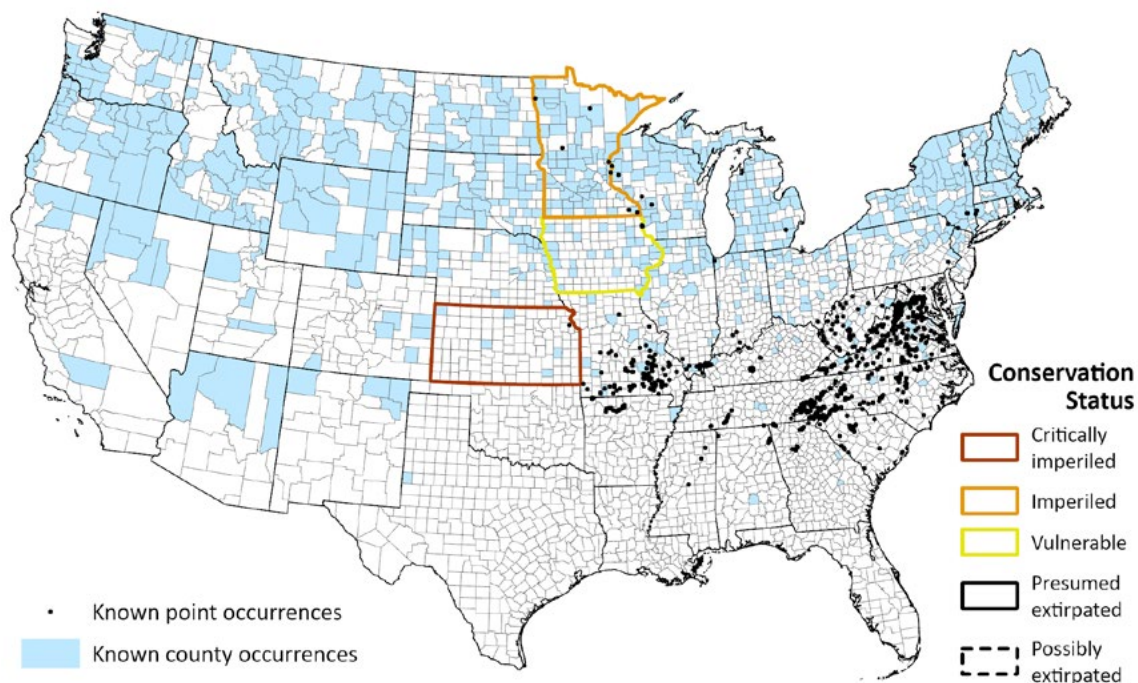


Figure A41.1. Distribution and state-level conservation status of *Desmodium nudiflorum*. Known point occurrences were used to assess species deposition responses and critical loads.

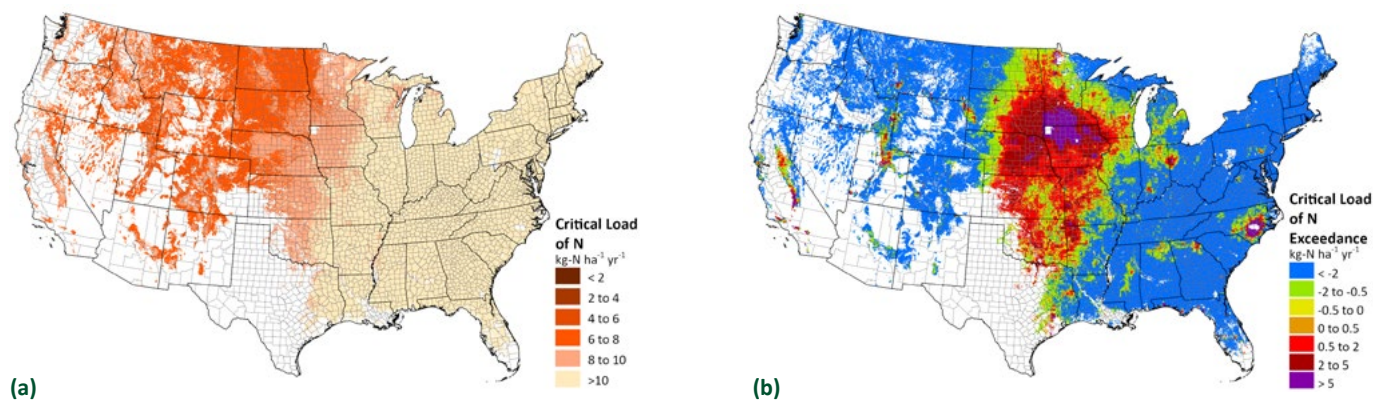


Figure A41.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Desmodium nudiflorum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

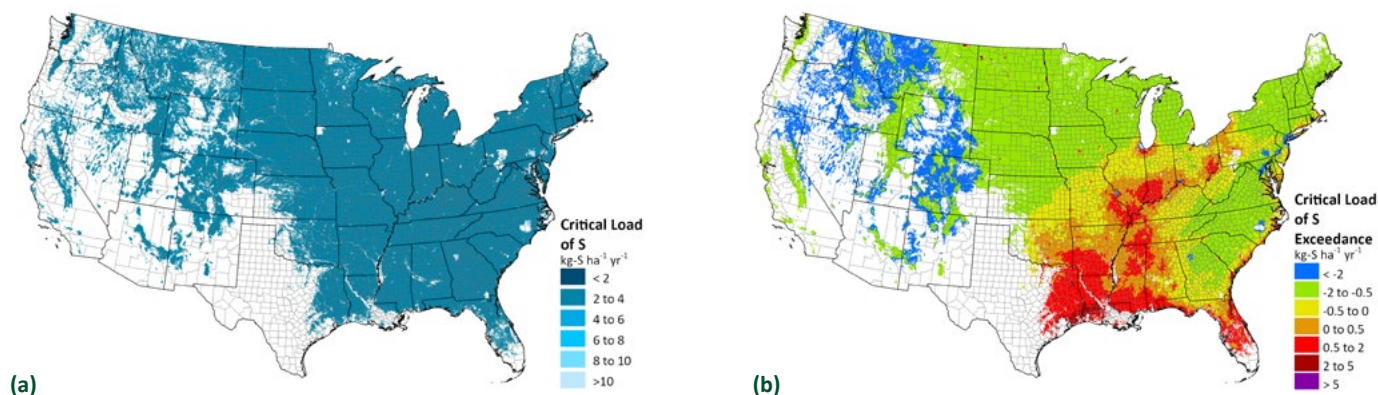


Figure A41.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Desmodium nudiflorum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A42. *Desmodium perplexum* (perplexed ticktrefoil)

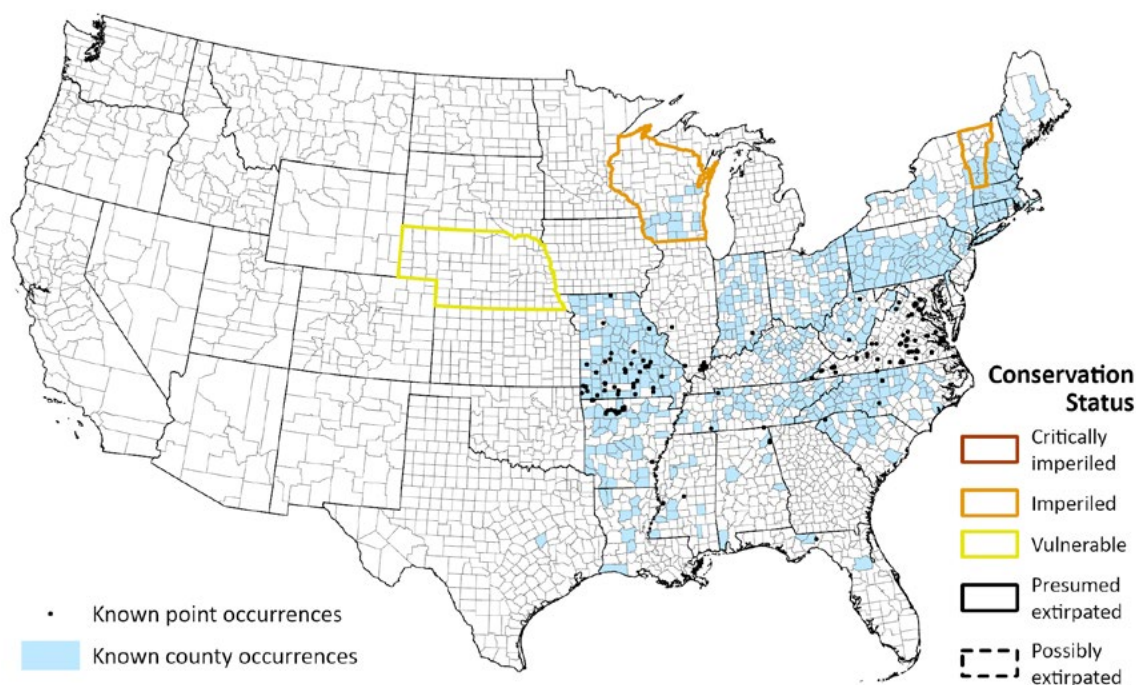


Figure A42.1. Distribution and state-level conservation status of *Desmodium perplexum*. Known point occurrences were used to assess species deposition responses and critical loads.

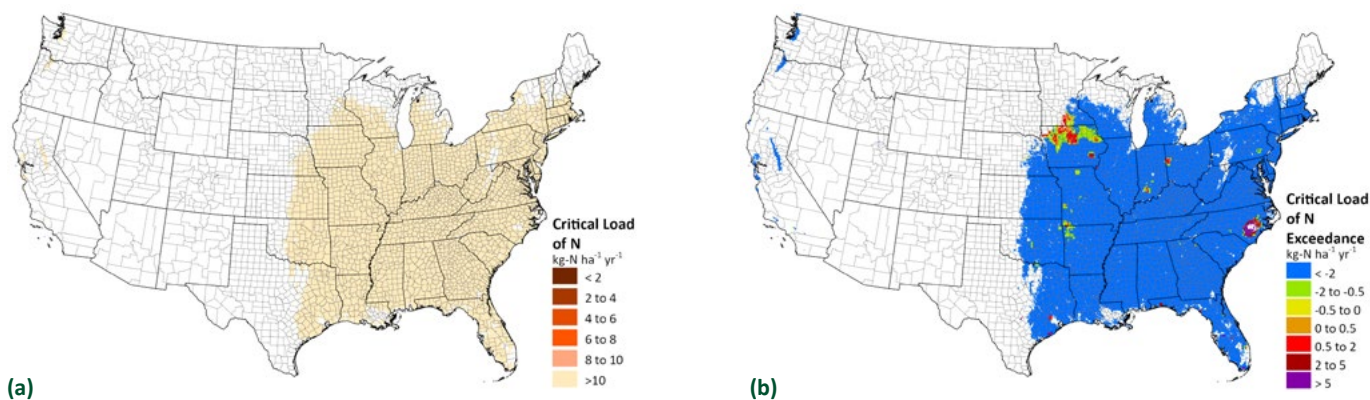


Figure A42.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Desmodium perplexum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

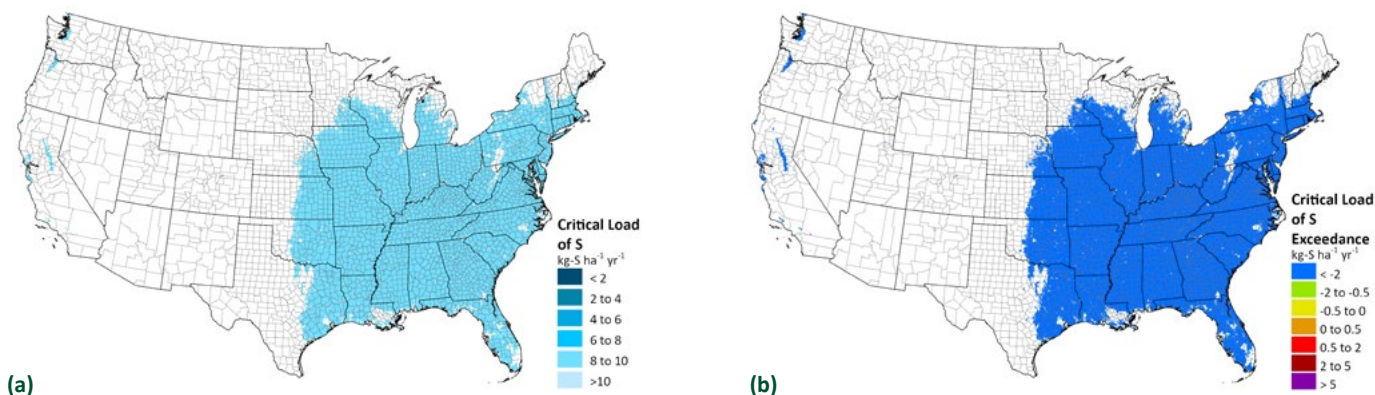


Figure A42.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Desmodium perplexum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A43. *Dicentra cucullaria* (dutchman's breeches)

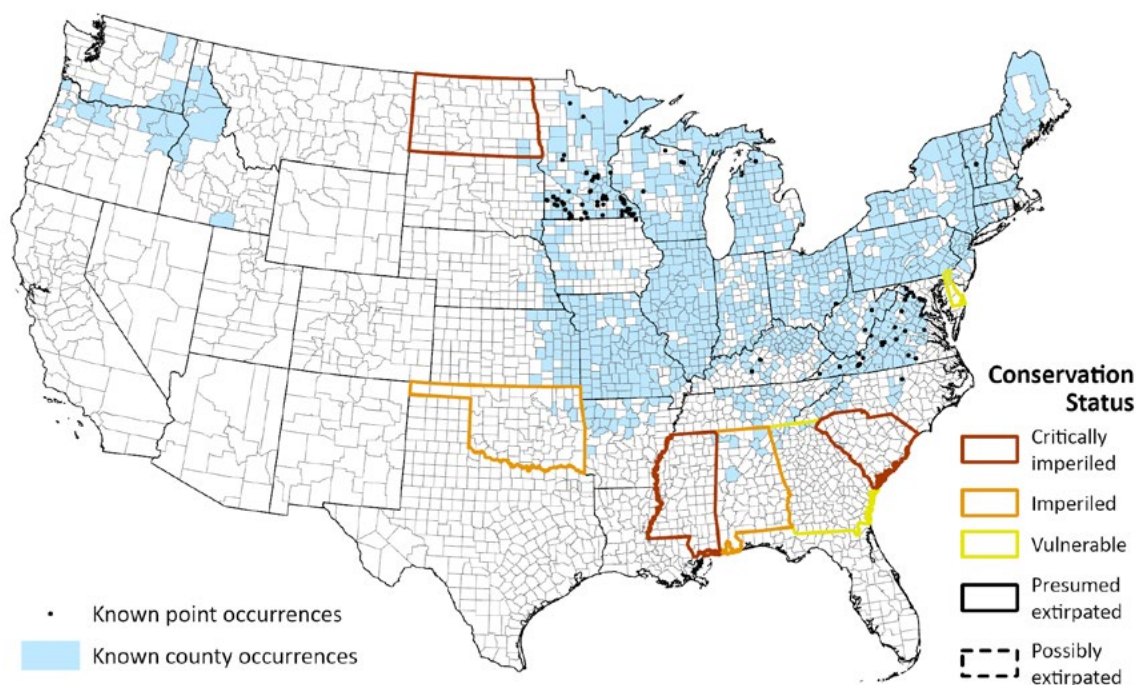


Figure A43.1. Distribution and state-level conservation status of *Dicentra cucullaria*. Known point occurrences were used to assess species deposition responses and critical loads.

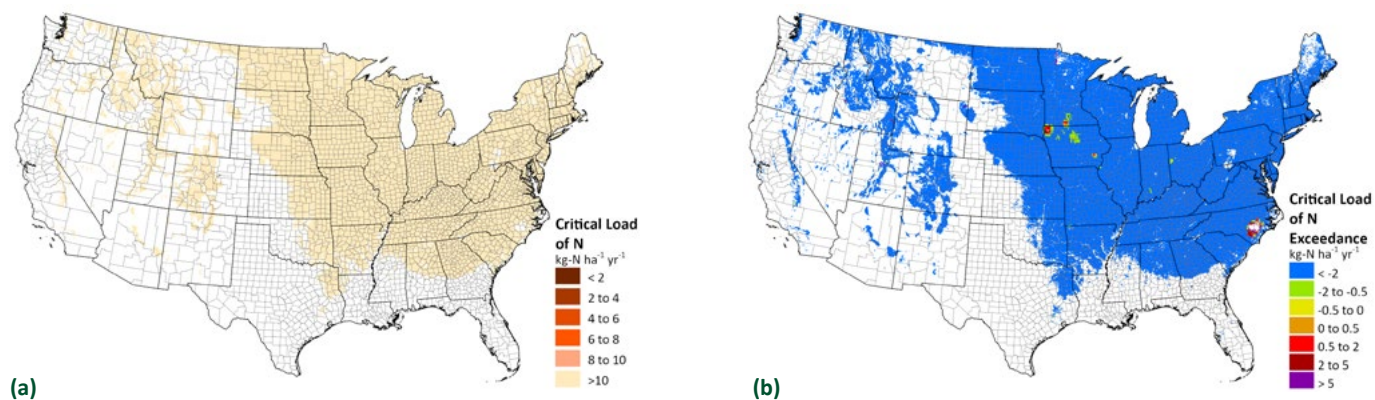


Figure A43.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Dicentra cucullaria* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

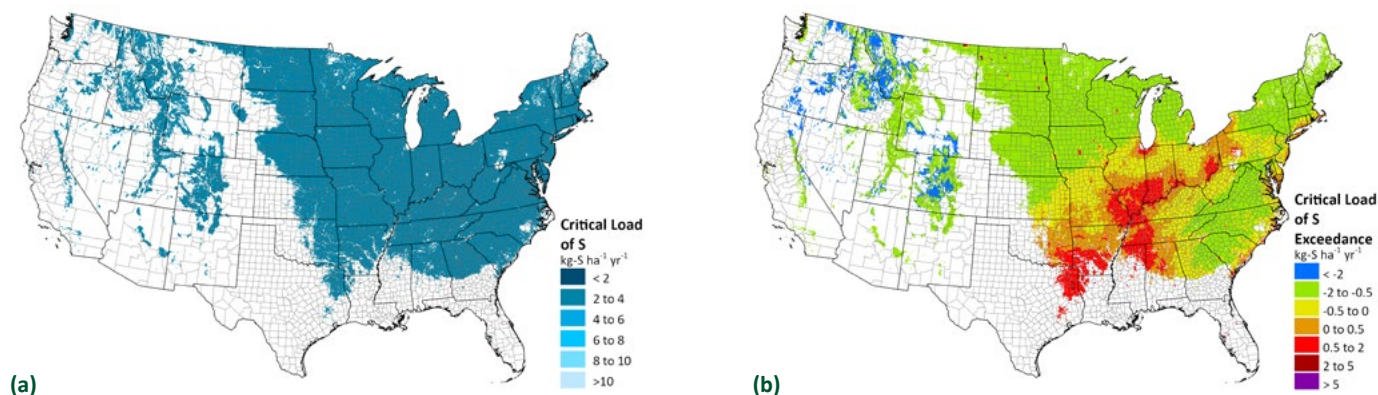


Figure A43.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Dicentra cucullaria* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A44. *Dichanthelium ovale* (eggleaf rosette grass)

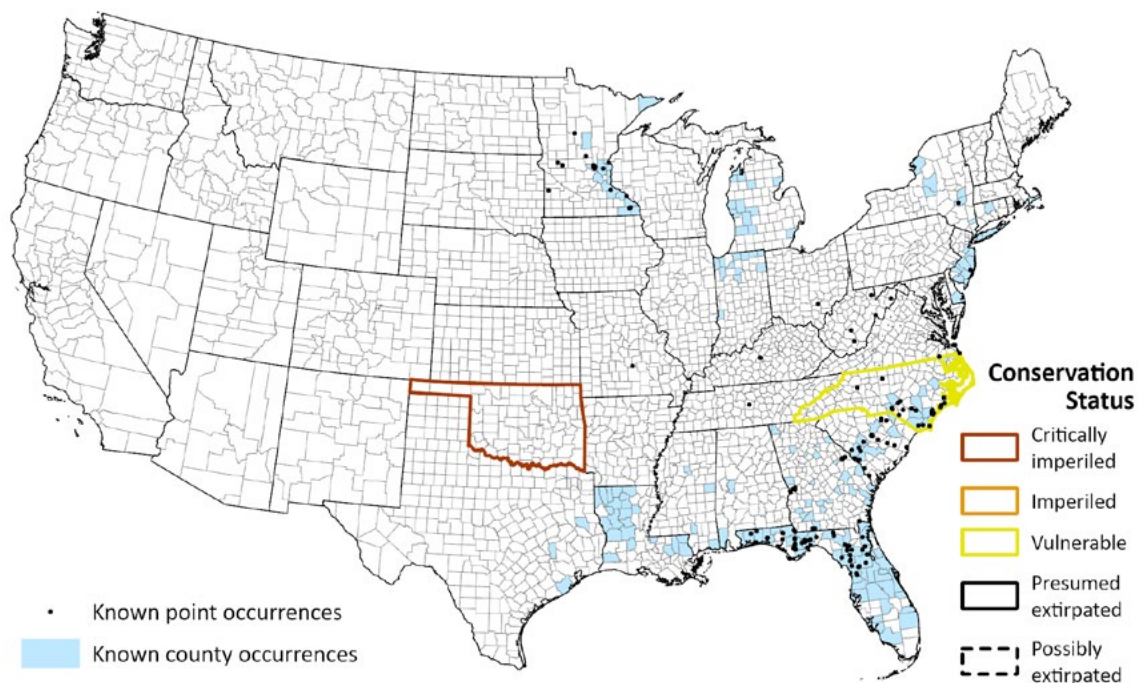


Figure A44.1. Distribution and state-level conservation status of *Dichanthelium ovale*. Known point occurrences were used to assess species deposition responses and critical loads.

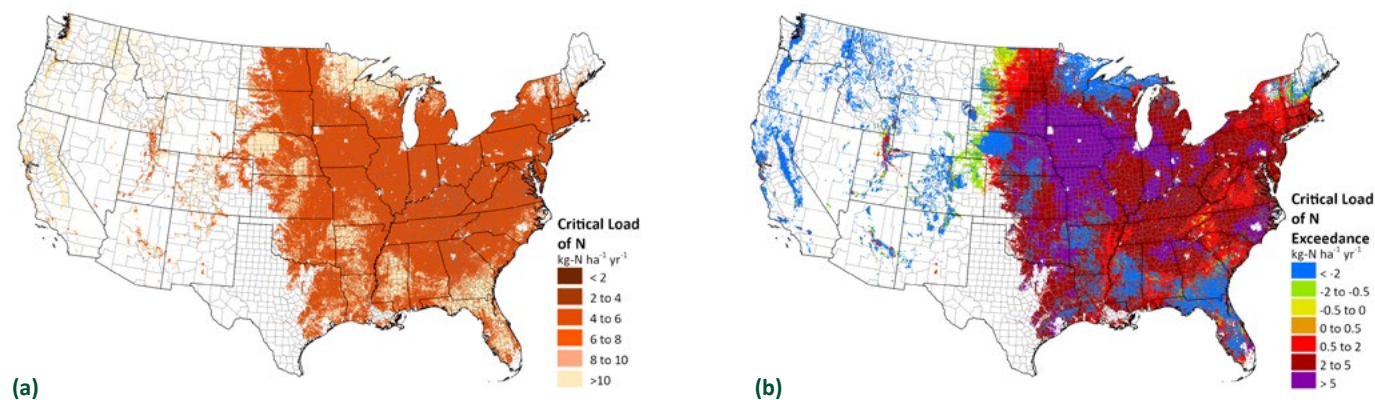


Figure A44.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Dichanthelium ovale* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

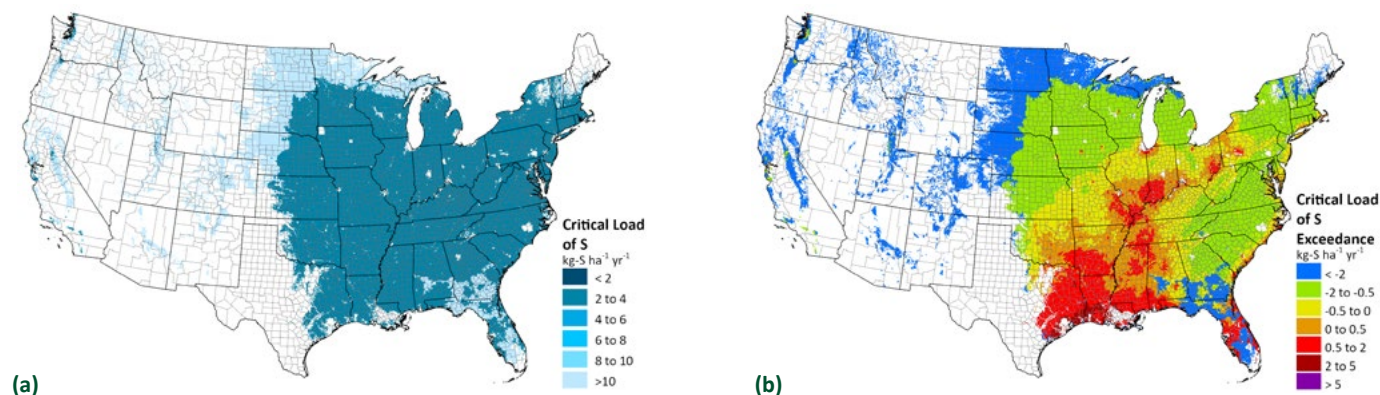


Figure A44.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Dichanthelium ovale* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A45. *Dryopteris cristata* (crested woodfern)

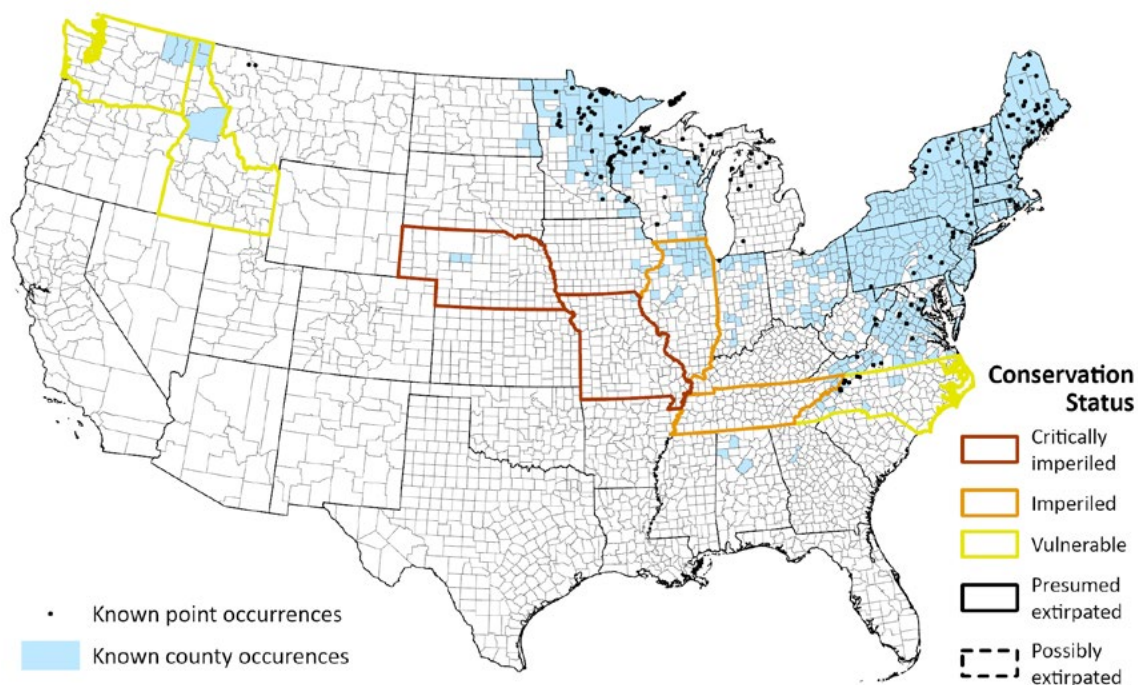


Figure A45.1. Distribution and state-level conservation status of *Dryopteris cristata*. Known point occurrences were used to assess species deposition responses and critical loads.

A46. *Elymus hystrix* (eastern bottlebrush grass)

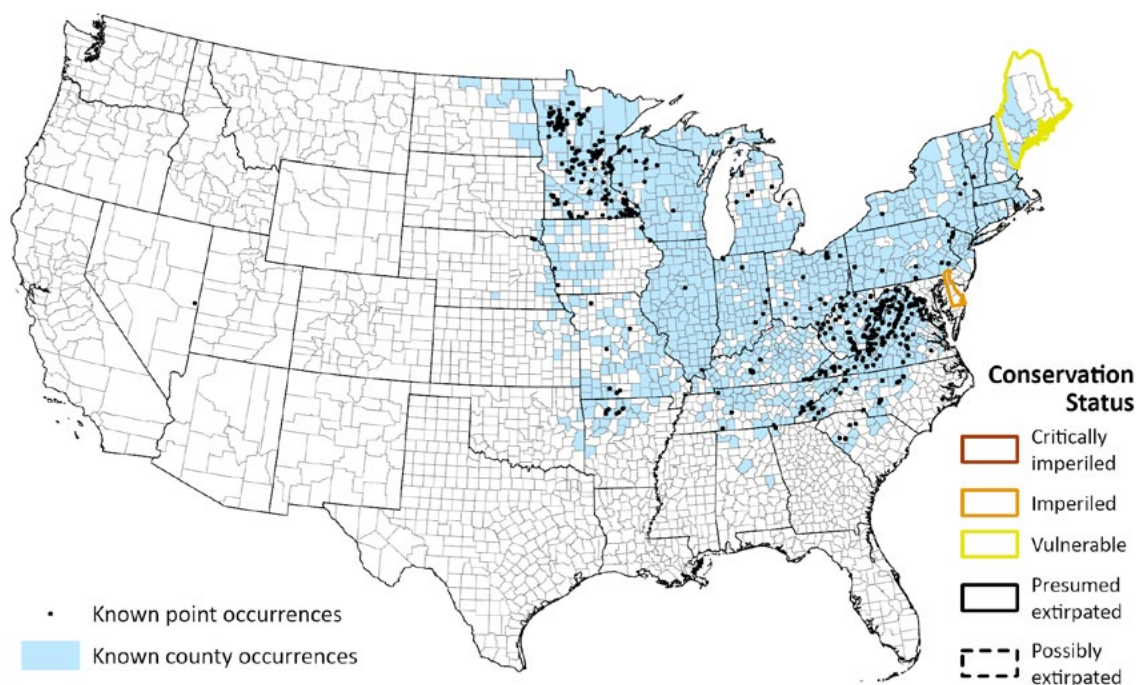


Figure A46.1. Distribution and state-level conservation status of *Elymus hystrix*. Known point occurrences were used to assess species deposition responses and critical loads.

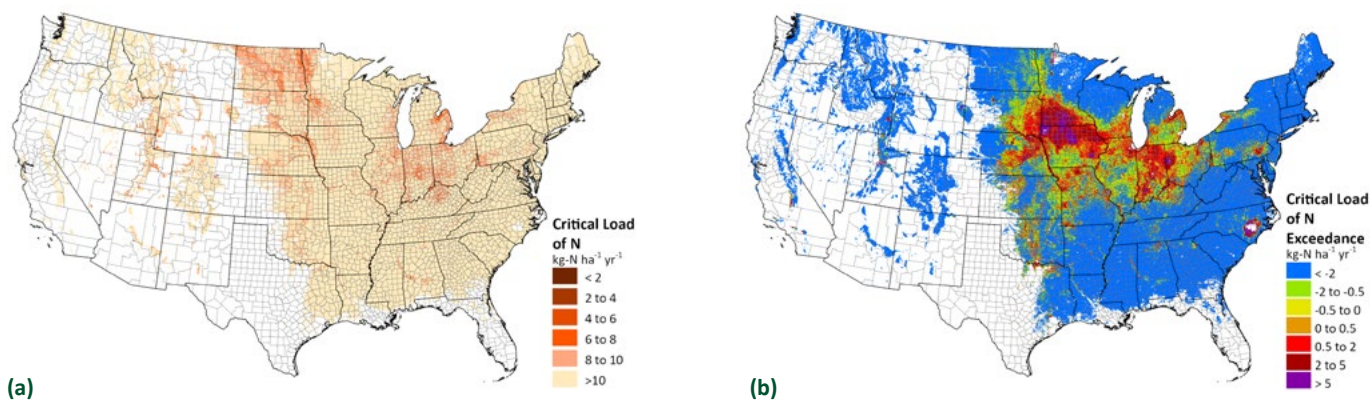


Figure A46.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Elymus hystrix* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

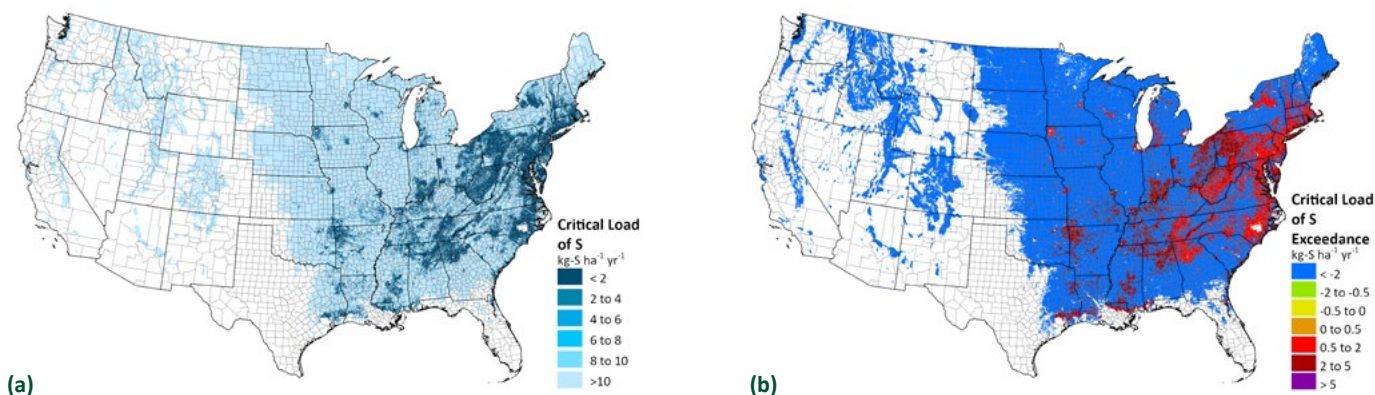


Figure A46.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Elymus hystrix* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A47. *Epifagus virginiana* (beechdrops)

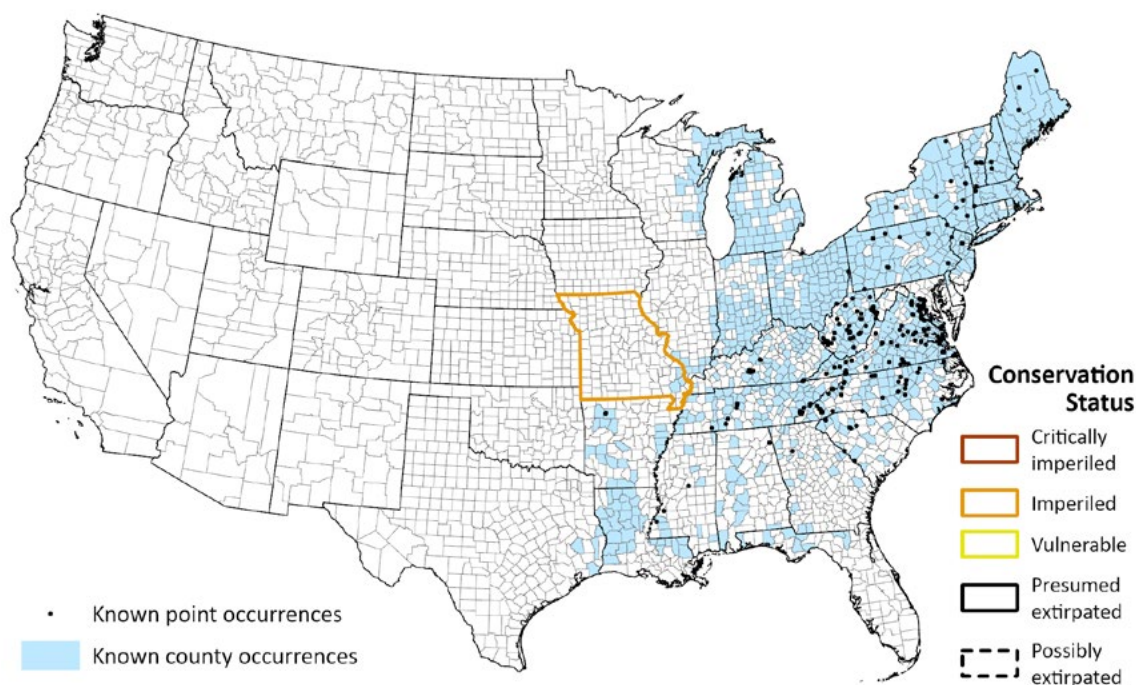


Figure A47.1. Distribution and state-level conservation status of *Epifagus virginiana*. Known point occurrences were used to assess species deposition responses and critical loads.

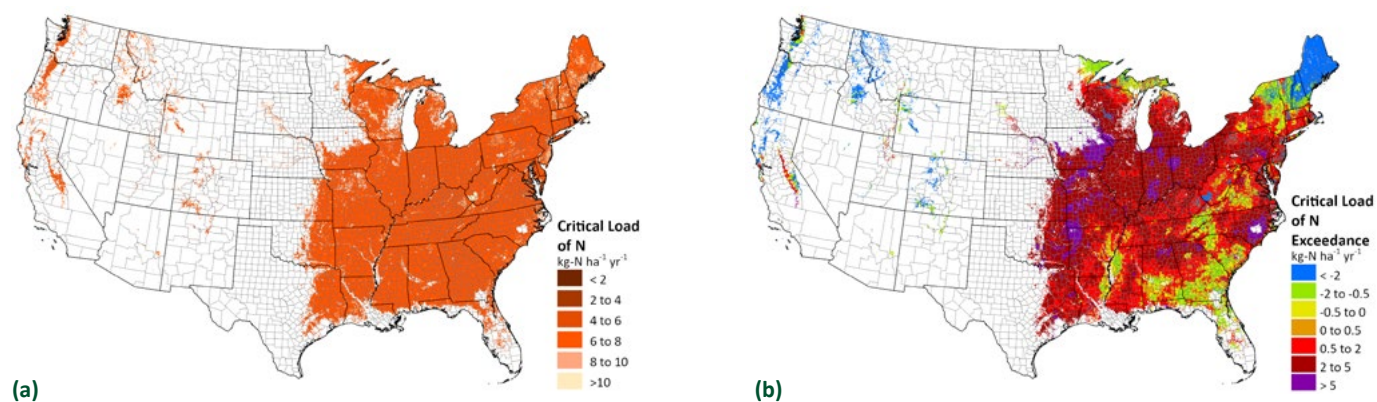


Figure A47.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Epifagus virginiana* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

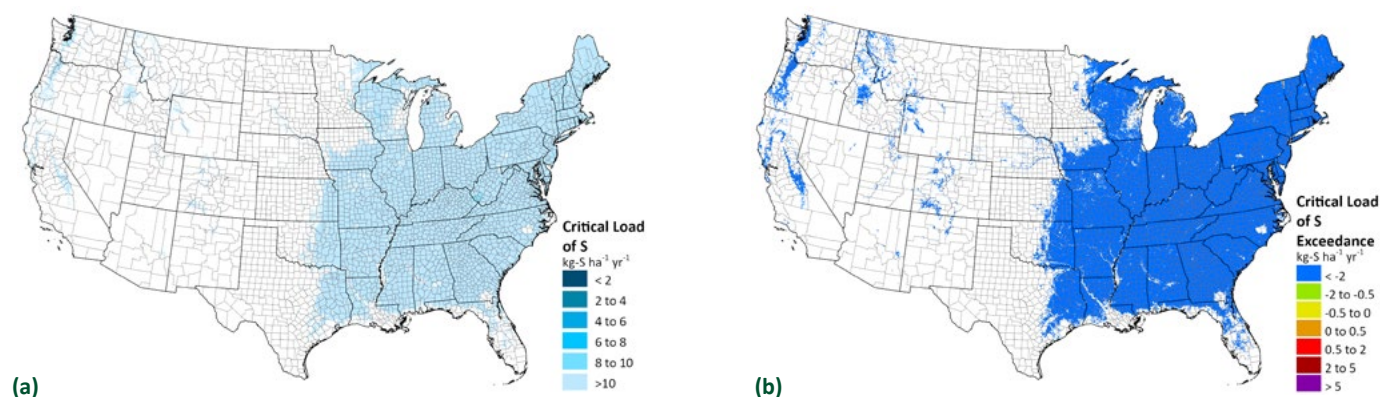


Figure A47.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Epifagus virginiana* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A48. *Erechtites hieraciifolia* (American burnweed)

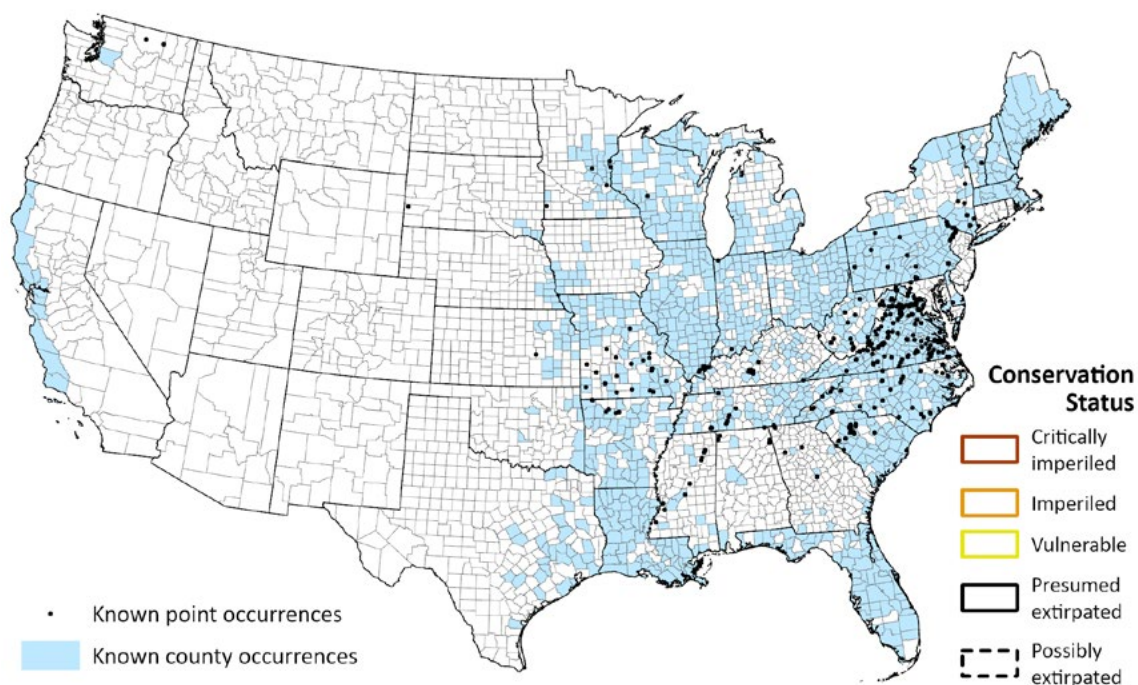


Figure A48.1. Distribution and state-level conservation status of *Erechtites hieraciifolia*. Known point occurrences were used to assess species deposition responses and critical loads.

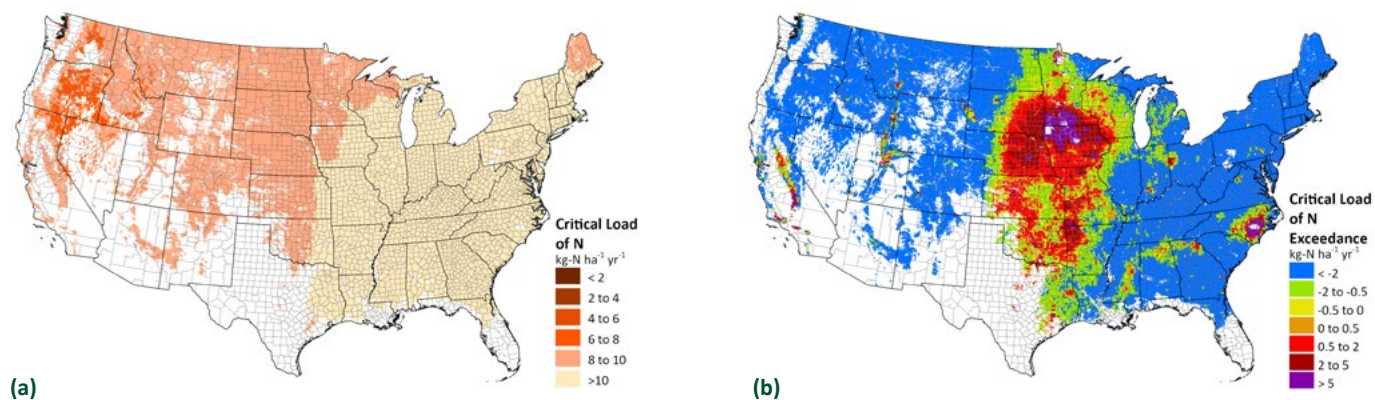


Figure A48.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Erechtites hieraciifolia* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

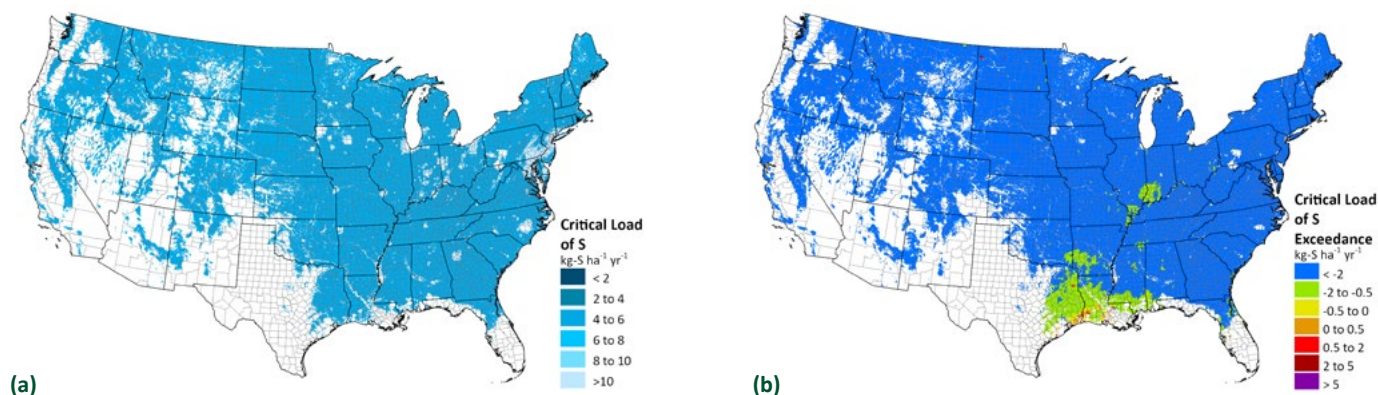


Figure A48.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Erechtites hieraciifolia* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A49. *Euphorbia corollata* (flowering spurge)

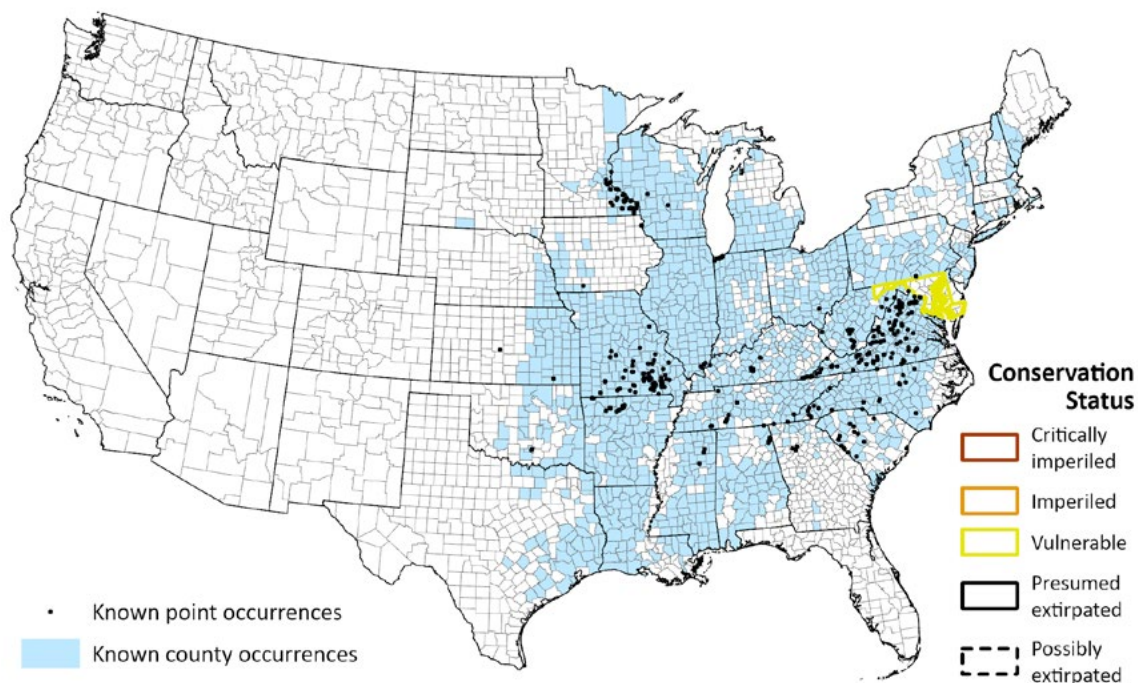


Figure A49.1. Distribution and state-level conservation status of *Euphorbia corollata*. Known point occurrences were used to assess species deposition responses and critical loads.

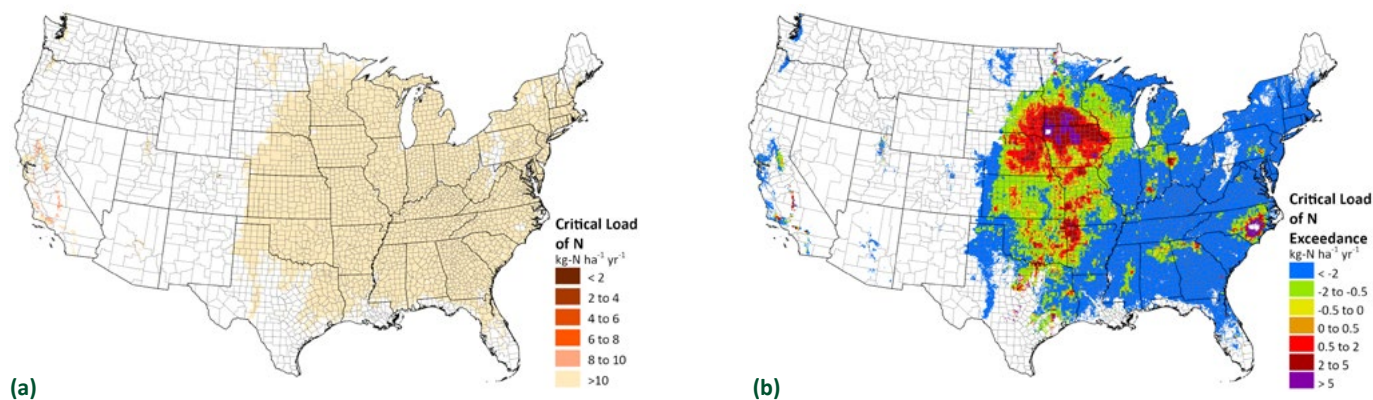


Figure A49.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Euphorbia corollata* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

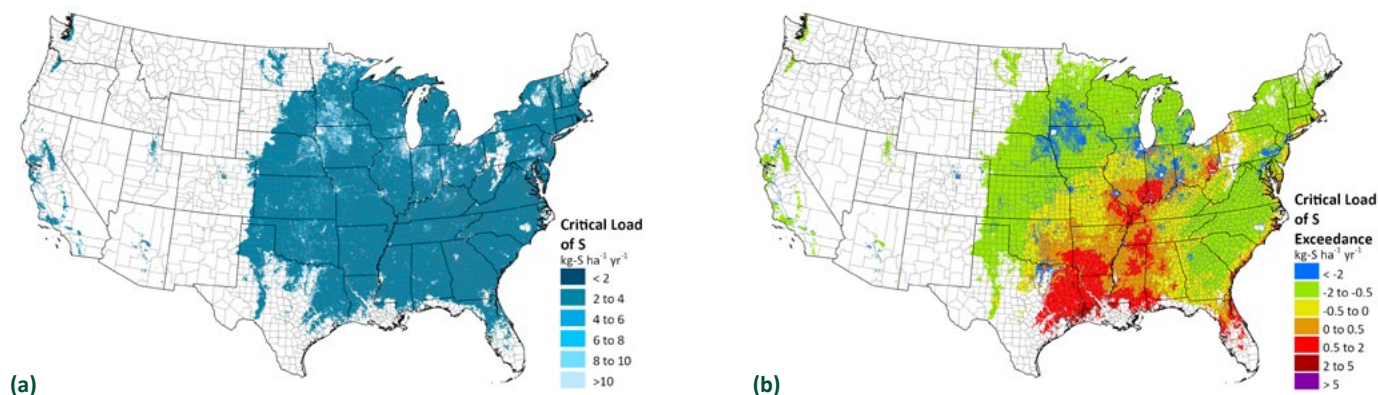


Figure A49.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Euphorbia corollata* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A50. *Galium concinnum* (shining bedstraw)

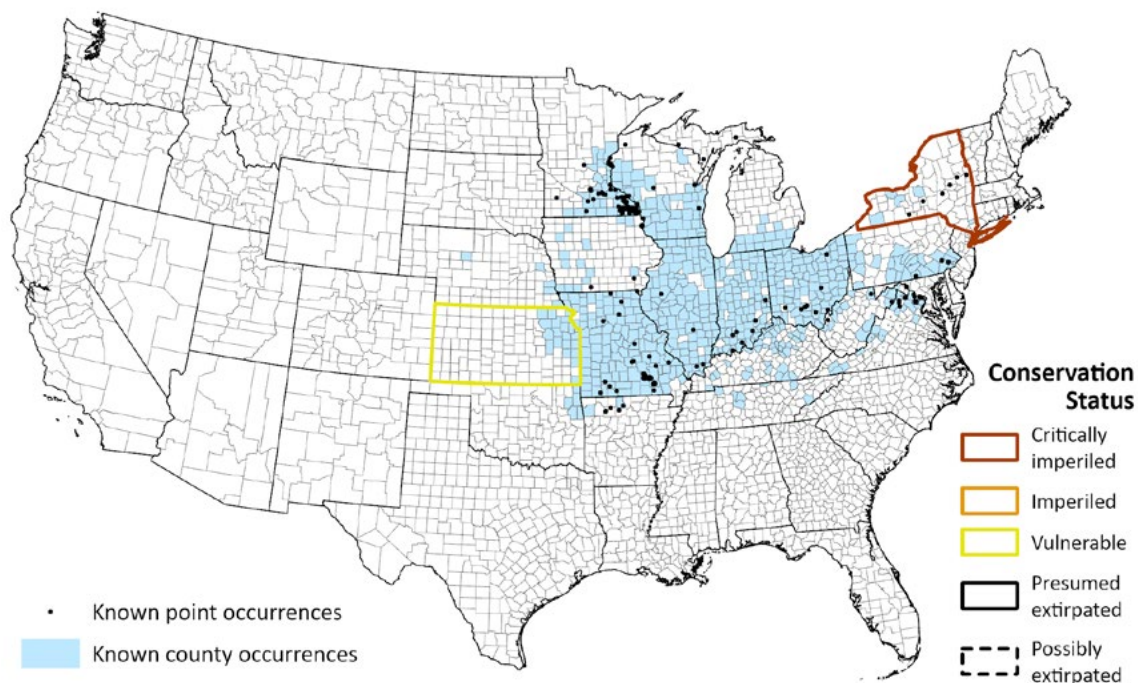


Figure A50.1. Distribution and state-level conservation status of *Galium concinnum*. Known point occurrences were used to assess species deposition responses and critical loads.

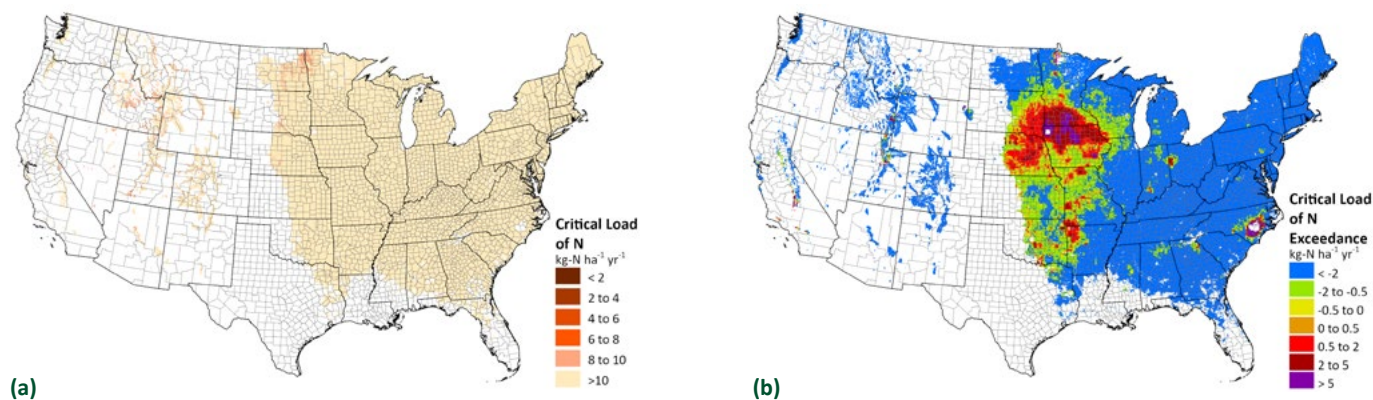


Figure A50.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Galium concinnum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

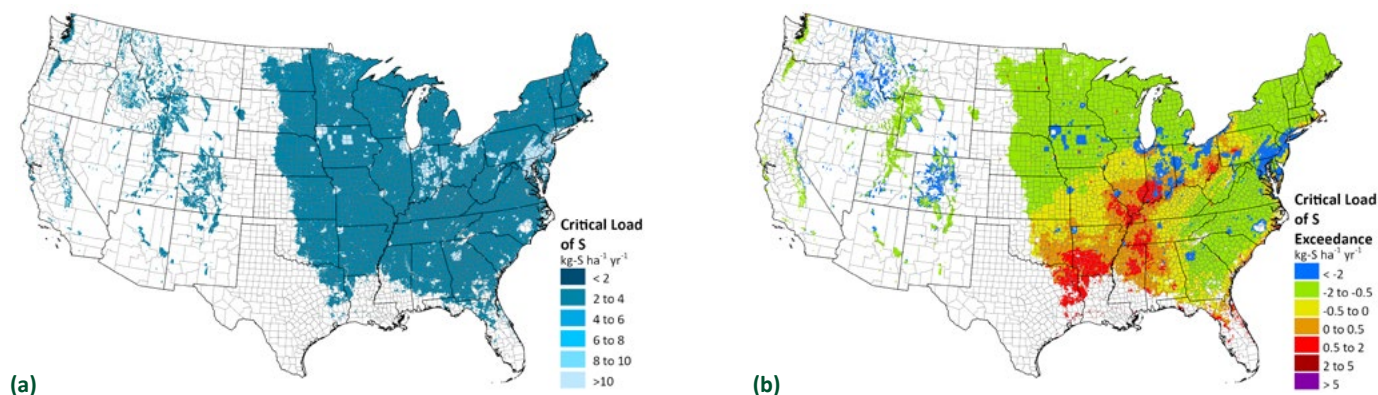


Figure A50.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Galium concinnum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A51. *Geum canadense* (white avens)

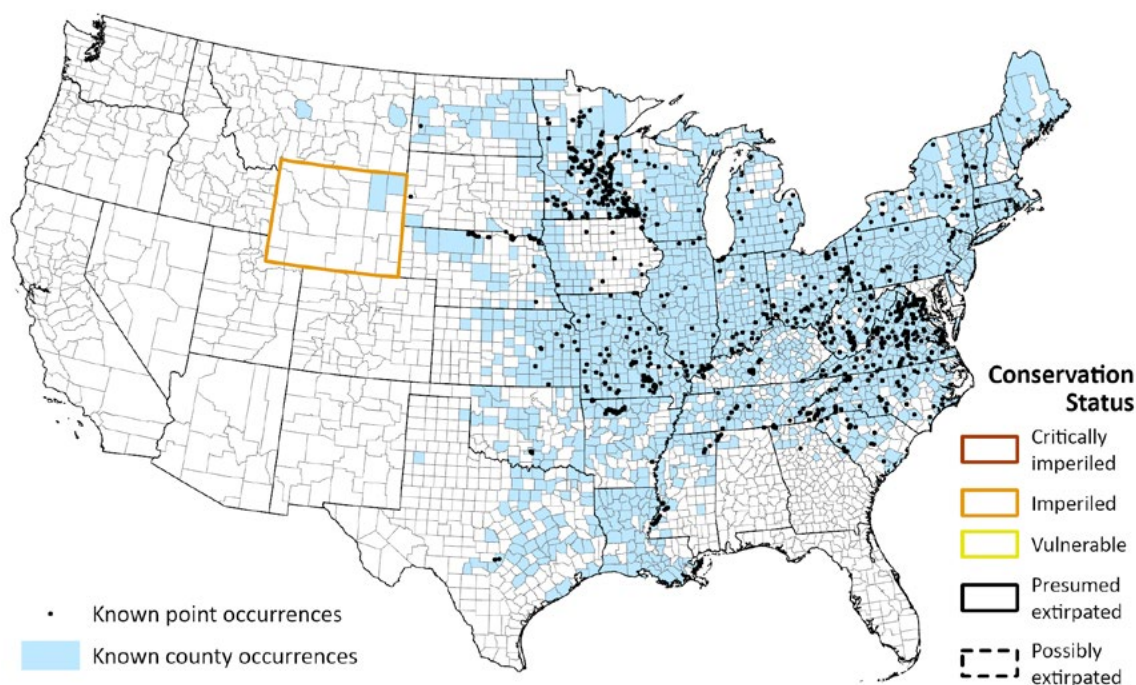


Figure A51.1. Distribution and state-level conservation status of *Geum canadense*. Known point occurrences were used to assess species deposition responses and critical loads.

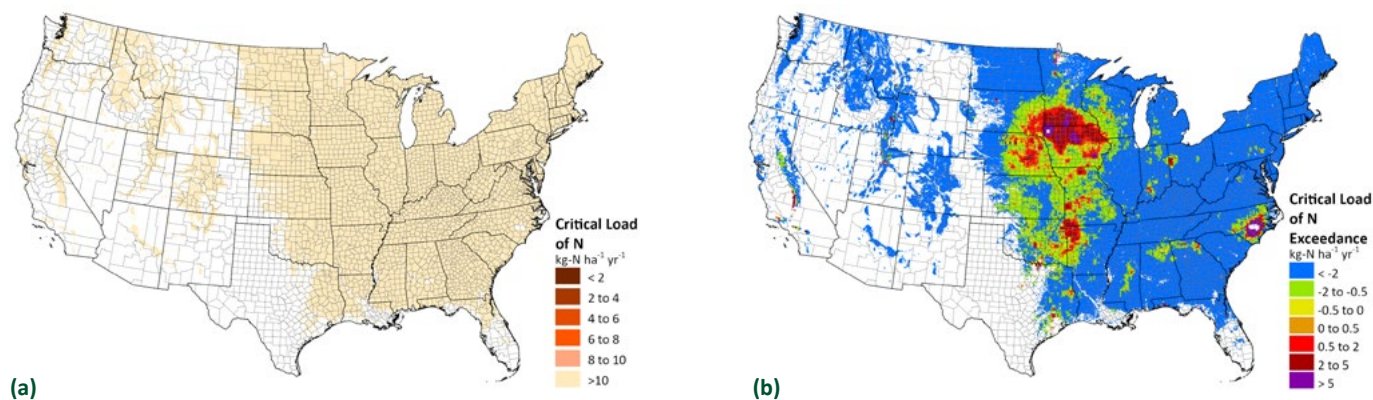


Figure A51.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Geum canadense* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

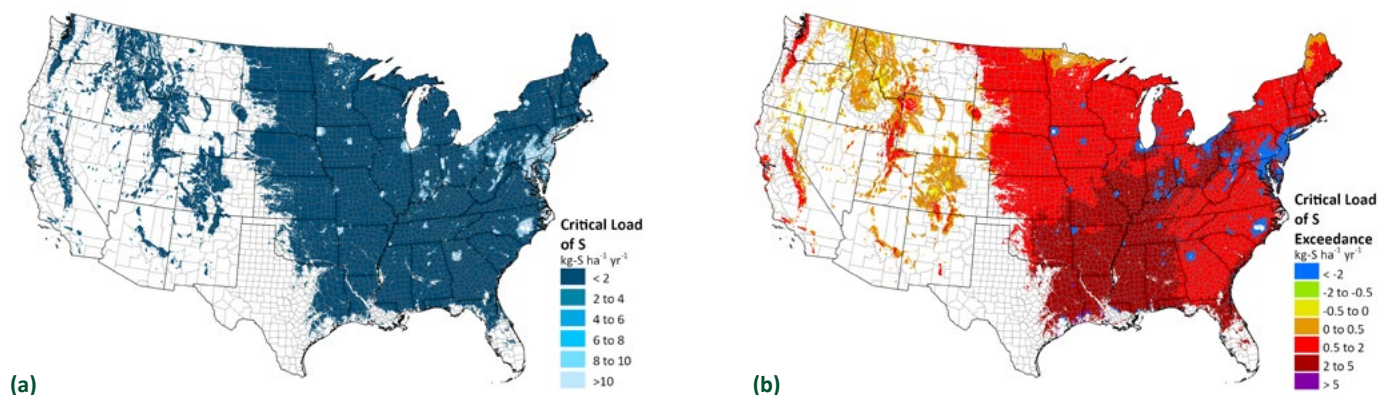


Figure A51.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Geum canadense* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A52. *Geum virginianum* (cream avens)

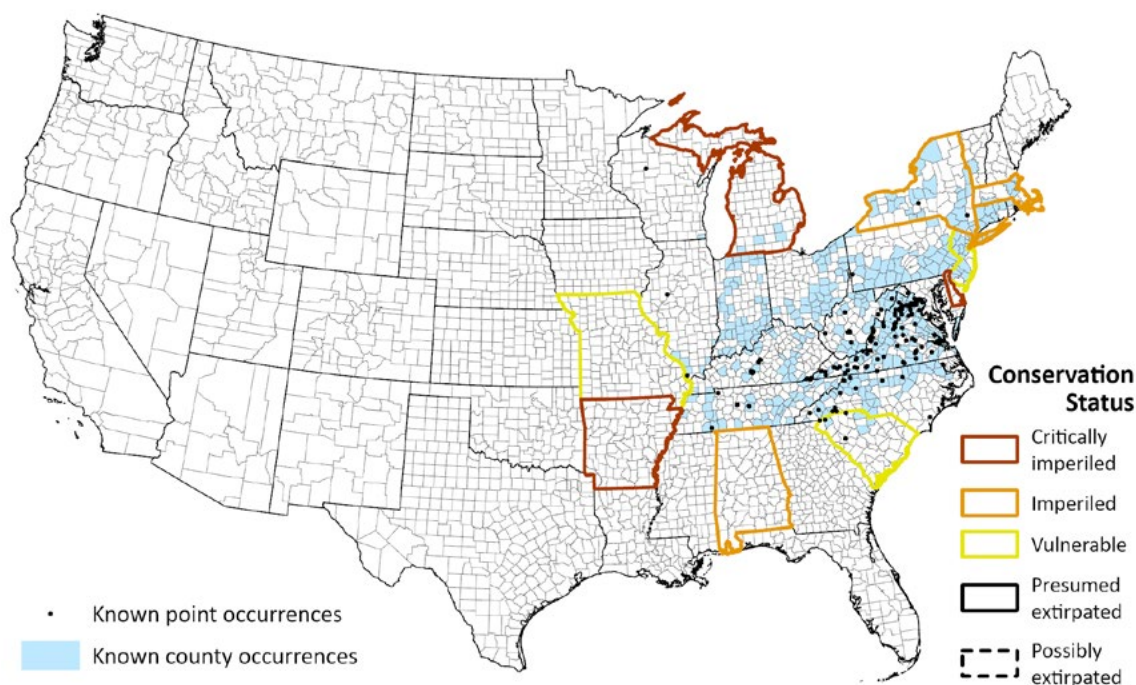


Figure A52.1. Distribution and state-level conservation status of *Geum virginianum*. Known point occurrences were used to assess species deposition responses and critical loads.

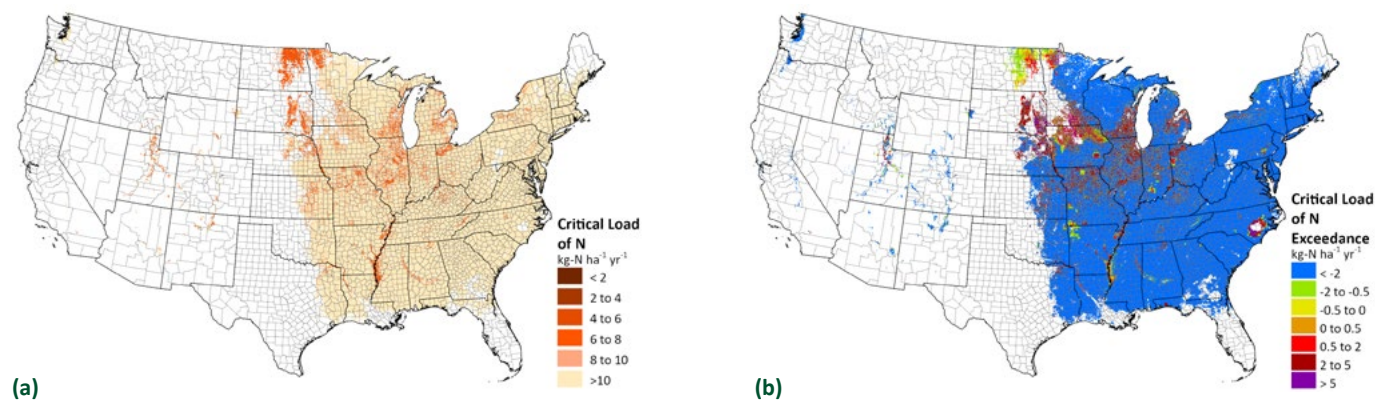


Figure A52.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Geum virginianum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

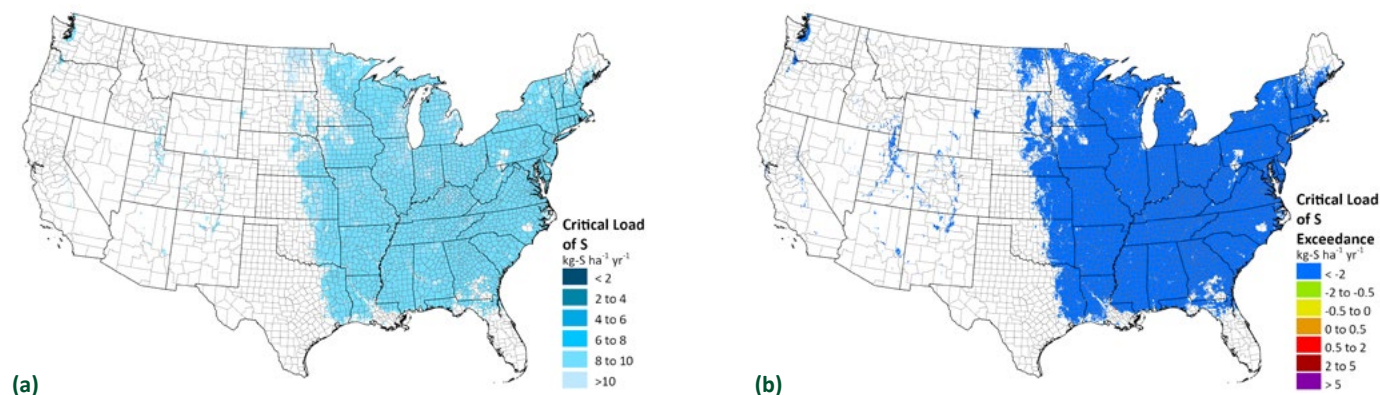


Figure A52.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Geum virginianum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A53. *Helianthus giganteus* (giant sunflower)

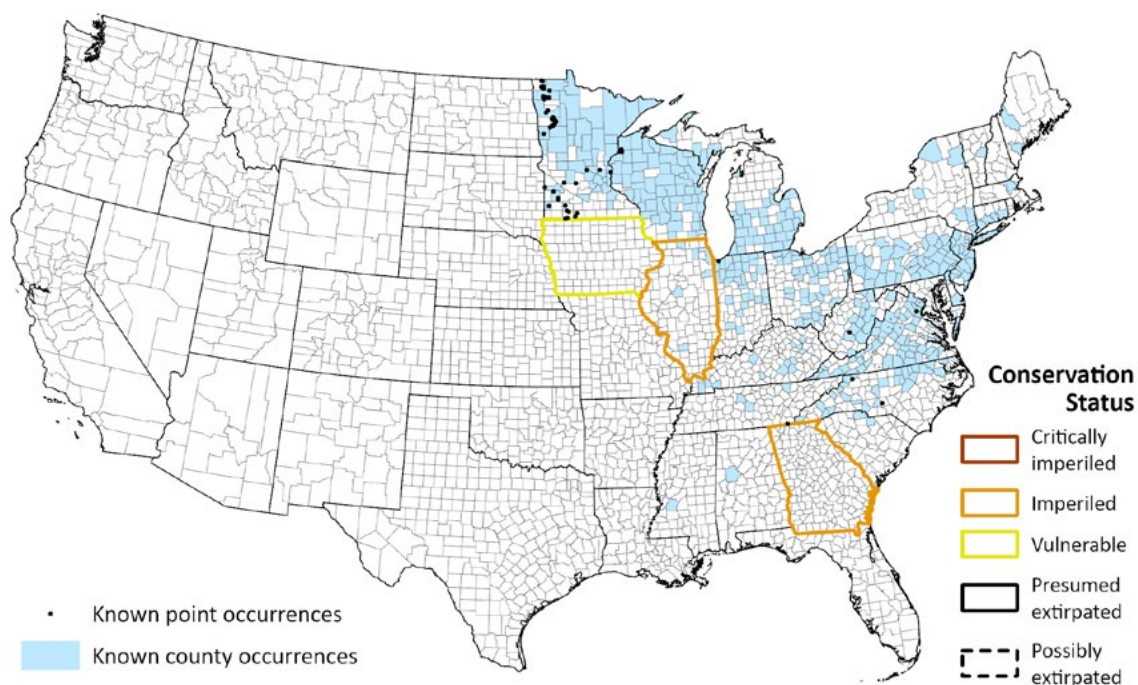


Figure A53.1. Distribution and state-level conservation status of *Helianthus giganteus*. Known point occurrences were used to assess species deposition responses and critical loads.

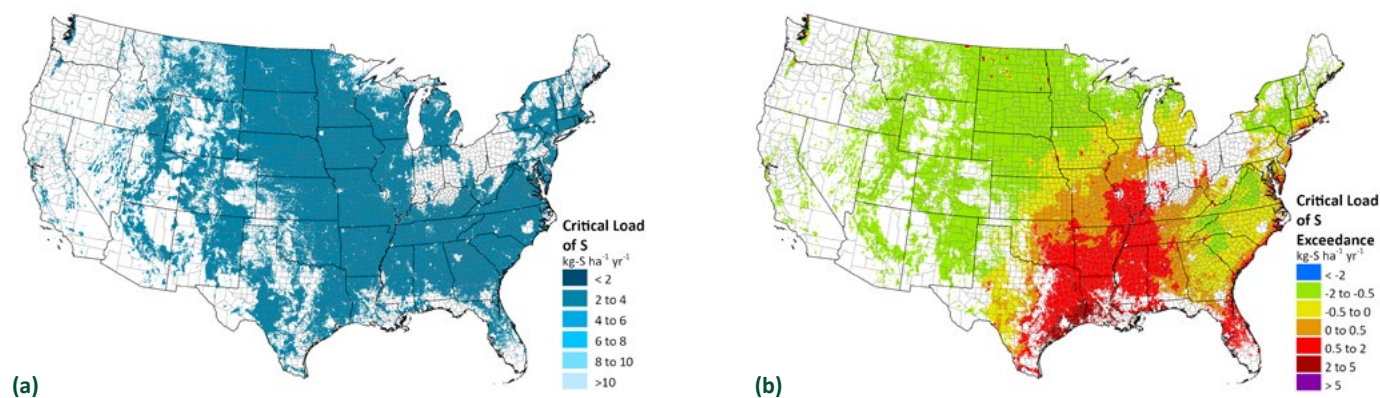


Figure A53.2. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Helianthus giganteus* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A54. *Helianthus grosseserratus* (sawtooth sunflower)

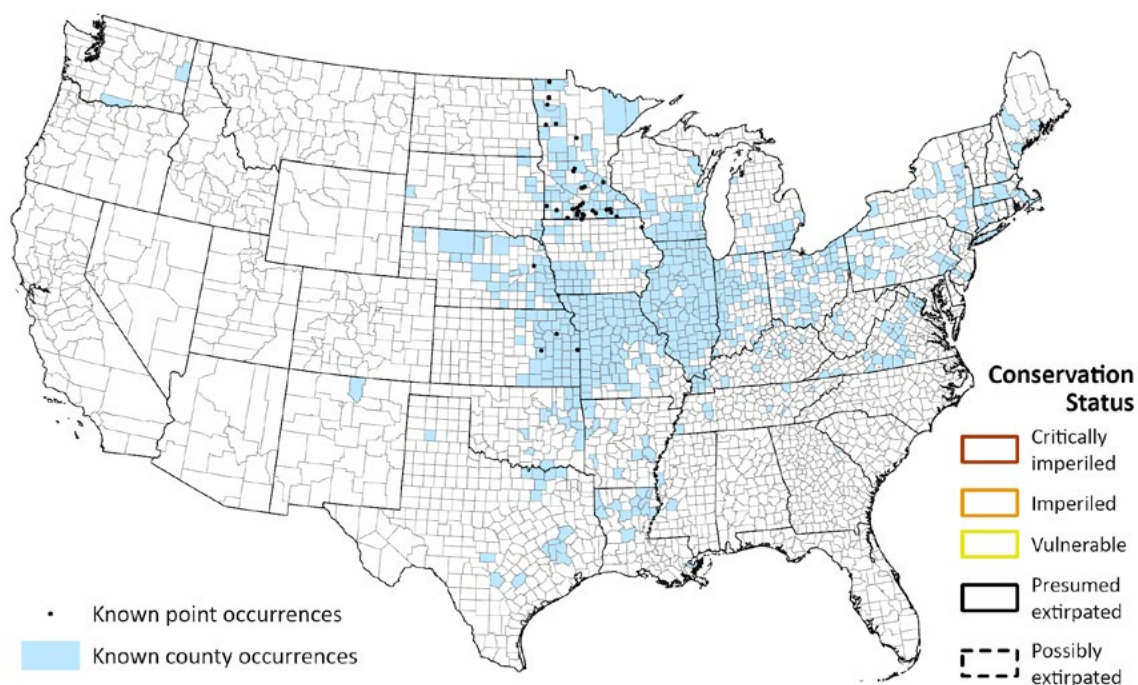


Figure A54.1. Distribution and state-level conservation status of *Helianthus grosseserratus*. Known point occurrences were used to assess species deposition responses and critical loads.

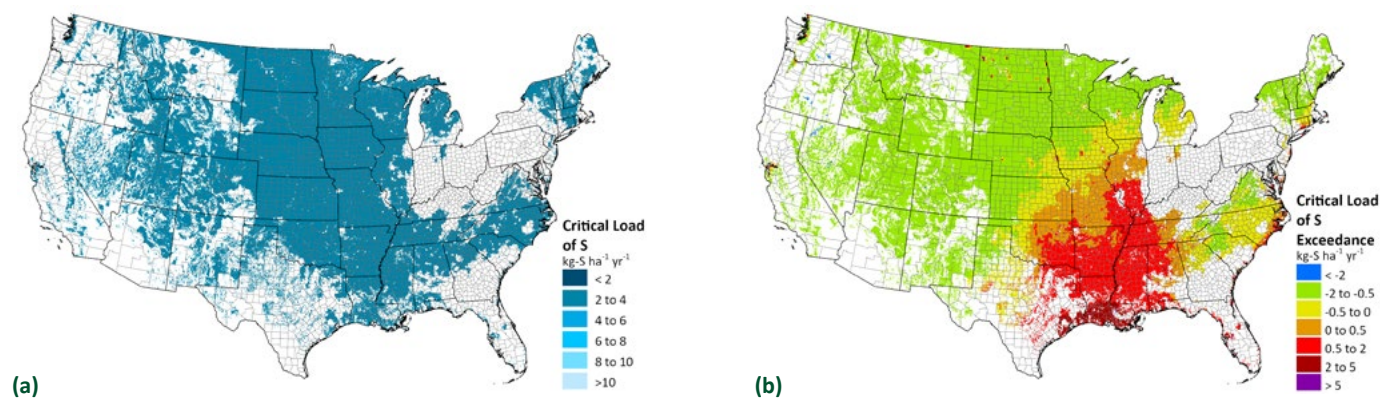


Figure A54.2. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Helianthus grosseserratus* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A55. *Hexastylis virginica* (Virginia heartleaf)

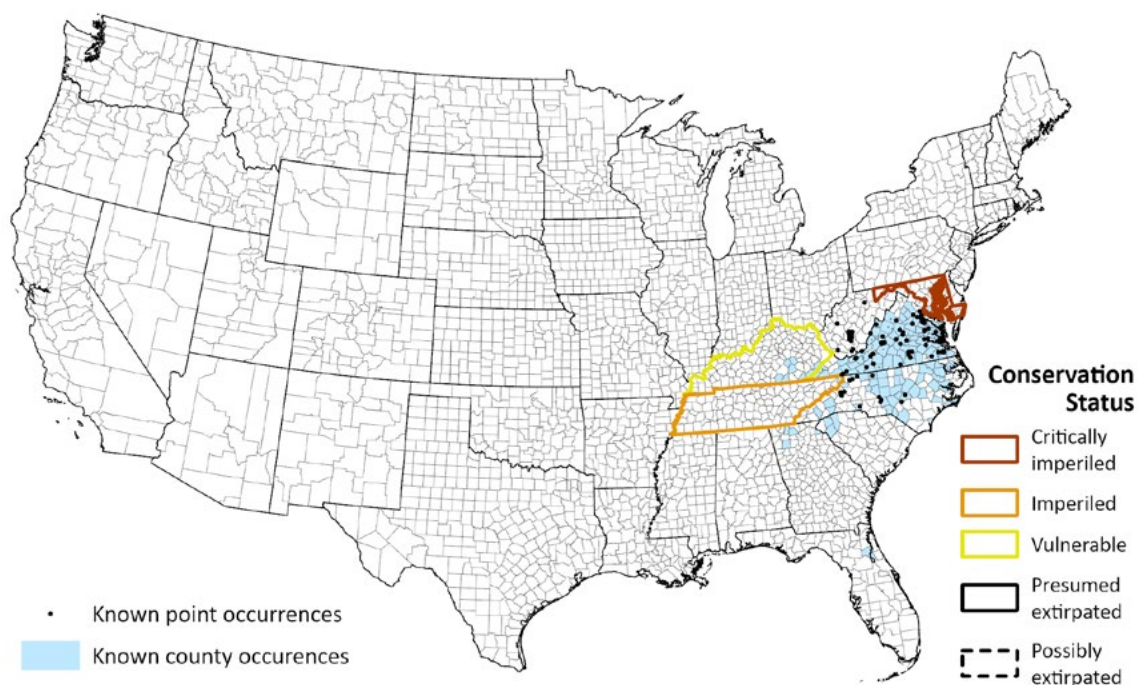


Figure A55.1. Distribution and state-level conservation status of *Hexastylis virginica*. Known point occurrences were used to assess species deposition responses and critical loads.

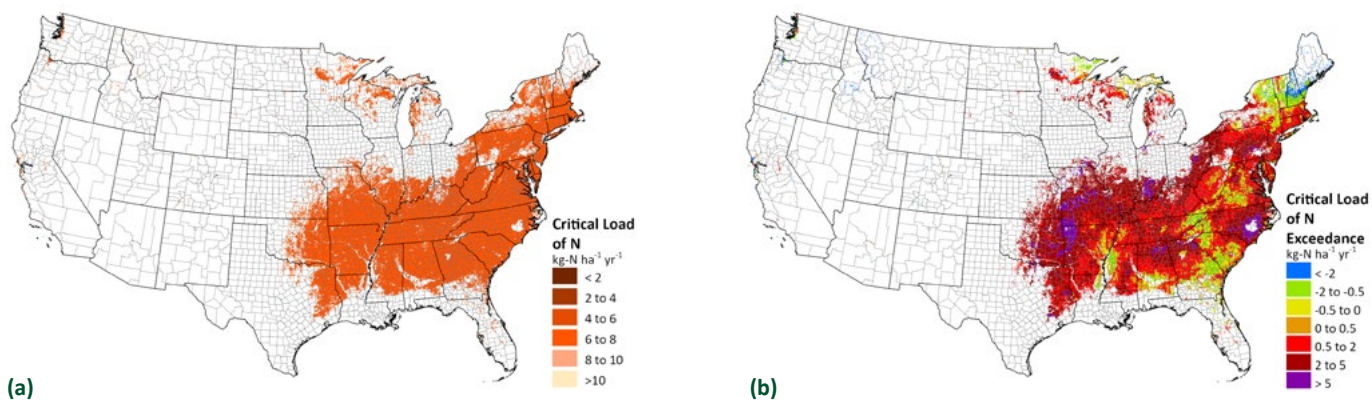


Figure A55.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Hexastylis virginica* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

A56. *Houstonia purpurea* (Venus' pride)

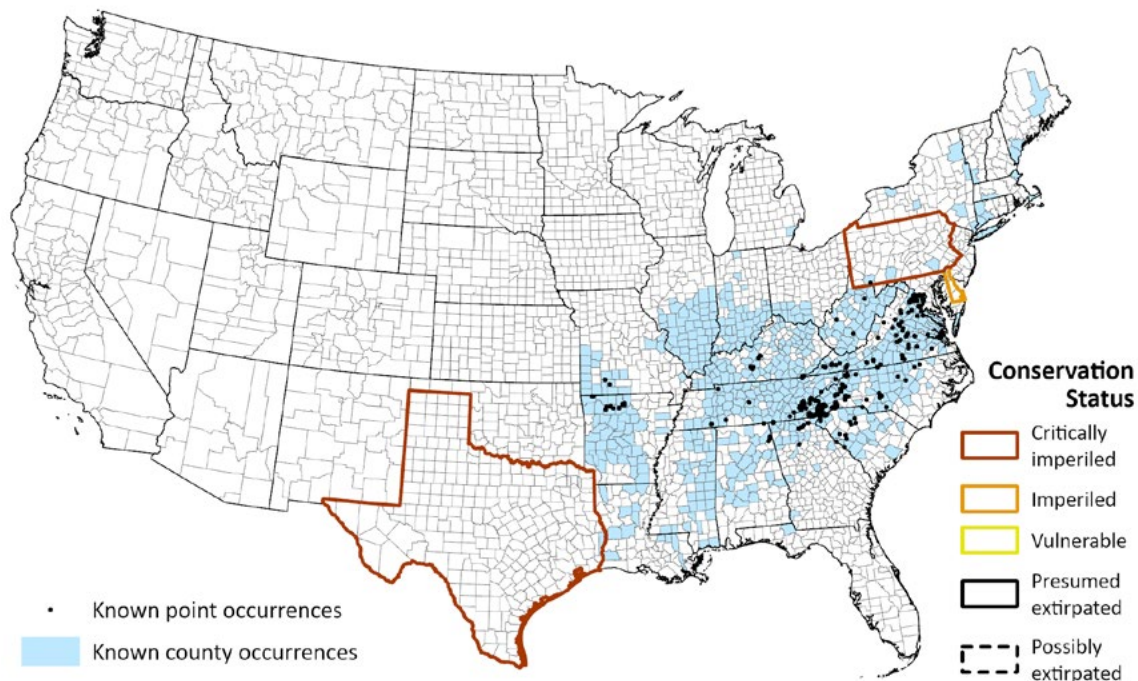


Figure A56.1. Distribution and state-level conservation status of *Houstonia purpurea*. Known point occurrences were used to assess species deposition responses and critical loads.

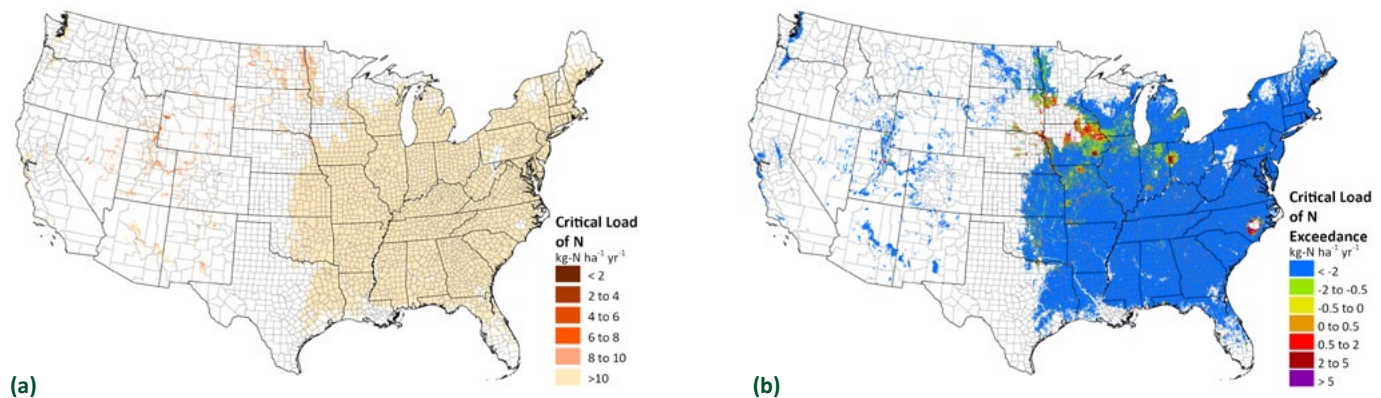


Figure A56.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Houstonia purpurea* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

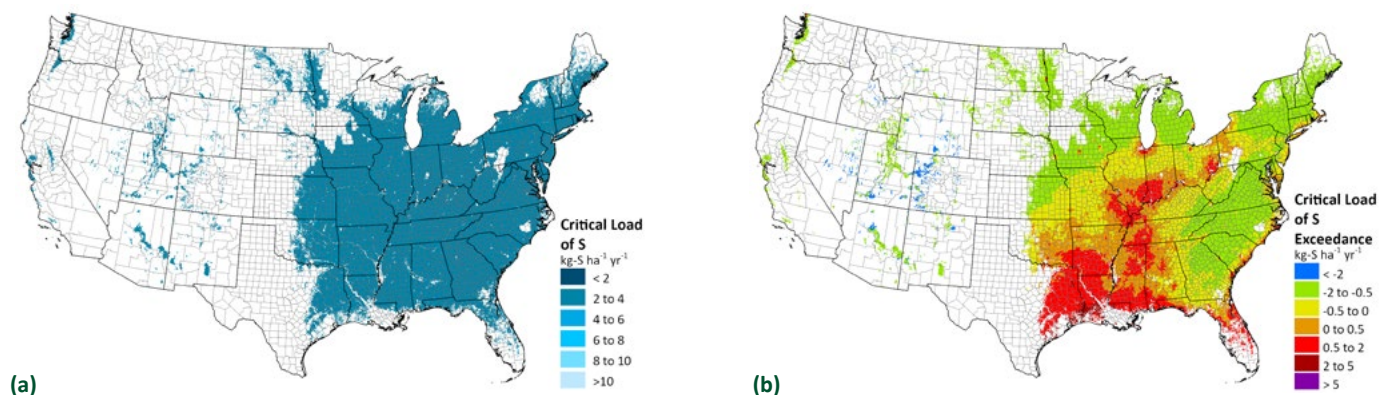


Figure A56.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Houstonia purpurea* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A57. *Hydrophyllum canadense* (bluntleaf waterleaf)

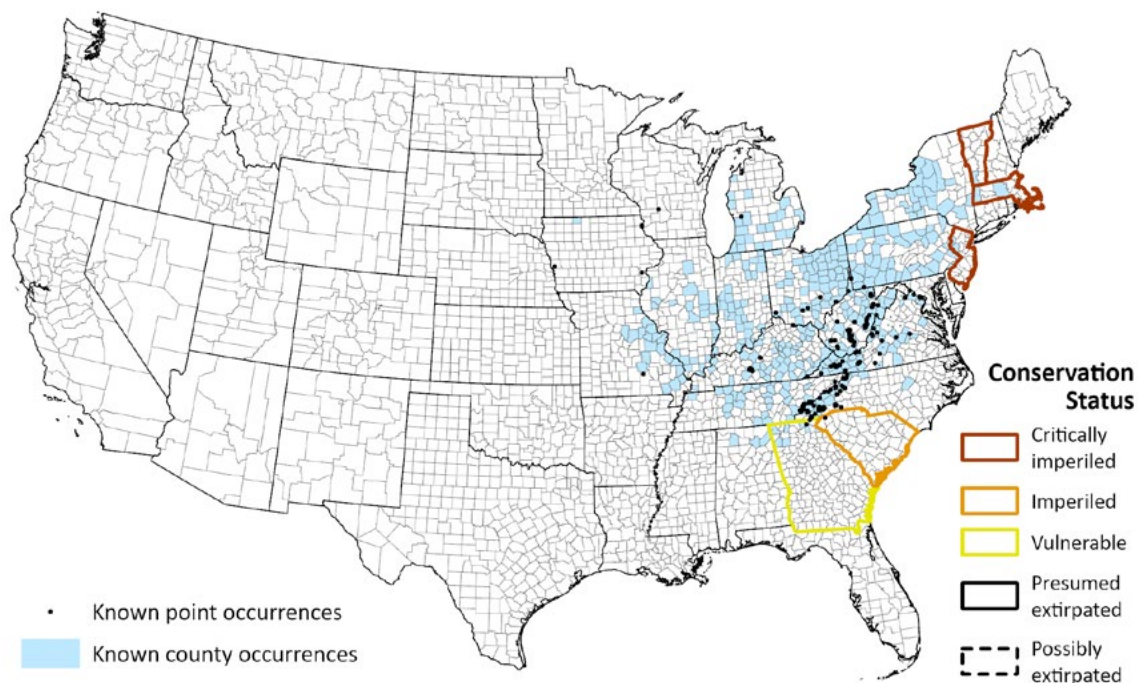


Figure A57.1. Distribution and state-level conservation status of *Hydrophyllum canadense*. Known point occurrences were used to assess species deposition responses and critical loads.

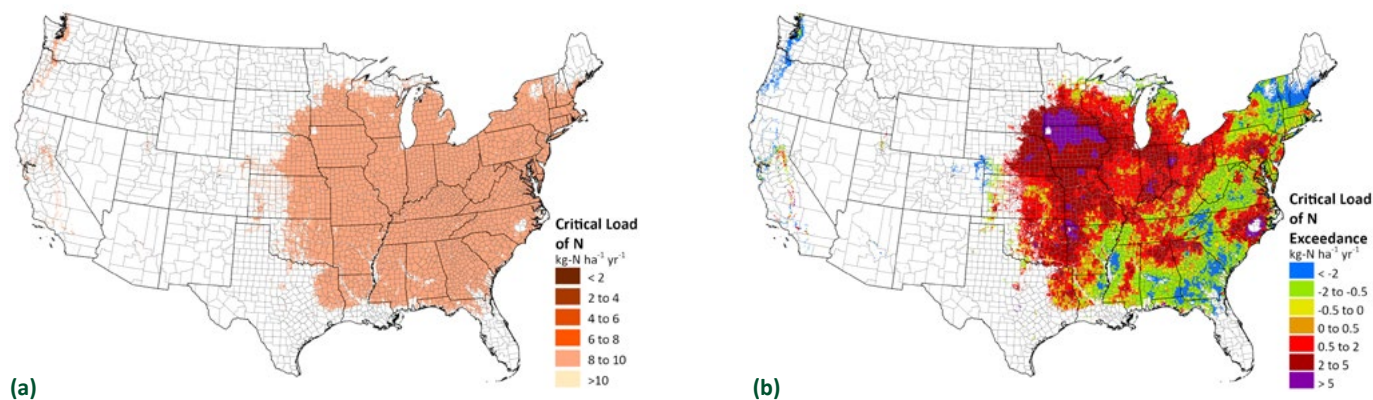


Figure A57.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Hydrophyllum canadense* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

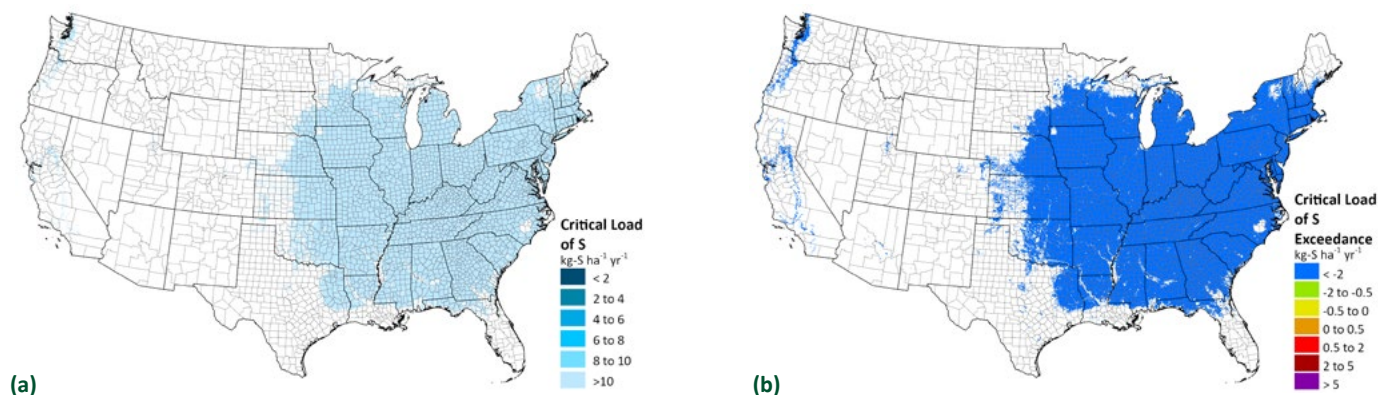


Figure A57.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Hydrophyllum canadense* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A58. *Hydrophyllum virginianum* (eastern waterleaf)

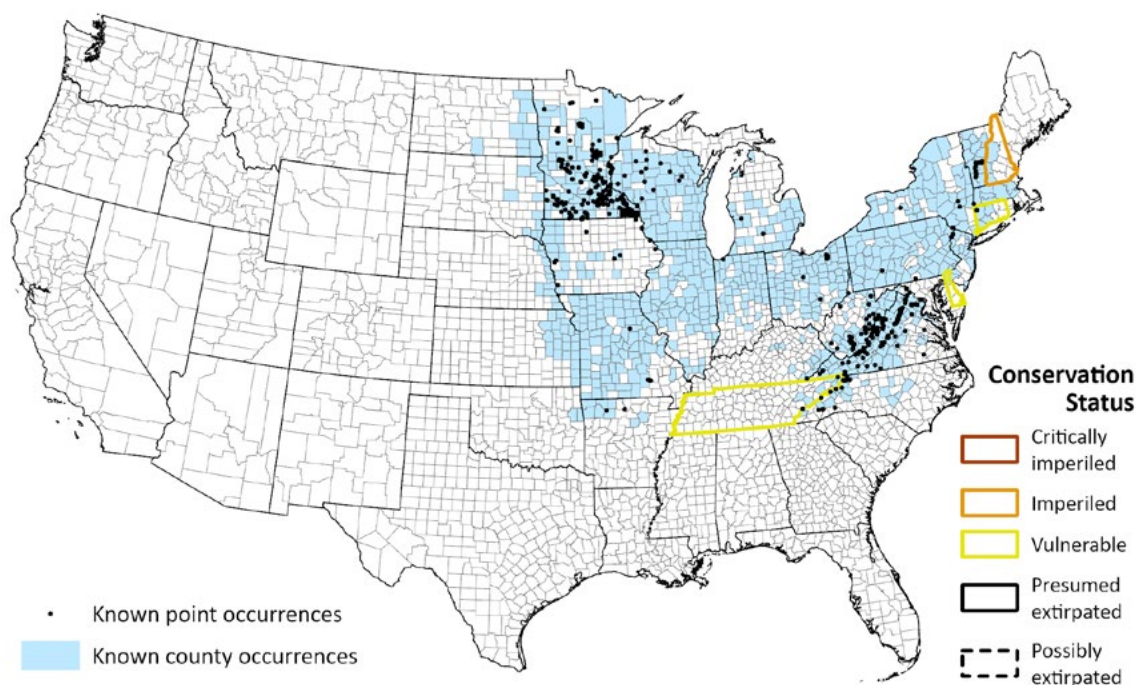


Figure A58.1. Distribution and state-level conservation status of *Hydrophyllum virginianum*. Known point occurrences were used to assess species deposition responses and critical loads.

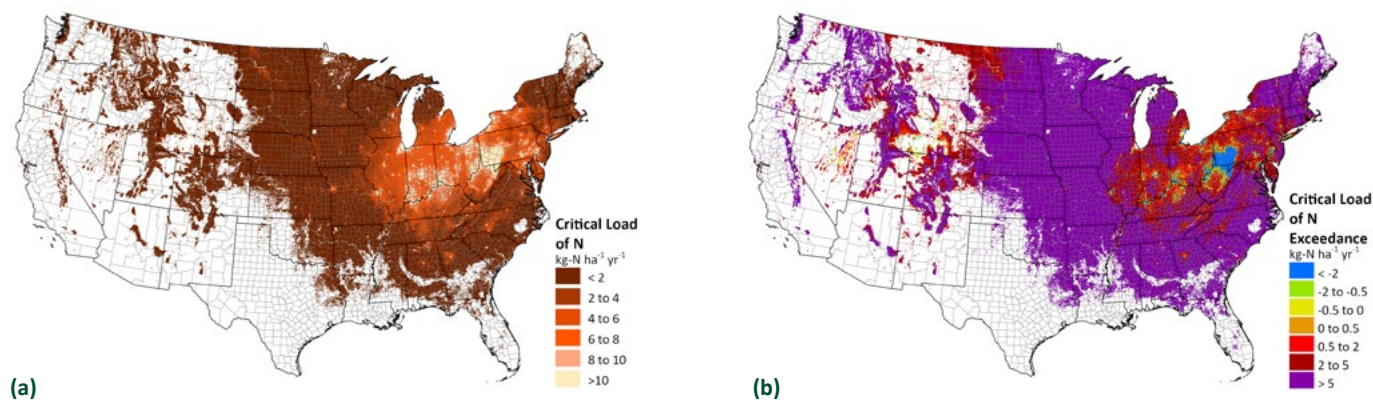


Figure A58.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Hydrophyllum virginianum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

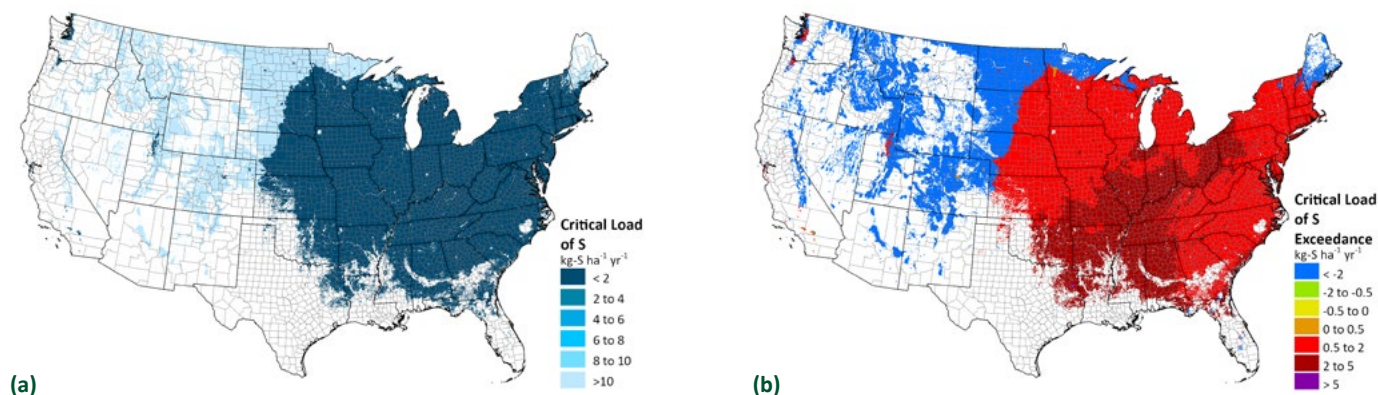


Figure A58.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Hydrophyllum virginianum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A59. *Lespedeza procumbens* (trailing lespedeza)

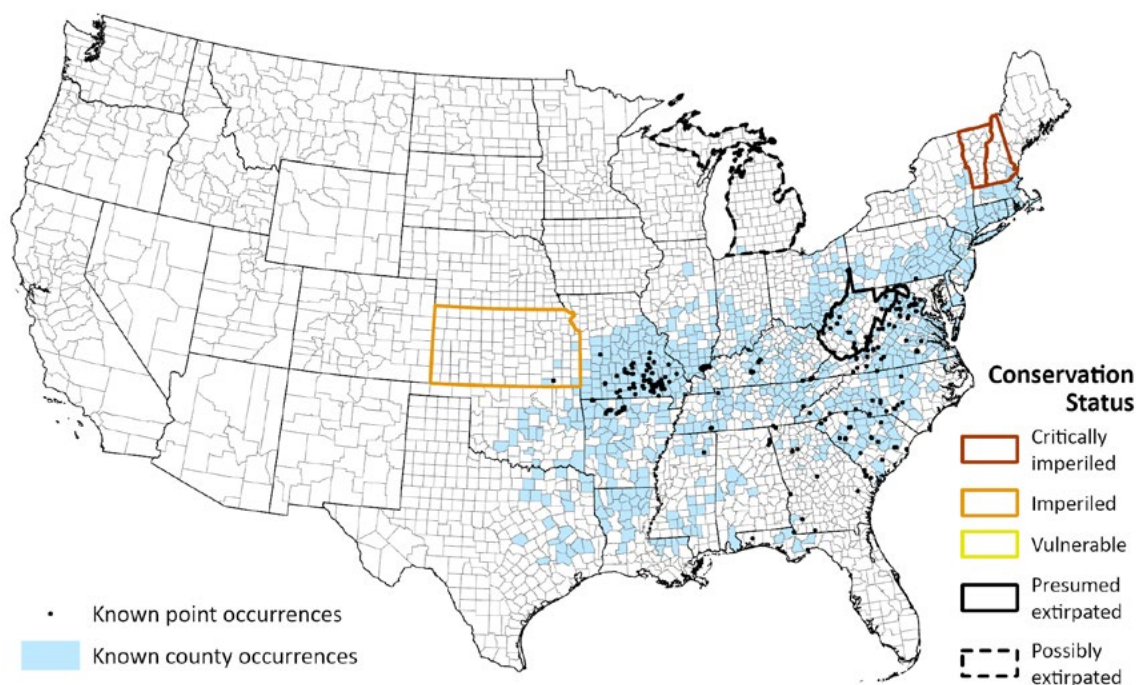


Figure A59.1. Distribution and state-level conservation status of *Lespedeza procumbens*. Known point occurrences were used to assess species deposition responses and critical loads.

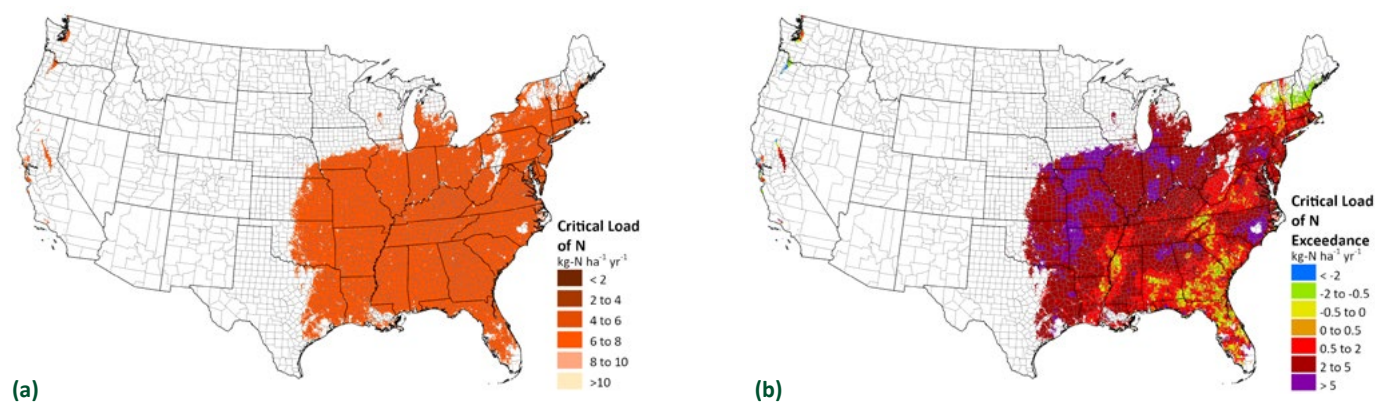


Figure A59.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Lespedeza procumbens* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

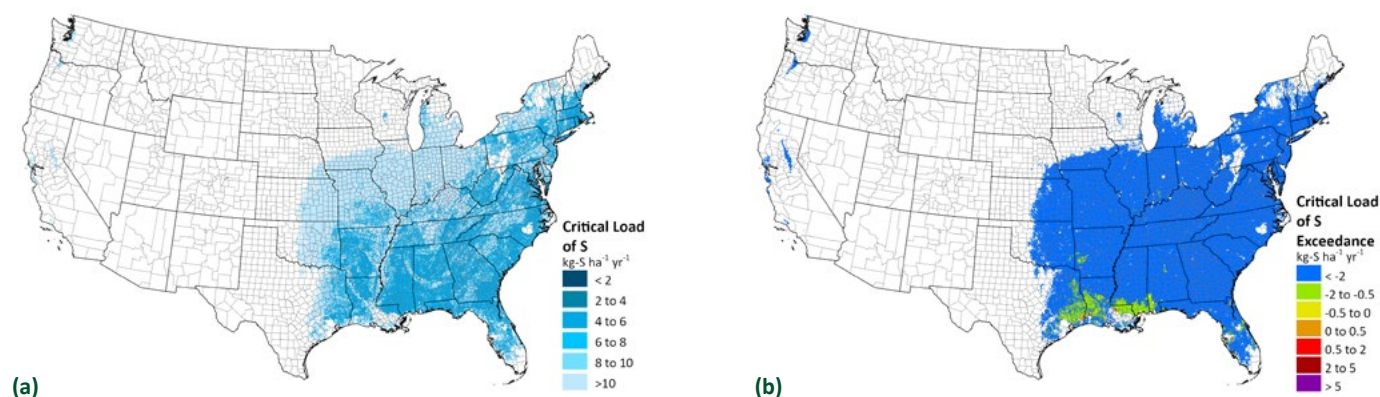


Figure A59.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Lespedeza procumbens* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A60. *Lespedeza repens* (creeping lespedeza)

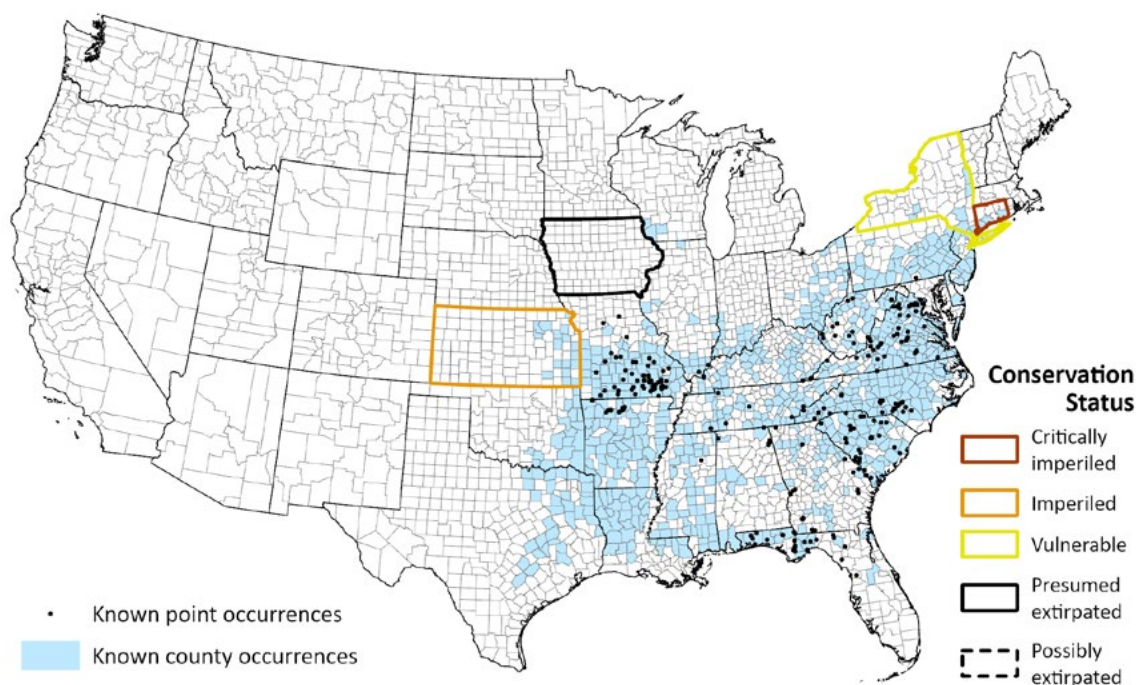


Figure A60.1. Distribution and state-level conservation status of *Lespedeza repens*. Known point occurrences were used to assess species deposition responses and critical loads.

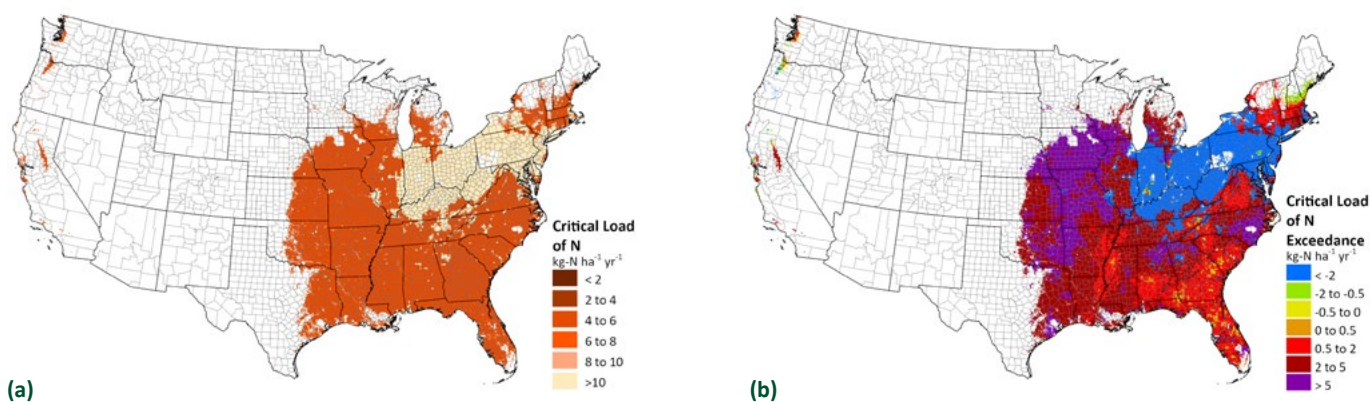


Figure A60.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Lespedeza repens* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

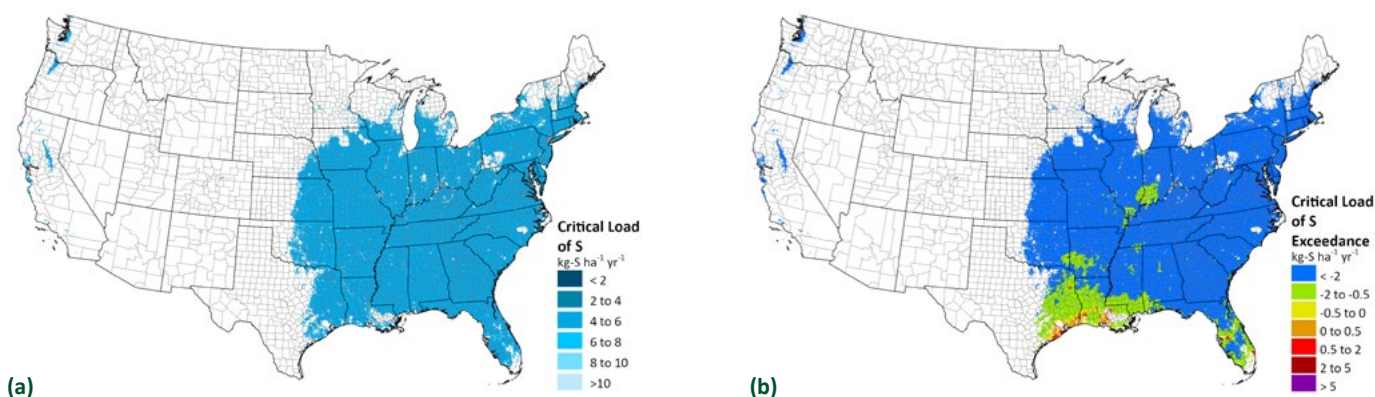


Figure A60.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Lespedeza repens* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A61. *Lysimachia quadriflora* (fourflower yellow loosestrife)

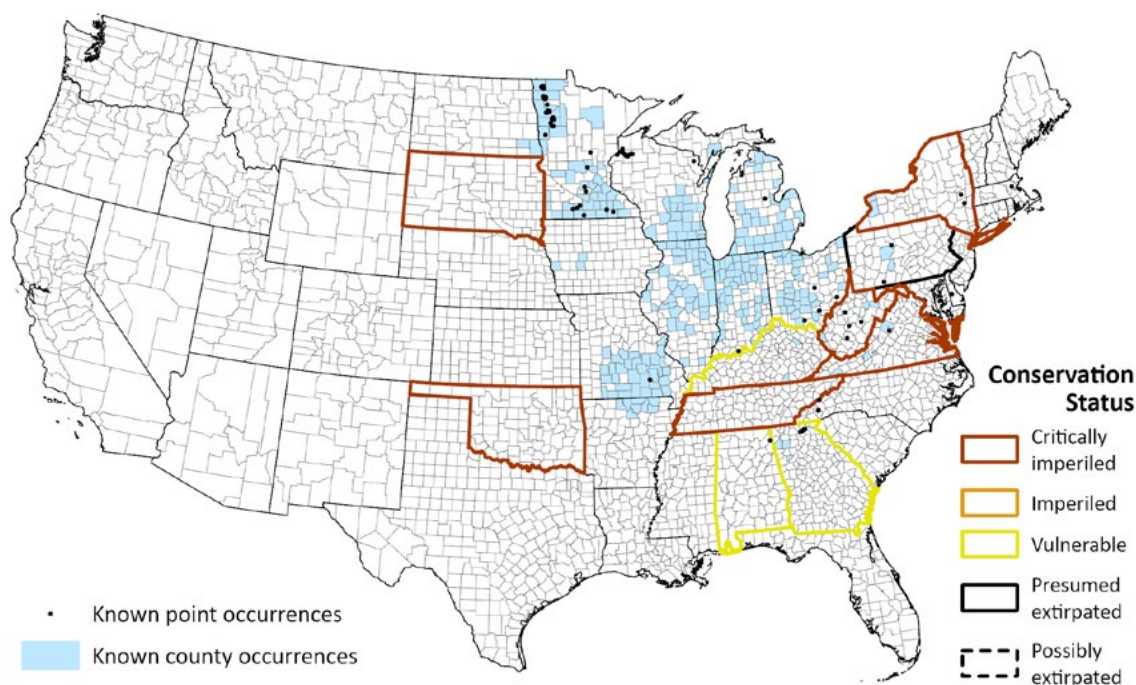


Figure A61.1. Distribution and state-level conservation status of *Lysimachia quadriflora*. Known point occurrences were used to assess species deposition responses and critical loads.

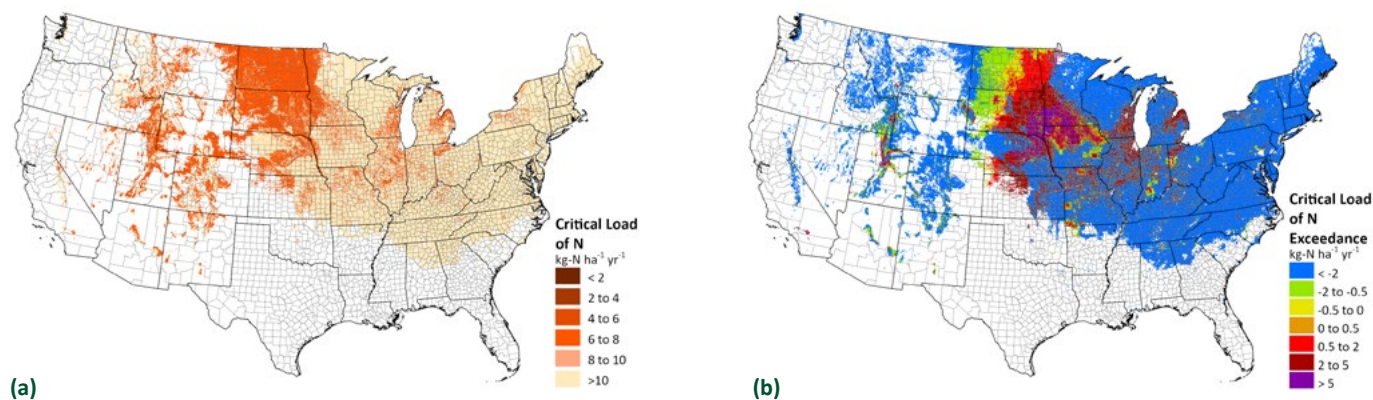


Figure A61.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Lysimachia quadriflora* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

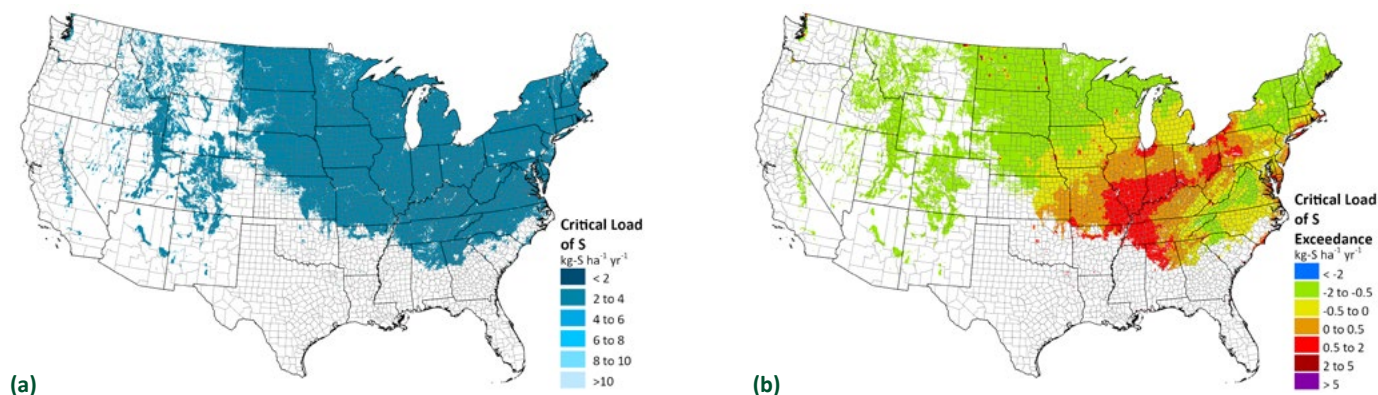


Figure A61.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Lysimachia quadriflora* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A62. *Lysimachia quadrifolia* (whorled yellow loosestrife)

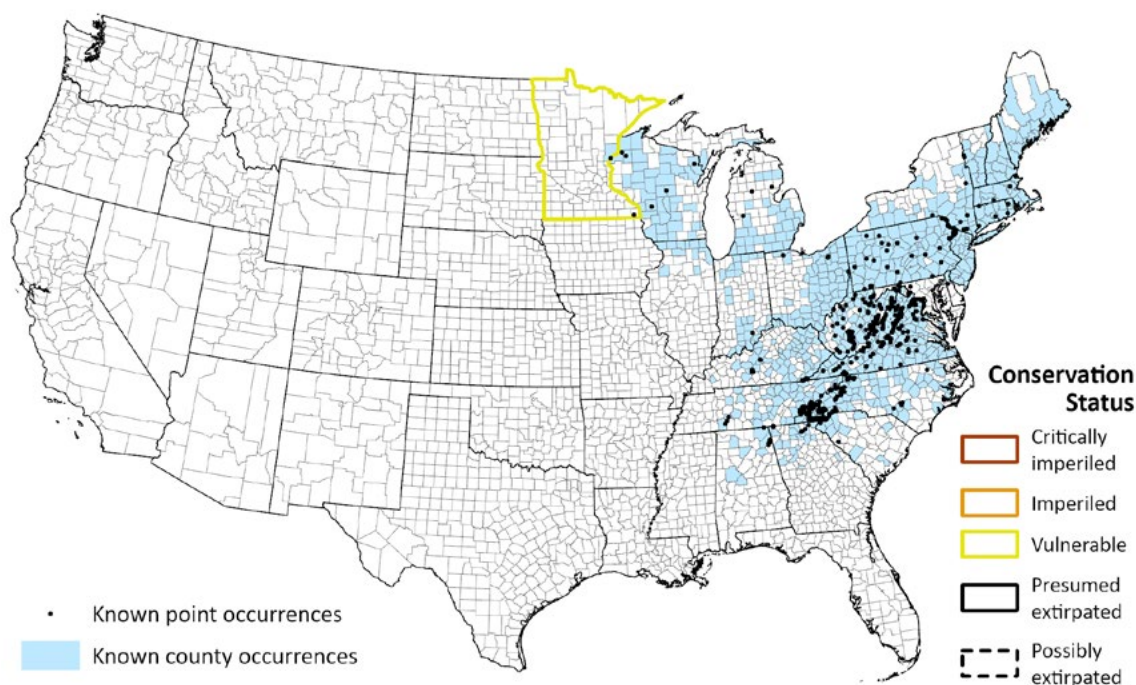


Figure A62.1. Distribution and state-level conservation status of *Lysimachia quadrifolia*. Known point occurrences were used to assess species deposition responses and critical loads.

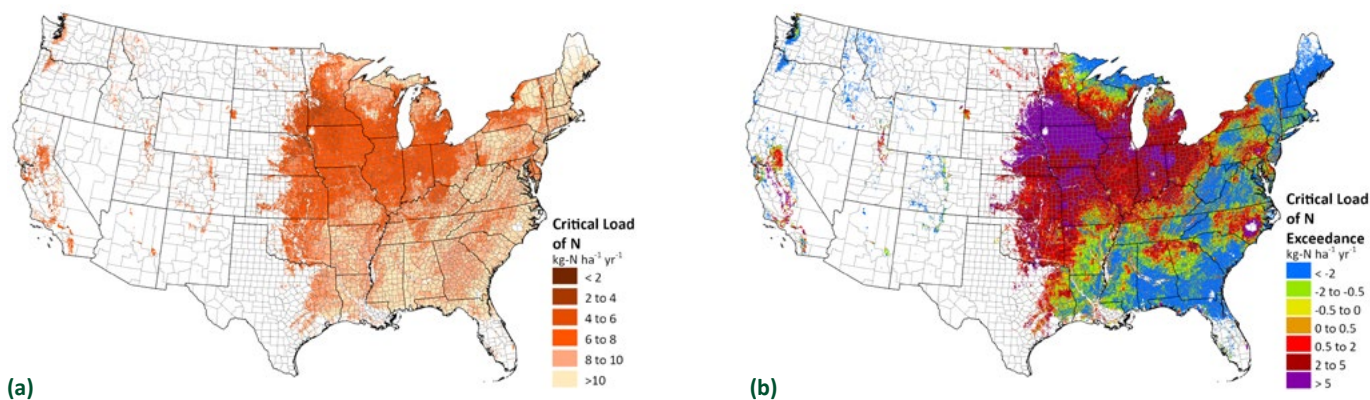


Figure A62.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Lysimachia quadrifolia* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

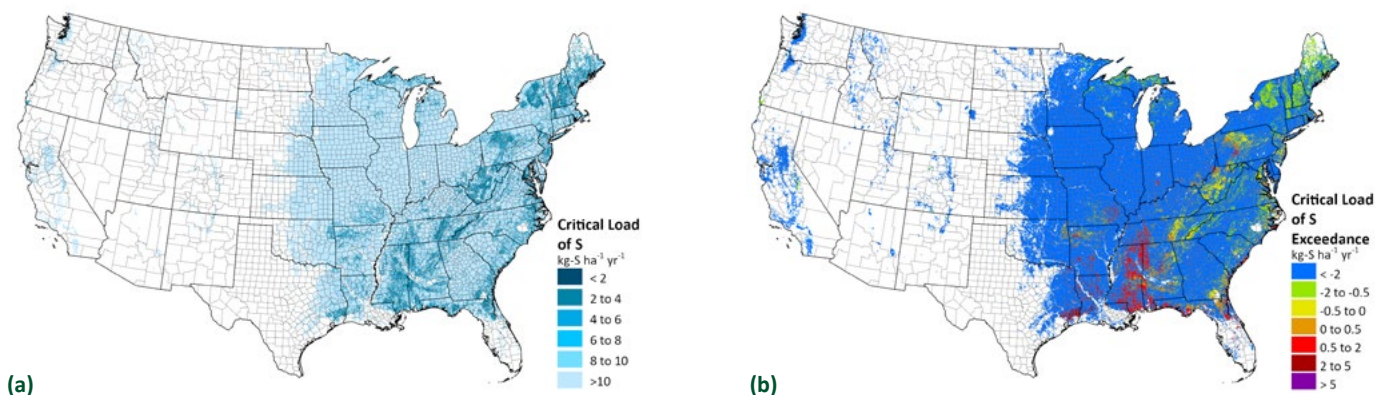


Figure A62.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Lysimachia quadrifolia* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A63. *Melampyrum lineare* (narrowleaf cowwheat)

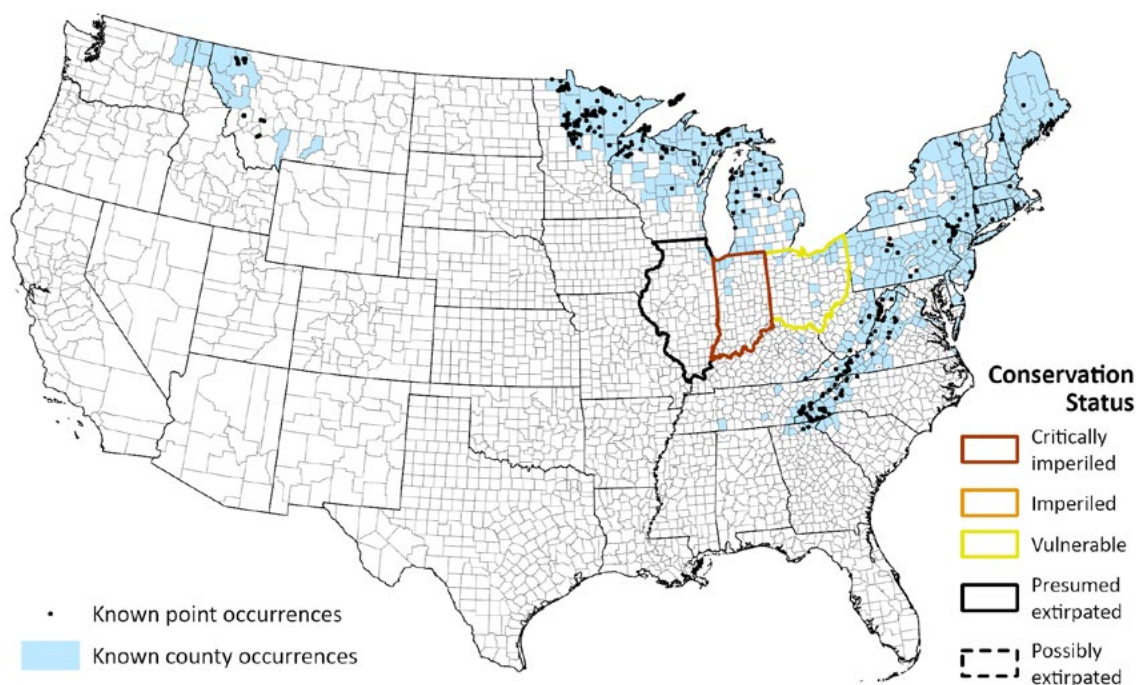


Figure A63.1. Distribution and state-level conservation status of *Melampyrum lineare*. Known point occurrences were used to assess species deposition responses and critical loads.

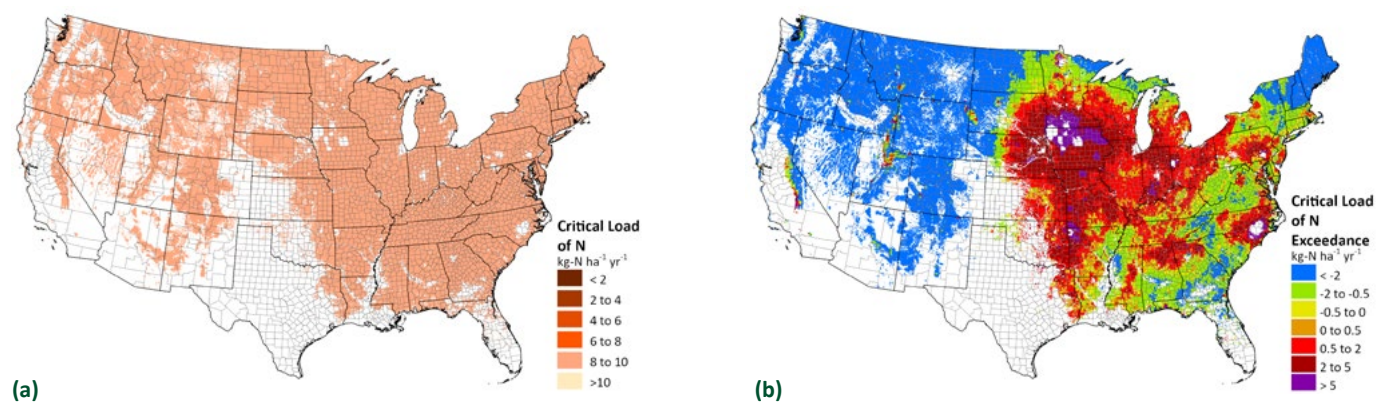


Figure A63.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Melampyrum lineare* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

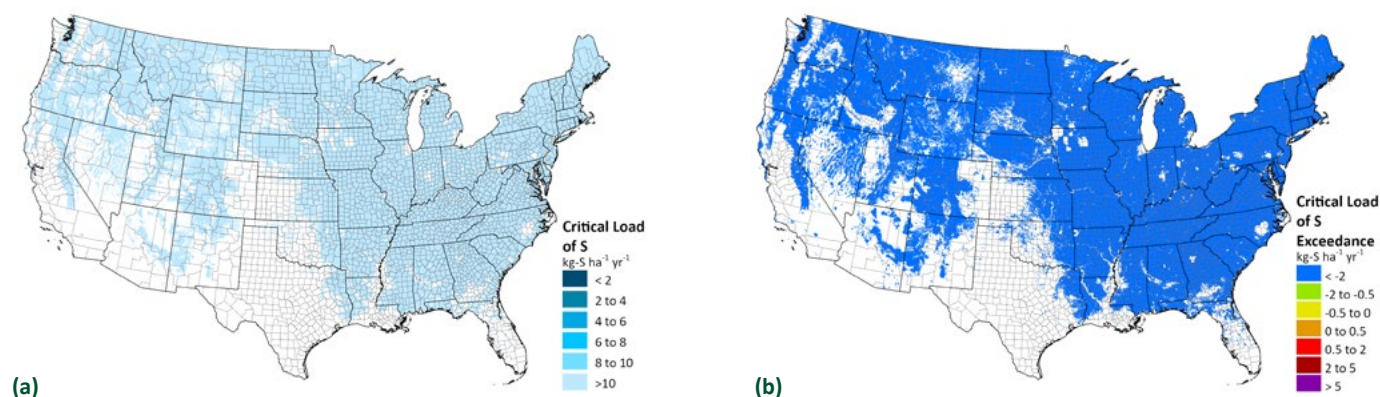


Figure A63.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Melampyrum lineare* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A64. *Milium effusum* (American milletgrass)

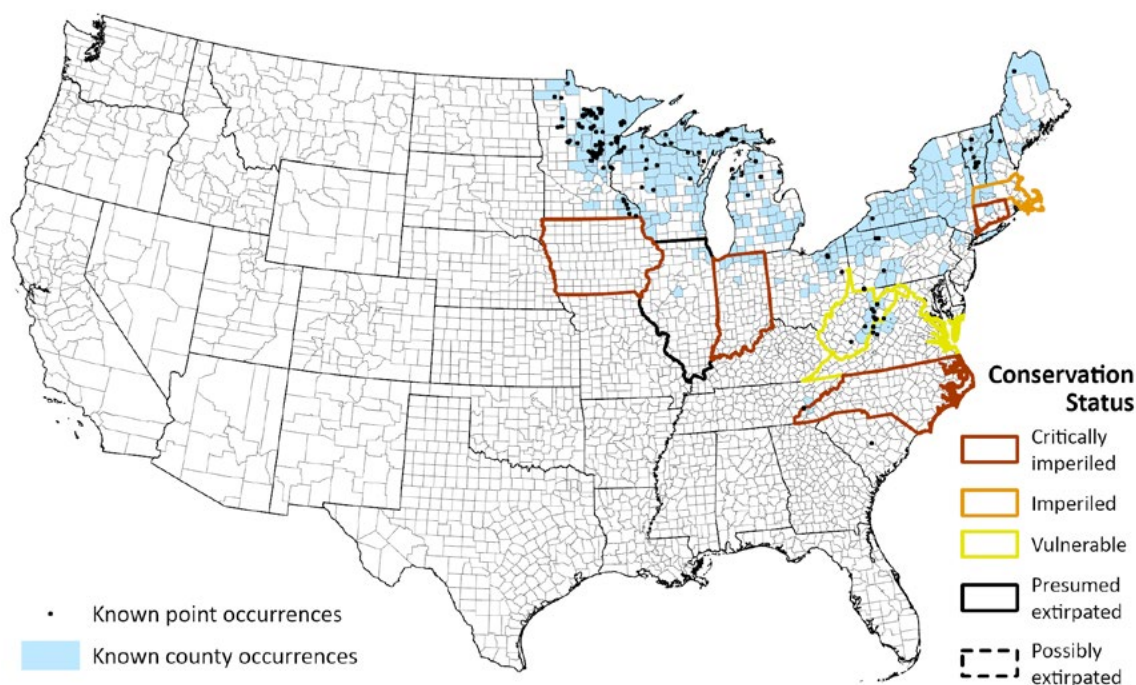


Figure A64.1. Distribution and state-level conservation status of *Milium effusum*. Known point occurrences were used to assess species deposition responses and critical loads.

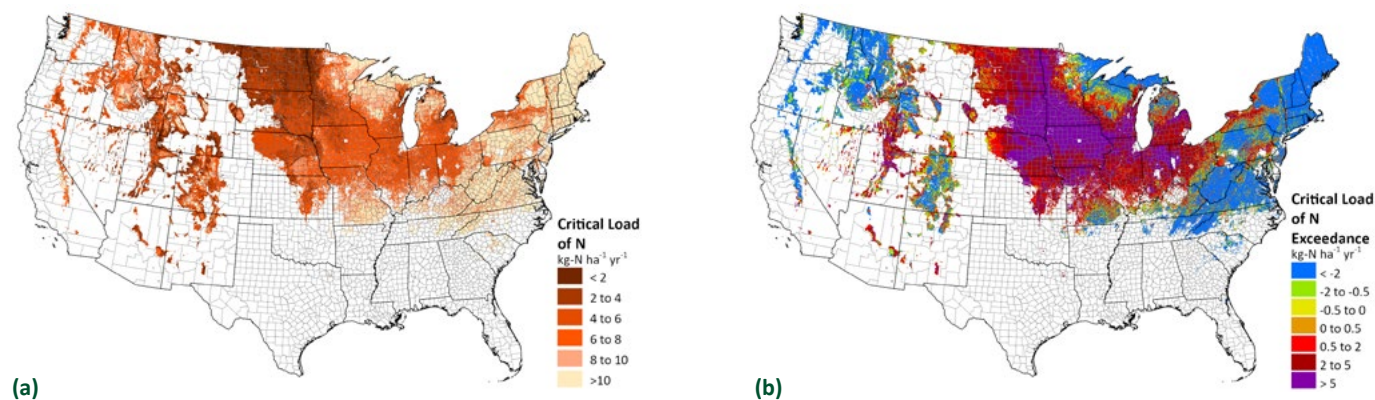


Figure A64.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Milium effusum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

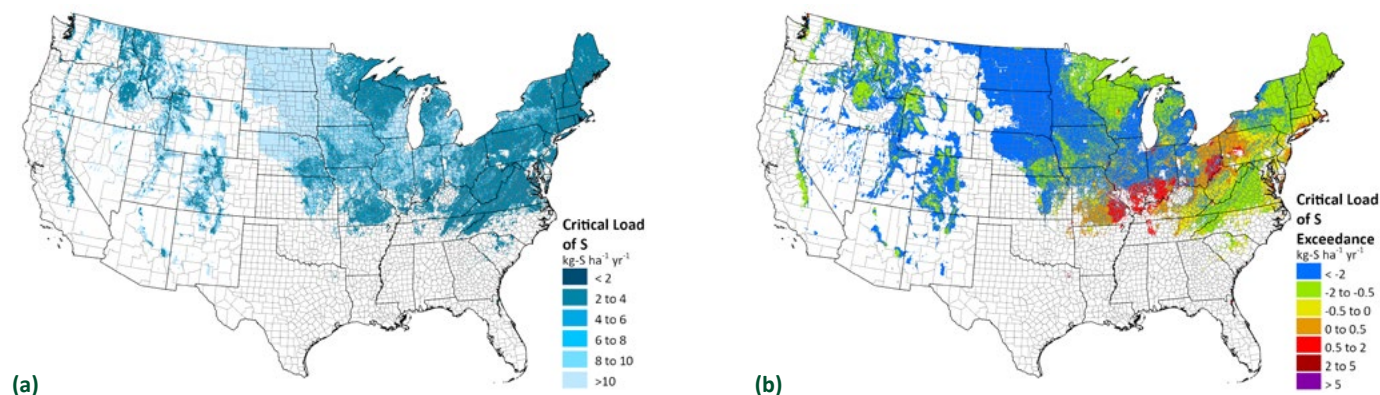


Figure A64.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Milium effusum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A65. *Mitella nuda* (naked miterwort)

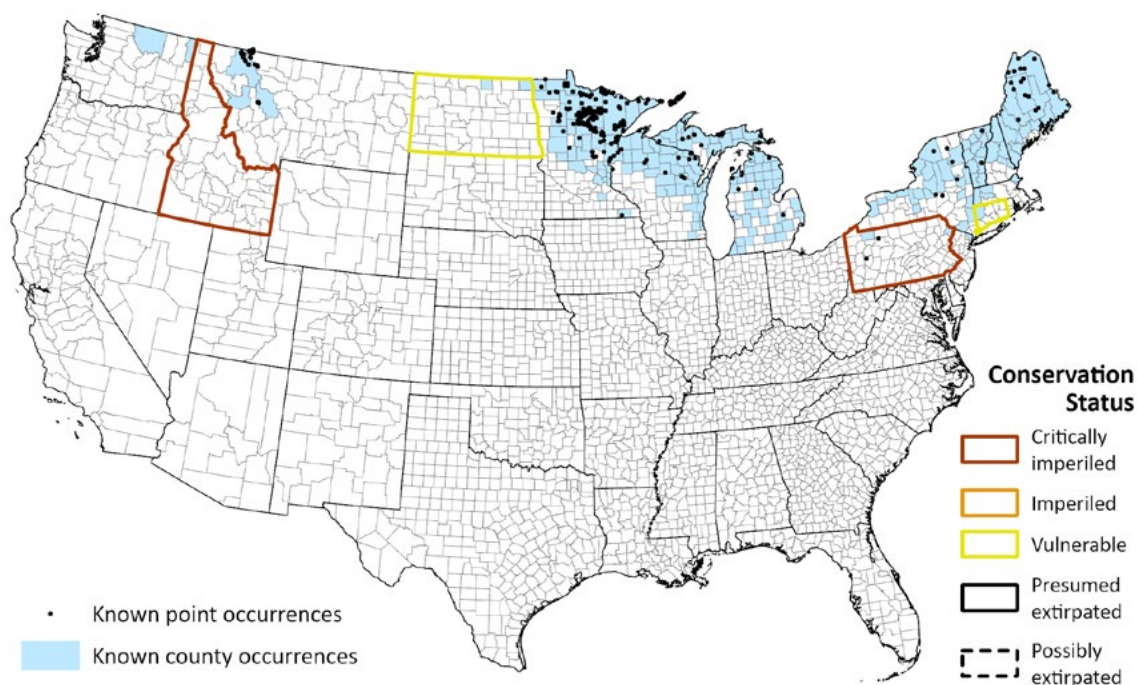


Figure A65.1. Distribution and state-level conservation status of *Mitella nuda*. Known point occurrences were used to assess species deposition responses and critical loads.

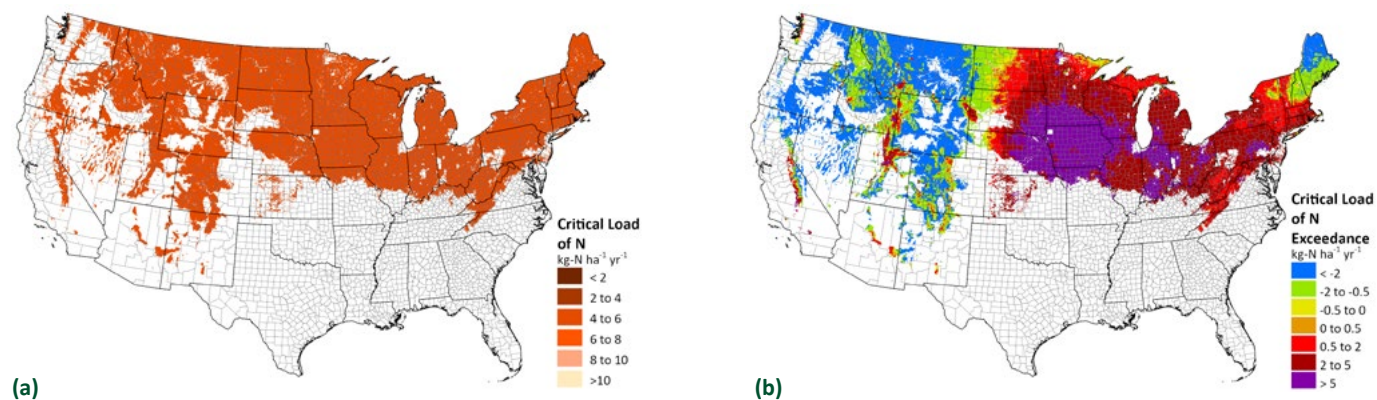


Figure A65.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Mitella nuda* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

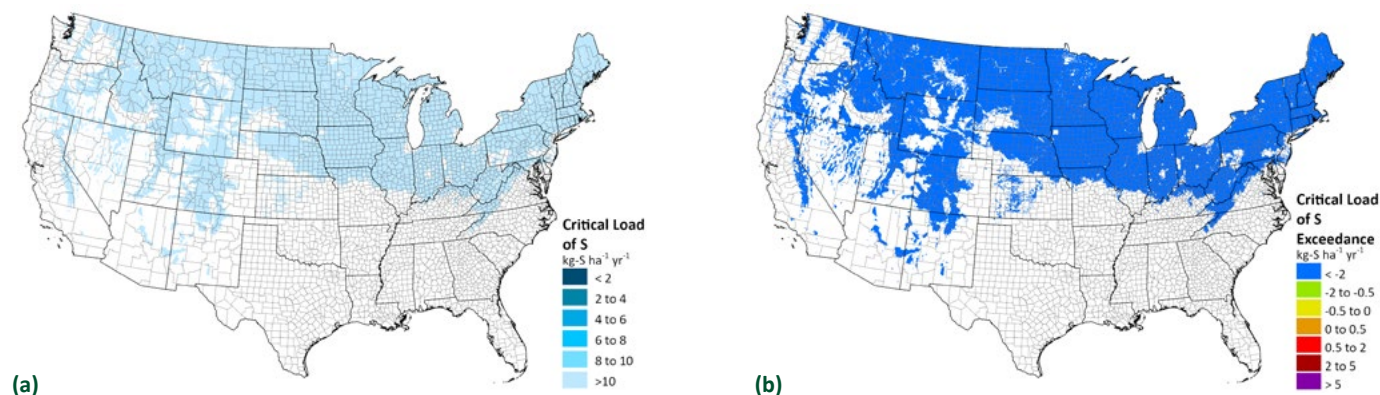


Figure A65.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Mitella nuda* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A66. *Muhlenbergia sobolifera* (rock muhly)

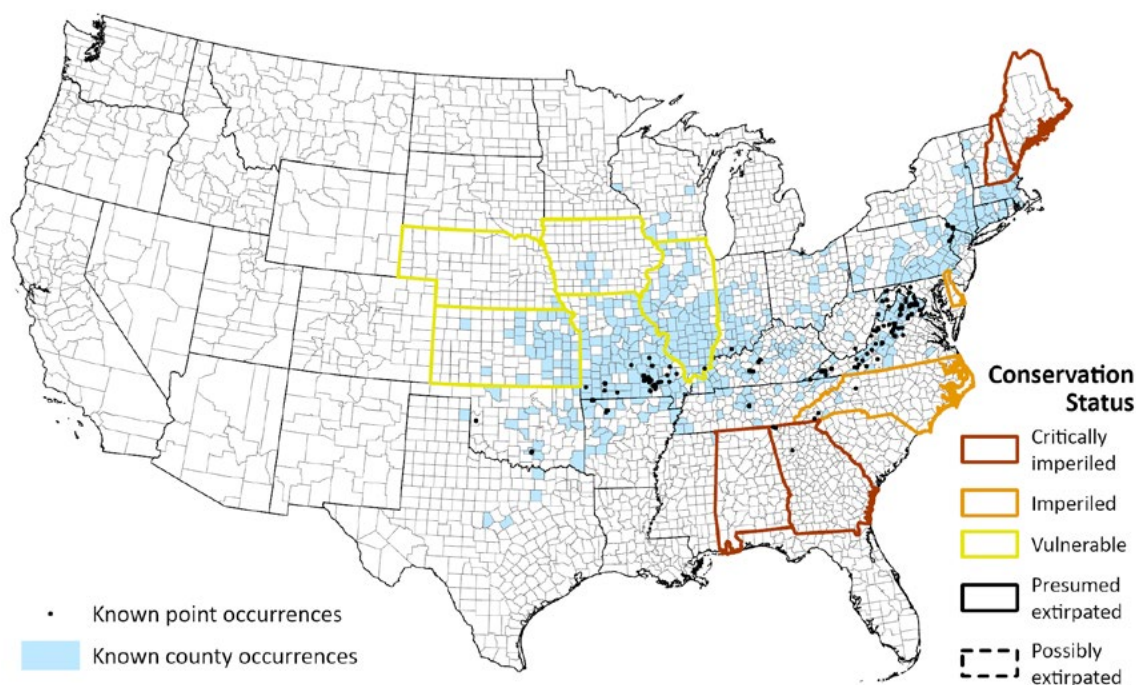


Figure A66.1. Distribution and state-level conservation status of *Muhlenbergia sobolifera*. Known point occurrences were used to assess species deposition responses and critical loads.

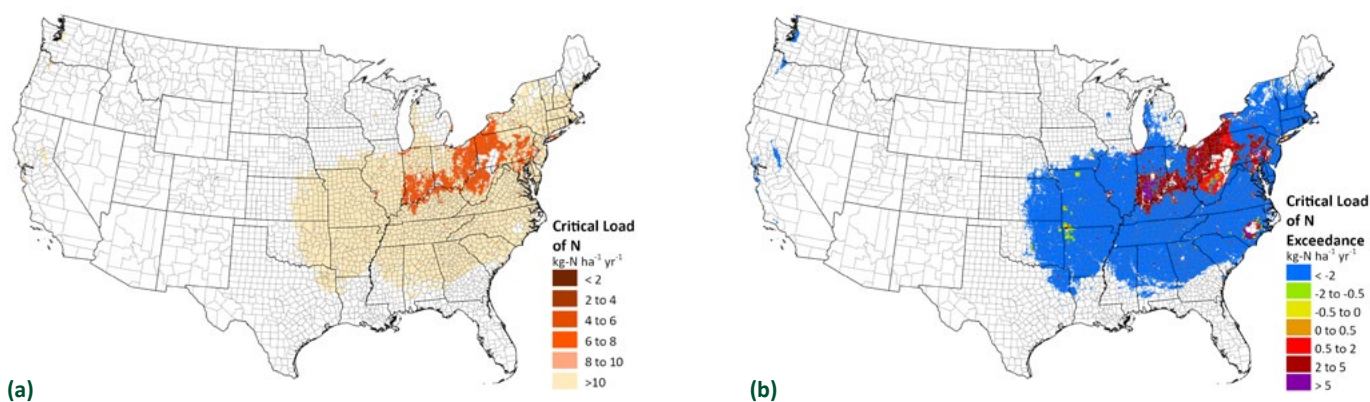


Figure A66.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Muhlenbergia sobolifera* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

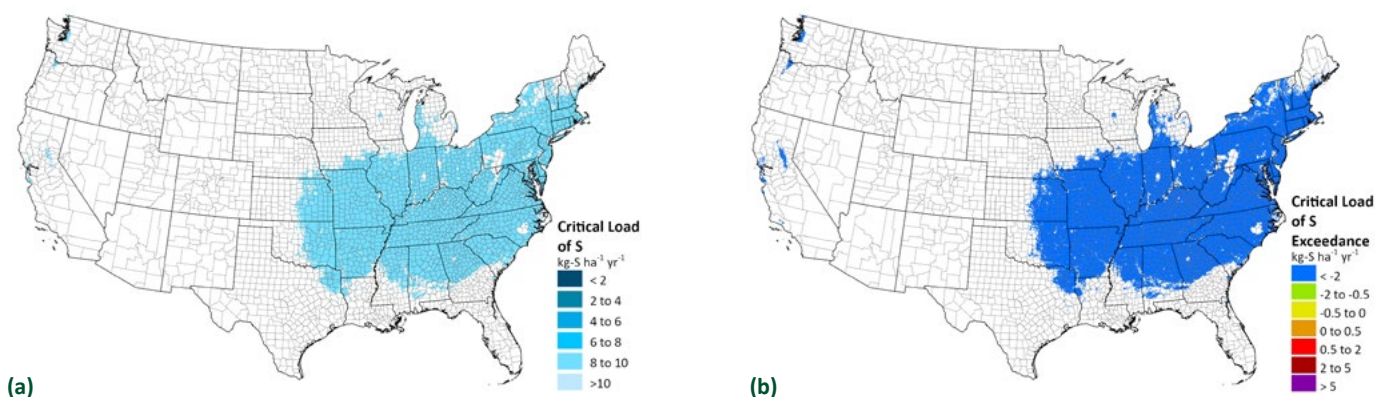


Figure A66.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Muhlenbergia sobolifera* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A67. *Murdannia keisak* (wartremoving herb)

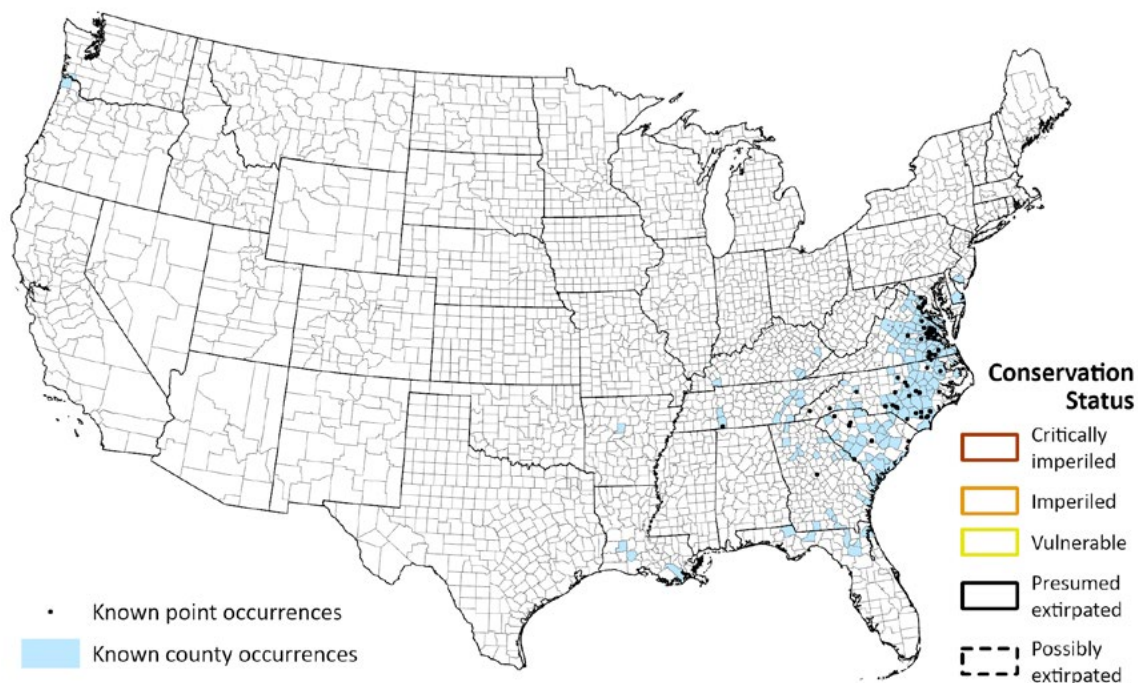


Figure A67.1. Distribution and state-level conservation status of *Murdannia keisak*. Known point occurrences were used to assess species deposition responses and critical loads.

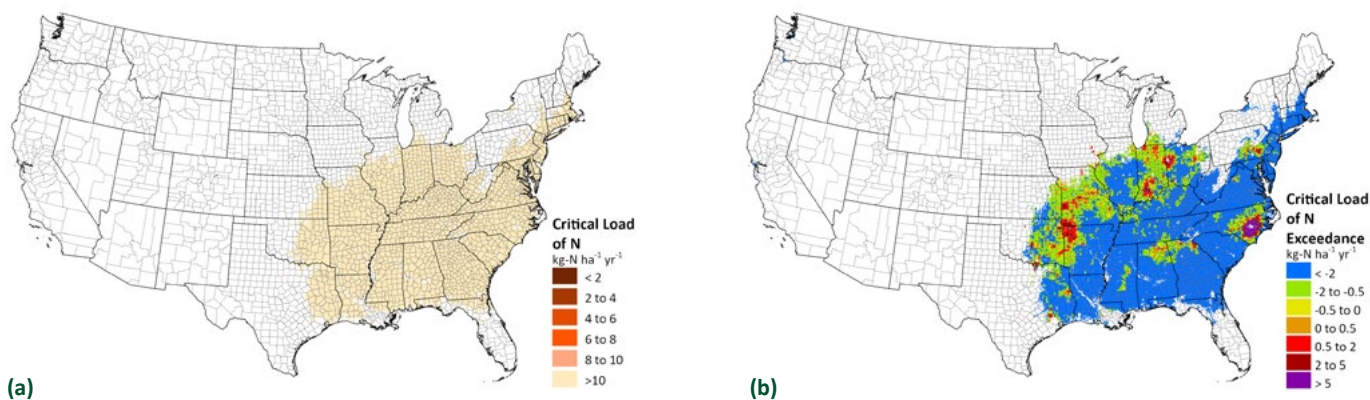


Figure A67.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Murdannia keisak* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

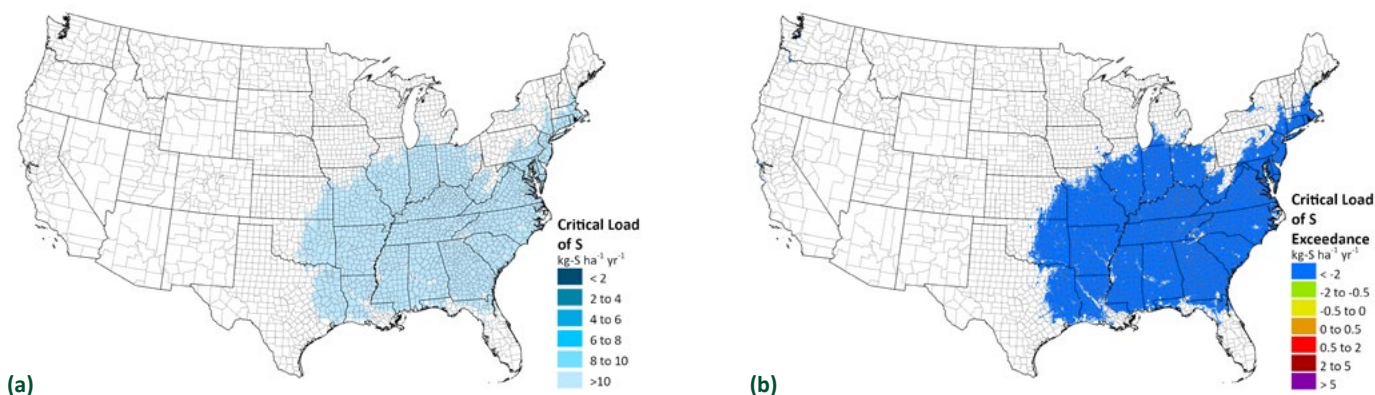


Figure A67.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Murdannia keisak* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A68. *Oligoneuron riddellii* (Riddell's goldenrod)

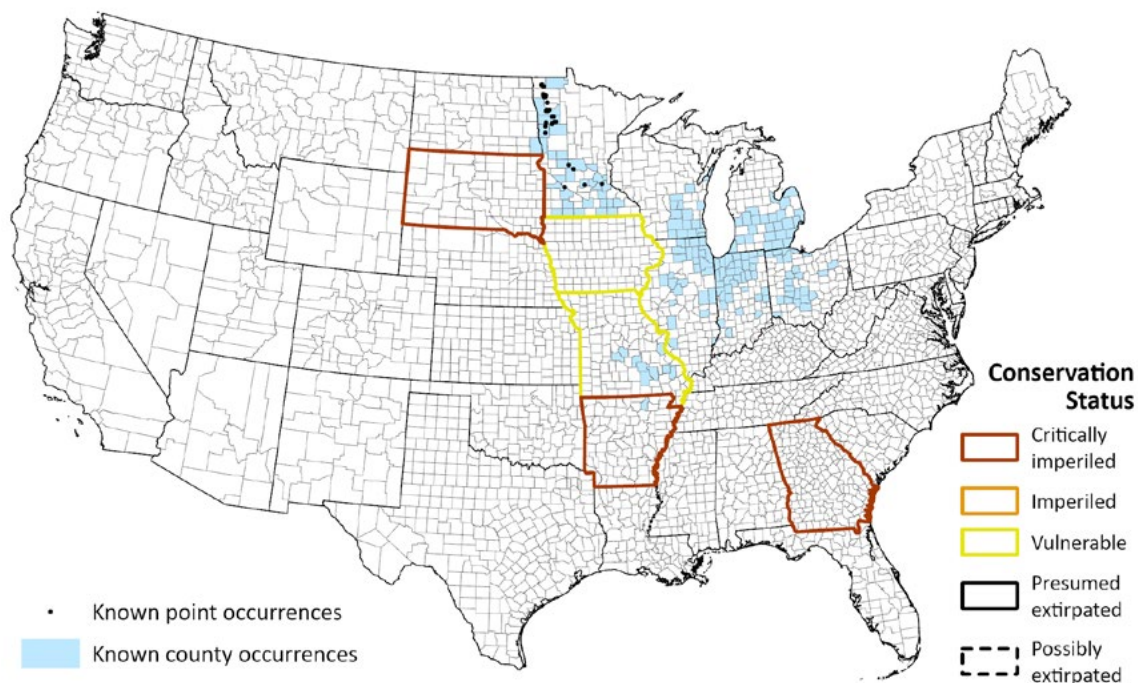


Figure A68.1. Distribution and state-level conservation status of *Oligoneuron riddellii*. Known point occurrences were used to assess species deposition responses and critical loads.

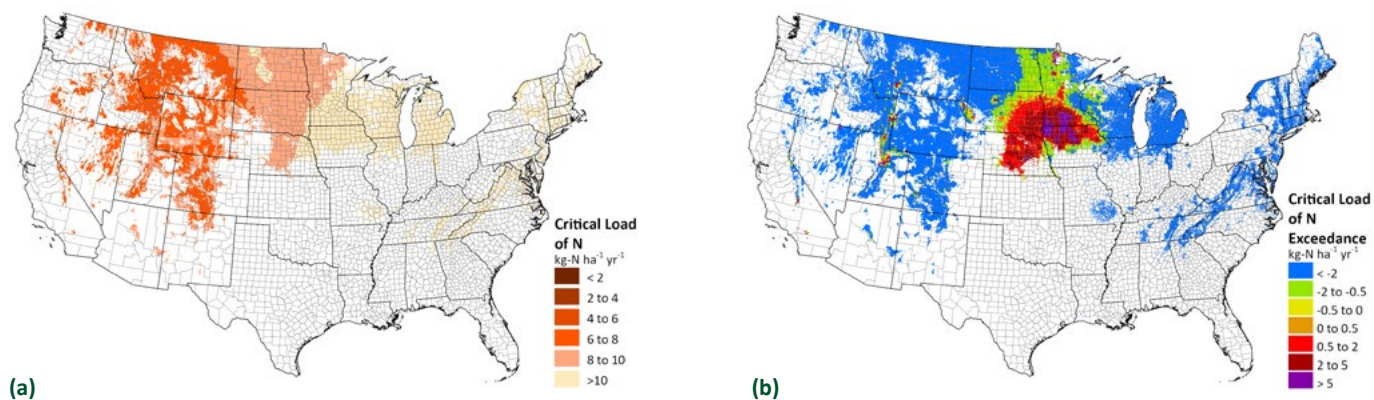


Figure A68.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Oligoneuron riddellii* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

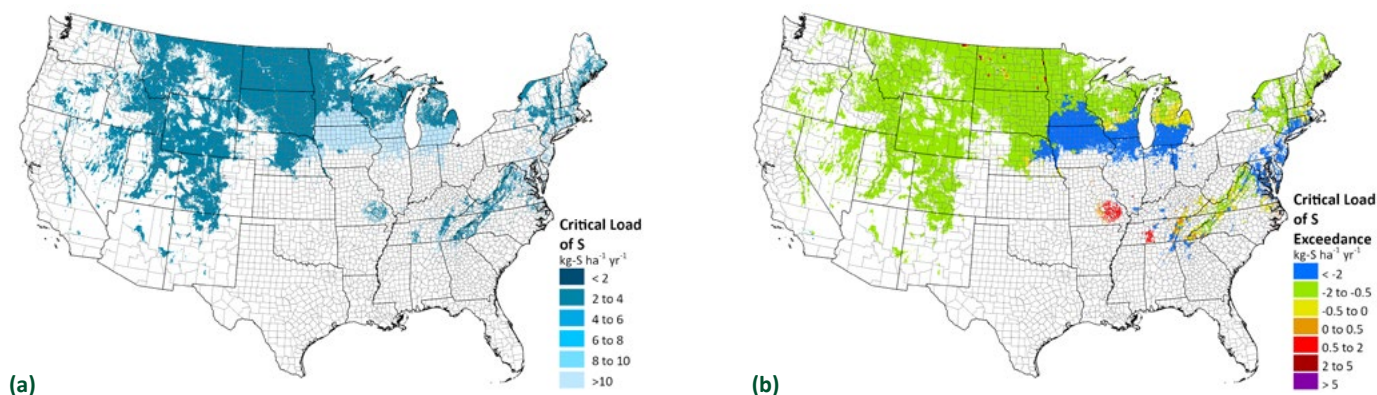


Figure A68.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Oligoneuron riddellii* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A69. *Onoclea sensibilis* (sensitive fern)

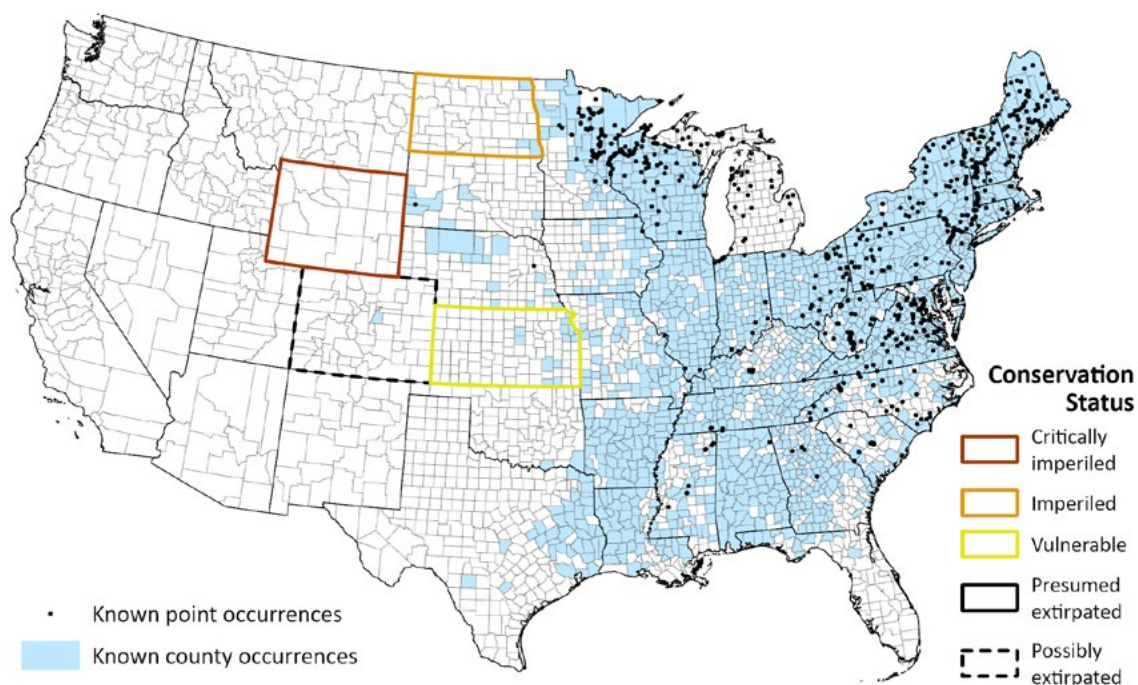


Figure A69.1. Distribution and state-level conservation status of *Onoclea sensibilis*. Known point occurrences were used to assess species deposition responses and critical loads.

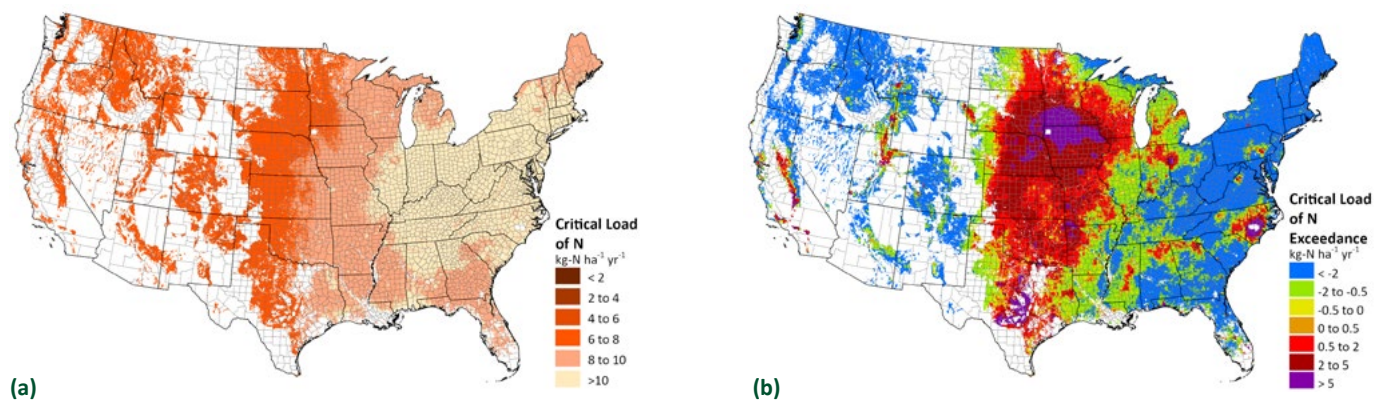


Figure A69.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Onoclea sensibilis* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

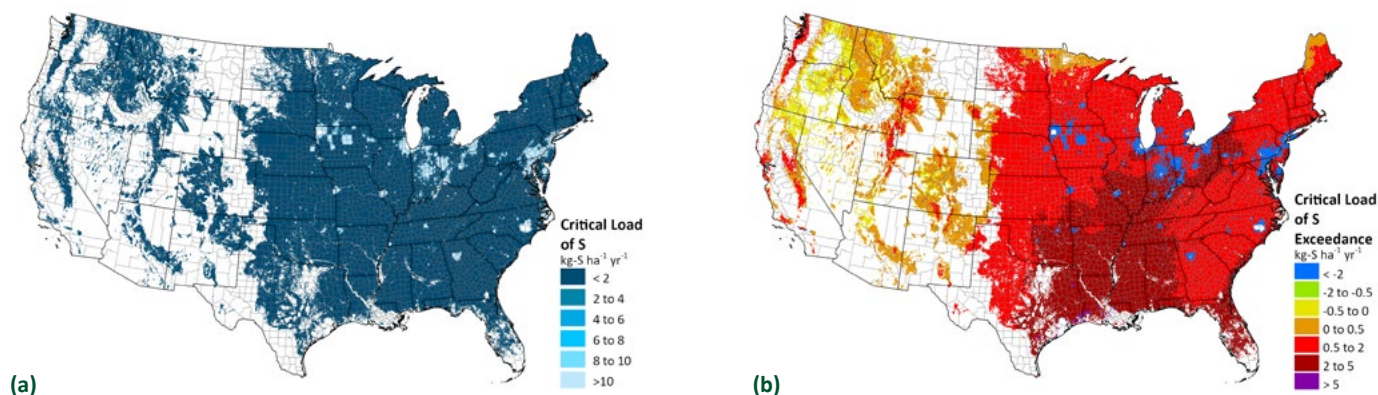


Figure A69.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Onoclea sensibilis* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A70. *Oryzopsis asperifolia* (roughleaf ricegrass)

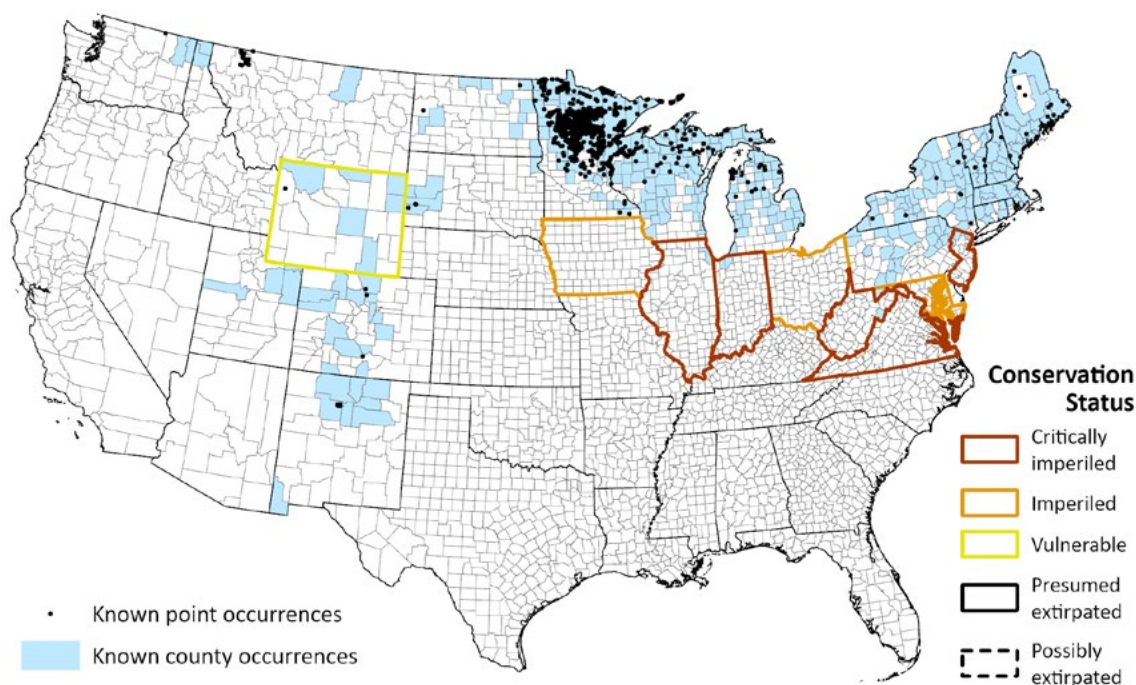


Figure A70.1. Distribution and state-level conservation status of *Oryzopsis asperifolia*. Known point occurrences were used to assess species deposition responses and critical loads.

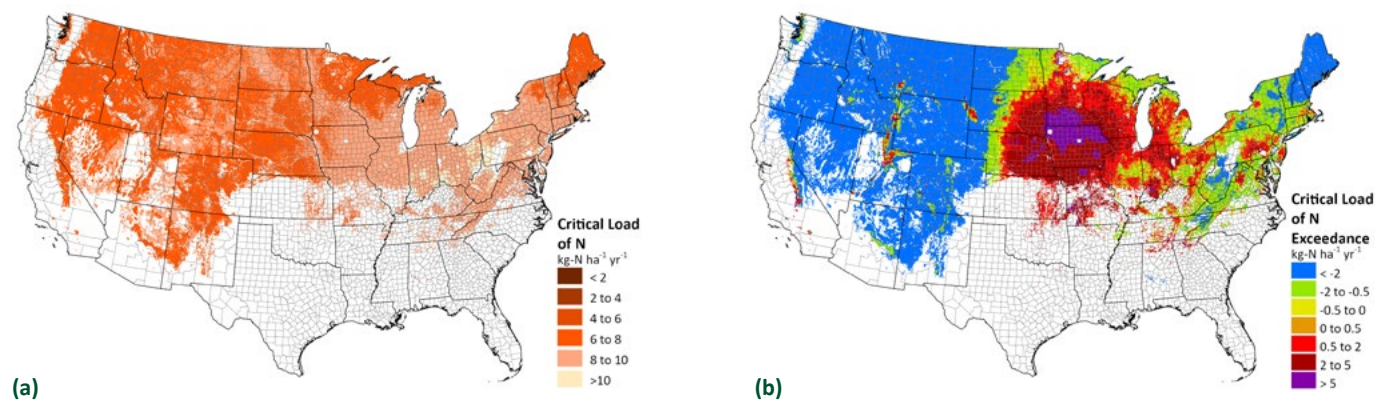


Figure A70.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Oryzopsis asperifolia* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

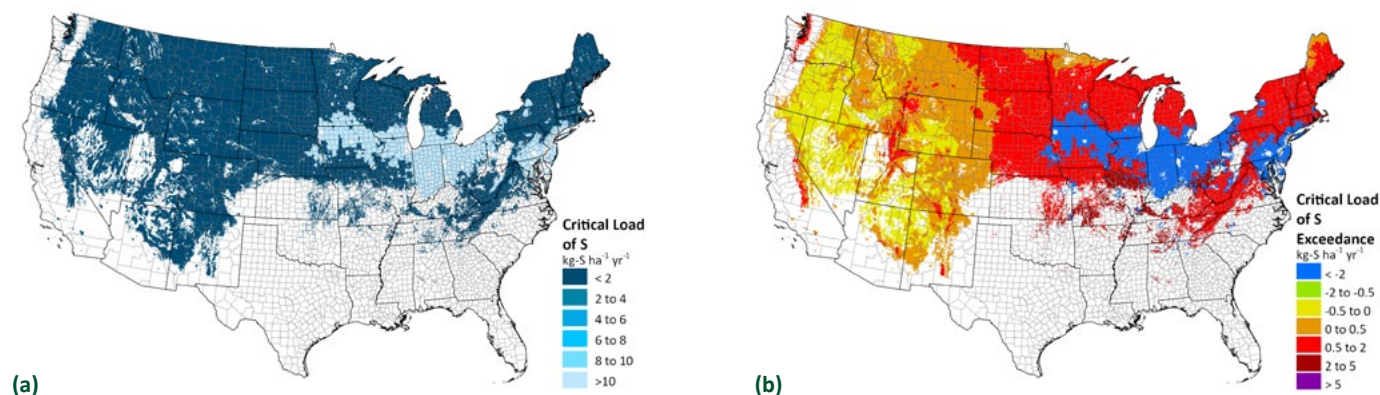


Figure A70.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Oryzopsis asperifolia* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A71. *Osmunda claytoniana* (interrupted fern)

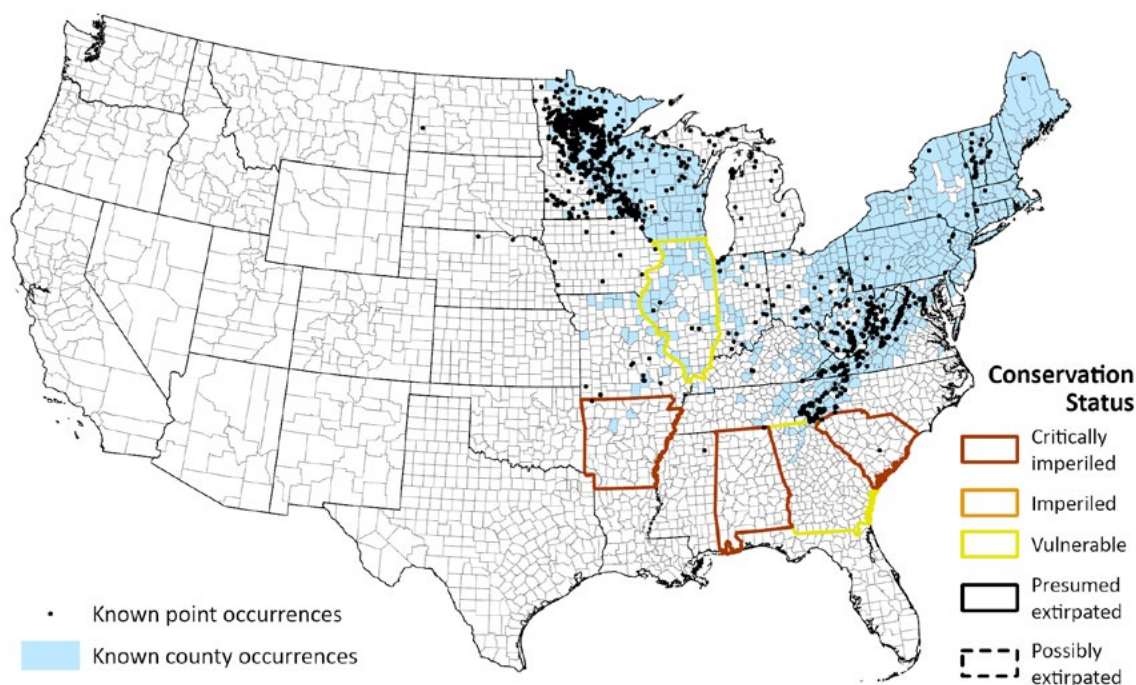


Figure A71.1. Distribution and state-level conservation status of *Osmunda claytoniana*. Known point occurrences were used to assess species deposition responses and critical loads.

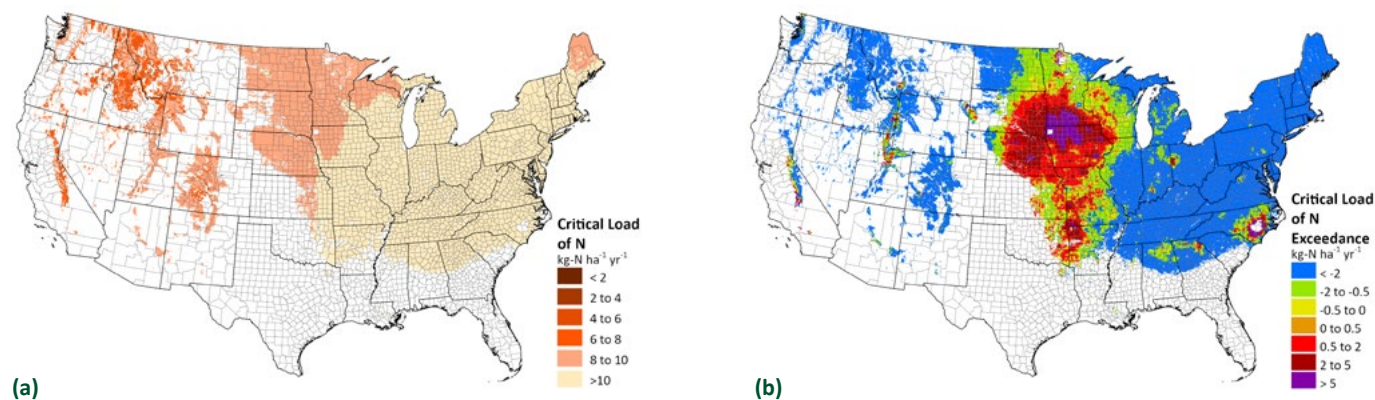


Figure A71.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Osmunda claytoniana* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

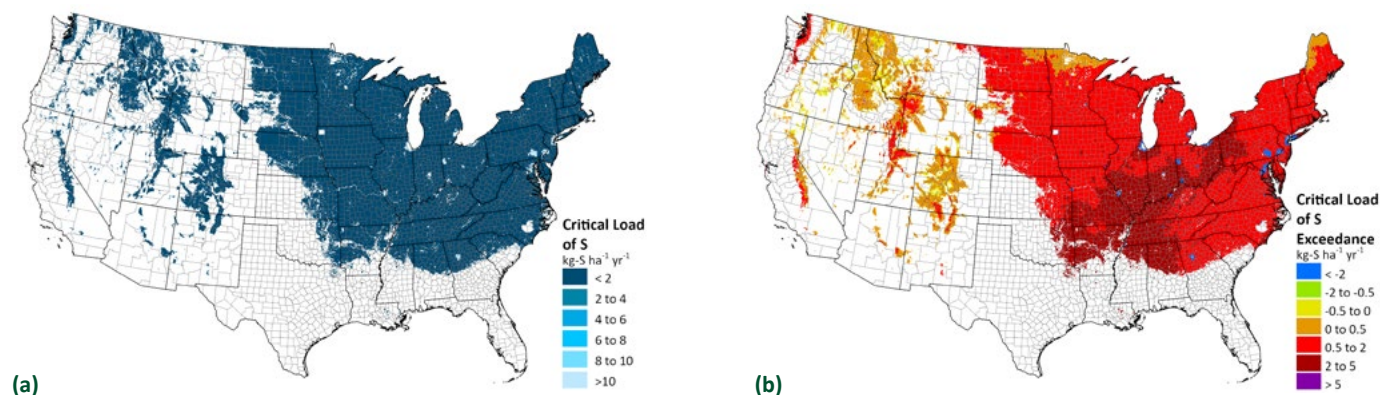


Figure A71.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Osmunda claytoniana* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A72. *Oxalis dillenii* (slender yellow woodsorrel)

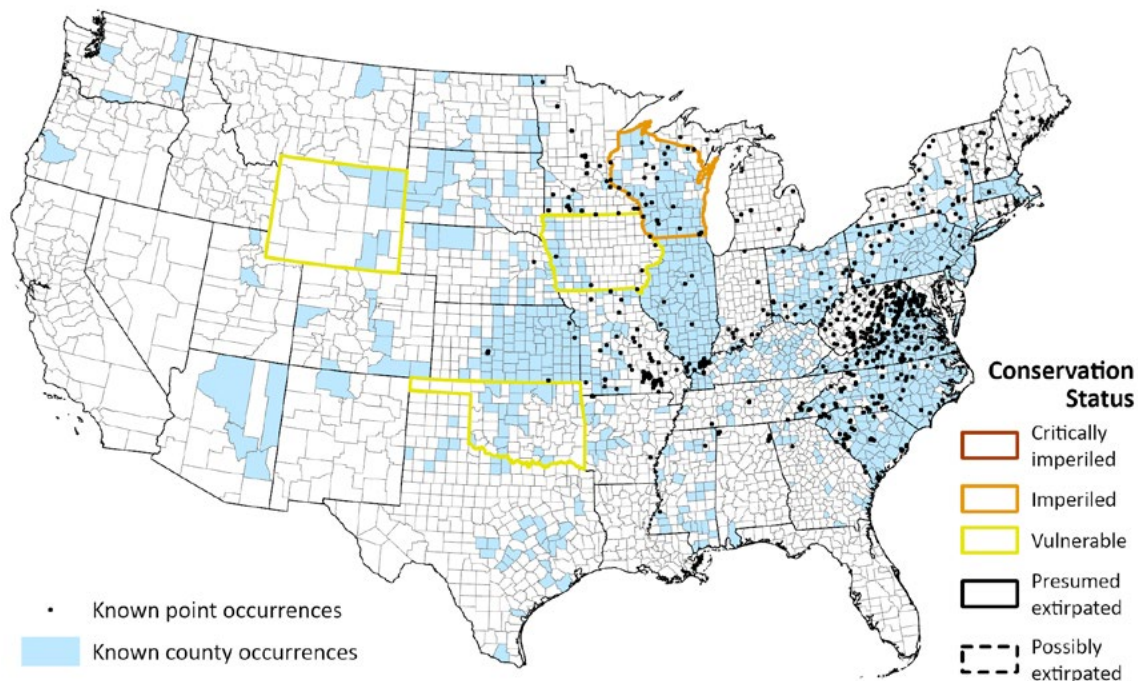


Figure A72.1. Distribution and state-level conservation status of *Oxalis dillenii*. Known point occurrences were used to assess species deposition responses and critical loads.

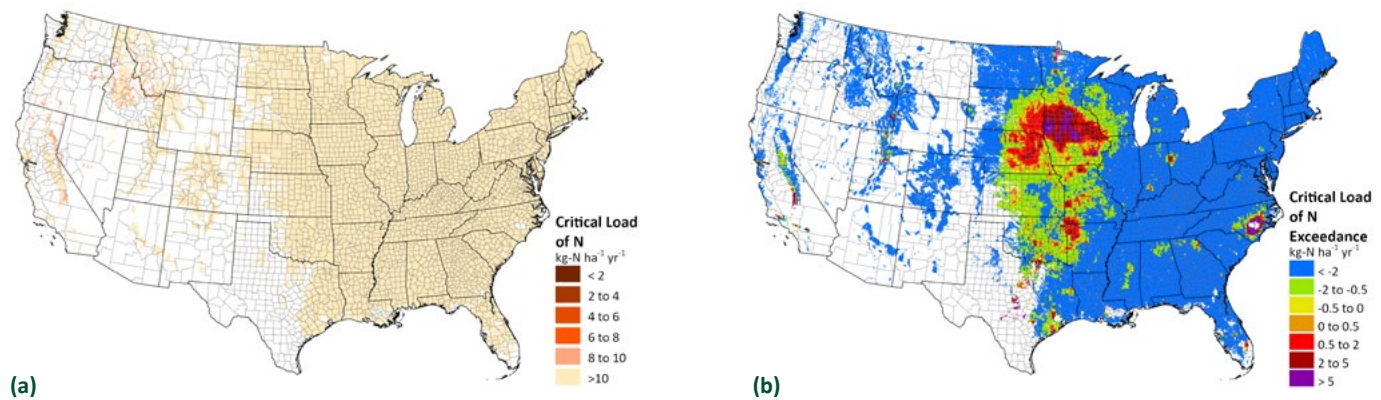


Figure A72.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Oxalis dillenii* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

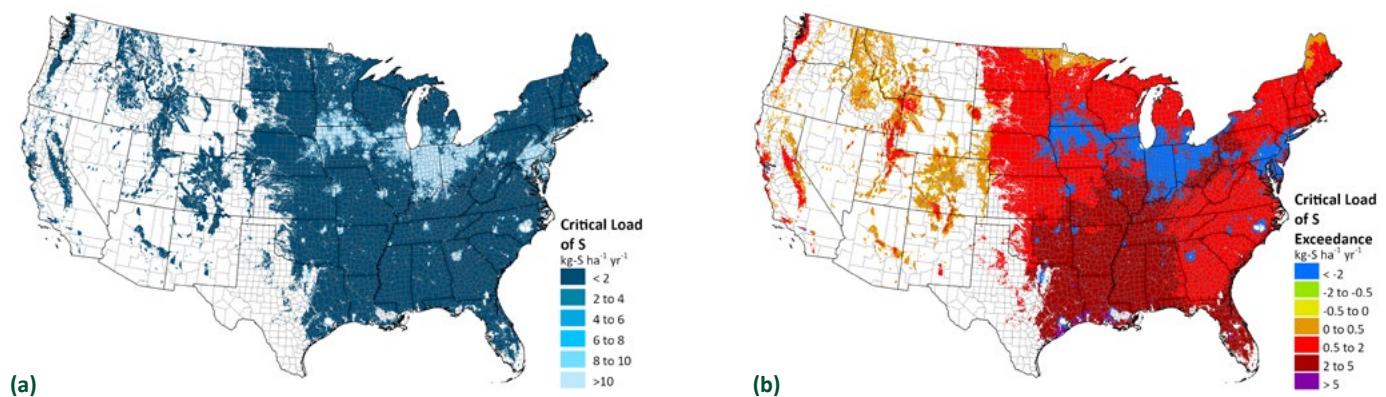


Figure A72.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Oxalis dillenii* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A73. *Pediomelum esculentum* (large Indian breadroot)

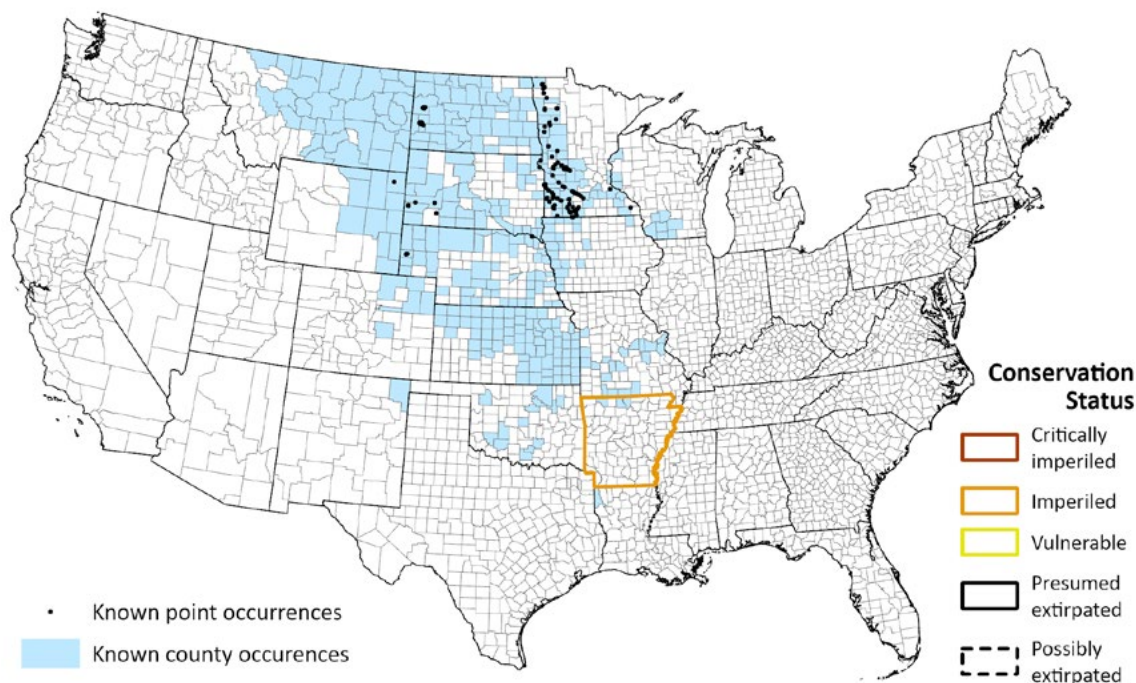


Figure A73.1. Distribution and state-level conservation status of *Pediomelum esculentum*. Known point occurrences were used to assess species deposition responses and critical loads.

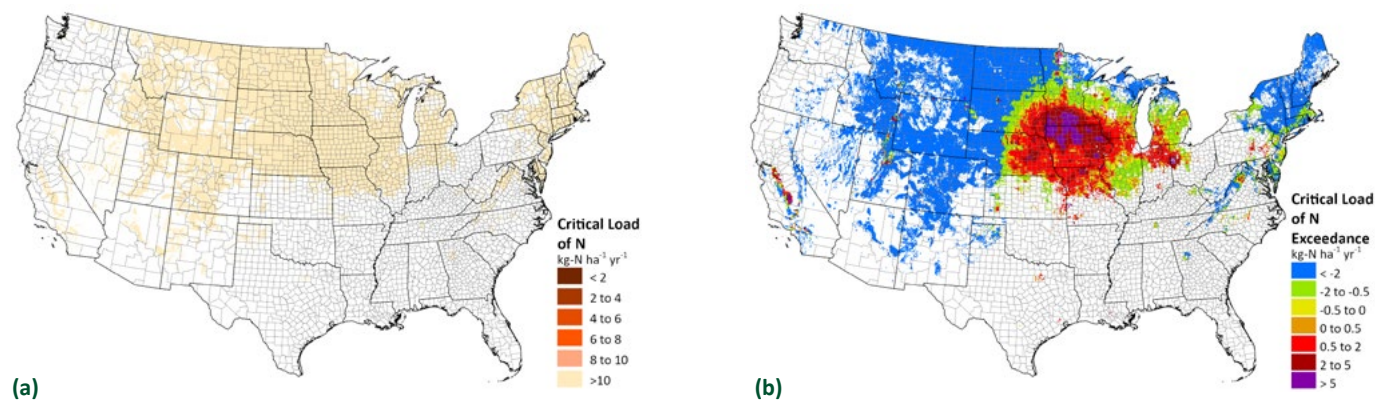


Figure A73.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Pediomelum esculentum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

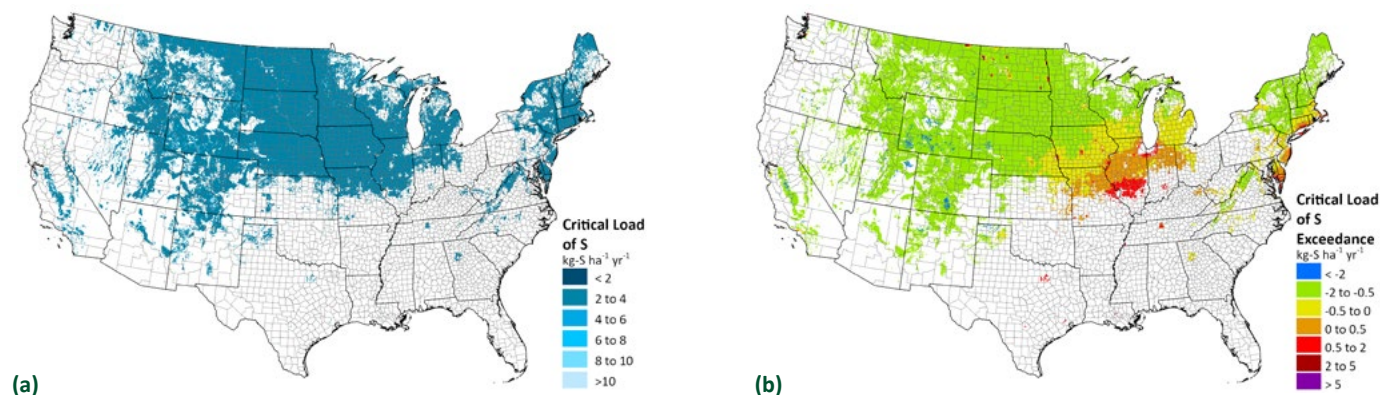


Figure A73.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Pediomelum esculentum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A74. *Phegopteris connectilis* (long beechfern)

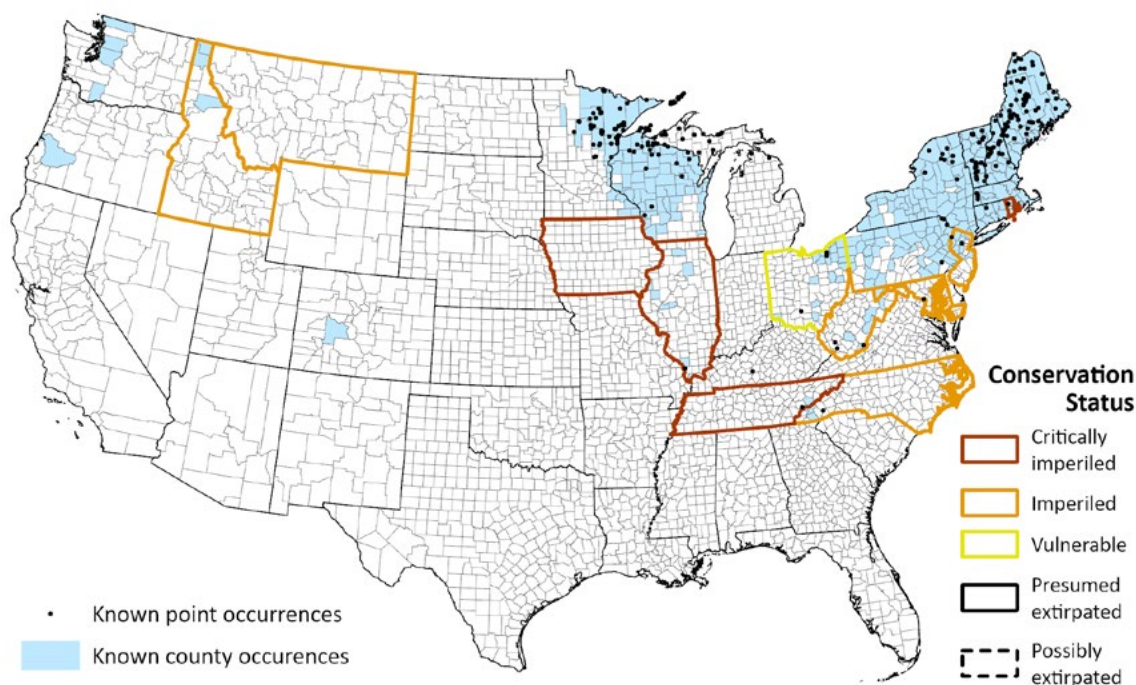


Figure A74.1. Distribution and state-level conservation status of *Phegopteris connectilis*. Known point occurrences were used to assess species deposition responses and critical loads.

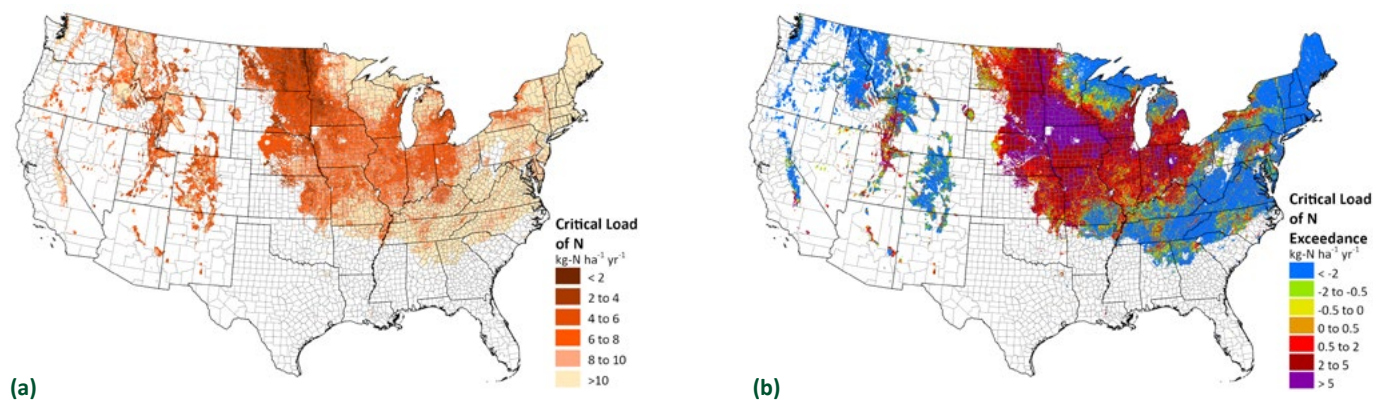


Figure A74.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Phegopteris connectilis* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

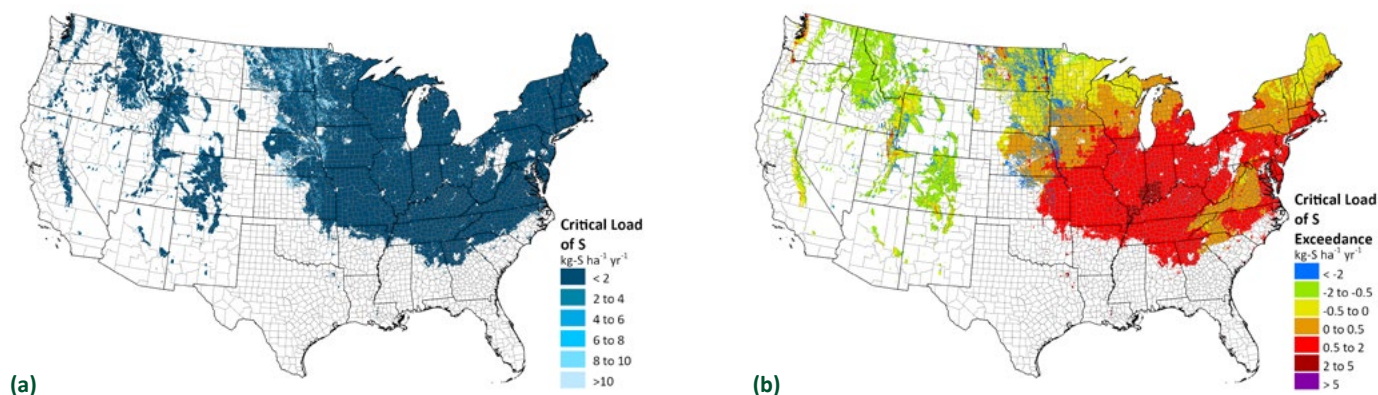


Figure A74.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Phegopteris connectilis* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A75. *Phryma leptostachya* (American lopseed)

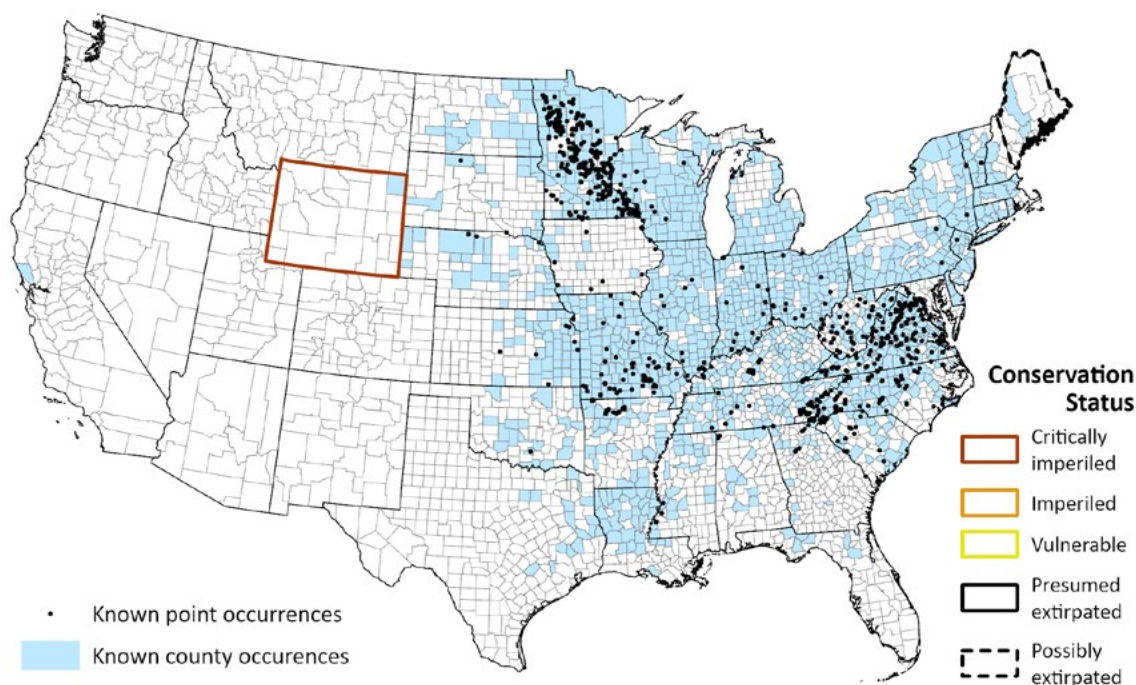


Figure A75.1. Distribution and state-level conservation status of *Phryma leptostachya*. Known point occurrences were used to assess species deposition responses and critical loads.

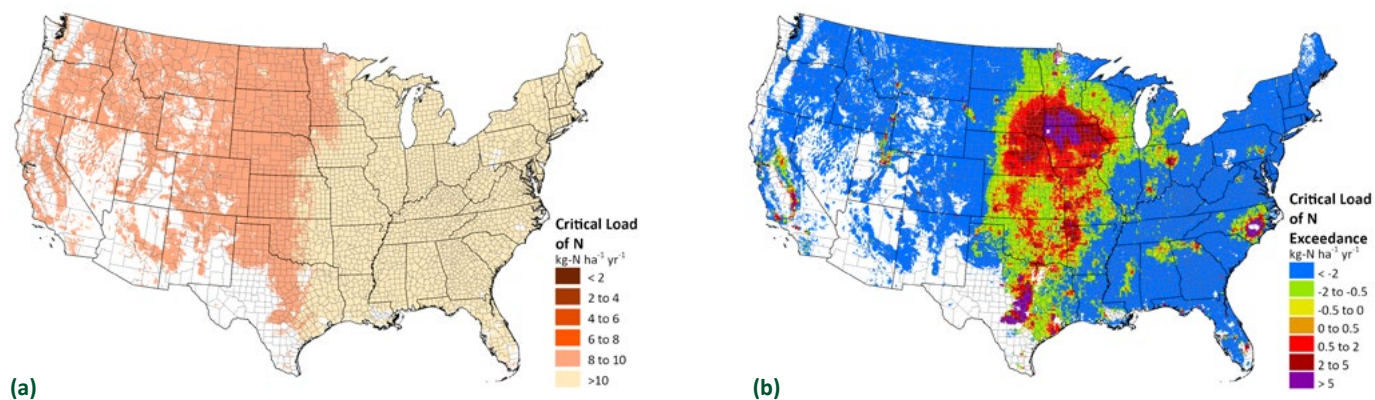


Figure A75.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Phryma leptostachya* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

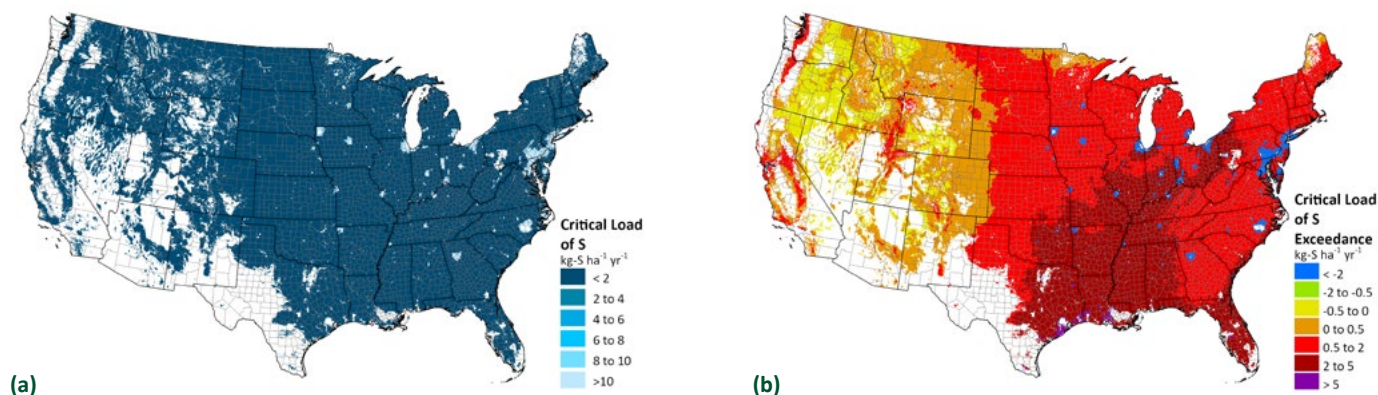


Figure A75.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Phryma leptostachya* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A76. *Phytolacca americana* (American pokeweed)

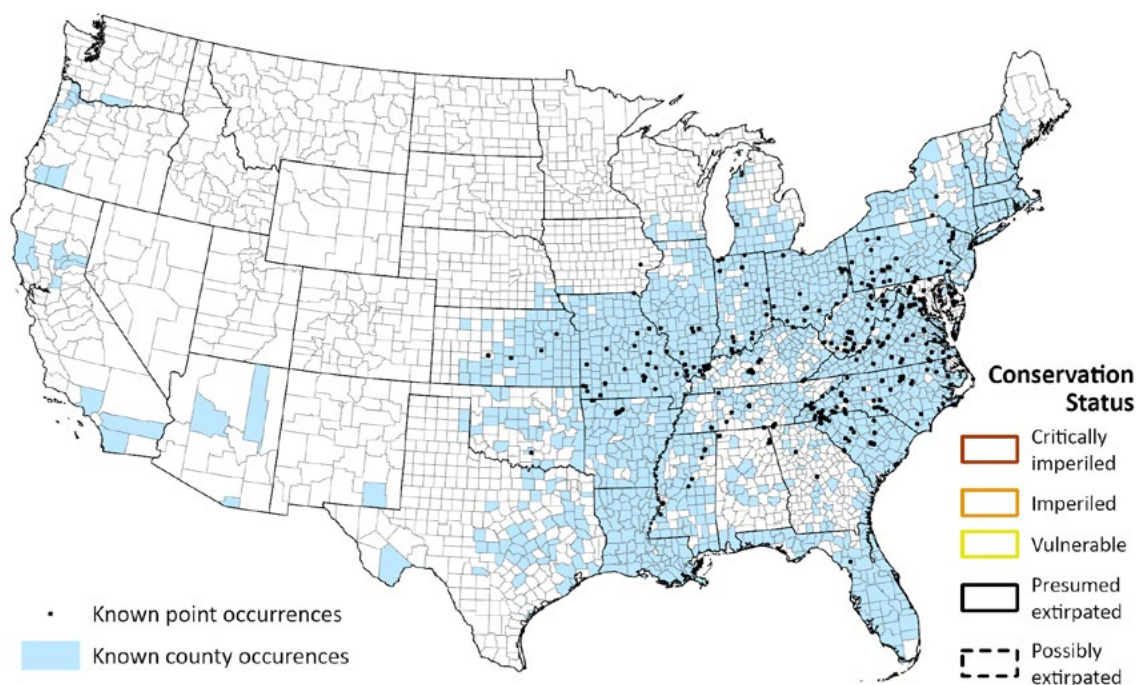


Figure A76.1. Distribution and state-level conservation status of *Phytolacca americana*. Known point occurrences were used to assess species deposition responses and critical loads.

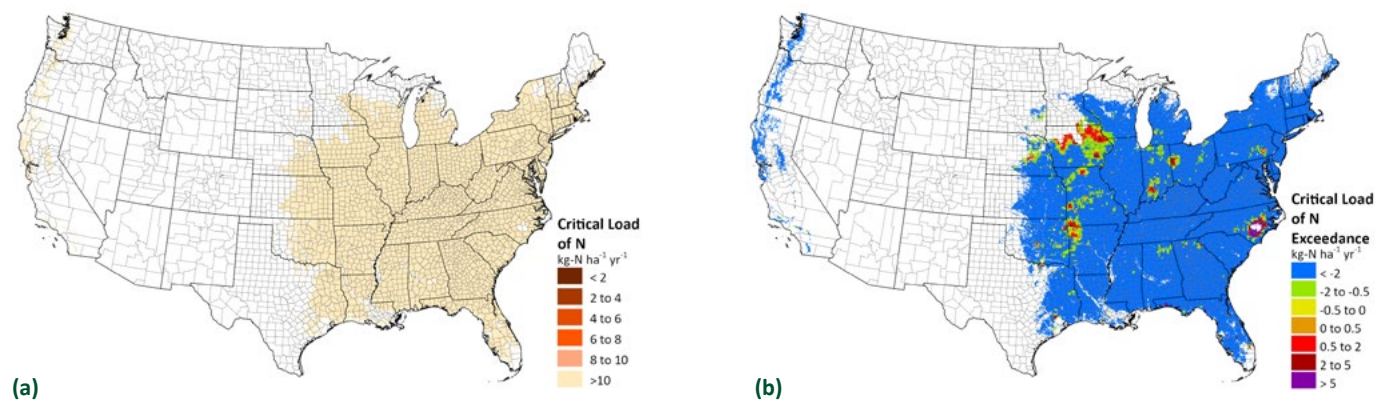


Figure A76.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Phytolacca americana* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

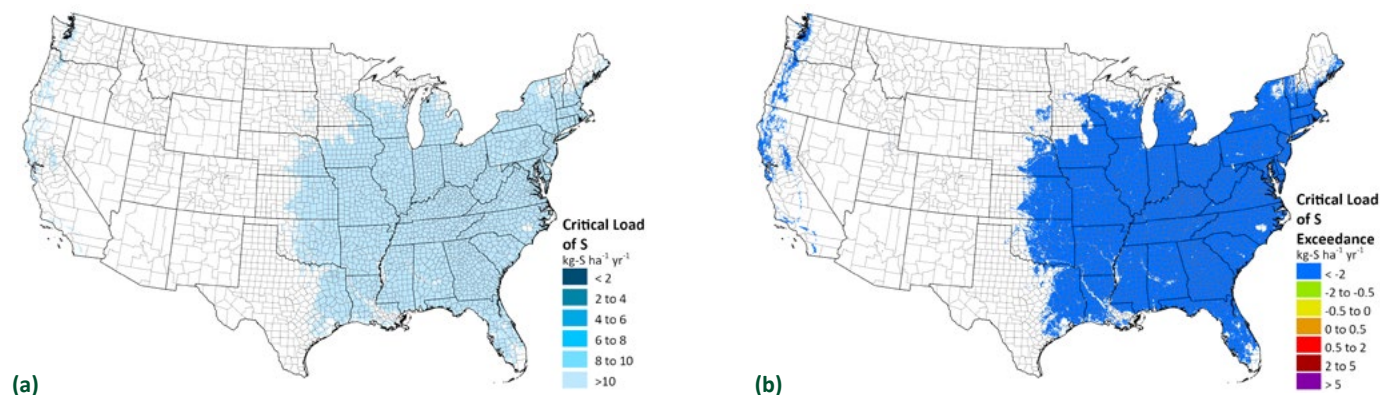


Figure A76.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Phytolacca americana* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A77. *Pilea pumila* (Canadian clearweed)

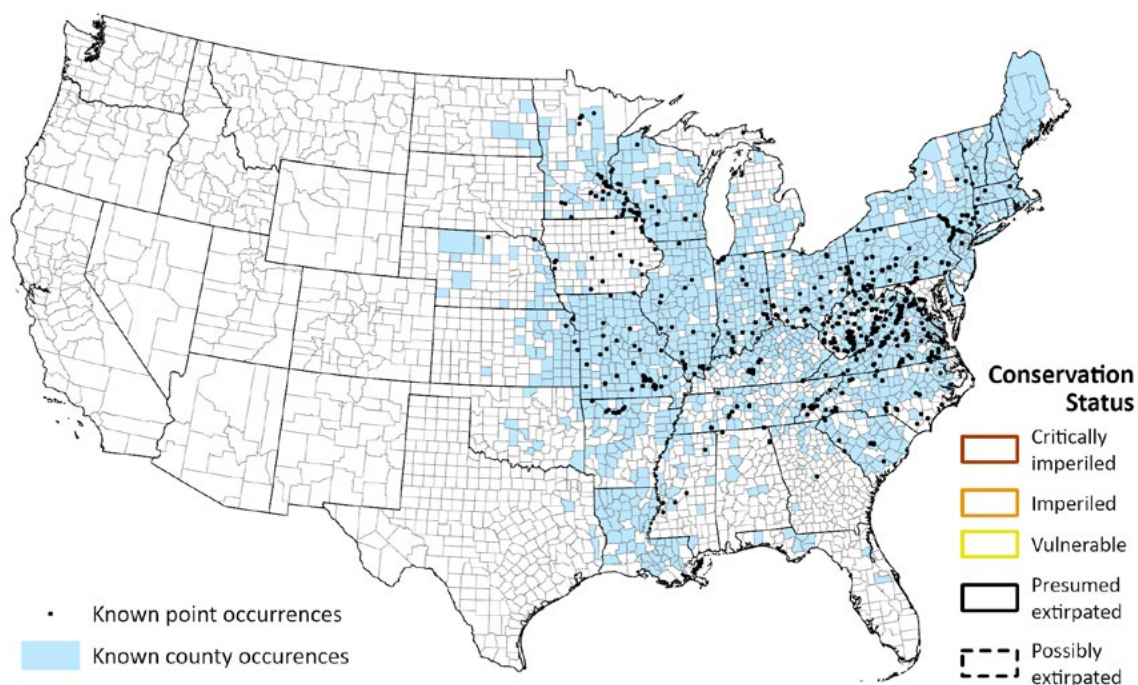


Figure A77.1. Distribution and state-level conservation status of *Pilea pumila*. Known point occurrences were used to assess species deposition responses and critical loads.

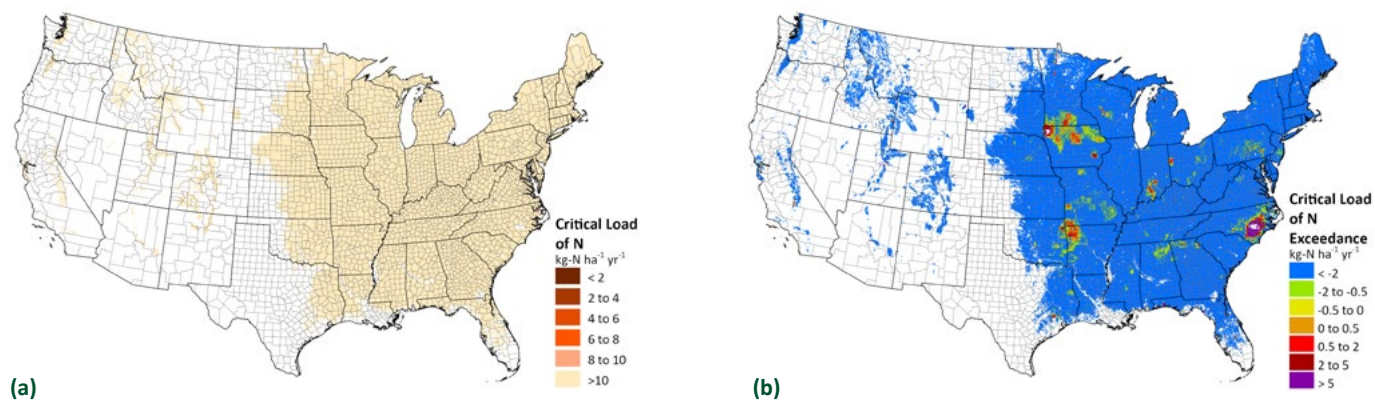


Figure A77.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Pilea pumila* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

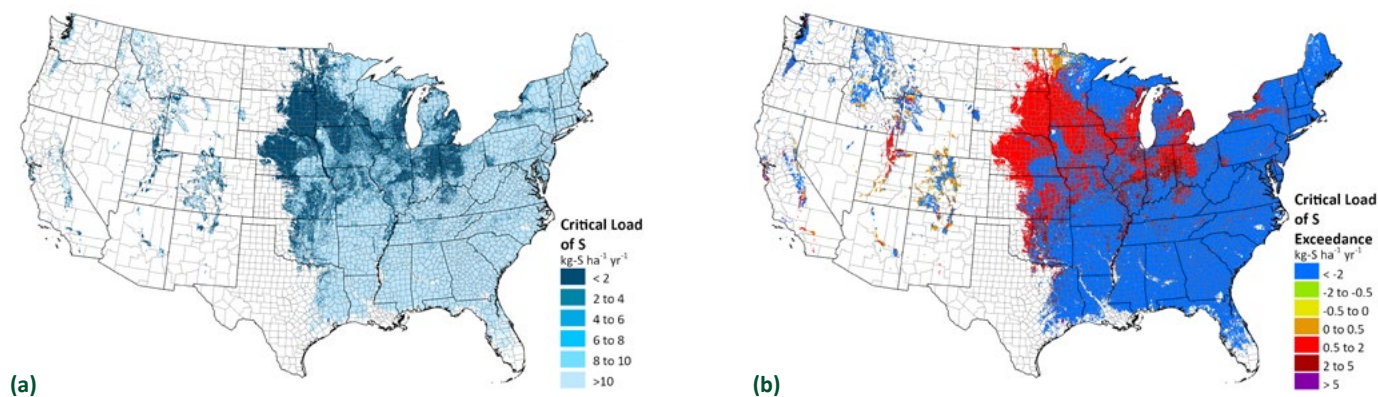


Figure A77.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Pilea pumila* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A78. *Poa cuspidata* (early bluegrass)

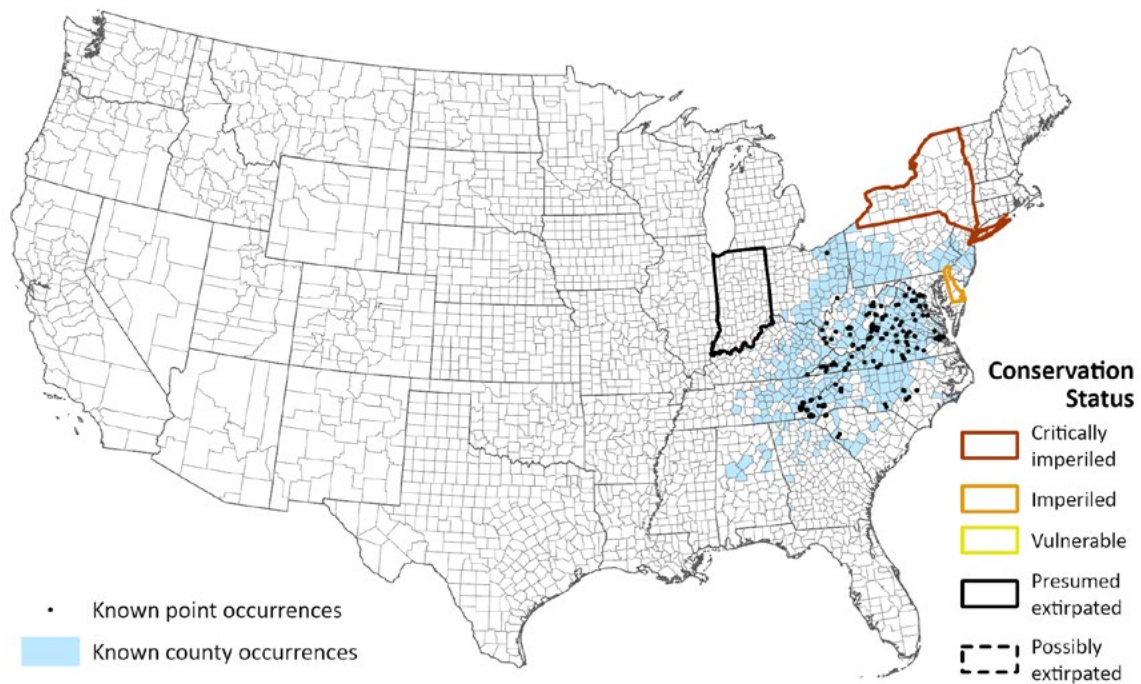


Figure A78.1. Distribution and state-level conservation status of *Poa cuspidata*. Known point occurrences were used to assess species deposition responses and critical loads.

A79. *Polygonatum biflorum* (smooth Solomon's seal)

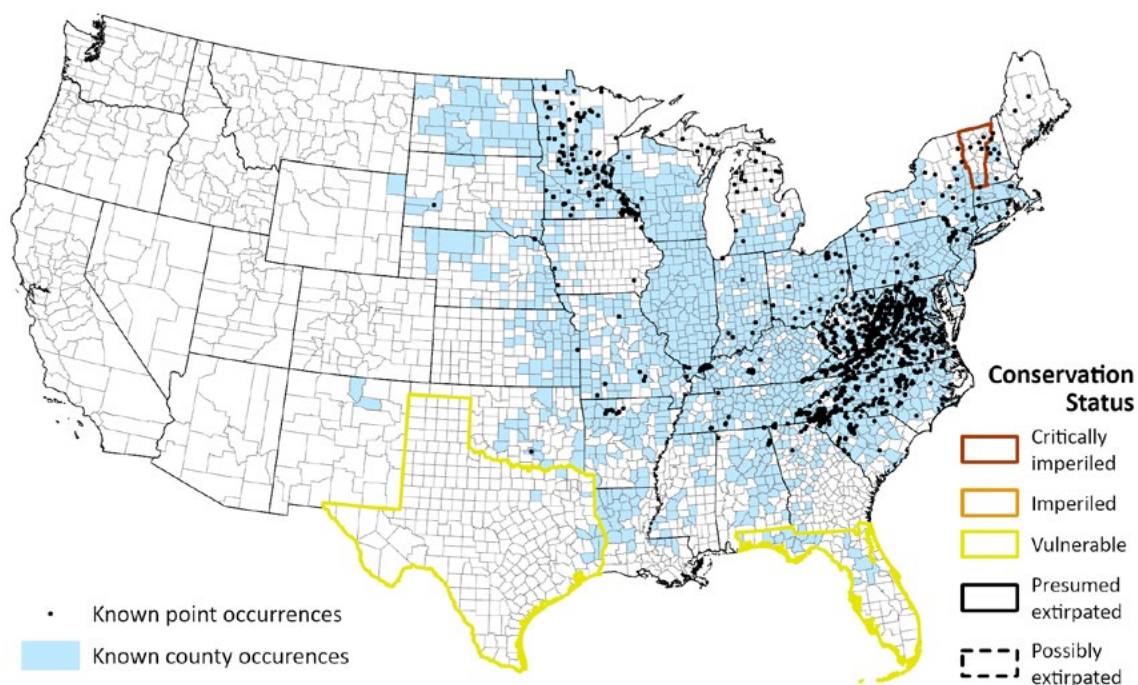


Figure A79.1. Distribution and state-level conservation status of *Polygonatum biflorum*. Known point occurrences were used to assess species deposition responses and critical loads.

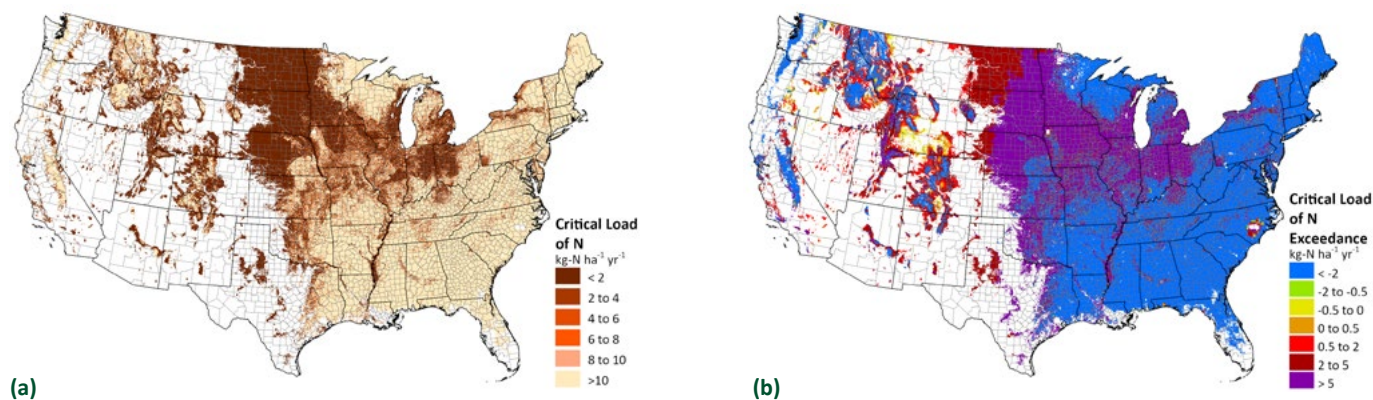


Figure A79.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Polygonatum biflorum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

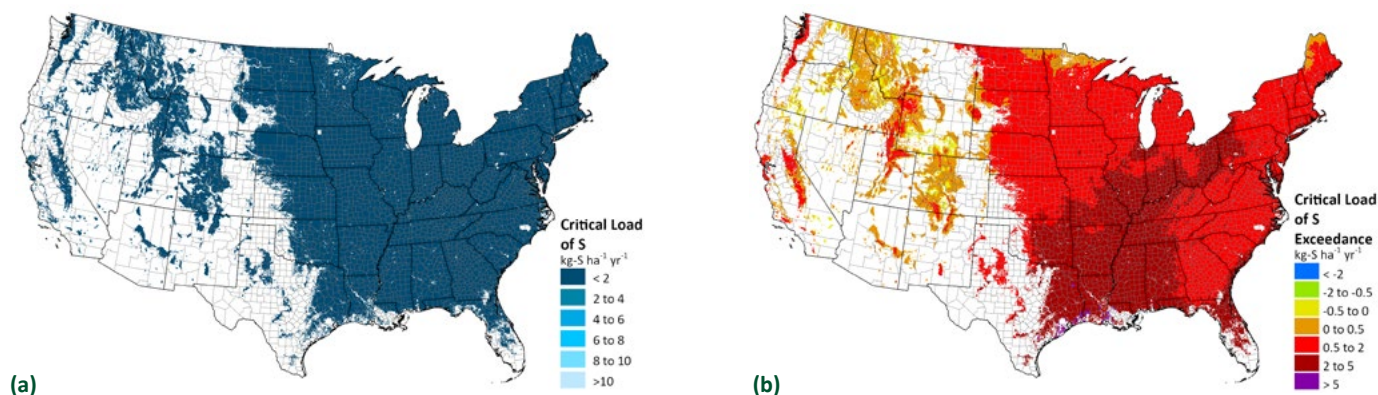


Figure A79.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Polygonatum biflorum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A80. *Polygonatum pubescens* (hairy Solomon's seal)

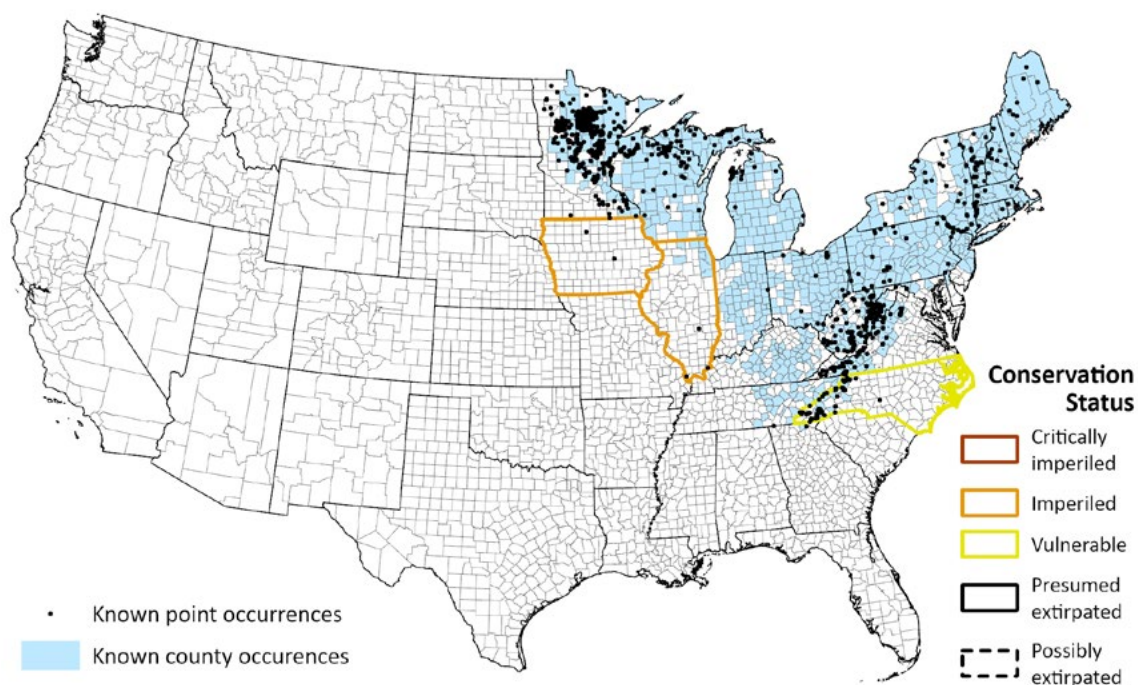


Figure A80.1. Distribution and state-level conservation status of *Polygonatum pubescens*. Known point occurrences were used to assess species deposition responses and critical loads.

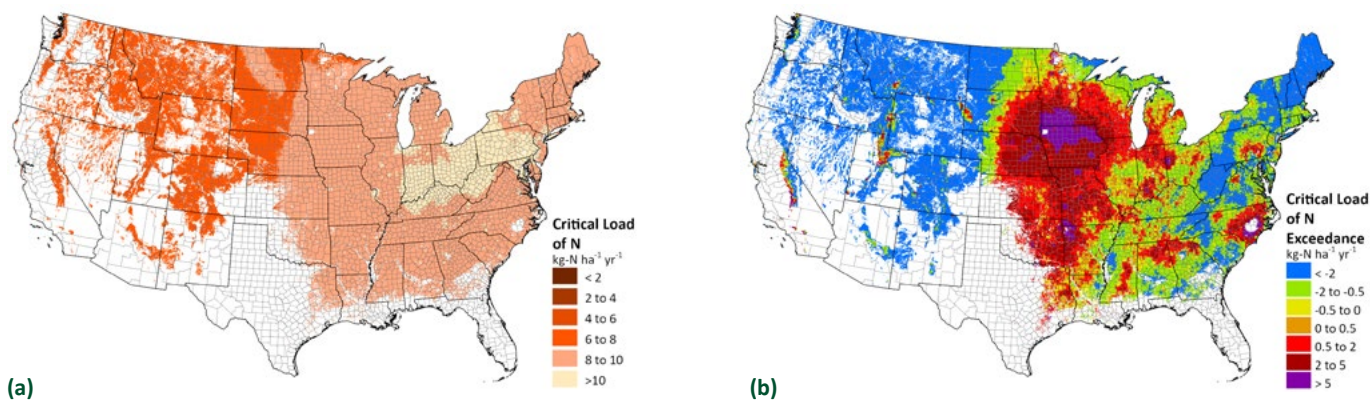


Figure A80.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Polygonatum pubescens* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

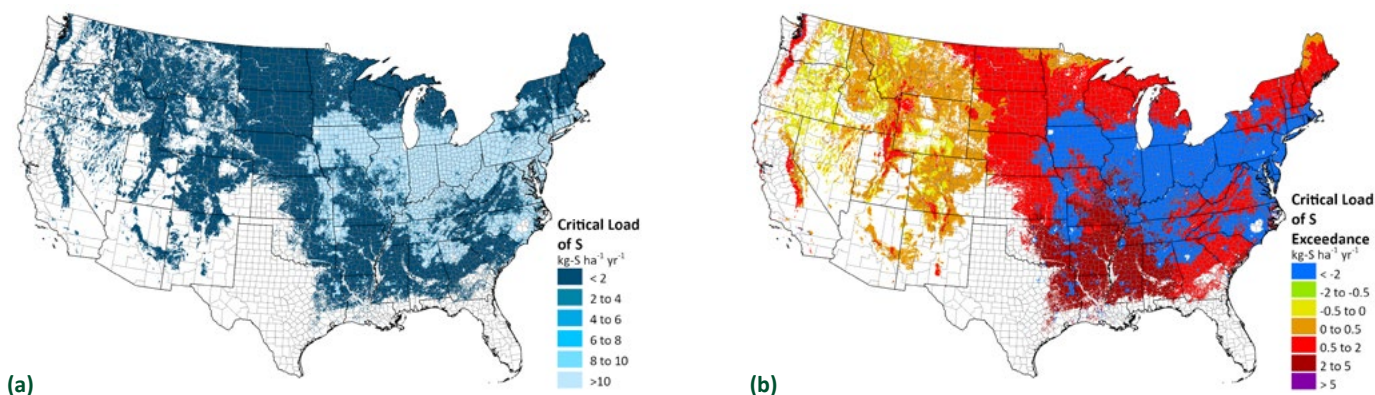


Figure A80.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Polygonatum pubescens* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A81. *Polygonum virginianum* (jumpseed)

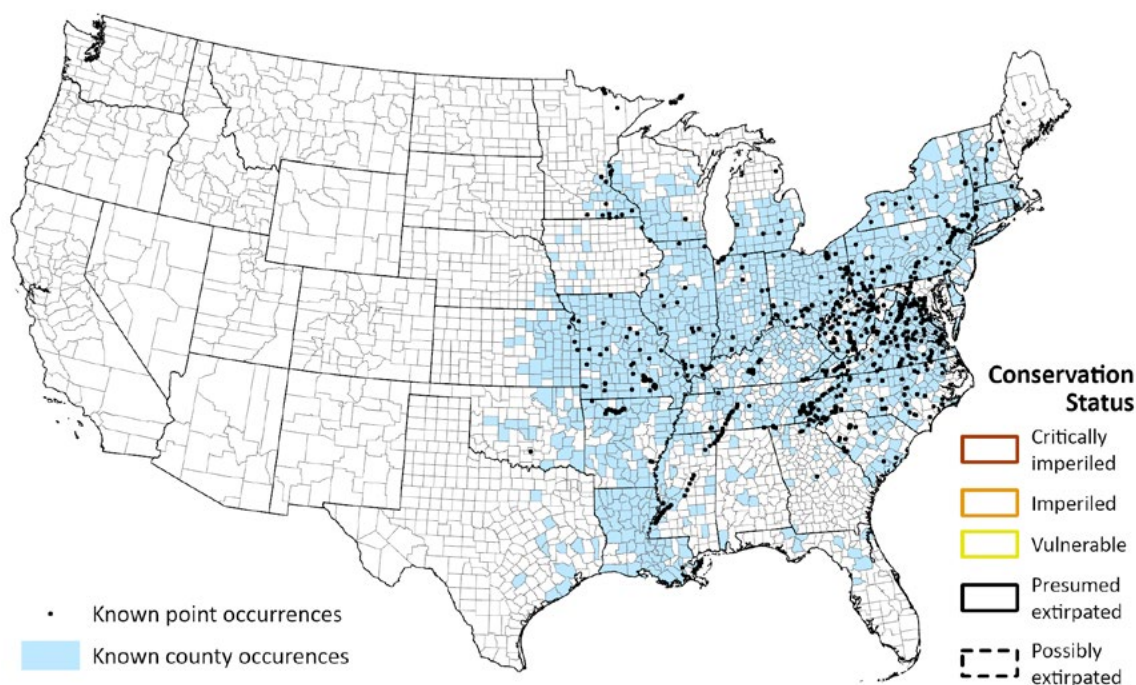


Figure A81.1. Distribution and state-level conservation status of *Polygonum virginianum*. Known point occurrences were used to assess species deposition responses and critical loads.

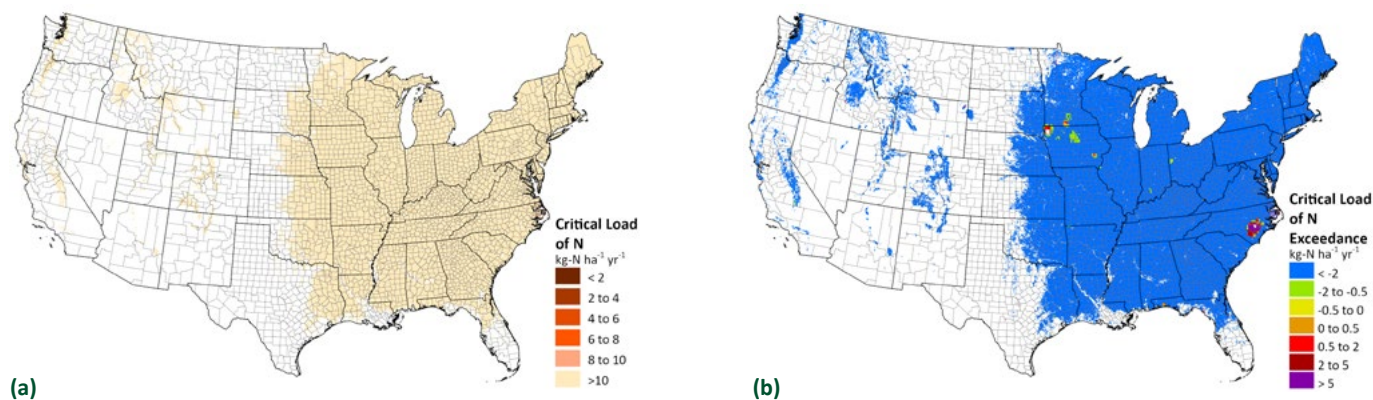


Figure A81.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Polygonum virginianum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

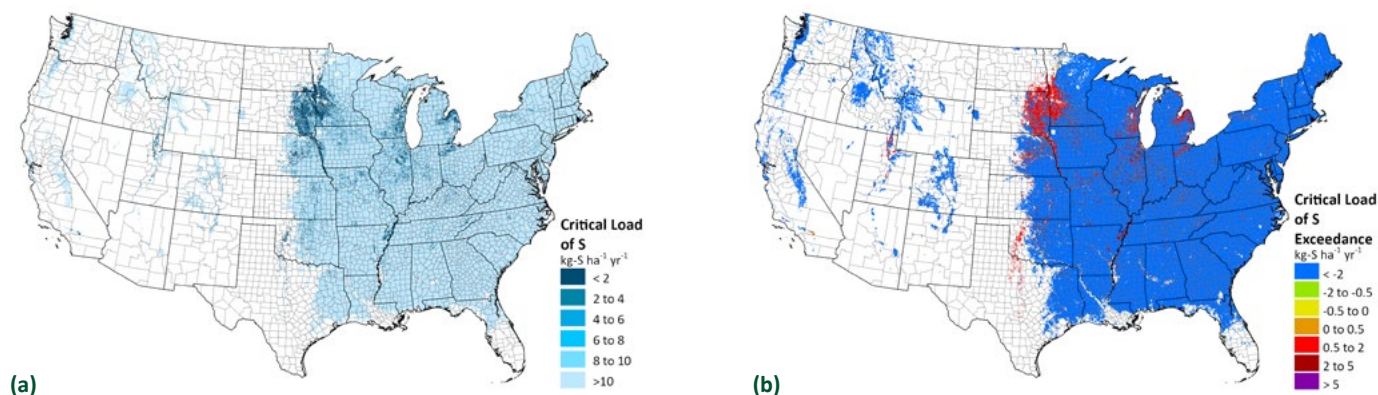


Figure A81.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Polygonum virginianum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A82. *Polypodium appalachianum* (Appalachian polypody)

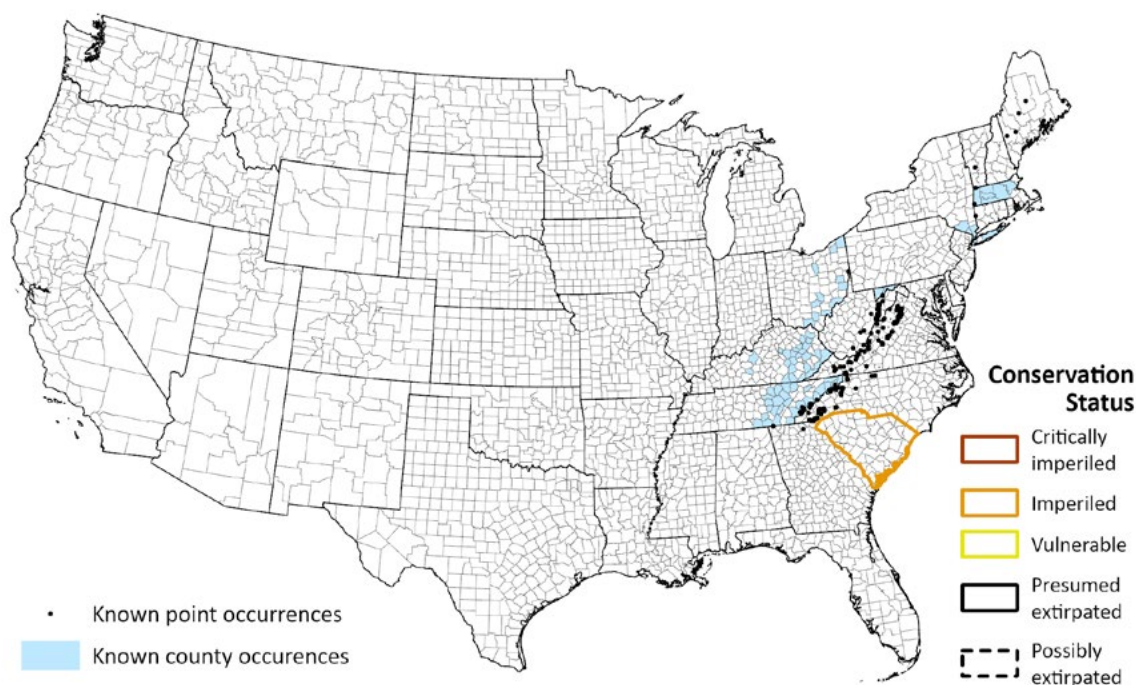


Figure A82.1. Distribution and state-level conservation status of *Polypodium appalachianum*. Known point occurrences were used to assess species deposition responses and critical loads.

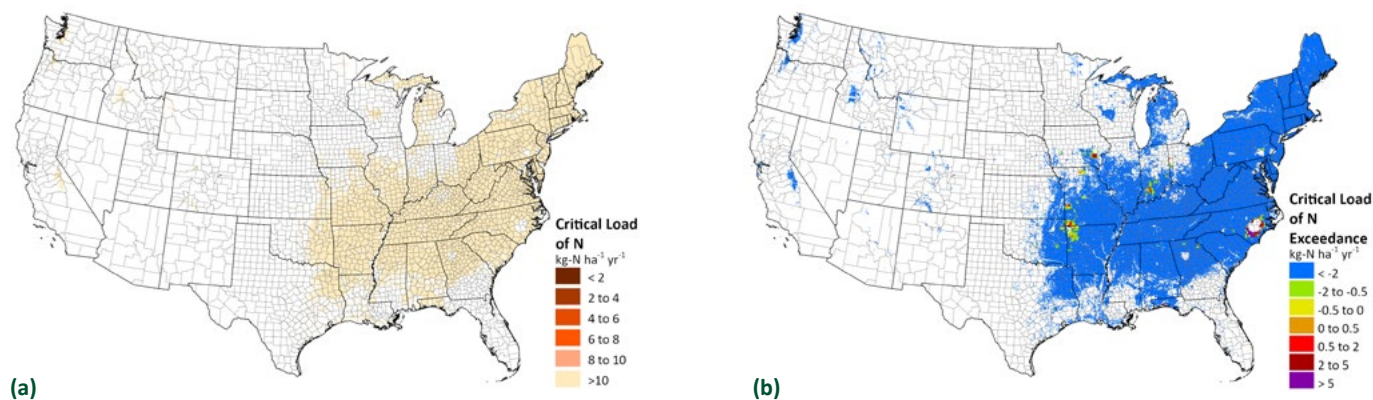


Figure A82.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Polypodium appalachianum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

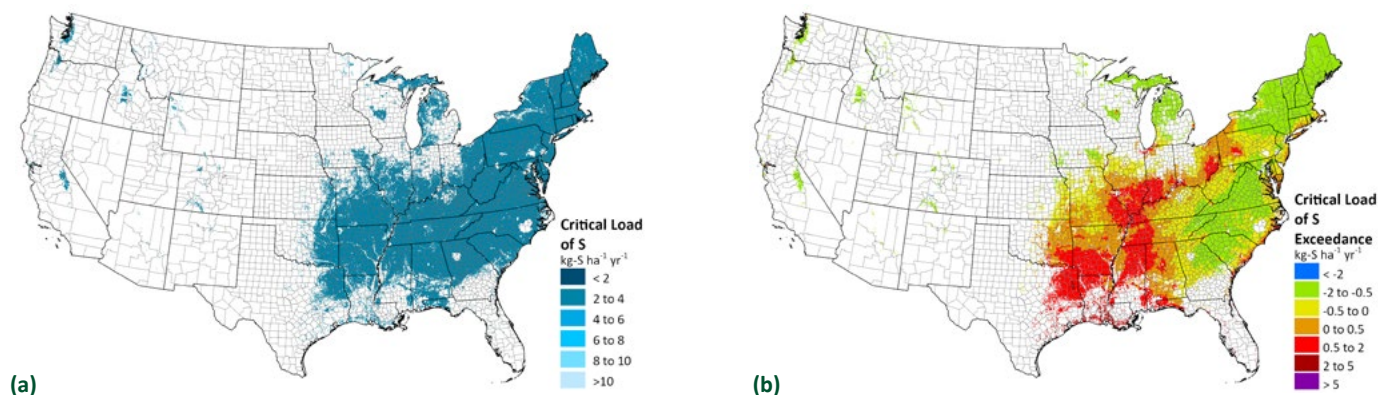


Figure A82.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Polypodium appalachianum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A83. *Prenanthes racemosa* (purple rattlesnakeroot)

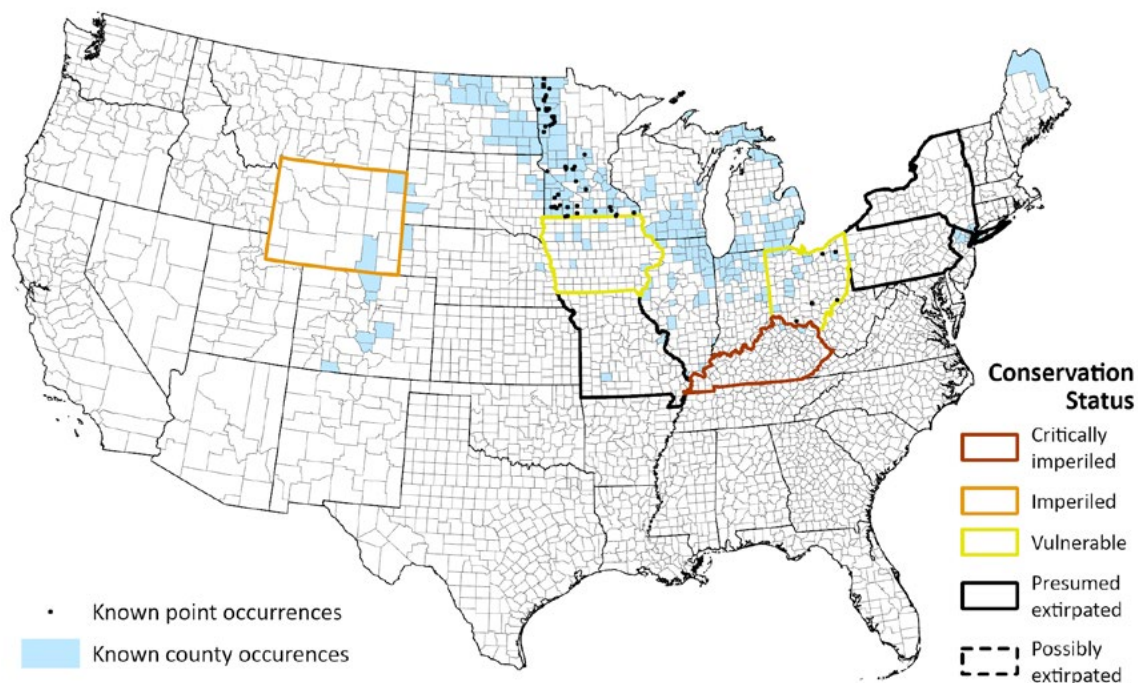


Figure A83.1. Distribution and state-level conservation status of *Prenanthes racemosa*. Known point occurrences were used to assess species deposition responses and critical loads.

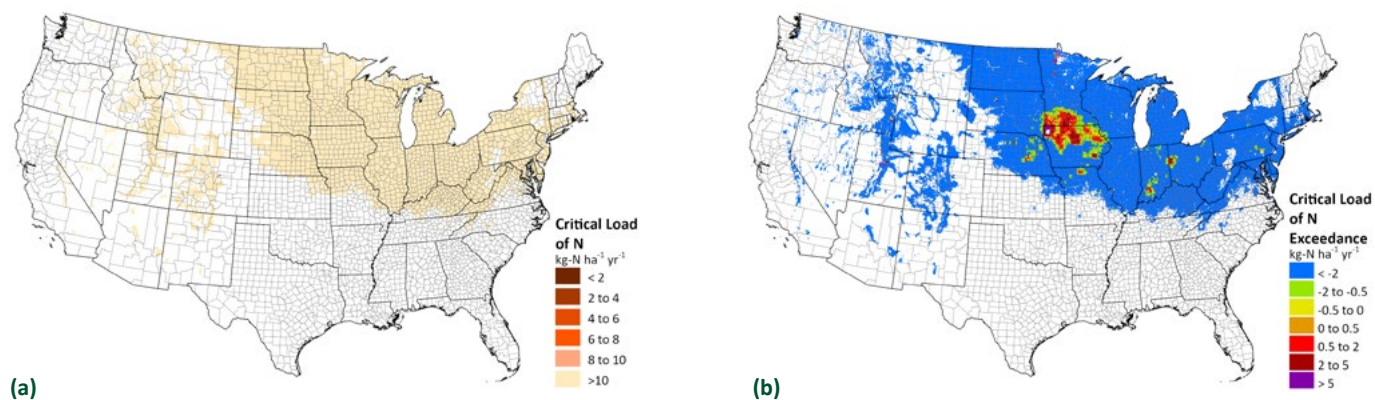


Figure A83.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Prenanthes racemosa* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

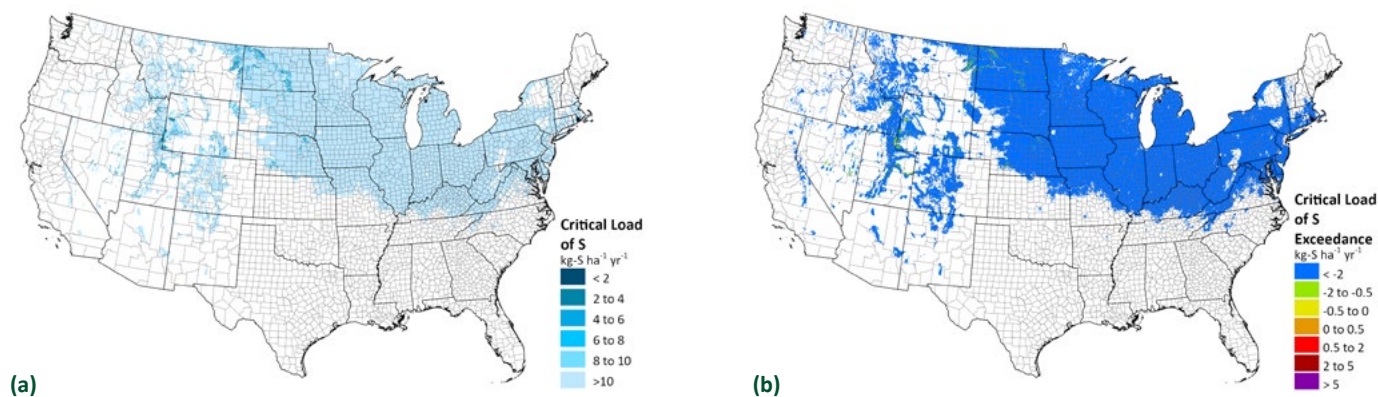


Figure A83.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Prenanthes racemosa* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A84. *Prosartes lanuginosa* (yellow fairybells)

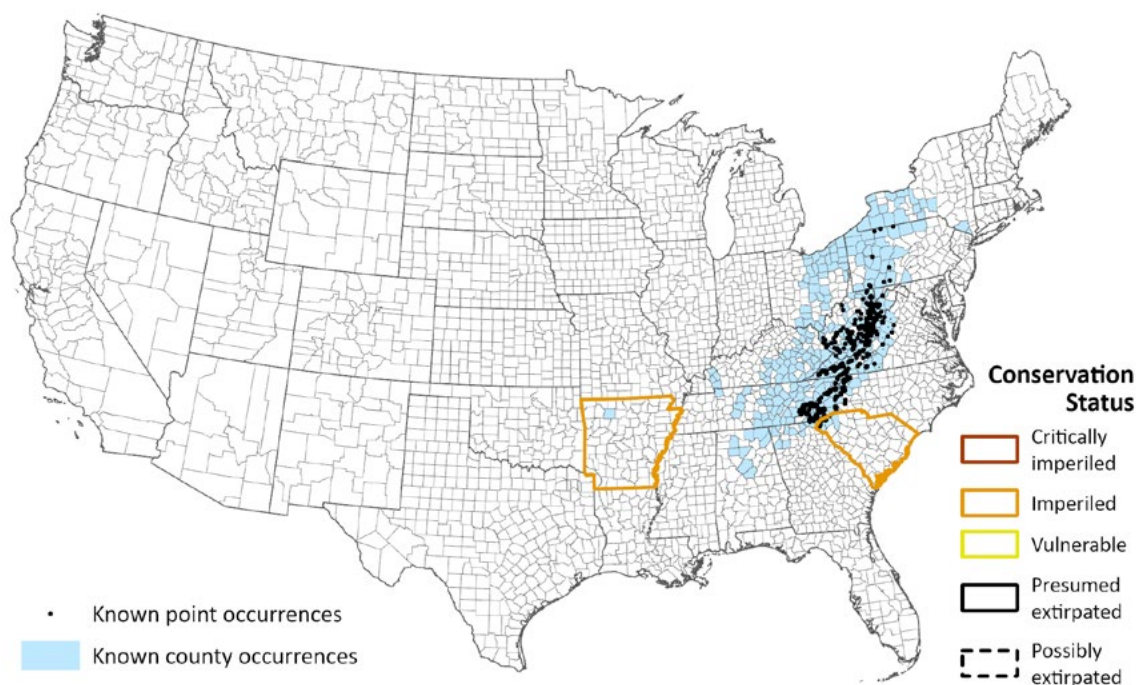


Figure A84.1. Distribution and state-level conservation status of *Prosartes lanuginosa*. Known point occurrences were used to assess species deposition responses and critical loads.

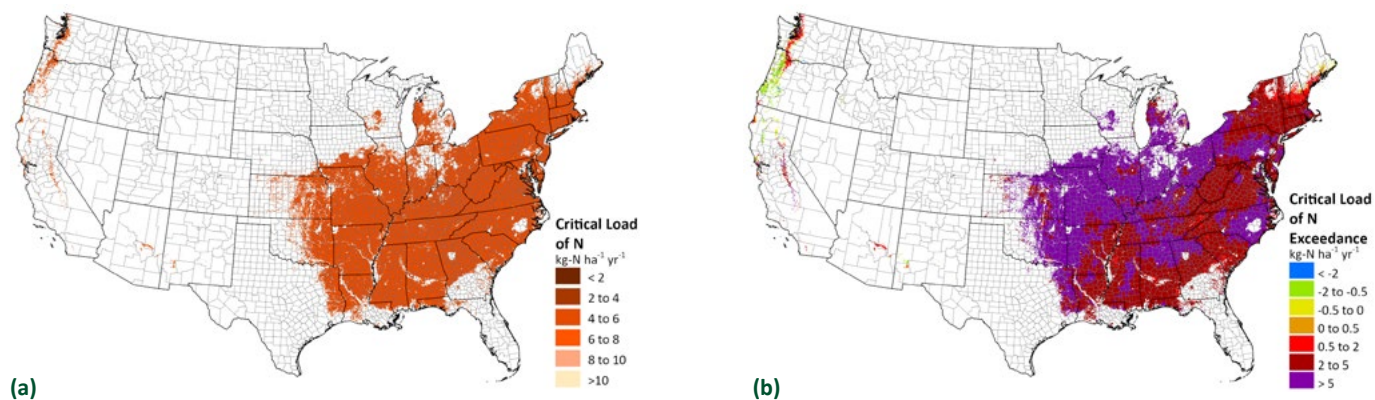


Figure A84.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Prosartes lanuginosa* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

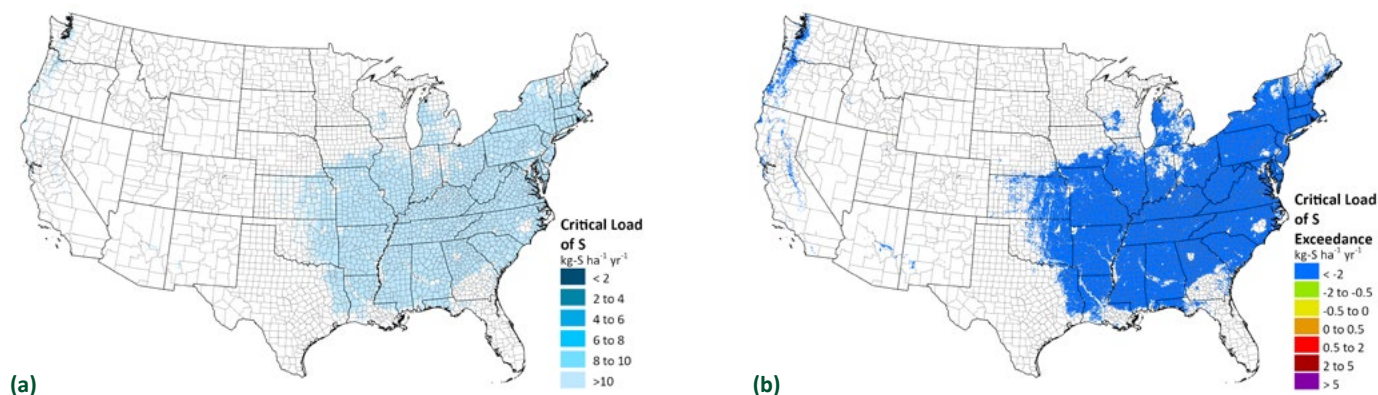


Figure A84.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Prosartes lanuginosa* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A85. *Pulsatilla patens* (eastern pasqueflower)

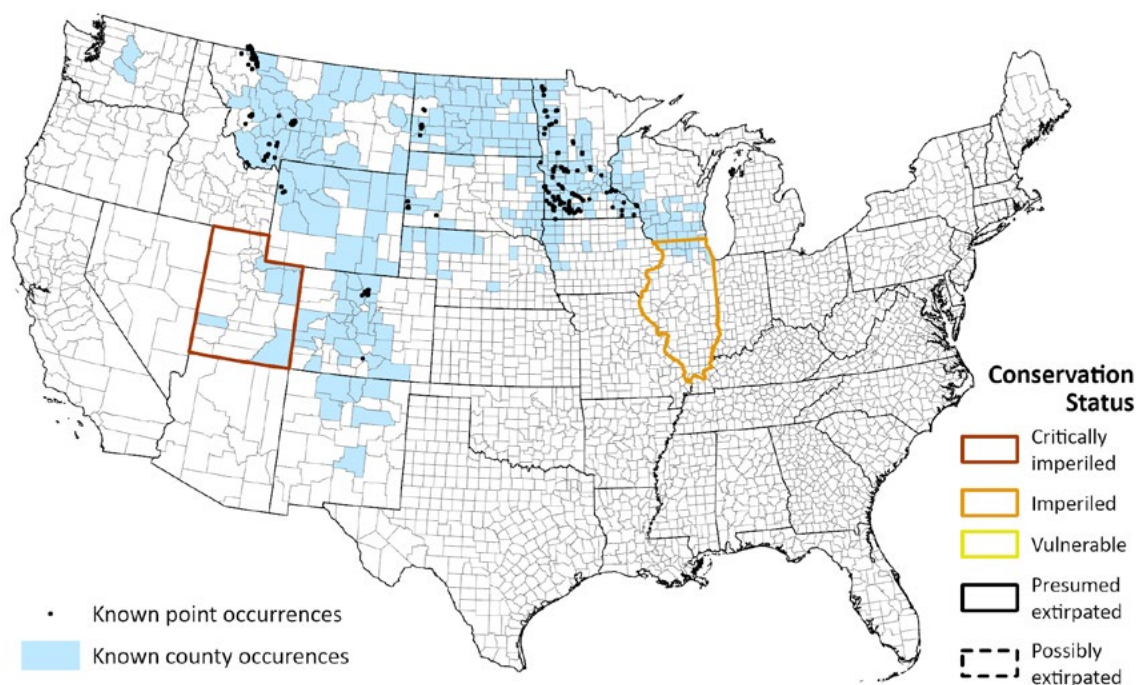


Figure A85.1. Distribution and state-level conservation status of *Pulsatilla patens*. Known point occurrences were used to assess species deposition responses and critical loads.

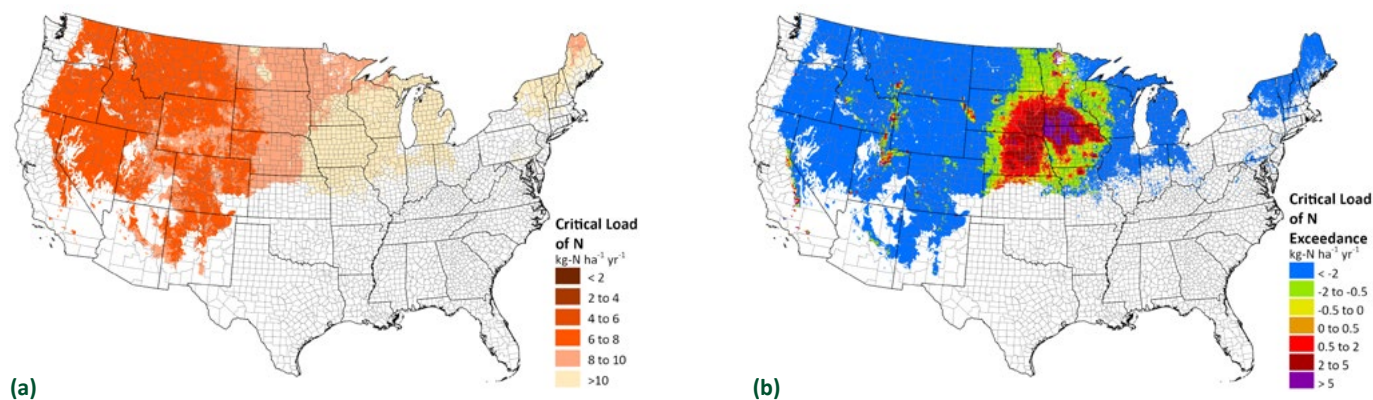


Figure A85.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Pulsatilla patens* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

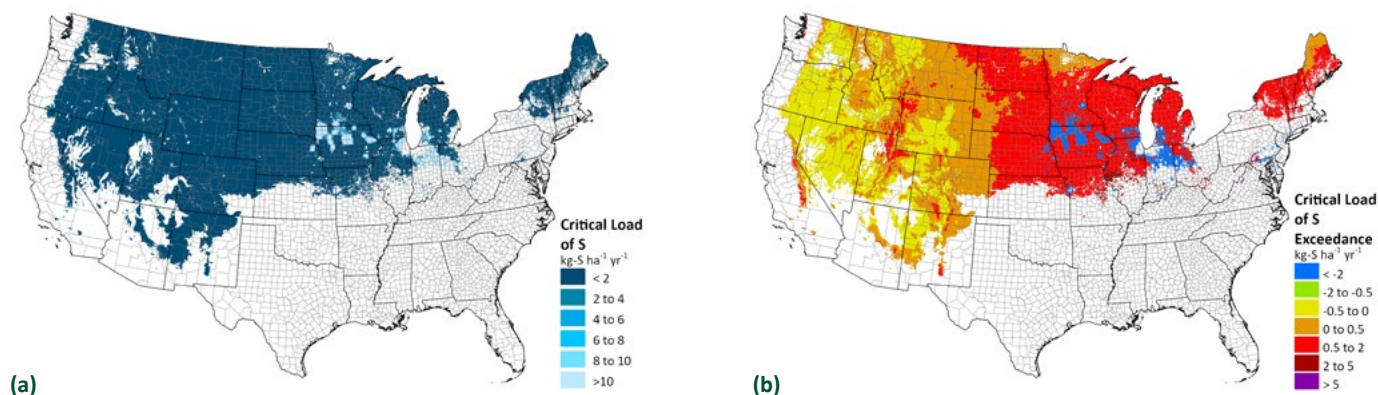


Figure A85.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Pulsatilla patens* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A86. *Pycnanthemum virginianum* (Virginia mountainmint)

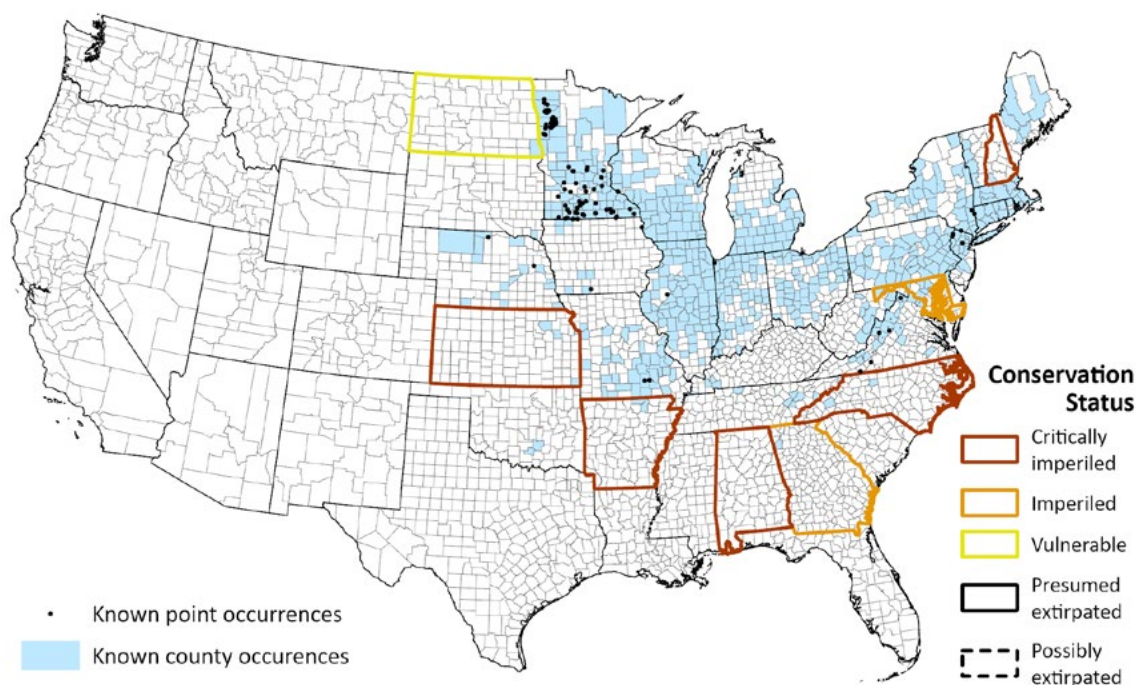


Figure A86.1. Distribution and state-level conservation status of *Pycnanthemum virginianum*. Known point occurrences were used to assess species deposition responses and critical loads.

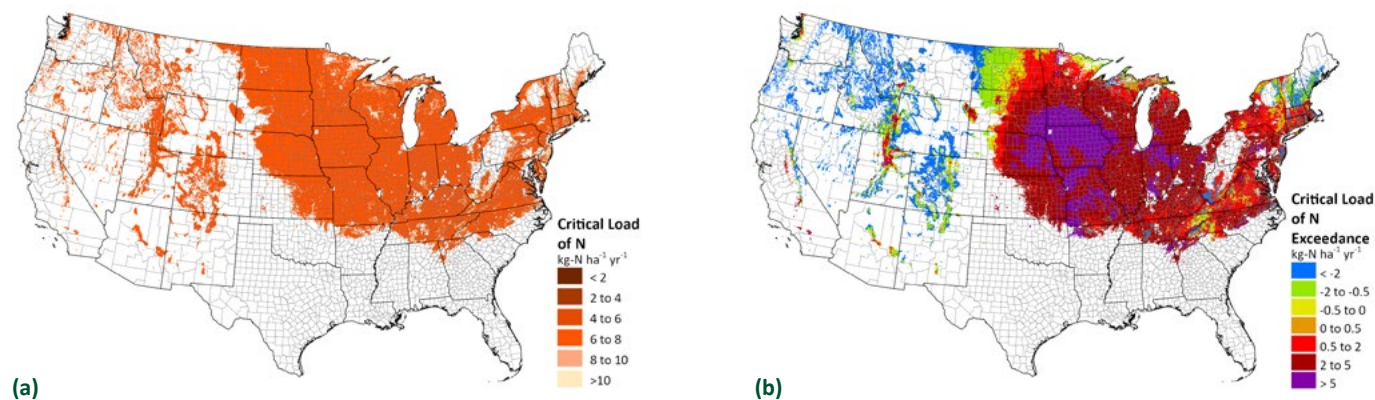


Figure A86.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Pycnanthemum virginianum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

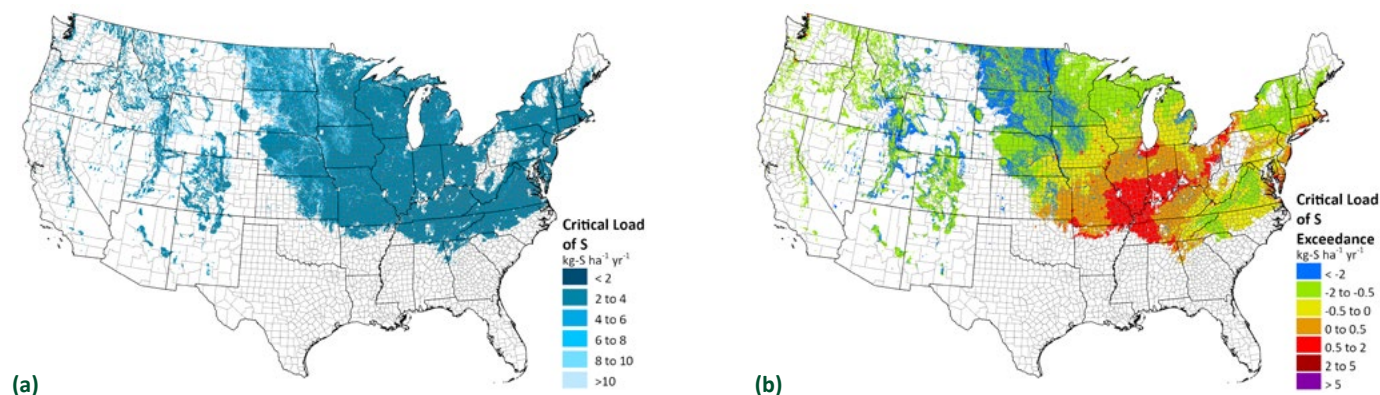


Figure A86.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Pycnanthemum virginianum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A87. *Ranunculus hispidus* (bristly buttercup)

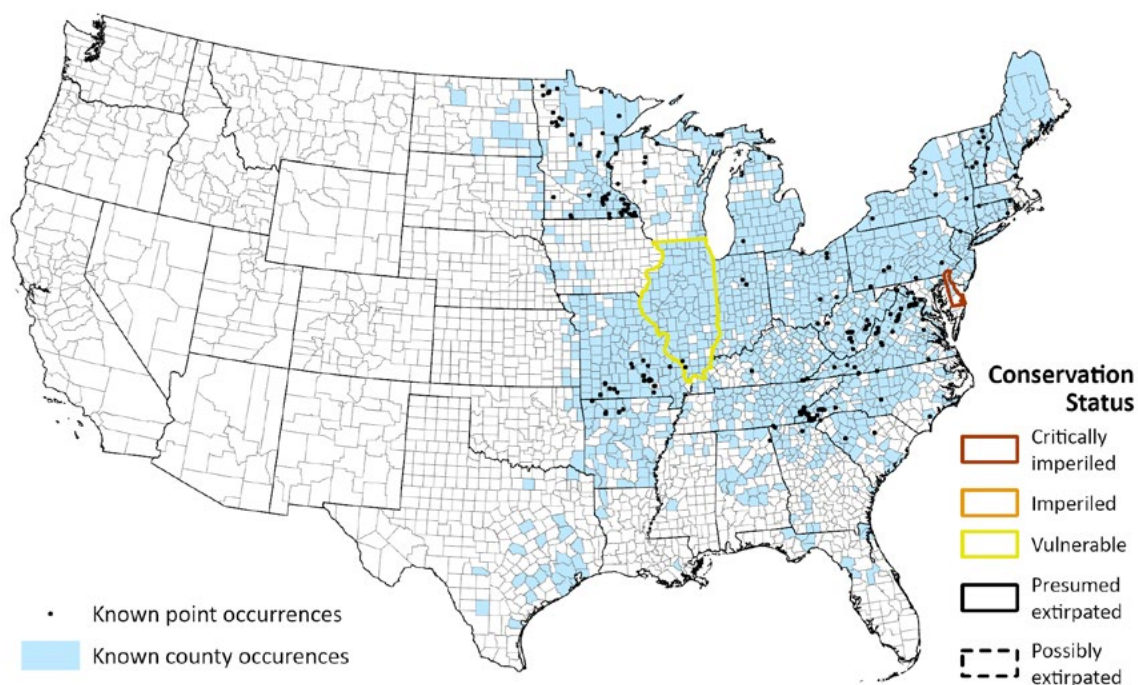


Figure A87.1. Distribution and state-level conservation status of *Ranunculus hispidus*. Known point occurrences were used to assess species deposition responses and critical loads.

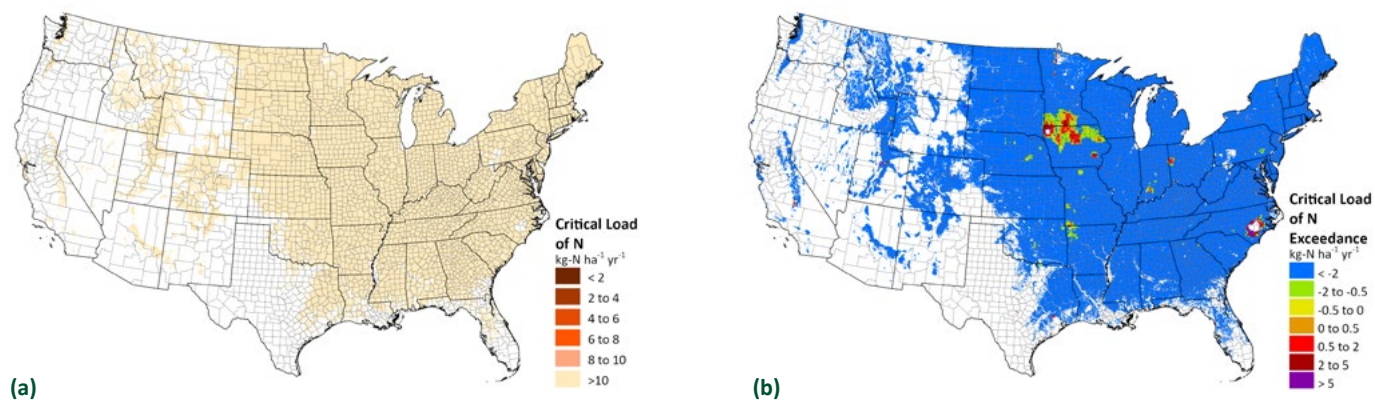


Figure A87.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Ranunculus hispidus* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

A88. *Ranunculus recurvatus* (blisterwort)

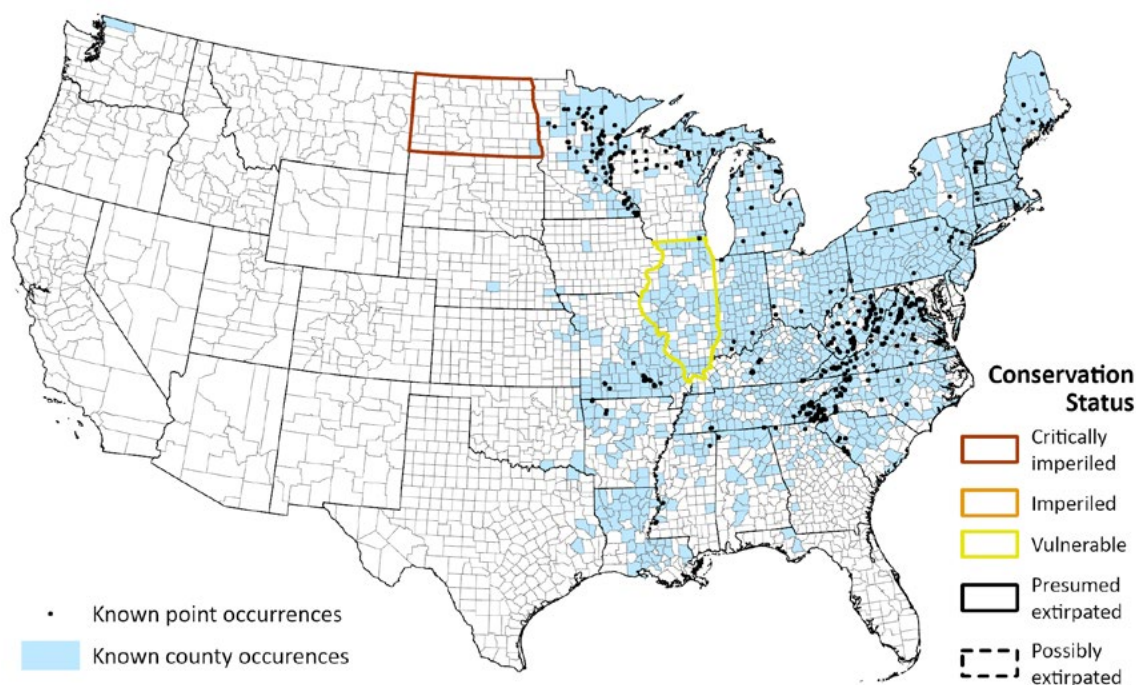


Figure A88.1. Distribution and state-level conservation status of *Ranunculus recurvatus*. Known point occurrences were used to assess species deposition responses and critical loads.

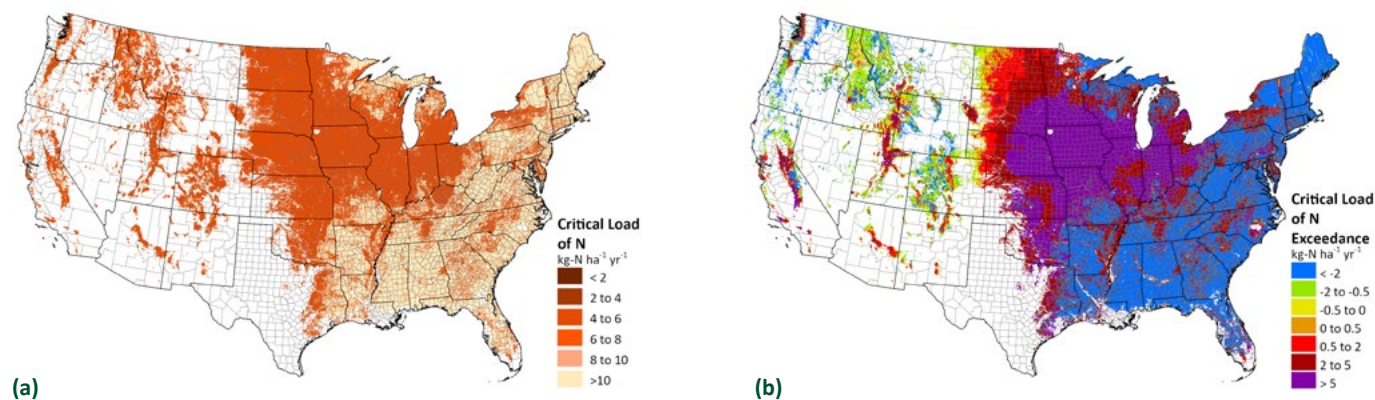


Figure A88.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Ranunculus recurvatus* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

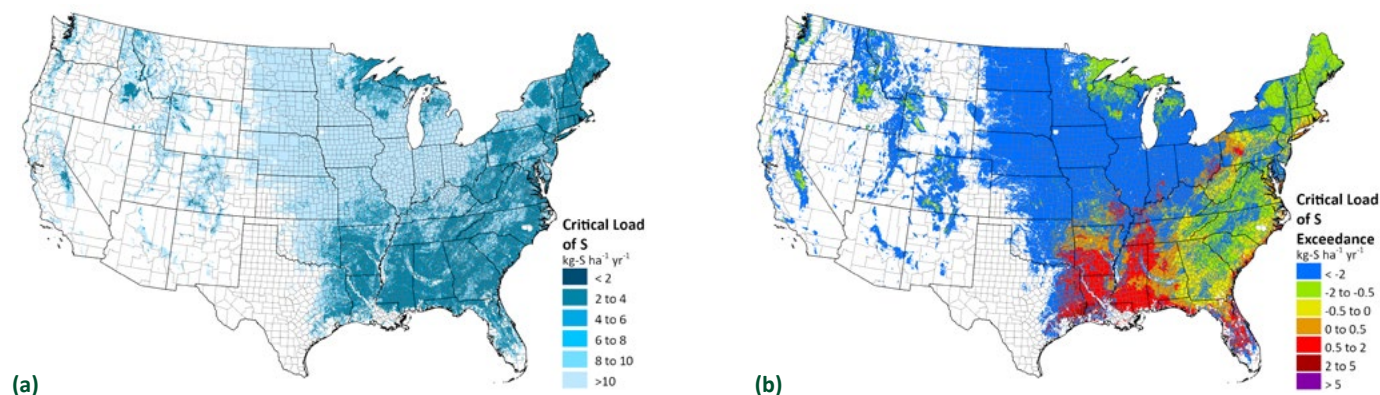


Figure A88.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Ranunculus recurvatus* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A89. *Sanguinaria canadensis* (bloodroot)

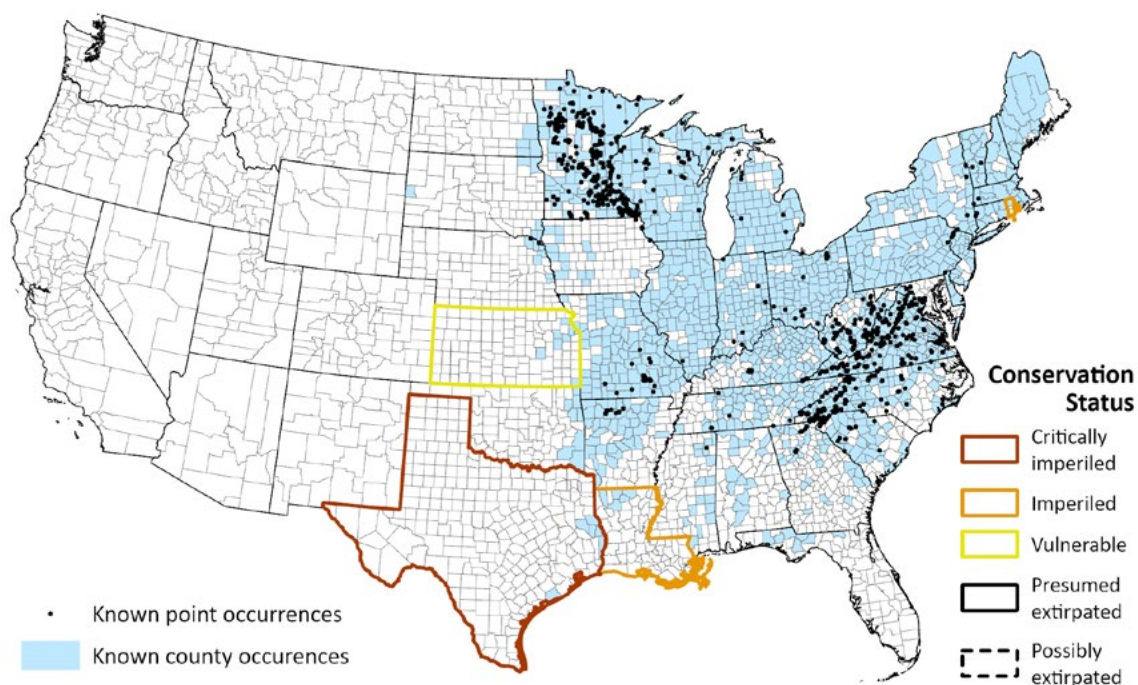


Figure A89.1. Distribution and state-level conservation status of *Sanguinaria canadensis*. Known point occurrences were used to assess species deposition responses and critical loads.

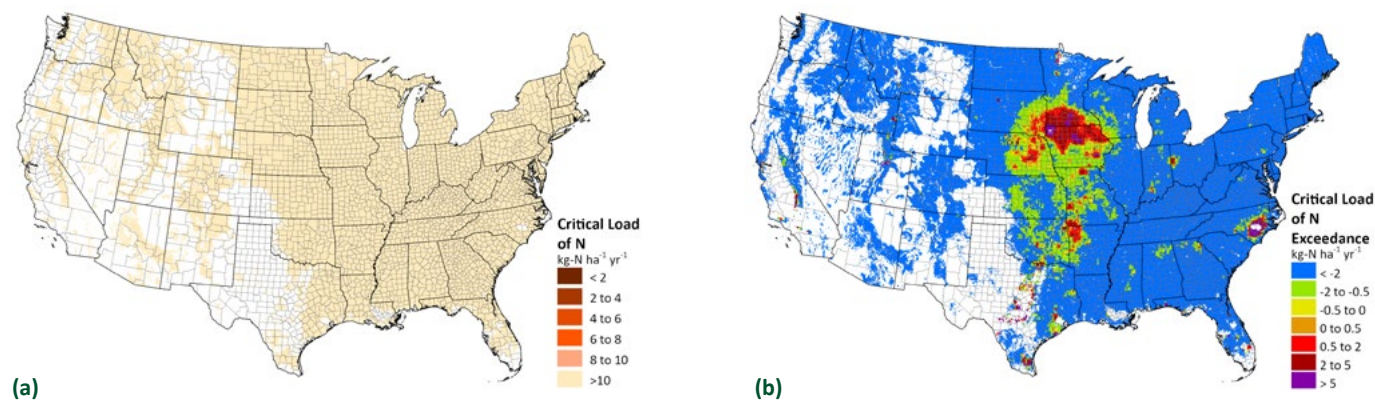


Figure A89.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Sanguinaria canadensis* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

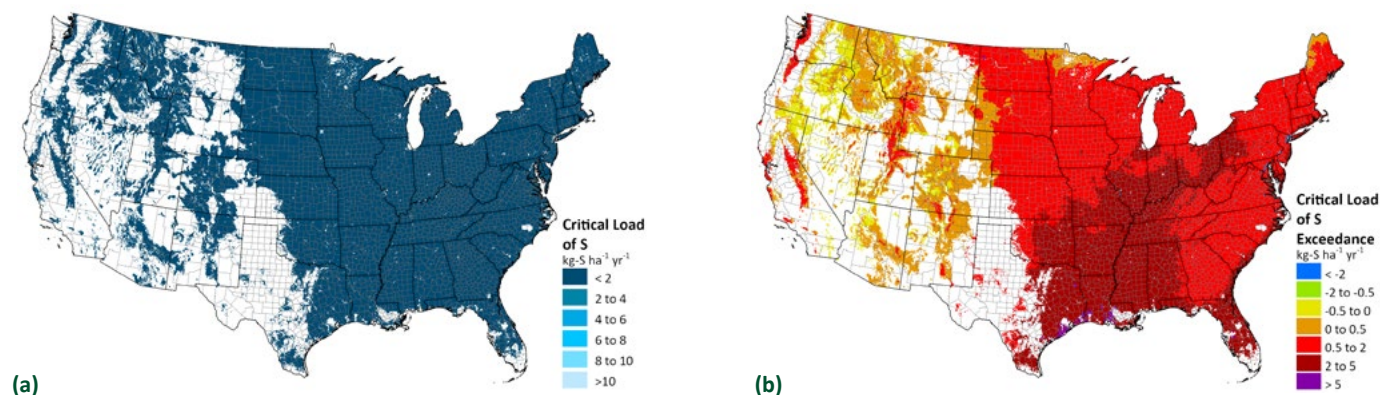


Figure A89.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Sanguinaria canadensis* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A90. *Sanicula canadensis* (Canadian blacksnakeroot)

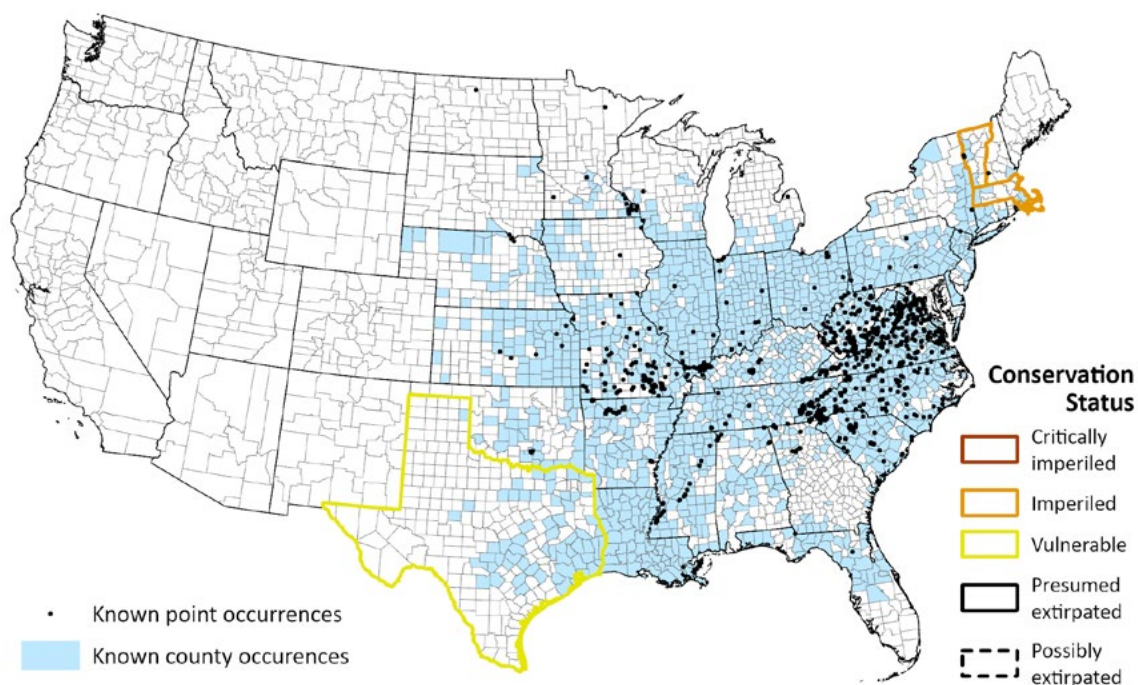


Figure A90.1. Distribution and state-level conservation status of *Sanicula canadensis*. Known point occurrences were used to assess species deposition responses and critical loads.

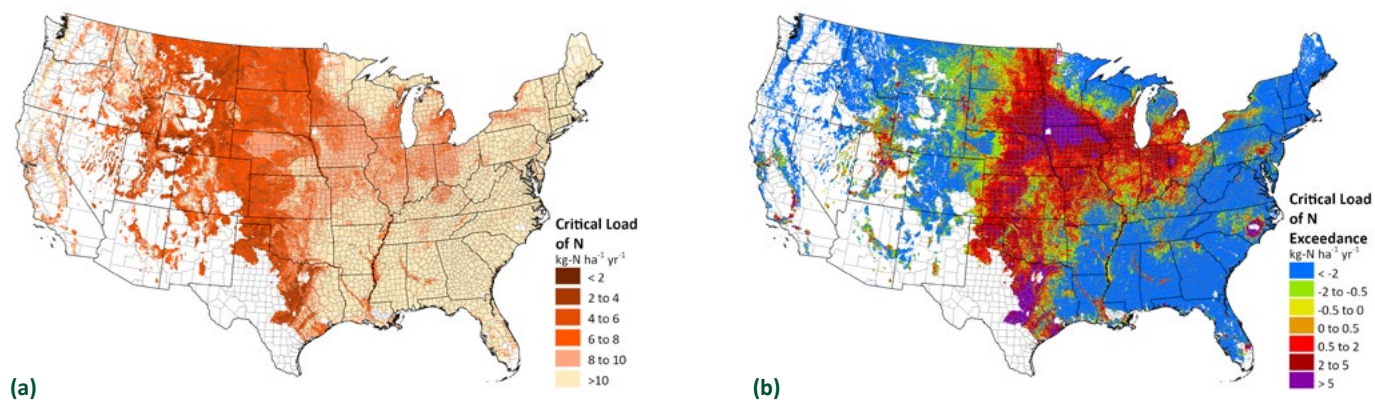


Figure A90.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Sanicula canadensis* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

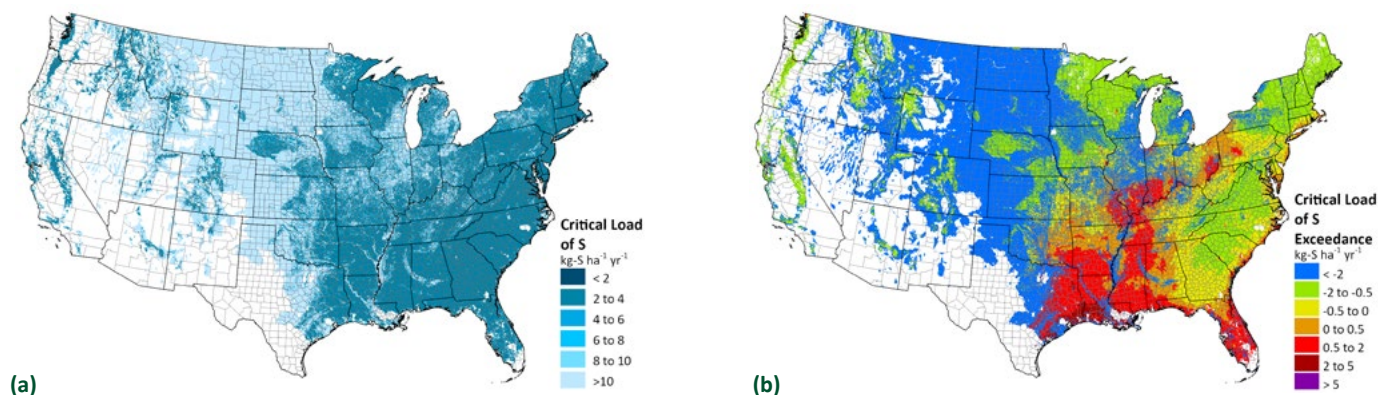


Figure A90.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Sanicula canadensis* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A91. *Sanicula marilandica* (Maryland sanicle)

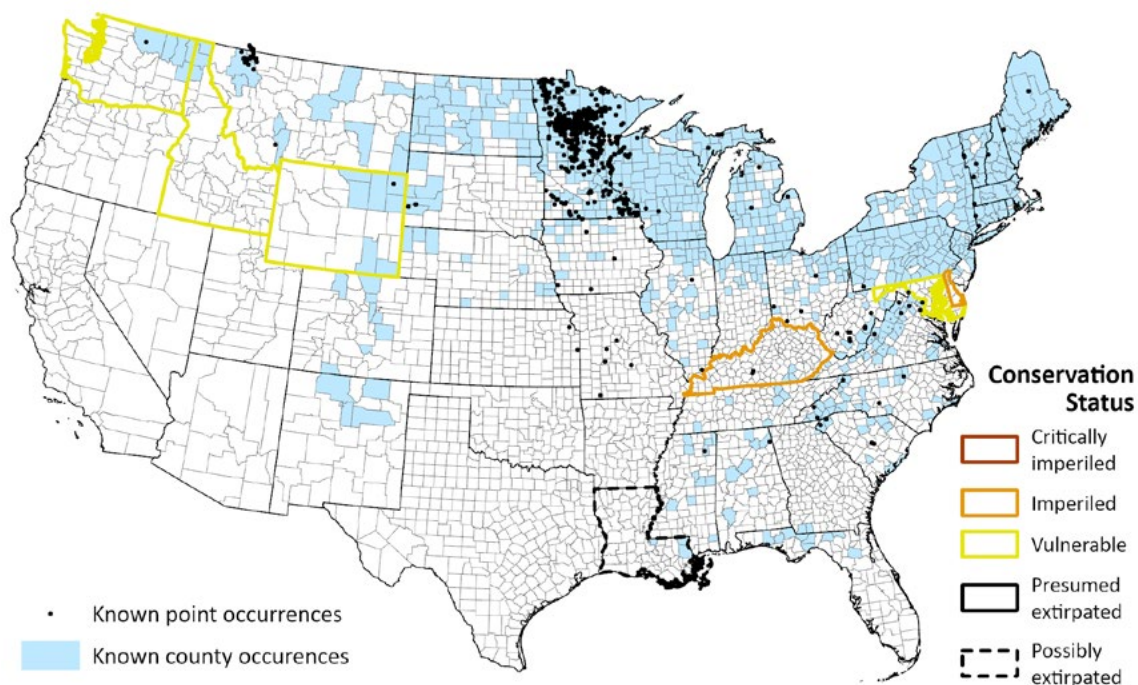


Figure A91.1. Distribution and state-level conservation status of *Sanicula marilandica*. Known point occurrences were used to assess species deposition responses and critical loads.

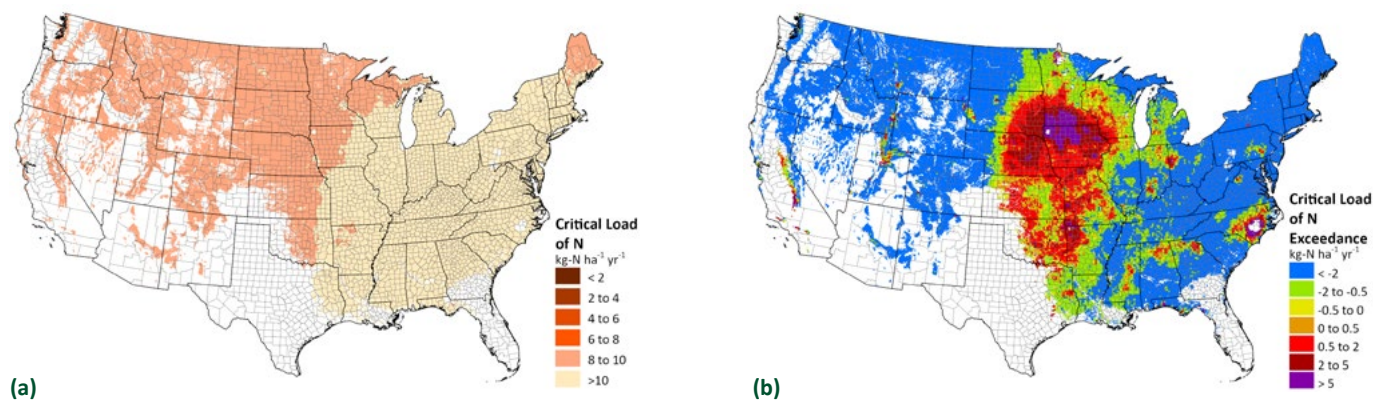


Figure A91.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Sanicula marilandica* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

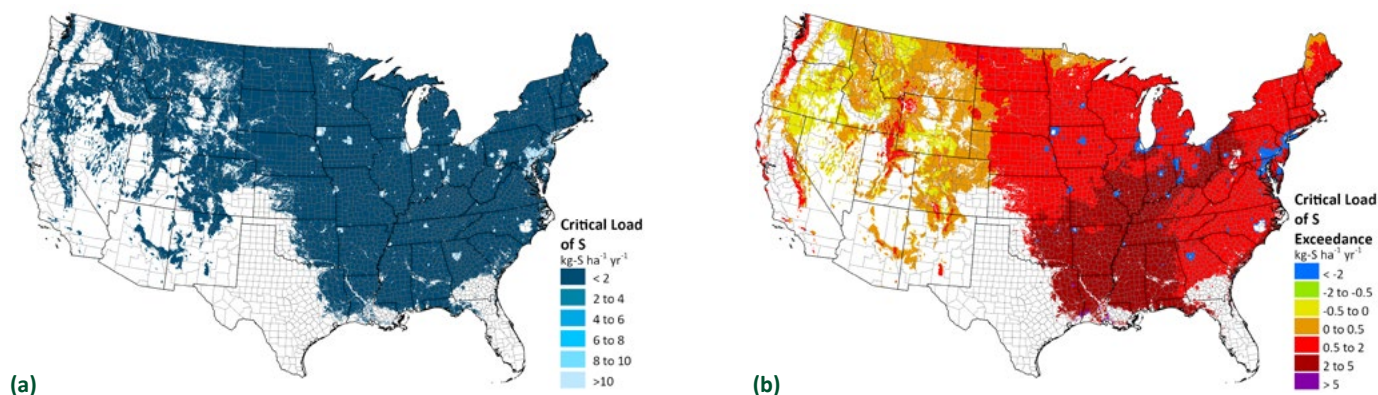


Figure A91.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Sanicula marilandica* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A92. *Sanicula odorata* (clustered blacksnakeroot)

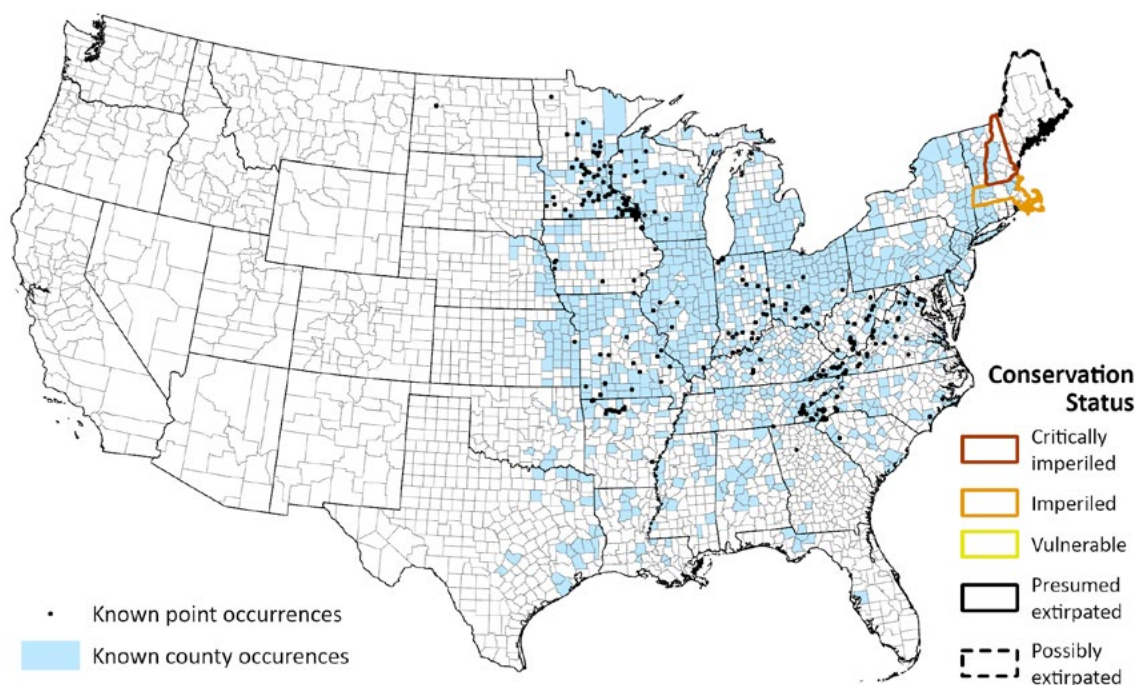


Figure A92.1. Distribution and state-level conservation status of *Sanicula odorata*. Known point occurrences were used to assess species deposition responses and critical loads.

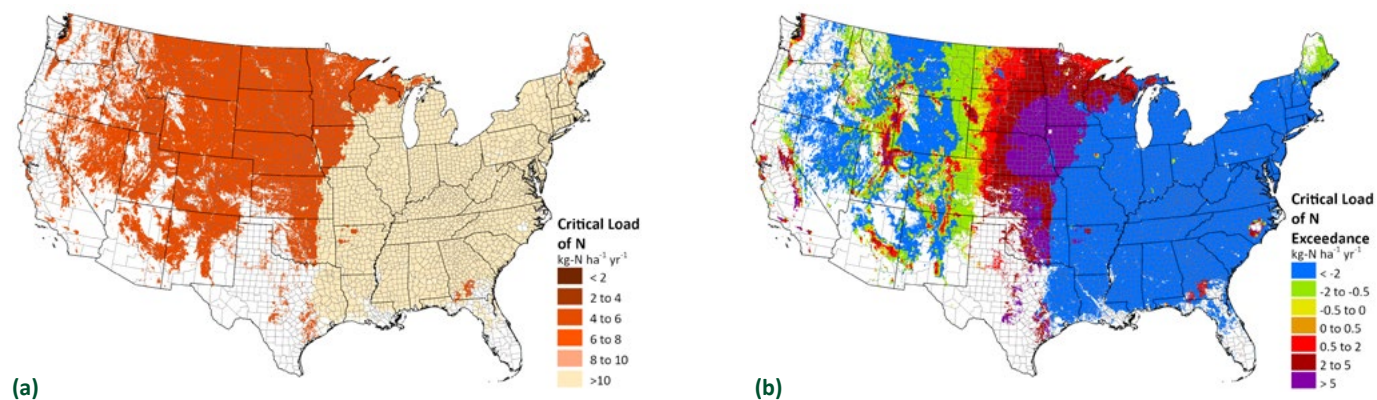


Figure A92.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Sanicula odorata* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

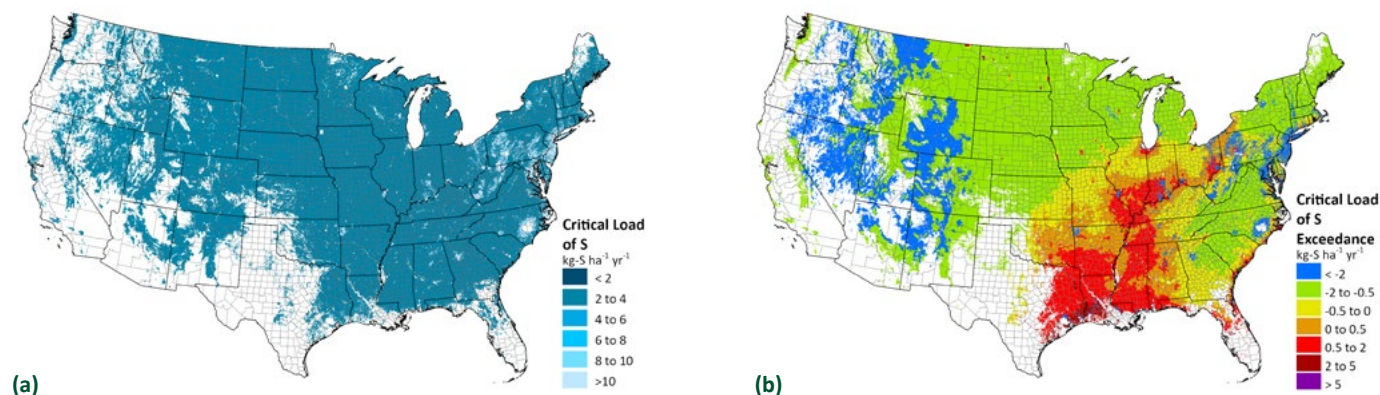


Figure A92.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Sanicula odorata* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A93. *Saururus cernuus* (lizard's tail)

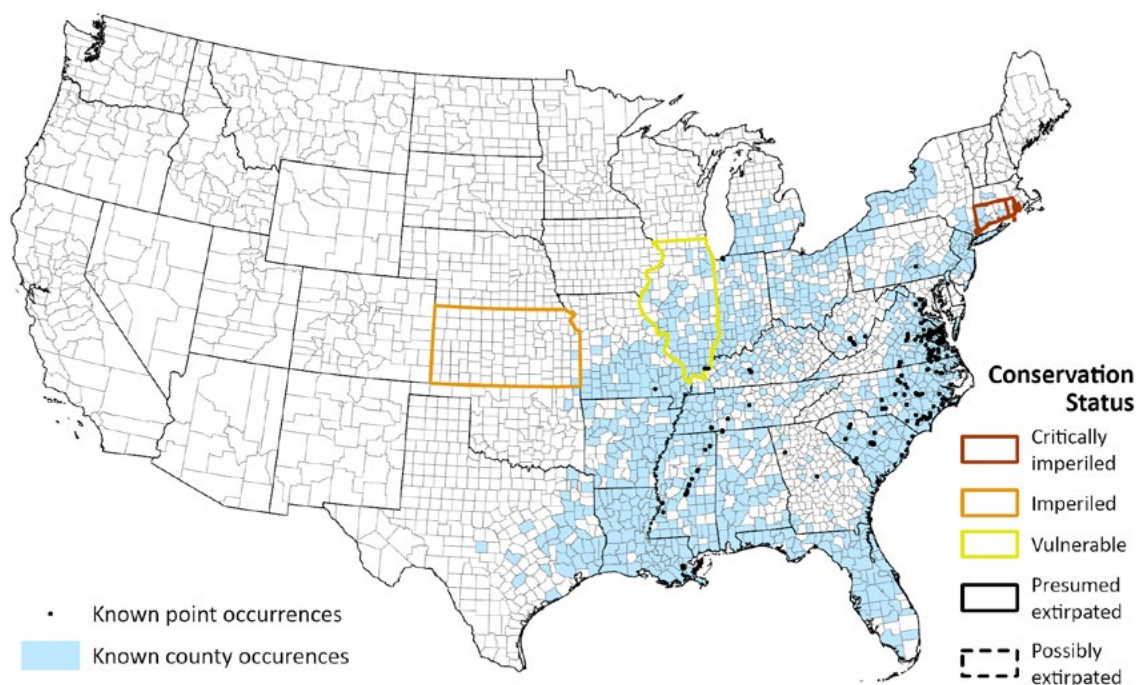


Figure A93.1. Distribution and state-level conservation status of *Saururus cernuus*. Known point occurrences were used to assess species deposition responses and critical loads.

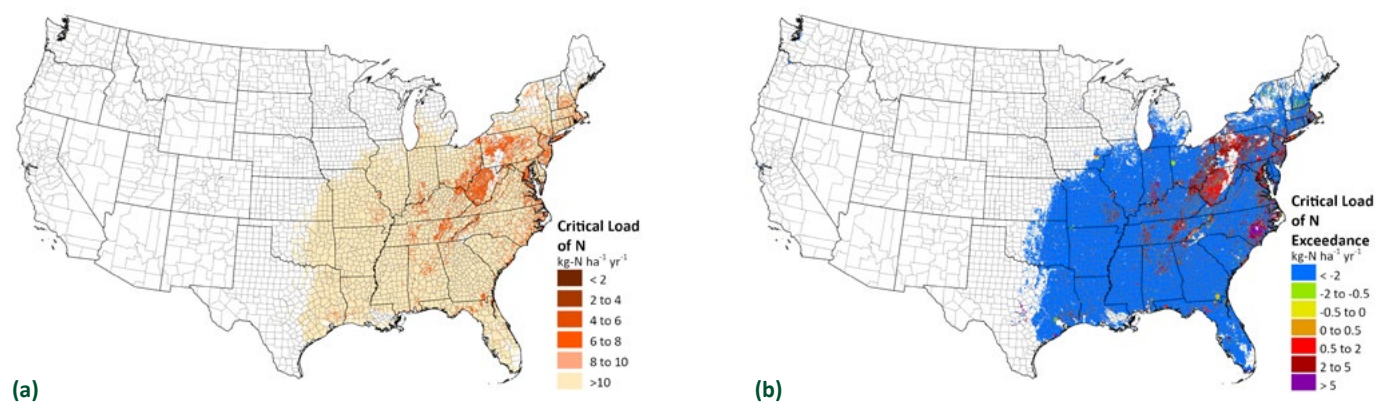


Figure A93.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Saururus cernuus* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

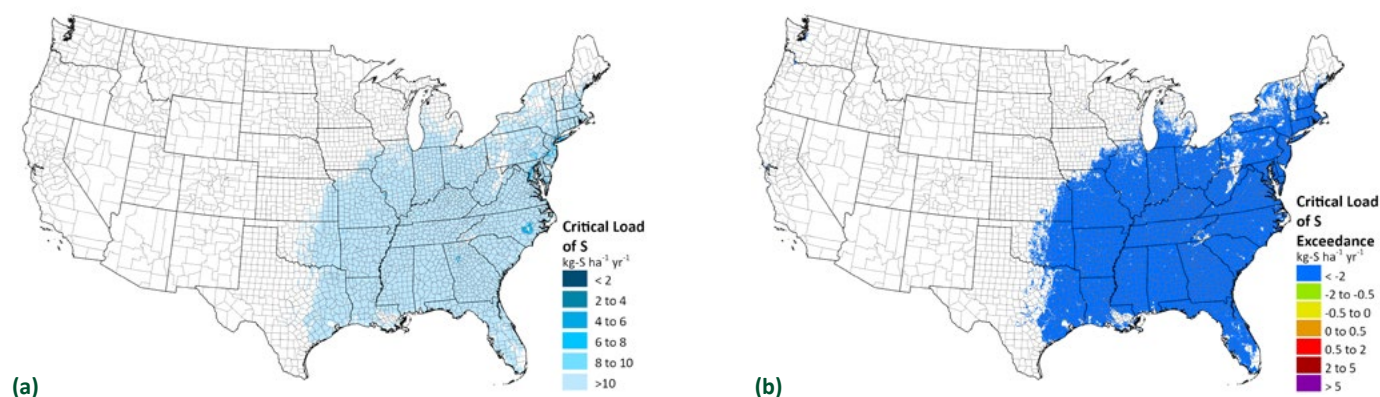


Figure A93.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Saururus cernuus* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A94. *Scutellaria elliptica* (hairy skullcap)

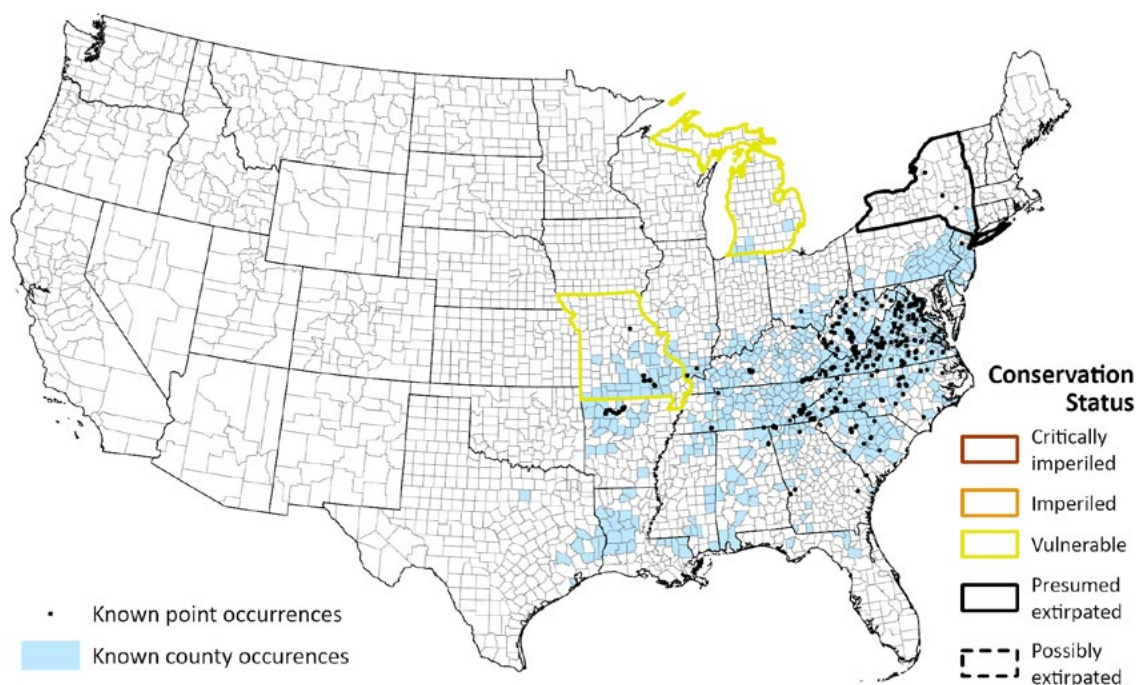


Figure A94.1. Distribution and state-level conservation status of *Scutellaria elliptica*. Known point occurrences were used to assess species deposition responses and critical loads.

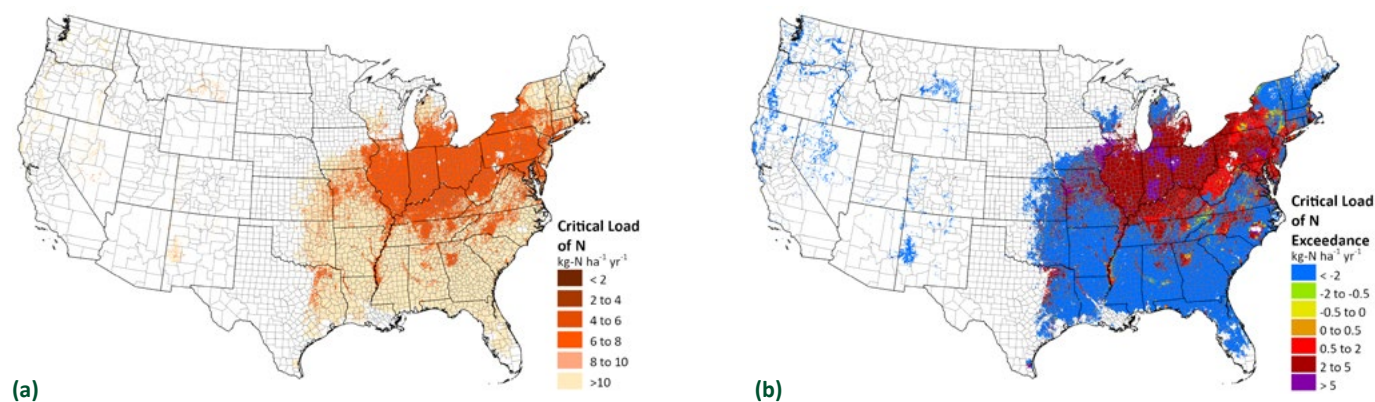


Figure A94.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Scutellaria elliptica* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

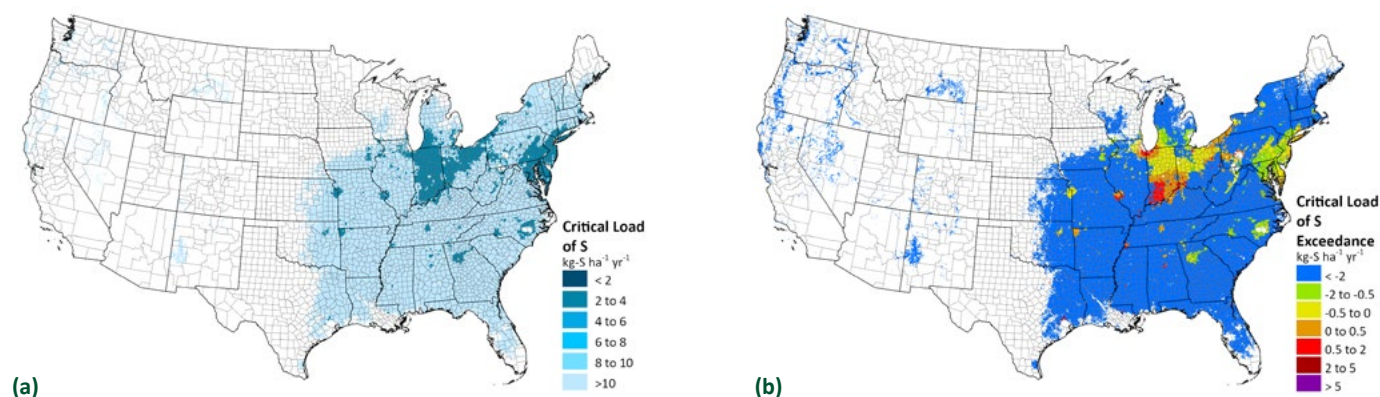


Figure A94.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Scutellaria elliptica* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A95. *Sericocarpus tortifolius* (Dixie whitetop aster)

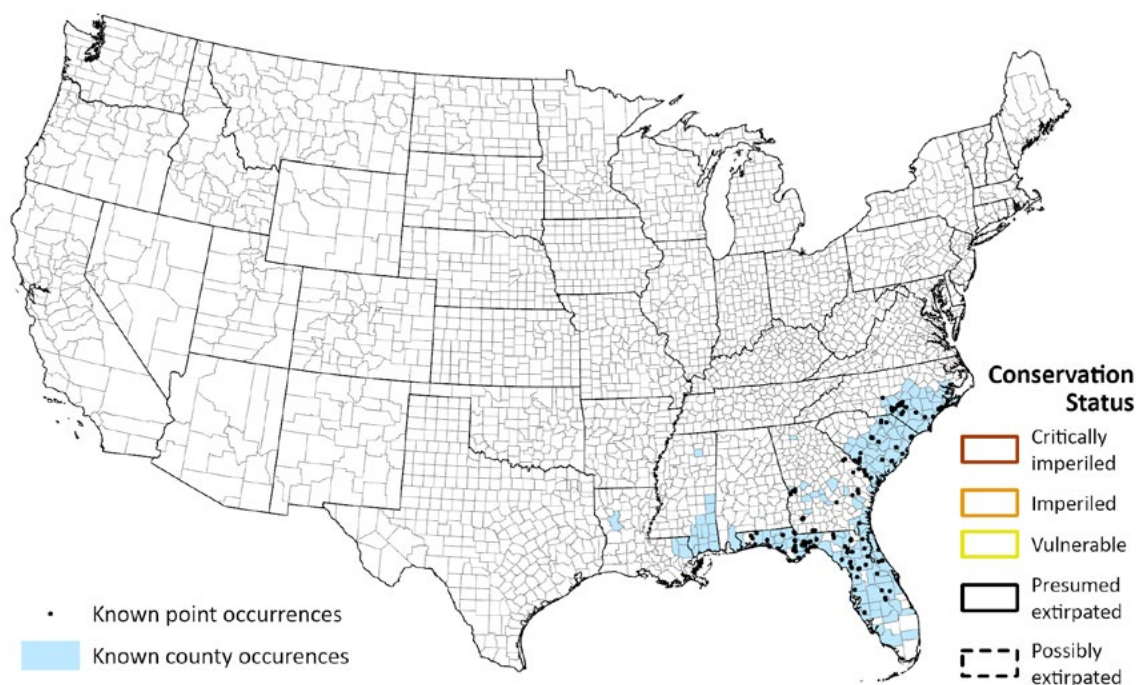


Figure A95.1. Distribution and state-level conservation status of *Sericocarpus tortifolius*. Known point occurrences were used to assess species deposition responses and critical loads.

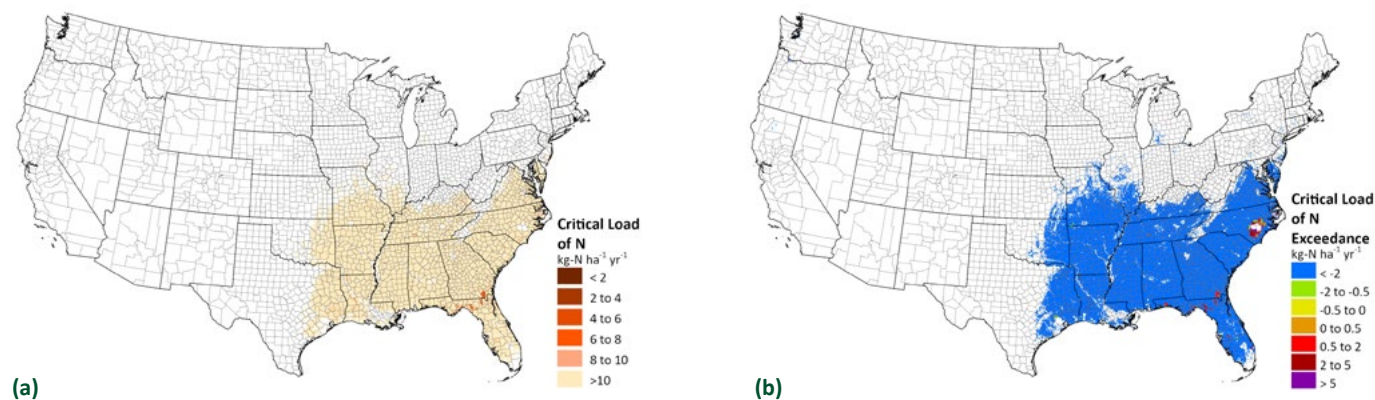


Figure A95.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Sericocarpus tortifolius* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

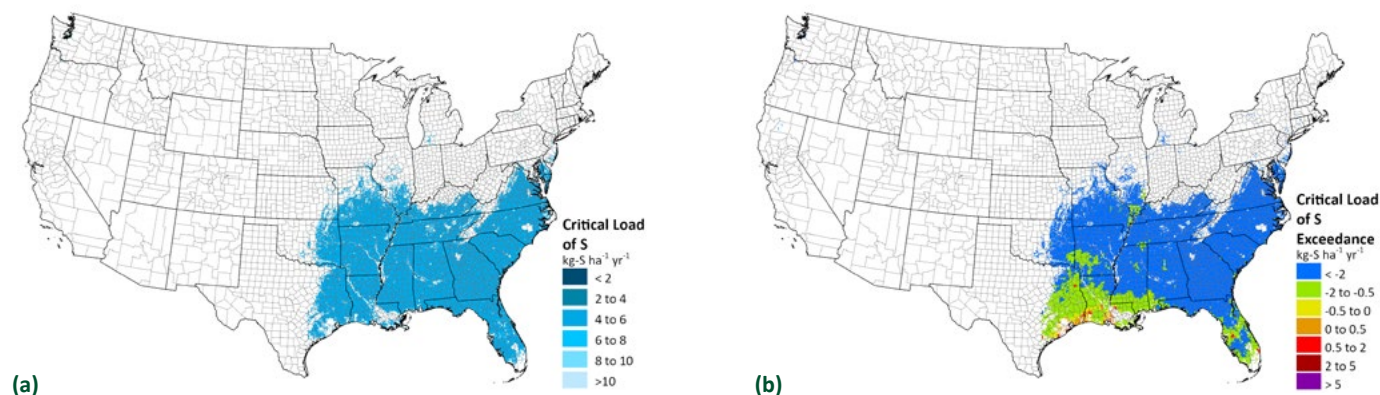


Figure A95.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Sericocarpus tortifolius* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A96. *Silphium asteriscus* (starry rosinweed)

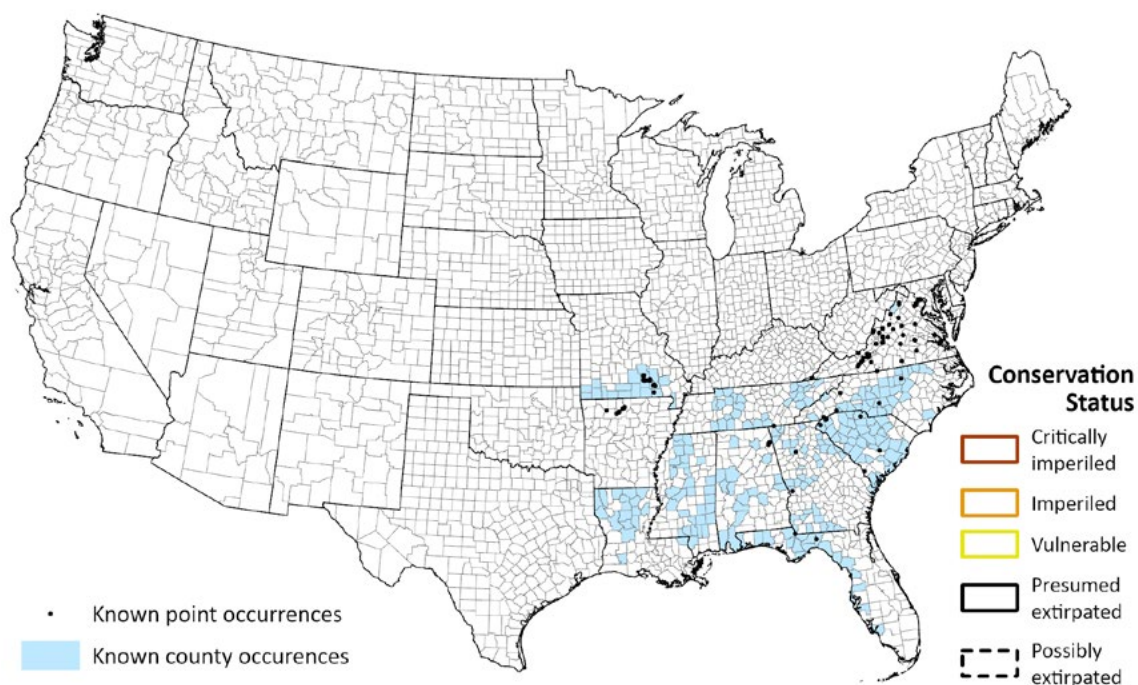


Figure A96.1. Distribution and state-level conservation status of *Silphium asteriscus*. Known point occurrences were used to assess species deposition responses and critical loads.

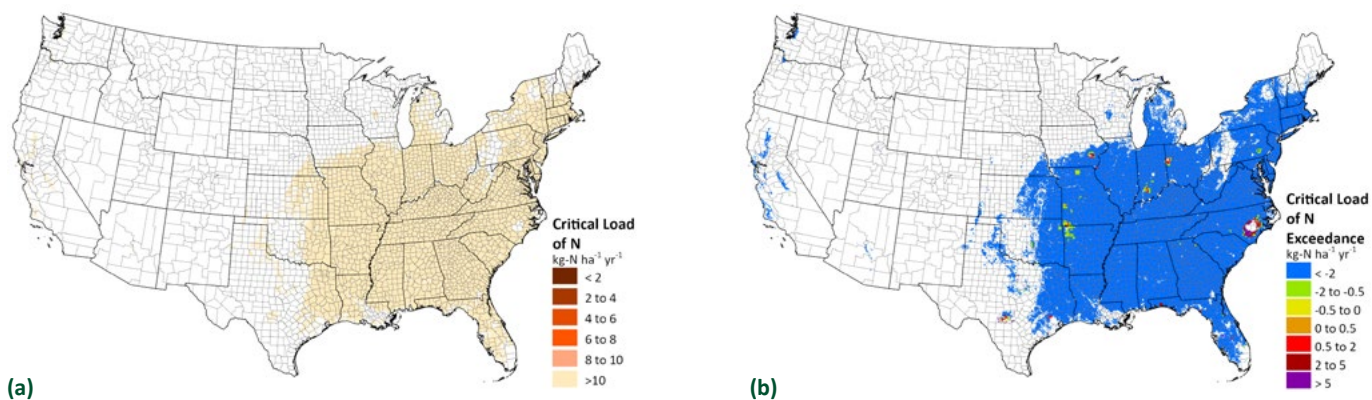


Figure A96.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Silphium asteriscus* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

A97. *Silphium compositum* (kidneyleaf rosinweed)

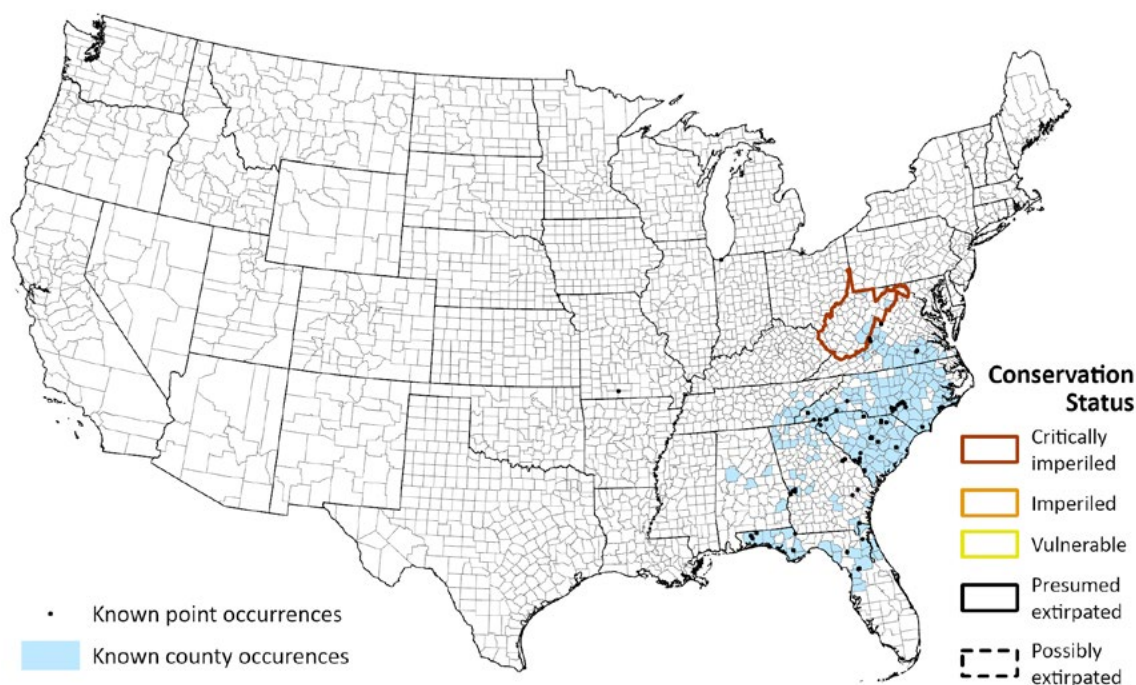


Figure A97.1. Distribution and state-level conservation status of *Silphium compositum*. Known point occurrences were used to assess species deposition responses and critical loads.

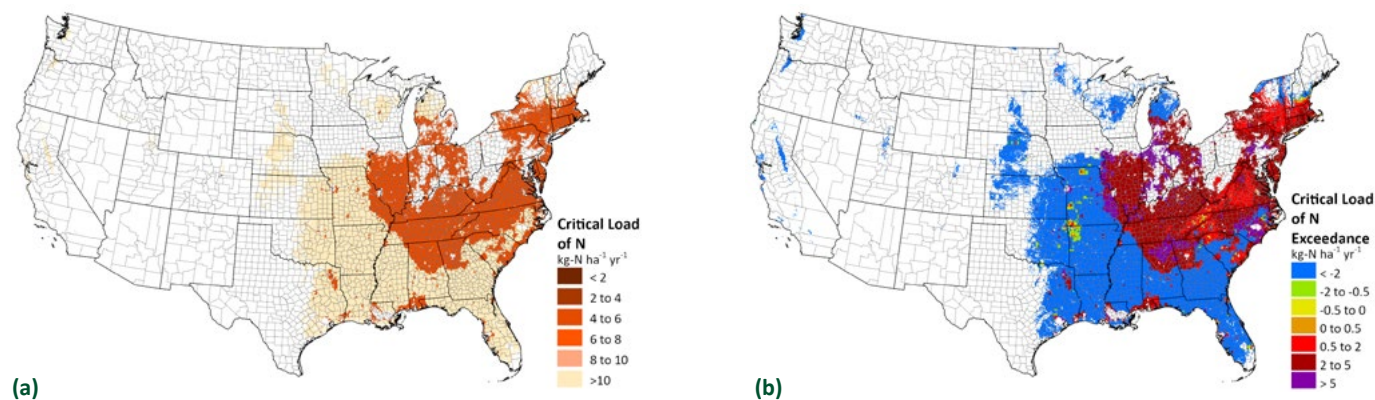


Figure A97.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Silphium compositum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

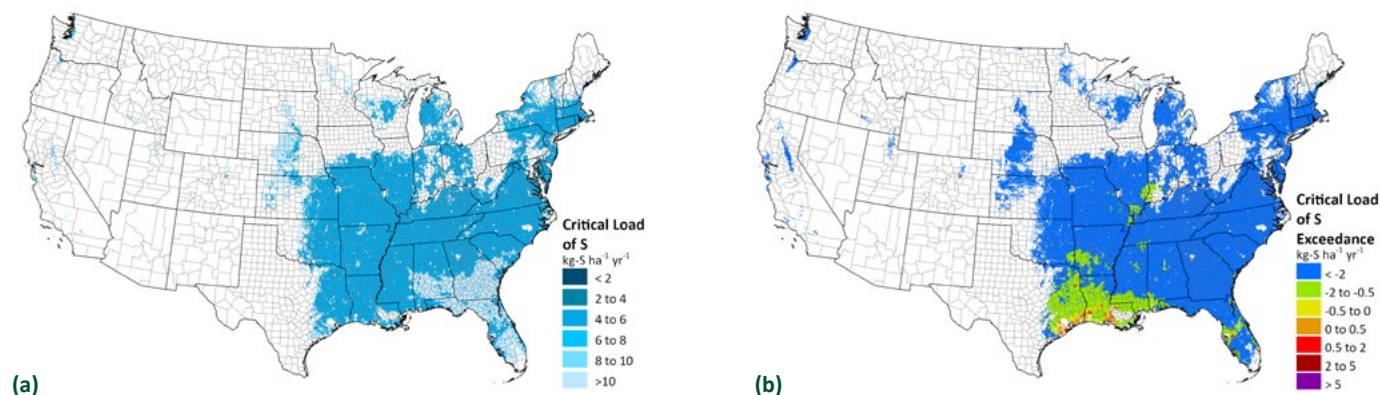


Figure A97.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Silphium compositum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A98. *Solidago bicolor* (white goldenrod)

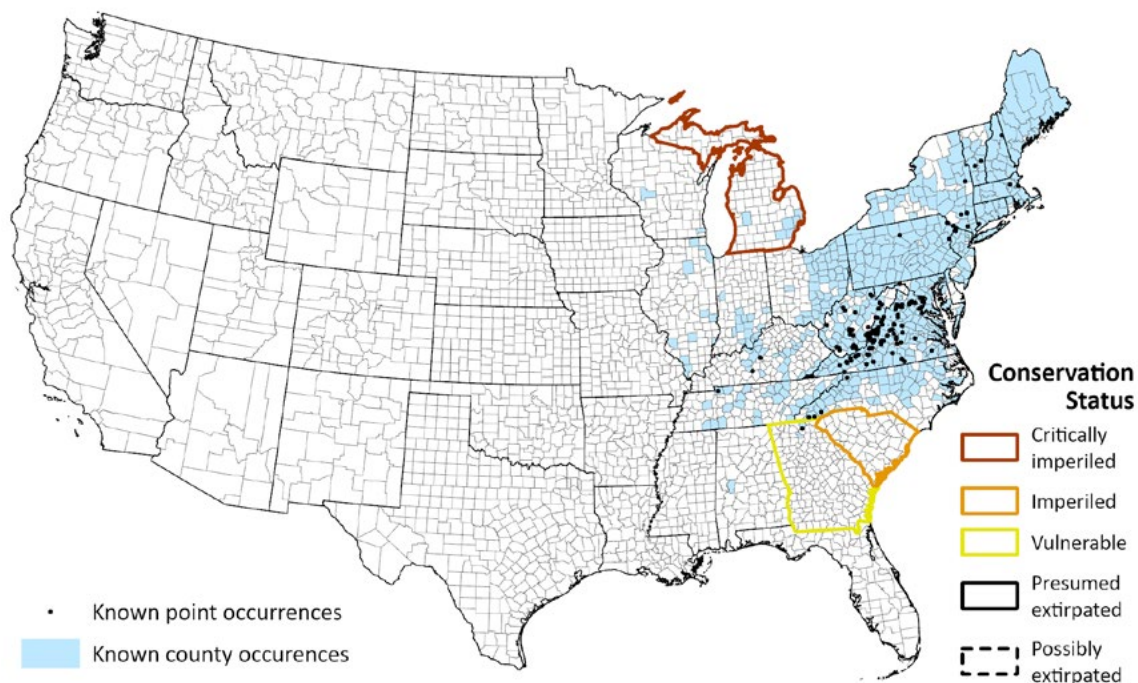


Figure A98.1. Distribution and state-level conservation status of *Solidago bicolor*. Known point occurrences were used to assess species deposition responses and critical loads.

A99. *Solidago caesia* (wreath goldenrod)

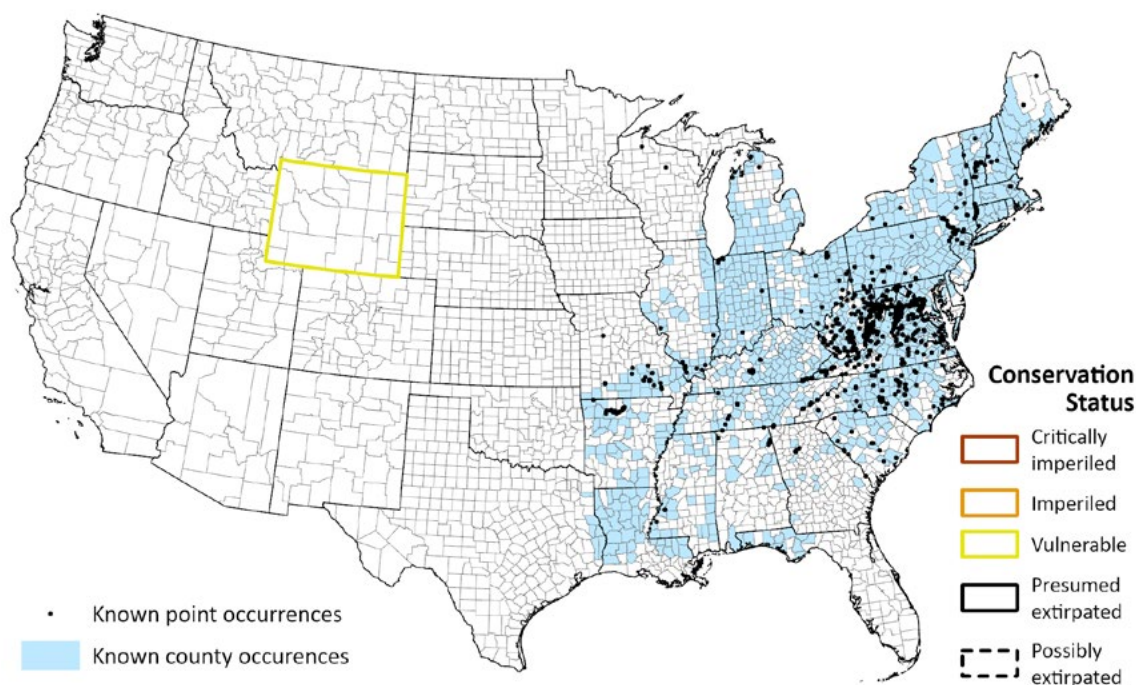


Figure A99.1. Distribution and state-level conservation status of *Solidago caesia*. Known point occurrences were used to assess species deposition responses and critical loads.

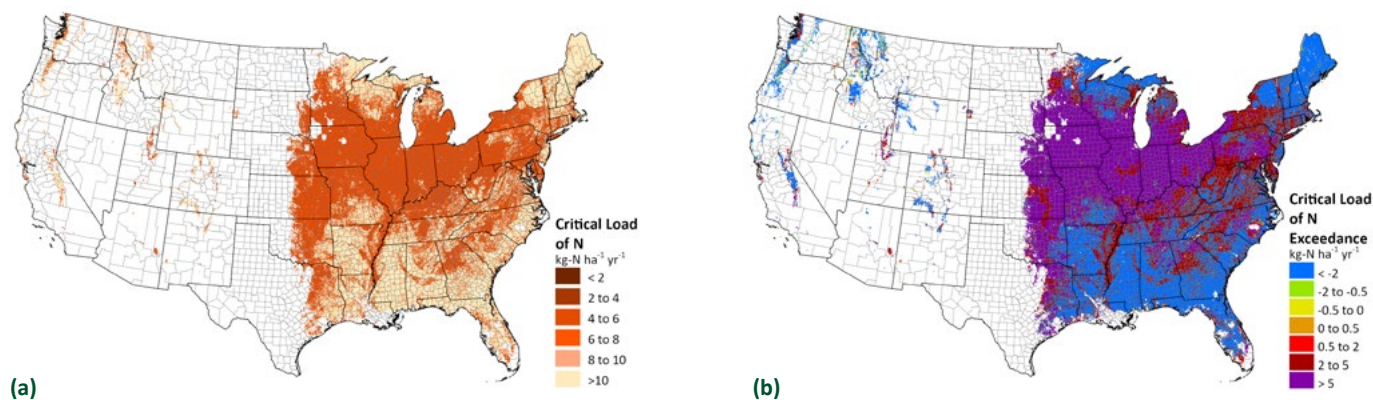


Figure A99.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Solidago caesia* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

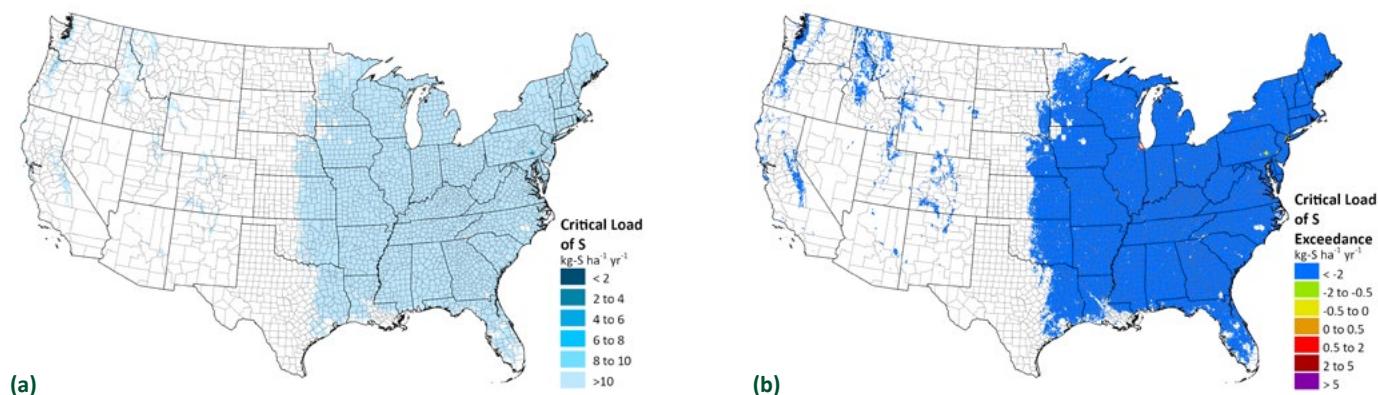


Figure A99.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Solidago caesia* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A100. *Solidago flexicaulis* (zigzag goldenrod)

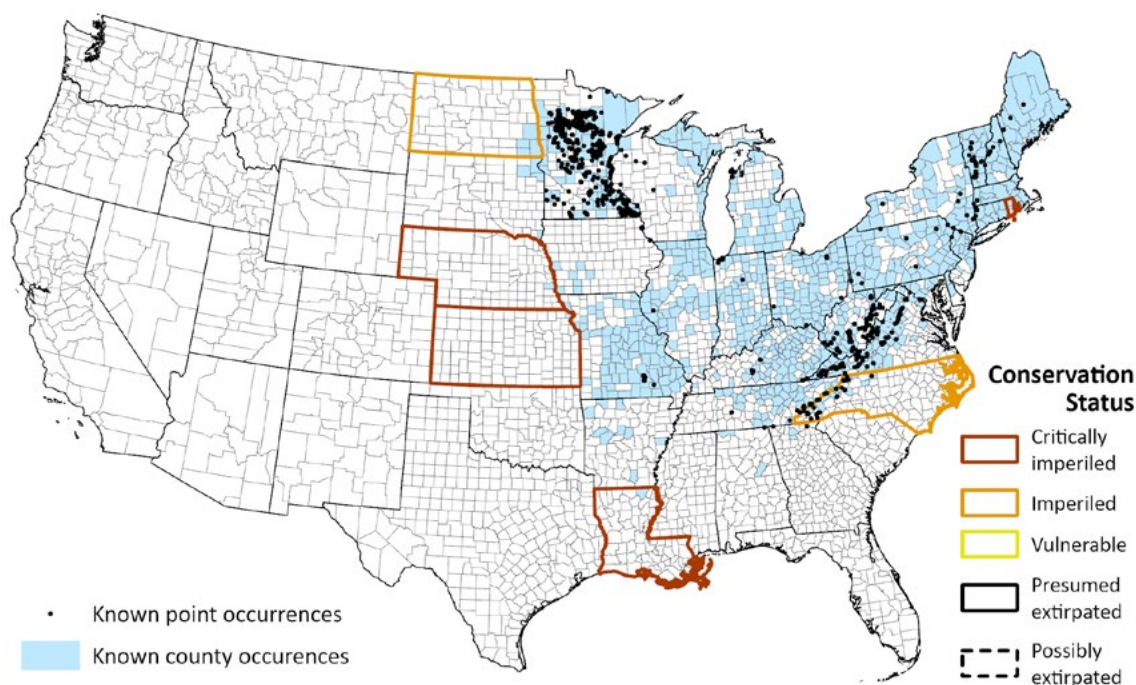


Figure A100.1. Distribution and state-level conservation status of *Solidago flexicaulis*. Known point occurrences were used to assess species deposition responses and critical loads.

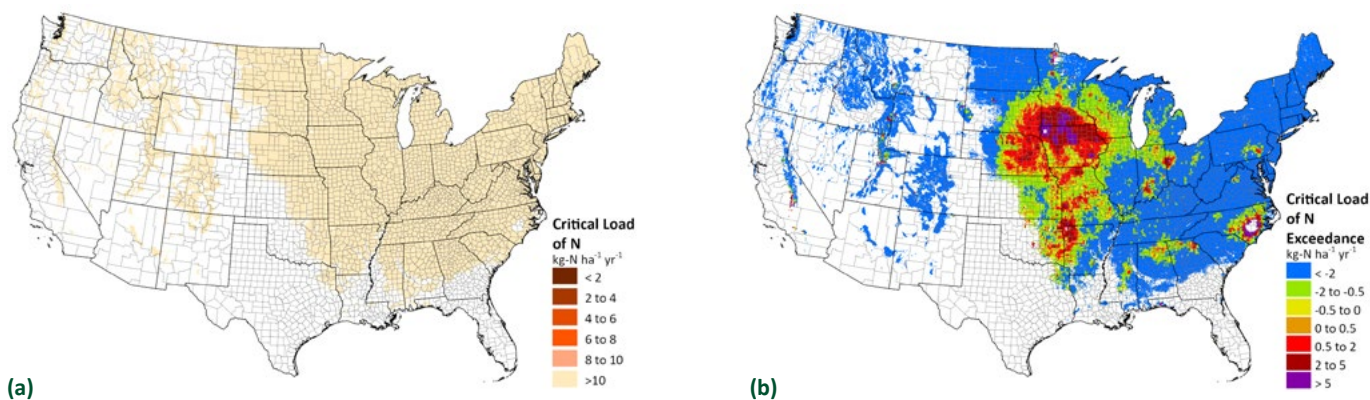


Figure A100.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Solidago flexicaulis* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

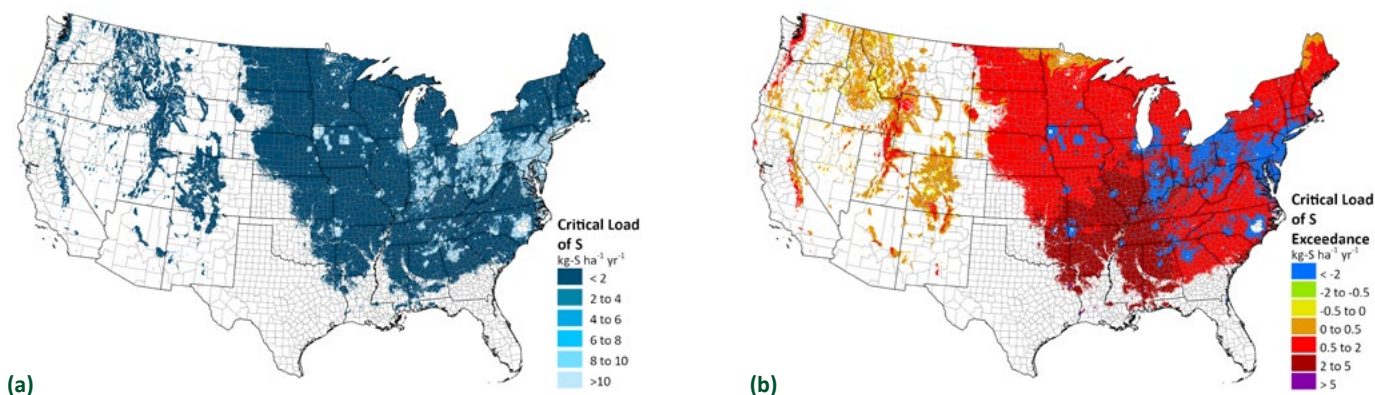


Figure A100.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Solidago flexicaulis* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A101. *Solidago odora* (anisescented goldenrod)

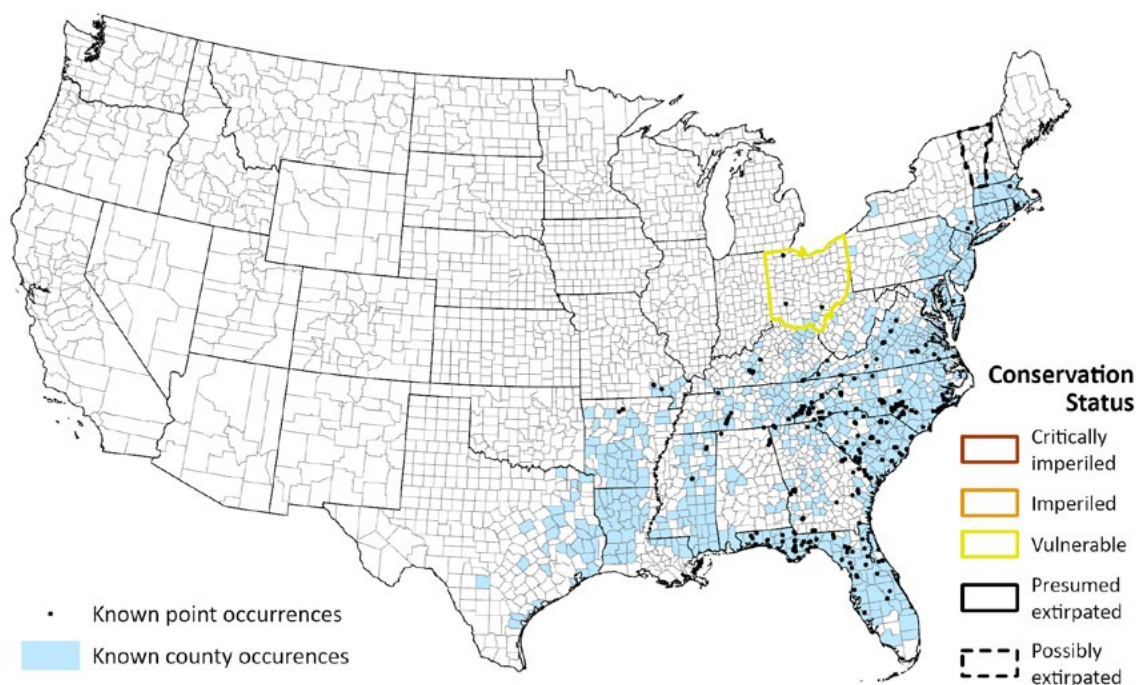


Figure A101.1. Distribution and state-level conservation status of *Solidago odora*. Known point occurrences were used to assess species deposition responses and critical loads.

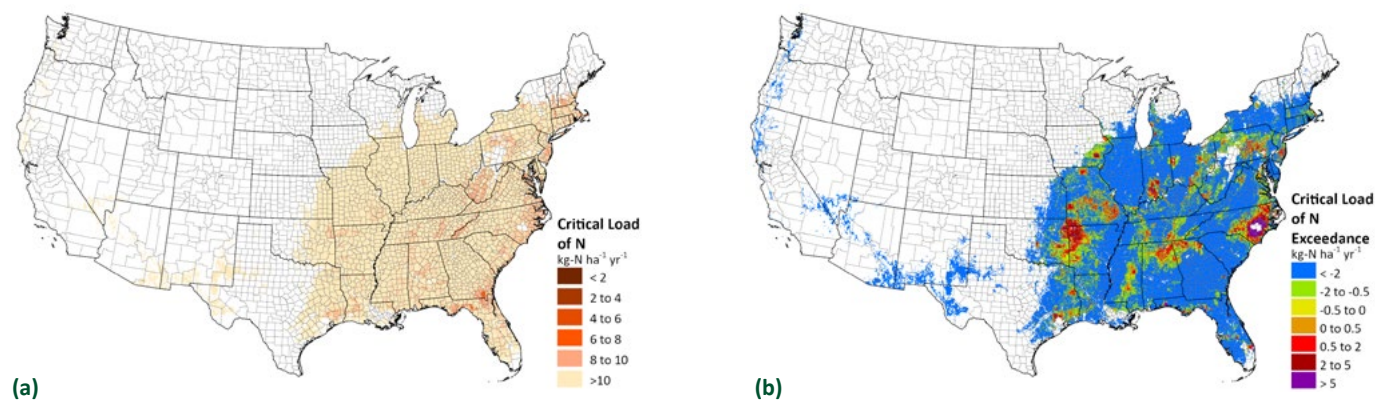


Figure A101.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Solidago odora* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

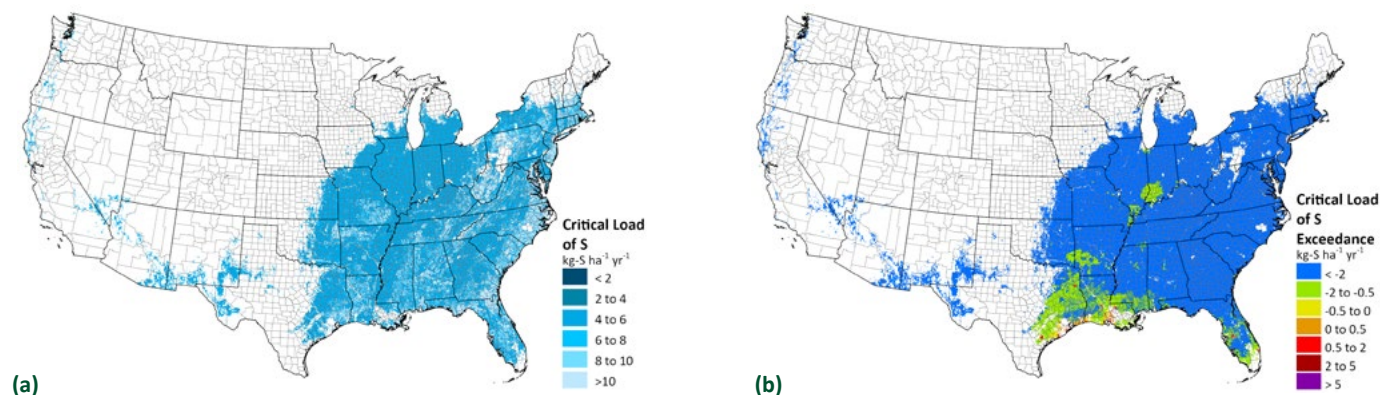


Figure A101.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Solidago odora* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A102. *Streptopus lanceolatus* (twistedstalk)

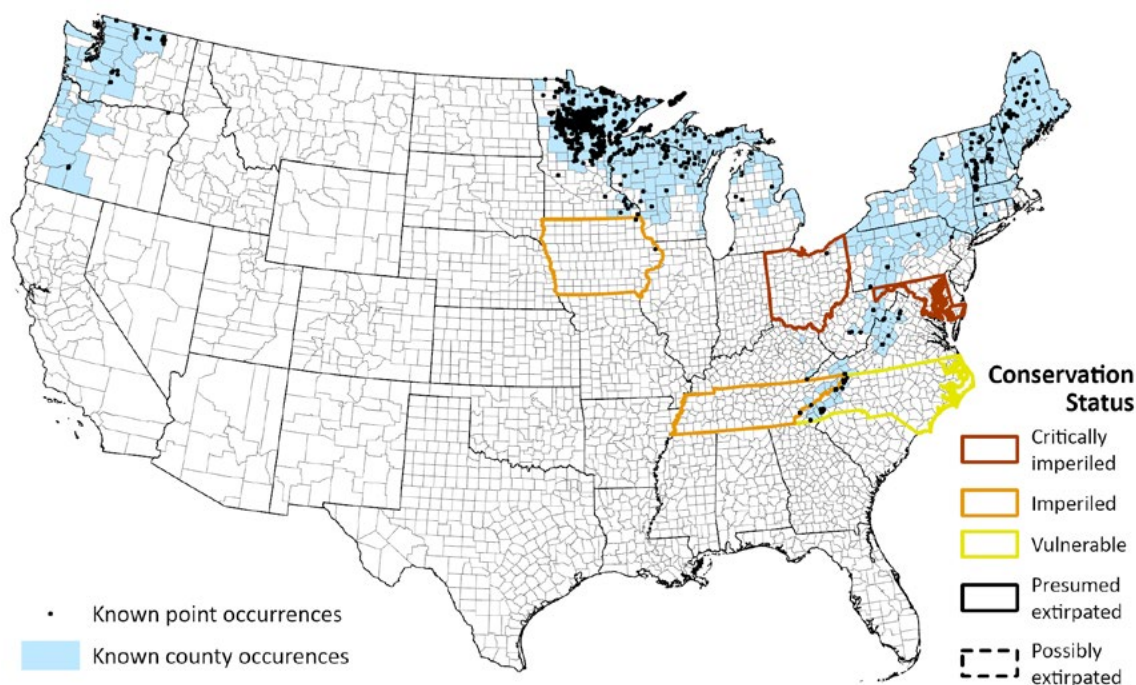


Figure A102.1. Distribution and state-level conservation status of *Streptopus lanceolatus*. Known point occurrences were used to assess species deposition responses and critical loads.

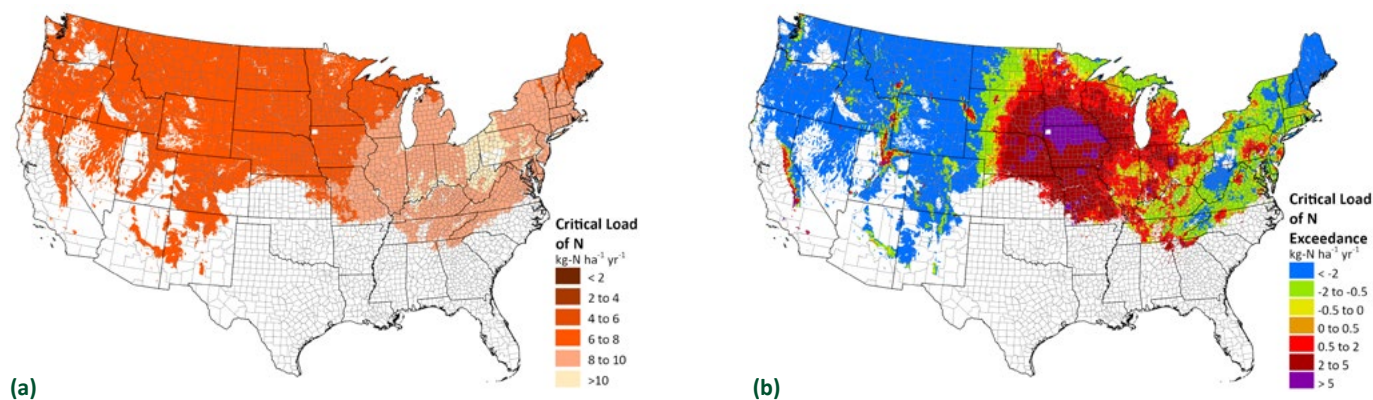


Figure A102.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Streptopus lanceolatus* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

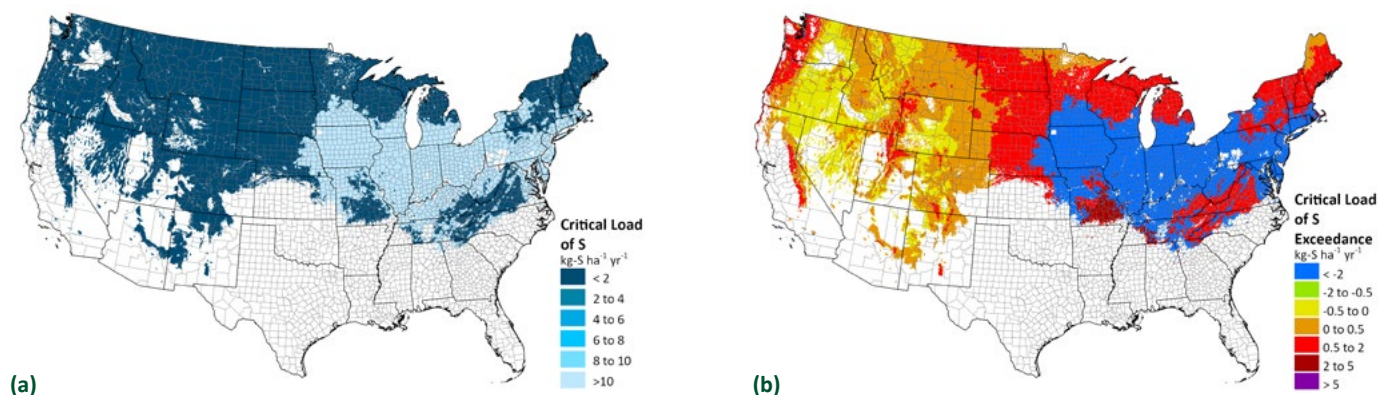


Figure A102.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Streptopus lanceolatus* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A103. *Stylosanthes biflora* (sidebeak pencilflower)

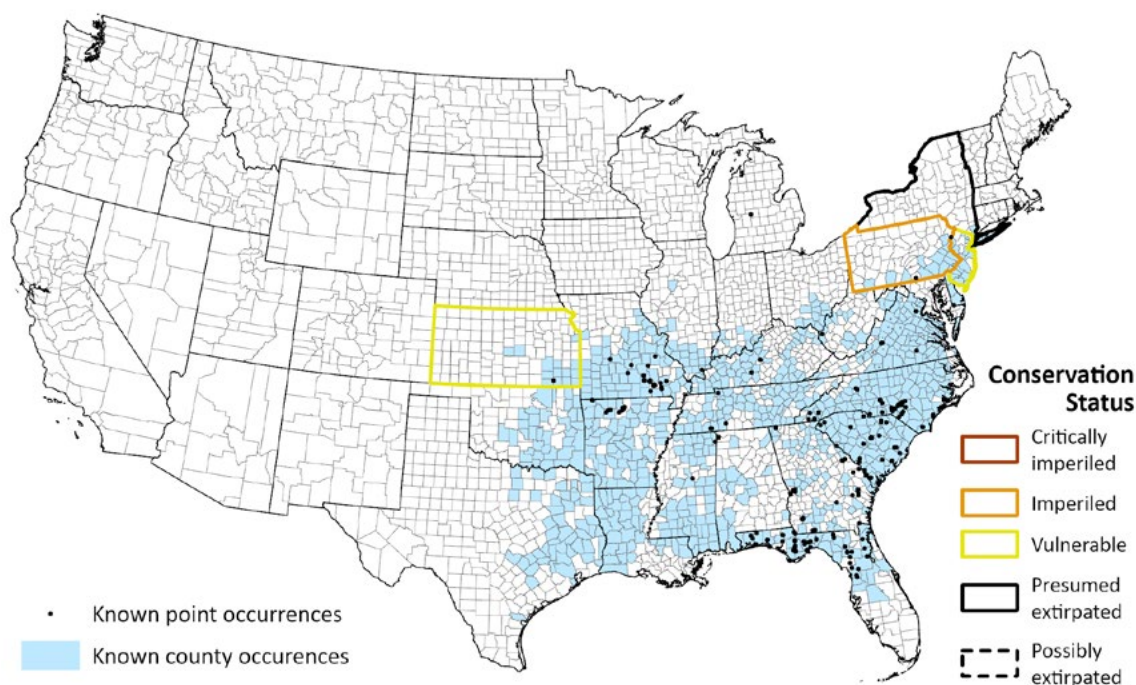


Figure A103.1. Distribution and state-level conservation status of *Stylosanthes biflora*. Known point occurrences were used to assess species deposition responses and critical loads.

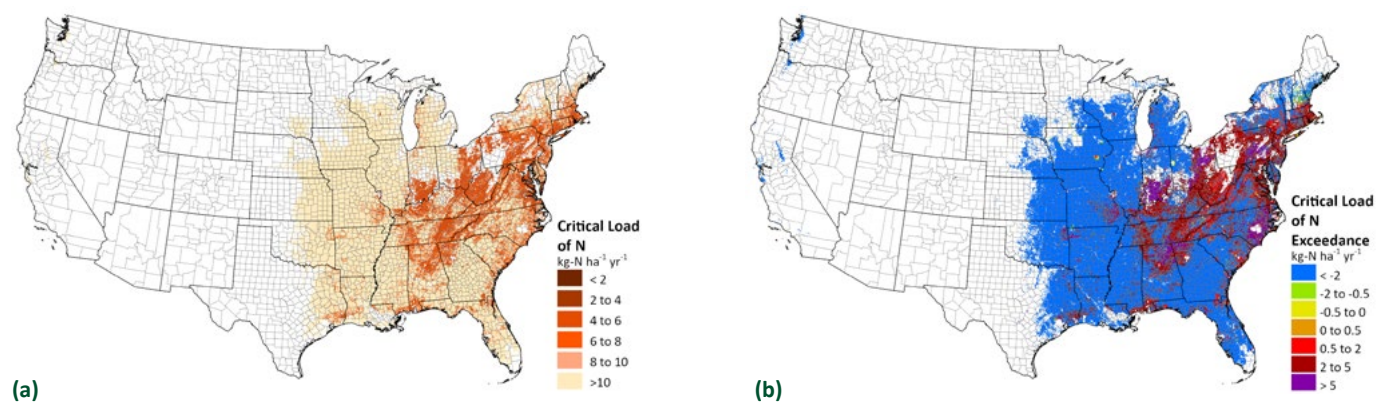


Figure A103.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Stylosanthes biflora* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

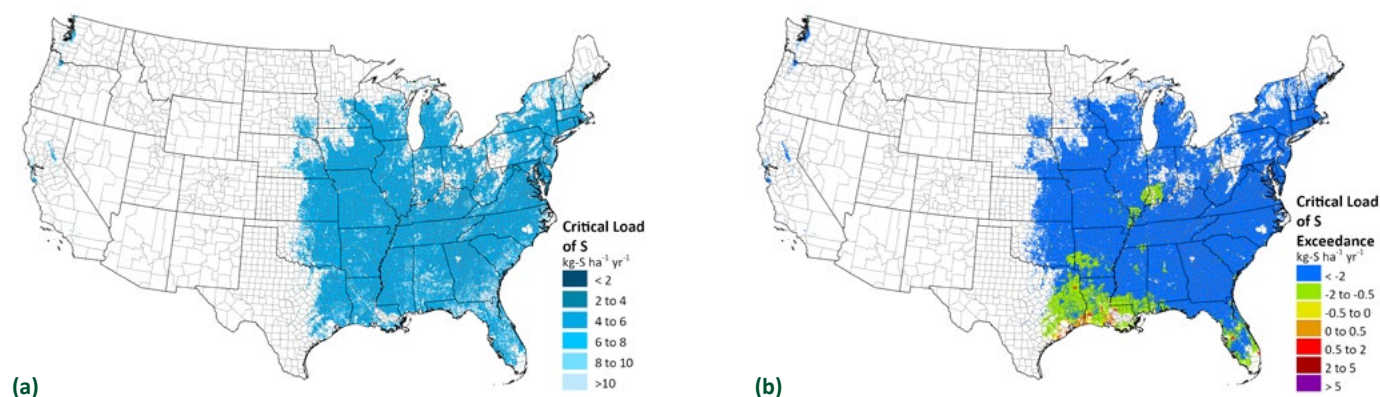


Figure A103.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Stylosanthes biflora* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A104. *Symphotrichum ciliolatum* (Lindley's aster)

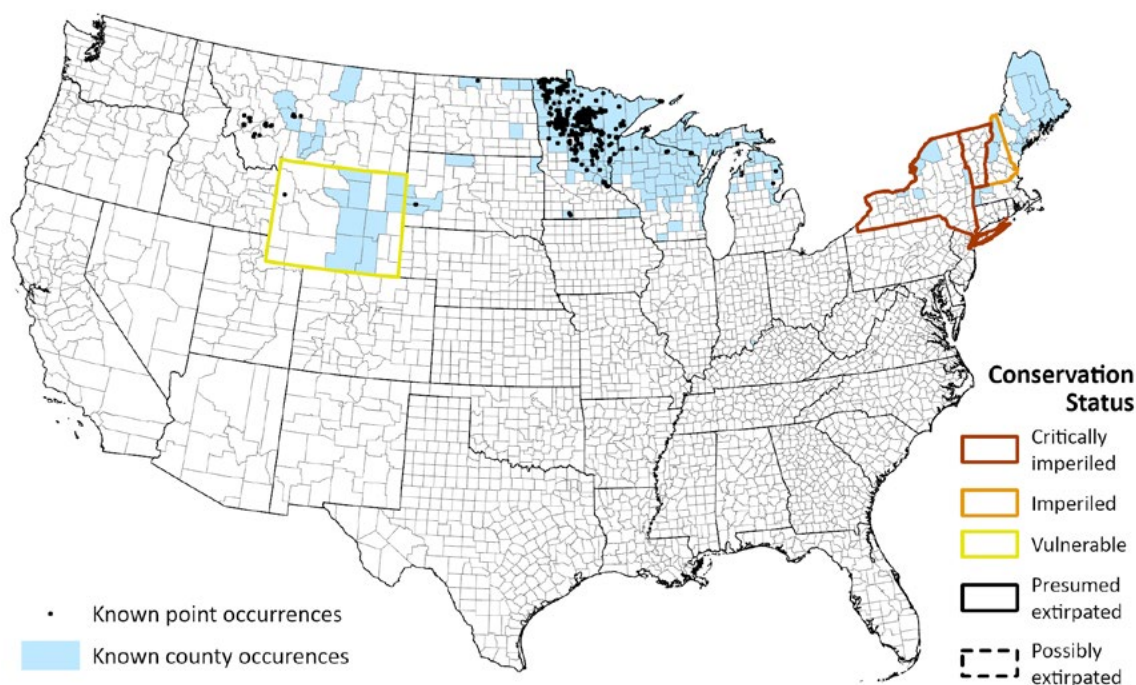


Figure A104.1. Distribution and state-level conservation status of *Symphotrichum ciliolatum*. Known point occurrences were used to assess species deposition responses and critical loads.

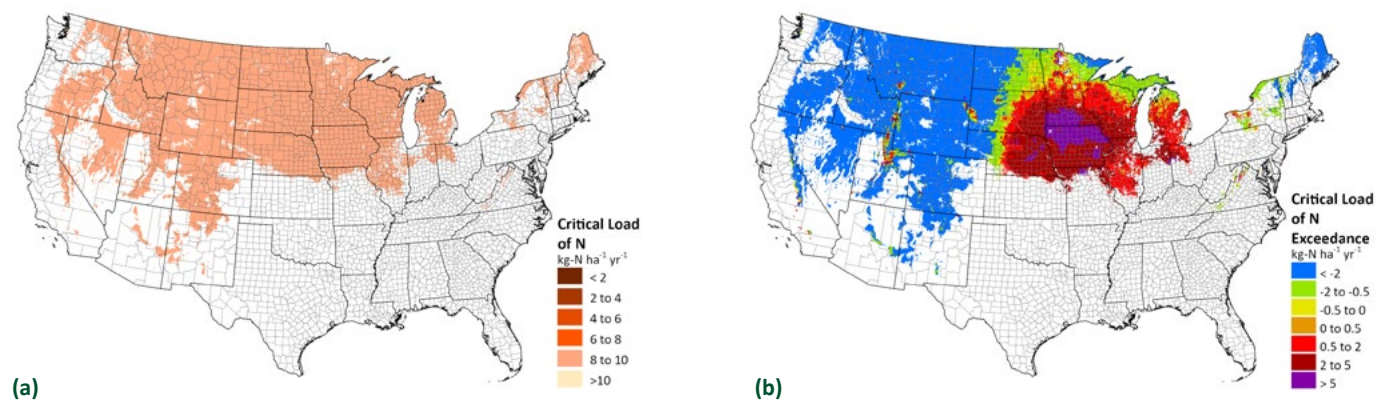


Figure A104.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Symphotrichum ciliolatum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

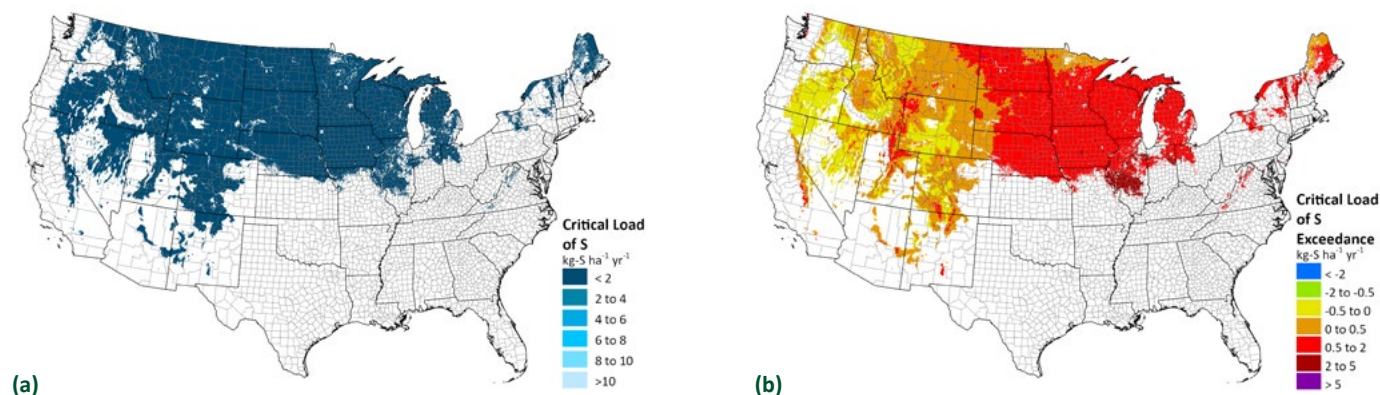


Figure A104.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Symphotrichum ciliolatum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A105. *Symphotrichum oolentangiense* (skyblue aster)

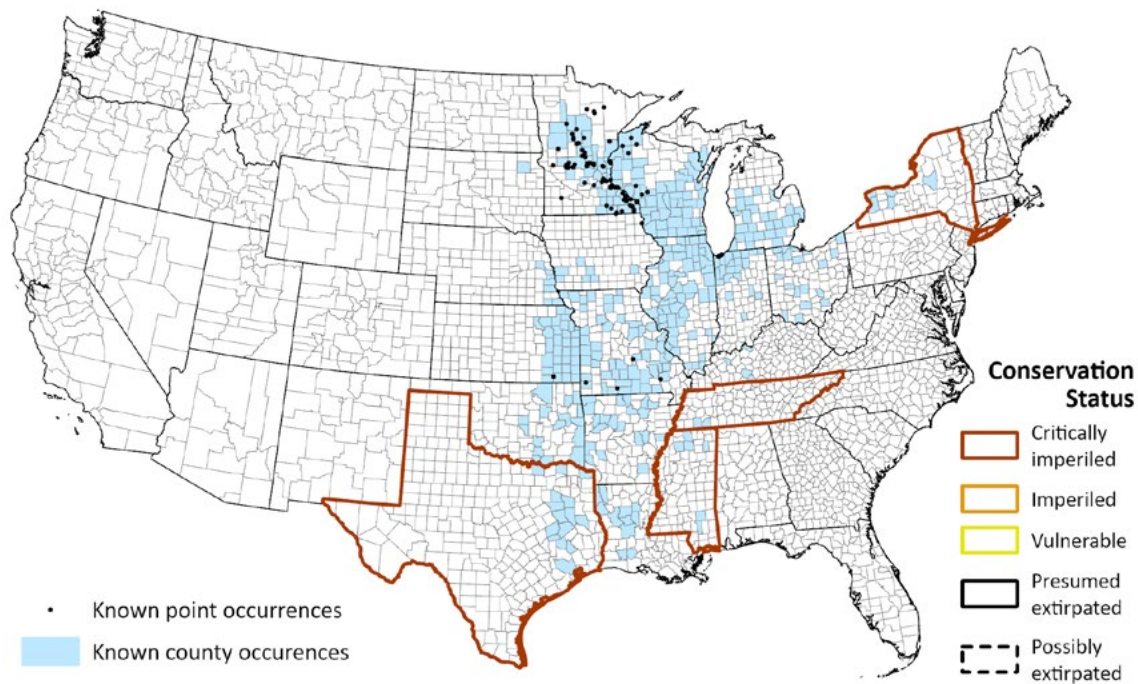


Figure A105.1. Distribution and state-level conservation status of *Symphotrichum oolentangiense*. Known point occurrences were used to assess species deposition responses and critical loads.

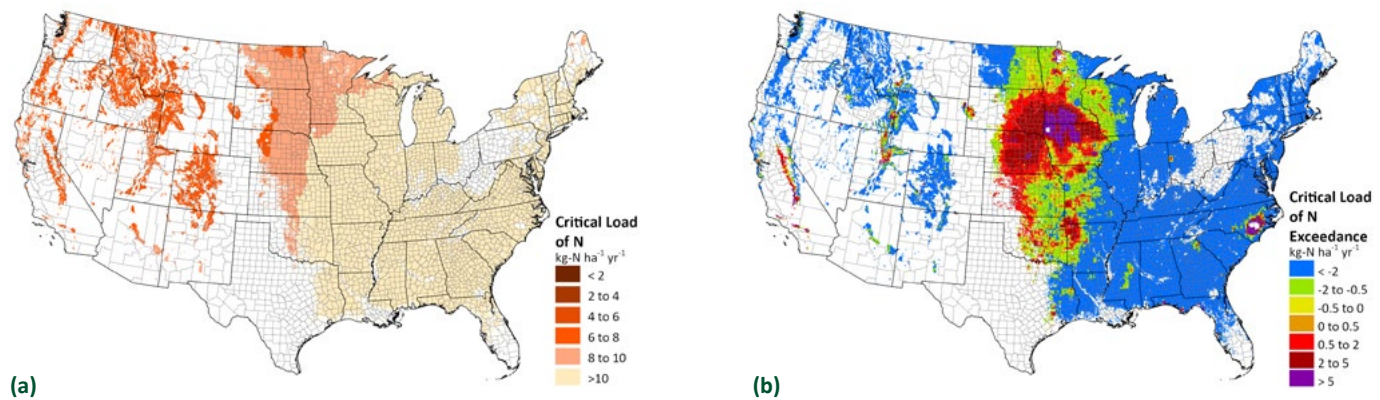


Figure A105.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Symphotrichum oolentangiense* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

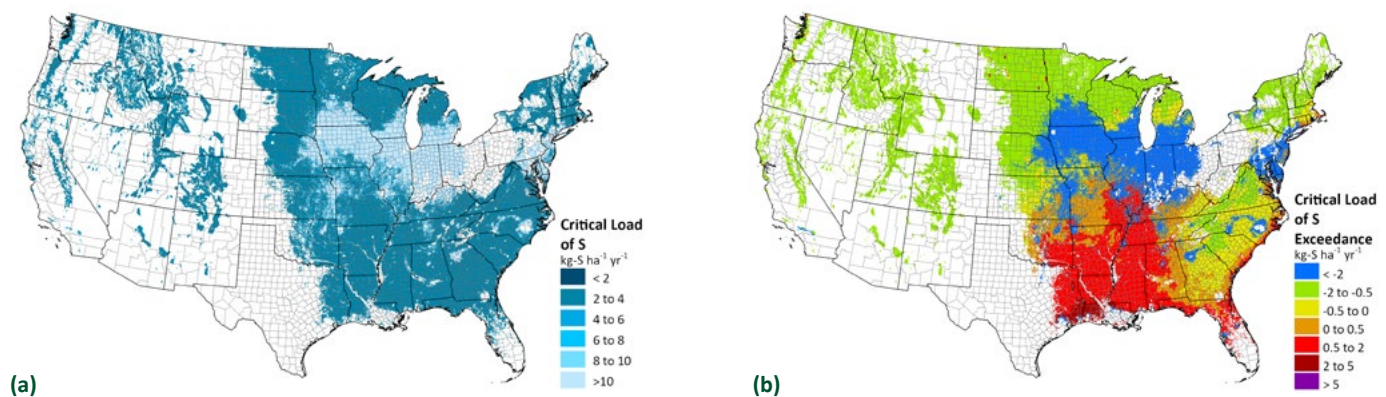


Figure A105.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Symphotrichum oolentangiense* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A106. *Symphyotrichum patens* (late purple aster)

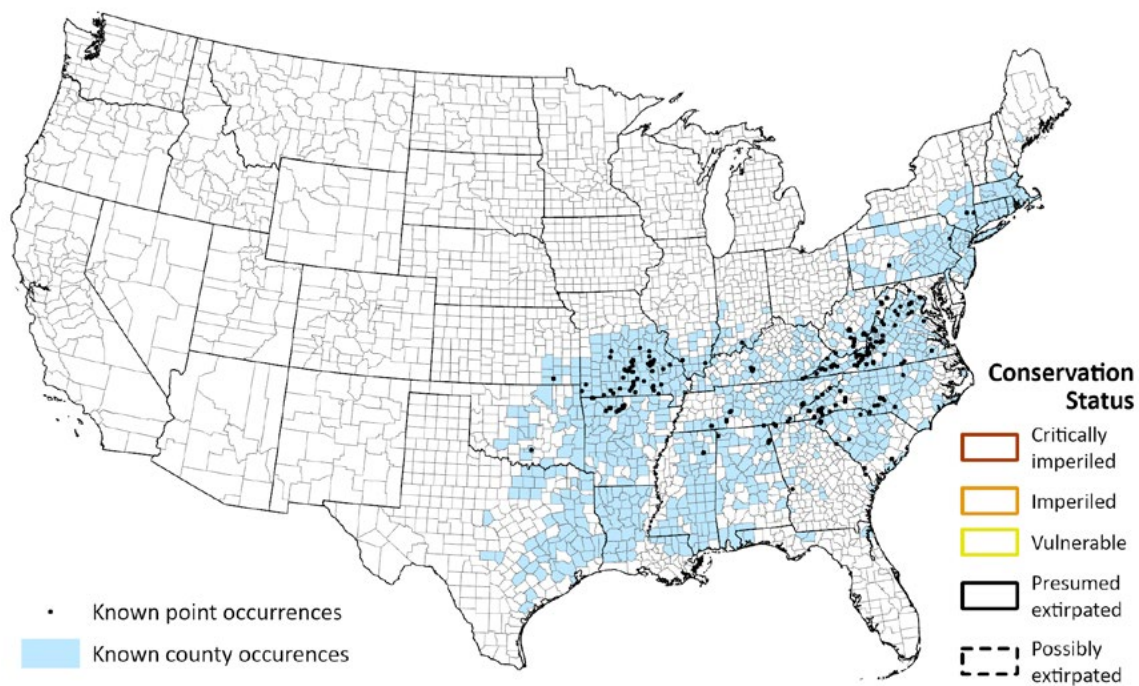


Figure A106.1. Distribution and state-level conservation status of *Symphyotrichum patens*. Known point occurrences were used to assess species deposition responses and critical loads.

A107. *Symphotrichum sericeum* (western silver aster)

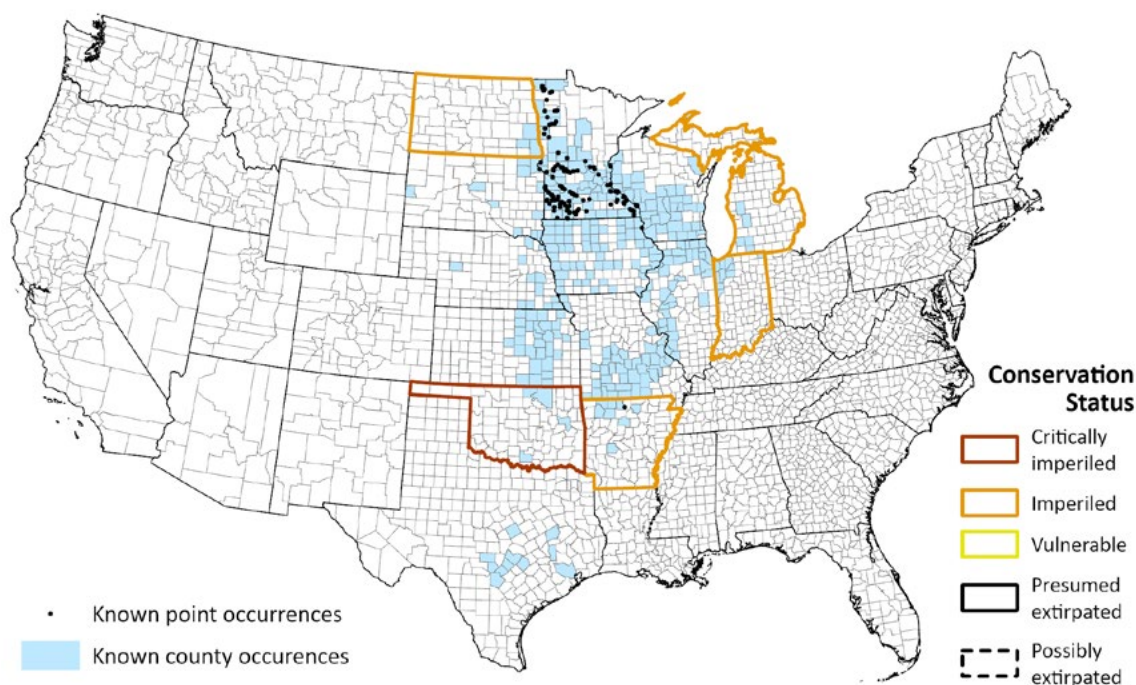


Figure A107.1. Distribution and state-level conservation status of *Symphotrichum sericeum*. Known point occurrences were used to assess species deposition responses and critical loads.

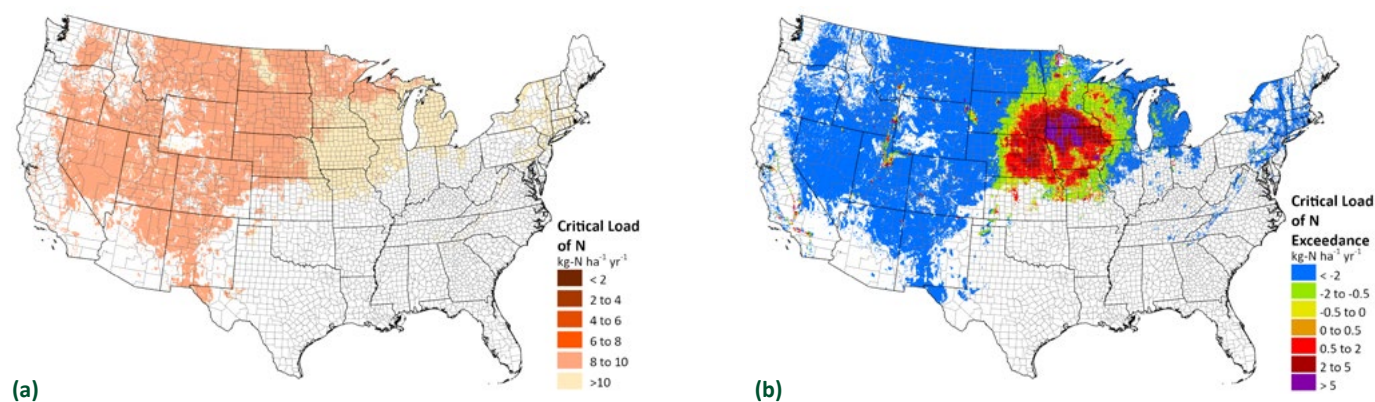


Figure A107.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Symphotrichum sericeum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

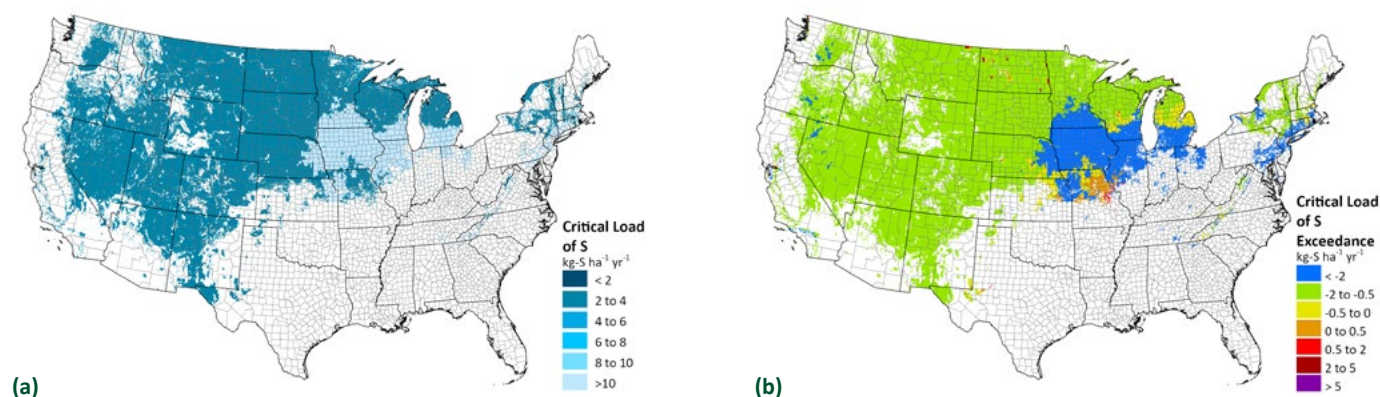


Figure A107.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Symphotrichum sericeum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A108. *Symphotrichum undulatum* (wavyleaf aster)

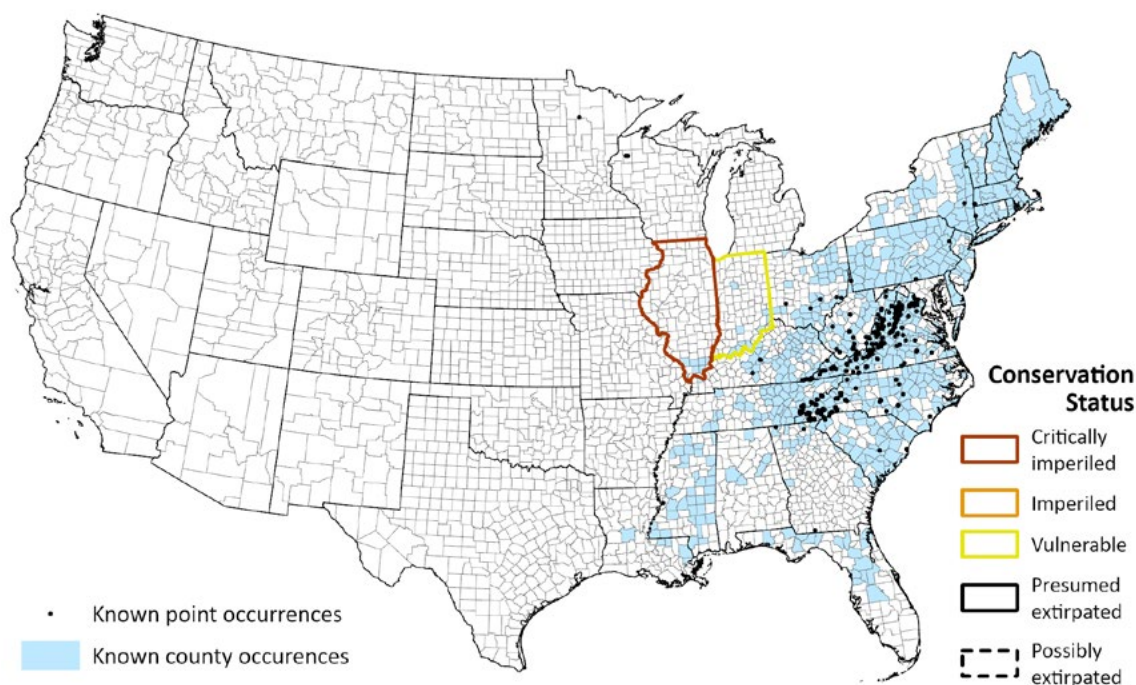


Figure A108.1. Distribution and state-level conservation status of *Symphotrichum undulatum*. Known point occurrences were used to assess species deposition responses and critical loads.

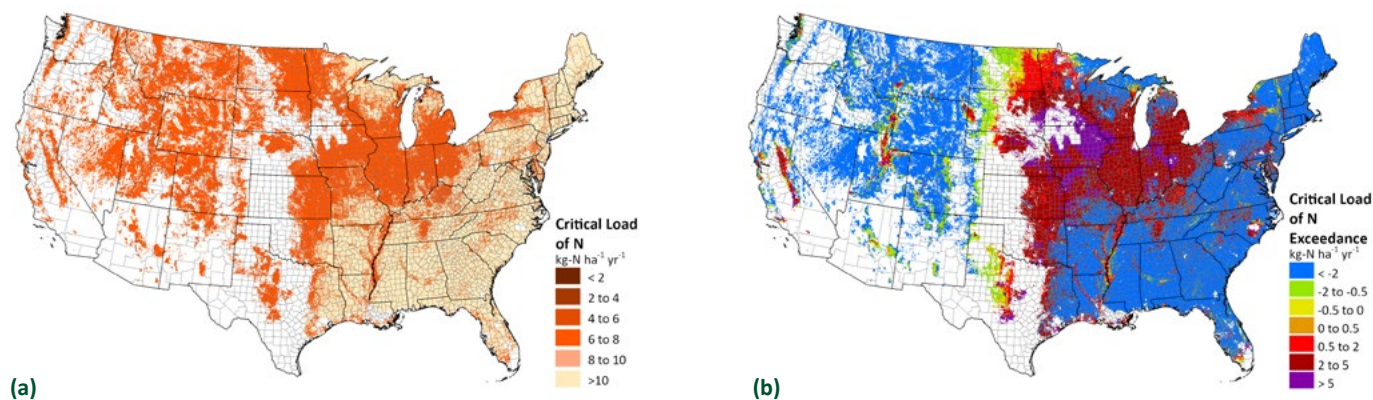


Figure A108.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Symphotrichum undulatum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

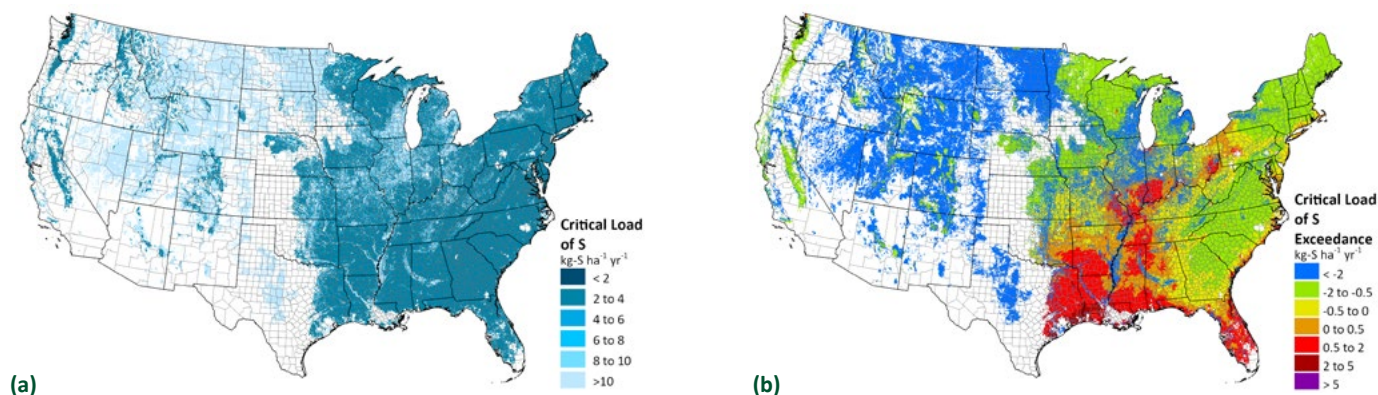


Figure A108.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Symphotrichum undulatum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A109. *Thalictrum dasycarpum* (purple meadow-rue)

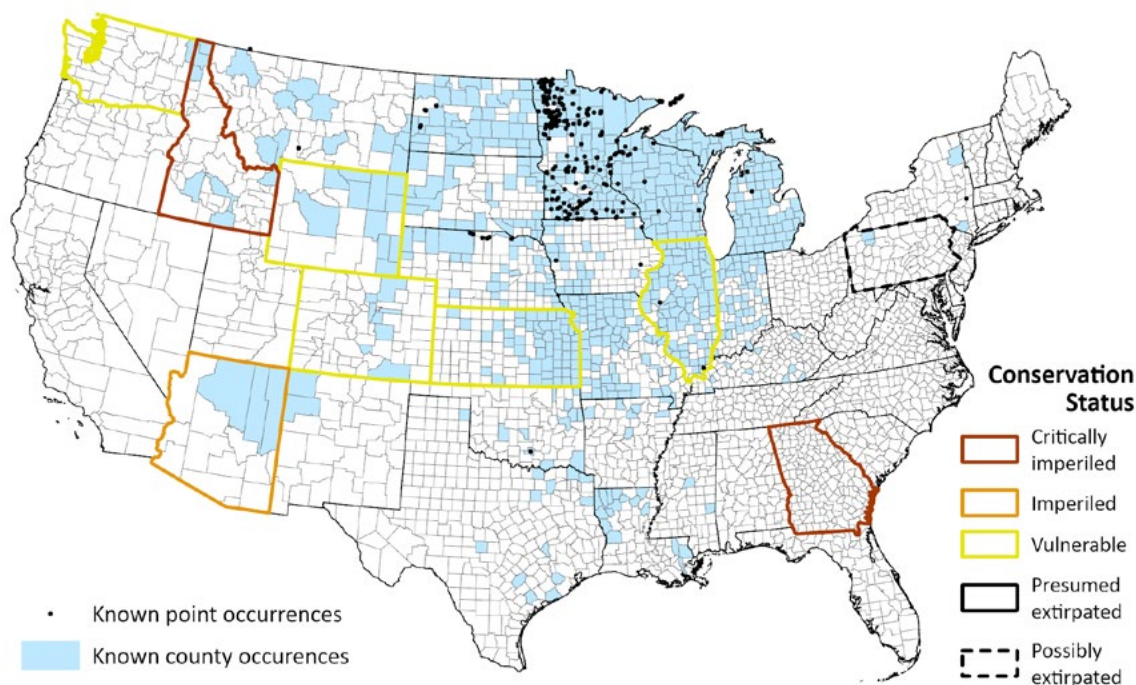


Figure A109.1. Distribution and state-level conservation status of *Thalictrum dasycarpum*. Known point occurrences were used to assess species deposition responses and critical loads.

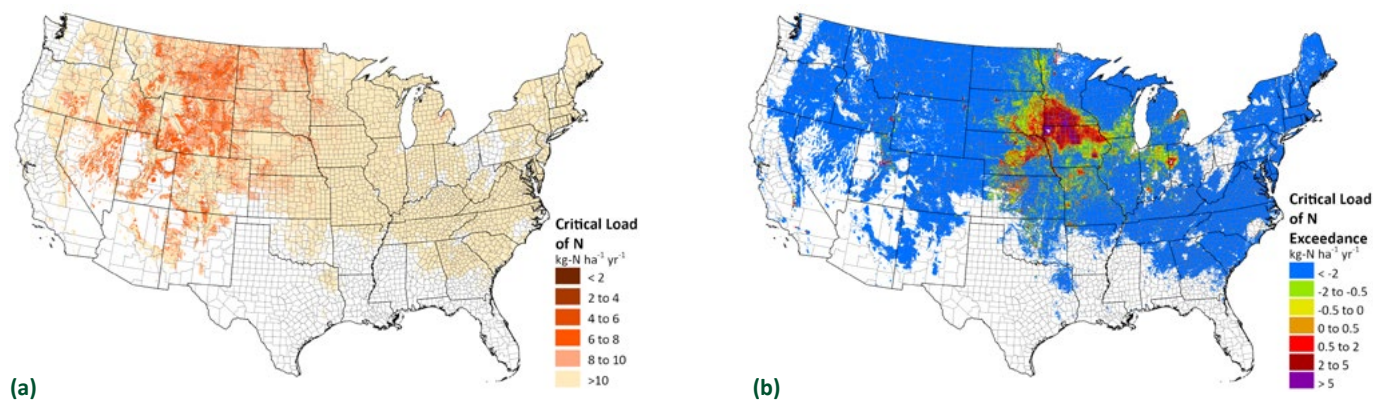


Figure A109.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Thalictrum dasycarpum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

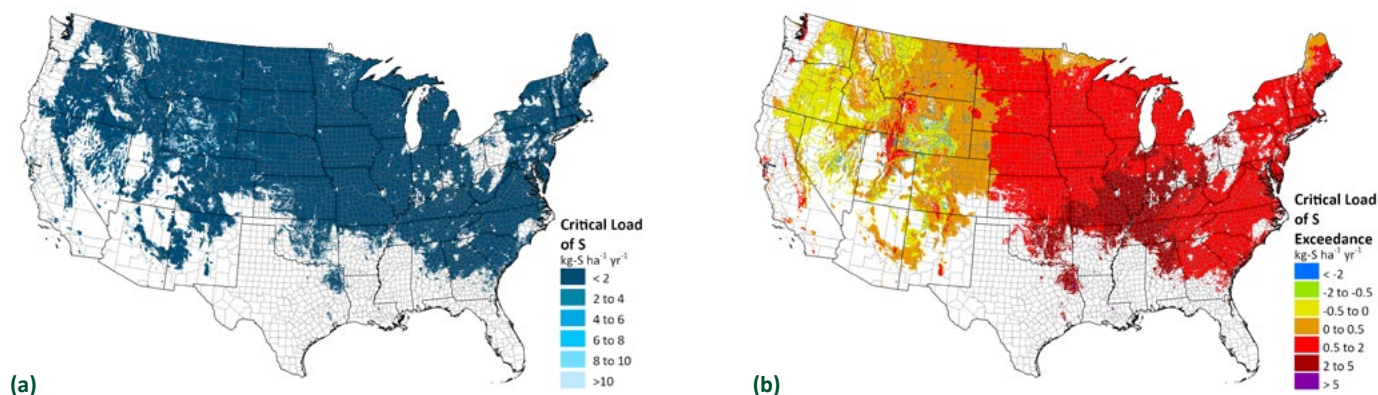


Figure A109.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Thalictrum dasycarpum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A110. *Thalictrum thalictroides* (rue anemone)

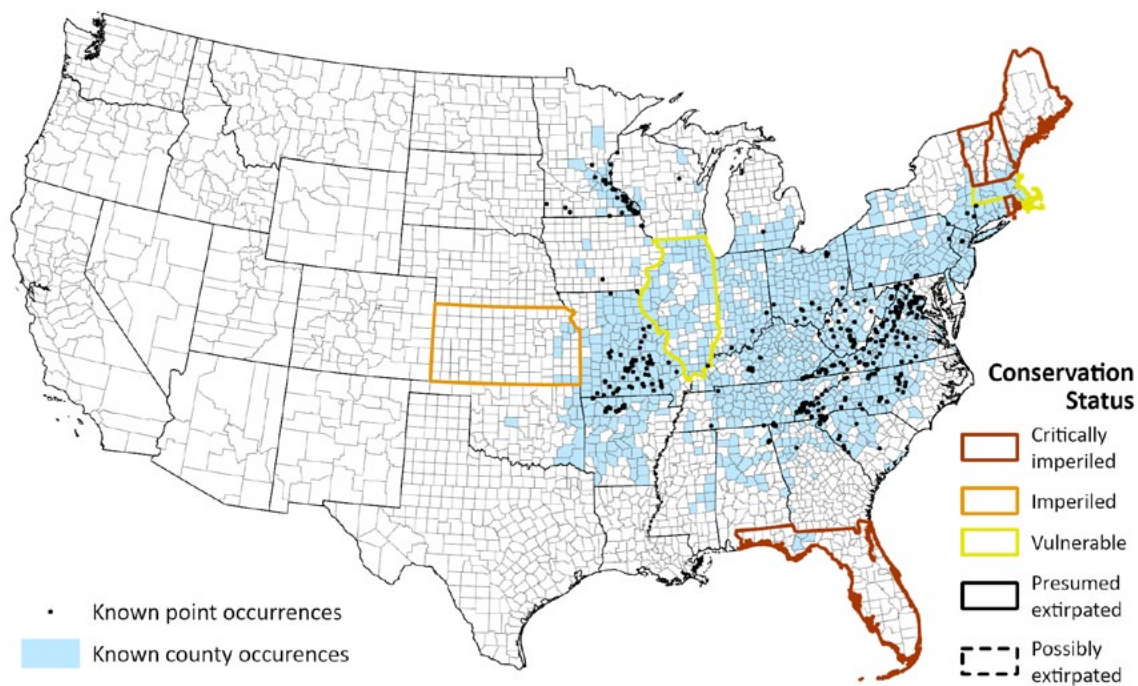


Figure A110.1. Distribution and state-level conservation status of *Thalictrum thalictroides*. Known point occurrences were used to assess species deposition responses and critical loads.

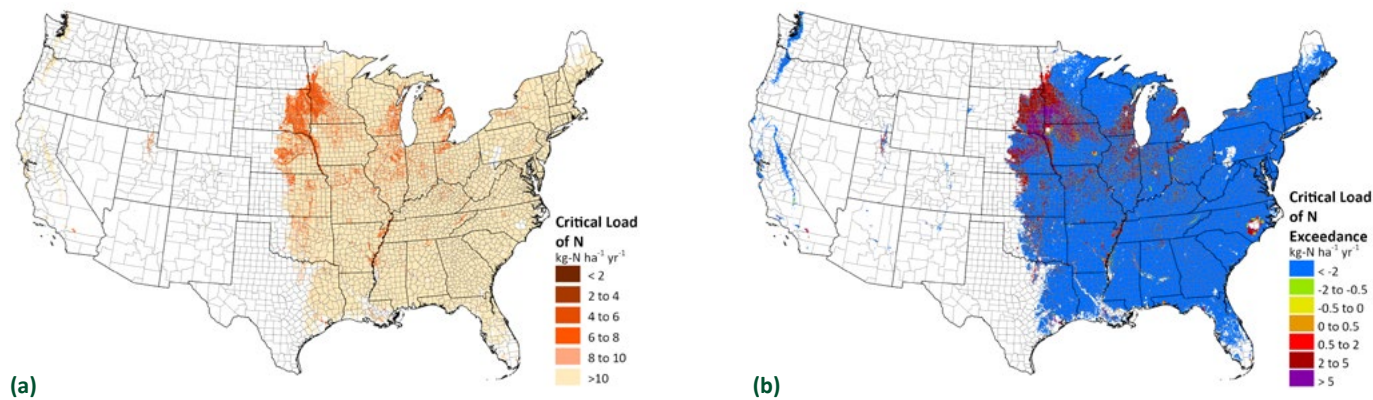


Figure A110.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Thalictrum thalictroides* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

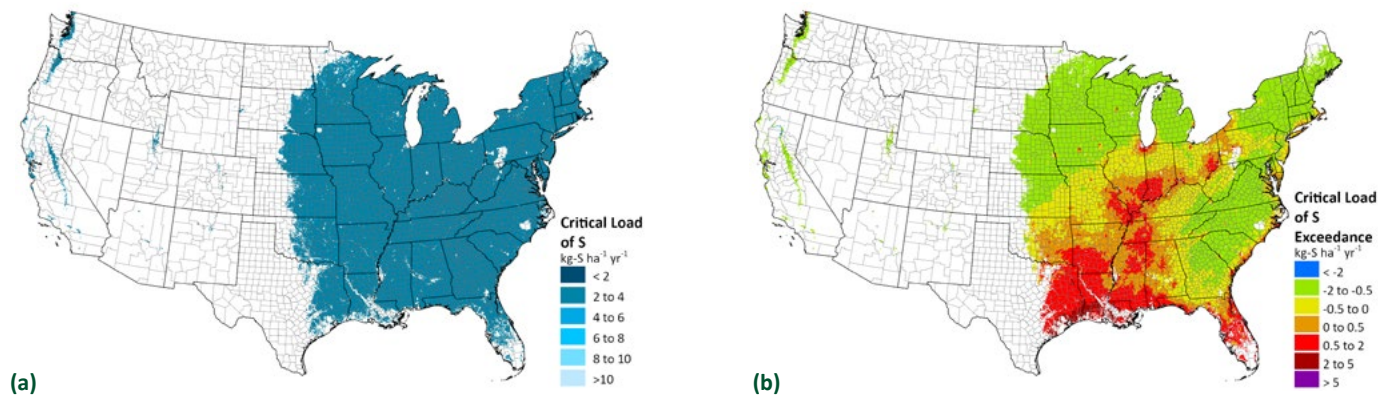


Figure A110.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Thalictrum thalictroides* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A111. *Tiarella cordifolia* (heartleaf foamflower)

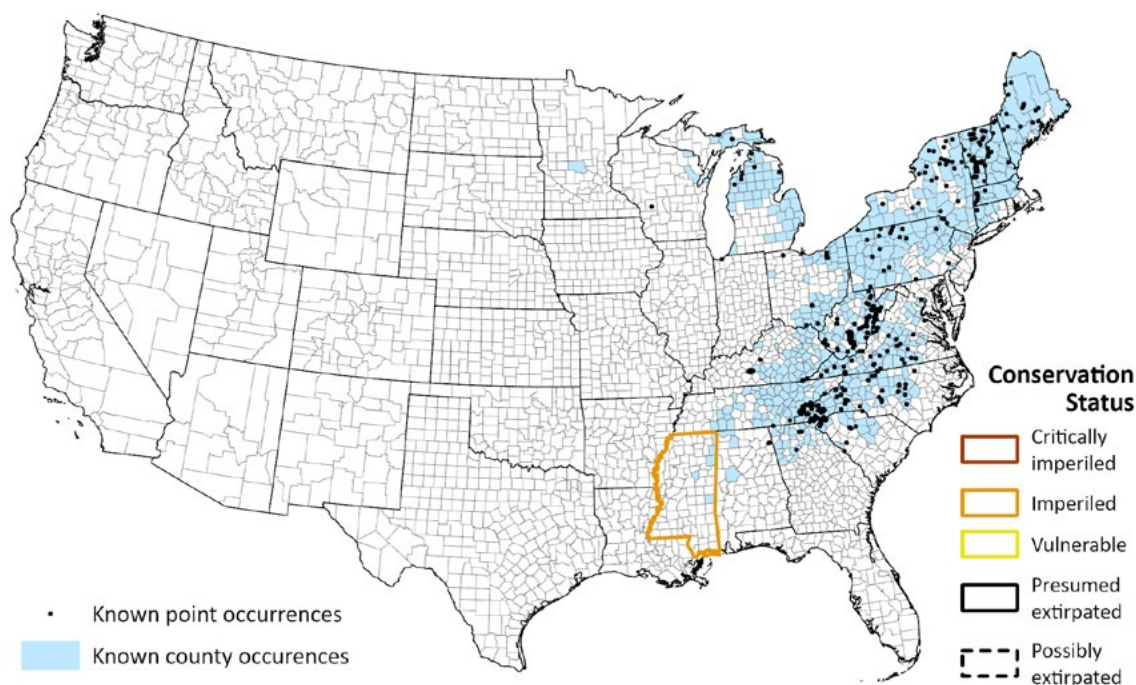


Figure A111.1. Distribution and state-level conservation status of *Tiarella cordifolia*. Known point occurrences were used to assess species deposition responses and critical loads.

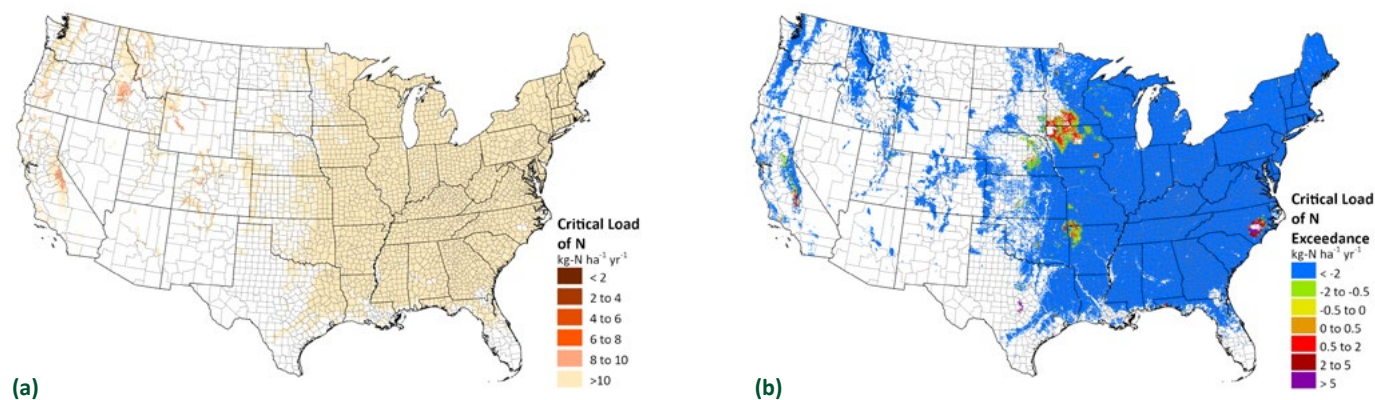


Figure A111.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Tiarella cordifolia* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

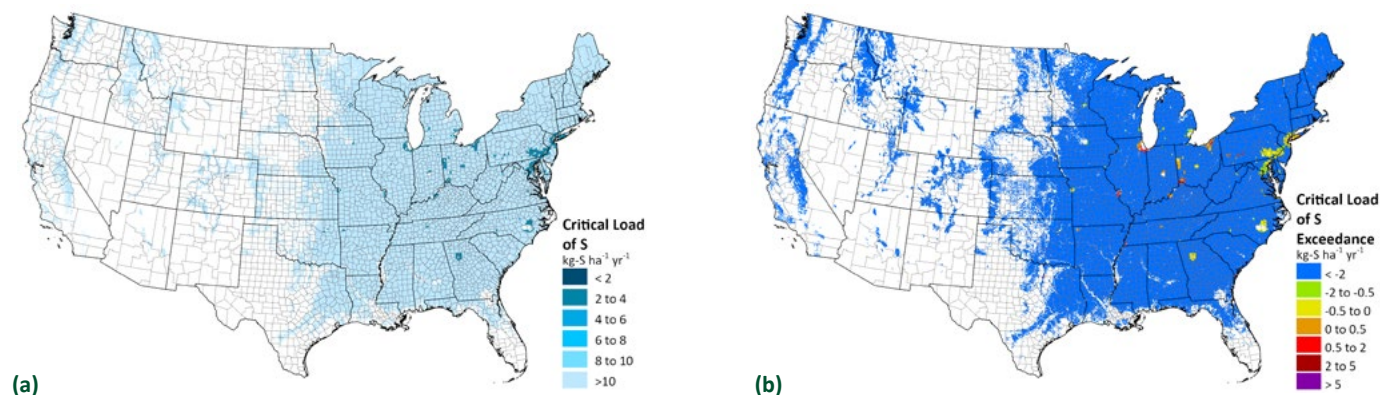


Figure A111.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Tiarella cordifolia* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A112. *Tragia urens* (wavyleaf noseburn)

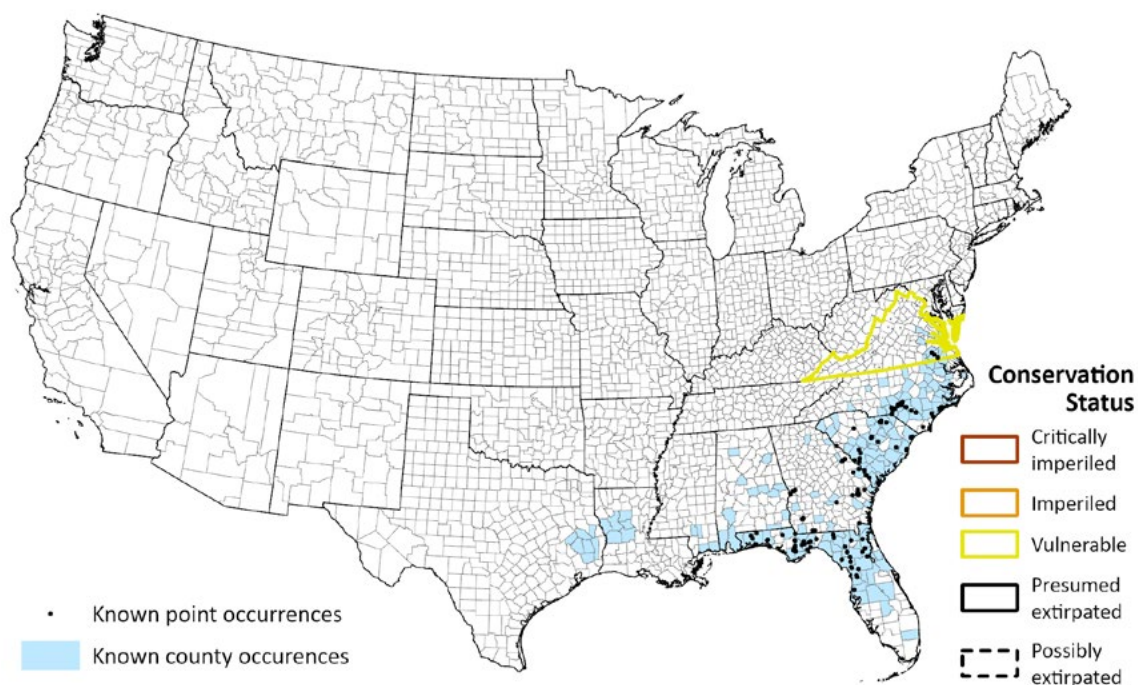


Figure A112.1. Distribution and state-level conservation status of *Tragia urens*. Known point occurrences were used to assess species deposition responses and critical loads.

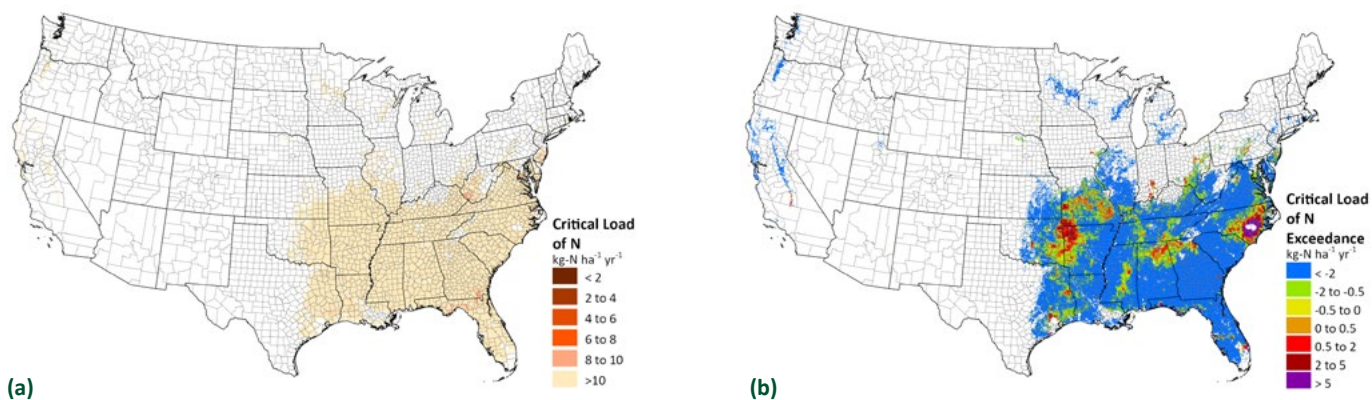


Figure A112.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Tragia urens* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

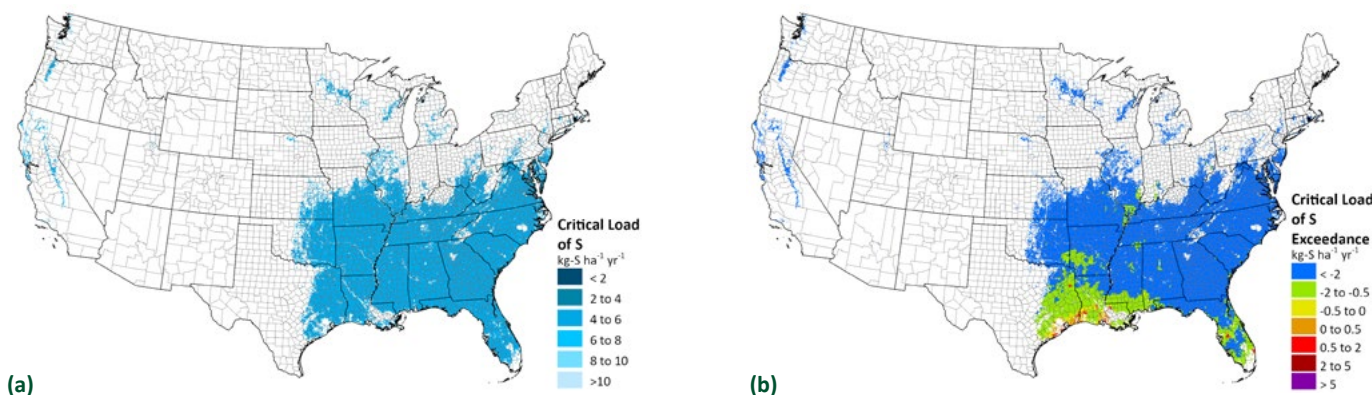


Figure A112.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Tragia urens* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A113. *Trientalis borealis* (starflower)

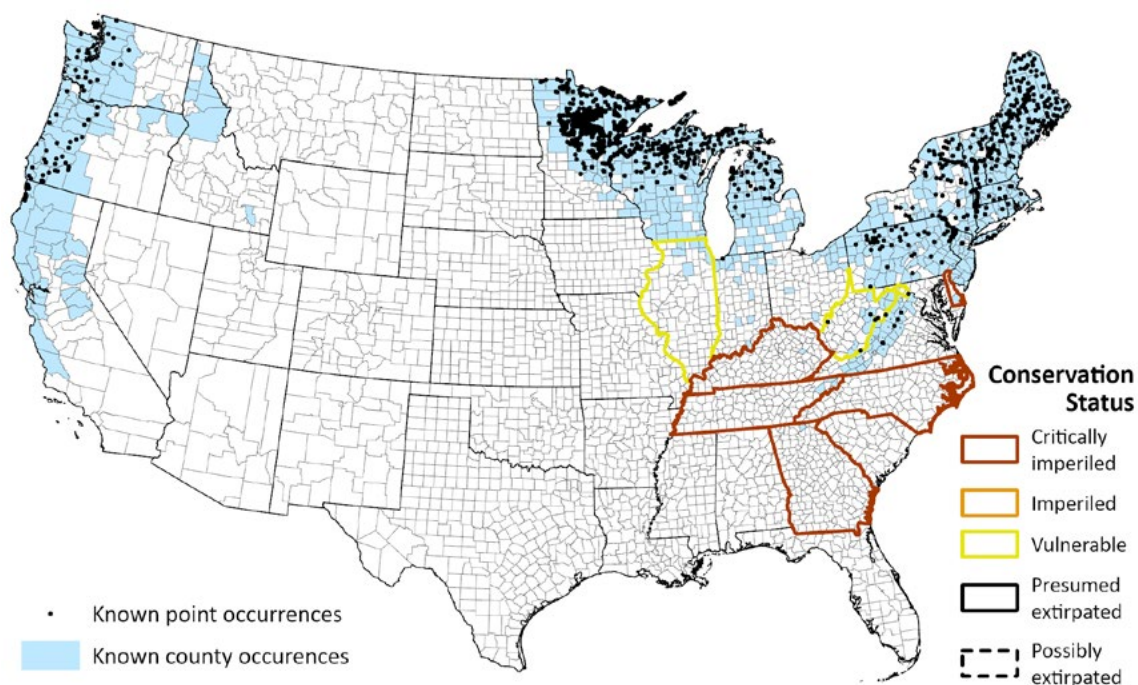


Figure A113.1. Distribution and state-level conservation status of *Trientalis borealis*. Known point occurrences were used to assess species deposition responses and critical loads.

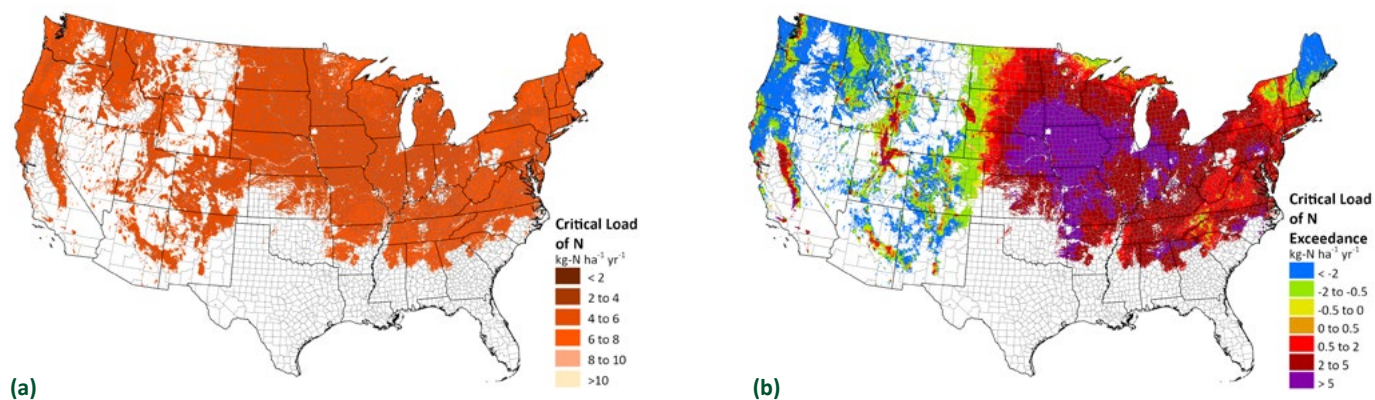


Figure A113.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Trientalis borealis* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

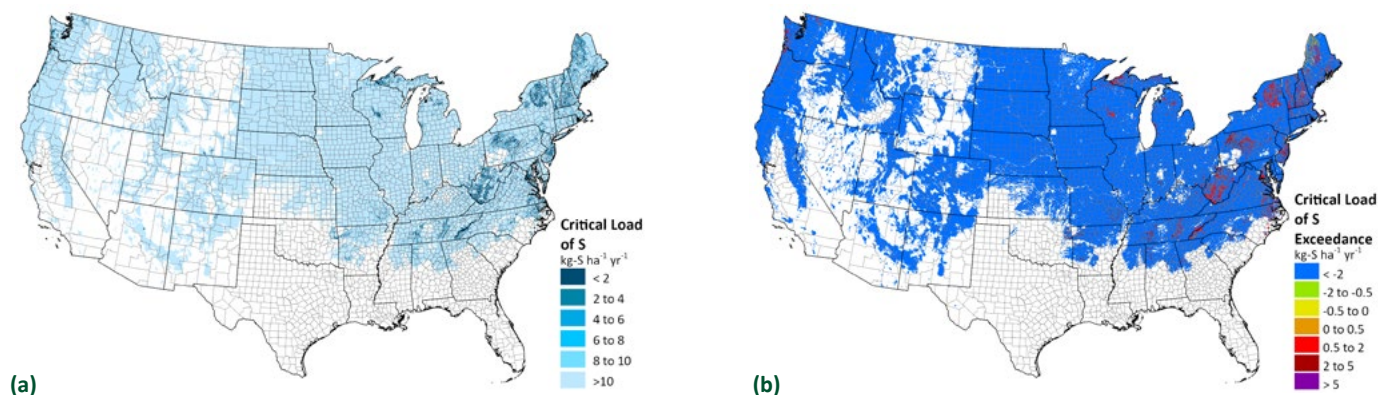


Figure A113.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Trientalis borealis* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A114. *Trillium erectum* (red trillium)

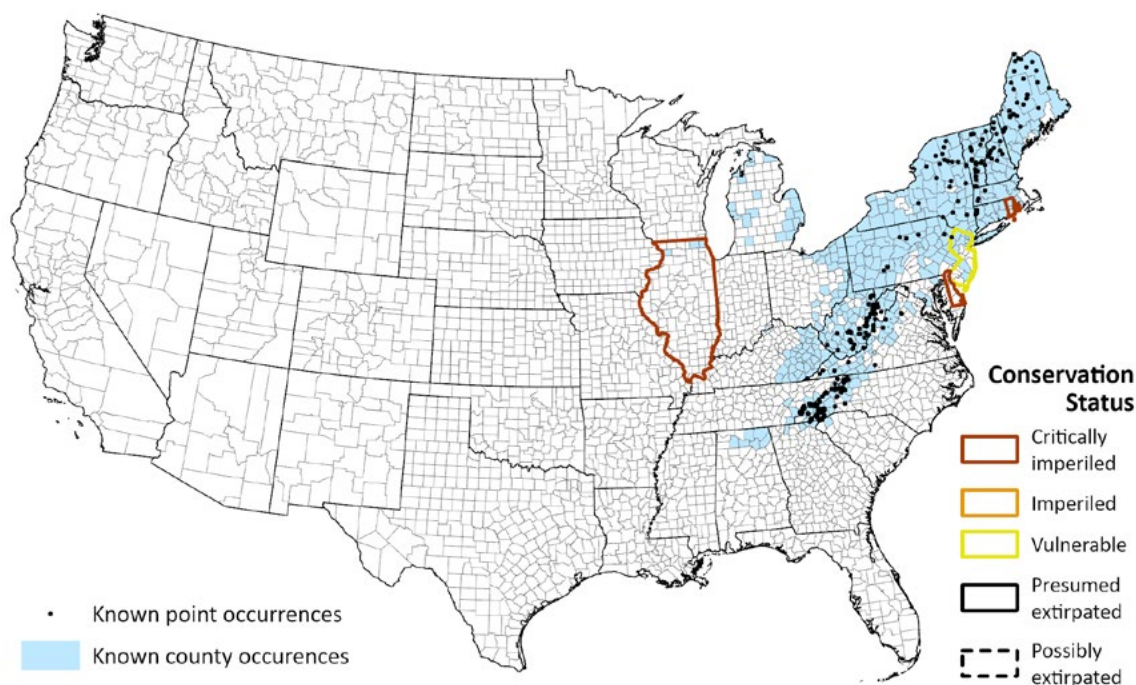


Figure A114.1. Distribution and state-level conservation status of *Trillium erectum*. Known point occurrences were used to assess species deposition responses and critical loads.

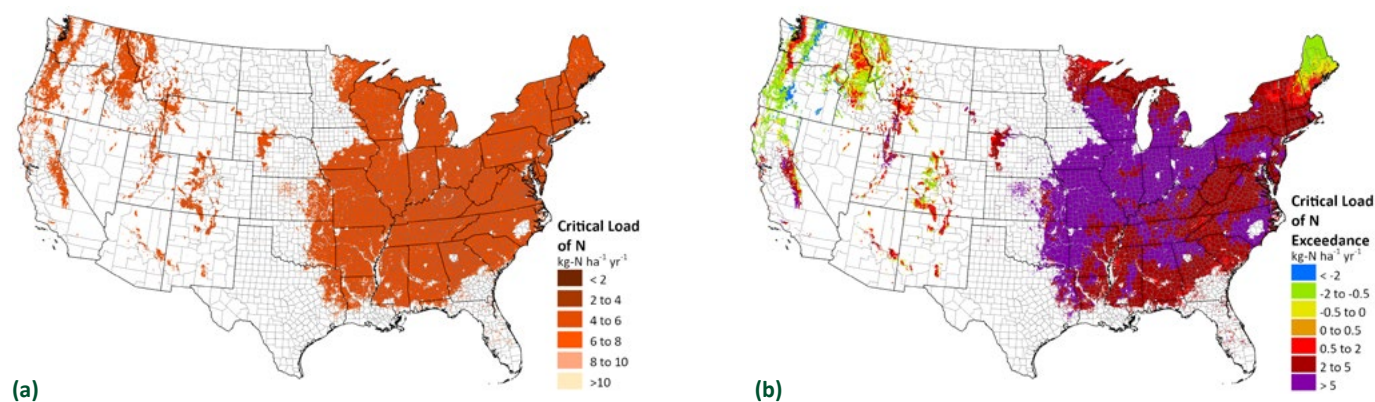


Figure A114.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Trillium erectum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

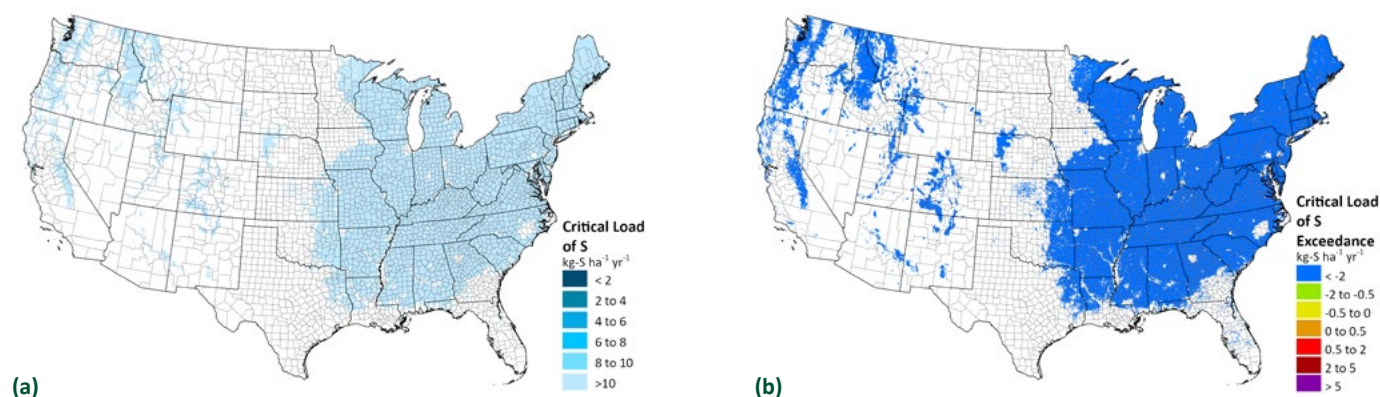


Figure A114.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Trillium erectum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A115. *Trillium grandiflorum* (white trillium)

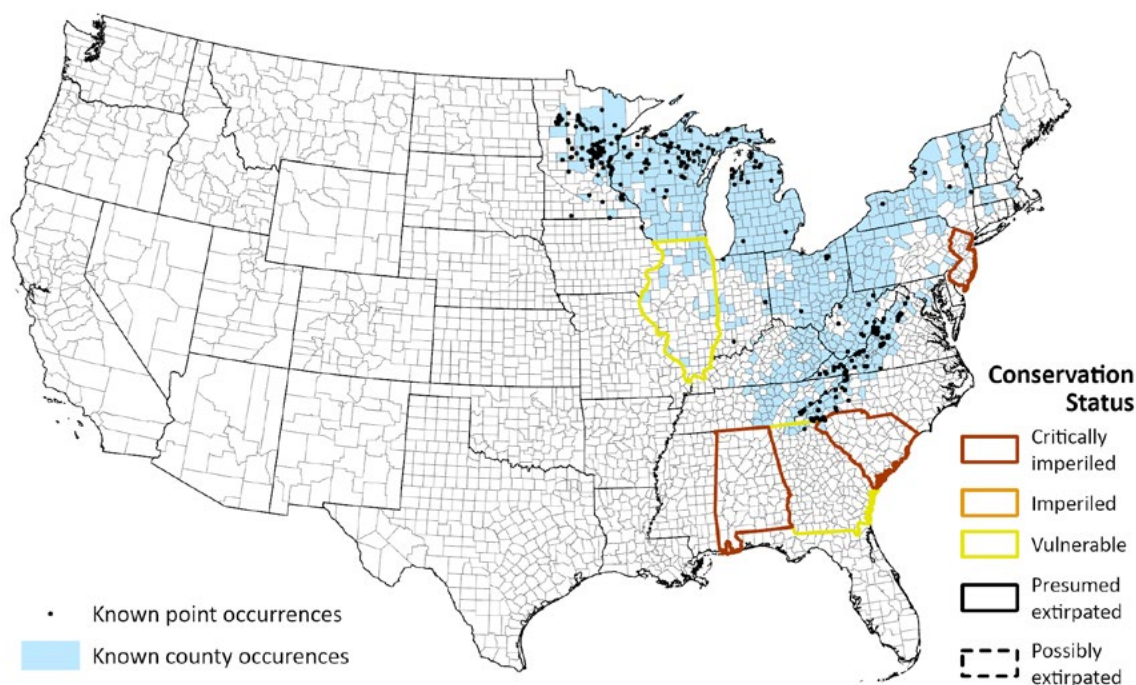


Figure A115.1. Distribution and state-level conservation status of *Trillium grandiflorum*. Known point occurrences were used to assess species deposition responses and critical loads.

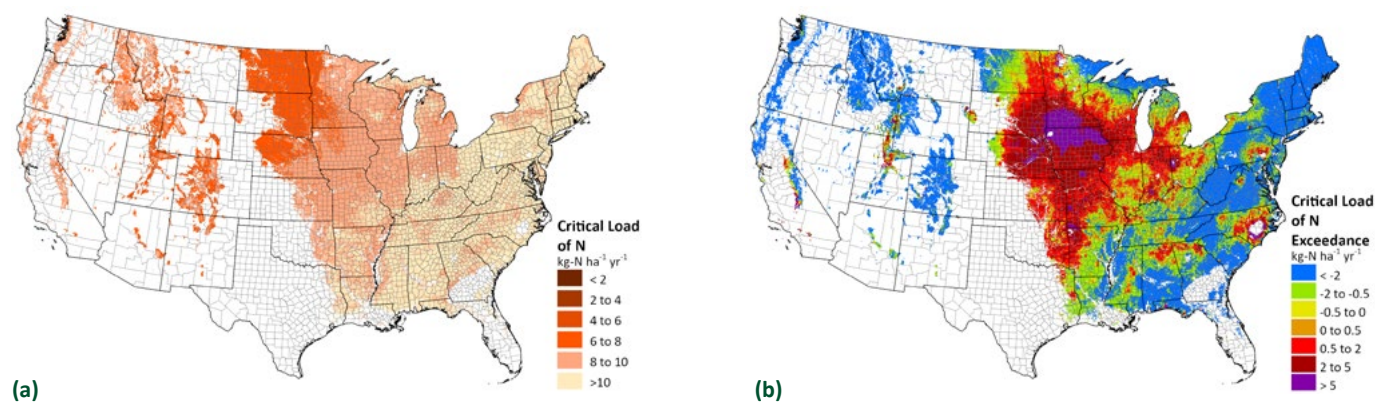


Figure A115.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Trillium grandiflorum* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

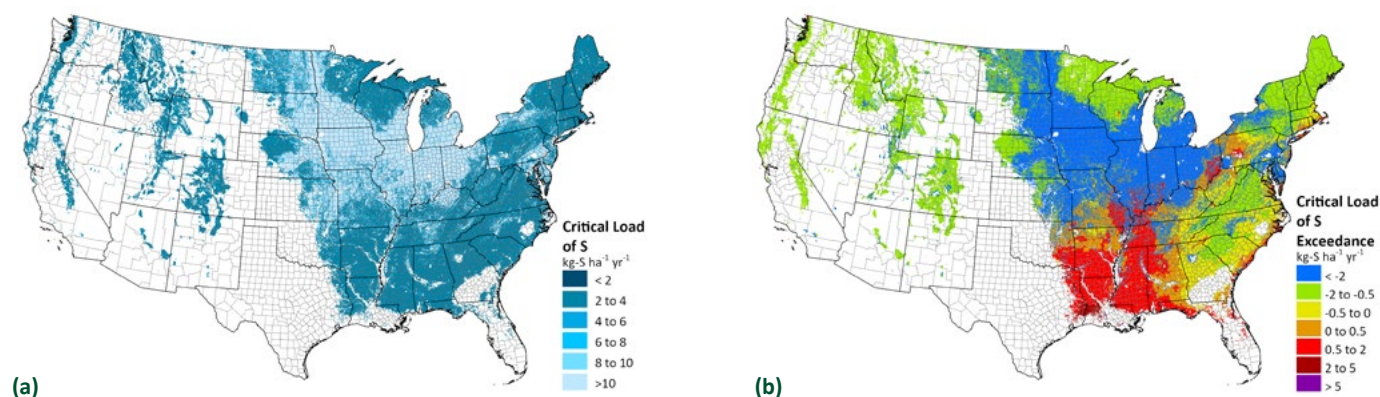


Figure A115.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Trillium grandiflorum* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A116. *Trillium sessile* (toadshade)

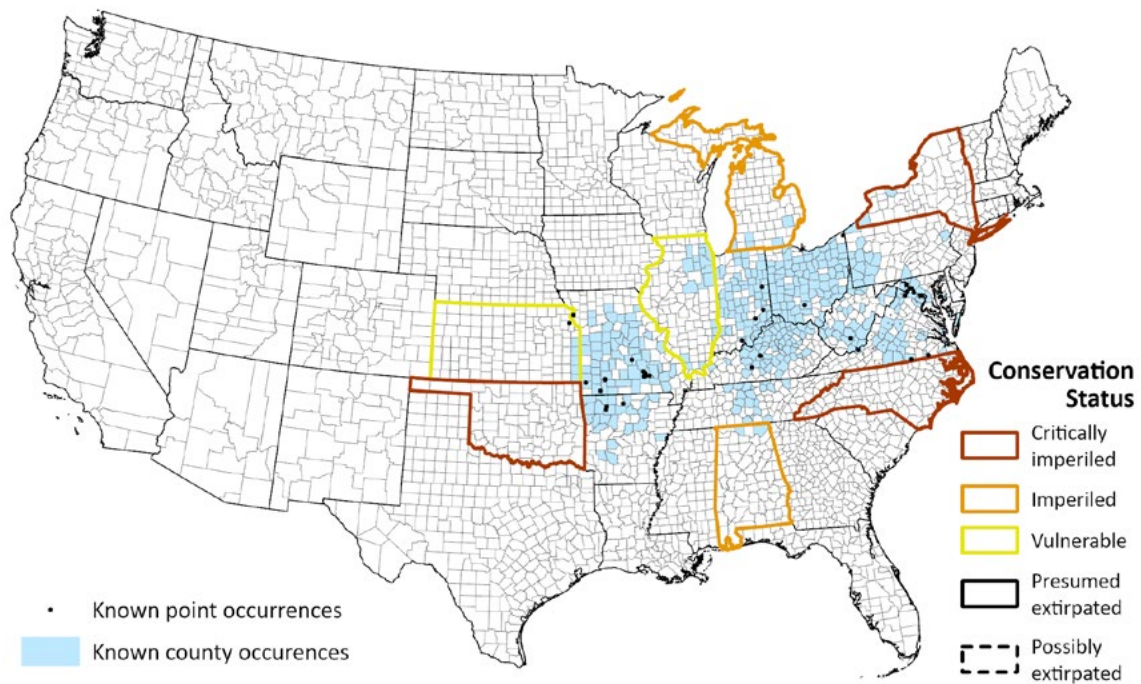


Figure A116.1. Distribution and state-level conservation status of *Trillium sessile*. Known point occurrences were used to assess species deposition responses and critical loads.

A117. *Uvularia grandiflora* (largeflower bellwort)

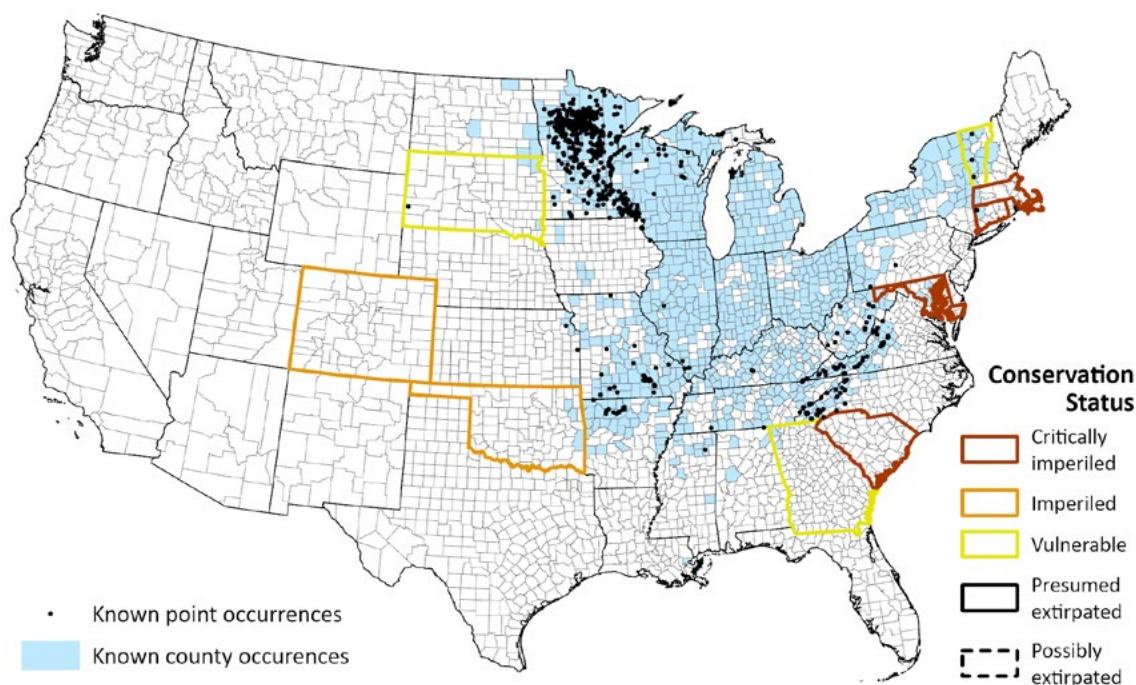


Figure A117.1. Distribution and state-level conservation status of *Uvularia grandiflora*. Known point occurrences were used to assess species deposition responses and critical loads.

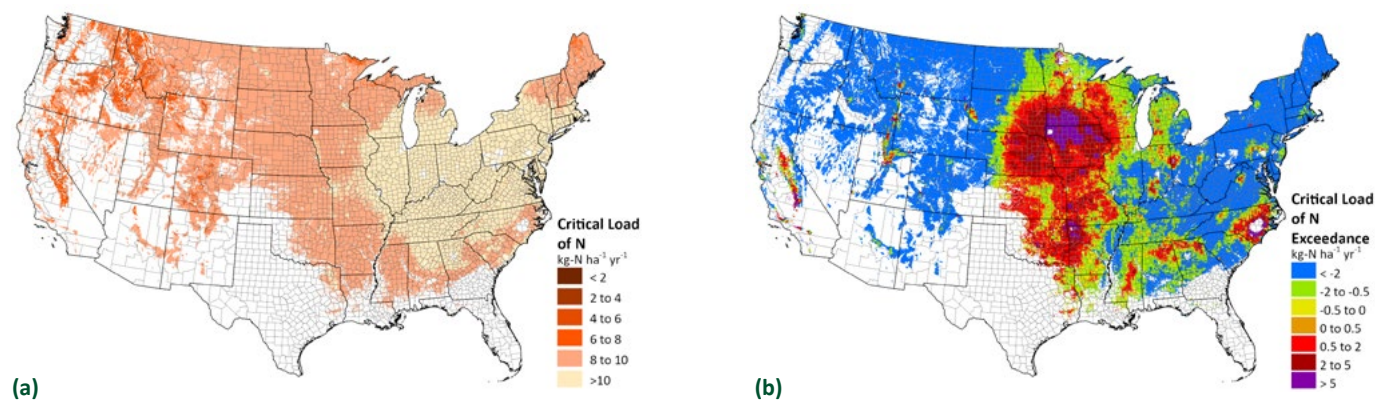


Figure A117.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Uvularia grandiflora* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

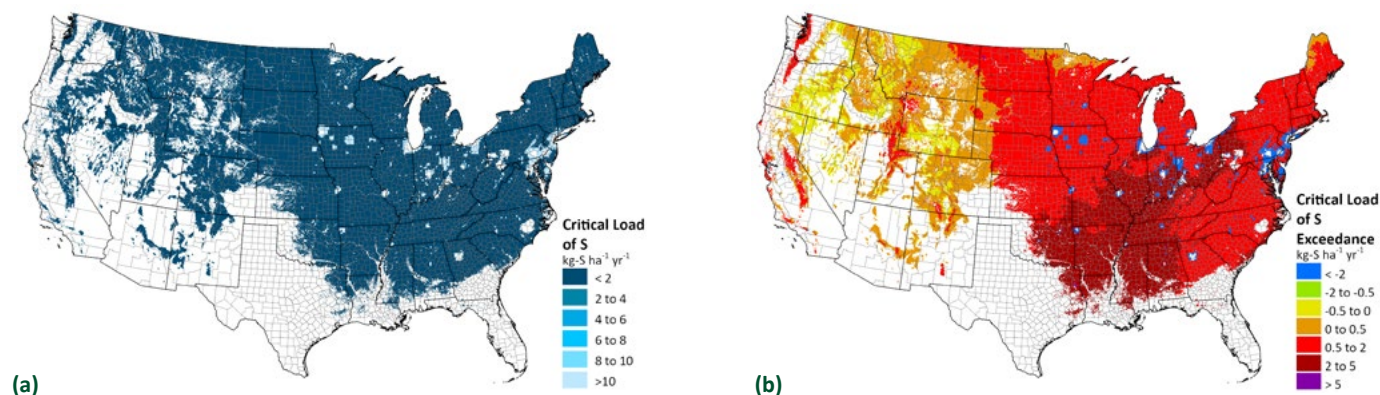


Figure A117.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Uvularia grandiflora* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A118. *Uvularia sessilifolia* (sessileleaf bellwort)

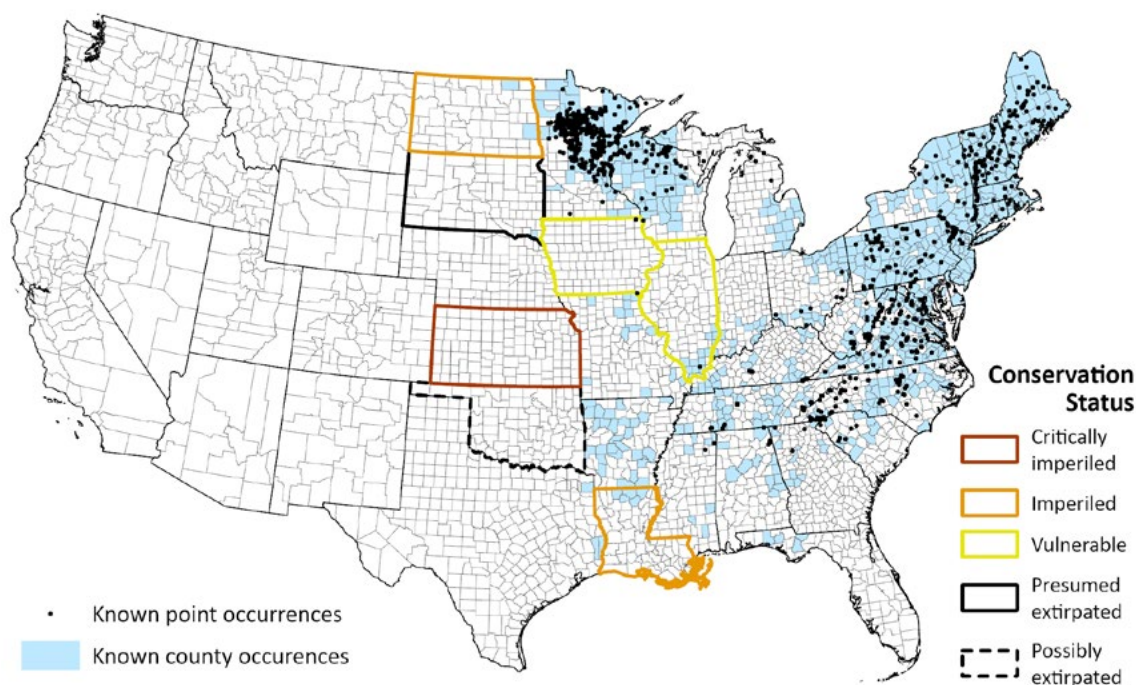


Figure A118.1. Distribution and state-level conservation status of *Uvularia sessilifolia*. Known point occurrences were used to assess species deposition responses and critical loads.

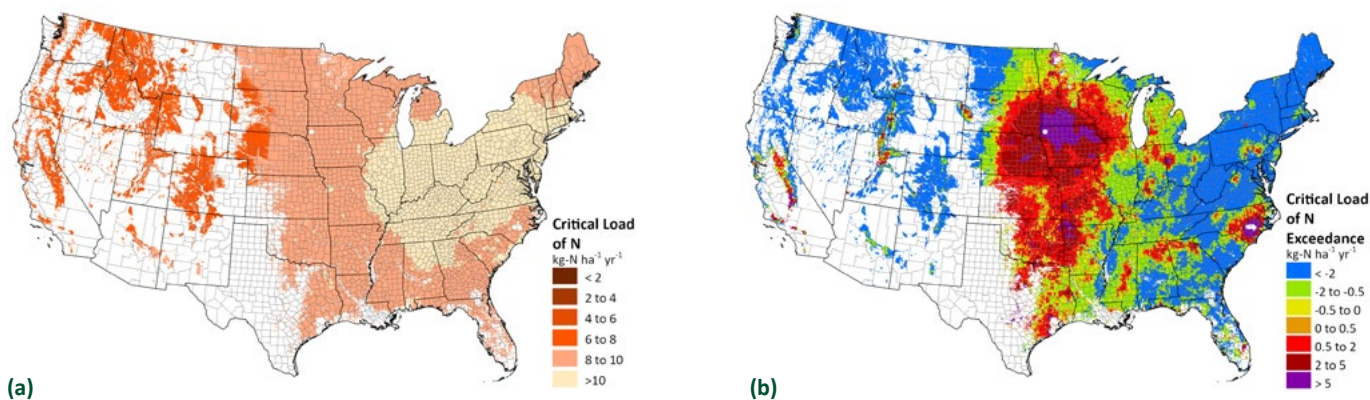


Figure A118.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Uvularia sessilifolia* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

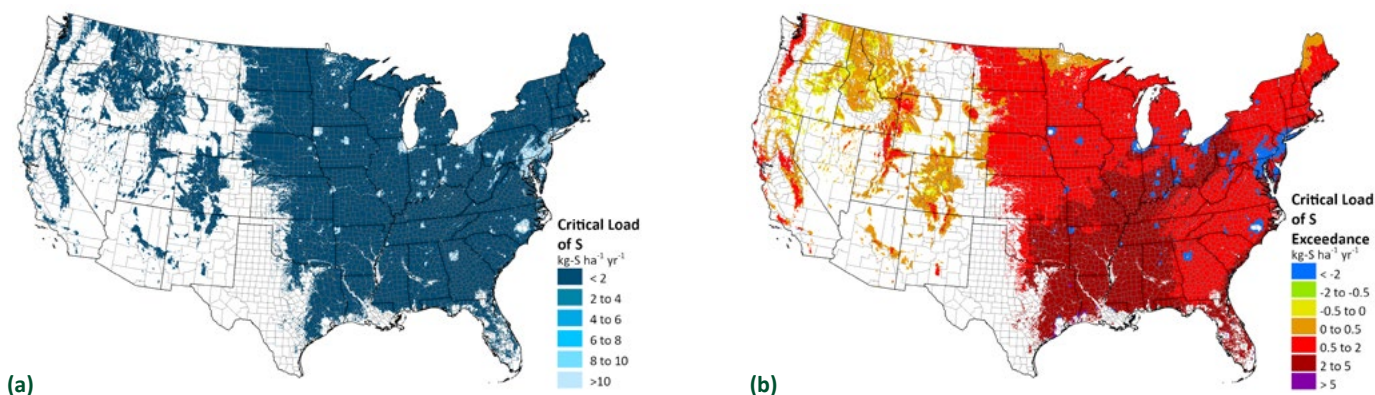


Figure A118.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Uvularia sessilifolia* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A119. *Veronica hederifolia* (ivyleaf speedwell)

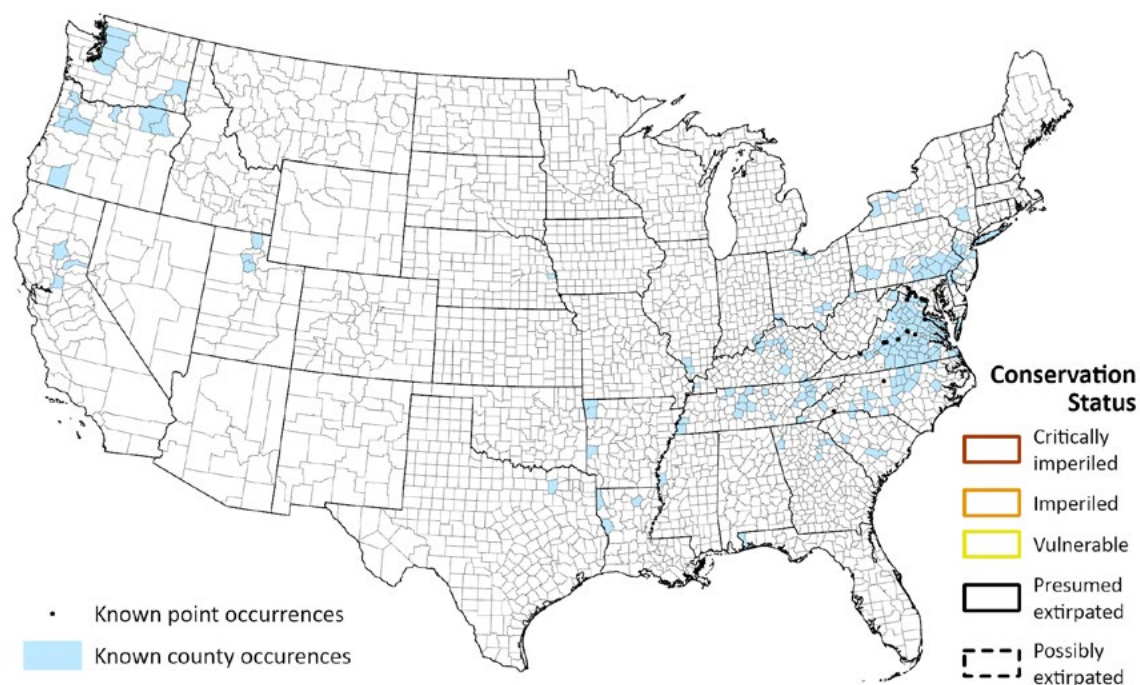


Figure A119.1. Distribution and state-level conservation status of *Veronica hederifolia*. Known point occurrences were used to assess species deposition responses and critical loads.

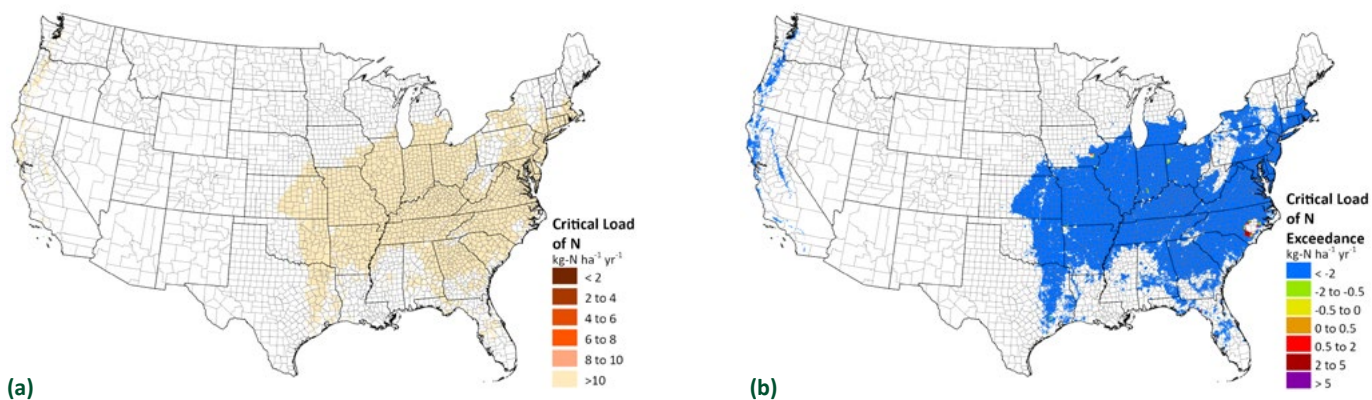


Figure A119.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Veronica hederifolia* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

A120. *Viola canadensis* (Canadian white violet)

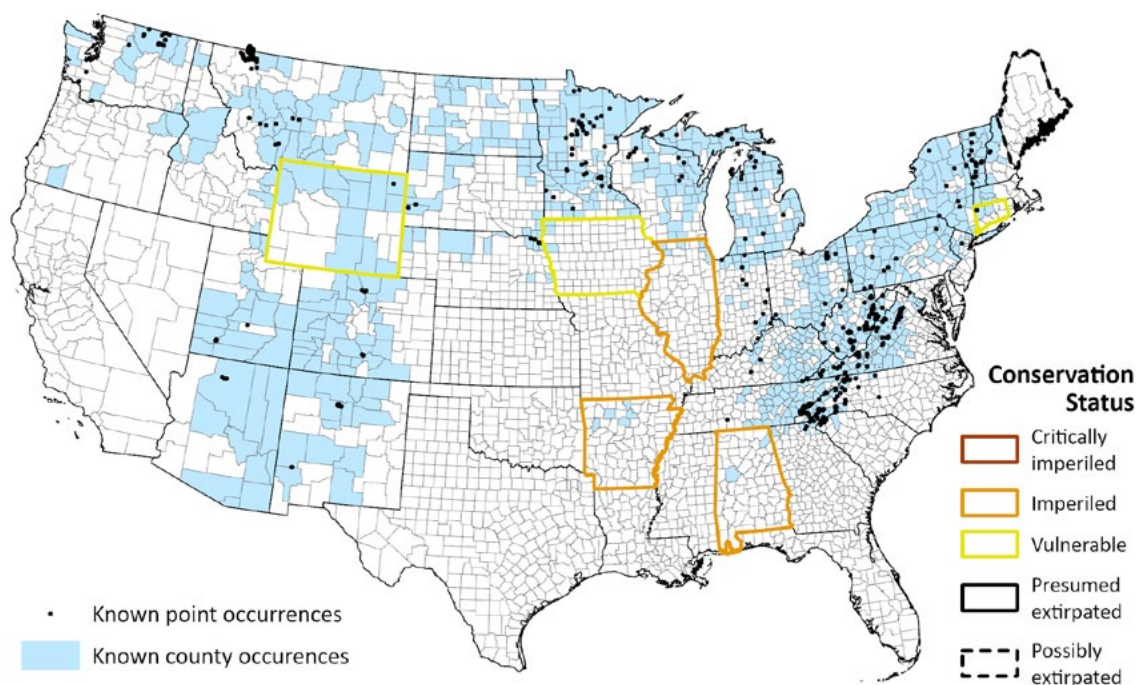


Figure A120.1. Distribution and state-level conservation status of *Viola canadensis*. Known point occurrences were used to assess species deposition responses and critical loads.

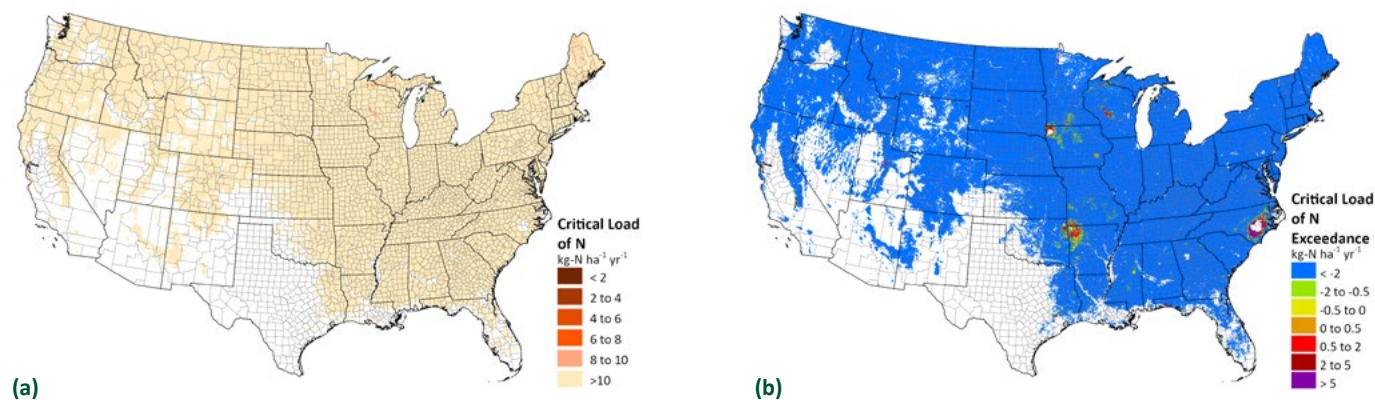


Figure A120.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Viola canadensis* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

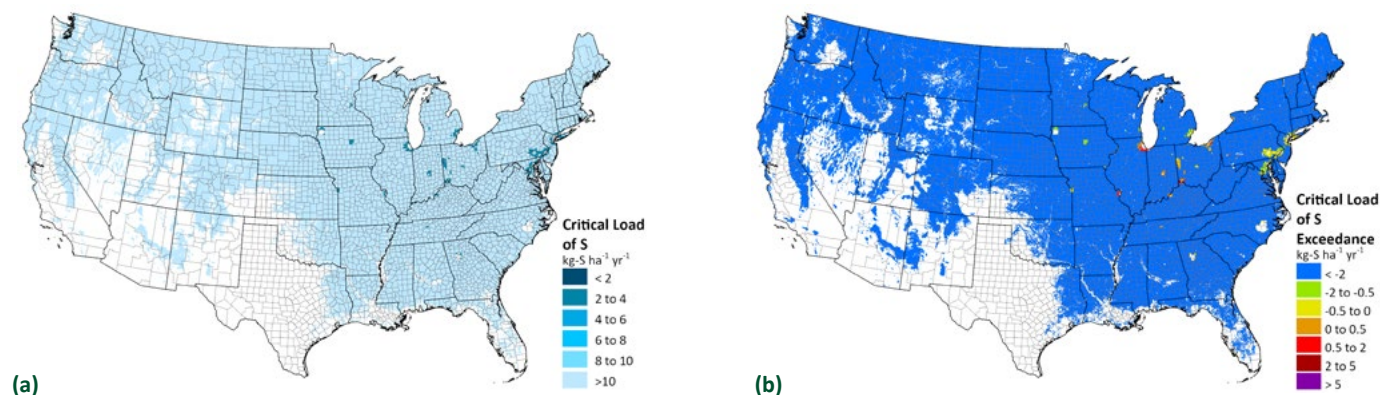


Figure A120.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Viola canadensis* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A121. *Viola hastata* (halberdleaf yellow violet)

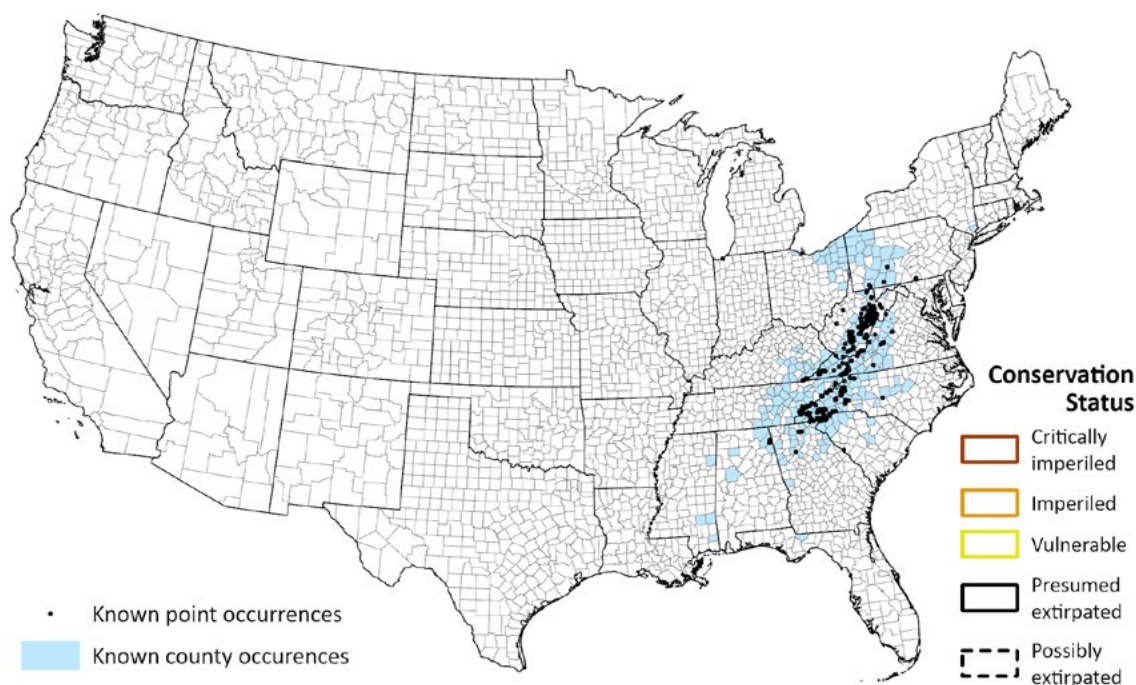


Figure A121.1. Distribution and state-level conservation status of *Viola hastata*. Known point occurrences were used to assess species deposition responses and critical loads.

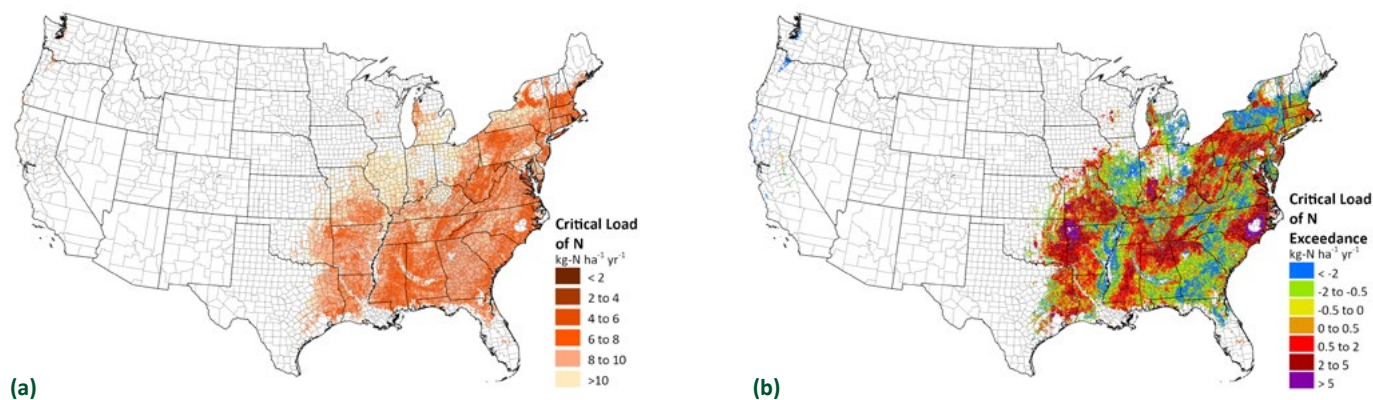


Figure A121.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Viola hastata* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

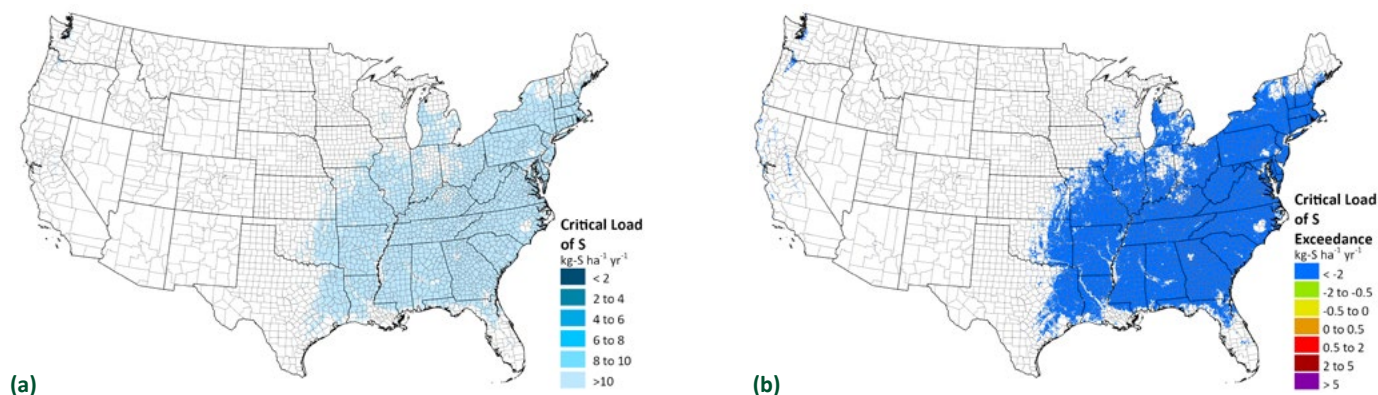


Figure A121.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Viola hastata* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A122. *Viola pubescens* (downy yellow violet)

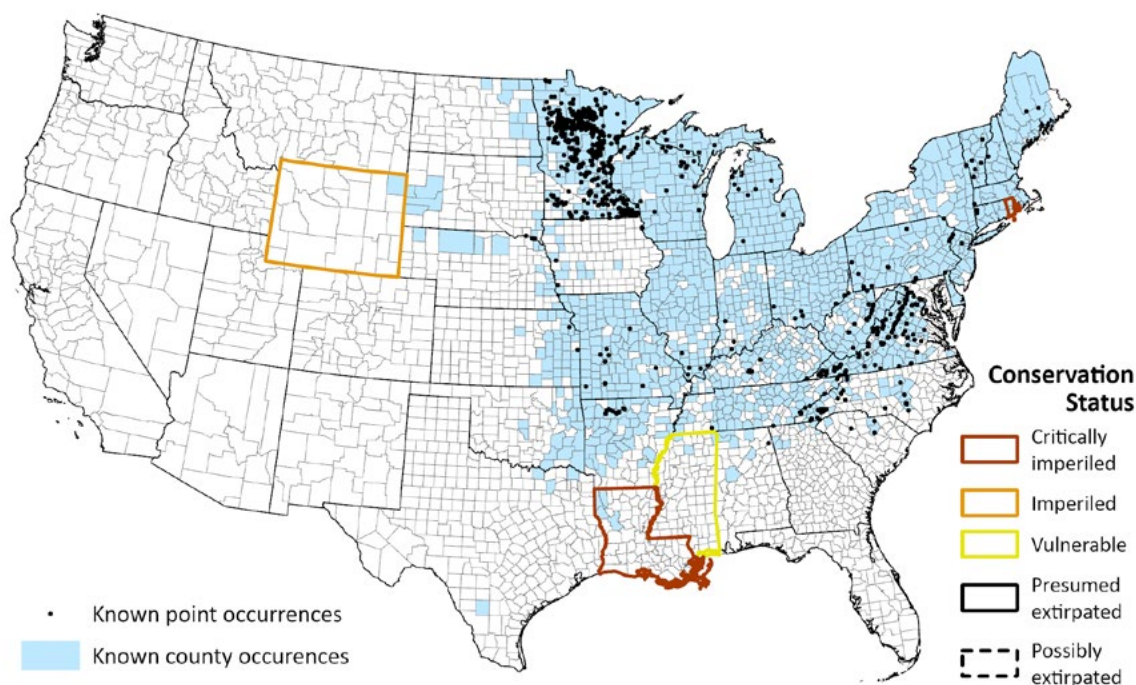


Figure A122.1. Distribution and state-level conservation status of *Viola pubescens*. Known point occurrences were used to assess species deposition responses and critical loads.

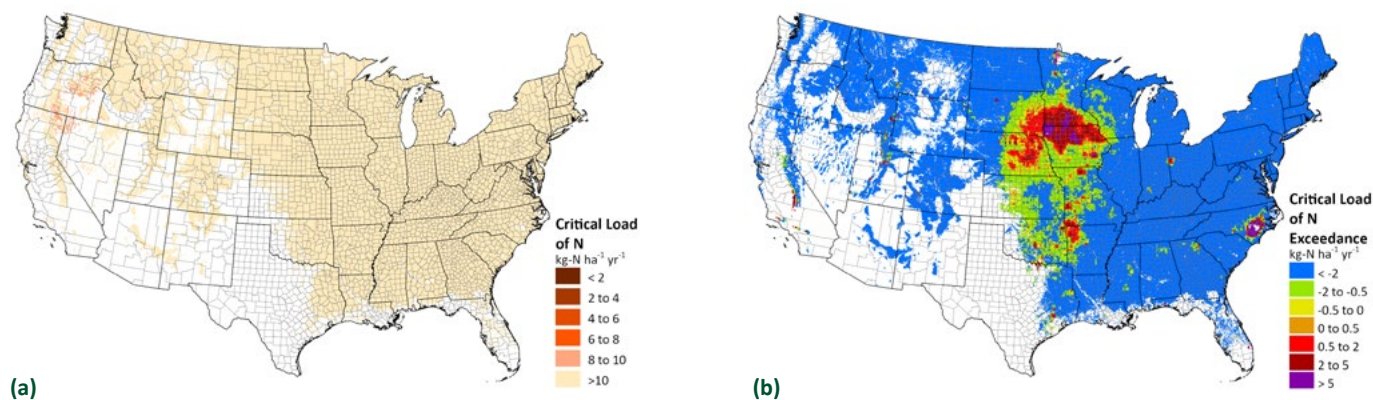


Figure A122.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Viola pubescens* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

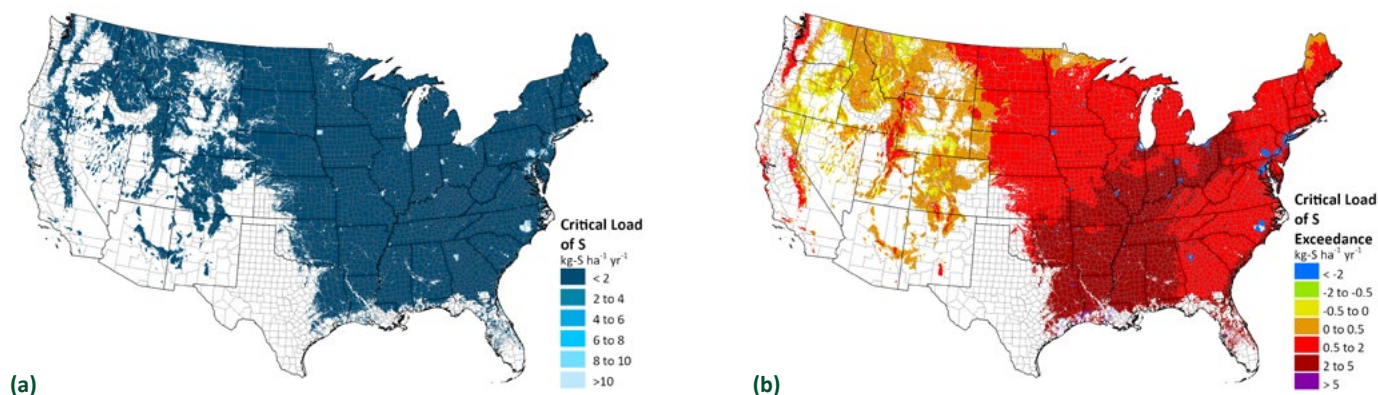


Figure A122.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Viola pubescens* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A123. *Viola rotundifolia* (roundleaf yellow violet)

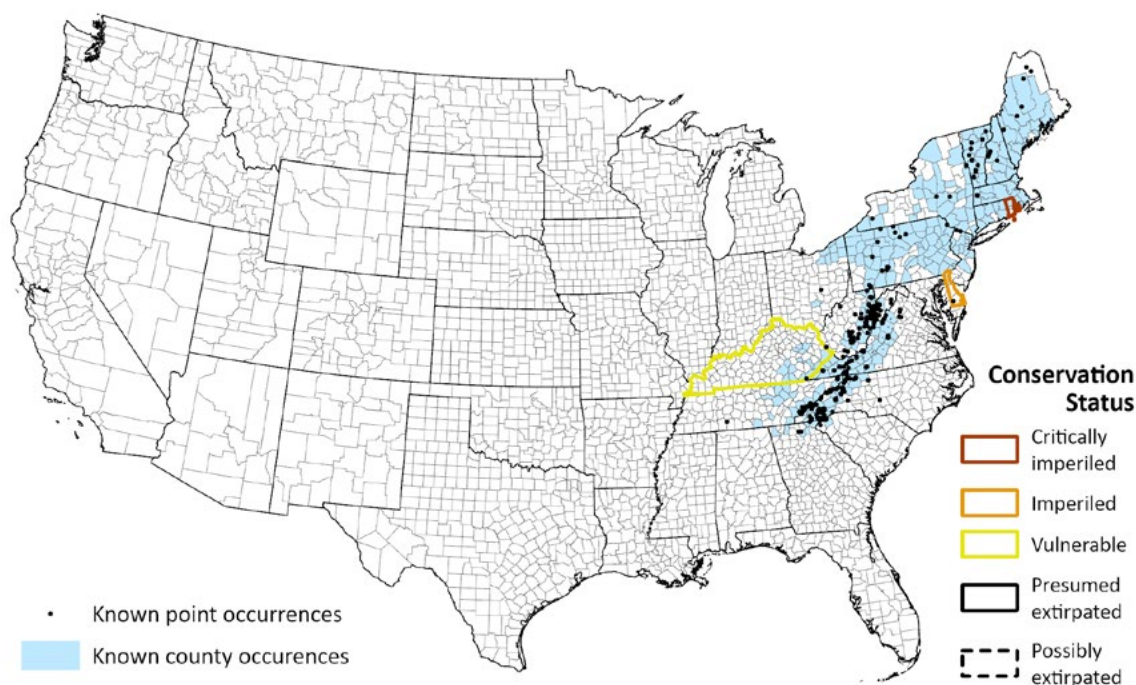


Figure A123.1. Distribution and state-level conservation status of *Viola rotundifolia*. Known point occurrences were used to assess species deposition responses and critical loads.

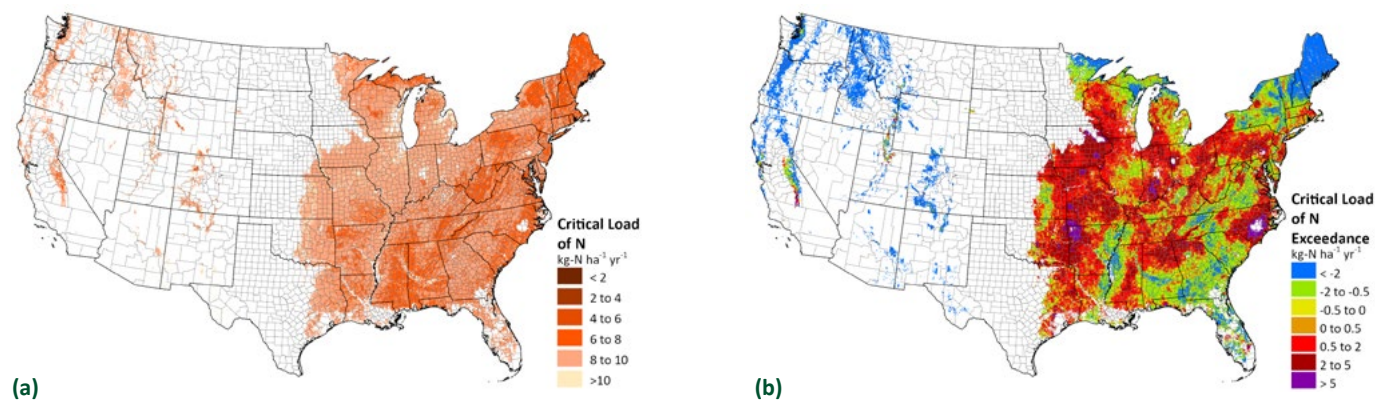


Figure A123.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Viola rotundifolia* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

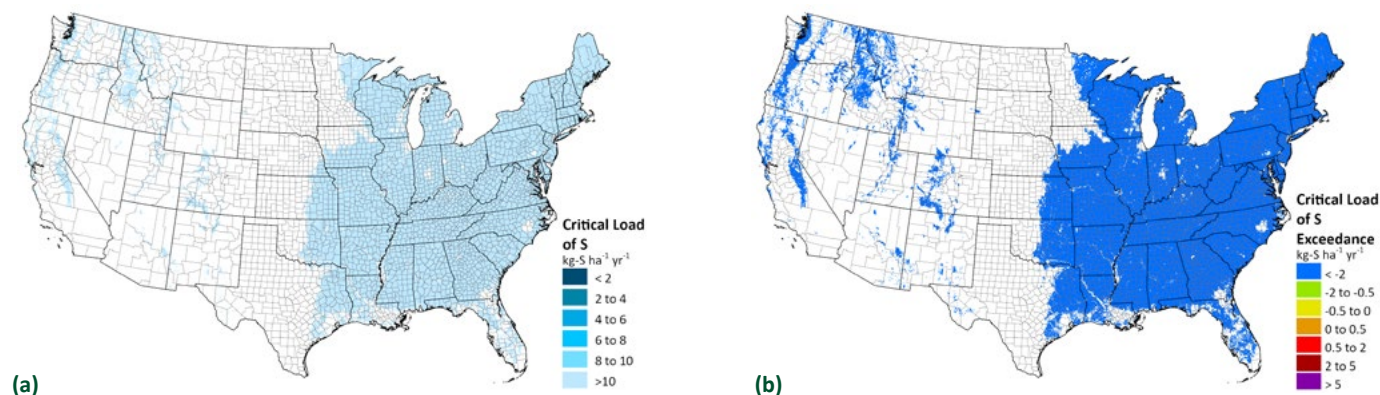


Figure A123.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Viola rotundifolia* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A124. *Viola sororia* (common blue violet)

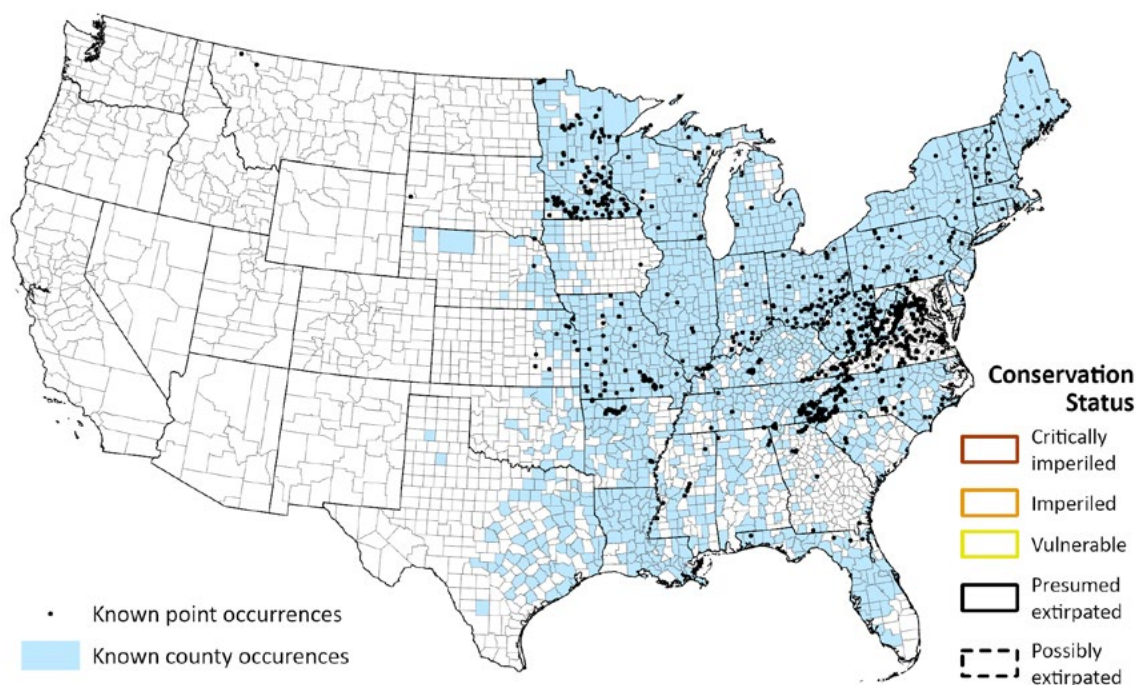


Figure A124.1. Distribution and state-level conservation status of *Viola sororia*. Known point occurrences were used to assess species deposition responses and critical loads.

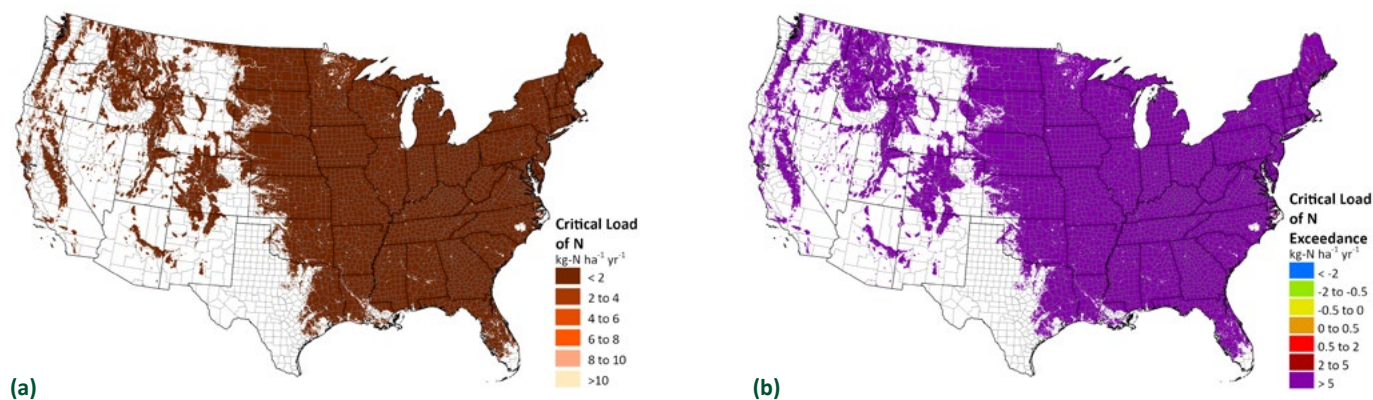


Figure A124.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Viola sororia* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

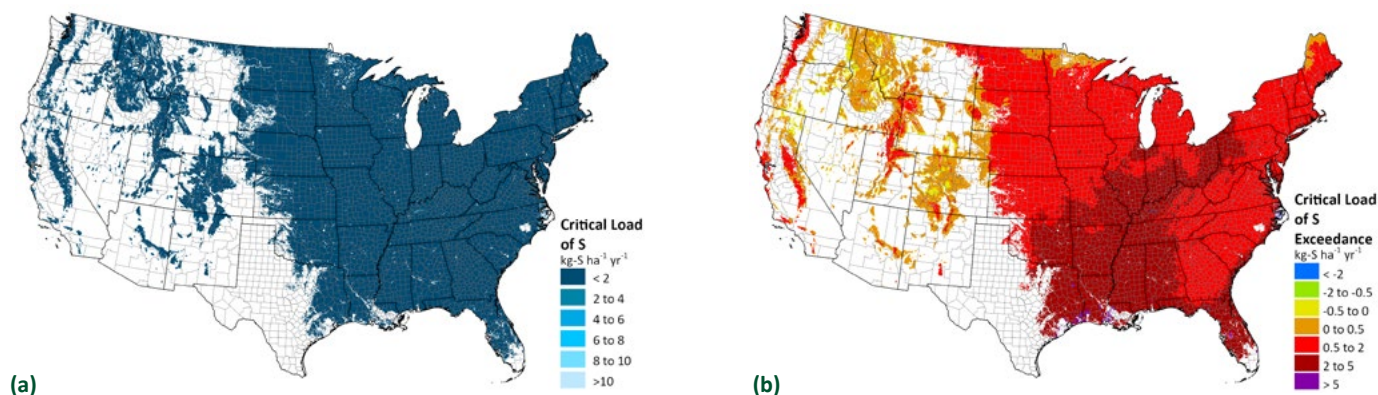


Figure A124.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Viola sororia* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A125. *Woodwardia areolata* (netted chainfern)

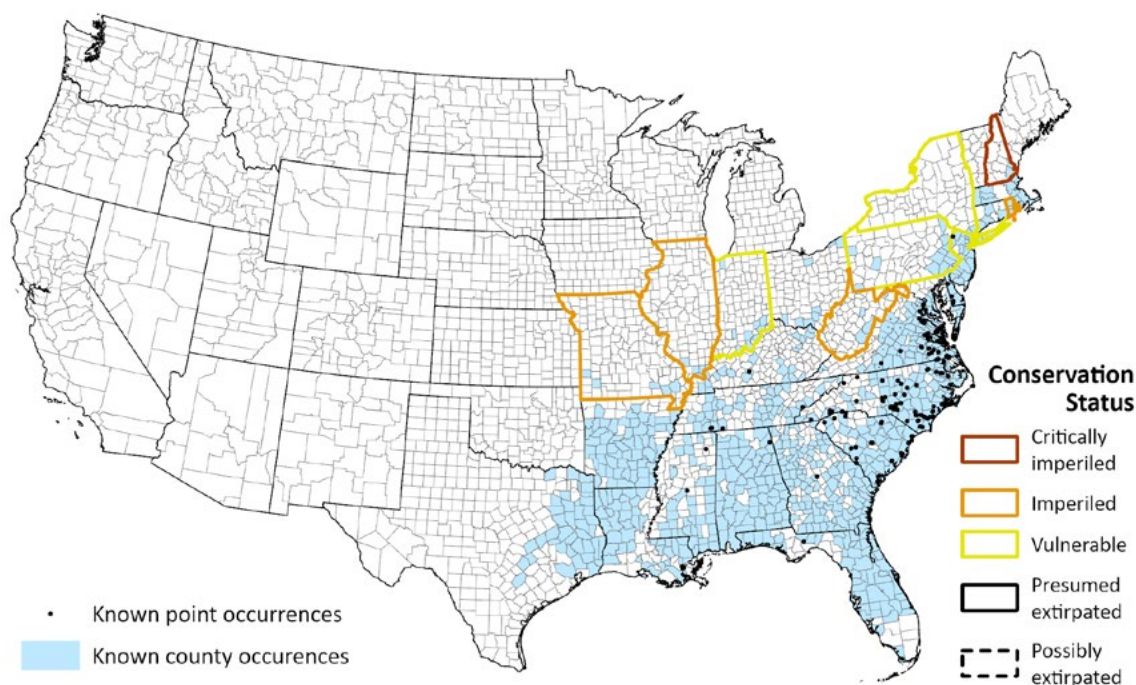


Figure A125.1. Distribution and state-level conservation status of *Woodwardia areolata*. Known point occurrences were used to assess species deposition responses and critical loads.

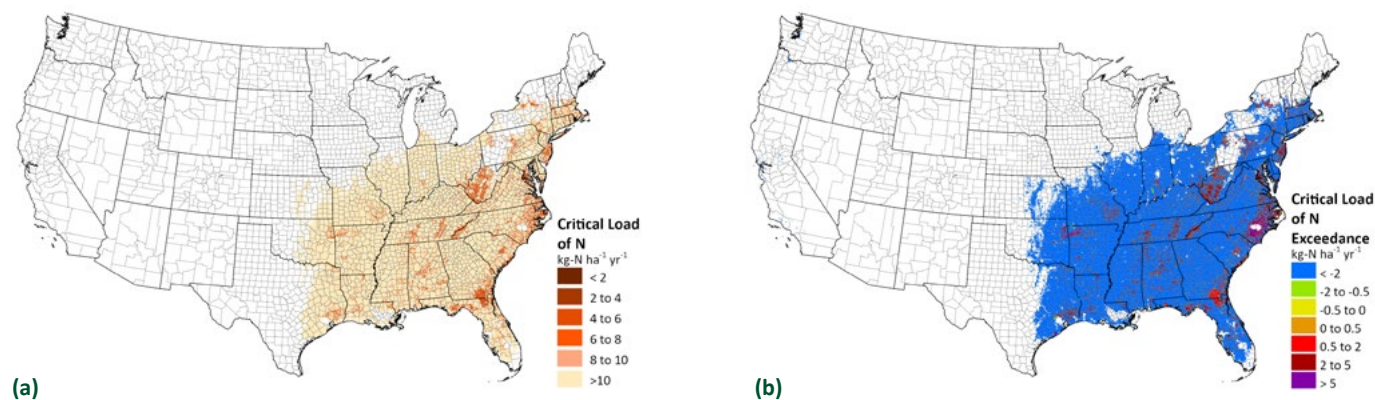


Figure A125.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Woodwardia areolata* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

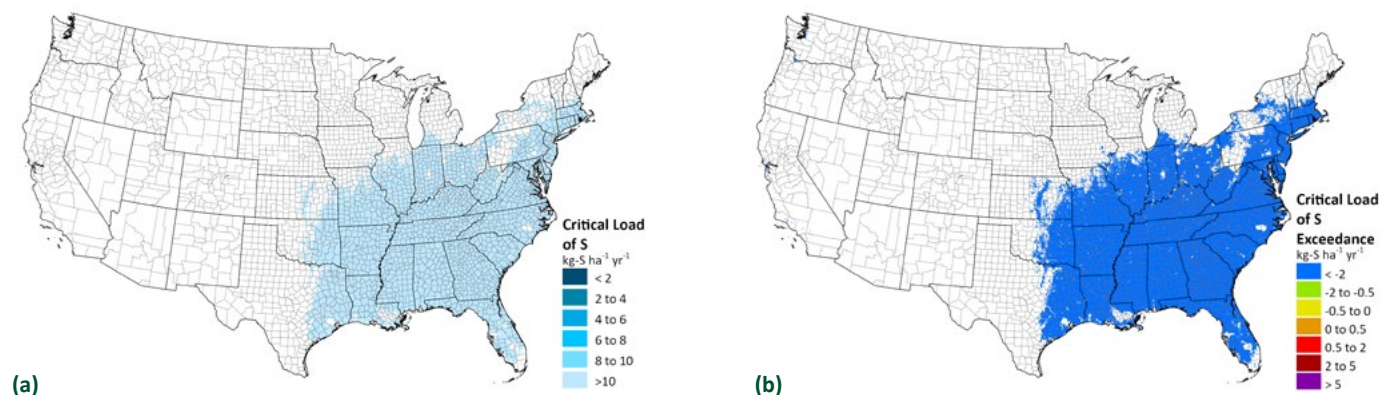


Figure A125.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Woodwardia areolata* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

A126. *Zigadenus elegans* (mountain deathcamas)

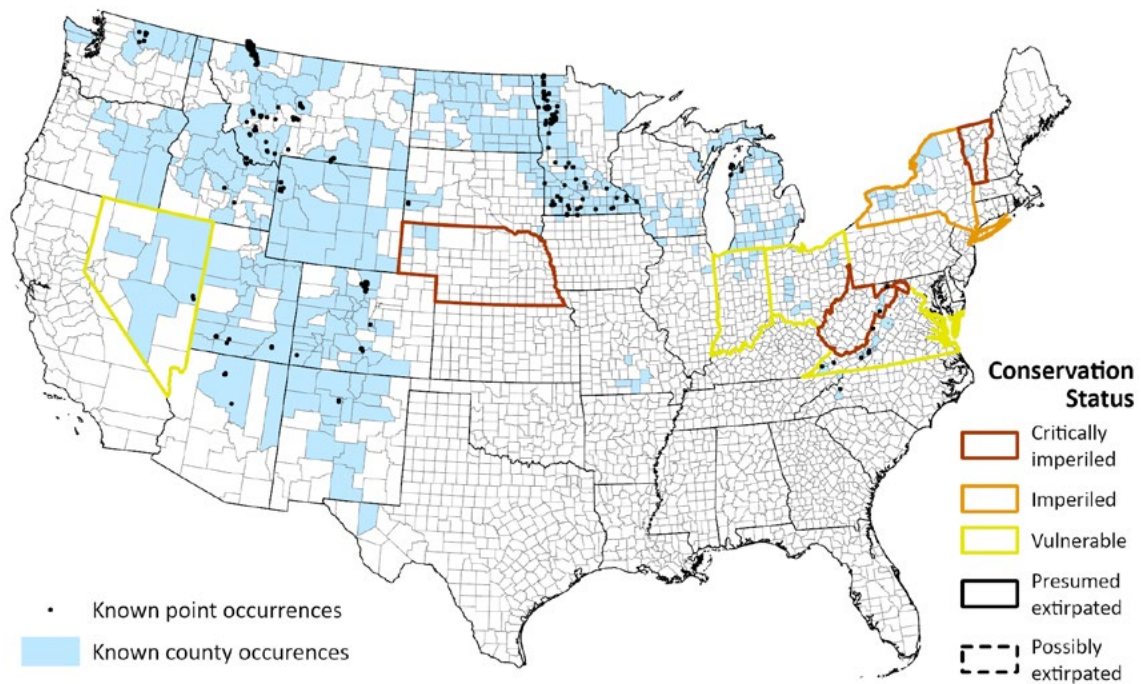


Figure A126.1. Distribution and state-level conservation status of *Zigadenus elegans*. Known point occurrences were used to assess species deposition responses and critical loads.

A127. *Zizia aptera* (meadow zizia)

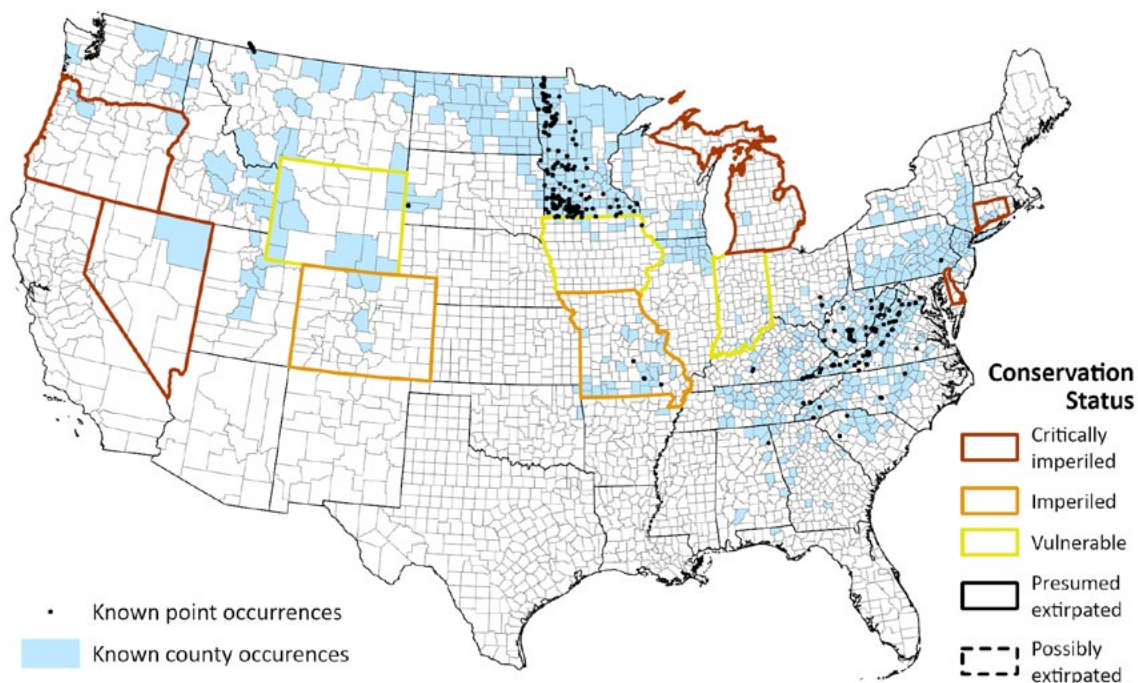


Figure A127.1. Distribution and state-level conservation status of *Zizia aptera*. Known point occurrences were used to assess species deposition responses and critical loads.

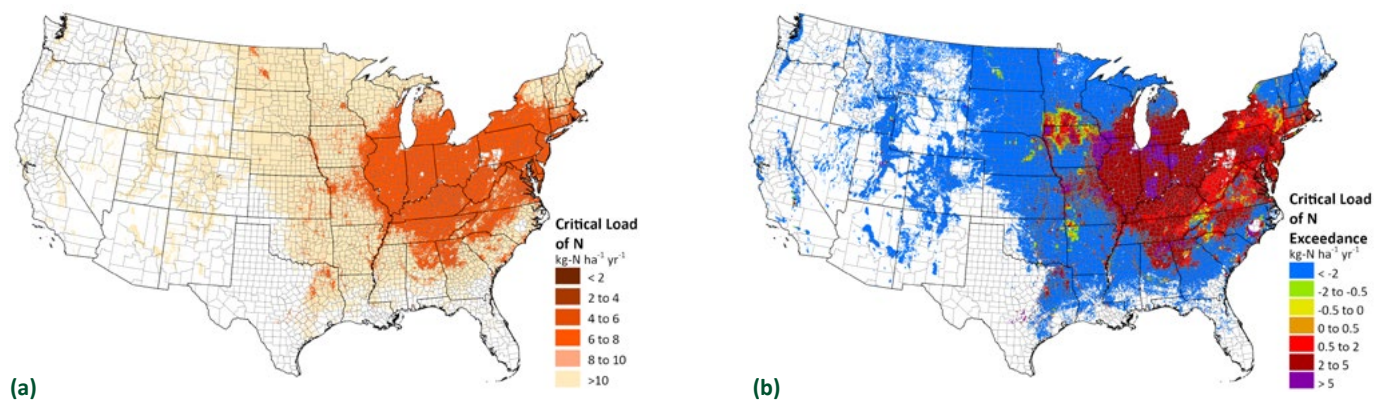


Figure A127.2. The distribution of (a) N critical loads for a decline in the probability of occurrence of *Zizia aptera* and (b) the exceedance of N critical loads based on TDep 2019-2021 total N deposition.

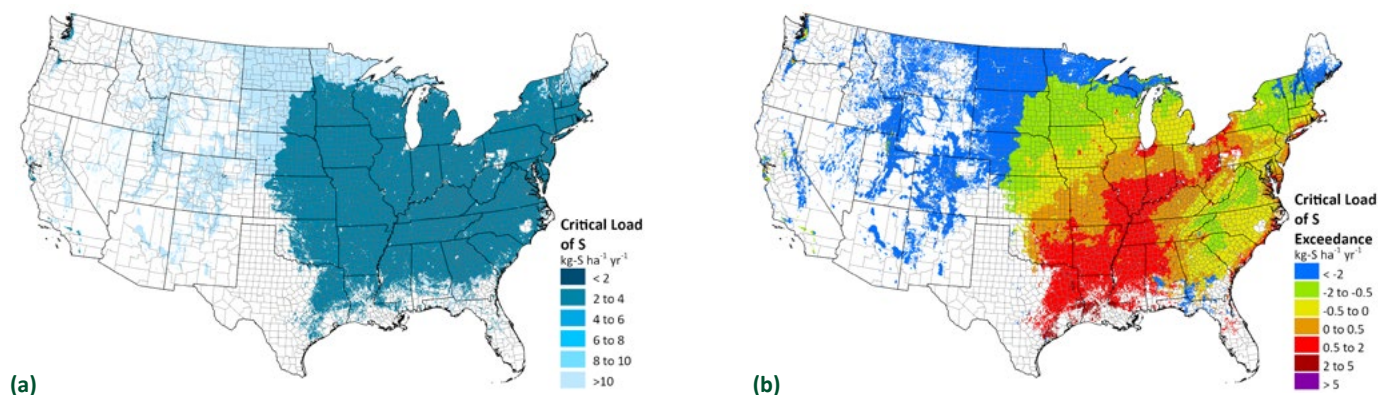


Figure A127.3. The distribution of (a) S critical loads for a decline in the probability of occurrence of *Zizia aptera* and (b) the exceedance of S critical loads based on TDep 2019-2021 total S deposition.

NOTES

[illegible]



This report assesses the risks from nitrogen and sulfur deposition on 198 herbaceous plant species of the continental United States. Information for each species has been compiled from several peer-reviewed Federal and non-Federal sources.

This report is the second of a three-volume series concerning air pollution impacts to trees (Volume 1), herbs (Volume 2), and lichens (Volume 3).