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

Trees (Volume 1)

Forest Service FS-1156 August 2021

Cover Photos
Left - Crown of *Quercus laurifolia.* Photo by Douglas Goldman, USDA.
Right - Specimen of *Abies amabilis*. Photo by Susan McDougall, hosted by the USDA-NRCS PLANTS Database.

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Trunk of *Quercus chrysolepis*. Photo by R.H. May, hosted by the USDA-NRCS PLANTS Database.

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CONTENTS

EXECUTIVE SUMMARY

Anthropogenic emissions of nitrogen (N) and sulfur (S) to the atmosphere from sources such as fossil fuel combustion and industrialized agriculture have increased atmospheric deposition of N and S several times over preindustrial levels in most developed nations. Recent efforts to reduce emissions in the United States, regulated under the Clean Air Act and Amendments, have succeeded in decreasing deposition, especially in the eastern United States. However, current deposition of N and S still remains well above preindustrial levels, and N deposition appears to be increasing or unchanged in much of the Midwest and western United States. N deposition, along with S deposition, is a major stressor to tree species because of its wide-ranging and multi-faceted impacts. N deposition can alter tree growth rates, contribute to soil acidification, alter below-ground mycorrhizal communities essential to tree health, and increase nitrate (NO_3^-) leaching that impairs downstream water quality. N deposition can also increase the vulnerability of tree species to secondary factors such as pest and disease outbreaks, drought, and freezing injury.

This report summarizes the potential impacts of N and S deposition on 94 of the most common tree species across the contiguous United States, compiling information from several peer-reviewed Federal and non-Federal sources. We provide information on how the rates of growth and survival for each species respond to N and S deposition, and the ecological roles and ecosystem services provided by these species. This report is part of a three-volume series covering trees (this Volume 1), lichens (Volume 2), and herbaceous understory species (Volume 3). In this volume, we include five categories of information for each tree species: (1) the geographic range and abundance, (2) the associated N and S deposition across that geographic range, (3) how species' rates of growth and survival change with the rate of N and S deposition, (4) a basic description of the ecology of and ecosystem processes supported by the species, and (5) a summary of the final ecosystem goods and services provided by the species.

This report documents that many tree species are potentially sensitive to atmospheric deposition of N and S. For N, 48 species had a negative response for either growth or survival along some portion of the N deposition gradient. For S, 66 species had a negative response for either growth or survival along some portion of the S deposition gradient. These responses are summarized in Table ES-1 and listed by species in Appendix Table 1. Thus, many of the ecological processes and ecosystem services provided by the tree species examined here may be affected by current and future N and S deposition. Chapter 2 describes this information individually by species.

This information may also be of help to: 1) support air quality goals that are protective of the biological diversity of trees and the web of associated soil and epiphytic plants (especially roots), fungi, microbes, invertebrates, and wildlife that foster forest integrity and resilience, 2) select trees that can grow robustly in polluted environments where they can help to cleanse the air, water, and soil, provide shade and windbreaks, beautify urban environments, and prevent erosion, 3) select species of appropriate tolerance for restoration, reforestation, and afforestation of air quality-compromised landscapes and 4) select location-specific species for carbon sequestration initiatives.

Table ES-1: Summary of responses to S (top) and N (bottom) for the 94 species examined in Horn et al. (2018). For N, growth and survival could have a decreasing, threshold, flat, or increasing relationship, while for S, only decreasing and flat relationships were observed. Threshold relationships are when the response increased on the low end of the deposition gradient and decreased on the high end (this is often called a 'hump-shaped' relationship). Column and row colors indicate vulnerability, with decreasing relationships indicating high vulnerability (red), threshold relationships indicating vulnerability conditional on the rate of deposition (orange), flat relationships indicating insensitivity (gray), and increasing relationships indicating a benefit from deposition (green). Numbers in cells represent the number of species with each combination of relationships. Columns and row totals are also shown in the margins.

Sulfur		Survival		*Totals*
		Decreasing	Flat	
Growth	Decreasing	26	15	41
	Flat	25	28	53
Totals		51	43	94

Nitrogen		Survival				*Totals*
		Decreasing	Threshold	Flat	Increasing	
Growth	Decreasing	0	2	4	0	6
	Threshold	3	4	11	1	19
	Flat	2	12	25	0	39
	Increasing	1	8	17	4	30
Totals		6	26	57	5	94

CHAPTER 1: INTRODUCTION

Overview and Background

Trees are a vital part of our social, economic, and environmental well-being as a Nation. They provide the raw materials for our country's forest products industry, form an integral component of our national parks and other wild places so treasured by visitors and recreationists, and they influence our environment by contributing to air and water purification and climate regulation. Collectively, the benefits people obtain directly from natural systems, including but not limited to those provided by trees, are termed "final ecosystem goods and services" or FEGS (Landers and Nahlik 2013; Bell et al. 2017b). FEGS are related to, yet distinct from, ecological processes that trees support or conduct in the ecosystem that do not directly benefit humans, such as net primary production and providing habitat for birds or other wildlife. These processes may, in turn, yield FEGS such as timber, wildlife viewing, and carbon sequestration, and are sometimes termed "intermediate ecosystem goods and services" to distinguish them from the entities directly consumed, enjoyed, or somehow utilized by people.

Climate change, land use change, atmospheric deposition, over harvesting, pest and disease outbreaks, fire, and drought are just some of the many anthropogenic and natural stressors to forest trees across our Nation. Atmospheric deposition of nitrogen (N) and sulfur (S) often occurs when emissions of N and S from sources such as fossil fuel combustion (N and S) and modern industrialized agriculture (N mostly; e.g., widespread fertilizer applications, concentrated animal feeding operations [CAFOs]) enter the atmosphere, after which they can travel great distances and be deposited downwind on natural and urban systems (Galloway et al. 2003, 2004). Recent levels of N and S deposition are shown in Figure 1. Once deposited, N and S can have a variety of effects, including altering tree growth rates, contributing to soil acidification, shifting below-ground mycorrhizal communities essential to tree health, and increasing nitrate (NO_3^-) leaching that impairs downstream water quality (Bobbink et al. 2010; Pardo et al. 2011a, 2011b). Much more work to date has focused on the impacts of acidification from S deposition, but it is becoming increasingly clear that N deposition can have similar (and additional) effects on forested areas. Nitrogen deposition can also increase the vulnerability of tree species to secondary stressors such as pest and disease outbreaks, drought, windthrow, and freezing injury. Because of its wide-ranging and multi-faceted impacts, N deposition is a primary stressor to forests and other natural ecosystems (Bobbink et al. 2010; Pardo 2011a, Pardo et al. 2011b).

Implementation of the Clean Air Act and the 1990 Amendments has resulted in steadily declining emissions of oxidized N (NO_x) and S (SO_x) to the atmosphere, especially in the eastern United States (Burns et al. 2011, Lloret and Valiela 2016, Figure 2). Although deposition levels are subsequently decreasing across much of the eastern United States, they remain elevated several times above preindustrial levels over most of the contiguous United States, and may be increasing or unchanged in the Midwest and West (Figure 2; Houlton et al. 2012). Indeed, short term trends comparing changes in total N (Figure 2a) and S (Figure 2b) from 2012-2014 to 2000-2002, suggest that both are decreasing in the East, while in the West there are large areas where N deposition is increasing. Longer term trends are only available for wet deposition (Figure 2c-d), but also indicate that wet S deposition has decreased across much of the country while N deposition has actually increased in some areas outside of the eastern United States. Furthermore, due to decreases in NO_x emissions, the types of N-containing compounds deposited to the landscape are also shifting toward reduced forms of N that are not listed as criteria air pollutants under the Clean Air Act (Figure 3). This shift is concerning because reduced N may have more numerous impacts on ecosystems than oxidized N. This is thought to occur because reduced N is "higher" in the N-cascade—the sequence of N-transformations that N atoms may undergo during movement through the environment (Figure 4) (Galloway et al. 2004, Carter et al. 2017). By being higher in the N-cascade, reduced forms of N can lead to additional effects, such as ammonia volatilization (which NO_x does not undergo), even greater soil acidification (because of nitrification, which NO_x does not undergo), and more plant N uptake (because NH_x is better retained in the soil than NO_x). Thus, although the reduction of NO_x emissions and deposition to the environment is a positive step, especially in the East, there remain many potential effects from N deposition across the United States.

The purpose of this report is to summarize the potential impacts from N and S deposition on 94 common tree species across the contiguous United States for which there are sufficient data to assess ecological impacts. We emphasize N effects because much more work historically has been conducted on S than N in forested ecosystems; and, thus, a key knowledge gap is in better understanding how forest trees respond to N deposition and the potential ramifications of those impacts. In this report, we provide information on how each species responds to N and S deposition, as well as the ecology of, and ecosystem services provided by, these species. This report is part of a three-volume series published by the U.S. Department of Agriculture, Forest Service, covering trees (this Volume 1), lichens (Volume 2), and herbaceous understory species (Volume 3). In this volume, we include five categories of information for each tree species: (1) the reported range and abundance, (2) the associated N and S deposition across that range, (3) the species' growth and mortality responses to N and S deposition, (4) a basic description of the ecology of and ecosystem processes supported by the species (including intermediate ecosystem services), and (5) a summary of the final ecosystem goods and services provided by the species. This report is not intended to be a comprehensive assessment of all known information on all 94 tree species, but rather a synopsis of several of the more recent and comprehensive individual studies and databases.

Methods and Data Sources

Information for the five categories above comes from various peer-reviewed sources that are described below and summarized in Table 1. At the end of this section, Figure 5 shows an example species entry including where different pieces of information appear for each entry in Chapter 2.

Species range and abundances

Species range maps (Figure 6) outline the historical range of a species in North America and are adapted from the Atlas of United States Trees by Elbert L. Little, Jr., (USGS 1999); http://esp.cr.usgs.gov/data/little/). Species abundance maps are compiled from Forest Service live tree species basal area data for 2000–2009 from the contiguous United States (Wilson et al. 2013); http://www.fs.usda.gov/rds/archive/Product/RDS-2013-0013). Wilson et al. (2013) integrated vegetation phenology from satellite data with extensive plot-level Forest Service Forest Inventory and Analysis (FIA) data to derive maps of tree species abundance and distribution for the contiguous United States. For more information, see the references and Table 1.

Total nitrogen and sulfur deposition

The maps of total N and S deposition show the average annual rate (in kg ha^{-1} yr^{-1}) of deposition across the United States from 2012 to 2014 (Figure 7). Total N and S deposition estimates are from the Total Deposition (TDEP) project of the National Atmospheric Deposition Program ((Schwede 2014); http://nadp.sws.uiuc.edu/committees/tdep/). TDEP estimates were developed by combining measured concentrations of pollutants in the air and in wet deposition with modeled deposition velocity and dry deposition data. Methodological details and comparisons of various deposition estimates are provided by Schwede and Lear (2014).

Species growth and mortality responses to N and S deposition

Species growth and survival responses show how each species is affected across the range of N and S deposition where the species occur in the FIA database. Changes in tree species growth are quantified as annual changes in aboveground biomass carbon. Changes in survival are quantified as the probability of surviving over a 10-year interval. These response curves are the result of Polytechnic Institute and State University analysis (Horn et al. 2018). The analysis follows a similar approach as an earlier effort (Thomas et al. 2010), and is summarized in brief here. Researchers compiled information from the FIA database from millions of individual trees and 94 tree species. FIA-based rates of tree growth and mortality were related to N and/or S deposition and five other factors that can strongly influence tree health and productivity: tree size, position of the tree in the canopy, mean annual temperature, mean annual precipitation, and basal area. Four statistical models were compared: (1) a base model with only the five non-deposition factors included, (2) the base model plus N deposition, (3) the base model plus S deposition, and (4) the base model plus both N and S deposition. The N relationship was allowed to take any shape (positive, flat, negative, hump-shaped), while the S relationship was constrained to being flat or negative based on observations that S deposition for nearly all species has a negative effect through acidification and does not commonly limit production. The best overall model is presented in this report, but see Horn et al. (2018) for additional information. For this report, we present the growth response (solid line) and survival response (dotted line) for the species across its range at the average levels of the other five factors (Figure 8). Details of the study and analysis are available in Horn et al. (2018).

There are a few important caveats to mention regarding these sensitivity categories. These scores represent the potential sensitivity moreso than the actual sensitivity at a point on the landscape because actual sensitivity is a combination of the response curve and the deposition experienced at that site (which could be low or high). The boxplots in Figure 8 give a rough indication of how many trees of each species are experiencing which conditions along the deposition gradient. This caveat is more relevant for species with hump-shaped relationships, where the direction of impact can change across the range of deposition, rather than for species with increasing or decreasing relationships, where the direction of impact is consistent. Furthermore, because deposition can increase or decrease over time, sensitivity is not static. We do not capture the temporal aspect of sensitivity in this effort but plan to do so in the future. The observation that N and S deposition are declining in much of the East, and unchanged or increasing in the West and Midwest, gives some indication of trends in sensitivity (Figure 2).

Another important caveat when interpreting these functional response curves is the potential for correlations between N and S, and between N or S and other variables. This is extensively discussed in Horn et al. (2018) and briefly summarized here. When N and S emissions originate from a common source (e.g., power plants or automobiles burning fossil fuels), N and S deposition may be highly correlated. When other sources co-dominate (e.g., agriculture), the correlation may be weaker. Thus, for each species, Horn et al. (2018) provided three additional pieces of diagnostic information to help interpret these curves: (1) the simple correlation between N and S (Pearson's r correlation), response, (2) the variance inflation factor for N (VIF-N), and (3) the variance inflation factor for S (VIF-S) (Appendix Table 4). While simple correlations only describe how linearly related two variables are, the variance inflation factor summarizes how correlated a variable is with all other variables in the model. For N or S, there are six variables with which they could each be correlated: the five variables in the base model, plus either S (for VIF-N) or N (for VIF-S). One of the underlying assumptions in statistical models like those in Horn et al. (2018), is that variables are independent of one another. The larger these diagnostic r (range: 0-1) and VIF (range: 1-∞) values are, the less independent N and/or S are, and thus the less confident we are that the actual driver of the growth or survival relationship is the variable in question. There is no objective rule regarding when correlations are problematic, but there are heuristics to guide the interpretation of these results (Table 2). For all species, the bivariate correlation between N and S was a more conservative measure for confidence compared with VIFs, so the designation in chapter 2 ultimately was based on the bivariate correlation. This is not unexpected, as the VIFs include multiple variables, some which may be highly correlated (or not) with the variable of interest.

Ecology and ecosystem processes

This section describes the basic ecology of each tree species, as well as its relationship to other organisms in the forest, and gives a brief summary of the extensive information published on each species in the USDA Forest Service Fire Effects Information System (FEIS) (USDA FS 2016). To the extent possible, language (data) used in the FEIS was retained and the user can access the full FEIS entry from the reference information provided at the end of the individual species pages. Although the FEIS was originally designed for forest managers to manage the effects of wildland fire, it is a useful and comprehensive source covering a range of topics, including tree species taxonomy, species protection status, geographic distribution, soil preferences, associations with other tree and non-tree plant species, wood products, importance to livestock and wildlife, use in silviculture and site rehabilitation, botanical characteristics, successional status, and uses by traditional cultures. Each of these is fully referenced to the source literature, resulting in an FEIS library of more than 80,000 references. For more information on the FEIS database, see http://www.feis-crs.org/feis/. The specific ecological information presented includes the five broad categories described in Table 3, and are summarized in a table at the end of each species chapter (see Figure 5).

These five categories do not represent all relevant categories for silvicultural purposes or forest dynamic processes, but are a snapshot of categories especially relevant for responses to N and S deposition and associated ecological impacts. We also considered other traits important to the ecology of tree species (e.g., status as an N-fixer, fire tolerance, pest pressures, etc.) but found that other existing resources were better suited to describe these more specific and numerous characteristics of tree species.

Final ecosystem goods and services (FEGS)

This section, drawn primarily from the FEIS database (USDA FS 2016), describes the FEGS provided by each species. We supplemented the FEIS database with information on uses by traditional cultures from the Native American Ethnobotany Database at the University of Michigan, Dearborn (http://naeb.brit.org/). The specific FEGS presented include nine broad categories commonly provided by trees: wood products, traditional uses, ornamental uses, fuelwood, protection, rehabilitation, food products, and oils and other non-timber and non-food products (Table 4). The ninth category (General Services) captures the fact that all trees photosynthesize and grow, contribute to biogeochemical cycles, provide shade and inspiration for passersby. This includes supporting services (e.g., primary production and soil formation), provisioning services (e.g., lumber and genetic material), regulating services (e.g., climate regulation and air and water purification), and cultural services (e.g., subjects in paintings and locations for ceremonial activities), as described by the Millennium Ecosystem Assessment (MEA 2005). Because of the importance of these services, we included them in this report. However, because all trees perform these services to a greater or lesser degree, to reduce the redundancy of repeating individual supporting, provisioning, regulating, and cultural services for all tree species, we included a general category to acknowledge the many services that all trees provide to humankind. As with the species ecology, FEGS are summarized in a table at the end of each species chapter (see Figure 5).

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Table 1. Summary of the data sources used in this report.

Topical Area	Source(s)	Webpage
Species range and abundance	Wilson et al. (2013); USGS (1999)	http://www.fs.usda.gov/rds/archive/Product/RDS-2013-0013; http://esp.cr.usgs.gov/data/little/
Nitrogen and sulfur deposition	Schwede and Lear (2014)	http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1219&context=usepapapers; http://nadp.sws.uiuc.edu/committees/tdep/
Tree species responses	Horn et al. (2018)	https://doi.org/10.1371/journal.pone.0205296
Tree species ecology	USDA FS (2016) and references therein	http://www.feis-crs.org/feis/
Tree species ecosystem services	USDA FS (2016); University of Michigan (2003)	http://www.feis-crs.org/feis/; http://naeb.brit.org/
Species photos	University of Georgia (2001)	http://www.forestryimages.org/index.cfm

Table 2. Confidence levels (high, medium, low) for Pearson correlations (r) between N and S, and for variance inflation factors (VIF) between N or S and the other five factors. A lower r or VIF is associated with higher confidence due to higher statistical independence of predictors. Note: r and VIF values are on different scales (r: 0-1; VIF: 1-∞); and, although confidence categories based on r versus VIF are related, they are not directly interchangeable. See Appendix Table 4 for confidence levels in growth and mortality relationships of individual tree species to S and N deposition.

Confidence	r	VIF
High	0-0.4	1-3
Medium	0.4-0.6	3-5
Low	>0.6	>5

Table 3. Five ecological characteristics summarized for each species.[a]

Characteristic	Description
Shade tolerance	The ability of the tree species to persist in low light conditions, ranked low (L), medium (M), or high (H) shade tolerance. This characteristic is often related to the successional status of the tree species—species with a low shade tolerance (L) often are "pioneer" species that populate a site soon after disturbance, while species with a high shade tolerance (H) are often late-successional species that grow slowly in the shade of other species until an opportunity for growth release (e.g., after the death or removal of adjacent trees) arises.
Leaf morphology and phenology	Whether the morphology of the leaf is wide and flat like a maple or oak (broadleaf, graphically depicted, B) or appears as needles or scales like a pine or fir (coniferous, graphically depicted, C); and, whether the tree species loses its leaves annually (deciduous, D) or whether it retains green leaves year-round (evergreen, E). Most species are either deciduous broadleaves (upper left quadrant) or evergreen conifers (lower right quadrant), but some exceptions occur.
Region and abundance	Illustration of the range and abundance of the species.
Mammal uses	Whether mammals browse this tree species for food and/or if it serves other uses for mammals.
Bird uses	Whether birds use the tree species for nesting material, food, and/or other uses for birds.

[a] More information is available in the main text for each species.

Table 4. Nine ecosystem services summarized for each species.[a]

Ecosystem Services	Description
Wood products	Wood products derived from that species, including pulpwood for paper products; unfinished wood products such as fence posts, railroad ties, and crates; building materials such as plywood and particleboard; and finished products such as furniture.
Traditional uses	Whether the tree species has known cultural significance for indigenous peoples.
Ornamental uses	Whether the tree species is commonly planted as an ornamental.
Fuelwood	Whether the tree species is commonly used as a source of firewood.
Protection	Whether the species is planted as protection against erosion or as a windbreak.
Rehabilitation	Whether the species is planted to rehabilitate sites such as mines or other mechanical operations.
Food products	Whether the species or its component parts (e.g., nuts) are directly harvested or extracted for food and/or beverage products.
Oils and other non-timber and non-food products	Whether oils and other non-food and non-timber products (e.g., perfumes) are produced from this tree species.
General services	General supporting, provisioning, regulating, and cultural services that all trees provide to a greater or lesser extent.

[a] More information is available in the main text for each species.

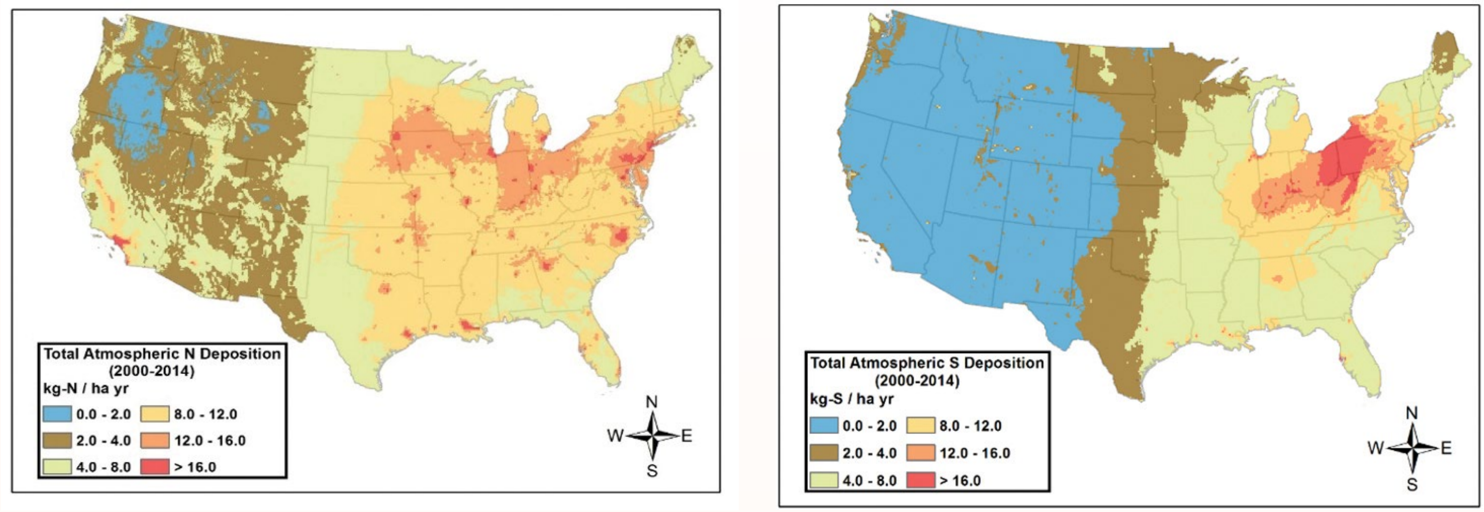


Figure 1. Total atmospheric deposition of nitrogen (N) and sulfur (S) for the contiguous United States averaged over 2000–2014 (data from TDEP [Total Deposition] project, Schwede and Lear 2014). TDEP = Total Deposition

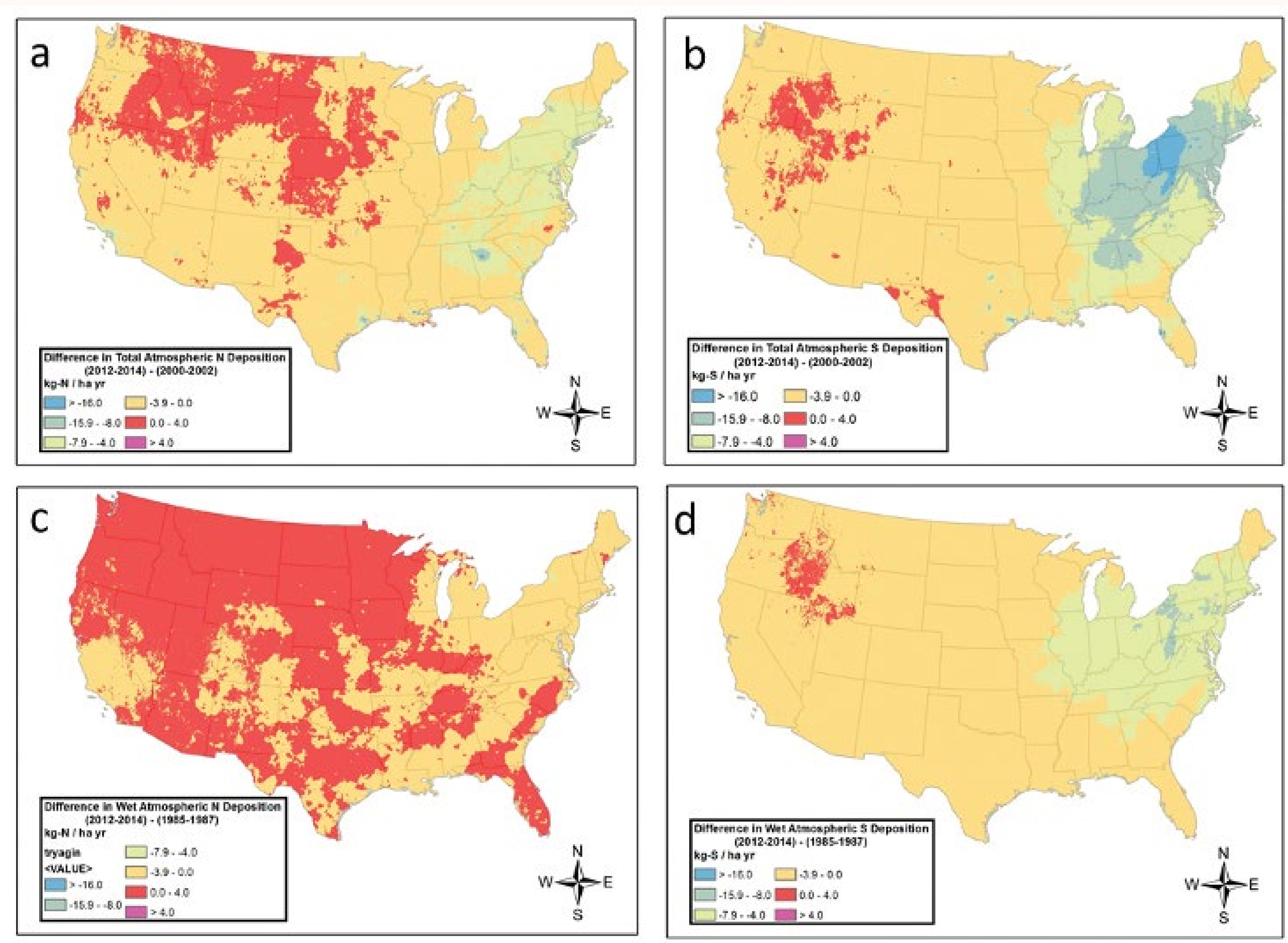


Figure 2. Trends in nitrogen (N) and sulfur (S) deposition. Shown above are recent trends for total deposition of N (a) and S (b) (i.e., average of 2012–2014 minus average of 2000–2002), along with longer trends (i.e., average of 2012–2014 minus average of 1985–1987) for wet deposition of N (c) and S (d). Negative numbers indicate decreases in deposition through time (cooler colors) and positive numbers indicate increases in deposition (hotter colors). Wet deposition estimates are from National Atmospheric Deposition Program and total deposition estimates are from Total Deposition (TDEP) project, which does not span earlier years.

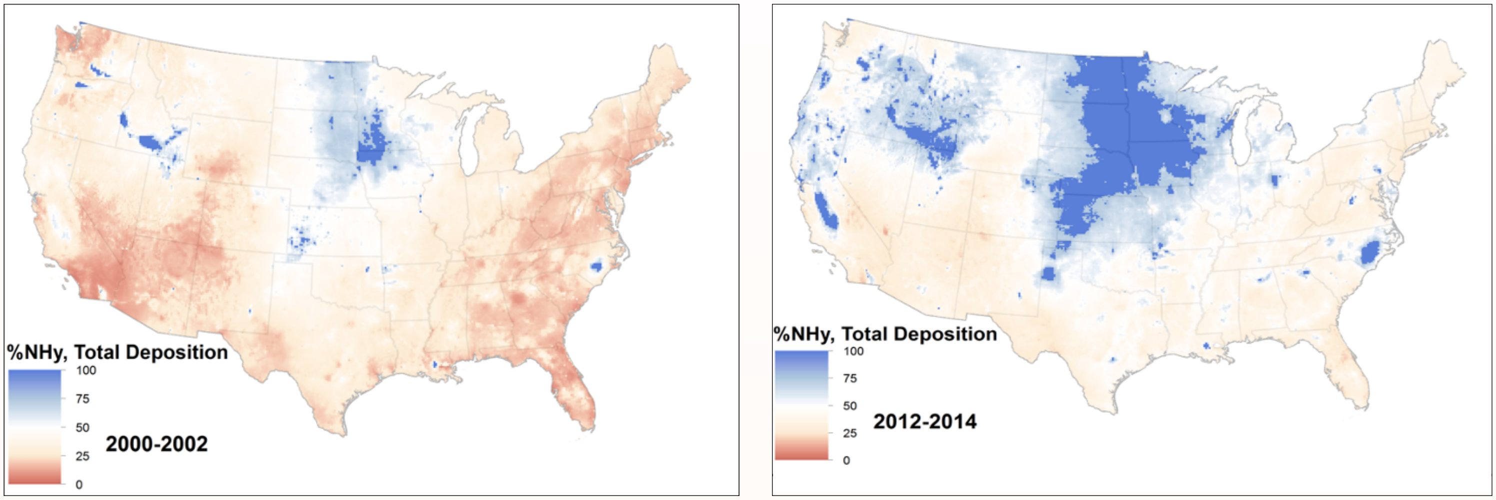


Figure 3. Percentage of wet deposition as reduced nitrogen (NH_4^+, more blue) versus oxidized nitrogen (NO_3^-, more red) in 2000–2002 (left) versus 2012–2014 (right). Data are from Schwede and Lear (2014). NH_4^+ = ammonium; NO_3^- = nitrate.

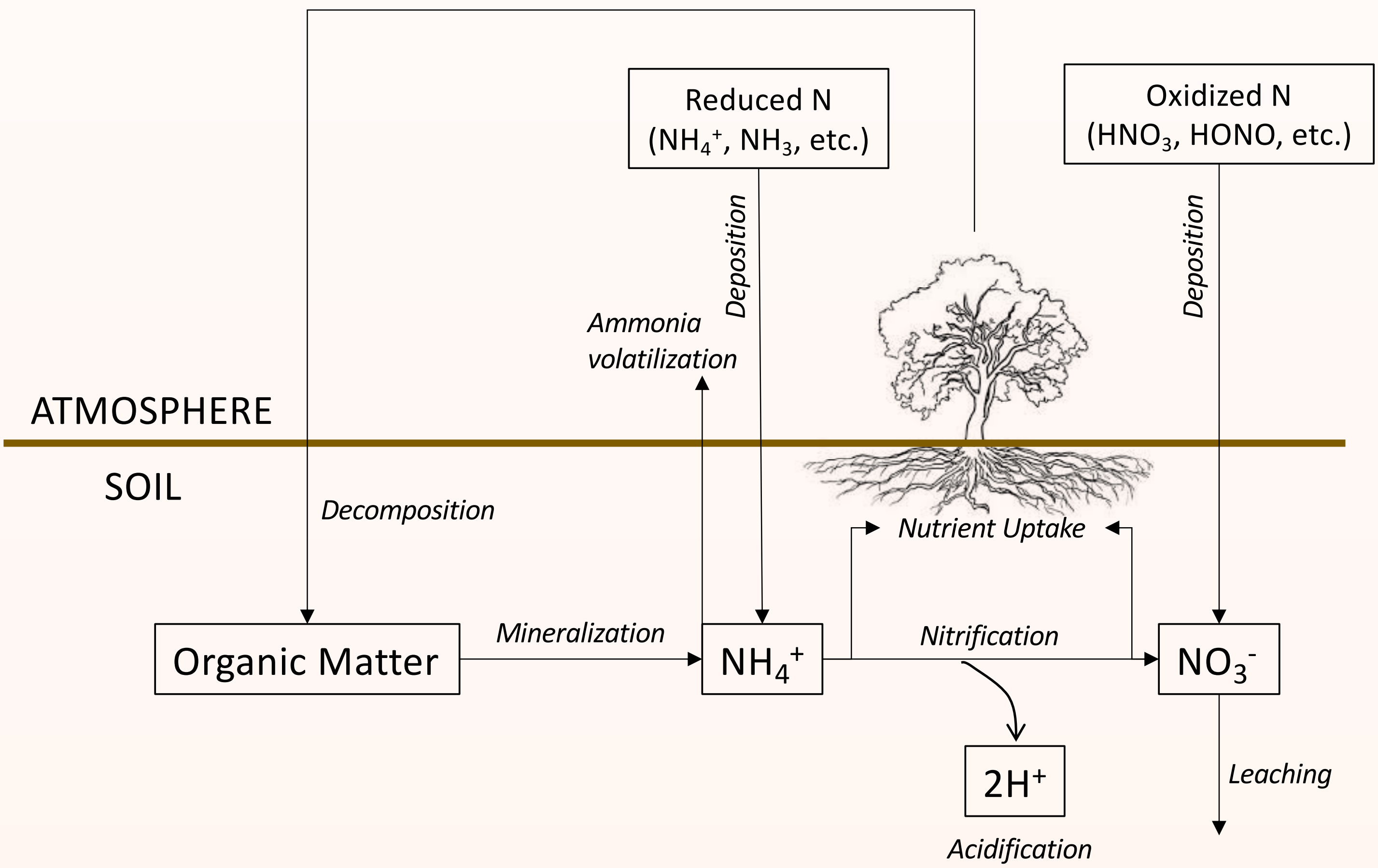


Figure 4. Flowchart of a portion of the nitrogen cascade. The sequence of N transformations that N atoms undergo during movement through the environment illustrates how reduced forms of N can have more numerous ecological effects than oxidized N. HNO_3 = nitric acid; HONO = nitrous acid; N = nitrogen; NH_3 = ammonia; NH_4^+ = ammonium; NO_3^- = nitrate.

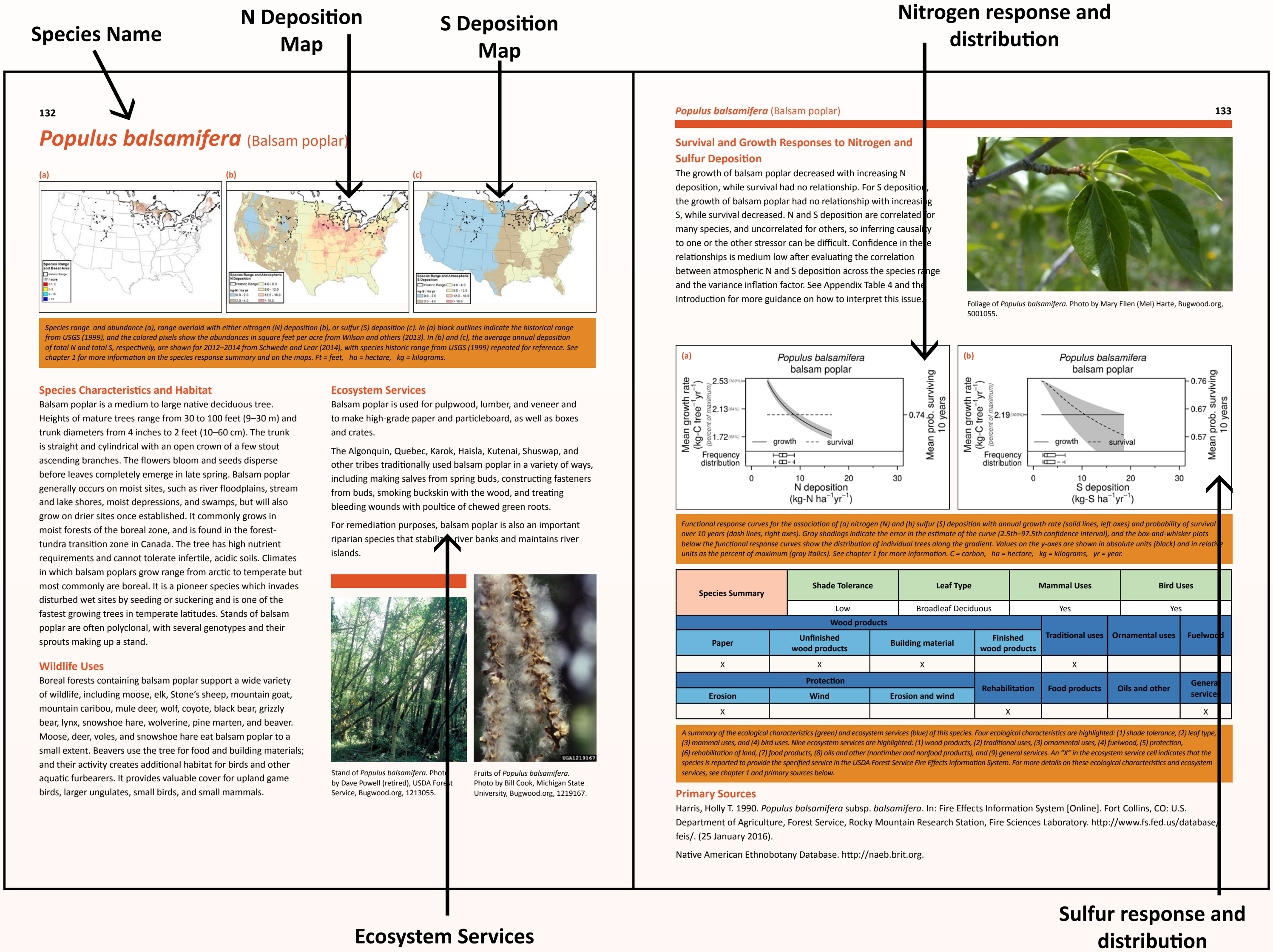


Figure 5. Example entry for *Populus balsamifera* (balsam poplar) showing where the relevant information is presented for each species.

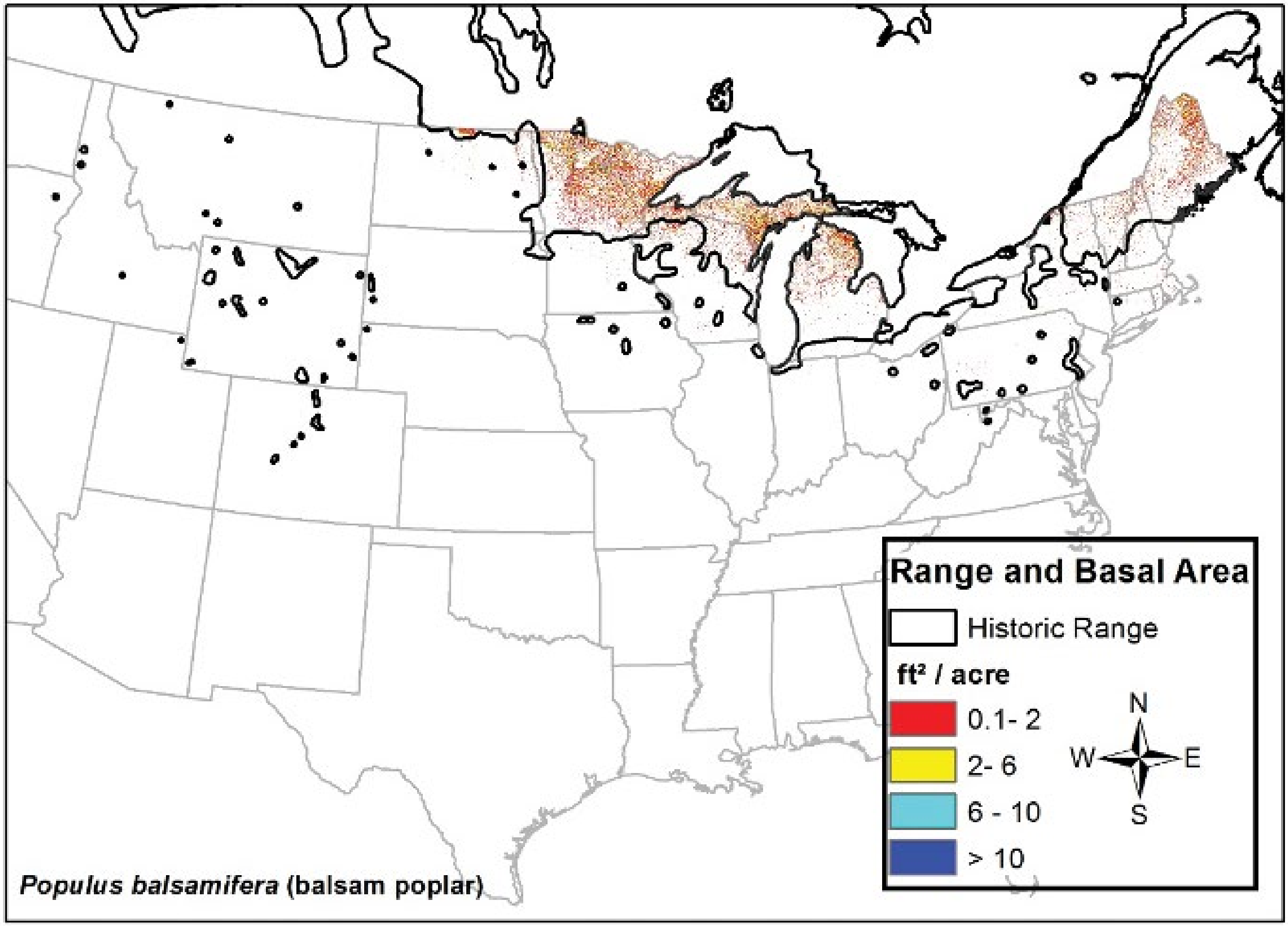
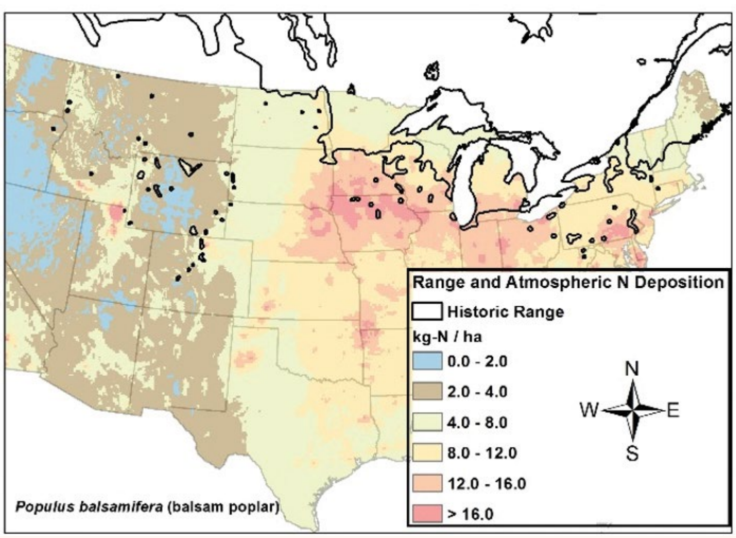


Figure 6. Species range and abundance map for the example of balsam poplar (*Populus balsamifera L.*). Black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in feet per acre from Wilson et al. (2013).



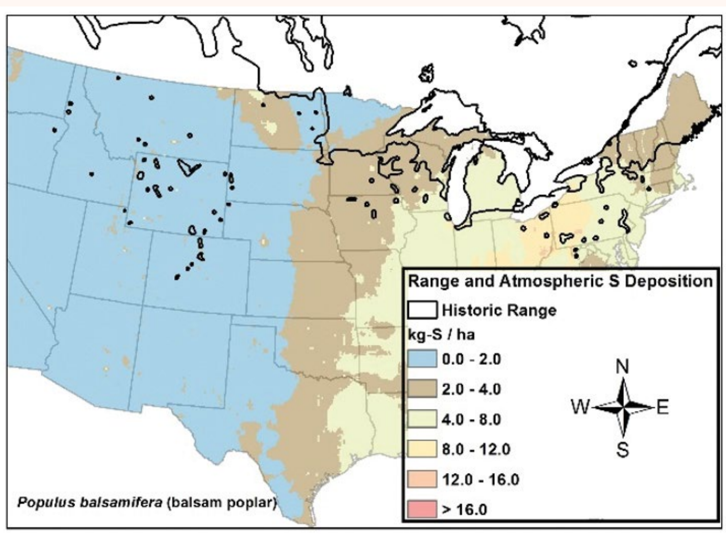
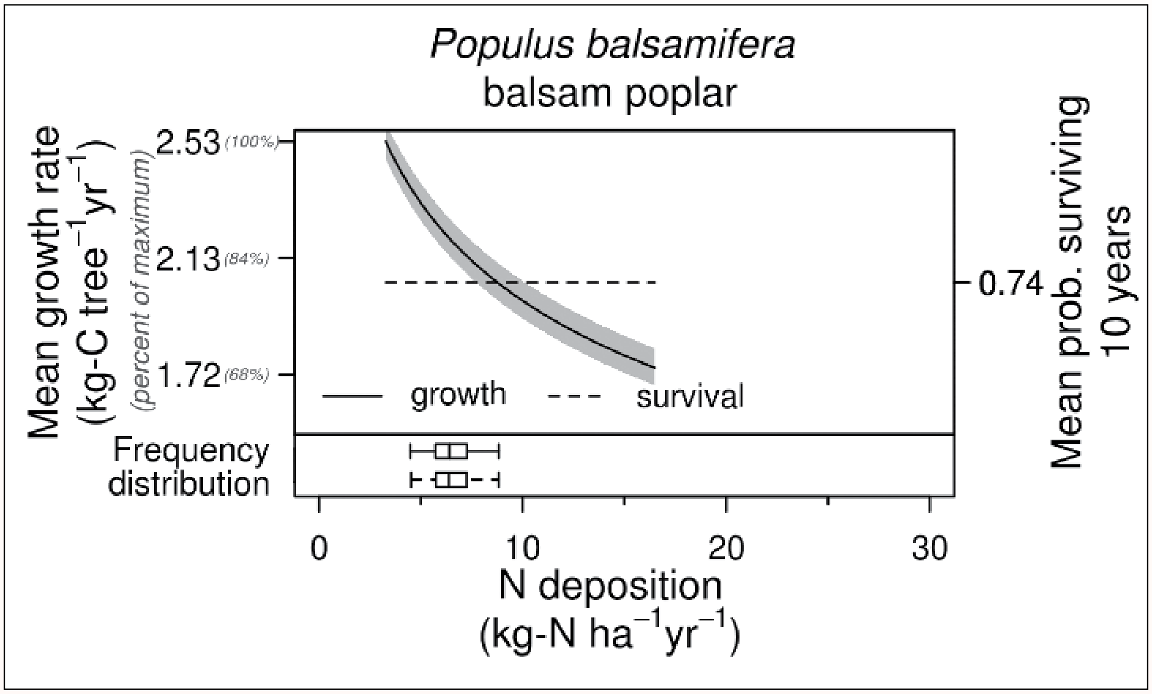


Figure 7. Maps of average annual deposition of total nitrogen (N) (left) and total sulfur (S) (right) for 2011–2013 from Schwede and Lear (2014) for the example of balsam poplar (*Populus balsamifera L.*). The historical range from USGS (1999) is repeated on deposition maps for reference.

a



b

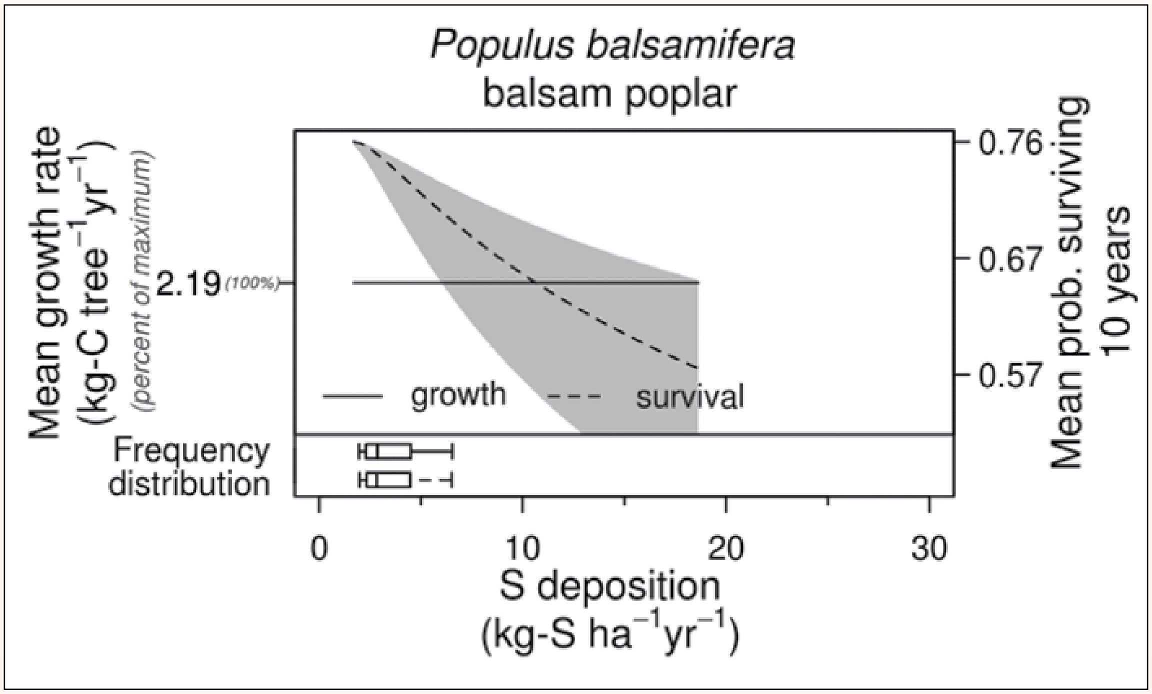
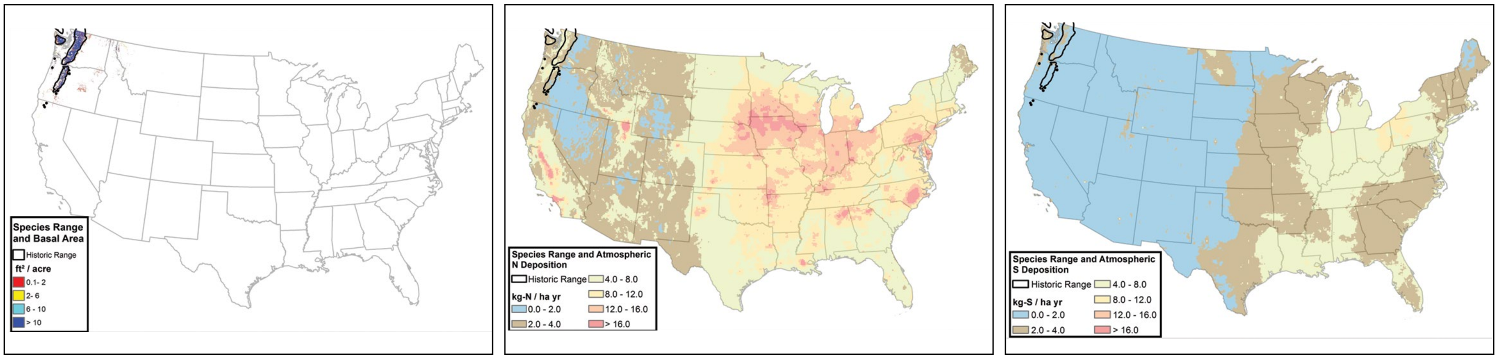


Figure 8. Functional response curves and frequency distributions for nitrogen (a) and sulfur (b) for the example of balsam poplar (*Populus balsamifera L.*). For both nitrogen (N) and sulfur (S) the figure structure is the same, with deposition (x-axis) related to mean annual growth rate (kg carbon tree^{-1} yr^{-1}, solid lines, left y-axis) and mean probability of surviving 10 years (proportion, dashed lines, right y-axis). For flat relationships (e.g., survival response to N in the example above), only one value is displayed on the y-axis for the average, while for non-flat relationships (e.g., growth response to N) the minimum, midpoint, and maximum values are displayed. Grey shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval). Grey text in the left y-axis are growth rates relative to maximum growth. Below each functional response, the distribution of trees along the deposition gradient is shown as box-and-whisker plots for growth (solid whiskers) and survival (dashed whiskers). Growth and survival tree populations differed only slightly. Box-and-whisker plots display the 2.5th percentile (lower whisker), 25th–50th–75th percentile (box), and 97.5th percentile (upper whisker). Note that functional response curves are scaled independently for each species to improve their readability.

Abies amabilis (Pacific silver fir)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Pacific silver fir is a monoecious, long-lived, native conifer. At maturity, it can reach heights of 100 to 230 feet (30–70 m) and diameters of 36 to 44 inches (90–110 cm). The average maximum age for Pacific silver fir is 400 to 500 years on good sites, and 250 to 350 years on more adverse sites. As the tree becomes older, growth is commonly deformed. The crown is rigid and symmetrical with lateral branches perpendicular to the stem. The tree produces cones that are stiffly erect and barrel-shaped. Pacific silver fir reproduces only from seed. The climate throughout the range of Pacific silver fir is maritime to submaritime. This species is an indicator of very moist soils, and can grow in soils where the water table is extremely close to the surface. Soil parent materials include basalt, glacial till, volcanic ash, pumice, and sedimentary rock. Soils tend to be acidic. Pacific silver fir can survive in the shade and emerge in uneven-aged stands. It is a late seral or climax species in most habitats because it is very shade tolerant and has low spatial requirements. Pacific silver fir tends to be one of the last species to establish after disturbance—it migrates slowly because seed dispersion depends on wind. Therefore, it is common in mixed stands and rare in even-aged stands.

Wildlife Uses

Birds, rodents, and squirrels eat the seeds of Pacific silver fir. It is the least preferred of trees browsed by elk. The tree's dense growth offers hiding, cover, and thermal protection for wildlife. Old-growth stands provide good mountain goat habitat. Northern spotted owls depend on the availability of old-growth stands for nest site selection and sufficient prey. Other species with a preference for old-growth stands include Vaux's swift, fisher, western red-backed vole, and Olympic salamander. Small nongame birds prefer late seral or old-growth Pacific silver fir stands.

Ecosystem Services

The most common uses of Pacific silver fir are light construction frames, subfloor, construction plywood, sheaths, container veneer, and pulpwood. As a "white wood," the species is a major export to Japan for business construction. It is also used for Christmas trees and decorative greenery. The tree is grown as an ornamental and is a major component of recreational and wilderness areas.

The Bella Coola traditionally used Pacific silver fir to make a liquid pitch to treat infected eyes. They, the Haisla, and others created various infusions to alleviate tuberculosis, stomach ailments, hemorrhoids, and colds. They used the inner bark and cambium for food and chewed on a hardened pitch for pleasure.

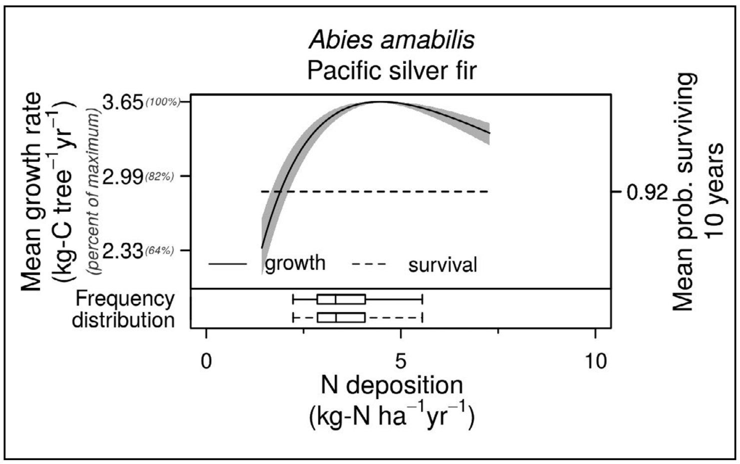
Pacific silver fir is a good choice for planting in watersheds and locations with large amounts of mountain snowpack. It is also well suited for developments such as campgrounds and trails.

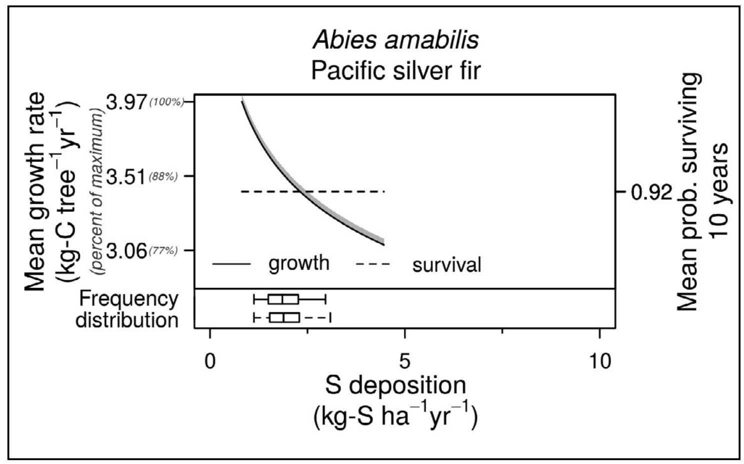
Specimen of *Abies amabilis*. Trunk of *Abies amabilis*. Photos by Susan McDougall, hosted by the USDA-NRCS PLANTS Database.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of Pacific silver fir has a hump-shaped relationship with increasing N deposition and decreases with increasing S deposition. Survival has no relationship to N or S deposition. Confidence in these relationships is medium low based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for additional information.

Foliage of *Abies amabilis.* Photo by Susan McDougall, hosted by the USDA-NRCS PLANTS Database.





Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	**Shade Tolerance**	**Leaf Type**	**Mammal Uses**	**Bird Uses**
	High	Coniferous Evergreen	Yes	Yes

Wood products				**Traditional uses**	**Ornamental uses**	**Fuelwood**
Paper	**Unfinished wood products**	**Building material**	**Finished wood products**			
X	X	X	X	X	X	

Protection			**Rehabilitation**	**Food products**	**Oils and other**	**General services**
Erosion	**Wind**	**Erosion and wind**				
		X			X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

Primary Sources

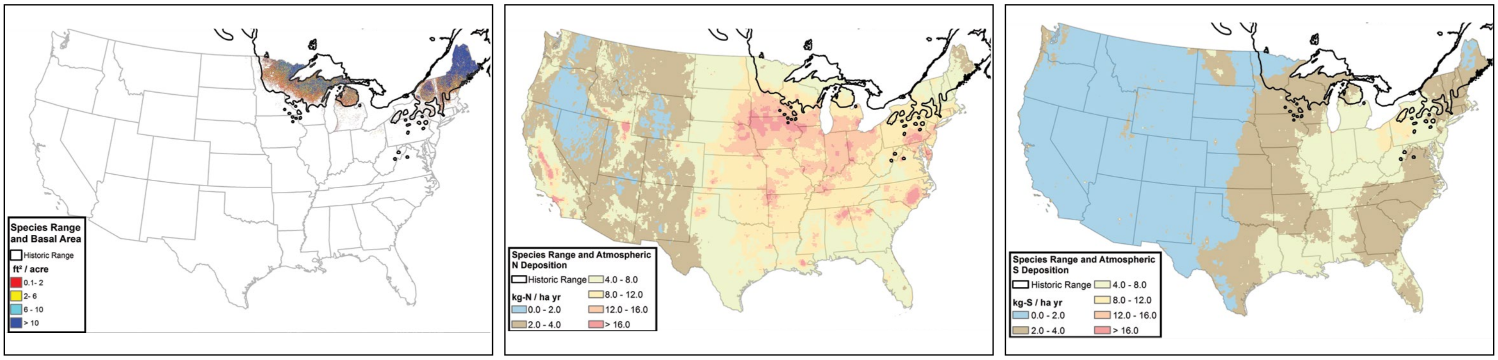
Cope, Amy B. 1992. *Abies amabilis*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (24 March 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2017. The PLANTS Database (http://plants.usda.gov, 1 March 2016). National Plant Data Team, Greensboro, NC 27401–4901 USA.

Abies balsamea (balsam fir)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Balsam fir is a native, coniferous, evergreen, small- to medium-sized, upright tree. At maturity it may reach a height of 40 to 90 feet (12–27 m) and a diameter of 12 to 30 inches (30–75 cm). Maximum age is about 200 years. Balsam fir has a dense, narrowly pyramidal crown terminating in a slender, spire-like top. The needles are flat, resinous, and the tree bears erect cones. On older trees, the bark becomes brown and scaly. Balsam fir is a prolific seed producer and is capable of layering in swamps and mossy areas. The species occurs on mountain slopes and glaciated uplands as well as on alluvial flats, peatlands, and swamps. It is found in pure, mixed coniferous, and mixed coniferous-deciduous stands. It grows on sites underlain by a variety of soil textures and parent materials, including gneiss, schist, anorthosite, diabase, slate, sandstone, and limestone. Balsam fir is a late successional or climax species. Balsam fir is easily killed by fire, so that following fire, pioneering hardwoods and conifers, such as aspen, paper birch, balsam poplar *(Populus balsamifera)*, jack pine, and black spruce all replace balsam fir. Therefore, it is mostly absent for the first few postfire decades.

Wildlife Uses

During winter, moose rely on balsam fir as a major food source, particularly when snow is deep and moose population is high, but the tree is unimportant in the diets of caribou and white-tailed deer. Spruce and ruffed grouse feed on balsam fir needles, tips, and buds. Red squirrels feed on the male flower buds and, less frequently, on leader and lateral buds in late winter and spring when other foods are scarce. Stands attacked by the spruce budworm attract numerous insect-eating birds, especially warblers and woodpeckers. Balsam fir provides important winter cover for white-tailed deer and moose—the stands attract ungulates because snow is not as deep as in adjacent hardwood stands. During summer, deer, bear, and moose often rest under the shade of balsam fir trees. The trees provide cover for small mammals and birds, such as martens, hares, and songbirds, and even deer hide from predators in balsam fir thickets. Grouse and songbirds seek shelter during winter within the evergreen foliage. In Maine, fishers often nest in witches brooms in balsam fir trees.

Ecosystem Services

Balsam fir wood is used primarily for pulpwood and lumber for light frame construction. It is also used extensively for cabin logs. Minor wood products include paneling, crates, and other products not requiring high structural strength. Balsam fir is a popular Christmas tree in the East, grown on plantations for this purpose, and the branches are used to make Christmas wreaths. The fragrant needles are also used as a stuffing in souvenir pillows sold in New England. The tree's bark blisters contain oleoresin, which is used in the optics industry as a medium for mounting microscope specimens and as a cement for various parts of

Cones of *Abies balsamea*. Photo by Paul Wray, Iowa State University, Bugwood.org, 0008196.

Bark of *Abies balsamea*. Photo by Brett Marshall, Sault College, Bugwood.org, 5468107.

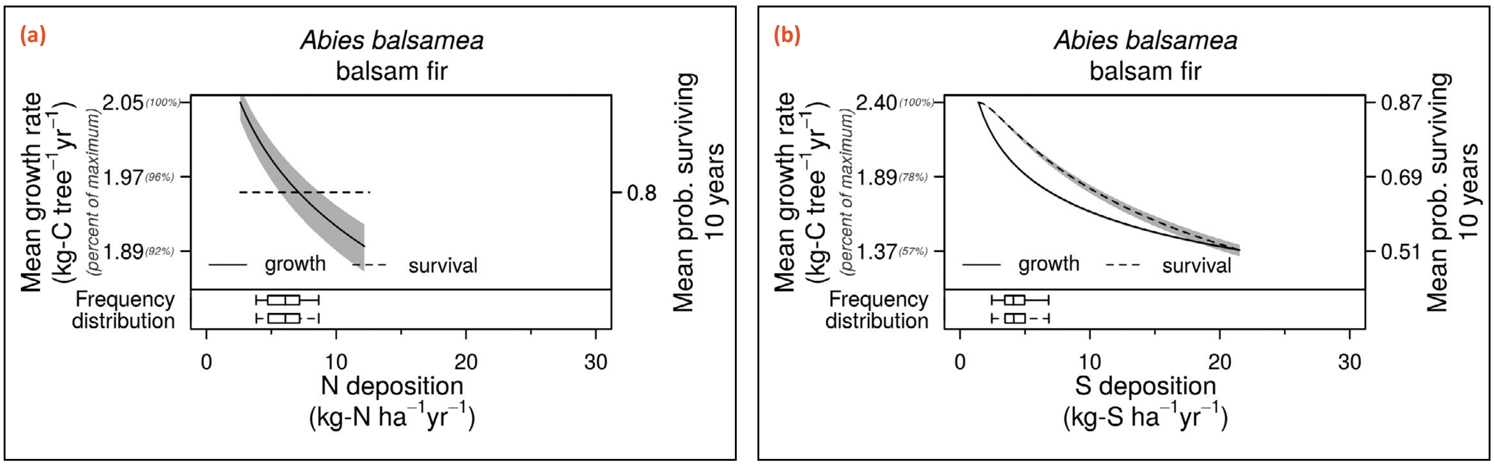
optical systems. Balsam fir is occasionally used in landscaping and can be used in screenings, mass plantings, and windbreaks but requires abundant soil moisture for these purposes.

The Algonquin, Iroquois, and Ojibwa peoples used the gum to treat chest pain and headaches and as an antiseptic for wounds, sores, and burns. Gum decoctions were used to treat coughs, sore throats, rheumatism, lung and kidney ailments, gonorrhea and tuberculosis. The gum can be used to waterproof canoes; the roots as thread; the needles and bark for mats, rugs, bedding, and shelter; and the wood for fuel and canoe paddles.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of balsam fir decreases with increasing N deposition, while survival has no relationship to N deposition. Growth and survival decreases with increasing S deposition. Confidence in these relationships is medium-high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are correlated for many species, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Tender young foliage of *Abies balsamea.* Photo by Bruce Watt, University of Maine, Bugwood.org, 5533036.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	High	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X		X	X	

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
	X				X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

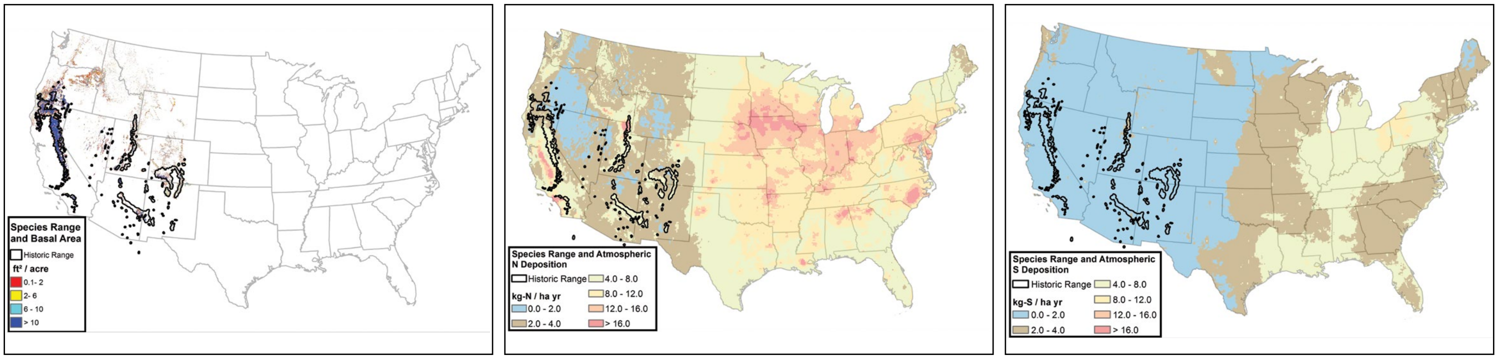
Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

Uchytil, Ronald J. 1991. *Abies balsamea*. In: Fire Effects Information System. [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). http://www.fs.fed.us/database/feis/. (29 July 2016).

Abies concolor (white fir)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

White fir is a large, native, coniferous tree. Mature white fir trees in the central Sierra Nevada are 140 to 180 feet (43–55 m) tall and 40 to 80 inches (1–2 m) in diameter, but may grow larger. Rocky mountain white fir rarely exceeds 125 feet (38 m) tall or 3 feet (0.9 m) in diameter. White fir is thought to be a slow growing species. It can survive for exceptionally long periods as a suppressed tree and still respond to release by increasing growth dramatically. White fir may reach ages of 300–400 years. Reproduction is by seed, and it shows no tendency to reproduce by sprouting or layering. White fir grows on a variety of slightly to strongly acid soils from almost every type of parent material and tolerates a wide range of soil conditions, nutrient availability, and pH values. The species grows from canyon bottoms and ravines up to ridgetops on gentle, moderate, and steep slopes of all aspects. It is a major climax component throughout the mixed conifer forests within its range because it reproduces abundantly under conditions of dense shade, and is also an aggressive pioneer species. In general, successional relationships of white fir are complicated by floristic differences over its large range of occurrence. Young white fir is highly susceptible to fire, and mature trees are only moderately fire tolerant. These trees are sensitive to damage from oxidizing air pollutants, but less sensitive than some associated species.

Wildlife Uses

Stands dominated by white fir seldom produce enough forage for domestic livestock grazing except on harvested or open forest sites, or where grasses and sedges dominate the understory. These forests do, however, provide abundant browse and cover for large and small wildlife species. Mule and black-tailed deer generally eat small amounts of white fir during the spring, fall, and winter, and sometimes larger amounts during the summer. Porcupines enjoy the bark and may destroy saplings in their enthusiasm. Rodents feed on the cambial tissue and mice and pocket gophers feed on the seedlings of small white firs. White fir needles make up an important part of the diet of blue grouse. Several species of small mammals and birds, including grouse, chipmunks and mice, flying squirrels, chickadees, crossbills, and Clark's nutcracker, eat the seeds. Hollow logs and snags of white fir can be important to various birds and animals for foraging in the interior wood: black bears, for hibernation; American martens, for dens and rest sites; and bushy-tailed woodrats, flying squirrels, and other small mammals for cover. Forest songbirds nest within the foliage. In the southwestern part of its range, white fir woodlands tend to be small in area, but provide unique and critical habitat for many species of wildlife such as the Arizona gray squirrel, river otter, zone-tailed hawk, common black hawk, American dipper, summer tanager, bullock oriole, yellow warbler, Arizona alligator lizard, Sonoran mud turtle, and canyon tree frog. Cavity-nesters using white fir snags include the American kestrel, mountain chickadee, brown creeper, mountain bluebird, house wren, tree swallow, northern flicker, and several nuthatch, sapsucker, and woodpecker species.

Individual specimen of *Abies concolor*. Photo by Paul Wray, Iowa State University, Bugwood.org, 0008161.

Bark of *Abies concolor*. Photo by Donald Owen, California Department of Forestry and Fire Protection, Bugwood.org, 5454012.

Ecosystem Services

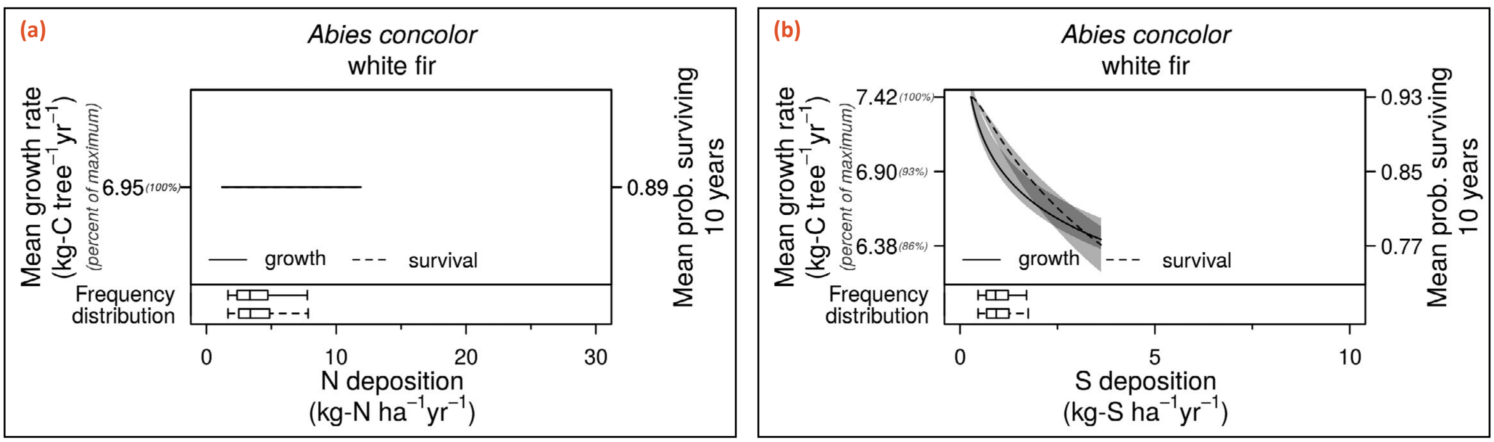
White fir is a general, all-purpose, construction-grade wood used extensively for solid construction framing and plywood, and to a lesser extent, for pulpwood. Its straight grain and low taper make it appropriate for poles and pilings, but it requires large amounts of preservatives because the heartwood decays rapidly. Although it is poorly suited for firewood, it is used anyway. White fir is used extensively in the Christmas tree industry. A valuable ornamental, it is often used for ornamental plantings in northern landscapes because it is attractive and frost-hardy. However, the species is not very tolerant of air pollution and therefore seems best suited for suburbs or rural areas. The tree's eventual great size makes it more appropriate for parks and other open public areas.

The Keres, Paiute, Klamath, Tewa, and others use the needles of the white fir for tea, the bark to dye hides, and the twigs for pipe stems. They brewed infusions and decoctions from various parts of the plant and made warm pitch for treating a variety of ailments.

White fir can be planted on disturbed sites within forest vegetation types where it naturally occurs because it is a good soil stabilizer. The species may be particularly useful on road cuts.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth and survival of white fir have no relationship with N deposition. For S deposition, the growth and survival of white fir decrease with increasing S. Nitrogen and S deposition are often correlated across species geographic distributions, so inferring causality to one or the other stressor can be difficult. Confidence in these relationships is low based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. See Appendix Table 4 and the Introduction for additional guidance.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X		X	X	X

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
X			X			X

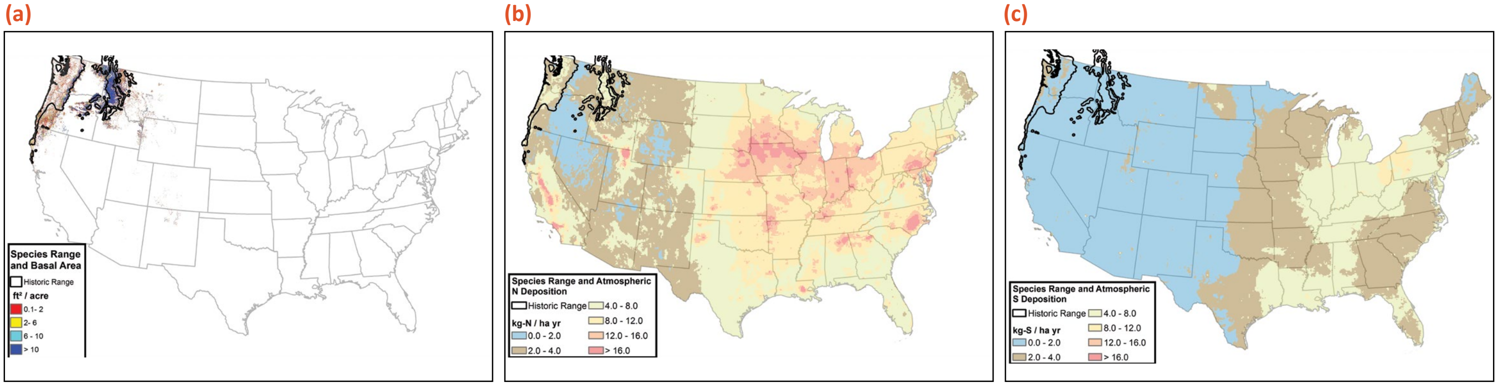
A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

Zouhar, Kris. 2001. *Abies concolor*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (24 March 2016).

Abies grandis (grand fir)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Grand fir is a native, evergreen conifer. Heights of mature trees range from 140 to 200 feet (43–61 m) along the coast and from 131 to 164 feet (40–50 m) inland. The bole of mature trees ranges from 20 to 40 inches in diameter (51–102 cm). Grand fir is the fastest growing of all North American firs. Older grand fir trees support pervasive rotting fungi but frequently reach 250 years of age and occasionally exceed 300 years. Cones bear winged seeds that are of medium weight compared to other conifers and are wind-dispersed a few hundred feet from the parent. Grand fir tends to dominate moderately moist habitats. Soil parent materials include sandstone, pumice, weathered lava or granite, and gneiss. The tree is not generally restricted by soil type but does best on streamside alluvium and deep, nutrient-rich valley bottoms. Grand fir occurs in the overstory of both seral and late-successional forests. It is climax throughout the grand fir series and is a major seral species in some western redcedar, western hemlock, subalpine fir, and Pacific silver fir habitat types. Also, grand fir does not require disturbance to establish and persist on most sites. It is moderately drought-tolerant, but several morphological characteristics of grand fir make it vulnerable to fire. However, the thicker bark of older individuals makes them moderately resistant to fire.

Wildlife Uses

Livestock seldom browse grand fir but do use it for shade. Deer, elk, and moose may resort to eating fir (*Abies* spp.) needles in winter. Fir needles are a major part of the diet of blue, ruffed, and sharp-tailed grouse. Squirrels, other rodents, and some birds such as nuthatches and chickadees eat the seeds. Mature grand fir provides nesting and feeding sites for a variety of arboreal animals. Several species of owl, including the flammulated and northern spotted owl, use grand fir habitats. Marbled murrelets nest in old-growth grand fir/coastal Douglas-fir habitat in northern California. Most big game species do not prefer mature grand fir forests, but they use early seral stage grand fir habitats. Unlike most big game, moose do prefer old-growth grand fir forests. Young stands of grand fir provide good thermal and hiding cover, often close to water, for big game animals. Young trees provide good cover for grouse and small mammals including squirrels, chipmunks, and pikas. Old-growth live grand fir and grand fir snags offer nesting sites for woodpeckers, sapsuckers, deer mice, bushy-tailed woodrat, American marten, fisher, spotted skunk, squirrels, and weasels. Pileated woodpecker and flammulated owl in the Blue Mountains of Oregon and Washington select large-diameter live grand fir—especially trees with broken tops that are extensively decayed by Indian paint fungus (*Echinodontium tinctorium*)—for nesting. Rats, mice, squirrels, weasels, and bears use downed grand fir logs and hollowed trunks as dens.

Abies grandis in the shade. Photo by Chris Schnepf, University of Idaho, Bugwood.org, 1171049.

Trunk of *Abies grandis*. Photo by Dave Powell (retired), USDA Forest Service, Bugwood.org, 0808056.

Ecosystem Services

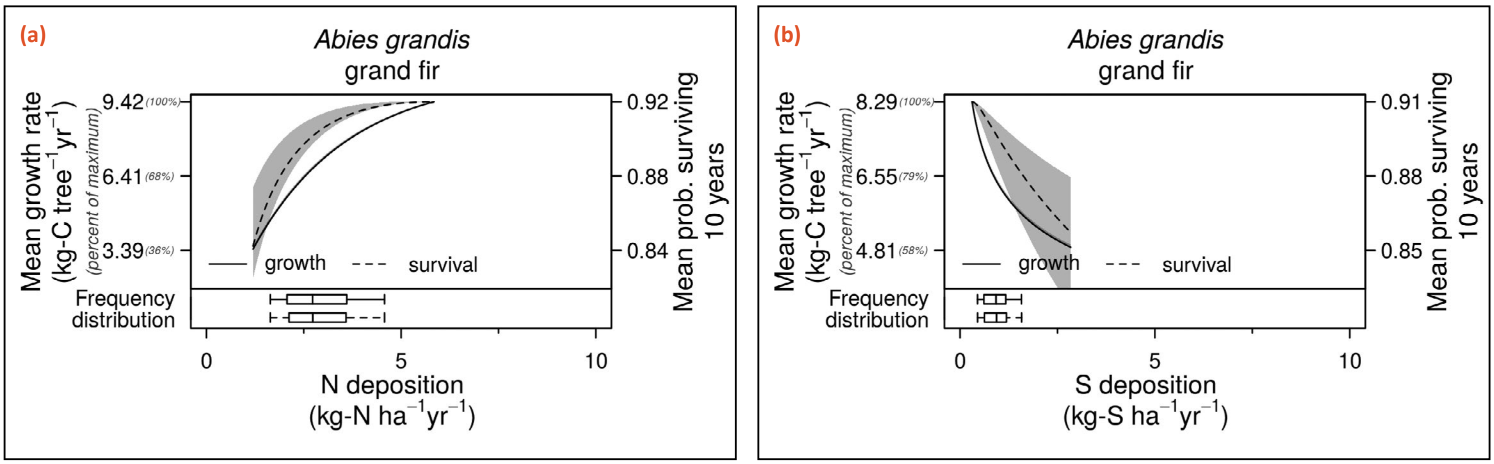
Grand fir is a commercially valuable timber and pulping species. It is grown commercially for Christmas trees and is planted as an ornamental.

The Salish of Vancouver Island, British Columbia, collect pitch from grand fir blisters, rub it into wooden implements, and scorch it to provide a varnished finish. Traditionally, they made a decoction from the branches and cones to treat respiratory ailments; a poultice from the pitch to treat wounds, burns, and sore eyes; and decoctions of bark, sap, and sapwood to treat gonorrhea.

Since grand fir grows well in a variety of environments including riparian areas, it is a good candidate for planting on disturbed sites.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth and survival of grand fir increase with N deposition. and decrease with increasing S deposition. Confidence in these relationships is low based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium, High	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X		X	X	

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
X			X		X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

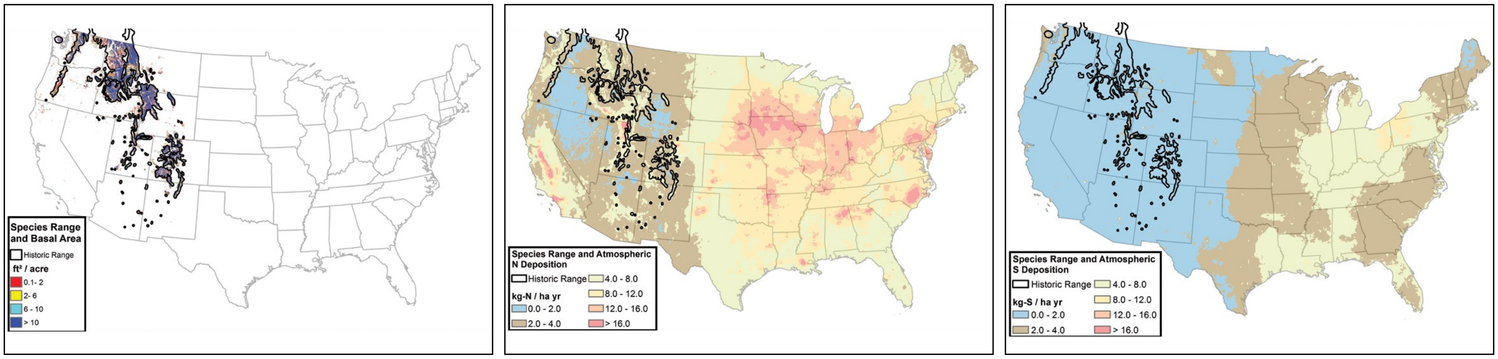
Primary Sources

Howard, Janet L.; Aleksoff, Keith C. 2000. *Abies grandis*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (24 March 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Abies lasiocarpa (subalpine fir)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Subalpine fir is a native, coniferous, evergreen tree. It is the smallest of the eight species of fir native to the Western United States. Five growth forms, each apparently an adaptation to a particular environment, are found throughout its range. The typical form often grows to heights of 60 to 100 feet (18–30 m), and trunk diameters reach 18 to 24 inches (46–61 cm). Trees seldom live more than 250 years because they are very susceptible to heart rots. Fir cones bear seeds that have a large wing and are dispersed primarily by wind in the fall as cones disintegrate on the tree. The species generally occupies sites with a short growing season caused by cold winters, cool summers, frequent summer frosts, and heavy snowpack. At its lower elevational limits, subalpine fir is often restricted to stream bottoms, ravines, frosty basins, or north exposures. In the Rocky Mountains, subalpine fir is a shade-tolerant climax species favored by long fire-free intervals. Near treeline, it may take 100 years or more for subalpine fir to establish seedlings following fire because an increase in herbaceous species prevents seeds from reaching mineral soil and the harsh climate kills many seedlings that do establish. Throughout much of the Cascade Mountains, subalpine fir grows as a shade-intolerant, seral species and is gradually replaced by more shade-tolerant associates such as Pacific silver fir, grand fir, and mountain hemlock. Subalpine fir is very fire sensitive and generally suffers high mortality even from low-intensity fires.

Wildlife Uses

Subalpine-fir-dominated stands generally do not produce enough forage for livestock but do provide browse and cover for large and small wildlife species. Mule deer, elk, bighorn sheep, and snowshoe hares sometimes eat the young growth, but it is not an important food item. Throughout much of Montana, Idaho, and Wyoming, the tree provides an important winter food of moose. In Yellowstone National Park, grizzly bears sometimes strip the bark to feed on the underlying cambium. The winter diet of blue grouse consists primarily of conifer needles. Several species of small mammals and birds eat subalpine fir seeds. Red squirrels, chipmunks, and mice, as well as birds, including chickadees, nuthatches, crossbills, the pine siskin, and the Clark's nutcracker, eat the seeds from the cones. Mule deer, elk, moose, woodland caribou, black bear, and grizzly bear often use subalpine fir habitats as a summer range, and use the trees for thermal and hiding cover. Subalpine fir forests are generally not suitable winter range for deer and elk because of heavy snowpack, but moose and woodland caribou use some lower elevation subalpine fir habitat types during the winter.

Subalpine fir forests support numerous species of small mammals—snowshoe hare, flying squirrel, red squirrel, porcupine, pine marten, fisher, lynx, and several species of mice, voles, chipmunks, and shrews all inhabit subalpine fir forests. Numerous species of birds nest and feed in these forests, including several woodpeckers, flycatchers, kinglets, nuthatches, juncos, thrushes, chickadees, crossbills, the pine siskin, owls, and grouse. Dense thickets of small trees—often nearly impenetrable—provide hiding places for small mammals such as snowshoe hares and porcupines. Blue grouse often overwinter in the trees and rely almost exclusively on them for escape cover. Subalpine fir snags are used by numerous cavity-nesting birds, but are generally less preferred than those of associated conifers. Certain low-elevation subalpine fir forests may be used by elk during calving, and high-elevation subalpine fir forests by bighorn sheep during lambing and lamb rearing. Old-growth subalpine fir stands in northern Idaho may provide critical habitat for woodland caribou.

Foliage of *Abies lasiocarpa*. Photo by Chris Schnepf, University of Idaho, Bugwood.org, 1172059.

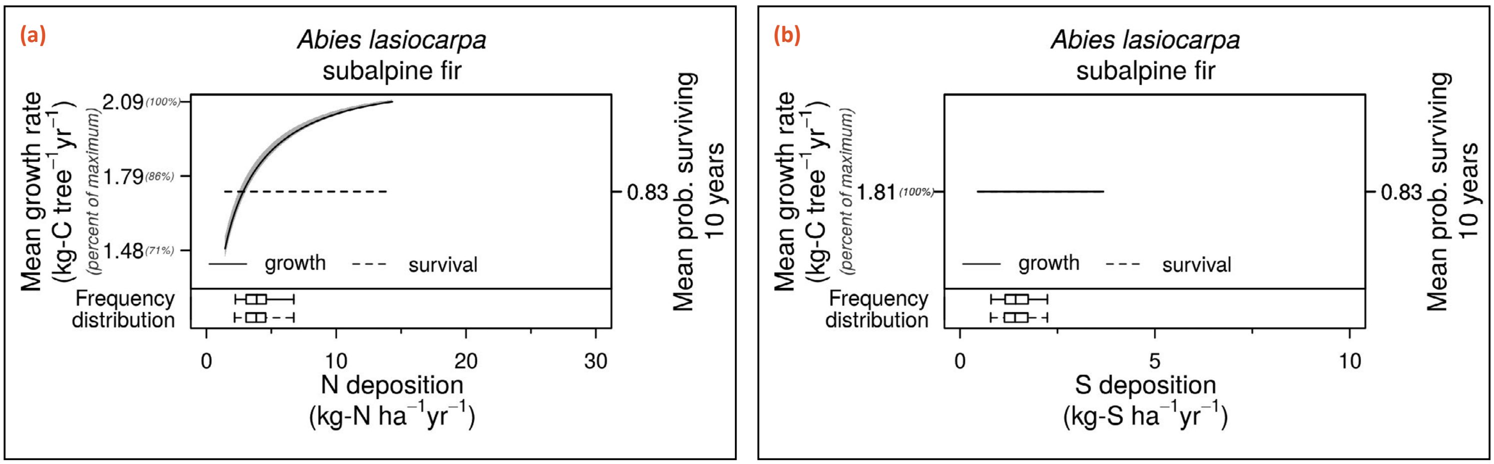
Ecosystem Services

The wood is primarily used for products such as lumber for home construction, poles, pilings, and for prefabricated wood products. Subalpine fir also has excellent pulping properties. Resin from the bark is used in the optical industry and in laboratories as a cement for lenses and microscope slides. The tree is sometimes used as a landscape plant to produce screenings or windbreaks. In the Pacific Northwest, it is sometimes transplanted into rock gardens or simulated subalpine settings. It can be planted on disturbed sites within forest vegetation types where it naturally occurs.

Indigenous peoples used various parts of subalpine fir for numerous purposes. They prepared hair tonic by mixing powdered needles with deer grease and sprinkled ground needles on open cuts. Bark was collected and the sticky resin boiled from it for use as an antiseptic for wounds and as a tea. It was also used for aromatic boughs to scent rooms and the pulverized needles for a body scent and to perfume clothing.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of subalpine fir increases with increasing N deposition and has no relationship to S deposition. Survival has no relationship to N or S deposition. Confidence in these relationships is low based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are correlated for many species, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon,   ha = hectare,   kg = kilograms,   yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Low	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X	X	X	X	

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
	X		X		X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

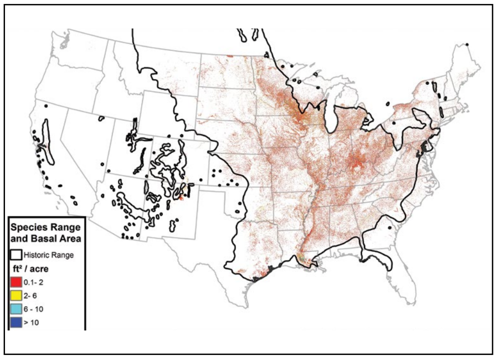
Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

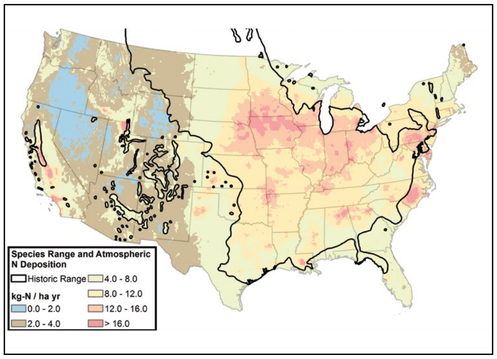
Uchytil, Ronald J. 1991. *Abies lasiocarpa*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/plants/tree/abilas/all.html. (23 March 2016).

Acer negundo (boxelder)

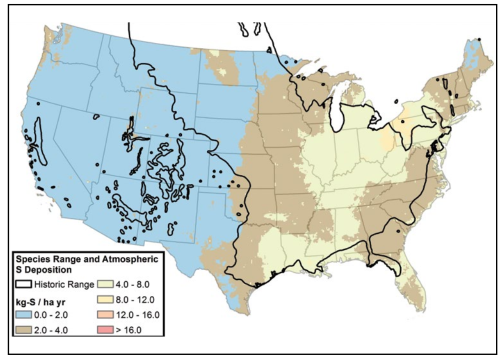
(a)



(b)



(c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Boxelder is a native deciduous, small to large tree with an irregular form. The trunk often divides near the ground into a few long, spreading, rather crooked limbs, which branch irregularly to support a broad, uneven crown. This variable-sized tree typically reaches 40 to 50 feet (12–15m) high and 1 to 2 feet (0.3–0.6 m) in diameter. Boxelder may also appear as a large shrub. It has a fast growth rate and a short life span; it typically lives for 75 years. The bark is light grey and smooth but becomes furrowed into narrow, firm ridges and darkens with age. Boxelder is the only maple with divided leaves. The tree has pale green male and female flowers. The fruit is composed of two fused, winged samaras which eventually separate upon shedding. The species can also reproduce vegetatively with new shoots sprouting from exposed or injured roots. Boxelder generally grows on moist sites along lakes and streams, on floodplains, and in low-lying wet places where its shallow root system can find abundant moisture. Hardy to extremes of climate and variety of soil types, boxelder is drought-tolerant once well established and can also withstand short periods of flooding. It occurs in a variety of forest types ranging from early to late seral, making its successional position difficult to determine. It is moderately shade-tolerant but does not reproduce in its own shade. It usually establishes under pioneering species such as cottonwood and willow, but is then followed by more shade-tolerant, climax species. In the Southwest, however, boxelder is a dominant or codominant overstory species in several high-elevation riparian communities.

Wildlife Uses

Mule deer and white-tailed deer use it in the fall as a browse species. However, this tree may be poisonous to livestock. Many species of birds and squirrels feed on the seeds. Riparian boxelder communities provide important habitat and cover for many wildlife species and protect livestock from temperature extremes in summer and winter. Animals that commonly utilize boxelder habitat for cover include cattle, sheep, horses, elk, mule deer, white-tailed deer, pronghorn, upland game birds, waterfowl, small nongame birds, and numerous small mammals.

Ecosystem Services

The low-quality wood of boxelder is used locally for boxes and rough construction, and occasionally for cheap furniture and woodenware. It was once used for posts, fencing, and fuel, but the soft, spongy wood generally makes poor firewood. Boxelder was first cultivated in 1688, but it is often held in low regard as an ornamental tree in cities. However, because of its fast growth and drought- and cold-hardiness, boxelder is popular in rural communities for street and ornamental plantings and for shelterbelts. Boxelder's abundant sap contains a large proportion

Individual specimen of *Acer negundo*. Photo by Rob Routledge, Sault College, Bugwood.org, 5454129.

Bark of *Acer negundo*. Photo by Karan A. Rawlins, University of Georgia, Bugwood.org, 5407928.

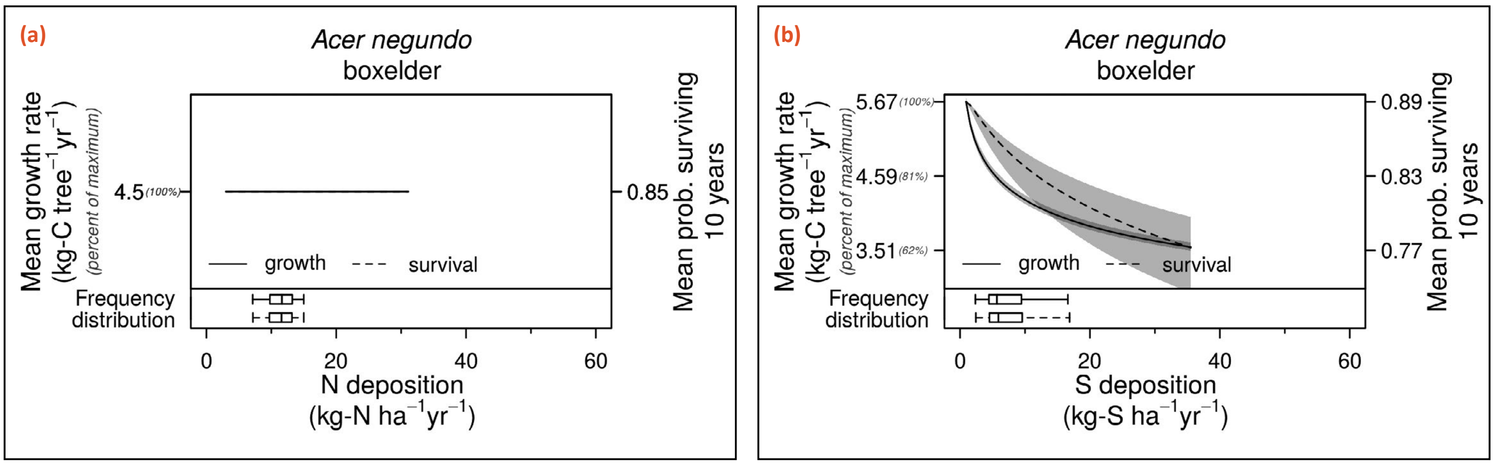
of sugar as well as mucilaginous and demulcent properties, and can be made into a pleasant beverage.

The Plains Indians traditionally used the sap as a syrup, and it is still used today, but the product is not as sweet as sugar maple syrup. The sap added to the shavings of animal hides makes a relished candy. Charcoal from boxelder was used for tattooing.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth and survival of boxelder has no relationship to N deposition and decrease with S deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species distributions so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for additional information.

Foliage of *Acer negundo.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008304.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Broadleaf Deciduous	Yes	Yes

Wood products: Paper	Wood products: Unfinished wood products	Wood products: Building material	Wood products: Finished wood products	Traditional uses	Ornamental uses	Fuelwood
	X		X	X	X	X

Protection: Erosion	Protection: Wind	Protection: Erosion and wind	Rehabilitation	Food products	Oils and other	General services
	X			X		X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

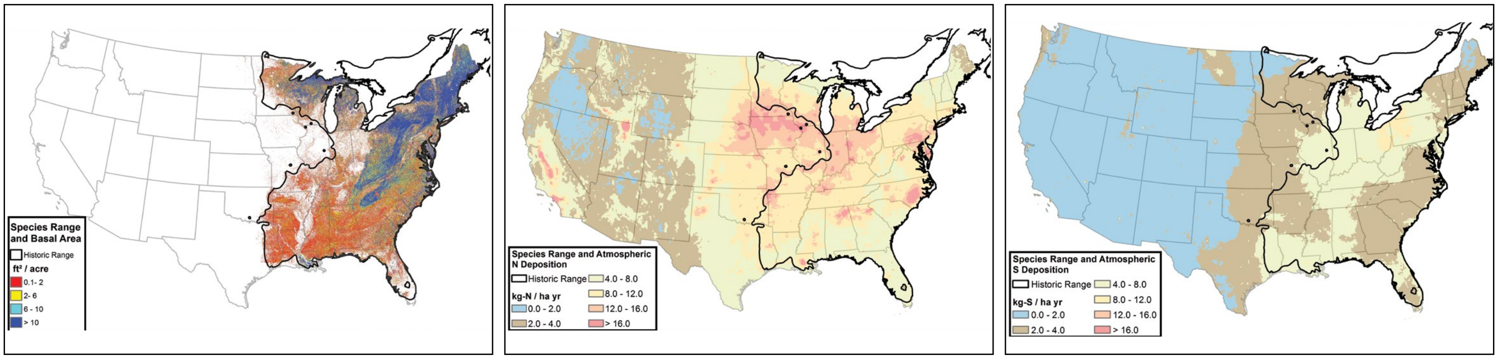
Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

Rosario, Lynn C. 1988. *Acer negundo*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/plants/tree/aceneg/all.html. (23 March 2016).

Acer rubrum (red maple)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Red maple is a deciduous tree that grows 30 to 90 feet (9–28 m) tall and up to 4 feet (1.6 m) in diameter. The bark is smooth and gray but darkens and becomes furrowed in narrow ridges with age. The small, fragrant flowers are borne in slender-stalked, drooping clusters. The fruit is a paired, winged samara, and is typically red, pink, or yellow. Red maple sprouts vigorously from the stump, root crown, or "root suckers" after fire or mechanical damage. It grows throughout much of the deciduous forest of eastern North America and into the fringes of the boreal forest. In much of the Northeast it occurs on a variety of wet to dry sites in dense woods openings. It is an overstory-dominant only in swamps and other wet sites. Red maple does well on a wider range of soil types, textures, moisture regimes, and pH than does any other forest species in North America. Red maple is characterized by a wide ecological amplitude and occupies a wide range of successional stages and tree associations. This tree lives longer than most seral species but generally does not persist in late successional stages. Red maple commonly increases after disturbances such as windthrow, clearcutting, or fire. In many locations, the species has increased in importance since pre-settlement times—Dutch elm disease and chestnut blight have led to increases in the number of red maple stems in many stands. In many parts of the East, oak decline and gypsy moth infestations have left gaps that red maple has filled in.

Wildlife Uses

Red maple browse is toxic to cattle and horses, particularly in the summer and late fall. However, some wildlife species, including white-tailed deer, elk, snowshoe hare, and occasionally moose, browse the tree; it is a valuable browse for white-tailed deer during late fall and winter. Red maples provide cover for many species of wildlife. The screech owl, pileated woodpecker, and common flicker nest in cavities in many species of maple. Cavities in red maples in river floodplain communities are often well suited for cavity-nesters such as the wood duck. Riparian red maple communities in central Ohio provide autumn roosts for blackbirds.

Ecosystem Services

Red maple is an important source of sawtimber and pulpwood but is often overlooked as a wood resource. The wood is used for furniture, veneer, pallets, cabinetry, plywood, barrels, crates, flooring, and railroad ties. The showy fruits and flowers and colorful fall foliage make the tree a common planting in urban-suburban landscapes. Red maple can be used to make maple syrup, although sugar maple is much more commonly used.

Many eastern indigenous peoples traditionally used infusions and decoctions of bark to treat cramps, hives, eyes, menstrual cramps, and hemorrhoids.

Individual specimen of *Acer rubrum*. Photo by T. Davis Sydnor, The Ohio State University, Bugwood.org, 5509693.

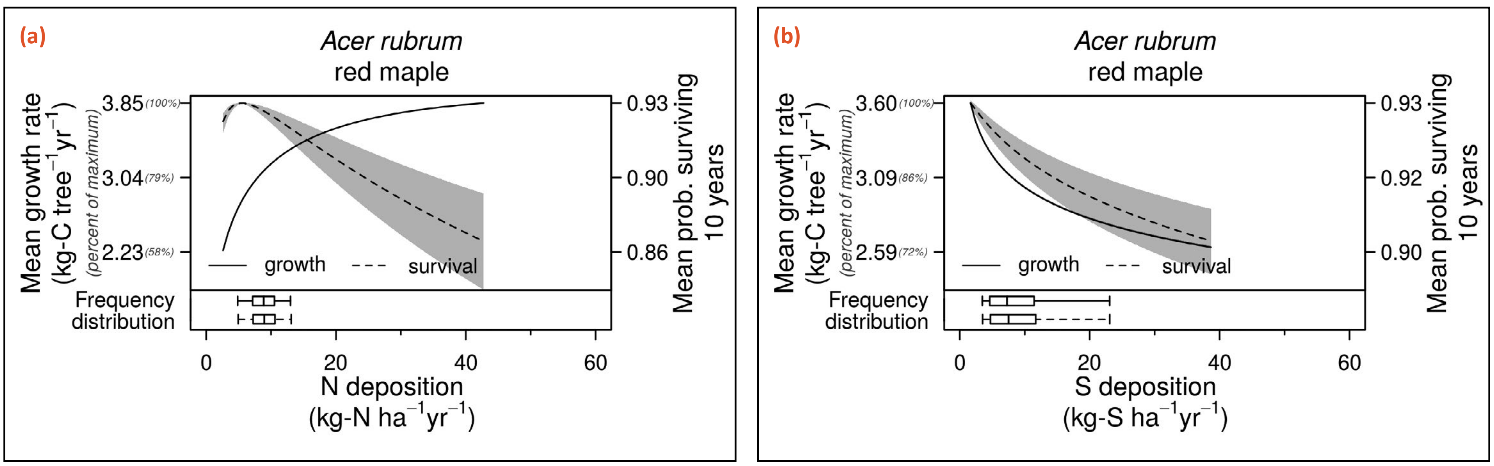
Foliage of *Acer rubrum*. Photo by Rob Routledge, Sault College, Bugwood.org, 5474914.

Red maple can be planted onto many types of disturbed sites, including strip-mine spoils.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

Red maple growth increases and survival decreases with increasing N deposition. Red maple growth and survival decrease with increasing S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for additional information.

Flowers of *Acer rubrum*. Photo by Chris Evans, University of Illinois, Bugwood.org, 1373040.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X	X	X	X	X

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
			X	X		X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

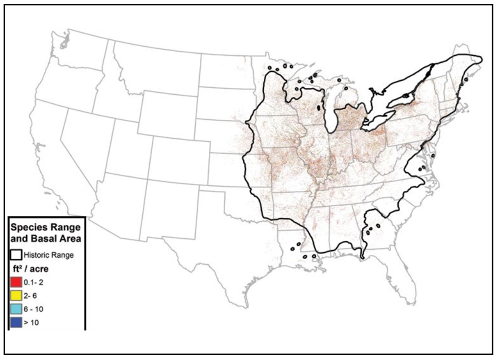
Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

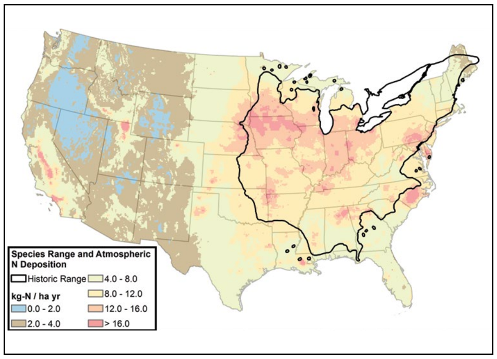
Tirmenstein, D.A. 1991. *Acer rubrum*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (22 March 2016).

Acer saccharinum (silver maple)

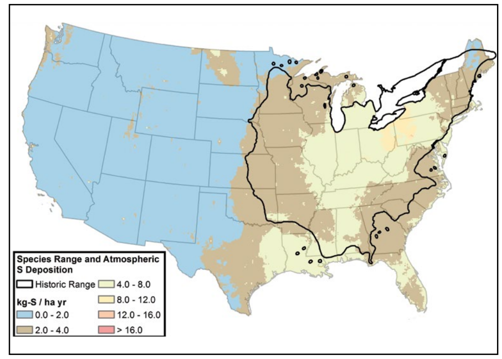
(a)



(b)



(c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

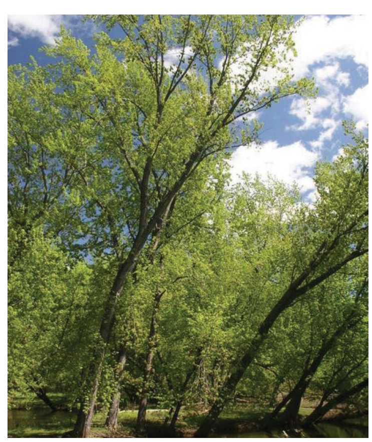
Silver maple is a native, deciduous, medium-sized tree. A fast-growing species, mature height ranges from 90 to 120 feet (27–36 m). The trunk is often separated into several upright branches near the ground. The bark of young stems is smooth, becoming darker and furrowed to flaky on older stems. Wind, primarily, and water, to a much lesser degree, disperse the fruits. The tree also sprouts prolifically from the stump or root crown, but larger trees tend to lose the ability to sprout. Silver maple is typical of wet bottomlands, riverbanks, riparian areas, and lake edges; it is less common on upland sites. Silver maple is intermediate in tolerance to water-saturated soils, but can tolerate prolonged periods of inundation. In the northeastern United States, the species is dominant or codominant on several types of sites: undifferentiated alluvial deposits of poorly drained silts high in organic matter and nitrogen, undifferentiated alluvium composed of well-drained silts with a high base content and nearly neutral soils; and rapidly aggrading alluvial areas and point bars composed of mixtures of sand and silt that are of intermediate fertility.

Wildlife Uses

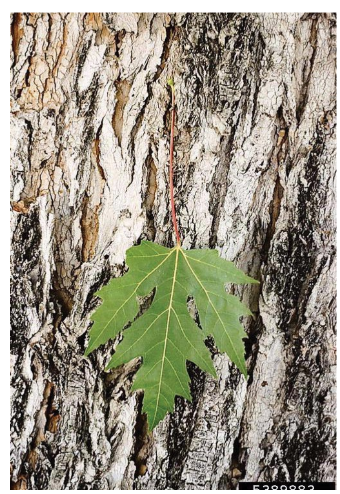
White-tailed deer and rabbits browse the foliage of silver maple. It produces abundant annual seed crops, providing food for many birds—including evening grosbeaks, wood ducks, finches, wild turkeys and other game birds—and small mammals, especially squirrels and chipmunks. The early buds constitute an important food for squirrels when they have depleted their cached food. The bark ranks high as a food source for beavers. In New Brunswick, wood ducks and goldeneyes frequently nest in silver maples. The tree's soft wood tends to develop cavities, offering nesting places for cavity-nesting birds and mammals and providing shelter for raccoons, opossums, squirrels, owls, woodpeckers, and other species. Silver maple is one of a few deciduous trees used as communal roosts by red-winged blackbirds, common grackles, starlings, and brown-headed cowbirds. It is often a dominant member of seasonally flooded flats, which are important to tree- and shrub-nesting species, colony-nesting waterbirds, and passerines. It also occurs in wooded swamps and other riparian communities which are valuable breeding habitat for wood ducks, black ducks, herons, egrets, warblers, flycatchers, woodpeckers, thrushes, nuthatches, vireos, rose-breasted grosbeaks, hawks, owls, grackles, and many passerines. In Indiana, silver maple is a dominant member of riparian communities that are important to the endangered Indiana bat.

Ecosystem Services

Silver maple wood is used for furniture, boxes, crates, food containers, paneling, and core stock. The wood is cut and sold with red maple as "soft maple" lumber. On good sites, silver maple can be managed for timber. On poor sites, it can be managed for cordwood. The species has been planted as an ornamental, but this use has declined because of a tendency to rot, prolific sprouting, and limbs that easily break in ice and snow storms. In addition, the shallow roots invade water systems, and



Specimens of *Acer saccharinum*. Photo by Steven Katovich, USDA Forest Service, Bugwood.org, 5468264.



A leaf and bark of *Acer saccharinum*. Photo by Tom DeGomez, University of Arizona, Bugwood.org, 5389883.

the large volume of shed samaras and twigs can be a nuisance. Silver maple sap can be used to make maple syrup.

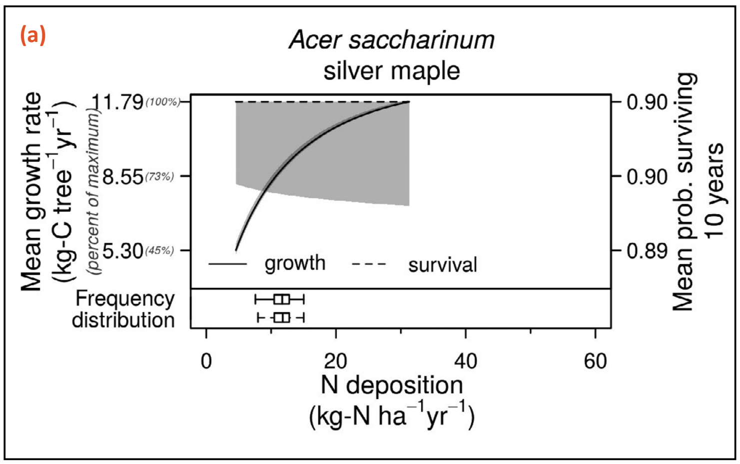
The Cherokee traditionally used an infusion of bark to treat cramps, dysentery, sore eyes, hives, and measles. The Ojibwa used a bark infusion to alleviate symptoms from venereal diseases.

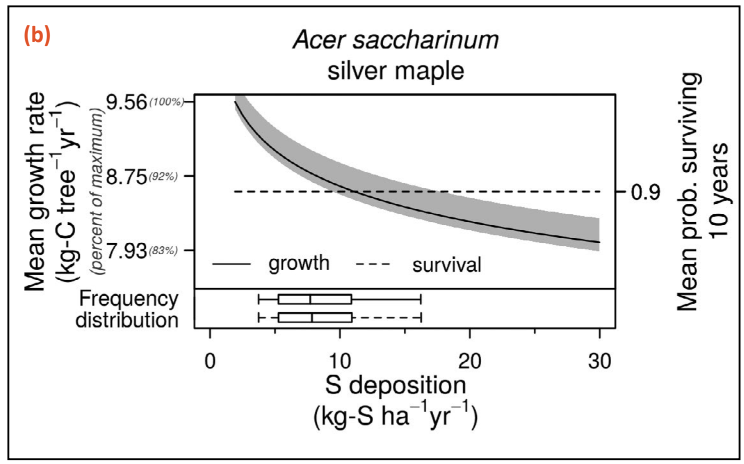
Silver maple is suitable for bottomland reforestation in the lower Mississippi River Valley and strip-mined lands in the Appalachians.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of silver maple increased with increasing N deposition, while survival had no relationship. For S deposition, the growth of silver maple decreased with increasing S, while survival had no relationship. N and S deposition are correlated for many species, and uncorrelated for others, so inferring causality to one or the other stressor can be difficult. Confidence in these relationships is high after evaluating the correlation between atmospheric N and S deposition across the species range and the variance inflation factor. See Appendix Table 4 and the Introduction for more information.

Fruits (samaras) of *Acer saccharinum*. Photo by Franklin Bonner (retired), USDA Forest Service, Bugwood.org, 5423989.





Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
	X	X	X	X	X	

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
X			X	X		X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

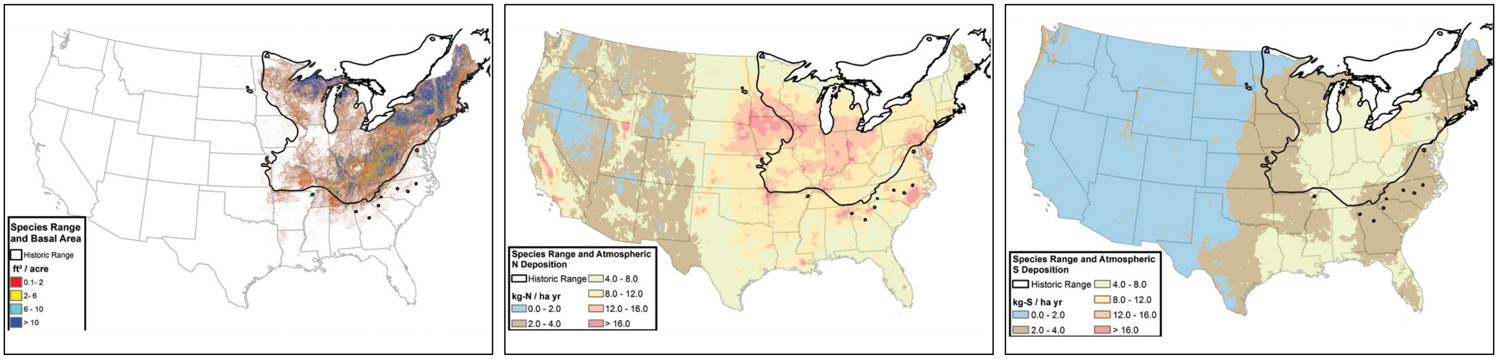
Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

Sullivan, Janet. 1994. *Acer saccharinum*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (22 March 2016).

Acer saccharum (sugar maple)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Sugar maple is a deciduous tree which reaches 90 to 120 feet (27–37 m) in height and 30 to 36 inches (76–91 cm) in diameter. This long-lived tree can survive for 300 to 400 years. The bark is light gray to gray-brown and becomes deeply furrowed and rough with age. It bears a paired, papery-winged fruit and is a prolific sprouter in the northern part of its range. Sugar maple most commonly occurs in rich, mesic woods but also grows in drier upland woods. It is often associated with stream terraces, streambanks, valleys, canyons, ravines, and wooded natural levees. It can grow on a wide variety of soils, including sand, loamy sand, sandy loam, silty loam, and loams, and is intolerant of flooded soils and generally grows poorly on dry, shallow soils. Sugar maple is very tolerant of shade and can persist for long periods beneath a dense forest canopy. It is noted for its ability to quickly occupy gaps created in the forest canopy. Sugar maple is generally regarded as a late seral or climax species in many eastern deciduous forests that have minimal disturbance. Causes of maple decline are unknown, but acid rain, sulfur oxides, chlorides, fluorides, nitrogen oxides, and other air pollutants are possible contributors.

Wildlife Uses

White-tailed deer, moose, and snowshoe hare commonly browse sugar maple, and red squirrels, gray squirrels, and flying squirrels feed on the seeds, buds, twigs, and leaves. Porcupines consume the bark and can, in some instances, girdle the upper stem. Numerous species of songbirds nest in sugar maple, and cavity-nesters such as the black-capped chickadee excavate nest cavities or use preexisting cavities. The common flicker, pileated woodpecker, and screech owl also nest in maples.

Ecosystem Services

Furniture, paneling, flooring, and veneer—as well as gunstocks, tool handles, plywood dies, cutting blocks, woodenware, novelty products, sporting goods, bowling pins, and musical instruments—are among the many products made from the wood of the sugar maple. Sugar maple is the primary source of maple sugar and syrup.

Many indigenous peoples of eastern North America use maple sugar and syrup as a staple and as trade items.

Sugar maple is an attractive shade tree and is widely planted as an ornamental. It is sometimes used in shelterbelt plantings, and is valuable for rehabilitation of disturbed sites.

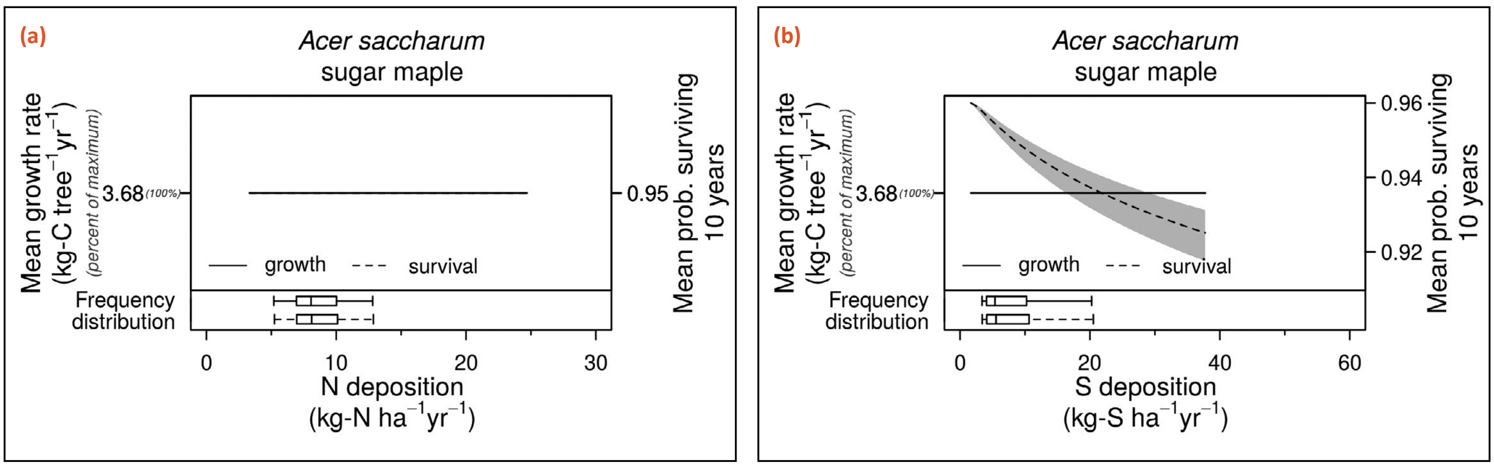
Canopy of *Acer saccharum*. Photo by Vern Wilkins, Indiana University, Bugwood.org, 5472995.

Bark of *Acer saccharum*. Photo by T. Davis Sydnor, The Ohio State University, Bugwood.org, 5509711.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth and survival of sugar maple had no relationship with N deposition. For S deposition, the growth of sugar maple had no relationship with increasing S, while survival decreased. N and S deposition are correlated for many species, and uncorrelated for others, so inferring causality to one or the other stressor can be difficult. Confidence in these relationships is medium low after evaluating the correlation between atmospheric N and S deposition across the species range and the variance inflation factor. See Appendix Table 4 and the Introduction for more guidance on how to interpret this issue.

Foliage of *Acer saccharum.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008379.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	High	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
		X	X	X	X	X

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
	X		X	X		X

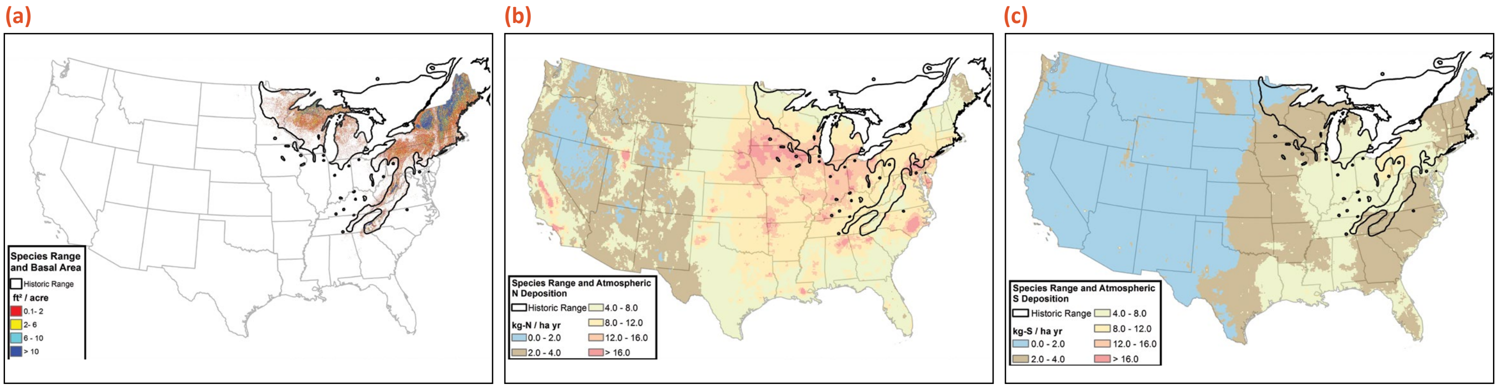
A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

Tirmenstein, D.A. 1991. *Acer saccharum*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (22 March 2016).

Betula alleghaniensis (yellow birch)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Yellow birch is a native, deciduous tree which usually ranges from 60 to 75 feet (18–23 m) in height and up to 2 feet (0.6 m) in diameter. Open-grown yellow birch crowns are long and wide-spreading; in more dense forests, crowns are short and irregularly rounded. The bark is somewhat lustrous. The fruit is a winged nutlet. Yellow birch is slow growing, and average longevity is approximately 150 years. It occurs on moist, well-drained soils of uplands and mountain ravines and occurs on various soil types including glacial tills, outwash sands, lacustrine deposits, shallow loess, and residual soils derived from sandstone, limestone, igneous, and metamorphic rock. Even though growth is poor, yellow birch is often abundant where drainage is restricted. Periodic droughts are damaging to the tree because of its shallow roots and thin leaf litter. It is intermediate in shade tolerance, and is described as opportunistic because it produces abundant small seed. Birches respond to gaps of all sizes, but do not successfully compete with advance regeneration of other northern hardwood species, grasses, and forbs. Yellow birch typically declines as stands age but the organism's longevity and opportunism allow it to persist in all successional stages. Early 20th century logging practices that favored shade-tolerant species resulted in a decrease in yellow birch, and heightened sulfur dioxide concentrations stress and injure current populations of the tree.

Wildlife Uses

Moose, white-tailed deer, and snowshoe hare browse yellow birch. Deer consume large numbers of seedlings in summer, and prefer green leaves and woody stems in fall. Beaver and porcupine chew the bark. Common redpoll, pine siskin, chickadees, and other songbirds consume the seeds, and ruffed grouse feed on seeds, catkins, and buds. Red squirrel cut and store mature strobili, eat yellow birch seeds, and feed on birch sap. The yellow-bellied sapsucker uses yellow birch as a summer food source.

Ecosystem Services

Yellow birch is an economically important source of lumber. The heavy, strong, and close-grained wood is used for furniture, cabinetry, charcoal, pulp, interior finish, veneer, tool handles, boxes, woodenware, and interior doors. Yellow birch can be tapped for sap, which is used to make an edible syrup. Tea can be made from the twigs and/or inner bark. Yellow birch chips can be used to produce ethanol and other products.

The Delaware, Iroquois, Ojibwa, and others used various parts of the tree to create emetics, blood purifiers, and sugary

Flowers of *Betula alleghaniensis*. Photo by David Lee, Bugwood.org, 5538975.

Bark of *Betula alleghaniensis*. Photo by Steven Katovich, USDA Forest Service, Bugwood.org, 5506064.

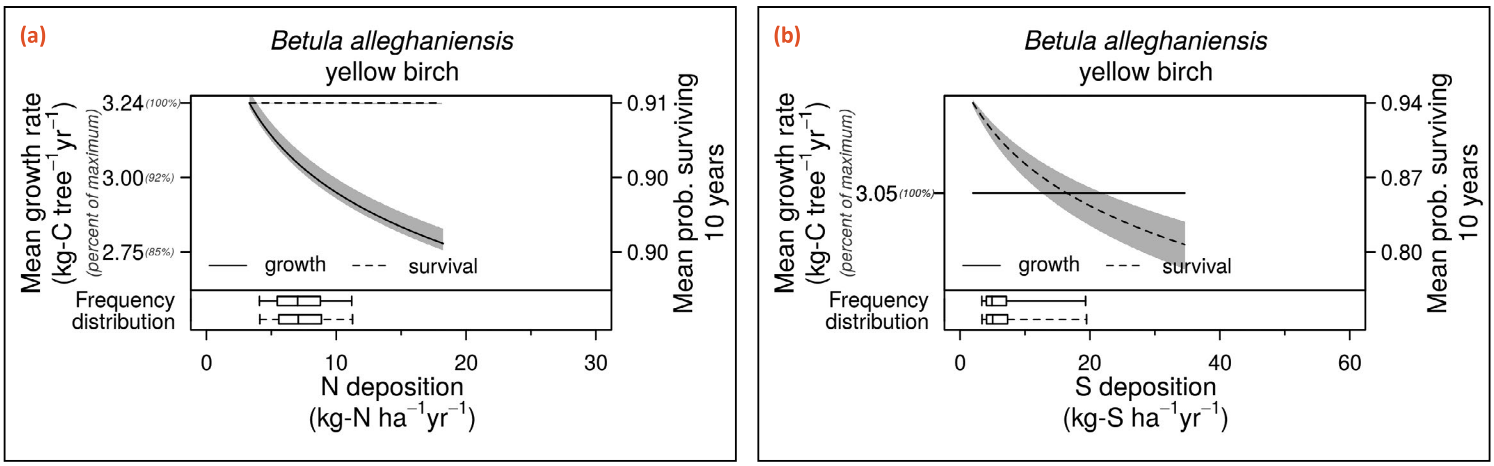
beverages. They constructed canoes and medicine lodges from the lumber.

Yellow birch has been observed as an early colonizer in denuded sites by brine application (product of well-injection fluid).

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of yellow birch decreased with increasing N deposition, while survival had no relationship. For S deposition, the growth of yellow birch had no relationship with increasing S, while survival decreased. N and S deposition are correlated for many species, and uncorrelated for others, so inferring causality to one or the other stressor can be difficult. Confidence in these relationships is medium low after evaluating the correlation between atmospheric N and S deposition across the species range and the variance inflation factor. See Appendix Table 4 and the Introduction for more guidance on how to interpret this issue.

Fruit of *Betula alleghaniensis.* Photo by David Lee, Bugwood.org, 5538975.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X	X	X	X	X

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
			X	X	X	X

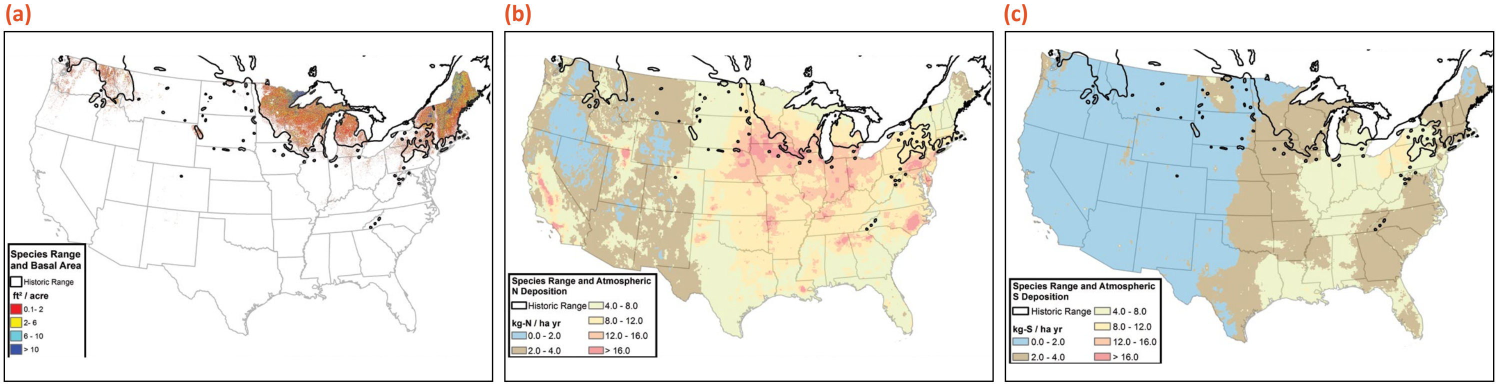
A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

Sullivan, Janet. 1994. *Betula alleghaniensis*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (22 March 2016).

Betula papyrifera (paper birch)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

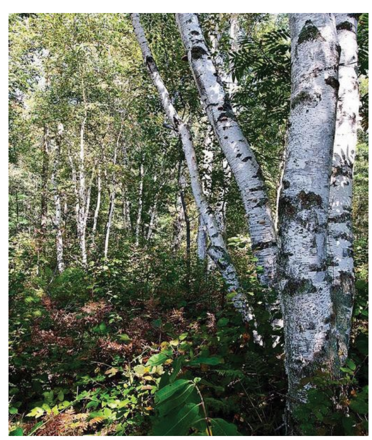
Paper birch is a medium-sized, single- or multiple-stemmed, deciduous tree. In forests, it typically has a slender trunk with a narrow crown, but in openings it has a wider crown spreading out from near the base. Multiple-stemmed trees are relatively common—the result of browsing by moose and snowshoe hares. Throughout much of its range, mature trees are 70 to 80 feet (21–24 m) tall and 10 to 12 inches (25–30 cm) in trunk diameter. Paper birch is short-lived, with few trees living more than 140 years. On mature trees, bark is thin, white, and smooth, often separating into papery strips, and easily peeled off in sheets. Catkins produce winged-nutlet fruits. Paper birch sprouts following browsing, cutting, or fire. The species is most abundant on rolling upland terrain and alluvial sites but grows on almost any soil and topographic situation, including rugged mountain slopes, open slopes, rock slides, muskegs, and borders of bogs and swamps. Paper birch grows in climates ranging from boreal to humid and tolerates wide variations in the amount and pattern of precipitation. It is shade-intolerant, and abundant on burned-over and cut-over lands, where it often forms pure stands. In older forests, it is restricted to openings. Paper birch is a short-lived, shade-intolerant, pioneer species. It rapidly colonizes open disturbed sites created by wildfire, windthrow, or avalanche but lasts only one generation before it is replaced by shade-tolerant conifers or northern hardwoods. Paper birch seeds-in aggressively after wildfire, often forming large, essentially pure stands. Paper birch leaf litter inhibits jack pine, red pine (*Pinus resinosa*), and eastern white pine (*P. strobus*) seed germination.

Wildlife Uses

Paper birch provides an important moose browse throughout most of its range—although in winter its nutritional quality is poor, its sheer abundance in young stands makes it important. The leaves constitute an important component of the diet of white-tailed deer. Snowshoe hares browse paper birch seedlings and saplings, and porcupines feed on the inner bark. Beaver eat paper birch, and voles, and shrews consume the seeds. Redpolls, siskins, and chickadees obtain a considerable portion of their annual diet from birch seeds. Ruffed grouse eat paper birch catkins and buds. It is a favorite feeding tree of yellow-bellied sapsuckers, which peck holes in the bark to feed on the sap. Hummingbirds and red squirrels also feed at sapwells in paper birch created by sapsuckers. Young paper birch stands provide prime deer and moose cover. Numerous cavity-nesting birds, including woodpeckers, chickadees, nuthatches, and swallows, nest in the tree.

Ecosystem Services

Paper birch wood is used commercially for veneer, plywood, and pulpwood, and the lumber for furniture, cabinets, and numerous specialty items. Tree chips go in to pulp and paper manufacture, reconstituted uses, and fuel. It is commonly used as fireplace and



Specimens of *Betula papyrifera*. Photo by DAVID LEE, Bugwood.org, 5445764.

Foliage of *Betula papyrifera*. Photo by Keith Kanoti, Maine Forest Service, Bugwood.org, 5349047.

wood stove fuel. Paper birch's graceful form and attractive bark make it a popular landscape plant. The sap is made into syrup, wine, beer, and medicinal tonics; currently only a few small sugaring operations in Alaska utilize paper birch.

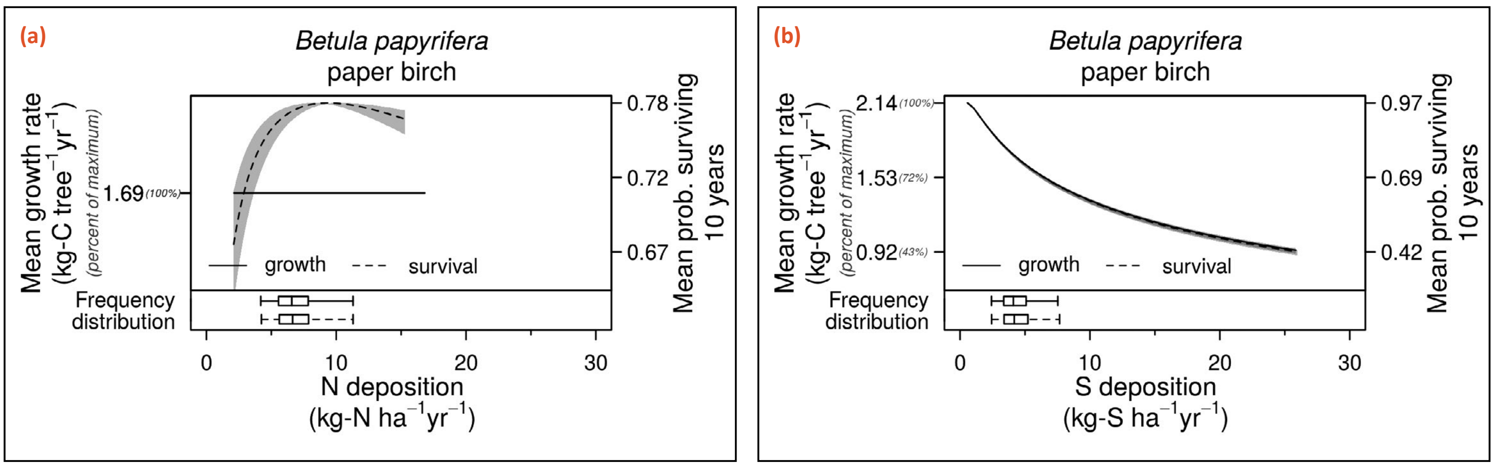
Native Americans throughout the range of the species traditionally make paper birch bark into baskets, storage containers, mats, baby carriers, moose and bird calls, torches, and household utensils. They also construct spears, bows, arrows, snowshoes, sleds, canoes, and other items from the strong, flexible wood.

Paper birch can provide long-term revegetation and soil stabilization of severely disturbed sites. It is often used to reclaim coal, lignite, rock phosphate, slate, gold, oil-shale, bauxite, and other mine spoils.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

Fruit of *Betula papyrifera*. Photo by Paul Wray, Iowa State University, Bugwood.org, 0008175.

Paper birch growth has no relationship to N deposition and decreases with increasing S deposition. Survival has a hump-shaped relationship to increasing N deposition and decreases with increasing S deposition. Confidence in these relationships is medium high based on the correlation between N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are correlated for many species, so inferring causality to a single stressor can be difficult. See also Appendix Table 4 and the Introduction for more information.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Low	Broadleaf Deciduous	Yes	Yes

Wood products						
Paper	**Unfinished wood products**	**Building material**	**Finished wood products**	**Traditional uses**	**Ornamental uses**	**Fuelwood**
X		X	X	X	X	X

Protection						
Erosion	**Wind**	**Erosion and wind**	**Rehabilitation**	**Food products**	**Oils and other**	**General services**
X			X	X	X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

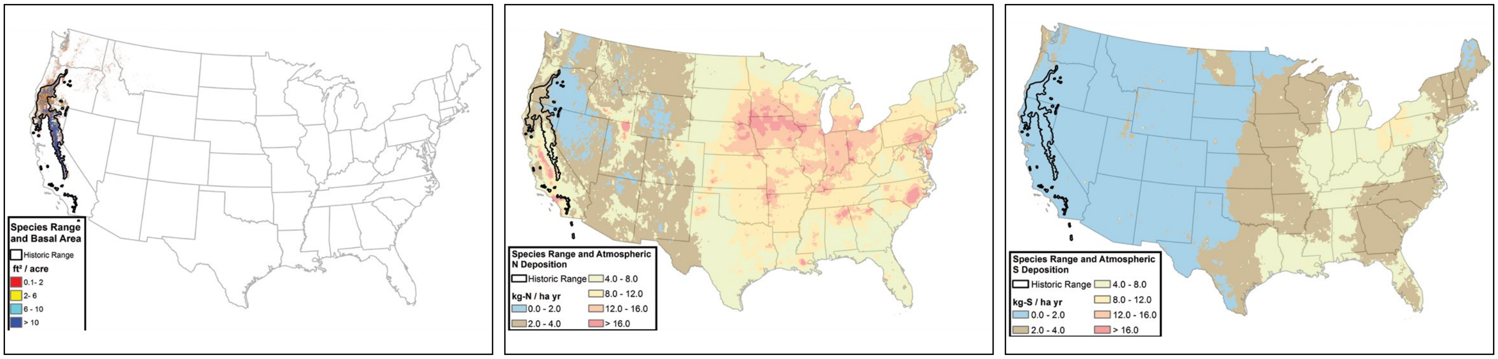
Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

Uchytil, Ronald J. 1991. *Betula papyrifera*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (22 March 2016).

Calocedrus decurrens (incense cedar)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Incense cedar is an evergreen tree that grows 66 to 187 feet (20–57 m) tall and up to 4 feet (1.2 m) in diameter. At high elevations and on dry, exposed sites, trees are small and scrubby. Young trees have dense, symmetrical, pyramid-shaped crowns with branches that reach to the ground. Old trees have swollen bases, rapidly tapering trunks, and open, irregular crowns. Trees grow slowly and can live more than 500 years. Incense cedar leaves are scale-like, and the bark is thick, fibrous, furrowed, and ridged. Incense cedar produces cones that contain winged seeds. The species grows on a wide variety of sites ranging from shaded stream courses to exposed slopes. It grows in many soil types originating from a wide variety of parent rocks, including rhyolite, pumice, andesite, diorite, sandstone, shale, basalt, peridotite, serpentinite, granite, and limestone, with soil textures that vary from coarse sand to fine clay. Its ability to extract soil phosphorus and calcium and exclude surplus magnesium allows incense cedar to grow on soils derived from peridotite or serpentinite. Incense cedar is shade-tolerant; seedlings establish readily in shade, and trees persist in the shaded understory for long periods. In many stands, incense cedar is an important component of both the understory and the overstory. It is reported as a late-seral canopy dominant in many forest types and has increased in abundance because of fire suppression.

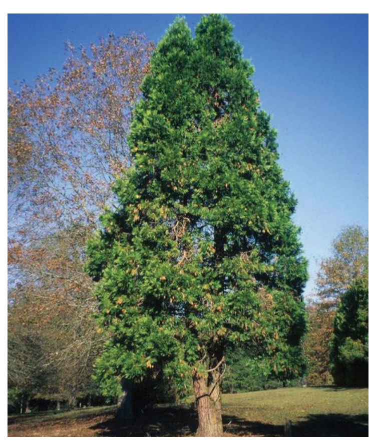
Wildlife Uses

Mule deer in California and Nevada browse incense cedar, and dusky-footed woodrats feed on the seeds. A variety of insectivorous birds forage on incense cedar. White-headed woodpeckers, brown creepers, red-breasted nuthatches, and golden-crowned kinglets are among the species that exhibit the greatest use of incense cedar. Brown creepers, in particular, forage for arthropods on the surface of the bark. A variety of raptors roost and/or nest in the large trees. The majority of known northern and California spotted owl sites are in mixed-conifer forest that include incense cedar. Great gray owls are also common in mixed-conifer forests and are known to nest in large, broken-topped incense cedars. Small incense cedar trees create a dense understory that provides cover for small birds, particularly during winter.

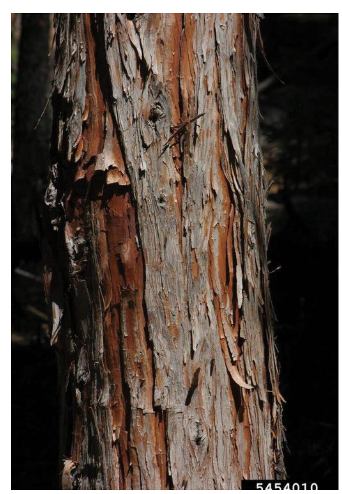
Ecosystem Services

Incense cedar is an important commercial softwood species used for products including lumber, fence posts, railroad ties, venetian blinds, greenhouse benches, siding, decking, cedar chests, and shingles. It is the major source of pencil stock in the United States. It is also widely grown as an ornamental tree. In California, incense cedar is commonly used for erosion control along road cuts and streams.

Indigenous peoples of California and Oregon constructed conical-



Specimens of *Calocedrus decurrens*. Photo by John Ruter, University of Georgia, Bugwood.org, 1581778.



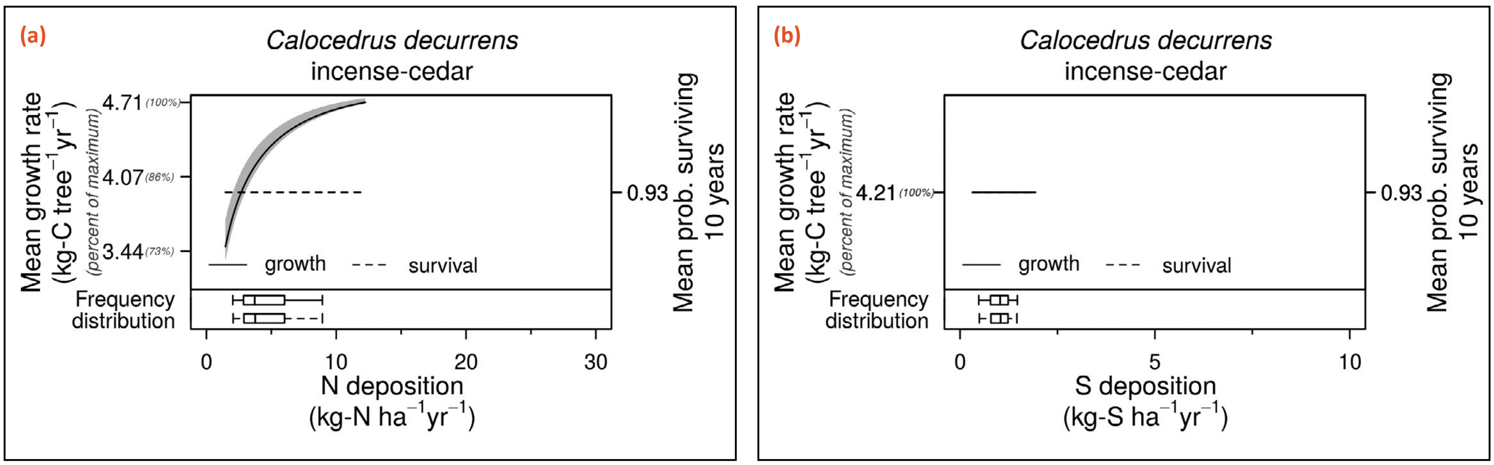
Bark of *Calocedrus decurrens*. Photo by Donald Owen, California Department of Forestry and Fire Protection, Bugwood.org, 5454010.

shaped houses from the bark to serve as temporary shelters during acorn gathering in fall. In some areas, incense-cedar slabs went into the construction of more permanent houses. People of the Mendocino area used the leaves in the process of leaching acorn meal and in a decoction for relieving upset stomach. Small limbs were used for bows.

Foliage of a *Calocedrus decurrens cultivar.* Photo by John Ruter, University of Georgia, Bugwood.org, 1581851.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

Incense cedar growth increases with increasing N deposition but has no relationship to S deposition. Survival has no relationship to either N or S deposition. Confidence in these relationships is low based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' ranges, so inferring causality to either stressor can be difficult. See also Appendix Table 4 and the Introduction for more information.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	High	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
	X	X	X	X	X	

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
X			X			X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

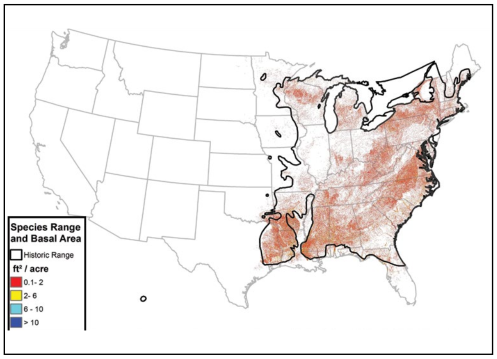
Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

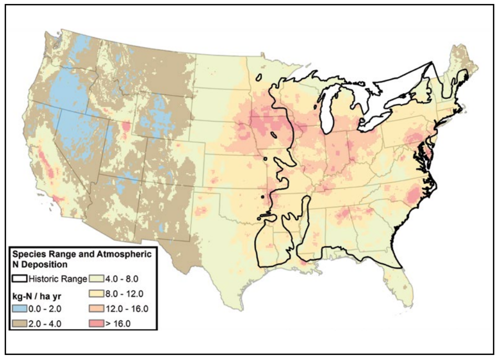
Tollefson, Jennifer E. 2008. *Calocedrus decurrens*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. Available: http://www.fs.fed.us/database/feis/plants/tree/caldec/all.html. (22 March 2016).

Carpinus caroliniana (American hornbeam or musclewood)

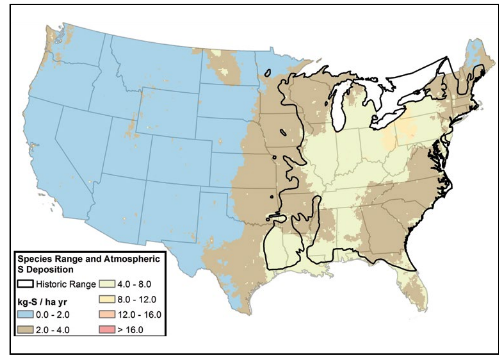
(a)



(b)



(c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

American hornbeam, also known as musclewood, is a native, deciduous small tree. It is usually described as slow-growing and short-lived. It typically grows 30 to 40 feet (9–12 m) tall. The bark is thin, close, and commonly smooth. The trunk is often crooked, and is usually coarsely fluted, resembling a flexed muscle. The fruit is a ribbed nutlet 0.16 to 0.24 inch (4–6 mm) long. The minimum seed-bearing age of American hornbeam is 15 years, and large seed crops are produced at 3- to 5-year intervals. Seeds are mainly dispersed by birds, and are windblown only a short distance. American hornbeam exhibits its best growth on rich, moist soils in bottomlands, coves, and lower protected slopes. American hornbeam is primarily found on poorly to imperfectly drained sites, although it grows on well-drained sites also. American hornbeam is tolerant of shade. It persists in the understory of late seral and climax communities. Shade tolerance is greatest in American hornbeam seedlings and declines with age, and it responds aggressively to overstory removal.

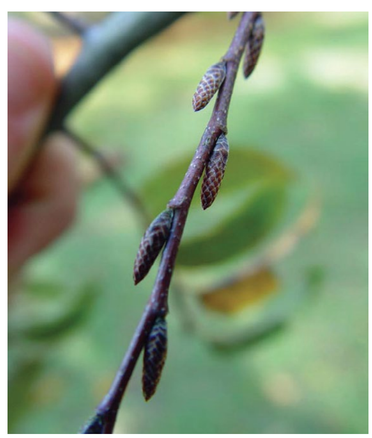
Wildlife Uses

American hornbeam is of secondary importance to wildlife. Ruffed grouse, ring-necked pheasant, and northern bobwhite eat small quantities of the seeds, buds, and catkins. Seeds are consumed by yellow-rumped warbler. The seeds are also consumed by ducks, but usually only when acorn production is limited. Seeds, bark, and wood are eaten by rabbits, beaver, turkey, fox squirrel, and eastern gray squirrel. White-tailed deer browse the twigs and foliage.

Ecosystem Services

American hornbeam wood is very hard, heavy, and close-grained. It is very difficult to work and is used only for tool handles, mallets, and golf club heads. Generally, American hornbeam is regarded as a weed tree. American hornbeam nuts are edible but small and therefore are seldom collected for food. The leaves of American hornbeam have been used as an astringent.

Traditional medicinal uses include treatment for diarrhea, dermatological issues, and cloudy urine. The Chippewa used the tree as the main supporting post for the wigwam or tent.



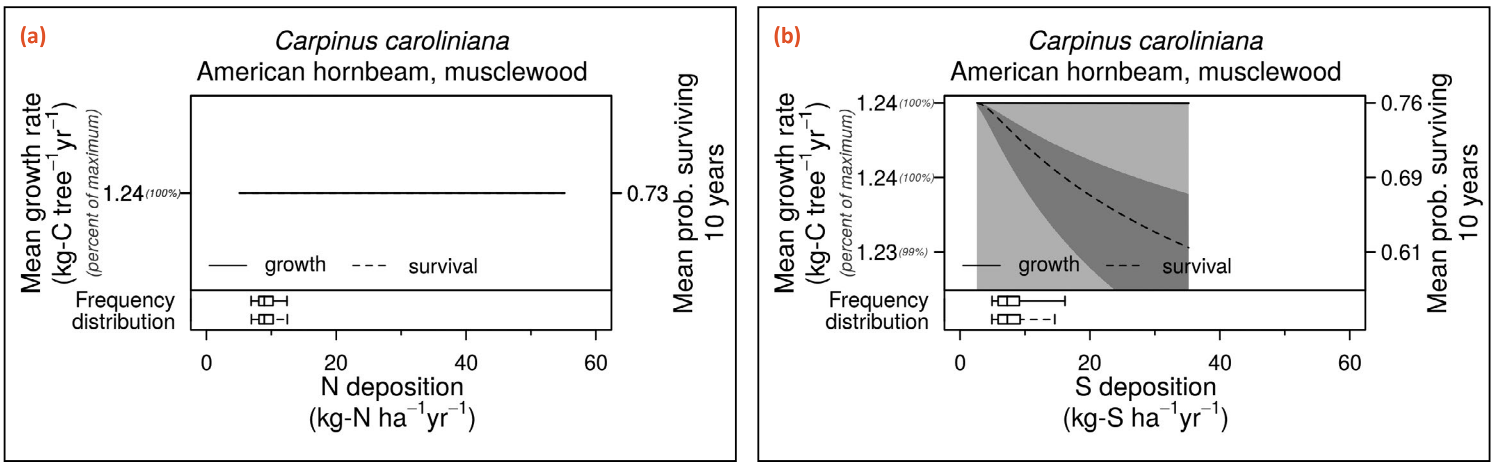
Shoots and buds of *Carpinus caroliniana*. Photo by Chris Evans, University of Illinois, Bugwood.org, 1346009.

Bark of *Carpinus caroliniana*. Photo by Bill Cook, Michigan State University, Bugwood.org, 1219084.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

Growth of American hornbeam has no relationship to N or S deposition. Survival has no relationship to N deposition but decreases with increasing S deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Foliage of *Carpinus caroliniana.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008302.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	**Shade Tolerance**	**Leaf Type**	**Mammal Uses**	**Bird Uses**
	High	Broadleaf Deciduous	Yes	Yes

Wood products				**Traditional uses**	**Ornamental uses**	**Fuelwood**
Paper	**Unfinished wood products**	**Building material**	**Finished wood products**			
	X		X	X		

Protection			**Rehabilitation**	**Food products**	**Oils and other**	**General services**
Erosion	**Wind**	**Erosion and wind**				
				X	X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

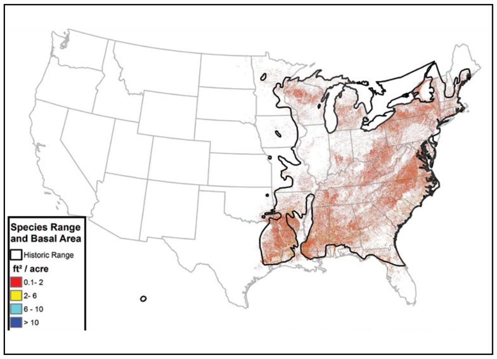
Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

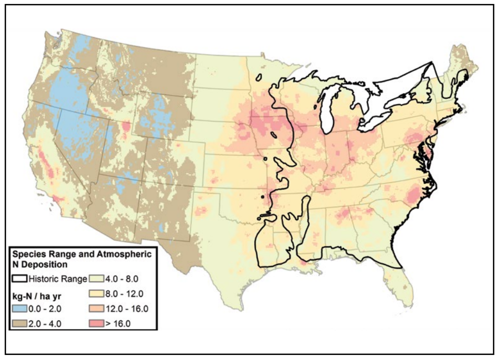
Sullivan, Janet. 1994. *Carpinus caroliniana*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/. (2017, May 15).

Carya alba (mockernut hickory)

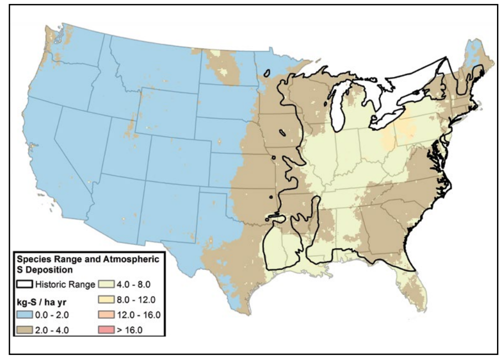
(a)



(b)



(c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Mockernut hickory is a medium-to-large native, deciduous tree, typically reaching a height of 65 to 100 feet (20–30 m). When grown in association with other trees, mockernut hickory develops a long, slender, straight trunk which is free of branchlets for about half the height of the tree. The crown is open, narrow, and rounded at the top. The trunk is often swollen at the base. Mockernut hickory has one of the heaviest seeds of the hickory genus; gravity, squirrels, and birds do most of the seed dissemination. The tree also sprouts prolifically from the stump after cutting or fire. In the North, mockernut hickory grows on rocky hills and slopes and less frequently on alluvial bottomlands. Further south, it grows on dry sites, typically south and west slopes or dry ridges. Mockernut hickory is classified as intolerant of shade, but at certain times during its life, may be variously classified as tolerant to intolerant. The low insulating capacity of the bark makes it extremely sensitive to fire; however, the tree recovers rapidly from disturbances and is probably a climax species on moist sites.

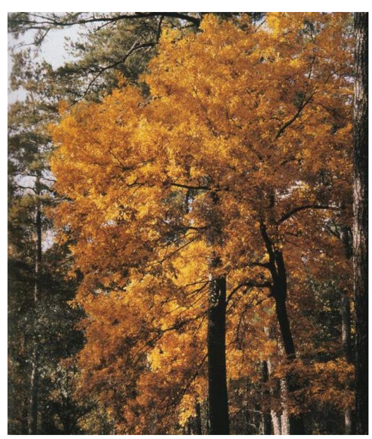
Wildlife Uses

Mockernuts are preferred mast for wildlife, especially squirrels. Black bears, foxes, beavers, and white-footed mice feed on the nuts, and sometimes the bark. White-tailed deer browse the foliage, twigs, and nuts. Mockernuts are also a minor source of food for ducks, quail, and turkey. The tree provides cavity-nesting sites for a variety of birds.

Ecosystem Services

Products produced from the wood include tool handles, agricultural implements, dowels, gymnasium equipment, poles, and furniture. It is also used for lumber, pulpwood, charcoal, and fuelwood. The sawdust and chips are often used commercially to smoke meats. Mockernut hickory kernels are edible, but small. The deep lateral roots make it a valuable species for watershed protection.

Eastern indigenous peoples used parts of the mockernut hickory to make analgesics (pain relievers). The nuts were also a food source.



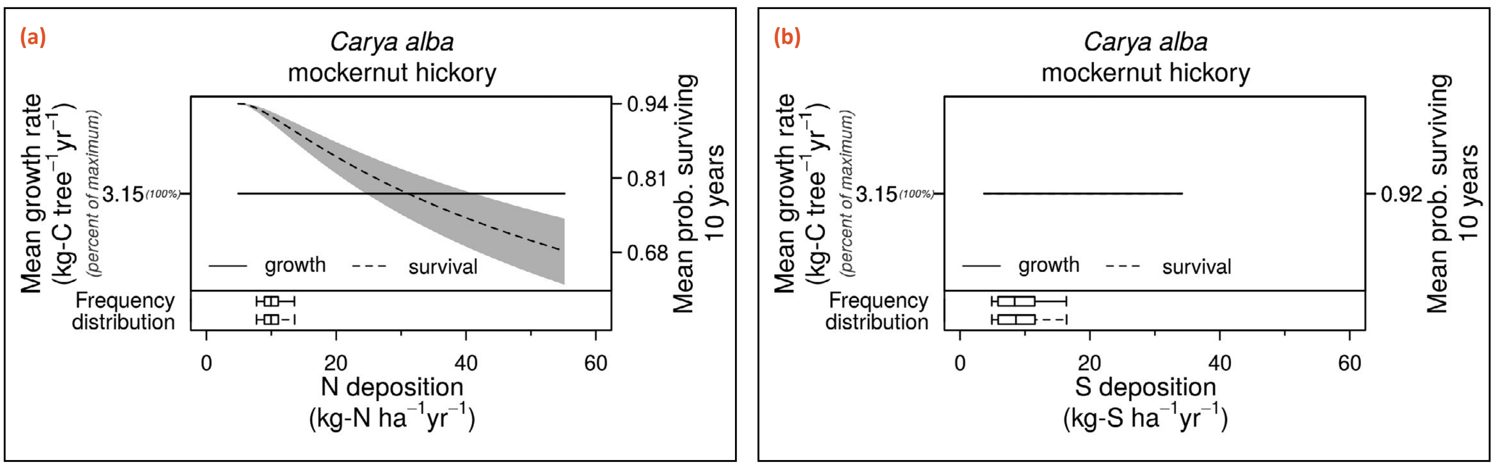
Specimens of *Carya alba*. Photo by John Ruter, University of Georgia, Bugwood.org, 1582102.

Bark of *Carya alba.* Photo by Chris Evans, University of Illinois, Bugwood.org, 1380219.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of mockernut hickory has no relationship to N or S deposition. The survival of mockernut hickory mostly decreases with increasing N deposition and has no relationship to S deposition. Confidence in these relationships is high and is based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Leaves and nuts of *Carya alba*. Photo by Vern Wilkins, Indiana University, Bugwood.org, 5481007.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Low	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X	X			X
Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
X				X		X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

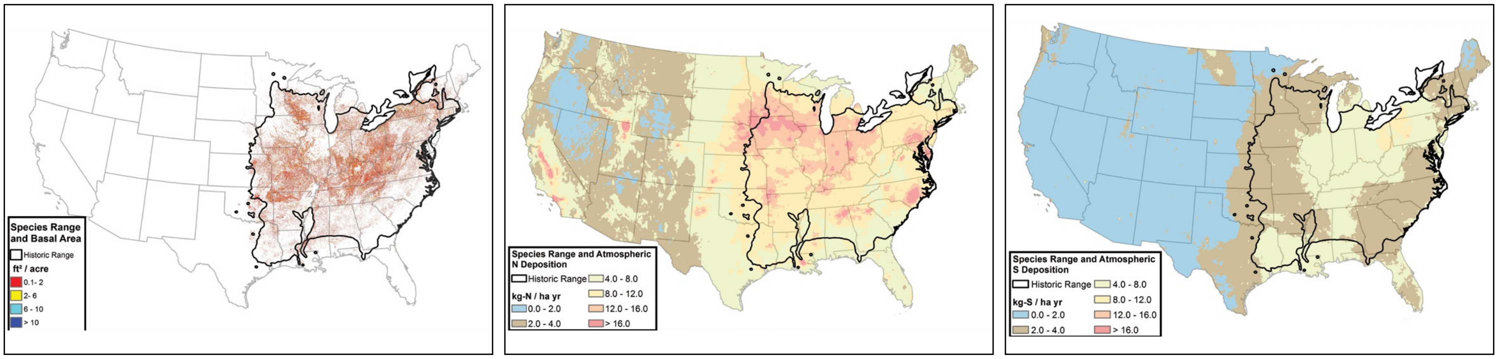
Primary Sources

Illinois State Musem. http://www.museum.state.il.us/muslink/forest/htmls/trees/C-tomentosa.html

Coladonato, Milo. 1992. *Carya tomentosa*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (22 March 2016).

Carya cordiformis (bitternut hickory)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Bitternut hickory is a medium-to-large native, deciduous tree, typically reaching a height of 60 to 80 feet (18–24 m). Under a forest canopy, it develops a long, branch-free trunk with little taper, and a short rounded crown of slender ascending branches that broaden the crown toward the top. The leaves are long and slender. Similar to other hickory species, bitternut hickory trees produce small pear-shaped nuts. The tree is the most prolific root and stump-sprouter of the northern species of hickories, with sprouts arising from stumps, root crowns, and roots. In the northern parts of its range, it occurs on a variety of sites, on rich, loamy or gravelly soil, low wet woods, and along borders of streams, but also on dry uplands. In the South, bitternut is more restricted to moist sites than in the North. The species is generally classified as intolerant of shade but seedlings appear to be more tolerant on overflow bottomlands than most of its associates. Top dieback and resprouting may occur frequently, with each successive shoot attaining a larger size and developing a stronger root system than its predecessor. By this process, hickory reproduction gradually accumulates and develops under moderate canopies, especially on sites dry enough to restrict reproduction of more shade-tolerant, but more fire- or drought-sensitive species. Bitternut hickory saplings are easily damaged by fire; older trees are also susceptible to fire damage because of the low insulating capacity of the bark.

Wildlife Uses

The foliage of bitternut hickory has a high calcium content, and livestock and deer browse it occasionally, but the fruit is generally considered unpalatable to wildlife. Rabbits, beavers, and small rodents will occasionally feed on the bark. The tree provides nesting sites for a variety of cavity-nesting birds.

Ecosystem Services

The hardwood of bitternut hickory is used for tools, furniture, paneling, dowels, and ladders. It is also desirable for fuelwood and charcoal—smoke from the wood of bitternut hickory gives hams and bacon a “hickory smoked” flavor.

The Iroquois, Meskwaki, and others used bitternut hickory nuts for food, the bark to create an infusion that acted as a laxative, and the nut oil to clean hair and repel mosquitoes.

The deep lateral roots of bitternut hickory make it valuable for watershed protection. The species has been grown successfully on zinc mine waste sites.

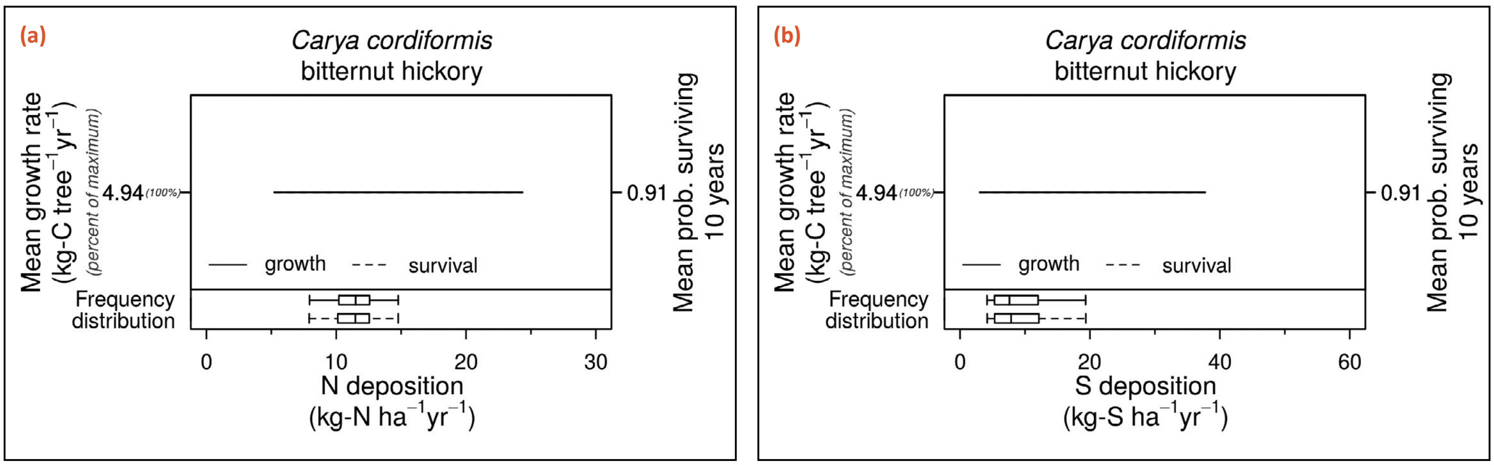
Specimen of *Carya cordiformis.* Photo by T. Davis Sydnor, The Ohio State University, Bugwood.org, 5497704.

Bark of *Carya cordiformis.* Photo by Vern Wilkins, Indiana University, Bugwood.org, 5473023.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth and survival of bitternut hickory has no relationship to N deposition or to S deposition. Confidence in this absence of relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Fruits of *Carya cordiformis.* Photo by Franklin Bonner (retired), USDA Forest Service, Bugwood.org, 5424002.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Low	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
		X	X	X		X

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
X			X	X		X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

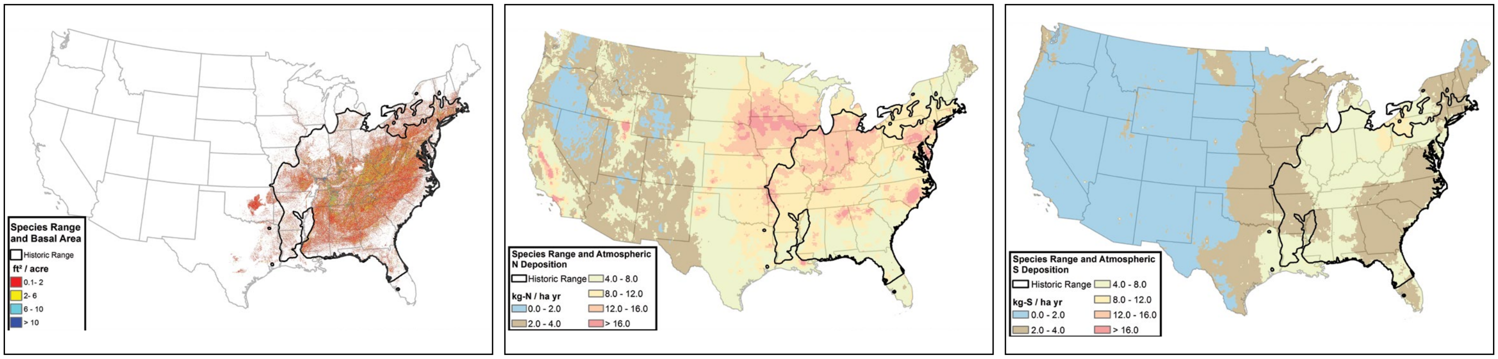
Primary Sources

Coladonato, Milo. 1992. *Carya cordiformis*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (22 March 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Carya glabra (pignut hickory)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Pignut hickory is a slow-growing deciduous tree which reaches 65 to 98 feet (20–30 m) in height and 11 to 39 inches (30–100 cm) in diameter. It has a narrow oblong crown and somewhat pendulous branches. The gray bark is shallowly ridged and furrowed. The fruit is a hard, pear-shaped nut. Pignut hickory sprouts from the root or stump after plants are cut or top-killed by fire. The tree grows in mesic to xeric mixed woodlands, bottomland woodlands, wet hammocks, on stable dunes, and rocky hillsides. It occurs in a humid climatic regime, and grows best on light, well-drained, loamy soils; it occurs on soils derived from a variety of metamorphic and sedimentary parent materials including limestone, granitic-basic and mica schist-phyllite, glacial till, and shale. In the Southeast, pignut hickory is tolerant of shade, but relatively intolerant in the northeastern portion of its range. Heavy-seeded species such as pignut hickory are generally slow to invade new areas. The tree grows as a common codominant in some climax communities. In the Northeast, however, reduced fire frequencies may have resulted in the conversion of oak-hickory forests to mixed mesophytic stands.

Wildlife Uses

White-tailed deer occasionally browse pignut hickory, and small mammals may eat the leaves. The nuts provide food for fox squirrels, grey squirrels, eastern chipmunks, black bear, gray fox, raccoon, red squirrel, pocket mouse, woodrat, and rabbits. Many song, non-game, and game birds—including the wood duck, ring-necked pheasant, northern bobwhite, wild turkey, common crow, blue jay, white-breasted nuthatch, red-bellied woodpecker, and yellow-bellied sapsucker—also eat the nuts. Pignut hickory presumably provides cover for a variety of birds and mammals. Many hickories are used as den trees by several species of squirrels.

Ecosystem Services

Early uses of the wood included broom handles, skis, wagon wheels, and early automobile parts. Currently, products include sporting goods, agricultural implements, tool handles, and specialty products such as shuttle blocks, mallets, and mauls. Nuts of pignut hickory are large and edible and in some areas are grown commercially, although they are of minor importance when compared to shagbark hickory nuts. Pignut hickory is used as a shade tree throughout much of its range.

The Omaha made snowshoes from the wood.

Pignut hickory has potential value for use on some types of disturbed sites because it has been observed to recolonize abandoned strip mines in Maryland and West Virginia.

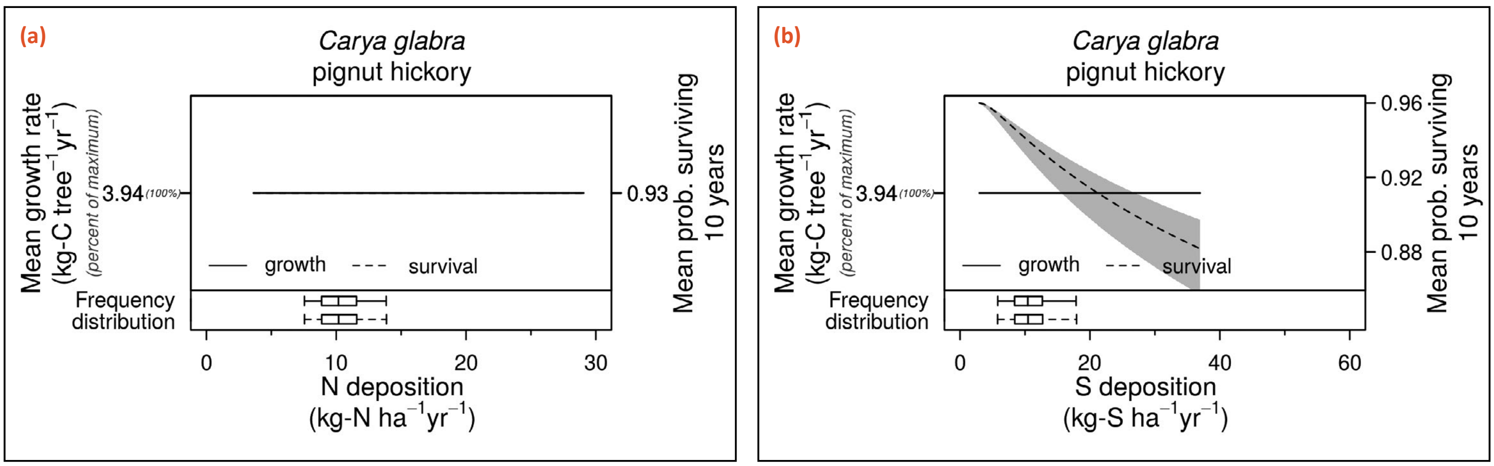
Specimen of *Carya glabra.* Photo by T. Davis Sydnor, The Ohio State University, Bugwood.org, 5497706.

Bark of *Carya glabra.* Photo by Vern Wilkins, Indiana University, Bugwood.org, 5449612.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of pignut hickory has no relationship to N or S deposition. Survival has no relationship to N deposition and decreases with increasing S deposition. Confidence in the absence of these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Foliage of *Carya glabra*. Photo by Chris Evans, University of Illinois, Bugwood.org, 2130046.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	**Shade Tolerance**	**Leaf Type**	**Mammal Uses**	**Bird Uses**
	Medium	Broadleaf Deciduous	Yes	Yes

Wood products				**Traditional uses**	**Ornamental uses**	**Fuelwood**
Paper	**Unfinished wood products**	**Building material**	**Finished wood products**			
			X	X		X

Protection			**Rehabilitation**	**Food products**	**Oils and other**	**General services**
Erosion	**Wind**	**Erosion and wind**				
			X	X		X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

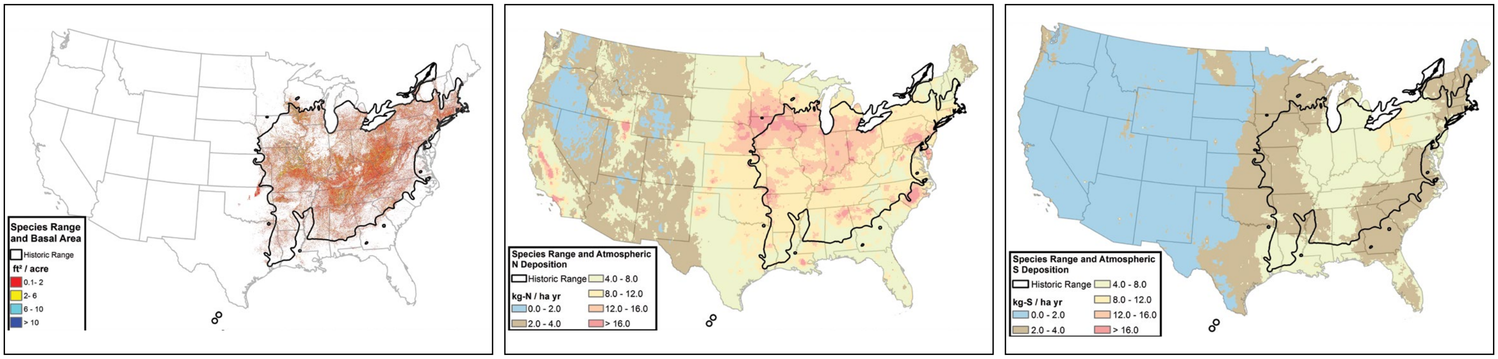
Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

Tirmenstein, D. A. 1991. *Carya glabra*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (22 March 2016).

Carya ovata (shagbark hickory)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Shagbark hickory is a medium to large deciduous tree which commonly grows to 60 or 80 feet (20–25 m) in height and up 20 inches (51 cm) in diameter. Open-grown plants are characterized by an oblong crown, whereas those growing in forested areas tend to have a straight, slender columnar crown. The shaggy gray bark exfoliates in long plate-like strips. Staminate flowers are borne on long-stalked catkins and bear fruit that is a nut. Shagbark hickory typically sprouts prolifically after plants are cut or damaged by fire. It is most commonly associated with upland slopes in the North, and with river bottoms and coves in the South, but it also grows on the lower slopes of wooded bluffs, in ravines, valleys, and at the edges of swamps. The tree reaches greatest abundance on deep, rich, moist soils, occurring on soils derived from a variety of sedimentary and metamorphic parent materials and grows across a wide range of soil fertility conditions. Shagbark hickory is slow-growing and intermediate in shade tolerance. Saplings can persist for many years beneath a forest canopy and respond rapidly when released. It grows as a climax species in most oak-hickory forests. Shagbark hickory generally occurs as scattered individuals or in small groups but rarely forms pure stands.

Wildlife Uses

Deer and livestock seldom browse shagbark hickory unless preferred foods are limited or unavailable. A wide variety of mammals—including black bear, fox squirrels, red fox, gray fox, white-footed mouse, eastern chipmunk, and rabbits—eagerly feed on the nuts. Many species of birds—including mallard, wood duck, northern bobwhite, wild turkey, ring-necked pheasant, common crow, blue jay, white-breasted nuthatch, red-bellied woodpecker, and yellow-bellied sapsucker—also feed on the nuts. The tree presumably provides cover for a variety of birds and mammals and is probably used as den trees by squirrels.

Ecosystem Services

The tough, heavy, hard, and resilient tree was formerly used to make wheels and spokes for wagons, carriages, carts, and early automobiles, and it goes into making furniture, flooring, tool handles, dowels, ladders, and sporting goods. Shagbark hickory makes excellent fuelwood and charcoal and imparts a hickory-smoked flavor to foods. The nuts are sweet and edible. A traditional staple food across some of its range, today it is the important hickory nut of commerce. At least one ornamental cultivar has been developed, but it has not been widely planted. Shagbark hickory is an important shade tree in some residential areas and is well suited for planting as a specimen tree in landscaping.

Foliage of *Carya ovata.* Photo by T. Davis Sydnor, The Ohio State University, Bugwood.org, 5497563.

Bark of *Carya ovata.* Photo by Keith Kanoti, Maine Forest Service, Bugwood.org, 5350008.

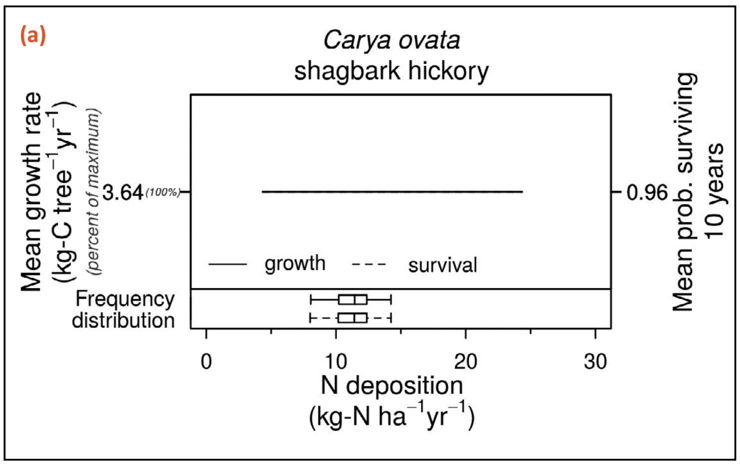
The Chippewa, Delaware, and others steamed and inhaled the shoots and leaves to alleviate headaches. They made soap from the nuts, extracted sugar from the sap, and made bows and arrows from the branches.

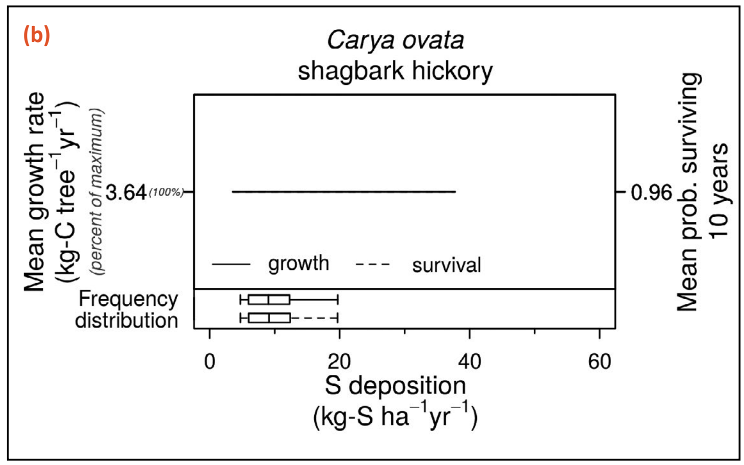
Shagbark hickory naturally recolonizes strip mines and lead pit mines with high levels of lead and zinc in the soil. Strains obtained from floodplain habitats are particularly well adapted to streambank plantings to prevent erosion.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth and survival of shagbark hickory has no relationship to either N or S deposition. Confidence in the absence of these relationships is high based on the correlation between atmospheric N and S deposition across the species range andthe variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Fruits (nuts) of *carya ovata.* Photo by Elmer Verhasselt, Bugwood.org, 5506995.





Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
			X	X	X	X
Protection			**Rehabilitation**	**Food products**	**Oils and other**	**General services**
Erosion	**Wind**	**Erosion and wind**				
X			X	X		X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

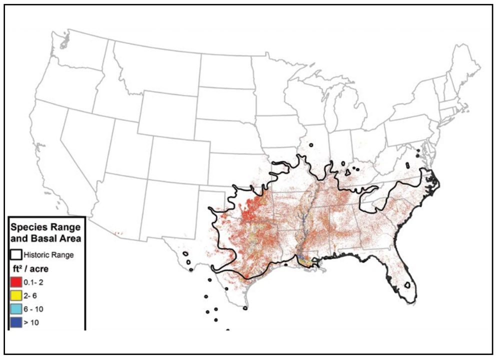
Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

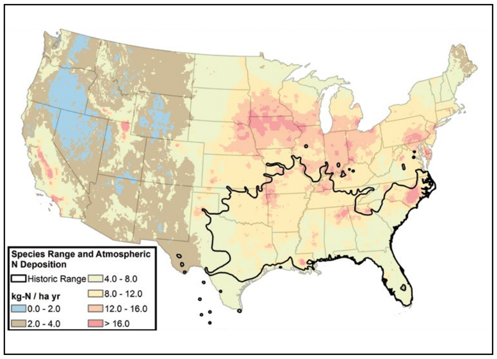
Tirmenstein, D. A. 1991. *Carya ovata*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (22 March 2016).

Celtis laevigata (sugarberry)

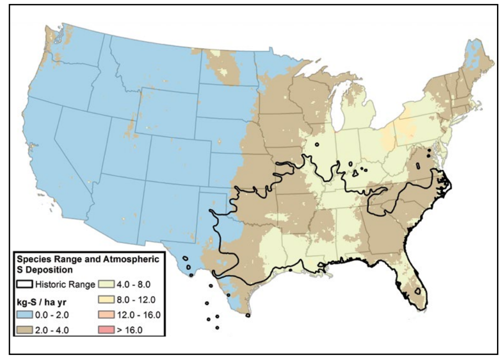
(a)



(b)



(c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Sugarberry is a native deciduous, moderately tall tree—60 to 100 feet (18–30 m). It has an intermediate life span, usually living not over 150 years. Mature trees are typically 18 inches (46 cm) in diameter, with the bole 30 feet (9 m) clear of branches in good stands. The crown is spreading and round-topped or oblong. The bark of young trees is gray and smooth; mature trees develop corky outgrowths that are scattered to dense with smooth areas in between. Sugarberry produces seeds in drupes; mammals, birds, and water disperse the seeds. The tree can also regenerate vegetatively through spouting on small stumps. It is found in moist alluvial woods and slough margins (but not deep swamps) up to 600 feet (180 m) elevation. It occurs on any soil type with fair drainage, from sandy loams and rocky or alluvial soils to heavy black clay. It cannot tolerate prolonged flooding or water-saturated soils. A shade-tolerant tree, seedlings can establish under most stands of southern bottomland hardwoods. It will respond when released, and can outgrow more desirable forest species. Sugarberry is a late successional species that needs high soil nitrogen and is capable of growing in shade, but it can grow in disturbed areas or grasslands at reduced rates depending on the presence of competition and soil nitrogen levels. Once the canopy is mature and other tolerant hardwoods are recruited, sugarberry numbers will decrease.

Wildlife Uses

Cattle browse sugarberry heavily, especially in winter on poor ranges. Although white-tailed deer will browse the tree, they prefer other plants. Many birds, including the ring-necked pheasant, waterfowl, quail, and ruffed grouse, eat the fruit, which is a preferred food of turkeys in fall and winter. Other game and nongame animals eat sugarberry fruit. Squirrels occasionally eat the fruit and, rarely, will also consume buds and bark.

Ecosystem Services

Sugarberry is used mostly for furniture but also is used for dimension stock, flooring, crating, fuel, cooperage, and fence posts. Sugarberry is planted as an ornamental and as a street tree. The berries can also be used as food for humans and dyes can be extracted from the leaves.

Indigenous peoples of southeastern North America used the bark to treat sore throats and venereal diseases, and ate the berries to alleviate indigestion.

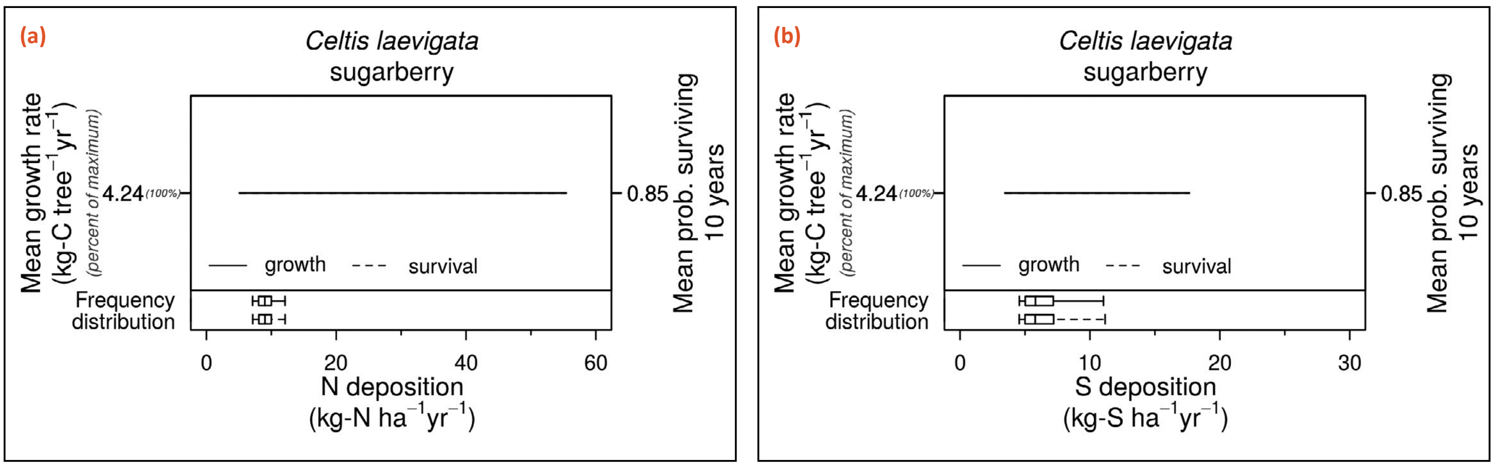
Foliage of *Celtis laevigata.* Photo by Chris Evans, University of Illinois, Bugwood.org, 5126003.

Bark of *Celtis laevigata.* Photo by John Ruter, University of Georgia, Bugwood.org, 1582280.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth and survival of sugarberry has no relationship to either N or S deposition. Confidence in the absence of these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Fruits of *Celtis laevigata.* Photo by Franklin Bonner (retired), USDA Forest Service, Bugwood.org, 5424007.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	High	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
	X		X	X	X	X

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
				X	X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

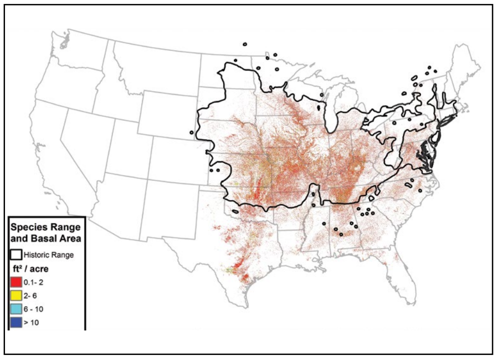
Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

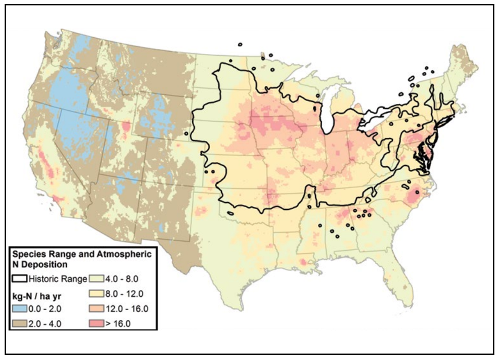
Sullivan, Janet. 1993. *Celtis laevigata*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (8 March 2016).

Celtis occidentalis (hackberry)

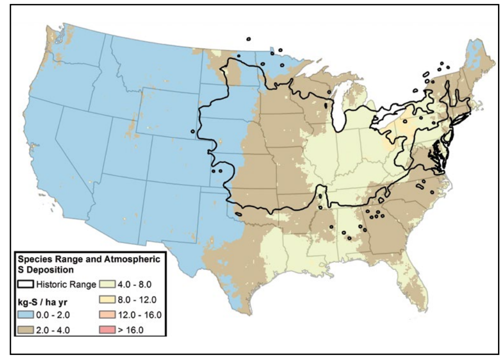
(a)



(b)



(c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Common hackberry typically grows as a broad tree measuring around 50 feet (15 m) tall and 20 inches (50 cm) in diameter. Trees usually live 150 to 200 years. The bark is thick, deeply furrowed, and develops warty cork projections with age. The tree is symmetrical and open branched, with larger branches 26 to 33 feet (8–10 m) above ground. Common hackberry produces solitary, single-seeded drupes, and the fruity flesh is sweet and edible but very thin. Gravity, as well as fruit-eating birds, mammals, and reptiles, disperse the seeds. The tree can also regenerate through sprouting. It tolerates a range of climatic and soil conditions—although most common along rivers and streams, it also occurs in open woodlands, rocky hillsides, limestone outcrops, and sand barrens throughout its North American range. Common hackberry occurs in early seral and climax communities and tolerates open as well as dense, closed-canopy conditions. It colonizes old fields as well as recently disturbed sites and persists and reproduces in old-growth forests. As a result, this tree occurs and reproduces in areas with canopy conditions ranging from full sun to nearly complete shade. An increased abundance of common hackberry is often reported when fires are excluded in prairies, oak savannas, and other deciduous woodlands.

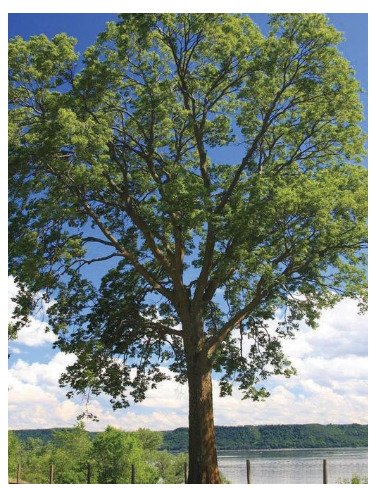
Wildlife Uses

Deer, rodents, rabbits, northern raccoons, cattle, eastern box turtles, woodchucks, and eastern fox squirrels commonly utilize common hackberry for food and cover. Cedar waxwings, eastern bluebirds, mockingbirds, American robins, bluebirds, yellow-bellied sapsuckers, northern flickers, wild turkeys, quail, and about 20 other bird species eat common hackberry seeds. Many birds prefer common hackberry snags for foraging, including northern flickers, yellow-bellied sapsuckers, other woodpeckers, white-breasted nuthatches, tufted titmice, and black-capped chickadees.

Ecosystem Services

The wood is commonly used for firewood or inexpensive furniture. Common hackberry is sometimes planted as an ornamental and is a popular bonsai species.

The Dakota ground common hackberry fruits and seeds into a powder to season meat, and the Pawnee made a meal out of fat, corn, and pounded common hackberry fruits. Traditionally, the bark was decocted to serve as a gynecological aid to induce regular menstrual cycles, an abortifacient, and to treat venereal diseases. Bark decoctions were also taken for sore throats.



Specimen of *Celtis occidentalis.* Photo by Steven Katovich, USDA Forest Service, Bugwood.org, 5443549.

Bark of *Celtis occidentalis*. Photo by Rob Routledge, Sault College, Bugwood.org, 5445648.

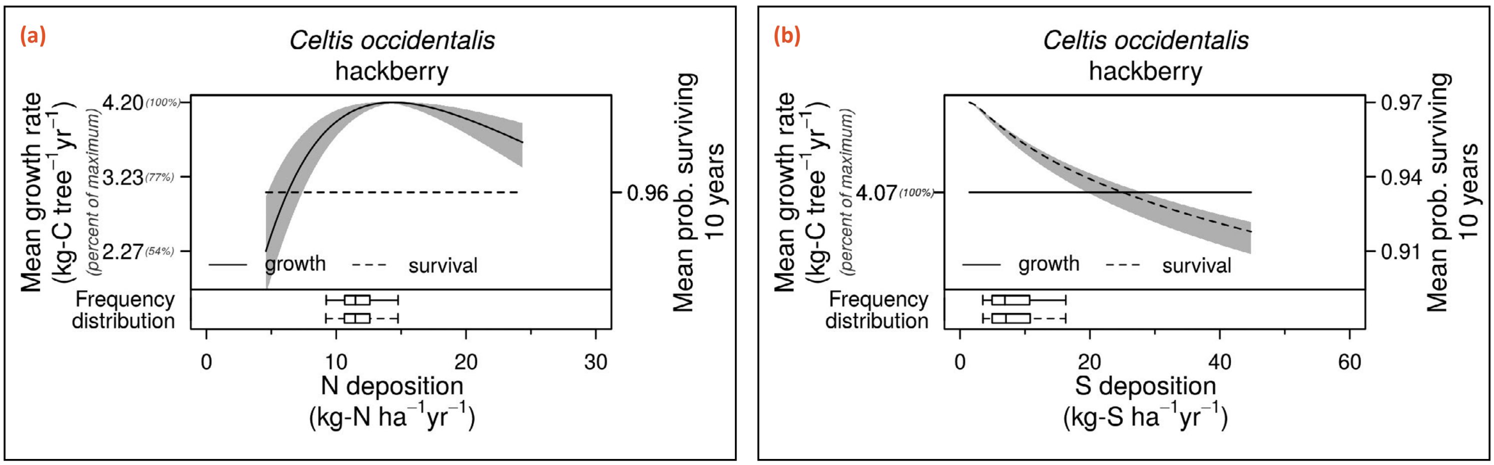
Common hackberry has been used successfully to rehabilitate mined sites.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of hackberry has a hump-shaped relationship with increasing N deposition and no relationship to sulfur deposition. Survival has no relationship to N deposition but decreases with increasing sulfur deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult.

See Appendix Table 4 and the Introduction for more information.

Foliage of *Celtis occidentalis.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008340.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	High	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
			X	X	X	X

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
			X		X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

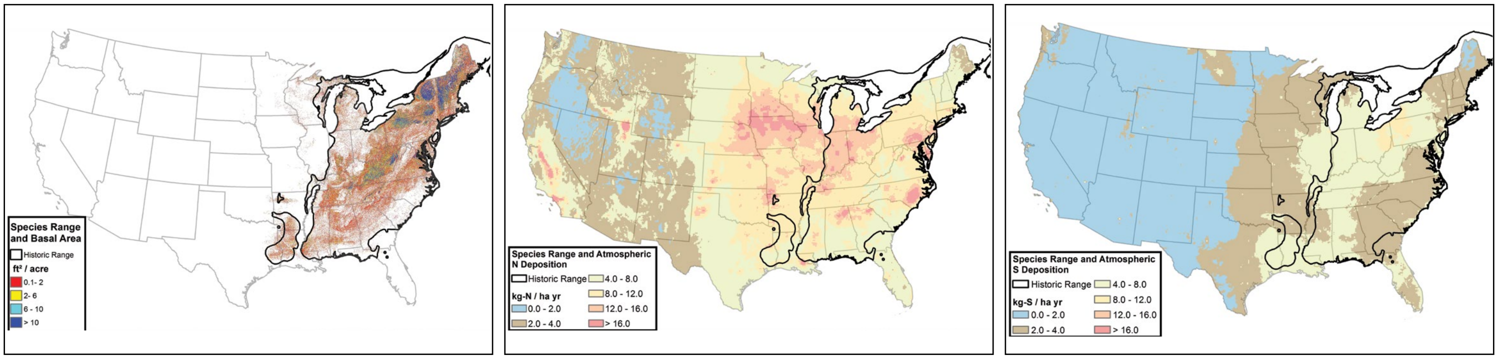
Primary Sources

Gucker, Corey L. 2011. *Celtis occidentalis*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (8 March 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Fagus grandifolia (American beech)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Beech is a large, native, deciduous tree. It normally grows 65 to 80 feet (20–25 m) tall and can live to over 300 years old. The bark is blue gray; the leaves are yellow green during the growing season. The branches are stout and horizontal, or ascending, with interlocking leaves forming a dense crown. The fruit is a bur, usually containing two nuts. Most seeds drop to the ground and rodents and blue jays do some seed dispersal. Beech can regenerate by root suckers or by stump sprouts; this is becoming more commonplace as beech bark disease kill overstory beech stems. The species is found at low elevations in the North and at relatively high elevations in the South. At altitudes in the middle of its range, beech is more abundant on the cooler, moister, northern slopes than on the southern slopes. It is seldom found on limestone soils and is only found on coarse, textured, dry to mesic soils in the northern part of its range. American beech is a climax species that grows slowly underneath an overstory of conifers or hardwoods. It grows faster in canopy openings and eventually ascends into the overstory, and maintains itself via root suckering. The thin bark of American beech makes this species highly vulnerable to injury by fire but root suckering is common postfire.

Wildlife Uses

A variety of birds and mammals—including mice, squirrels, chipmunks, black bear, deer, foxes, ruffed grouse, ducks, and blue jays—eat beech mast. American beech provides cover for the Carolina chickadee and the black-capped chickadee.

Ecosystem Services

Beech wood is used for flooring, furniture, veneer plywood, and railroad ties. Its high density and good burning qualities make it especially favored as fuel wood. Coal tar made from beech wood is used to protect wood from rotting. The creosote can treat various human and animal disorders. Beechnuts are roasted and eaten or used as a coffee substitute.

Besides utilizing nuts for food, indigenous peoples, including the Iroquois and Menominee, used beech leaves and bark to make dyes.

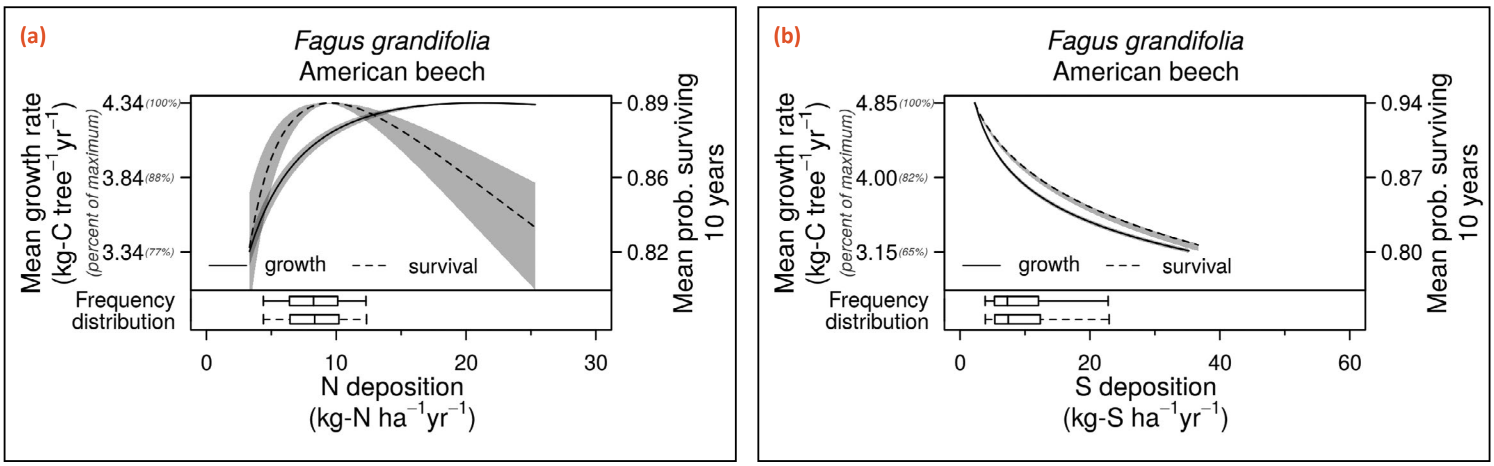
Fall foliage of *Fagus grandifolia.* Photo by T. Davis Sydnor, The Ohio State University, Bugwood.org, 5500267.

Trunk of *Fagus grandifolia.* Photo by Vern Wilkins, Indiana University, Bugwood.org, 5454083.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of American beech increases with increasing N deposition and decreases with increasing S deposition. Survival has a hump-shaped relationship to N deposition and decreases with increasing S deposition. Confidence in these relationships is low based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Buds of *Fagus grandifolia*. Photo by Rob Routledge, Sault College, Bugwood.org, 5472120.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	High	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
	X	X	X	X		X

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
				X	X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

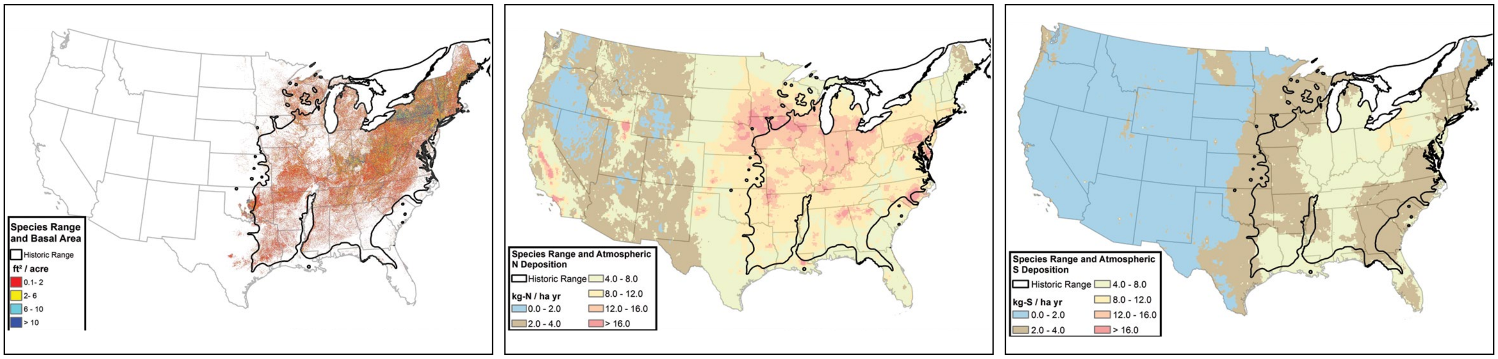
Primary Sources

Coladonato, Milo. 1991. *Fagus grandifolia*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (8 March 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Fraxinus americana (white ash)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

White ash is a native, deciduous, long-lived tree which grows to heights of 60 to 70 feet (18–21 m) and diameters of 24 to 48 inches (61–122 cm). The bole is long, straight, and free of branches for most of its length, and the crown is narrow and pyramidal when grown in a mixed stand. Open-grown specimens have a short bole with a rounded crown. Flowers bear winged fruit. In addition to sexual reproduction, white ash resprouts from the root crown after logging or fire. It grows best on deep, well-drained, moist soils with other hardwoods. In the Northeast, the species occurs on middle mesophytic slopes, and it is reduced or lacking on dry, cold ridges and mountaintops. Elsewhere, it occurs on elevated ridges or slopes above floodplains. It has a strong affinity for soils high in nitrogen and calcium. White ash is a pioneer species and, thus, is characteristic of early and intermediate stages of succession. Although mature white ash is classified as shade-intolerant, the seedlings are shade-tolerant—a seedling can survive at less than 3 percent of full sunlight for a few years. This attribute allows the species to quickly regenerate once gaps are formed in the overlying canopy. White ash has been found to be sensitive to ozone, sulfur dioxide, and acid deposition.

Wildlife Uses

White ash provides an important source of browse and cover for livestock and wildlife. White-tailed deer and cattle browse it, mostly in the summer. The samaras offer good forage for the wood duck, northern bobwhite, purple finch, pine grosbeak, fox squirrel, and mice, and many other birds and small mammals. Beaver, porcupine, and rabbits occasionally use the bark of young trees for food. White ash is highly valuable for primary cavity-nesters such as red-headed, red-bellied, and pileated woodpeckers. Once the primary nest excavators have opened up the bole of the tree, it offers excellent habitat for secondary nesters such as wood ducks, owls, nuthatches, and gray squirrels. The tree also provides hiding and thermal cover for a variety of mammals and birds.

Ecosystem Services

White ash wood is second only to hickory (*Carya* spp.) for use in the production of tool handles. Nearly all wooden baseball bats are made from white ash. The wood is also used in furniture, antique vehicle parts, railroad cars and ties, canoe paddles, snowshoes, boats, doors, and cabinets. The juice from the leaves can be applied topically to mosquito bites to relieve swelling and itching. The tree also has a specialized use as a prophylactic measure for snake bite. Open-grown white ash is useful as a shade and ornamental tree.

Specimen of *Fraxinus americana*. Photo by T. Davis Sydnor, The Ohio State University, Bugwood.org, 5500305.

Bark of *Fraxinus americana.* Photo by Keith Kanoti, Maine Forest Service, Bugwood.org, 5350049.

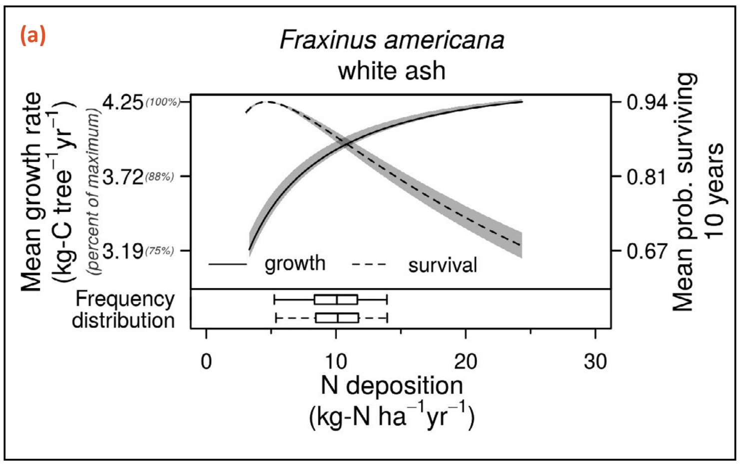
The Iroquois, Delaware, and others traditionally applied white ash compounds to treat sore necks, inserted branch sap to treat earaches, and topically applied a bark-infused poultice to treat syphilitic lumps.

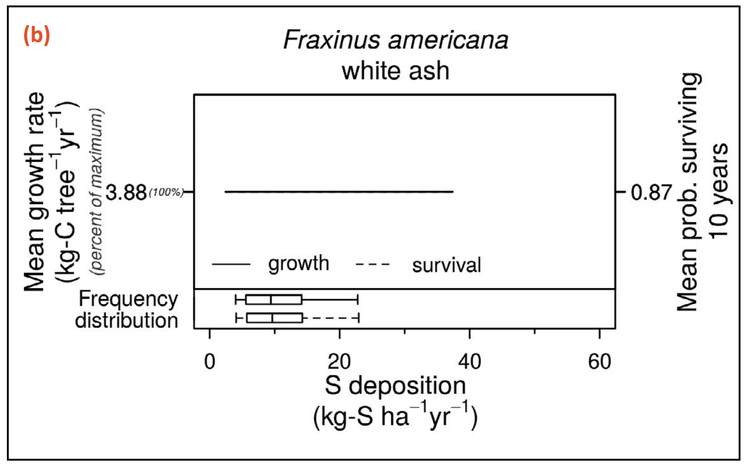
White ash has been used in the reclamation of surface coal mines and acid spoils.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of white ash increases with increasing N deposition and has no relationship to S deposition. Survival mostly decreases with increasing N deposition and has no relationship to S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Seeds of *Fraxinus americana.* Photo by Keith Kanoti, Maine Forest Service, Bugwood.org, 5349064.





Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	**Shade Tolerance**	**Leaf Type**	**Mammal Uses**	**Bird Uses**
	Medium	Broadleaf Deciduous	Yes	Yes

Wood products				**Traditional uses**	**Ornamental uses**	**Fuelwood**
Paper	**Unfinished wood products**	**Building material**	**Finished wood products**			
	X		X	X	X	
Protection			**Rehabilitation**	**Food products**	**Oils and other**	**General services**
Erosion	**Wind**	**Erosion and wind**				
			X		X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

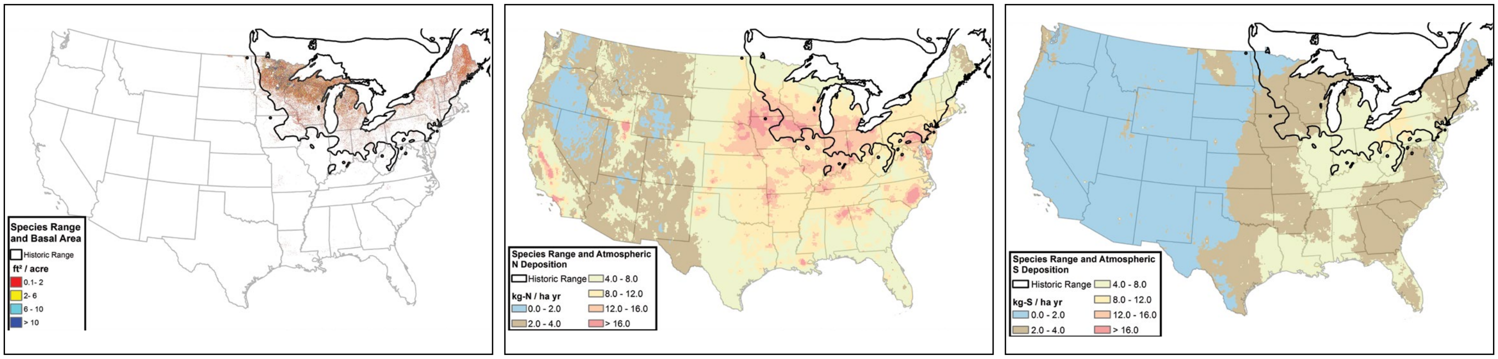
Primary Sources

Griffith, Randy Scott. 1991. *Fraxinus americana*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (8 March 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Fraxinus nigra (black ash)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Black ash—sometimes called “the slenderest broadleaf tree in the forest”—is a native tree, normally small, growing to just 40 to 60 feet (12–18 m). The tree is long-lived with a relatively rapid growth rate. Branches do not appear until high up on the trunk; tall trees may be without branches for up to 50 feet (15 m). The narrow trunk is rarely more than 2 feet (0.6 m) in diameter and is often leaning or bent. Black ash bark is soft with shallow grooves that give a scaly or flaky appearance. It can produce perfect or separate male and female flowers and is wind pollinated. The fruit has a spicy odor and often contains one seed that is wind dispersed. Black ash sprouts vigorously following fire, browsing, or cutting. The tree occupies poorly drained swamps, bogs, woodlands, gullies, depressions, lowlands, foothills, valley flats, and stream and lake shores throughout its range. It tends to grow on moist to wet, deep, fertile, mineral or organic soils. The species tolerates excessive moisture and is moderately tolerant of shade. It typically increases following canopy gap formation and is a mid-successional species, replacing flood-tolerant pioneers such as cottonwoods and willows, but later being replaced by beech, basswood, and white oak.

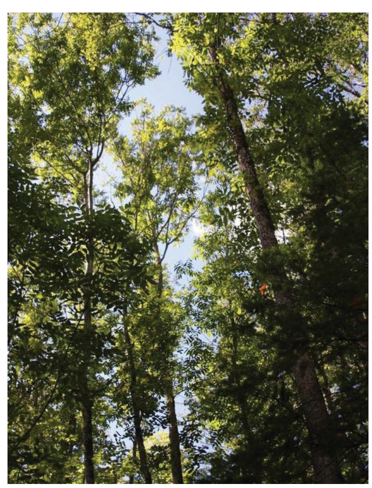
Wildlife Uses

Black ash is recognized as an important seed source for game birds, songbirds, and small animals. White-tailed deer and moose browse the tree, which can withstand heavy browsing, an important factor as ungulate populations increase. American beavers, rabbits, snowshoe hares, and other small mammals occasionally feed on the bark and stems. Black ash-associated woodlands also provide cover and habitat for various small mammals, ungulates, amphibians, and birds, and these habitats are important ruffed grouse roosting and brooding areas.

Ecosystem Services

The wood, which is not particularly strong, is used mainly for indoor furnishings, especially cabinets, veneer, paneling, short tool handles, baskets, and indoor furniture. Treated black ash wood is used for posts. Several black ash hybrids and cultivars are used in ornamental landscapes.

The Passamaquoddy, Penobscot, Maliseet, Micmac, and Mohawk use black ash in basket making. The wood splits easily into slats, making it ideal for this purpose. Black ash basketry is common in Maine, New Brunswick, Nova Scotia, and New York. Traditionally, the tree was also used for a variety of medicinal purposes.



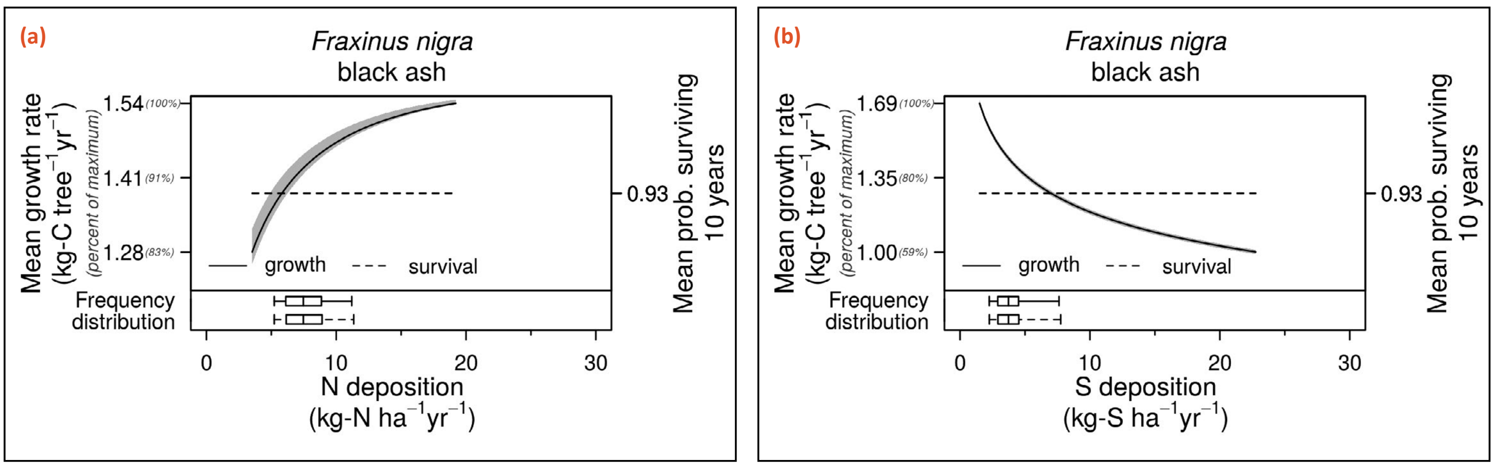
Specimens of *Fraxinus nigra*. Photo by Steven Katovich, USDA Forest Service, Bugwood.org, 5505591.

Bark of *Fraxinus nigra.* Photo by Keith Kanoti, Maine Forest Service, Bugwood.org, 5349074.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of black ash increases with increasing N deposition and decreases with increasing S deposition. Survival has no relationship to either N or S deposition. Confidence in these relationships is medium low based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Flowers of *Fraxinus nigra.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008055.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
	X	X	X	X	X	

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
					X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

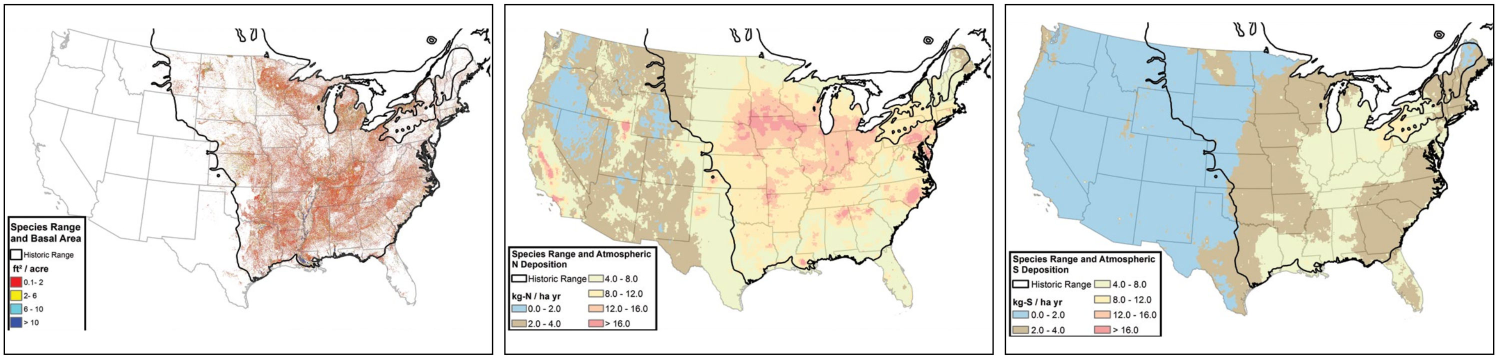
Primary Sources

Gucker, Corey L. 2005. *Fraxinus nigra*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (8 March 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Fraxinus pennsylvanica (green ash)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Green ash is a deciduous tree with high branches and a slender growth form. It grows to 100 feet (40 m) in the southern part of its range but is typically half that height in the northern portion of its range. The trunk is large and straight. Flowers appear before the leaves and are borne on old wood. Wind—primarily—along with water and animal caching disperse the seeds. Green ash is most often found in association with riparian areas, floodplains, and swamps, but also in areas that periodically experience drought conditions. Commonly it grows in fertile, clay, silt, and/or loam soils that range from poorly to well drained. The tree is moderately shade-tolerant, but that tolerance decreases with increasing age. Green ash easily colonizes disturbed sites when a seed source is available and responds readily to release. The trees sprout from the root crown following top-kill, but the trees may survive low-severity fires. All of these characteristics allow green ash to be described as a pioneering, early successional, mid-successional, subclimax, climax, and old-growth species. However, the emergence of the emerald ash borer has compromised green ash in many areas of its range.

Wildlife Uses

Green ash trees and habitats provide food for game and nongame birds, American beavers, other small mammals, deer, bison, livestock, insects, and aquatic species. Livestock browse the stems. The green ash/chokecherry habitat type provides fair cover for elk, mule deer, game and non-game birds, small mammals, white-tailed deer, and waterfowl, as well as wood ducks, grouse, northern bobwhites, screech owls, and wild turkeys. Blackbirds prefer green ash for roosting sites. Bison and deer use the trees for rubbing and horning. Ash trees are hosts for tiger swallowtails, ash and waved sphinxes, and polyphemus moths.

Ecosystem Services

The wood is used for tool handles, furniture, and interior furnishings. Green ash's salt and pollution tolerance make it a valuable choice in urban landscapes. The tree is used extensively in shelterbelts or other protective plantings.

Plains Indians have traditionally constructed bows, arrows, drums, tent poles, teepee pegs, and meat-drying racks from green ash. Green ash is associated with beneficial natural powers and is used by the Omaha and Pawnee to carry and/or display ceremonial or symbolic objects, by the Cheyenne in Sun Dance Lodge construction, and by Cheyenne warriors in whistles worn around the neck.

Specimen of *Fraxinus pennsylvanica.* Photo by T. Davis Sydnor, The Ohio State University, Bugwood.org, 5500343.

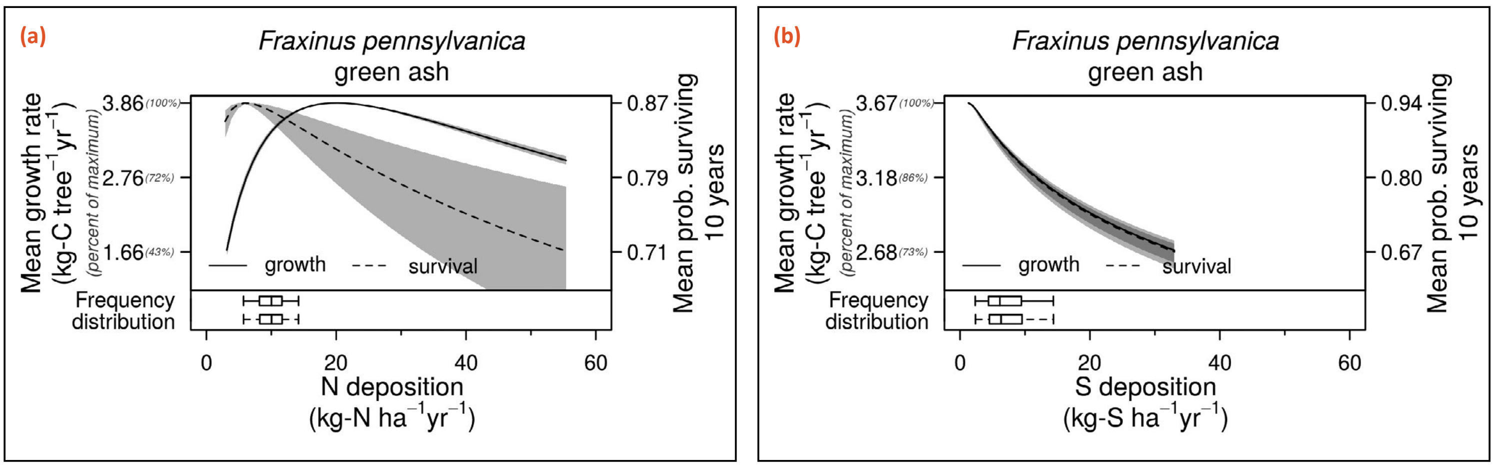
Bark of *Fraxinus pennsylvanica*. Photo by Karan A. Rawlins, University of Georgia, Bugwood.org, 5470341.

Green ash is widely used in revegetation, reclamation, and protection plantings on abandoned agricultural lands and abandoned mine sites.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of green ash has a hump-shaped relationship with increasing N deposition and decreases with increasing S deposition. Survival mostly decreases with increasing N deposition and decreases with increasing S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Foliage of *Fraxinus pennsylvanica.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008289.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
	X		X	X	X	

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
	X		X			X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

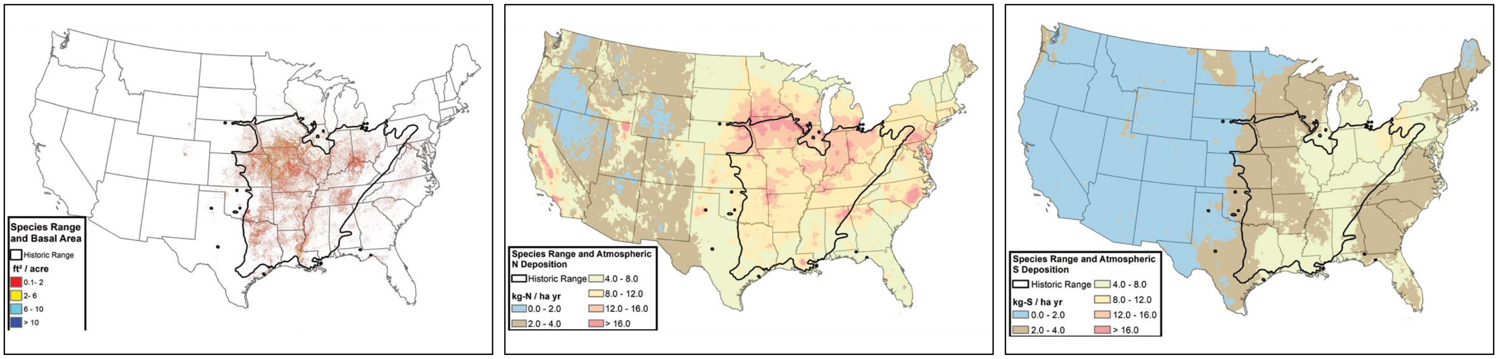
Primary Sources

Gucker, Corey L. 2005. *Fraxinus pennsylvanica*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (4 March 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Gleditsia triacanthos (honey-locust)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Honey-locust is a native, deciduous tree. It is usually described as rapid-growing. Average longevity for honey-locust is 125 years. Mature heights usually range from 49 to 98 feet (15-30 m). Honey-locust is armed with heavy branched thorns on the lower branches and trunk. The crown is plumelike and open. The bole is usually short and often divided near the ground. The bark peels in strips. The fruit is a legume, but the plant does not form *Rhizobium* nodules on its roots, and does not fix nitrogen. Honey-locust seed is viable for long periods due to an impermeable seedcoat. Seeds are dispersed by birds and mammals, including cattle. Honey-locust is adapted to a variety of soils and climates. It is common in both bottomlands and uplands, in the open or in open woods. Honey-locust occurs on well-drained sites, upland woodlands and borders, old fields, fencerows, river floodplains, hammocks, rich, moist bottomlands, and rocky hillsides. It is most commonly found on moist, fertile soils near streams and lakes. It has been rated highly tolerant to flooding. It is also drought-resistant. Honey-locust is intolerant of shade. Reproduction establishes only in open areas, gaps, and at the edges of woods. The ability of honey-locust to invade open prairie is thought to be related to its tolerance of xeric conditions. Honey-locust is also described as a mid-successional species and is found in gaps or on the edges of old-growth forests. The distribution of honey-locust appears to be related to the serendipitous combination of openings (disturbance) and seed dispersal. Honey-locust, however, appears to be excluded from prairies by frequent fire.

Wildlife Uses

White-tailed deer frequently strip and eat the soft bark of young trees in winter; rabbits also consume honey-locust bark in winter. Livestock and white-tailed deer consume young vegetative growth. Honey-locust pods are eaten by cattle, goats, white-tailed deer, Virginia opossum, eastern gray squirrel, fox squirrel, rabbits, quail (including northern bobwhite), crows, and starling. Honey-locust is a source of pollen and nectar for honey.

Ecosystem Services

Honey-locust wood is used locally for posts, pallets, crates, general construction, furniture, interior finish, turnery, and firewood. Thornless honey-locust is widely planted as an ornamental, particularly on dry sites. Honey-locust is also widely used in windbreaks and shelterbelts. Honey-locust pods are being fermented for ethanol production in studies to explore the feasibility of biomass fuels. Honey-locust pods are edible and the nectar is valuable for honey production. It is also used in agroforestry operations, where farmers harvest and process honey locust pods for livestock feed while maintaining open pasture and receiving high quality nectar for honey production. Honey-locust pioneers on strip-mine spoil banks in the Midwest. It is also often planted for erosion control.

Specimen of *Gleditsia triacantho.* Photo Richard Webb, Bugwood.org, 1480198.

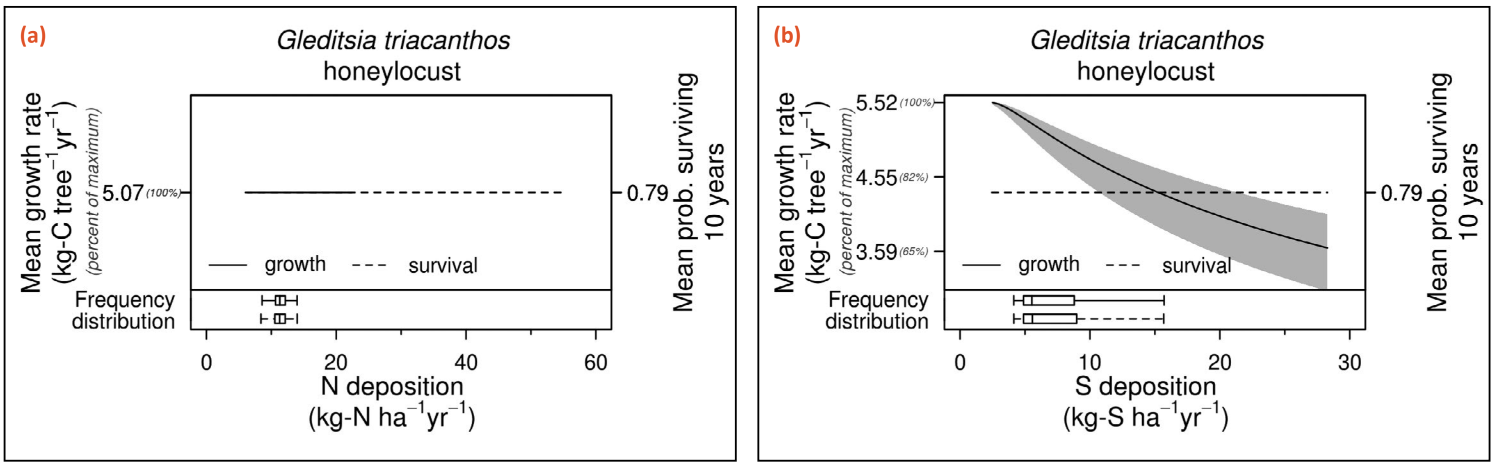
Fruit of *Gleditsia triacanthos.* Photo by Chris Evans, University of Illinois, Bugwood.org, 2126081.

Indigenous peoples in the southeastern US used the bark of honey-locust to make tonic and medicines for the treatment of blood, and gastrointestinal ailments, coughs, and colds. The seed pulp was also used to make a sugary beverage and the raw pods were used as food.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth and survival of honey-locust had no relationship to atmospheric N deposition. The growth of honey-locust decreased with increasing S deposition, while survival had no relationship to S deposition. N and S deposition are correlated for many species, and uncorrelated for others, so inferring causality to one or the other stressor can be difficult. Confidence in these relationships is low after evaluating the correlation between atmospheric N and S deposition across the species range and the variance inflation factor. See Appendix Table 1 and the Introduction for more information.

Flowers of *Gleditsia triacanthos.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008099.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	High	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
	X	X	X	X		X
Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
X			X	X		X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

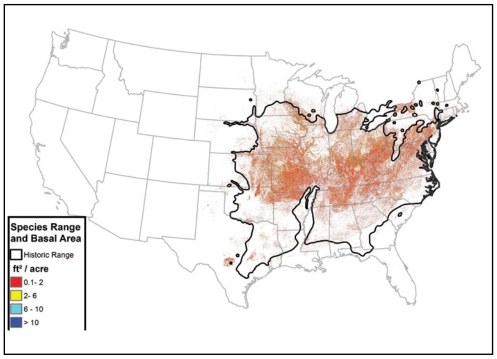
Primary Sources

Sullivan, Janet. 1994. Gleditsia triacanthos. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/ [2016, March 4].

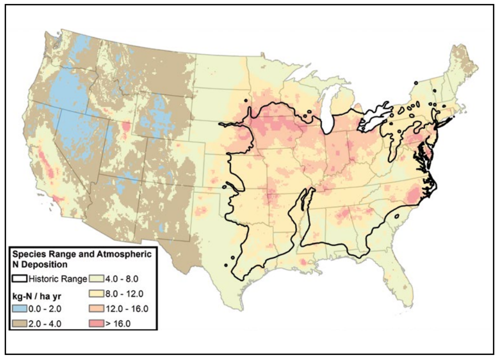
Native American Ethnobotany Database. http://naeb.brit.org.

Juglans nigra (black walnut)

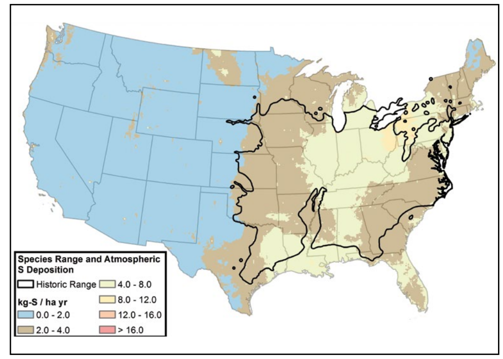
(a)



(b)



(c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Black walnut is a native, deciduous tree that ordinarily grows to heights around 80 feet (25 m). It develops a long, smooth trunk and a small rounded crown when growing in the forest. In the open, the trunk forks low with a few ascending and spreading coarse branches. The heavy seeds are dispersed by squirrels carrying them from beneath the tree and burying them at a distance. Small black walnut trees can also sprout from the stump when they are cut or killed back by fire. The tree is found on a variety of sites but grows best on deep, well-drained neutral soils that are moist and fertile. It grows slowly on wet bottomlands, dry ridges, and slopes. Black walnut is common on limestone soils and grows extremely well on deep loams and fertile alluvial deposits. Classified as shade-intolerant, in mixed forest stands, it must be dominant to survive, although it can survive in the relatively light shade of black locust. Black walnut is found in many of the climax associations, but because of its shade intolerance, it is not classified as a climax tree in the strict sense. In general, the species maintains itself in most stands as scattered single trees occupying openings in the canopy. It is well adapted to fire; mature trees have thick bark and naturally durable heartwood, which make them relatively resistant to damage and decay following fire.

Wildlife Uses

Although not considered a choice browse, black walnut leaves are palatable to white-tailed deer. The nuts furnish food for many rodents and birds. The eastern screech-owl roosts on the limbs of black walnut. An antagonism between black walnut and many other plants growing within its root zone has been recognized and attributed to juglone, a toxic substance found in the leaves, bark, nut husks, and roots of black walnut trees. Many garden vegetables and several conifers are susceptible to juglone.

Ecosystem Services

The wood and wood veneer are used for furniture, cabinetry, and plywood panels. Figured black walnut is used for gunstocks. Black walnut is also cultivated as an ornamental. The ground shells of black walnut are used as a nonslip agent in automobile tires, as an air pressure propellant in paint stripping, and as a filtering agent for scrubbers in smoke stacks. The automobile industry uses the ground shell products to deburr precision gears, and the airline industry uses the ground shells to clean jet engines. The nuts of black walnut are used as food by humans and are harvested commercially.

Indigenous peoples of eastern North America used the nuts for food and extracted black dye from the roots. The tree is also mentioned in some creation stories.

Specimen of *Juglans nigra.* Photo by T. Davis Sydnor, The Ohio State University, Bugwood.org, 5509643.

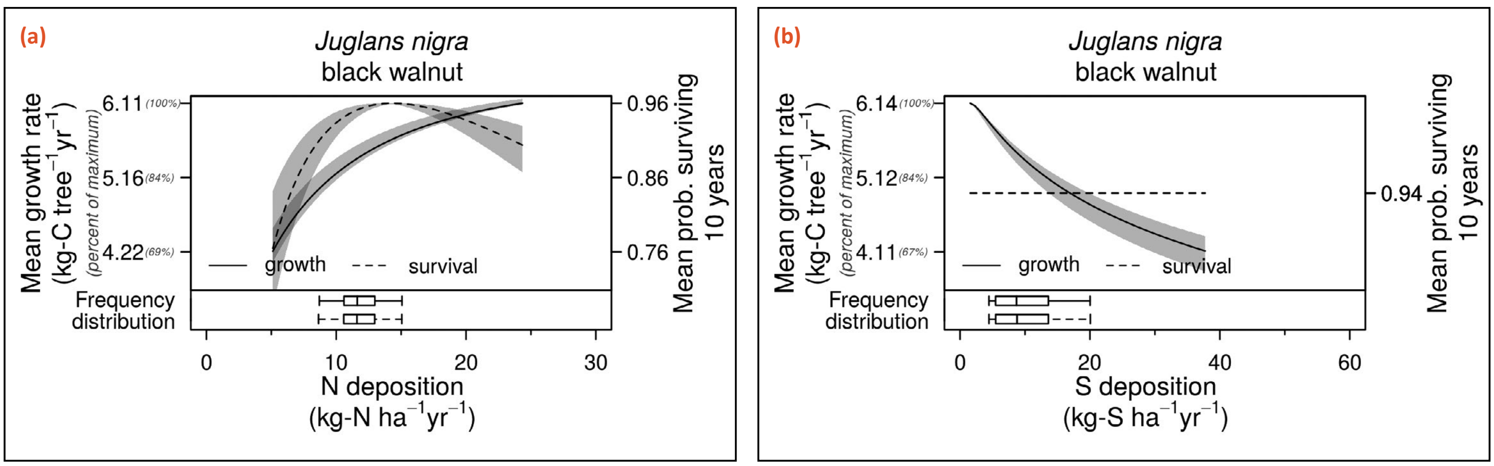
Foliage of *Juglans nigra.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008447.

Black walnut has also been successfully planted on surface mined areas in the eastern United States for site reclamation.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of black walnut increases with increasing N deposition and decreases with increasing S deposition. Survival has a hump-shaped relationship with increasing N deposition and no relationship to S deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Fruits of *Juglans nigra.* Photo by Rob Routledge, Sault College, Bugwood.org, 5474407.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	High	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
		X	X	X	X	

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
			X	X	X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

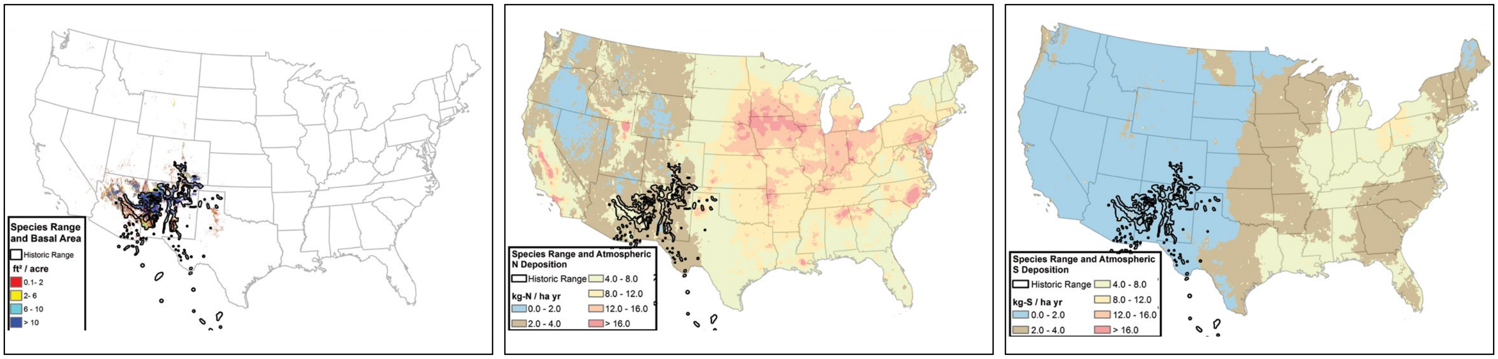
Primary Sources

Coladonato, Milo. 1991. *Juglans nigra*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (4 March 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Juniperus monosperma (oneseed juniper)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Oneseed juniper is a native, long-lived, evergreen tree with often shrubby form, 10 to 40 feet (3–12 m) high with several curved limbs arising near the base. Oneseed juniper is a slow-growing species, and has the ability to stop active growth when moisture is limited. Oneseed juniper produces small, “berry-like” cones that contain 1 seed. Dispersal of oneseed juniper seeds may occur through water, gravity, or by any of a number of birds and mammals. The tree occupies xeric sites in semiarid climatic zones and is typically found on dry, rocky, open flats, and slopes. It also occurs in canyons or foothills. Grasses can compete effectively with oneseed juniper seedlings for moisture and can limit its distribution in some areas. Oneseed juniper also competes with oaks for soil moisture, but juniper excels over oaks in more shallow soils. Populations of oneseed juniper have been classified as climax, seral, late seral, and postclimax. This classification is dependent on microclimatic conditions and competition with other species.

Wildlife Uses

Pinyon-juniper woodlands provide good habitat for mule deer, bighorn sheep, bison, wild horses, pronghorns, coyotes, bobcats, badgers, porcupines, rabbits, mice, voles, woodrats, squirrels, and numerous birds (e.g., plain titmouse, Stellar’s jay, northern flicker). The foliage and berries of oneseed juniper provide food for many species of birds and mammals. Deer utilize the foliage of oneseed juniper, but the foliage is of little value to domestic livestock. The succulent, berrylike cones of oneseed juniper serve as an abundant and readily available food source for a wide range of wildlife species year-round.

Ecosystem Services

The relatively small stature and multiple stems of oneseed juniper limit its usefulness as a timber species. Oneseed juniper is used locally for fuel, fenceposts, poles, and Christmas trees.

Indigenous peoples of the Southwest relied on oneseed juniper for many purposes. The wood was used for bows and arrows by the Kiowa, Comanche, Cheyenne, and Apache. The berries were eaten whole or ground into flour for bread. Prayer sticks were made from the wood, and dye, fibrous mats, and saddles were fashioned from the bark. Parts of the tree were also used as building materials and for medicinal purposes. Foliage was used as domestic sheep food during extreme winters. Oneseed juniper has also been used in the production of cellulose and chemical products. Many species

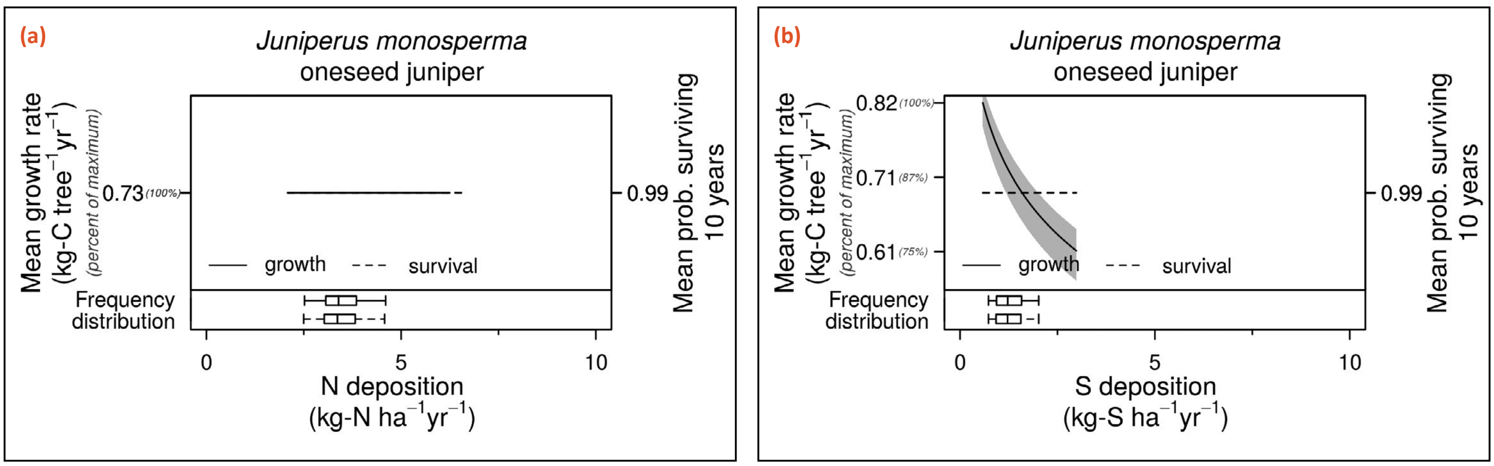
Specimens of *Juniperus monosperma*. Photo by Dave Powell, USDA Forest Service (retired), Bugwood.org, 1214093.

of juniper may have potential value for the production of charcoal, pulp, particleboard, chip products, fiber, or in certain chemicals. Oneseed juniper was first cultivated in 1900. It is rated as having low overall value for short-term rehabilitation but high value for long-term rehabilitation.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of oneseed juniper has no relationship to N deposition and decreases with increasing S deposition. Survival has no relationship to either N or S deposition. Confidence in these relationships is low based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Cones and foliage of *Juniperus monosperma*. Photo by Tom DeGomez, University of Arizona, Bugwood.org, 5389916.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

<table>
<tr><th rowspan="2">Species Summary</th><th>Shade Tolerance</th><th>Leaf Type</th><th>Mammal Uses</th><th>Bird Uses</th></tr>
<tr><td>Medium</td><td>Coniferous Evergreen</td><td>Yes</td><td>Yes</td></tr>
</table>

<table>
<tr><th colspan="4">Wood products</th><th rowspan="2">Traditional uses</th><th rowspan="2">Ornamental uses</th><th rowspan="2">Fuelwood</th></tr>
<tr><th>Paper</th><th>Unfinished wood products</th><th>Building material</th><th>Finished wood products</th></tr>
<tr><td></td><td>X</td><td>X</td><td></td><td>X</td><td></td><td>X</td></tr>
<tr><th colspan="3">Protection</th><th rowspan="2">Rehabilitation</th><th rowspan="2">Food products</th><th rowspan="2">Oils and other</th><th rowspan="2">General services</th></tr>
<tr><th>Erosion</th><th>Wind</th><th>Erosion and wind</th></tr>
<tr><td>X</td><td></td><td></td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
</table>

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

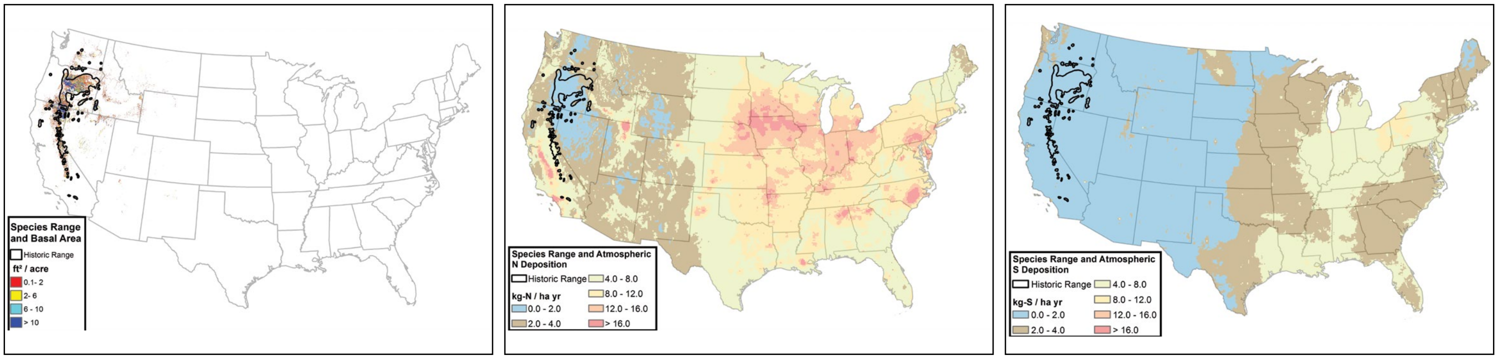
Primary Sources

Johnson, Kathleen A. 2002. *Juniperus monosperma*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/. (2017, May 15)

Native American Ethnobotany Database. http://naeb.brit.org.

Juniperus occidentalis (western juniper)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

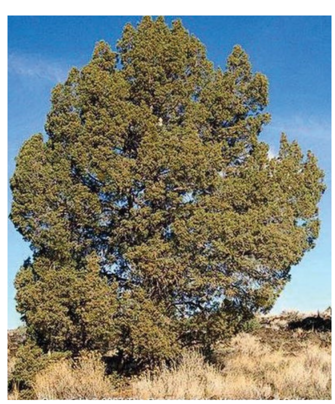
Western juniper typically grows 15 to 30 feet (4.6 to 9.1 m) and develops full crowns and heavy limbs at maturity. The bark is furrowed and shredding; taproots average 51 inches (130 cm) in depth but the root-to-shoot ratio decreases with age. Western juniper is long-lived and slow growing. Some individual trees are reported to be 3,000 years old or older. Cone-berries contain 1 to 4 (more rarely up to 12) brownish seeds. Seed of western juniper is dispersed by birds, mammals, water, and gravity. Western juniper occurs in open stands on mountain slopes and high plateaus. It grows as scattered individuals on rimrock or rock outcrops and in higher densities along streams, on scablands, and lower slopes where water has dispersed the seed. The growth of western juniper is favored by long, dry summers and cold winters with little moisture. Soils are typically shallow, stony, and low in organics. Western juniper is a highly competitive invasive species, but it is relatively intolerant of shade. This juniper has been expanding its range over the past 100–150 years. This expansion has been attributed to livestock grazing leading to a reductions in fine fuels and fire frequency. Old growth is typically found in "firesafe" spots. Climax stands are generally restricted to rimrock and the edges of mesas, whereas seral communities can dominate slopes and valley bottoms adjacent to older western juniper stands.

Wildlife Uses

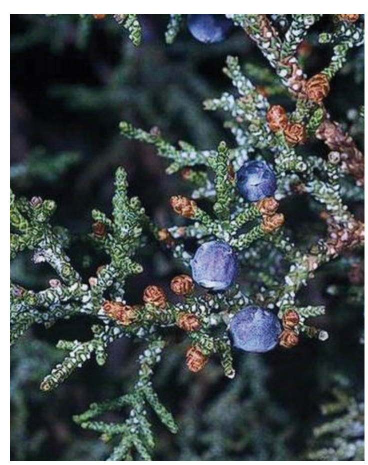
Western juniper provides food and cover for a variety of bird and mammal species. It is browsed to some extent by mule deer and elk, but is typically an emergency forage for most large game and livestock species. Western juniper is an important winter pronghorn food source, however. Western juniper seed cones or cone-berries are an important winter food source for migratory birds such as the American robin and Townsend solitaire. In addition, blue grouse, Lewis' woodpecker, scrub jay, and Stellar's jay eat the cone-berries in the fall. The northern flicker, mountain chickadees, and mountain blue birds nest in western juniper communities of the Blue Mountains of Oregon. Mule deer, elk, mountain cottontail, and coyote consume western juniper cone-berries. Western juniper cone-berries are the primary food source of the dusky-footed woodrat. Western juniper provides perching and nesting sites for at least 27 species of birds, as well as cover and hibernation sites for small mammals. It also provides thermal and hiding cover for mule deer, pronghorn, and domestic livestock. Nesting cavities in western juniper also provide hibernation sites for several species of bats.

Ecosystem Services

Western juniper has been used since historic times for firewood, charcoal, corrals, poles, and fence posts. More recently, western juniper has been used for paneling, interior studs, particleboard, veneer, plywood, and other lumber products. Western juniper has been cultivated as an ornamental since 1840. The wood is used in toys, sporting goods, jewelry boxes, suitcase and closet liners, inlay products, clocks, decorative items, and pencils. Pipe bowls are made from the roots of western juniper, and pet bedding from the shavings. Juniper boughs have been used for Christmas wreaths and other decorations. Over 100



Specimens of *Juniperus occidentalis.* Photo by Joseph M. DiTomaso, University of California - Davis, Bugwood.org, 5374944.



Flowers and cones of *Juniperus occidentalis*. Photo by Joseph M. DiTomaso, University of California - Davis, Bugwood.org, 5374945.

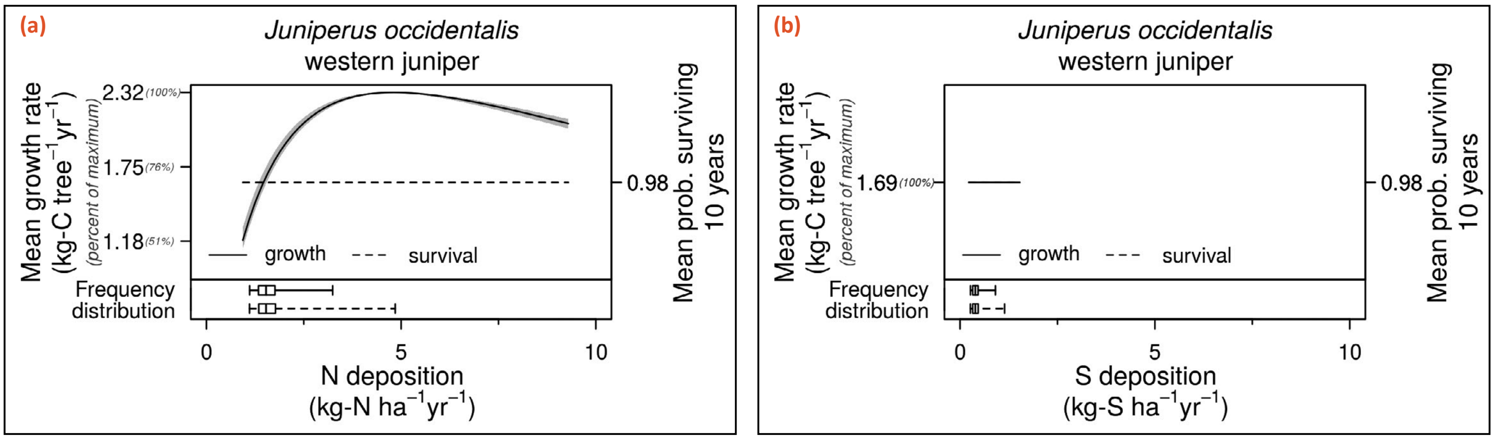
tons of boughs from central Oregon were sold in 1983 at 1 to 2 cents per pound. The essential oils of western juniper are used for flavoring or scenting agents in medicines, beverages, condiments, aerosols, insecticides, soaps, and men's cosmetics. The cone-berries of western juniper are edible and taste best when dried. Western juniper foliage has been added to chicken feed to produce gin-flavored eggs for human consumption.

Indigenous peoples used western juniper wood in making bow staves and other parts of the tree for medicinal purposes to treat sores, colds, and stomach aches. In addition, many used the berries for food including the Apache, Atsugewi, and Klamath tribes. The wood was also used to make wands for Navajo war dances; branchlets with needles were made into prayersticks.

Western juniper can be propagated from cuttings or by layering. Trees have been used as riprap for stabilizing streambanks.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of western juniper has a hump-shaped relationship with increasing N deposition and no relationship to S deposition. Survival has no relationship to N or to S deposition. Confidence in these relationships is low based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are correlated for many species, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	**Shade Tolerance**	**Leaf Type**	**Mammal Uses**	**Bird Uses**
	Low	Coniferous Evergreen	Yes	Yes

Wood products				**Traditional uses**	**Ornamental uses**	**Fuelwood**
Paper	**Unfinished wood products**	**Building material**	**Finished wood products**			
	X	X	X	X	X	

Protection			**Rehabilitation**	**Food products**	**Oils and other**	**General services**
Erosion	**Wind**	**Erosion and wind**				
X			X	X	X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

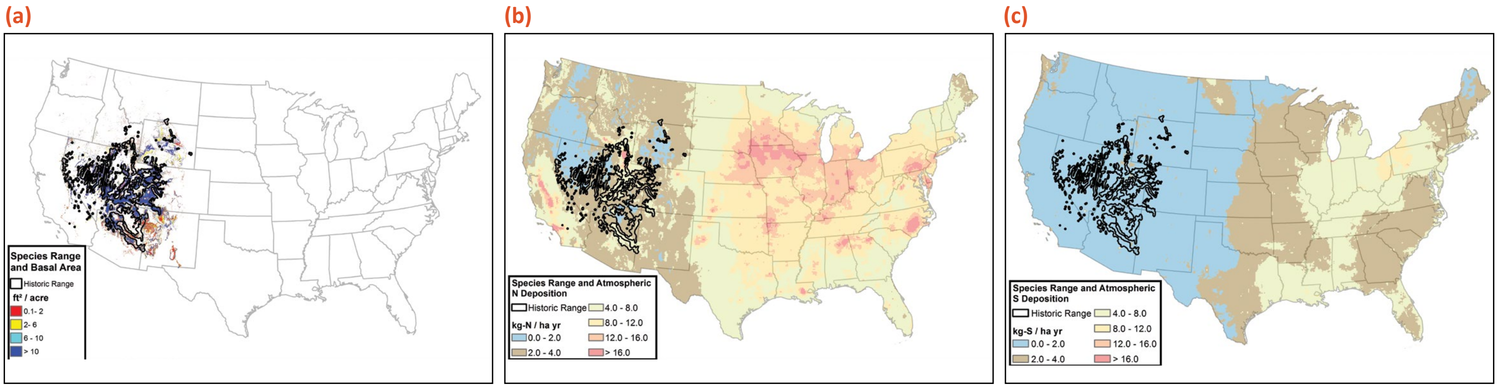
Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

Tirmenstein, D. 1999. *Juniperus occidentalis*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/plants/tree/junocc/all.html. (2017, May 15).

Revisions: On 22 January 2015, the synonym *Juniperus grandis* and citations of authorities supporting that name [93,109] were added. New citations of authorities [107,108] supporting the name used in this review (*Juniperus occidentalis* var. *australis*) were also added.

Juniperus osteosperma (Utah juniper)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

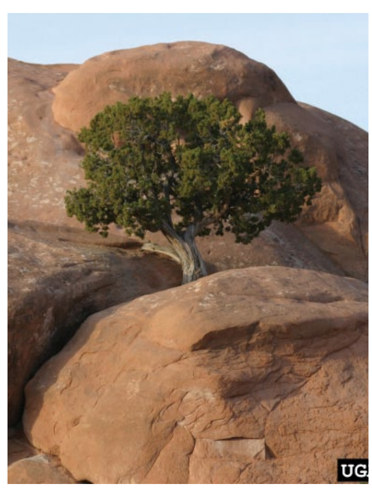
Utah juniper is a short tree that may live as long as 650 years. It grows to less than 26.4 feet (8 m), with a trunk 4 to 7.5 inches (10–30 cm) thick. Sometimes the tree has multiple stems. Under severe site conditions, the trees persist in very stunted forms. The species reproduces by seeds in cones and produces abundant seeds in most years. Animal, especially jackrabbits, factor importantly in disseminating the seeds. Utah juniper thrives on very dry sites—the tree does not rely on summer precipitation for moisture. It commonly grows on alluvial fans and dry, rocky hillsides, with shallow, alkaline soils; soil textures range, but most often are gravelly loams and gravelly clay loams with a pH range of 7.4 to 8.0. Utah juniper is not shade-tolerant. It is a climax species in harsh areas where stands are open and regeneration can occur without competition for light. Juniper litter has an allelopathic effect on some understory species, especially Idaho fescue (*Festuca idahoensis*), Sandberg bluegrass, and blue grama. Since European settlement, the range of Utah juniper has expanded into neighboring grasslands. Overgrazing, fire suppression, and climatic change have been identified as potential causes of juniper invasion.

Wildlife Uses

Many birds and animals, both wildlife and livestock, use Utah juniper for cover and food. Jackrabbits, deer mice, and coyotes eat the juniper “berries” or berry-cones. Many bird species and other small mammals depend on the berry-cones for fall and winter food. Mule deer and elk graze on the foliage when other foliage is scarce and during periods of deep snow. Utah juniper is an important cover and shelter species for several large animals, including mule deer throughout its range; elk for winter cover in Wyoming, Utah, and New Mexico; desert bighorn sheep throughout the Southwest; bison in Utah; wild horses throughout the West; mountain lion and lynx in Utah; Wyoming, and Arizona; and pronghorn in Utah and Nevada. Several small animals are also commonly found in pinyon-juniper woodlands, including porcupine, desert cottontail, deer mouse, Great Basin pocket mouse, chisel-toothed kangaroo rat, desert woodrat, various reptiles, and others. Seventy-three different bird species breed in pinyon-juniper habitat woodlands, although of those, only 5 are obligates (screech owl, gray flycatcher, scrub jay, plain titmouse, and gray vireo) and 13 semi-obligates. Ferruginous hawks nest in Utah juniper trees.

Ecosystem Services

Because the wood is resistant to decay, it has long been used for construction and fence posts, as well as for firewood, pencils, Christmas trees, and other purposes. Currently one of the most important economic values of pinyon-juniper woodlands is for livestock grazing.



Specimen of *Juniperus osteosperma*. Photo by Paul Bolstad, University of Minnesota, Bugwood.org, 5188089.

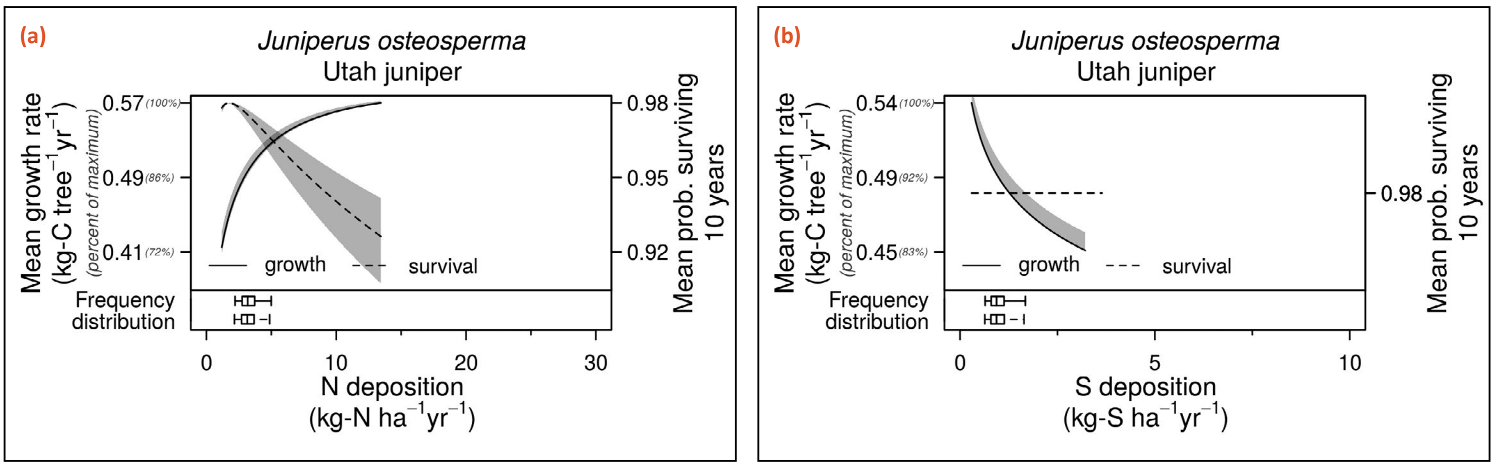
Bark of *Juniperus osteosperma*. Photo by Mary Ellen (Mel) Harte, Bugwood.org, 1353222.

Traditionally, the Hopi, Havasupai, Navajo, and other western indigenous peoples ate the seeds and inhaled the fumes of burning branches to alleviate headaches. They used the oil to wash hair, brewed a strong decoction of twigs as an antiseptic wash, and used a poultice of mashed twigs to treat burns.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of Utah juniper increases with increasing N deposition and decreases with increasing S deposition. Survival decreases with increasing N deposition has no relationship to S deposition. Confidence in these relationships is low based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to either stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Cones of *Juniperus osteosperma*. Photo by Tom DeGomez, University of Arizona, Bugwood.org, 5389920.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Low	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
	X	X	X	X		X

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
					X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

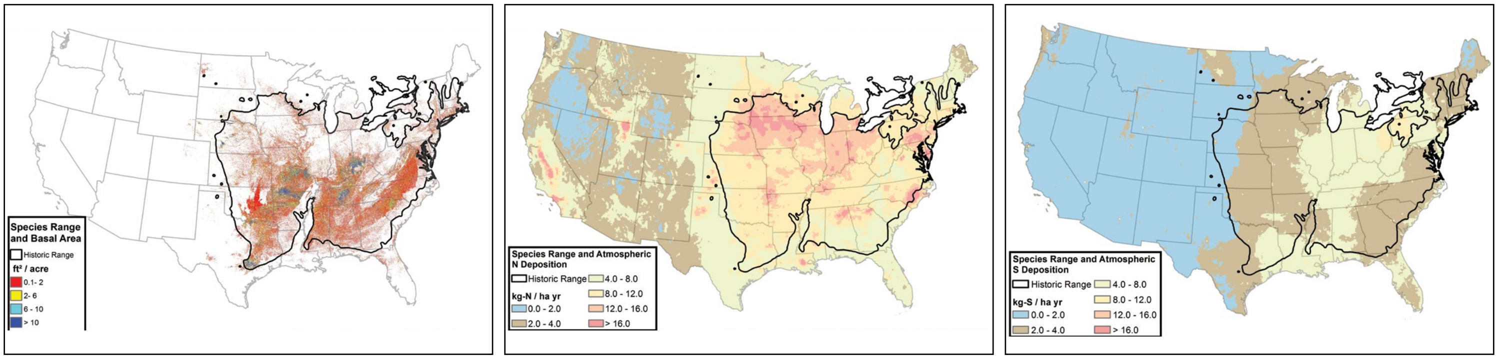
Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

Zlatnik, Elena. 1999. *Juniperus osteosperma*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (4 March 2016).

Juniperus virginiana (eastern redcedar)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Eastern redcedar is a relatively long-lived evergreen that may reach 450+ years. It has two distinct growth forms: The most familiar form is narrowly conical with its branches growing up and out at a sharp angle to form a compact tree; the second form is broadly conical with branches that spread widely. The tree has thin, fibrous bark. On seedlings and new twigs, leaves are pointed and awl-shaped. On mature branches, closely overlapping scale-like leaves fit tightly against the twig in opposite pairs. Eastern redcedar seeds are borne in small, fleshy, berrylike cones. Birds and small mammals disperse the seed. The species is generally more prevalent on more arid, south- and southwest-facing slopes. Throughout its range, it grows under diverse site conditions: in deep and shallow soils, on ridgetops, and in valleys, and in such varied habitats as thin, rocky soils and dry outcrops to finer textured, saturated soils of swamps, although it is not tolerant of flooding. Southern redcedar is saline-tolerant, growing on brackish marsh sites in the Southeast on barrier island swales subject to saltwater flooding, and on coastal dunes subject to salt spray.

Eastern redcedar is both a pioneer and an invader. It colonizes relatively open patches of eroded bare ground and is most competitive on exposed dry sites, and disturbed areas including abandoned pastures and cultivated fields, eroded areas, and open woods thinned by timber harvest. Eastern redcedar is, an early- to mid-seral component in cedar glades that result from the invasion of grasslands, and are succeeded by oak hardwood forests. Eastern redcedar forms persistent, stable communities in limestone outcrop areas due to exposure and shallow soil. Stands of red cedar, however, cannot persist with frequent fire.

Wildlife Uses

Many birds and small mammals eat the berrylike cones, especially in winter. Wildlife species that eat eastern redcedar fruits include waxwings, bobwhite quail, ruffed grouse, sharp-tailed grouse, ring-necked pheasant, wild turkeys, rabbits, foxes, raccoons, skunks, opossums, and coyotes. Deer may browse the tree's abundant foliage when no other food is available, and they are more likely to browse reproductively active mature trees than juvenile eastern redcedars. As an evergreen, it provides good nesting and roosting cover for many birds. These include nest sites for Cooper's hawks and roosting sites for eastern screech-owls, short-eared owls, and saw-whet owls. Dense thickets of eastern redcedar provide good escape and hiding cover for deer and small mammals.

Ecosystem Services

The principal product of eastern redcedar is fenceposts, though it is also used for lumber, poles, boats, paneling, closets, chests, and pencils. The aromatic heartwood is commonly used for chests or closet lining. The aromatic oils found in the heartwood repel clothing moths and are widely used in perfumes. Aromatic oils are toxic to some ant species (Argentine ant and odorous house

Specimen of *Juniperus virginiana*. Photo by Jason Sharman, Vitalitree, Bugwood.org, 5454533.

Bark of *Juniperus virginiana.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008012.

ant), and eastern redcedar mulch is effective in discouraging ant colonization. The oils are also effective in repelling Formosan subterranean termites. Heartwood extractives may inhibit growth of fungi and bacteria; it has approximately 10 times the oil extractives of sapwood. Eastern redcedar is commonly planted in shelterbelts, windbreaks, and snow fences. It also used for Christmas trees and ornamental plantings.

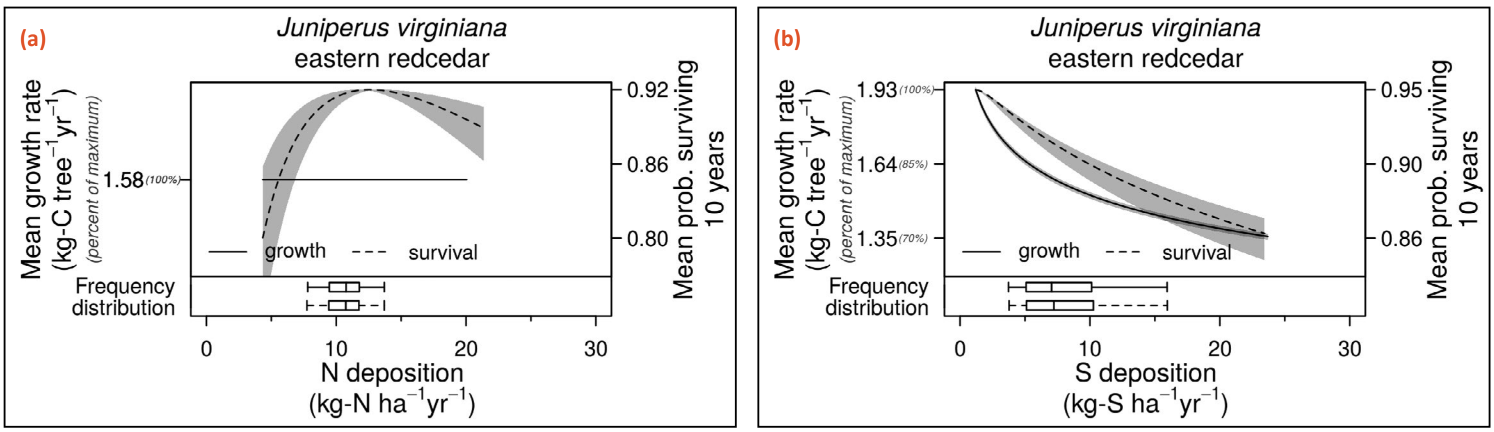
Traditionally, the Cherokee, Dakota, Seminole, and others made decoctions and infusions to treat fever, worms, arthritis, swelling, chills, and canker sores. They made flutes from the wood.

Eastern redcedar establishes well on abandoned surface mines, agricultural fields, and logging sites and is used to recover highly eroded, nutrient-poor soils.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

Growth has no relationship while survival has a hump-shaped relationship with increasing N. Growth and survival decreases with increasing S. Confidence in these relationships is high based on correlations between N and S deposition across the species range. Nitrogen and S deposition are correlated for many species, so inferring causality to either stressor can be difficult. See also Appendix Table 4 and the Introduction for more information.

Cones and foliage of *Juniperus virginiana.* Photo by Paul Wray, Iowa State University, Bugwood. org, 0008186.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
	X	X	X	X		
Protection			**Rehabilitation**	**Food products**	**Oils and other**	**General services**
Erosion	Wind	Erosion and wind				
	X		X		X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

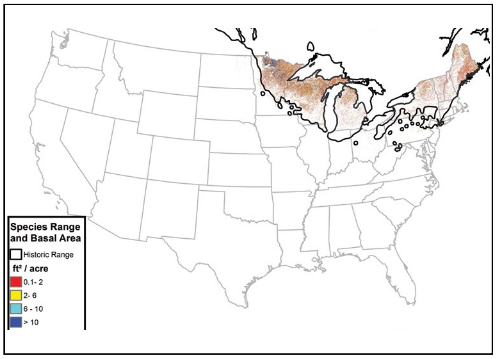
Primary Sources

Anderson, Michelle D. 2003. *Juniperus virginiana*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (4 March 2016).

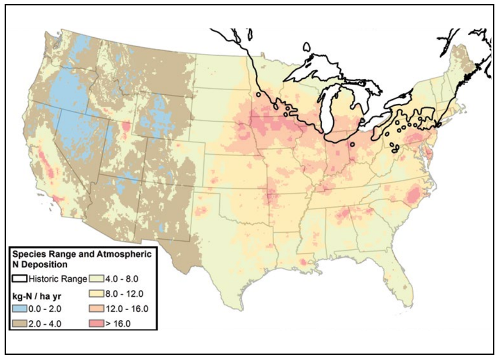
Native American Ethnobotany Database. http://naeb.brit.org.

Larix laricina (tamarack)

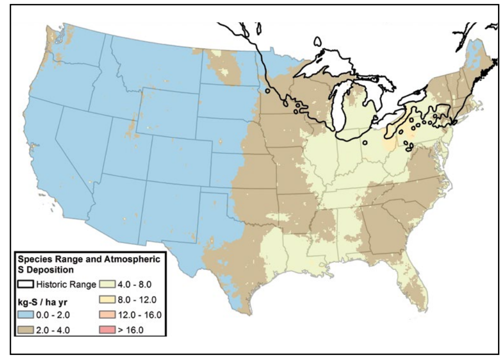
(a)



(b)



(c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

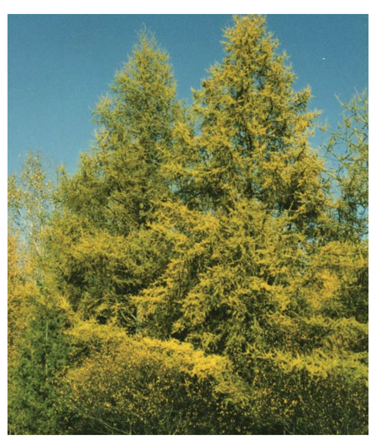
Tamarack is a native, deciduous, coniferous, small- to medium-sized upright tree. It has a straight bole with a narrow pyramidal crown. Trees generally reach 50 to 75 feet (15–23 m) in height and 14 to 20 inches (46–51 cm) diameter. The maximum age for tamarack is about 180 years, although older trees have been found. Tamarack has needles that occur in clusters of 10 to 20 on dwarf twigs and turn yellow in the fall before they are shed. The bark is smooth when young but becomes rough and scaly on older trees. Erect mature cones bear seeds that wind and red squirrels disperse in the fall over a relatively short time period. Layering is a dominant mode of reproduction at the northern limit of the species' range. It is most commonly found on cold, wet to moist, poorly drained sites such as swamps, bogs, and muskegs. It is also found along streams, lakes, swamp borders, and occasionally on upland sites. Tamarack can tolerate a wide range of soil conditions but most commonly grows on wet to moist organic soils, such as sphagnum or woody peat, and is especially common on nutrient-poor, acid peatlands. Because the species is intolerant of shade, tamarack stands are usually even-aged. The stands tend to cast light shade and have a dense undergrowth of shrubs, and the ground is usually covered with sphagnum and other mosses. Tamarack is a pioneer or early seral species. It is often the first tree to invade open bogs and burned peatlands. As the peat becomes consolidated and firm, other conifers replace it. Tamarack trees are easily killed by fire, thus the species relies on seed from surviving trees to revegetate burned areas.

Wildlife Uses

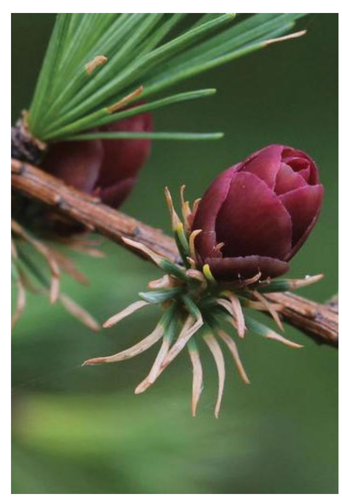
Very few wildlife species make tamarack an important component of their diet. Some animals do browse, but to a limited extent. Snowshoe hares feed on twigs and bark, and porcupines feed on the inner bark. Moose, caribou, and white-tailed deer generally avoid tamarack. Spruce, blue, and sharp-tailed grouse readily consume the needles and buds. Red squirrels cut and cache tamarack cones. The pine siskin, crossbills, and probably other seed-eating birds eat tamarack seeds. Mice, voles, and shrews consume large numbers of the seeds off the ground. Tamarack is probably of limited value as cover for mammals and birds because it sheds its needles in the winter and often occurs in rather open stands. In northern Minnesota, ospreys prefer to nest in dead tamarack trees. Bald eagles occasionally nest in tamarack.

Ecosystem Services

Tamarack is primarily used for pulpwood but is also used for posts, poles, mine timbers, and railroad ties. It is used less commonly for rough lumber, fuelwood, boxes, crates, and pails. In Alaska, young tamarack stems are used for dogsled runners, boat ribs, and fishtraps. In northern Alberta, duck and goose decoys are made from tamarack branches.



Specimens of *Larix laricina.* Photo by Bill Cook, Michigan State University, Bugwood.org, 1218018.



Cones and foliage of *Larix laricina.* Photo by Rob Routledge, Sault College, Bugwood.org, 5497008.

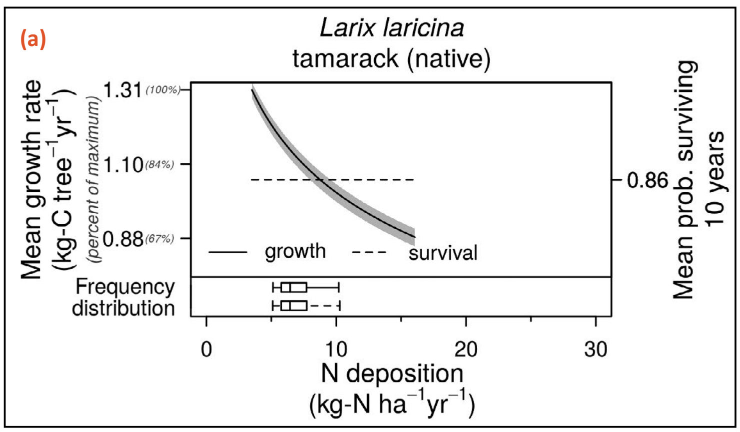
Indigenous peoples of eastern boreal North America used the roots for cordage, the wood for arrow shafts, and the bark for medicinal purposes. Early European settlers used the soft needles for stuffing pillows and mattresses; the roots of large trees were used for ship building.

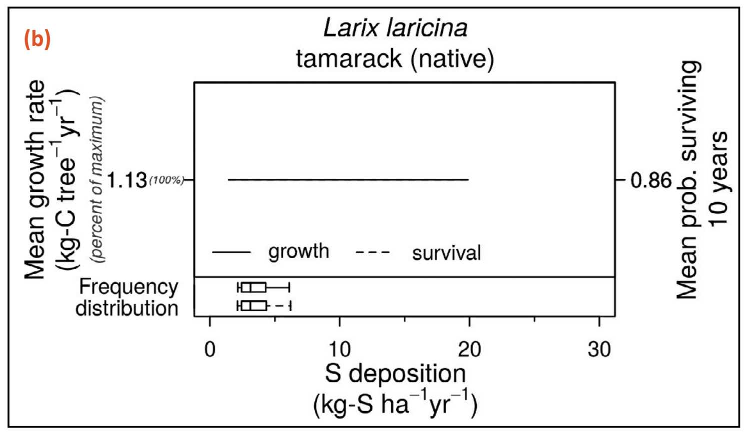
Tamarack may be useful for revegetating disturbed peatlands, sand tailings, and coal mine spoils.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of tamarack decreases with increasing N deposition, and has no relationship to S deposition. Survival has no relationship to N or to S deposition. Confidence in these relationships is medium low based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferringcausality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Foliage of *Larix laricina.* Photo by Becca MacDonald, Sault College, Bugwood.org, 5501425.





Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Low	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X	X	X		X

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
			X		X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

Primary Sources

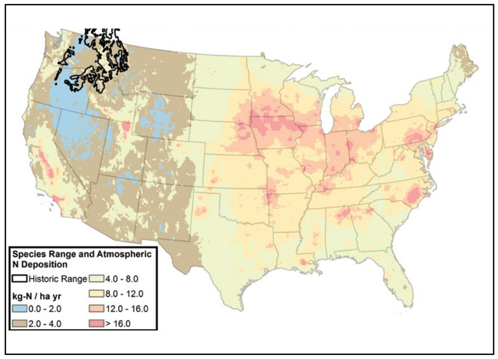
Native American Ethnobotany Database. http://naeb.brit.org.

Uchytil, Ronald J. 1991. *Larix laricina*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (4 March 2016).

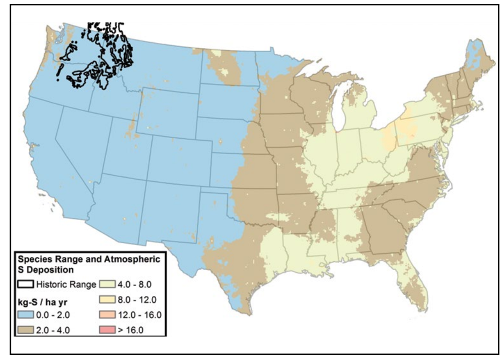
Larix occidentalis (western larch)

(a)

(b)



(c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Western larch is a fast-growing, long-lived, deciduous conifer native to alpine and subalpine forests of the northwestern United States and adjacent Canada. One of the world's largest larches, western larch typically grows 100 to 180 feet tall (30–55 m). A deep, spreading root system stabilizes these large trees. Bark in mature trees is thick and furrowed into large, flaky plates. Cone production begins generally around 25 years old and its pollen is distributed by wind. The small, light, long-winged seeds of western larch are dispersed by wind. Western larch occurs in mountain valleys and lower slopes, often in somewhat swampy areas. Western larch occupies relatively cool, moist climatic zones. Its upper elevational range is limited by low temperatures, while the lower extreme is limited by low precipitation. In order to reach maximum growth potential, western larch requires an open canopy and deep soils. Western larch is found on a wide variety of soil types, most of which, however, are derived from bedrock or glacial till, but some are of loessial or volcanic ash origin. Western larch is the least shade-tolerant conifer in its range. As such, it is a seral species whose populations have been historically maintained by disturbances such as wildfire and glacial retreats and is therefore usually found in even-aged stands. It is considered an aggressive pioneer capable of rapid growth and early onset of seed production relative to co-occurring conifers. In the absence of disturbance, shade-tolerant associates form understories that shade out future generations of western larch seedlings

Wildlife Uses

Larch forests provide food and cover for a wide range of fauna. Rodents eat seeds and seedlings, birds forage for insects and nest in western larch, and squirrels often cut and cache cones. Deer, elk, and moose browse larch, though probably only as a last resort, and black bears forage on sugars that are concentrated in the sap layer in the spring. Cavity nesters and woodpeckers, particularly the pileated woodpecker, utilize western larch. Flying squirrels, woodpeckers, owls, and various songbirds nest in rotting western larch cavities. Snags are used by osprey, bald eagles, and Canada geese for nesting, and raptors may nest in brooms of trees infected with dwarf mistletoe.

Ecosystem Services

Western larch is one of the most important timber-producing species in the western United States and western Canada. It has the densest wood of the northwestern conifers and is also very durable and moderately decay resistant. Its high heating value makes it one of the best fuel woods in the region. The wood is also used commercially for construction framing, railroad ties, pilings, mine timbers, interior and exterior finishing, and pulp, and burned snags are often used to make shakes. Arabinogalactan, the gum from the tree, is used for lithography

Commercial stand of *Larix occidentalis.* Photo by Chris Schnepf, University of Idaho, Bugwood.org, 1169007.

Cones and foliage of *Larix occidentalis.* Photo by Chris Schnepf, University of Idaho, Bugwood.org, 1171028.

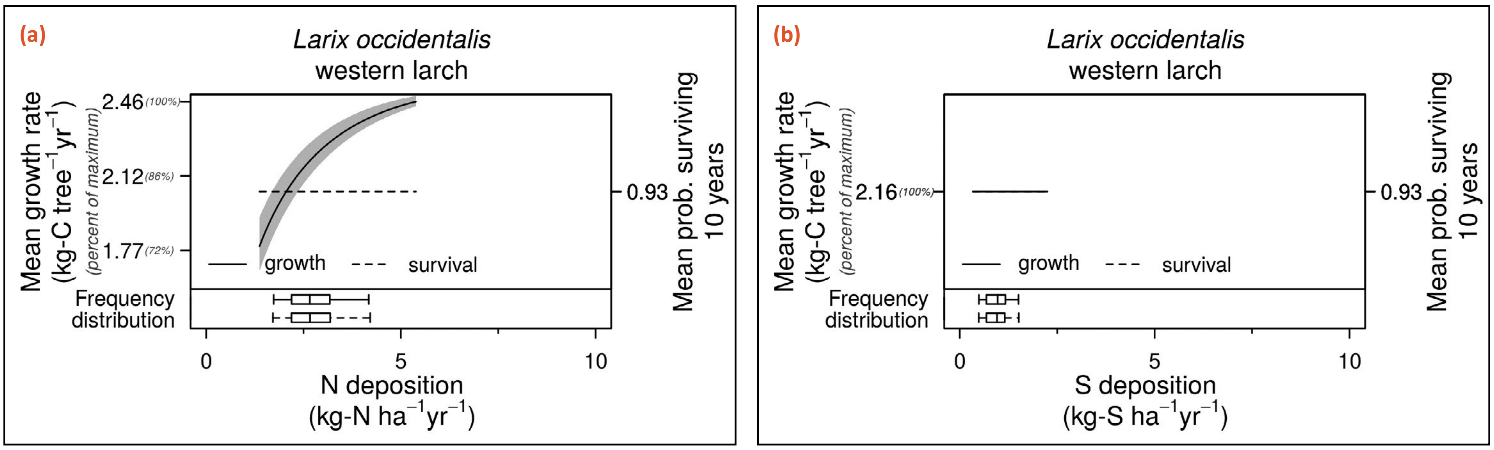
and in food, pharmaceutical, paint, ink, and other industries. The most desirable sources of this gum are waste butt logs. Oleoresin from western larch is used to produce turpentine and other products.

Indigenous peoples of northwestern North America, such as the Flathead Kutenai and Nez Perce, used western larch for treatment of cuts and bruises, tuberculosis, colds and coughs, sore throats, arthritis, skin sores, cancer, and for blood purification. They also made syrup from the sap, ate the cambium, and chewed solidified pitch as gum.

Besides traditional uses, western larch performs well on sites disturbed by fire, as well as on sites disturbed by shelterwood, seed tree, and clearcut logging methods followed by prescribed burning or scarification.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of western larch increases with increasing N deposition, and has no relationship to S deposition. Survival of western larch has no relationship to N or to S deposition. Confidence in these relationships is low based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Low	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X		X		X

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
			X	X	X	X

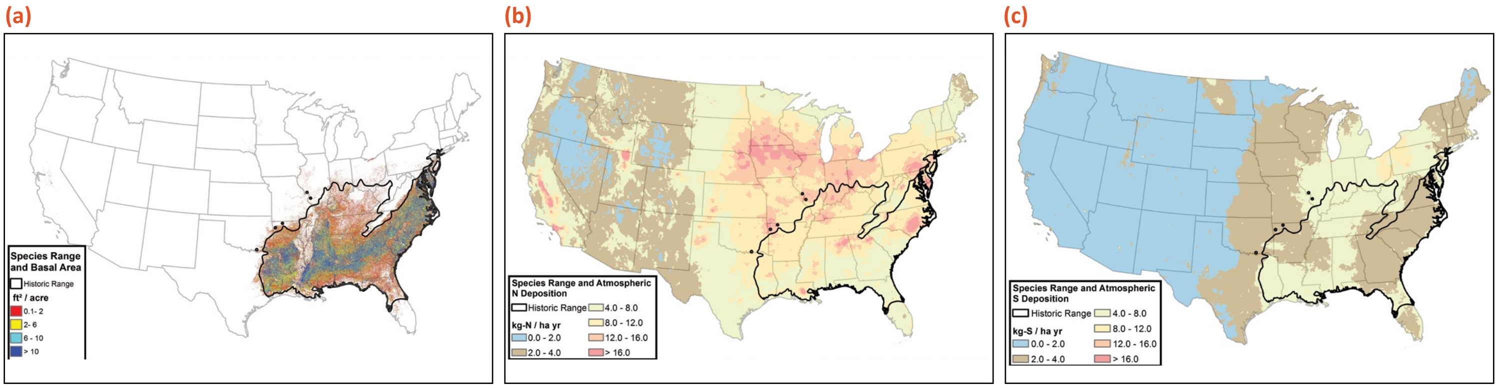
A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

Scher, Janette S. 2002. *Larix occidentalis*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/. (2017, May 16).

Liquidambar styraciflua (sweetgum)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Sweetgum is a large, native, long-lived, deciduous tree that reaches heights of 50 to 150 feet (15–45 m) at maturity. Young sweetgum trees have long conical crowns, while mature trees have crowns that are round and spreading. The species is easily recognizable by the star-shaped leaves which have five long-pointed, saw-toothed lobes. The brown bark is deeply furrowed into narrow scaly plates or ridges. Sweetgum is monoecious with the male flowers in several clusters and the female flowers hanging at the end of the same stalk. The ball-shaped fruits contain many individual seed-bearing sections, and persist throughout the winter. Wind, primarily, disperses the seed, and sweetgum is capable of sprouting if top-killed. It tolerates different soils and sites but grows best on the rich, moist, alluvial clay and loamy soils of river bottoms. Throughout the Piedmont Plateau, sweetgum shows good growth on river and stream bottoms and shows considerable potential on many upland sites. The tree is classified as shade-intolerant. In pure stands on bottomland sites, young sweetgum can endure some shade and crowding, but with increase in age, the tree becomes less tolerant of competition. Following natural decrease in the canopy, enough sunlight reaches the ground to permit an understory stand to develop. Although sweetgum is an early invader, it seldom becomes a dominant species.

Wildlife Uses

Sweetgum has moderate value as a winter browse for white-tailed deer, and birds, squirrels, and chipmunks eat the seeds. A variety of birds and mammals use the snags as breeding sites.

Ecosystem Services

The wood is primarily used for plywood, lumber—to make boxes, crates, furniture, interior trim, and millwork—and veneer—primarily for crates, baskets, and interior woodwork. Sweetgum is also used for crossties and fuel, and small amounts go into fencing, excelsior, and pulpwood. The beautiful red and yellow color variations of sweetgum's autumn foliage make it highly prized as an ornamental.

Medicinally, sweetgum is known as "copalm balsam" and the fragrant, resinous gum is used extensively in Mexico and Europe as a substitute for storax. Various ointments and syrups prepared from the resinous gum are used in the traditional and contemporary treatment of dysentery and diarrhea. The gum is used as a perfuming agent in soap and sometimes children chew the gum. Many of these uses were first practiced by the Houma, Rappahannock, and other indigenous peoples of eastern North America.

Sweetgum stem cuttings have been successfully planted for streambank protection and reclamation of sites disturbed by coal strip mining.

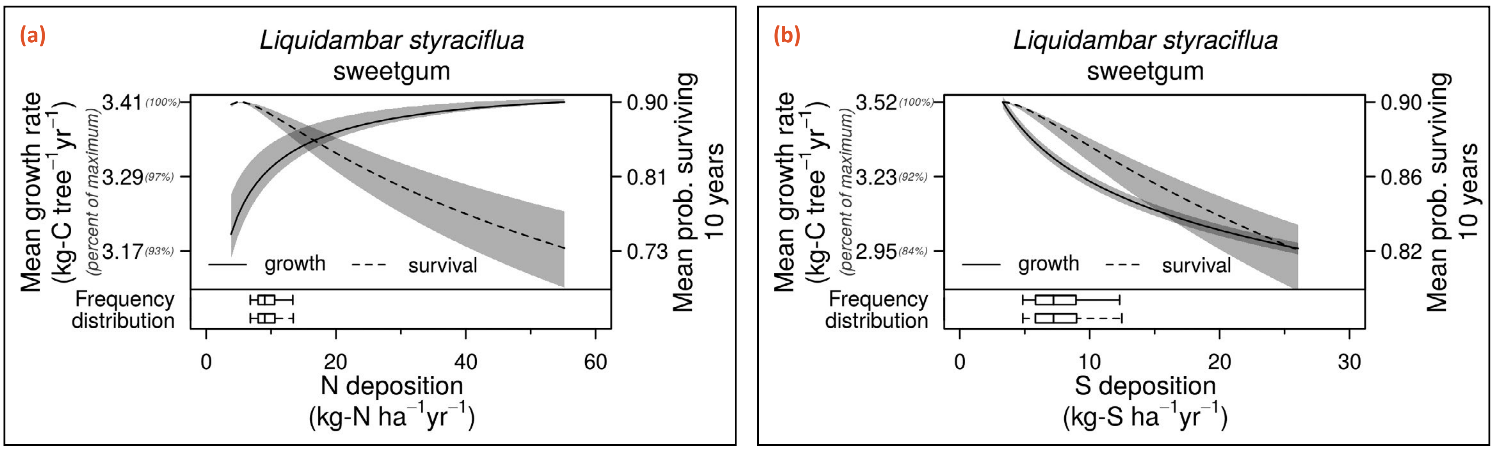
Foliage of *Liquidambar styraciflua.* Photo by Richard Webb, Bugwood.org, 1480267.

Bark of *Liquidambar styraciflua.* Photo by Vern Wilkins, Indiana University, Bugwood.org, 5454088.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of sweet gum increases with increasing N deposition and decreases with increasing S deposition. Survival decreases with increasing N and S deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Fruits and leaf of *Liquidambar styraciflua*. Photo by Michael Dowdy, University of Georgia, Bugwood.org, 5484607.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X	X	X	X	X
Protection			**Rehabilitation**	**Food products**	**Oils and other**	**General services**
Erosion	**Wind**	**Erosion and wind**				
			X	X	X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

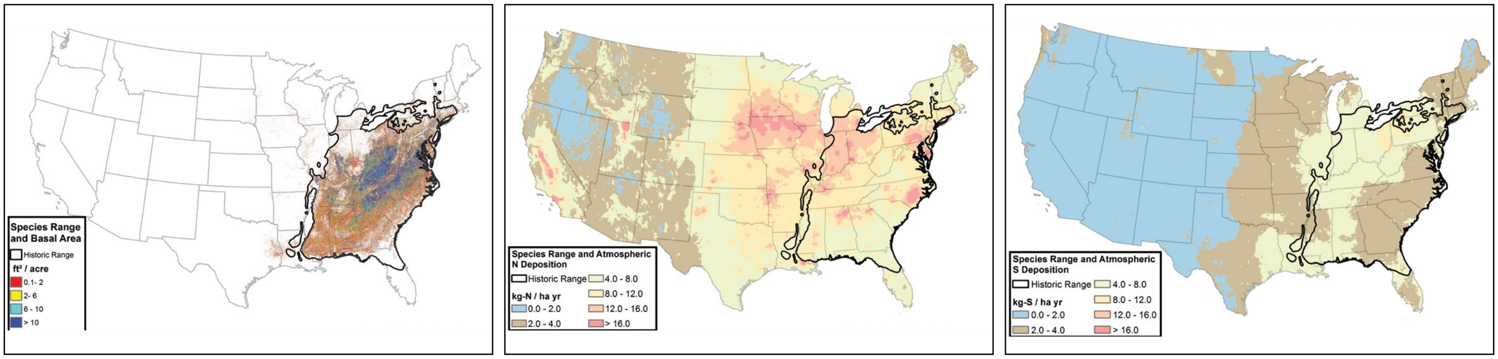
Primary Sources

Coladonato, Milo. 1992. *Liquidambar styraciflua*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (4 March 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Liriodendron tulipifera (yellow-poplar)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

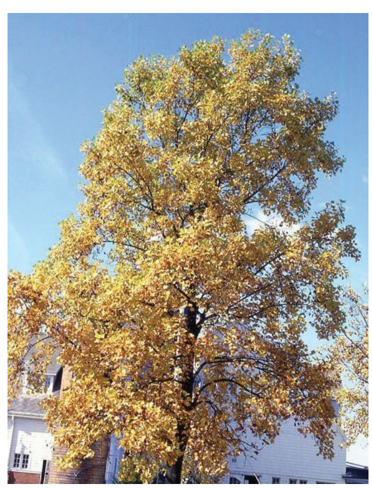
Yellow-poplar is a tall, deciduous, long-lived, broadleaf tree. The leaves are alternate with a distinctive tulip-like shape. In forest stands yellow-poplar is one of the straightest and tallest trees, with approximately 66 percent of the bole free of lateral branches. It can reach heights of 200 feet (61 m) and a diameter greater than 10 feet (3 m). The flowers are tulip-like in size and shape. A cone-like structure contains the winged fruit. The tree is mainly insect pollinated, with some selfing. It is a prolific seed producer. Yellow-poplar sprouts from dormant buds located on the root crown after cutting and/or fire. The species grows best on north and east aspects, lower slopes, sheltered coves, and gentle concave slopes, and on moderately deep loams that are moderately moist, well drained, and loose textured. Yellow-poplar is a shade-intolerant, pioneer species that often invades open sites, and in old-field succession, it occurs in pure or nearly pure stands. Mature yellow-poplars have bark sufficiently thick (> 0.5 inch [1 cm]) to insulate the cambium layer and allow trees to survive low- to moderate-severity fire. Fire actually enhances yellow-poplar seedling establishment by increasing light availability. Yellow-poplar is very sensitive to high ozone concentrations.

Wildlife Uses

Livestock prefer the foliage and stems of yellow-poplar over those of other tree species. Young trees are often heavily browsed, and browsing or trampling frequently eliminates seedlings. Cattle or other browsers create “browse lines” on older trees. White-tailed deer also browse yellow-poplar during all seasons. Northern bobwhites, purple finches, cottontails, red squirrels, gray squirrels, and white-footed mice consume the samaras. Yellow-bellied sapsuckers use the phloem, and ruby-throated hummingbirds consume nectar from the flowers. The trees in various stages of growth provide hiding and thermal cover for white-tailed deer, small mammals, upland game birds, waterfowl, and nongame birds. They provide habitat for the endangered red-cockaded woodpecker.

Ecosystem Services

The wood is used for construction-grade lumber and plywood, as well as for cabinets, veneer, furniture, and pulp. In the past, it was used for carriage bodies, shingles, saddle frames, and interior finish wood. Yellow-poplar has only fair value as a fuelwood but good value as kindling. The attractive tulip-like flowers and leaves have made yellow-poplar a valued ornamental since 1663. The flowers are also valuable nectar producers—the flowers from a 20-year-old tree produce enough nectar to yield 4 pounds (1.8 kg) of honey.



Specimen of *Liriodendron tulipifera*. Photo by T. Davis Sydnor, The Ohio State University, Bugwood.org, 5509781.

Flowers of *Liriodendron tulipifera*. Photo by Rob Routledge, Sault College, Bugwood.org, 5473613.

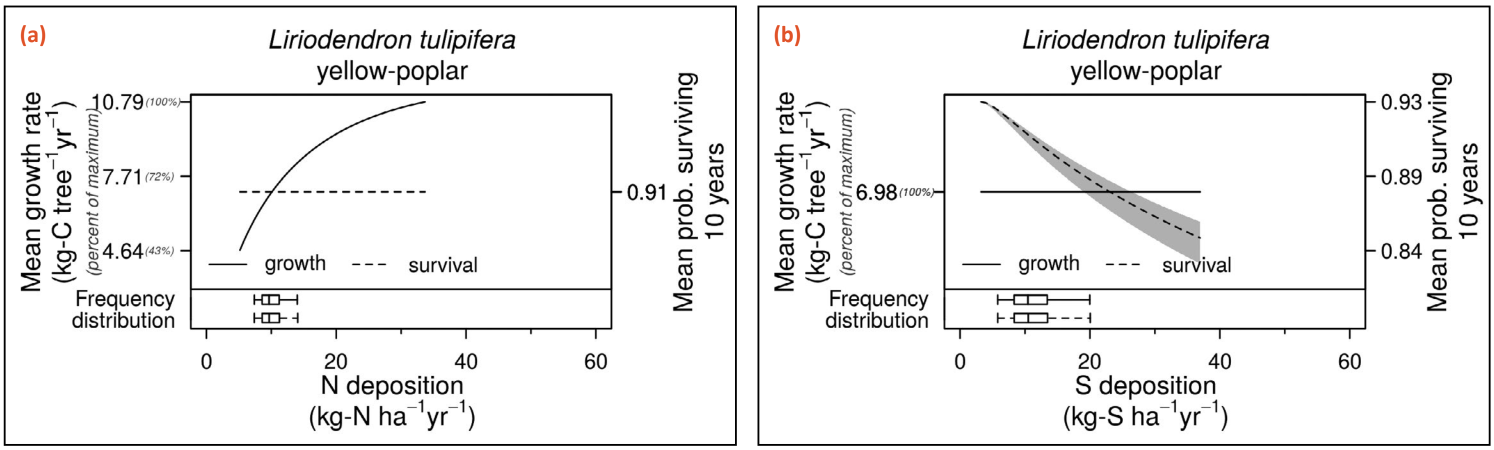
In the late 1800s, the tree was used medicinally: a heart stimulant was extracted from the inner bark of the root, and a tonic for treating rheumatism and dyspepsia was extracted from stem bark. The Cherokee made a cough syrup, bark infusions, decoctions, and steam bath to treat ailments such as cough, fevers, indigestion, cholera, and pinworm.

Yellow-poplar has been planted onto surface coal mine reclamation sites with variable results, but total failures are rare.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of yellow-poplar increases with increasing N deposition and has no relationship to S deposition. Survival has no relationship to N deposition, and decreases with increasing S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Foliage of *Liriodendron tulipifera.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008443.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	**Shade Tolerance**	**Leaf Type**	**Mammal Uses**	**Bird Uses**
	Low	Broadleaf Deciduous	Yes	Yes

Wood products				**Traditional uses**	**Ornamental uses**	**Fuelwood**
Paper	**Unfinished wood products**	**Building material**	**Finished wood products**			
X	X	X	X	X	X	X

Protection			**Rehabilitation**	**Food products**	**Oils and other**	**General services**
Erosion	**Wind**	**Erosion and wind**				
			X	X	X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

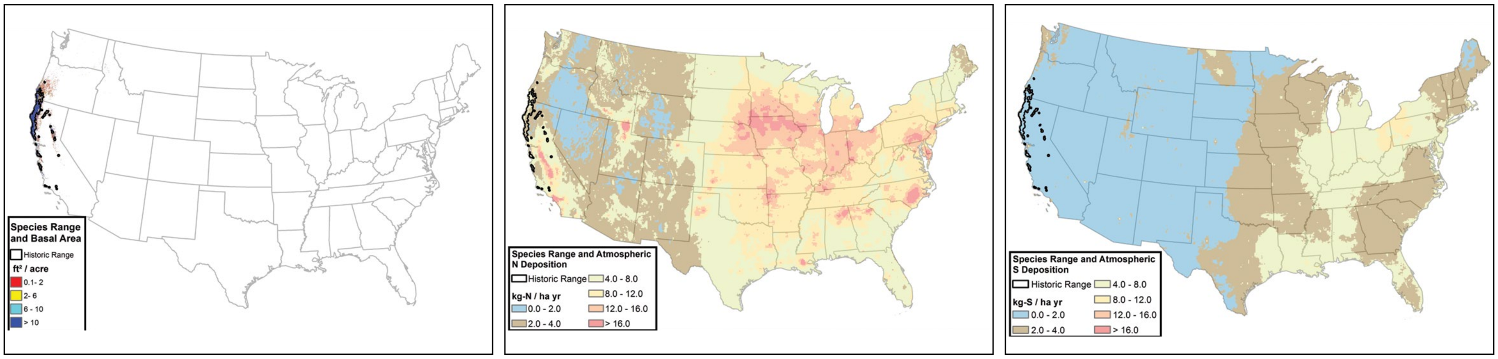
Primary Sources

Griffith, Randy Scott. 1991. *Liriodendron tulipifera*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (4 March 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Lithocarpus densiflorus (tanoak)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Tanoak grows as a tree or shrub. The typical variety is a medium-sized tree, usually 65 to 80 (20–24 m) feet tall. Dwarf tanoak is a shrub, usually less than 10 feet (3 m) tall. In the typical variety, trees in the subcanopy have narrow crowns, while open-grown trees have broad, rounded crowns. The boles are generally long and straight. Shaded trunks typically self-prune, so they are often clear of branches for 30 to 80 feet (9–24 m). Trunks may be crooked in dense stands. Leaves are sclerophyllous and evergreen. The large, heavy acorns generally fall and remain beneath the parent tree unless dispersed by animals. Tanoak strongly sprouts from the burl after fire, cutting, or other top-killing events. The tree requires relatively high moisture levels and mild temperatures, restricting it from xeric or cold sites. The typical variety occurs only where moisture is available from the atmosphere and/or soil. On unproductive sites and in the southern portion of its range, the typical variety is mostly restricted to riparian zones; shady, sheltered habitats; and north slopes. Soils supporting tanoak are typically deep and well drained, but it grows in a variety of soil textures and parent materials. The tree is shade tolerant when young and can persist in shade as a mature tree, but it also tolerates full sunlight, so it can be either a pioneer after fire or other top-killing disturbance or a subcanopy component in old-growth forests. Tanoak responds well to canopy release, but sudden exposure to full sunlight usually causes leaf scorch and initial crown die-back. Generally, tanoak can form dense, sometimes nearly pure stands in early succession but is typically overtopped by conifers decades later, which often become dominant in the subcanopy. It is an important part of mixed-conifer-hardwood ecosystems, because it facilitates conifer establishment. Its strong sprouting ability makes the species well adapted to fire.

Wildlife Uses

Tanoak provides habitat and food for a variety of forest-dwelling mammals and birds. As a consistent acorn producer, tanoak acorns may be especially important when oak acorn crops are scant. A number of species, among them northern flying squirrels, Allen's chipmunks, mule deer, Steller's jay, varied thrush, acorn woodpecker, and dusky-footed woodrats feed on tanoak acorns. Cattle, domestic goats, and domestic and feral pigs also eat them. Chickadees and other gleaning birds forage on tanoak. Mule deer, goats, cattle, horses, sheep, and goats browse the tree. Ectomycorrhizal fungi infecting tanoaks provide an important food source for the northern flying squirrels. Tanoak offers hiding, thermal, and nesting cover for many mammal and bird species—northern spotted owls, dusky-footed woodrats, squirrels, and chipmunks. Marbled murrelets, fishers, ringtails, spotted owls, sharp-shinned hawks, blue grouse, pileated woodpeckers, and Pacific giant salamanders all occur in Douglas-fir/tanoak or redwood/Douglas-fir/tanoak habitat.

Specimen of *Lithocarpus densiflorus* (Fryer 2008). Photo courtesy of Br. Alfred Brousseau, St. Mary's College.

Foliage of *Lithocarpus densiflorus.* Photo by Joseph O'Brien, USDA Forest Service, Bugwood.org, 1427043.

Ecosystem Services

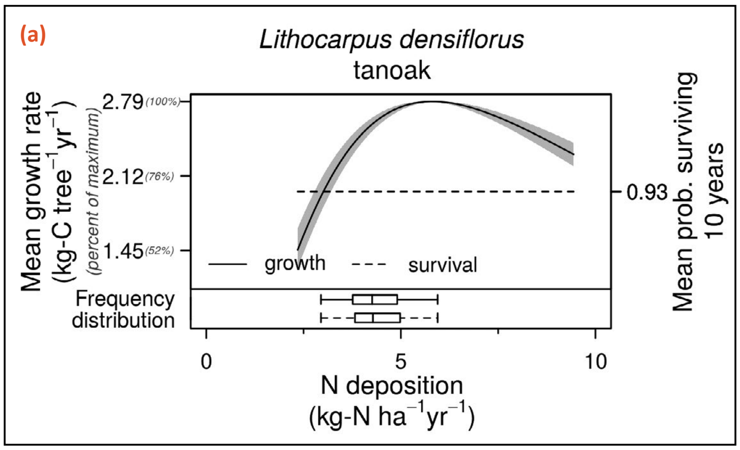
Tanoak wood is used for lumber and a variety of hardwood products. Tanoak's common name comes from tannin, which was extracted from the bark and used for tanning saddle and other heavy leathers.

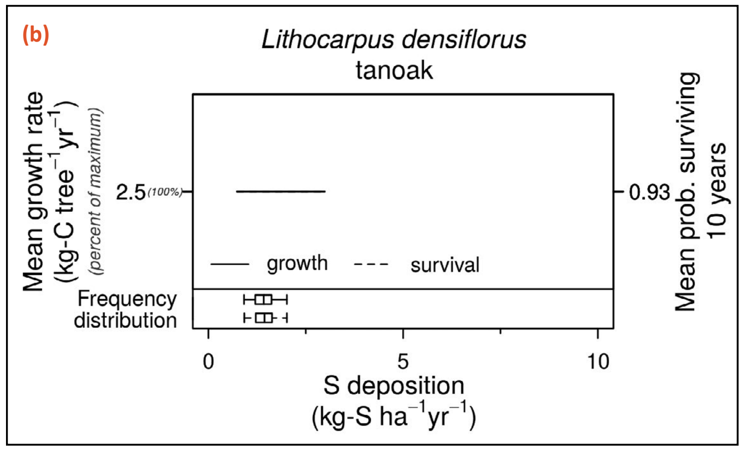
Indigenous peoples preferred tanoak acorns over those of other western oak species for food. After leaching the acorns, they ground them into meal for breads, porridges, and puddings. The Ohlone used a tanoak bark infusion as a wash for facial sores and to tighten loose teeth.

Tanoaks provide watershed protection and are valuable wildlife trees, so they are usually left to reproduce naturally on restoration sites.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of tanoak has a hump-shaped relationship with increasing N deposition and no relationship to S deposition. Survival has no relationship to N or to S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.





Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	High	Broadleaf Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
	X	X		X		

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
X			X	X	X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

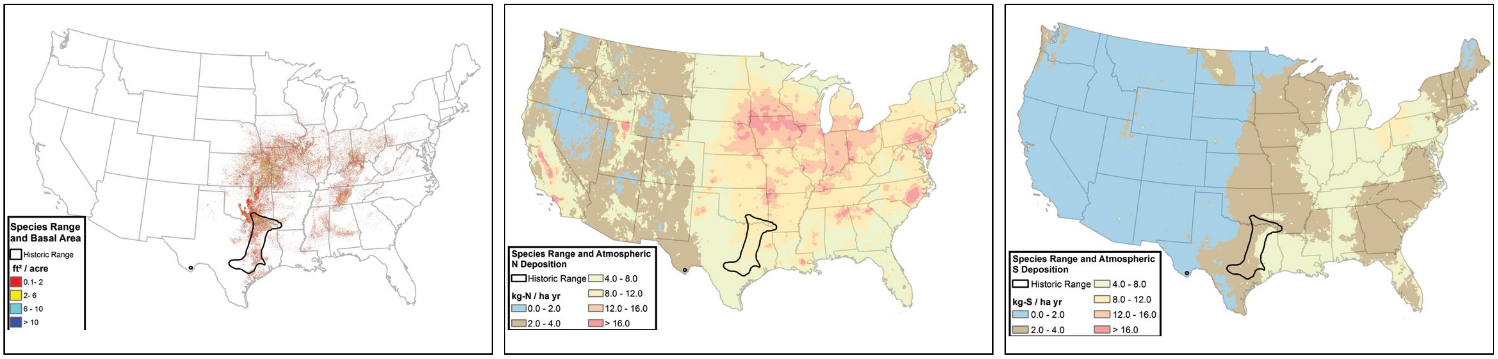
Primary Sources

Fryer, Janet L. 2008. *Lithocarpus densiflorus*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/. (4 March 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Maclura pomifera (Osage-orange)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Osage-orange is a small, native, deciduous tree that averages 30 feet (9 m) in height. It has a short trunk and rounded crown. Shade-killed lower branches remain on the tree for years, forming a dense thicket. Branches growing in full sun have sharp, stout thorns 0.5 to 1 inch (1.3–2.5 cm) long. Good seed crops are produced nearly every year, and animals, gravity, and water disseminate the seeds. Osage-orange sprouts vigorously from the stump and roots. The plant requires a moderate amount of precipitation and is sensitive to extreme cold. It grows on a variety of soils but does best on rich, moist, well-drained bottomlands. It occurs on alkaline soils, shallow soils overlaying limestone, clayey soils, and sandy soils. It can also tolerate seasonal flooding. The shade tolerance of osage-orange is uncertain—it grows in the subcanopy of bottomland forests, but it also invades overgrazed pastures and other open, disturbed sites with eroding soil. It regenerates naturally on sunny sites but grows when planted in dense hedges. Osage-orange tends to become more predominant in smaller forested fragments, and is considered a species well-adapted to disturbance.

Wildlife Uses

Osage-orange provides shelter and cover for wildlife. Seedlings and sprouts are browsed occasionally, but wildlife generally do not eat the bitter-tasting, fleshy fruit. Some animals, including squirrel, fox, red crossbill, and northern bobwhite, occasionally eat the seeds. Downy woodpeckers use osage-orange as forage sites. Small mammals and birds use the thorny tree for cover.

Ecosystem Services

Osage wood—hard, durable and resistant to decay—has been primarily used for fence posts. Early European settlers of the Great Plains planted the species for hedgerows because the diffuse, thorny branches form impenetrable hedges to fence-in livestock. It is still planted there for hedgerows and shelterbelts, and is planted as an ornamental. Osage-orange wood extractives are used for food processing, pesticide manufacturing, and dye making. The strong-smelling fruit repels cockroaches.

The Osage traditionally used the wood for dye and bows. It is favored for constructing ceremonial staffs in Kiowa peyote ceremonies for the singers.

Osage-orange is used for soil stabilization and strip-mine reclamation.

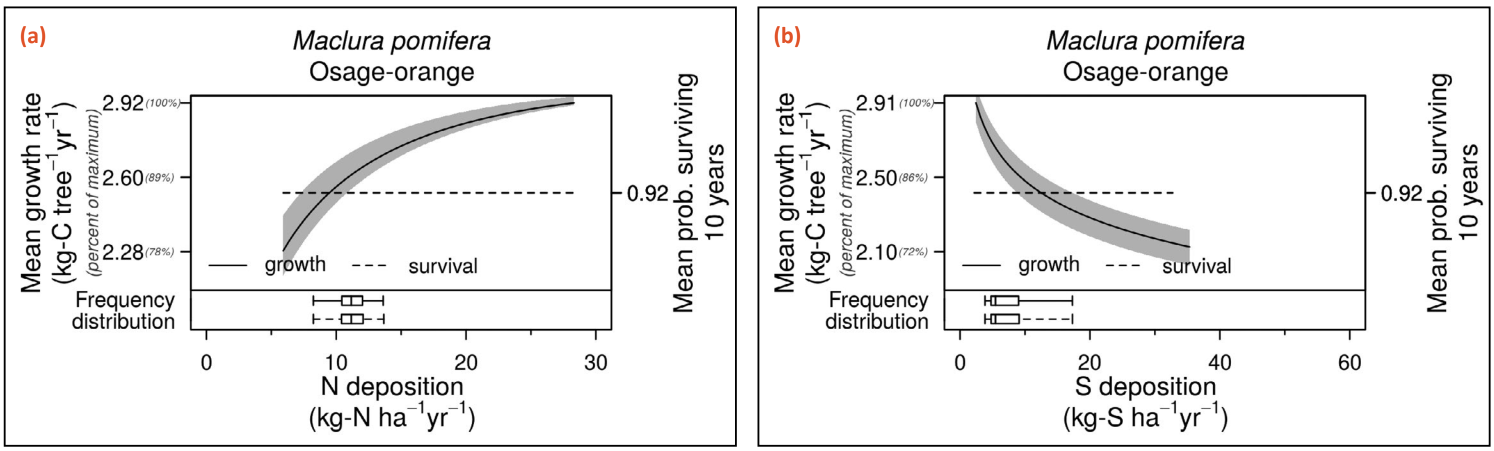
Specimens of *Maclura pomifera*. Photo by John D. Byrd, Mississippi State University, Bugwood.org, 1391146.

Bark of *Maclura pomifera*. Photo by Paul Wray, Iowa State University, Bugwood.org, 0008036.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of Osage-orange increases with increasing N deposition and decreases with increasing S deposition. Survival has no relationship to N or to S deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Fruit of *Maclura pomifera*. Photo by Franklin Bonner (retired), USDA Forest Service, Bugwood.org, 5424032.



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Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
	X			X	X	

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
		X	X	X	X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

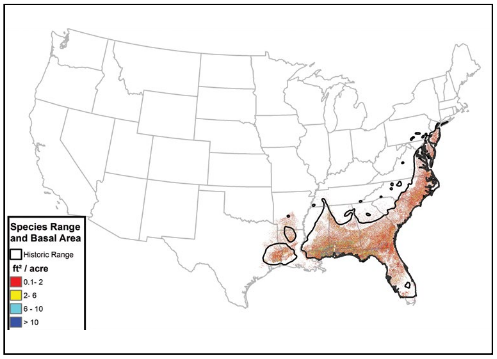
Primary Sources

Carey, Jennifer H. 1994. *Maclura pomifera*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (4 March 2016).

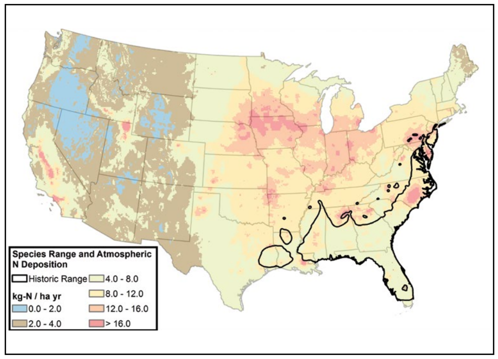
Native American Ethnobotany Database. http://naeb.brit.org.

Magnolia virginiana (sweetbay)

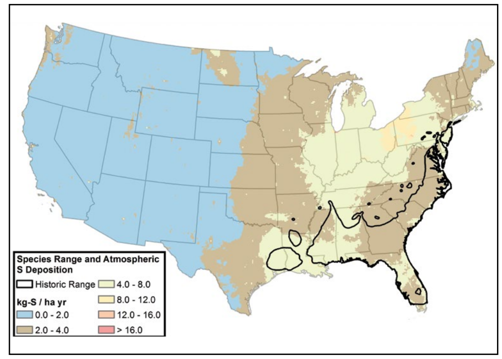
(a)



(b)



(c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Sweetbay normally grows as a multi-stemmed shrub or slender tree in the Northeast and as a single-trunked tree in the Southeast. In its more northern distribution, it may be only 33 to 66 feet (10–20 m) tall, and in its southern distribution, it may grow to 98 feet (30 m) tall. The crown spread is typically 10 to 20 feet (3–6 m). Sweetbay flowers occur singly at branch ends. The seeds are likely dispersed by mammals, birds, heavy rains, and/or gusty winds. The tree also vigorously sprouts from roots and root crown if top-killed. Throughout its range, sweetbay is most common in wet woods, swamps, swamp margins, savannas, hammocks, bogs, and floodplains. The species is common and often reaches its greatest abundance in areas generically and locally referred to as bay forests, Carolina bays, bayheads, baygalls, evergreen shrub bogs, or pocosins. Organic, acidic, moist to wet soils are most common in sweetbay habitats. In general, the tree is shade-tolerant, although tolerance may decrease with age; it typically sprouts following top-kill or damage, making it a potential species in both late- and early-seral communities. Several sweetbay habitats and their associated ecosystem processes are threatened by anthropogenic land use and resource extraction.

Wildlife Uses

Deer, black bear, beavers, and cattle browse the leaves and twigs throughout the year. Winter cattle diets may be up to 25 percent sweetbay. Squirrels, other small mammals, song birds, wild turkeys, American black bear, and bobwhite quail feed on the seeds, as do eastern kingbirds, mockingbirds, robins, wood thrushes, and red-eyed vireos. Those same bird species also use the leaves in constructing their nests.

Ecosystem Services

Sweetbay wood is used for a variety of products including furniture and interior finishing work.

The Houma and Rappahannock of Louisiana and Virginia, respectively, traditionally used the leaves, bark, and roots to treat colds, rheumatism, pleurisy, cough, consumption, typhoid fever, autumnal fever, and to prevent chills. It was also traditionally used as a hallucinogen.

Sweetbay may be useful in the reclamation of mined areas.

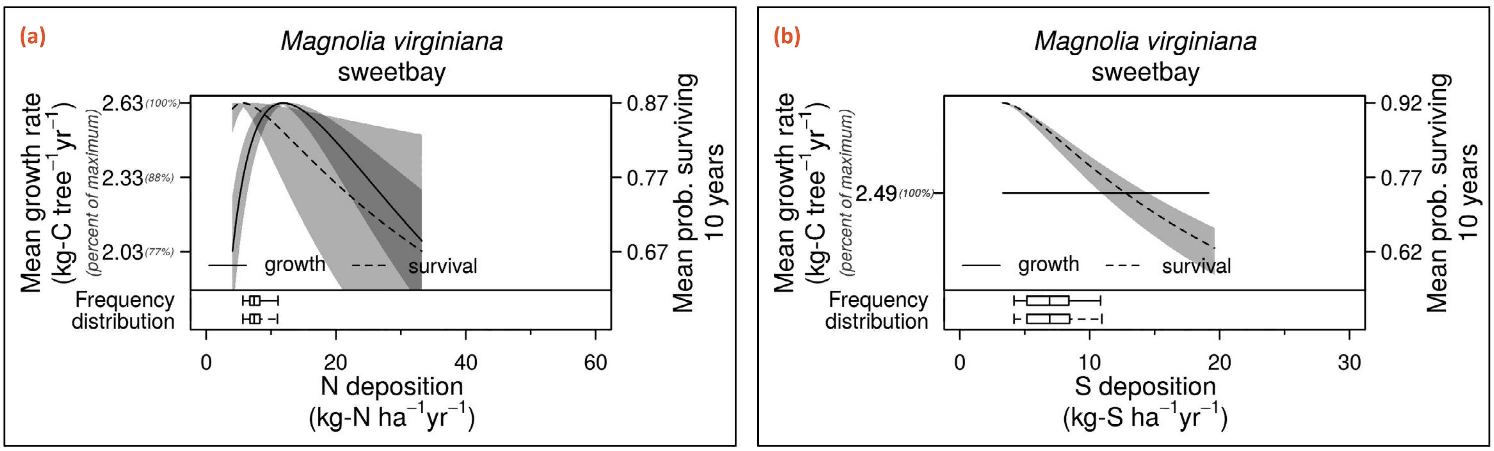
Canopy of *Magnolia virginiana*. Photo by David Stephens, Bugwood.org, 5445517.

Bark of *Magnolia virginiana.* Photo by David Stephens, Bugwood.org, 5445519.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of sweetbay has a hump-shaped relationship with increasing N deposition and no relationship to S deposition. Survival mostly decreases with increasing N deposition and decreases with increasing S deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Flower of *Magnolia virginiana.* Photo by Dow Gardens, Dow Gardens, Bugwood.org, 5142073.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Broadleaf Evergreen	Yes	Yes

Wood products: Paper	Wood products: Unfinished wood products	Wood products: Building material	Wood products: Finished wood products	Traditional uses	Ornamental uses	Fuelwood
	X		X	X		

Protection: Erosion	Protection: Wind	Protection: Erosion and wind	Rehabilitation	Food products	Oils and other	General services
			X			X

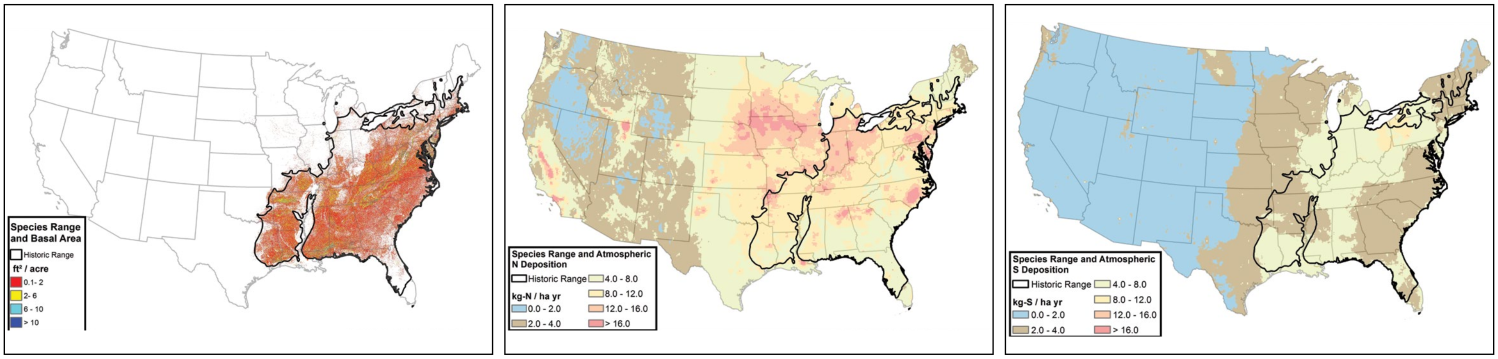
A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

Primary Sources

Gucker, Corey L. 2008. *Magnolia virginiana*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (3 March 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Nyssa sylvatica (black tupelo or blackgum)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Black tupelo is a medium to large-sized, native, deciduous tree, frequently 60 to 80 feet high (18–24 m). In the forest, it typically has a dense foliage with a conical crown on an erect trunk which extends continuously into the top. The simple, alternate leaves are leathery and densely clustered at the branchlets. The small greenish-white flowers are borne singly or in clusters. The bark is reddish brown and broken into deep irregular ridges and diamond-shaped plates. Gravity and birds disseminate the seeds. Birds consume the fleshy fruits and seeds pass through the digestive tract. Black tupelo can also reproduce vegetatively through sprouting from stumps following disturbance. The species is adapted to a wide variety of sites, from the creek bottoms of the southern Coastal Plain to altitudes of 3,000 feet (915 m) in North Carolina. It will tolerate brief spring flooding on alluvial sites and is common on the relatively dry upper and middle slopes in the Appalachian Mountains. On the drier uplands it will survive with a slower growth rate. Black tupelo is usually found with a mixture of other species. It is classed as shade-tolerant and rarely attains overstory dominance but usually grows in the intermediate crown class on most sites. Intermediate black tupelo stems respond favorably to release from overtopping vegetation. The tree is well adapted to fire—older trees have thick bark and relatively high moisture content, making them highly resistant even to intense fires.

Wildlife Uses

White-tailed deer commonly browse black tupelo sprouts but the tree loses its palatability with age. A variety of birds and mammals eat the high-nutrition fruit. The tree also provides cavity and nesting sites for various birds and mammals throughout the Appalachians.

Ecosystem Services

Black tupelo wood is used mainly for lumber, veneer, paper pulp, and to some extent for railroad ties. The veneer is used mainly for boxes, crates, baskets, furniture, and interior woodwork. Because of its toughness, the wood is also used for flooring, rollers in glass factories, blocks, gunstocks, and pistol grips. With its straight bole, shapely crown, and attractive autumn foliage, the tree is often planted as an ornamental. Bees draw nectar from the flowers to produce honey.

The Cherokee, Kossati, Houma, and other indigenous peoples of eastern North America made an infusion from the bark to treat worms and brewed bark decoctions to induce vomiting and to treat tuberculosis.

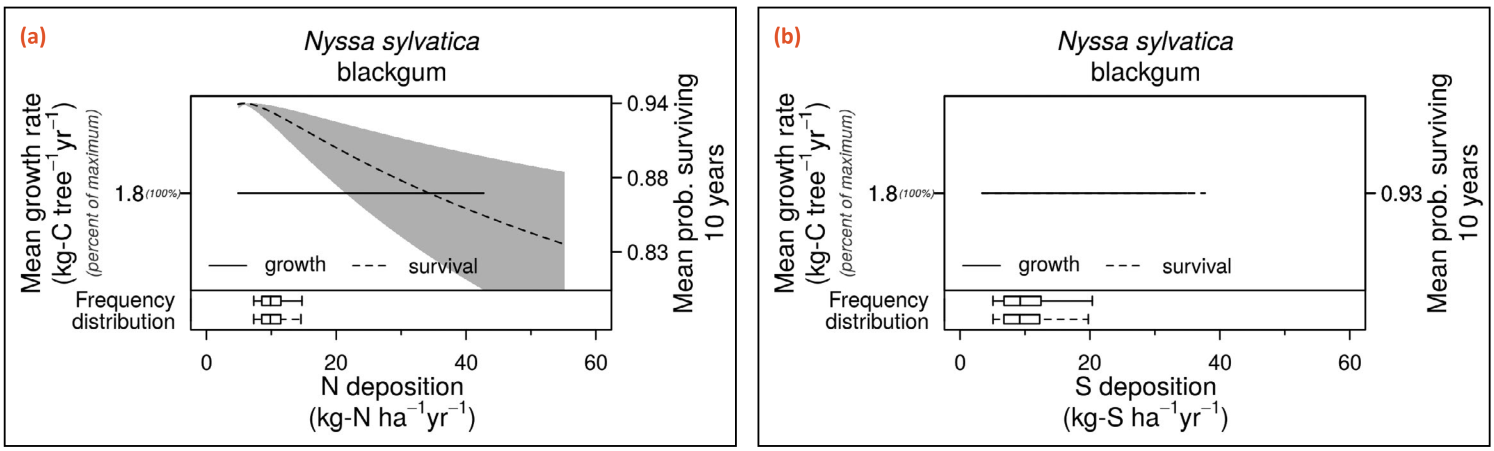
Fall foliage of *Nyssa sylvatica*. Photo by T. Davis Sydnor, The Ohio State University, Bugwood.org, 5509882.

Bark of *Nyssa sylvatica*. Photo by Vern Wilkins, Indiana University, Bugwood.org, 5454080.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of blackgum has no relationship to N or to S deposition. Survival decreases with increasing N deposition and has no relationship to S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Fruits of *Nyssa sylvatica.* Photo by Franklin Bonner (retired), USDA Forest Service, Bugwood.org, 5424039.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	High	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X	X	X	X	

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
				X		X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

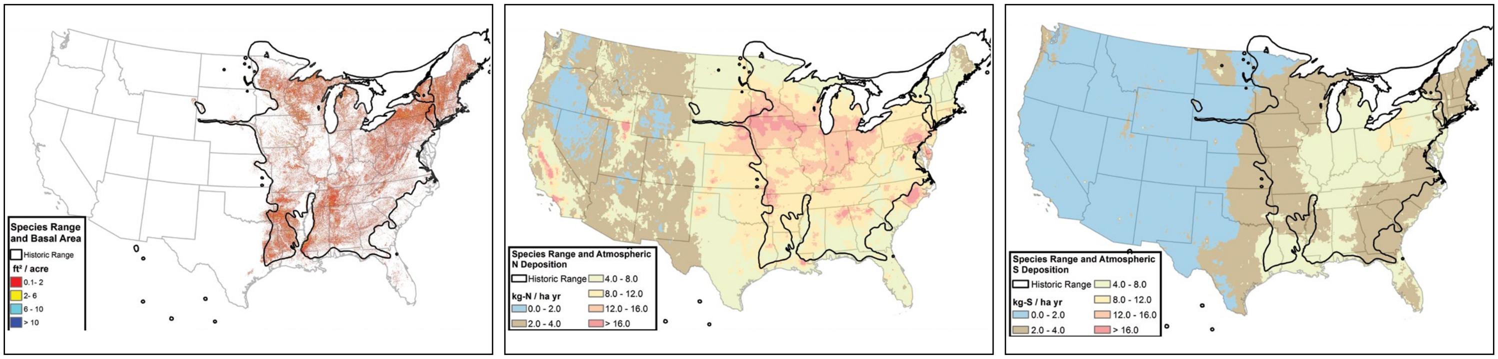
Primary Sources

Coladonato, Milo 1992. *Nyssa sylvatica* In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. 3 March 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Ostrya virginiana (eastern hophornbeam)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Eastern hophornbeam is a small, slow-growing, shapely tree usually not more than 35 feet (11 m) tall and 12 inches (30 cm) in diameter. The tree develops a broad top (sometimes as much as 50 feet [15 m] across) of small, spreading branches. The leaves are alternate with slender hairy stems. The pistillate flowers are in slender catkins. The hoplike fruit, a stobile, is 1 to 2 inches (2.5–5 cm) long and borne on short, slender stems. It begins to break up immediately after ripening, and wind and birds disperse the lightweight seeds throughout the fall and early winter. Cut, burned, or injured trees commonly sprout from the stump. Eastern hophornbeam grows on a wide variety of sites but is most common on dry-mesic and mesic valley bottoms and lower slopes. It typically grows in climax forests in the northern parts of its range. It is classed as shade-tolerant and will reproduce well under full shade. In the Southeast, eastern hophornbeam is associated with a later seral stage that follows the pioneer pine communities. After aboveground portions are killed by fire, the tree can reestablish by sprouting from the root crown.

Wildlife Uses

White-tailed deer only incidentally browse eastern hophornbeam throughout its range. The buds and catkins provide an important winter food for ruffed grouse, and the nuts are a secondary food in the fall. The nuts are also a preferred food for sharp-tailed grouse and wild turkey, and are eaten to a lesser extent by northern bobwhite, red and gray squirrels, cottontails, ring-necked pheasant, purple finch, rose-breasted grosbeak, and downy woodpecker.

Ecosystem Services

The strong, hard, heavy wood takes a fine polish, and is made into posts, golf club handles, tool handles, mallets, and other woodwares. However, the tree is not harvested for timber because of its relatively small size and scattered distribution. The tree has been cultivated as an ornamental in the Eastern United States.

Traditional uses of the eastern hophornbeam by the Iroquois, Delaware, Potawatomi, and others included painting the face with blossoms; treating hemorrhages, colds, coughs, and heart problems with a compound decoction of heart wood chips; and drinking a bark infusion for toothaches.

Eastern hophornbeam exhibits fast juvenile growth, indicating its potential to provide vegetative cover in areas that have been disturbed by overstory cutting.

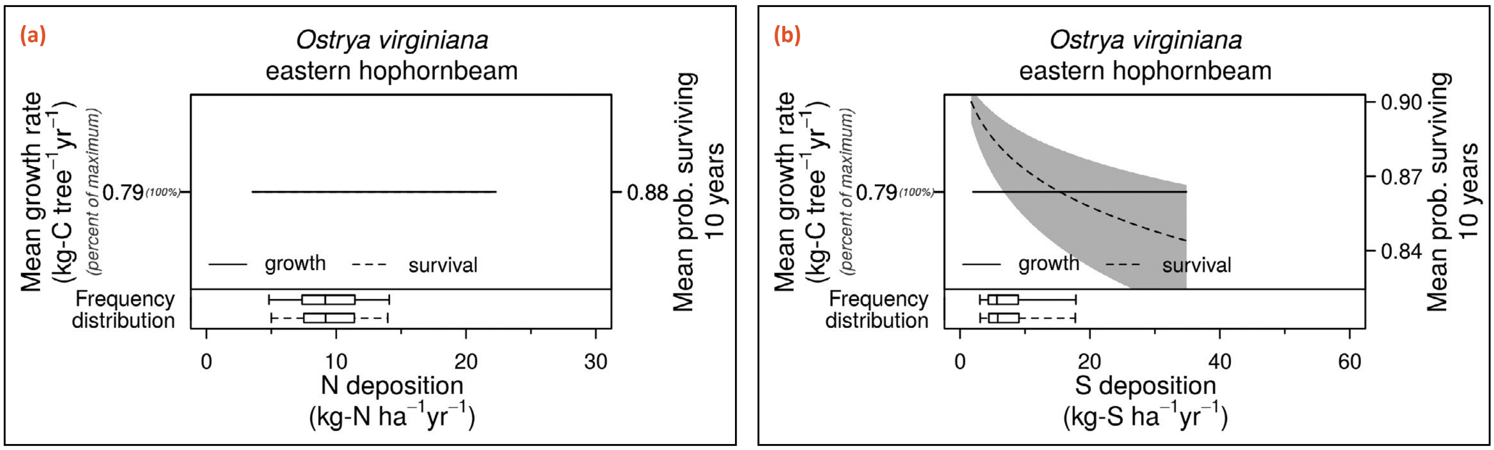
Fruits of *Ostrya virginiana*. Photo by Paul Wray, Iowa State University, Bugwood.org, 0008214.

Bark of *Ostrya virginiana*. Photo by T. Davis Sydnor, The Ohio State University, Bugwood.org, 5509902.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of eastern hophornbeam has no relationship to N or S deposition. Survival has no relationship to N deposition and decreases with increasing S deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Flowers of *Ostrya virginiana*. Photo by Vern Wilkins, Indiana University, Bugwood.org , 5497129.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	High	Broadleaf Deciduous	Yes	Yes

Wood products: Paper	Wood products: Unfinished wood products	Wood products: Building material	Wood products: Finished wood products	Traditional uses	Ornamental uses	Fuelwood
	X		X	X	X	

Protection: Erosion	Protection: Wind	Protection: Erosion and wind	Rehabilitation	Food products	Oils and other	General services
			X			X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

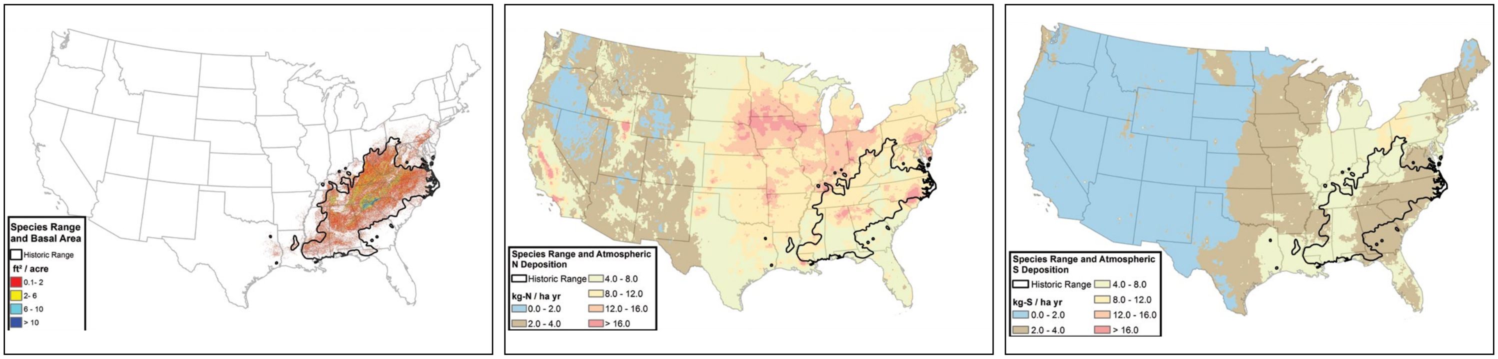
Primary Sources

Coladonato, Milo 1992. *Ostrya virginiana*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (3 March 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Oxydendrum arboretum (sourwood)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Sourwood is a native, deciduous, medium-sized tree, 40 to 60 feet (12–15 m) tall. It develops a slender trunk and small crown in dense stands. In the open, it forms a short, often leaning trunk dividing into several stout, ascending limbs. The simple, alternate leaves are 4 to 7 inches (10–18 cm) long and variable in shape. The fruit is a capsule that contains many tiny seeds. The fruits are shed in the fall, and the seeds are dispersed gradually throughout the winter by the dehiscing capsule. Sourwood sprouts prolifically and persistently from the stump and root crown. In the Central Appalachian Mountains, sourwood is most abundant on subxeric open slopes and ridges. The tree grows throughout the Piedmont uplands and is also found along Piedmont streams on well-drained lowland areas not subject to flooding. In the Coastal Plain it is found on gently rolling areas. It is a facultative seral species. Sourwood is shade-tolerant, but its response to release is unknown. It has the ability to sprout from the root crown or stump following fire.

Wildlife Uses

White-tailed deer often browse the sprouts. Sourwood snags provide cavity-nesting sites for various birds in southern Appalachian forests.

Ecosystem Services

Sourwood is of little value as a commercial timber species. The wood is used for tool handles and for fuel and mixed with other species for pulp. The tree is occasionally planted as an ornamental because of the brilliant fall color of its leaves and midsummer flowers. The flowers also provide an important source of honey.

The Catawba and Cherokee make pipe stems, butter paddles, and arrow shafts from the wood. Traditional uses included chewing the bark to treat mouth ulcers; and brewing of infusions and tonics to treat asthma, nerves, and diarrhea.

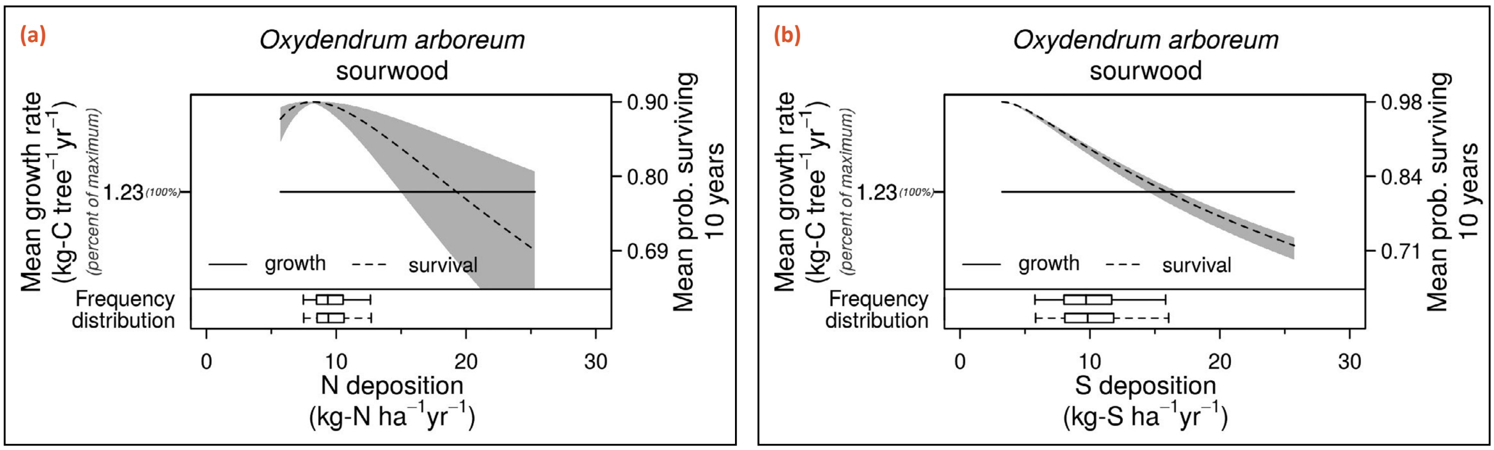
Fall foliage of *Oxydendrum arboretum*. Photo by David Stephens, Bugwood.org, 5445506.

Bark of *Oxydendrum arboretum*. Photo by Chris Evans, University of Illinois, Bugwood.org, 1380372.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of sourwood has no relationship to N or S deposition. Survival mostly decreases with increasing N deposition and decreases with increasing S deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Foliage of *Oxydendrum arboretum.* Photo by Chris Evans, University of Illinois, Bugwood.org, 1330075.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	High	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X			X	X	X	X
Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
				X		X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

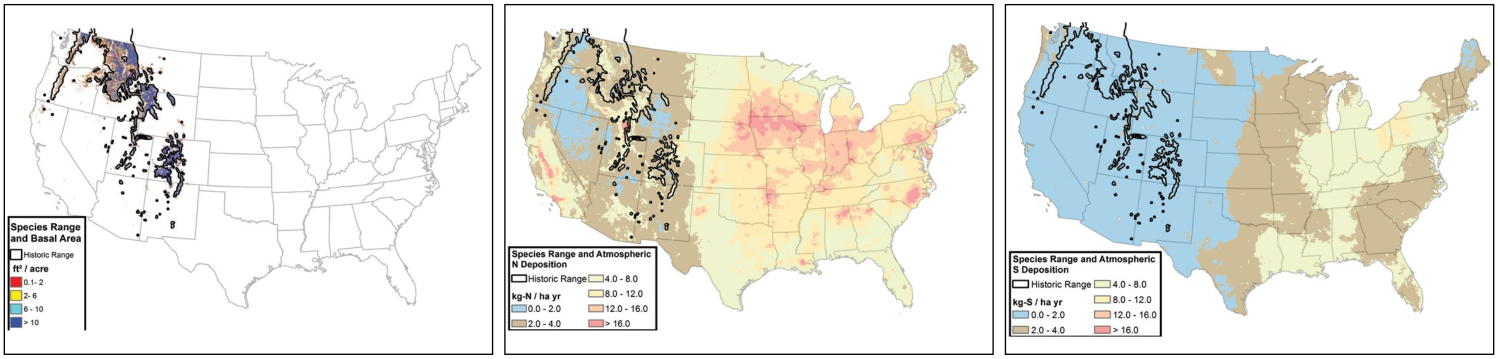
Primary Sources

Coladonato, Milo. 1992. *Oxydendrum arboreum*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (3 March 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Picea engelmannii (Engelmann spruce)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Engelmann spruce is a long-lived, native, coniferous, evergreen tree. It is one of the largest of the high-elevation mountain conifers. Mature trees have a narrow, pyramidal form and short, compact branches. Within natural stands, the average dominant height varies from 45 to 130 feet (14–40 m), and mature trees average 15 to 30 inches (38–76 cm) in diameter. Dominant trees of this long-lived species are often 350 to 450 years old, and 500- to 600-year-old trees are not uncommon. In alpine areas just above treeline, Engelmann spruce often forms a krummholz. The wind disperses the seed over glazed snow. Near timberline, where the species assumes a dwarf or prostrate form, it frequently reproduces by layering. The tree is found in some of the highest and coldest forest environments in the Western United States, characterized by long, cold winters with heavy snowpack and short, cool summers. It is generally found on moist and cool sites, but at timberline it may occur on somewhat dry sites. At middle elevations, pure stands are usually found on alluvial terraces, wet benches, bottomlands, slopes with seeps or cold north or east aspects. The tree occurs on a variety of soil types but grows best on moderately deep, well-drained, loamy sands and silts, and silt and clay loam soils developed from volcanic lava flows and sedimentary rock. In the Rocky Mountains north and south of Montana and Idaho, Engelmann spruce and subalpine fir often co-dominate at climax to form extensive Engelmann spruce-subalpine fir forests. In the Rocky Mountains of Montana and Idaho, and in the mountains of eastern Washington and eastern Oregon, Engelmann spruce is usually considered seral to subalpine fir. Typically, it succeeds aspen and lodgepole pine. However, frequent fires will prevent Engelmann spruce from achieving climax dominance or codominance.

Wildlife Uses

Livestock generally do not browse the tree. Engelmann spruce-subalpine fir forests provide forage and habitat for a wide variety of small and large wildlife species; however, these properties are characteristic of where spruce grows and the understory species associated with it rather than with the species itself. Occasionally ungulates browse the young growth, but it is not an important food item and is probably only taken as a last resort. Spruce grouse and blue grouse may feed extensively on buds and needles. Squirrels sometimes clip and eat twigs and buds. Several species of small mammals and birds eat Engelmann spruce seeds—red squirrels, chickarees, and chipmunks eat seeds from cached cones, and chipmunks, mice, and voles eat the seeds off the ground or snow. Numerous species of birds, including chickadees, nuthatches, crossbills, and the pine siskin, remove and eat seeds from spruce cones; small birds may make considerable use of the seeds, but their foraging is scattered and sporadic throughout subalpine forests. Engelmann spruce provides excellent hiding and thermal cover for deer, elk, moose, bighorn sheep, and bear. Dense stands of this species can provide cool summertime shade for big game. High-elevation stands provide bedding sites and protection from storms for bighorn sheep, mule deer, and elk. The small trees provide good year-round hiding cover for small animals. Blue grouse, which overwinter in conifers at high elevations, use spruce trees for protective cover and roosting sites. Spruce trees in the Engelmann spruce/soft-leaved sedge (Carex disperma) habitat type in central Idaho provide important nesting sites for the MacGillivray's warbler, American robin, and warbling vireo. Numerous cavity-nesting birds use the snags.

Cones and foliage of *Picea engelmannii*. Photo by Dave Powell, USDA Forest Service (retired), Bugwood.org, 1214097

Ecosystem Services

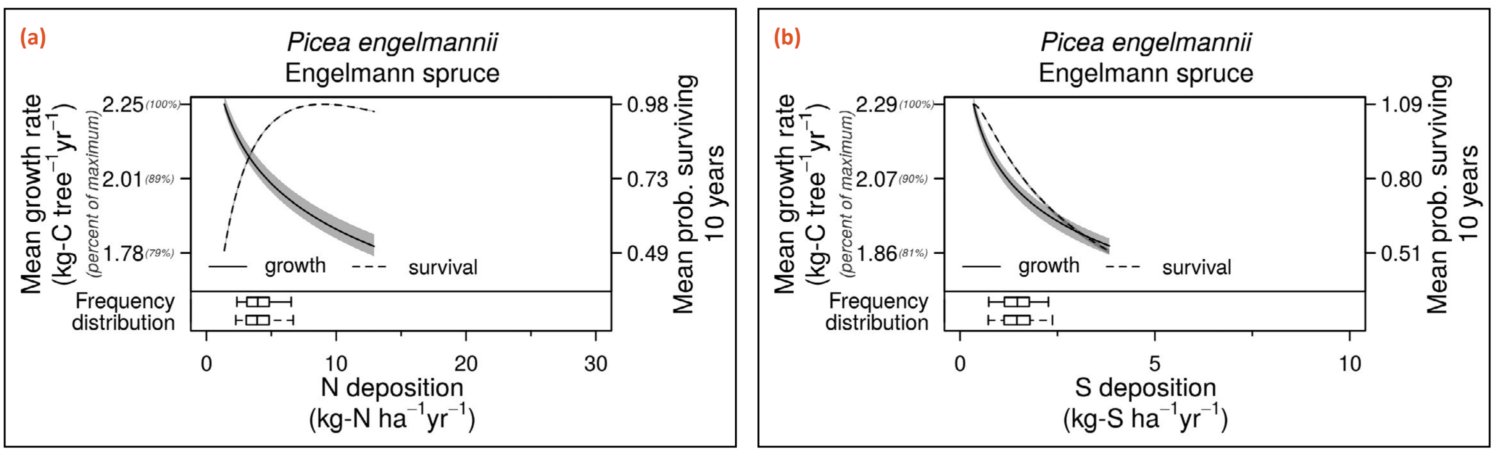
The wood—white, odorless, lightweight, straight-grained, soft, stiff—can be readily air dried and is primarily used for lumber for home construction and for prefabricated wood products. Less common uses include veneer in plywood manufacture, poles, and specialty items, such as food containers, violins, pianos, and aircraft parts. Spruce has not been used much for pulp and paper, although it has excellent pulping properties. Engelmann spruce is sometimes used as an ornamental landscape plant and has been planted for screenings, windbreaks, and as a specimen tree.

Indigenous peoples of western North America, including the Navajo, Okanagan-Colville, and Quileute have many uses for the tree. The bark is peeled into sheets and made into canoes, baskets, and roofing; the fibrous roots are made into rope; and the boughs and needles are made into incense, body scents, and cleansing agents. Traditional medicinal uses included teas and poultices; occasionally the inner bark was eaten.

Englemann spruce has been used to a limited extent for revegetation and long-term stabilization of high-elevation mine spoils.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of Engelmann spruce decreases with increasing N and S deposition. Survival has a hump-shaped relationship with increasing N deposition and decreases with increasing S deposition. Confidence in these relationships is low based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	High	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X	X	X	X	

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
	X		X			X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

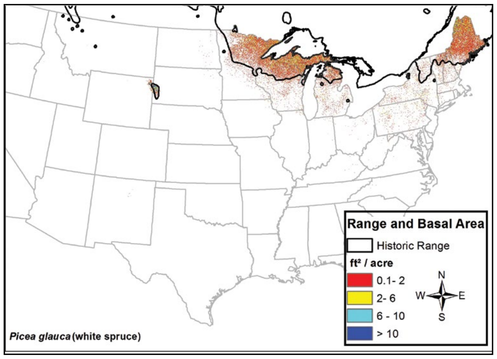
Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

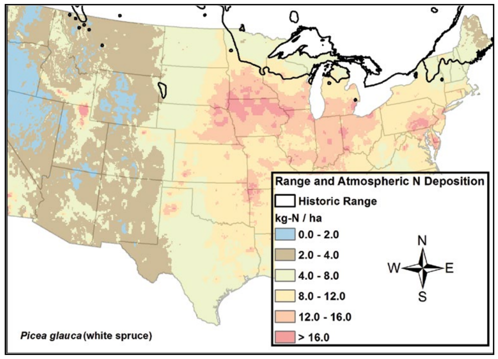
Uchytil, Ronald J. 1991. *Picea engelmannii*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (3 March 2016).

Picea glauca (white spruce)

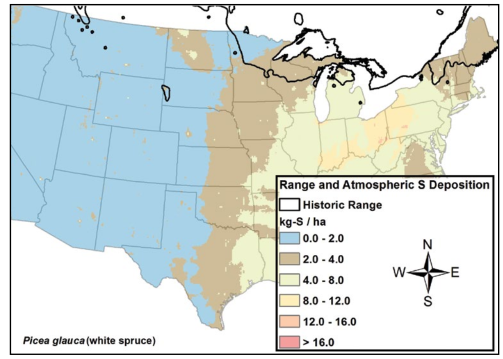
(a)



(b)



(c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

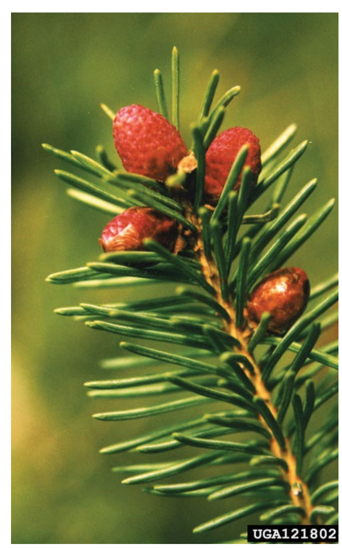
Species Characteristics and Habitat

White spruce is a conifer that grows as a medium-sized tree or as a shrub. Trees typically average 80 feet (25 m) tall and 24 to 36 inches (60–90 cm) in diameter. The trees typically have a straight bole with a broadly conical to narrow, almost linear crown and slightly drooping branches. Crowns are usually densely foliated, and branches and needles are often retained low on the trunk. The bole has thin smooth, scaly, or flaky bark. White spruce cone/seed production varies greatly from year to year, influenced by climatic conditions. Wind, primarily, disperses the winged seeds. In general, seeds that fall closer to the parent tree are more likely to be viable than seeds that are dispersed farther away. Although the species does not have serotinous cones, crown-stored seed may occasionally be available after fire depending on fire timing, severity, and type. However, layering may be important for regeneration when sexual reproduction is limited due to harsh climatic conditions, such as at treeline sites. Although white spruce may grow in a range of moisture conditions, it rarely occurs where permafrost is close to the surface, and it grows poorly in sites with stagnant water or high water tables. It tolerates a range of fertility levels and grows on both acidic and alkaline soils and in all soil textures, often dominating in sandy or gravelly alluvial soil. It is generally considered a mid- to late-successional species, but it occurs in all stages of boreal forest succession. Fire generally initiates succession throughout white spruce's range, but is more prevalent in Western than in eastern North America. In its eastern distribution (and on relatively wet sites in the West), insect outbreaks and subsequent gap succession may be more important than fire in initiating succession. White spruce tree density tends to decline with increasing stand age or peak before stands senesce.

Wildlife Uses

Mammals using white spruce communities as habitat include red squirrels, snowshoe hares, American marten, voles (northern red-backed voles, meadow voles, and yellow-cheeked voles), moose, American black bear, and caribou. Wild ungulates and livestock rarely browse white spruce. During the winter, caribou and moose occasionally eat the needles and branches of small saplings. Because it is rarely browsed, tree species composition may shift in favor of white spruce under heavy browsing pressure. White spruce does provide important browse for some birds and small mammals—in particular, snowshoe hares, which browse the tree throughout much of its range. Numerous birds, such as spruce grouse, and mammals, such as deer mice, northern red-backed voles, meadow voles, and shrews, eat the seeds. Various bird species, including woodpeckers and sharp-shinned hawks, use white spruce communities for nesting or foraging. Many wildlife species are adapted to particular

Specimen of *Picea glauca.* Photo by Bill Cook, Michigan State University, Bugwood.org, 1218029.



Needles and new flower buds of *Picea glauca.* Photo by Bill Cook, Michigan State University, Bugwood.org, 1218028.

successional stages in white spruce communities; for example, moose, black-backed woodpeckers, other woodpeckers, and northern hawk owls use early postfire stages; caribou use late-seral, open lichen woodlands dominated by white spruce as winter habitat for foraging grounds. Moose, white-tailed deer, and ruffed grouse take advantage of the cover provided by white spruce.

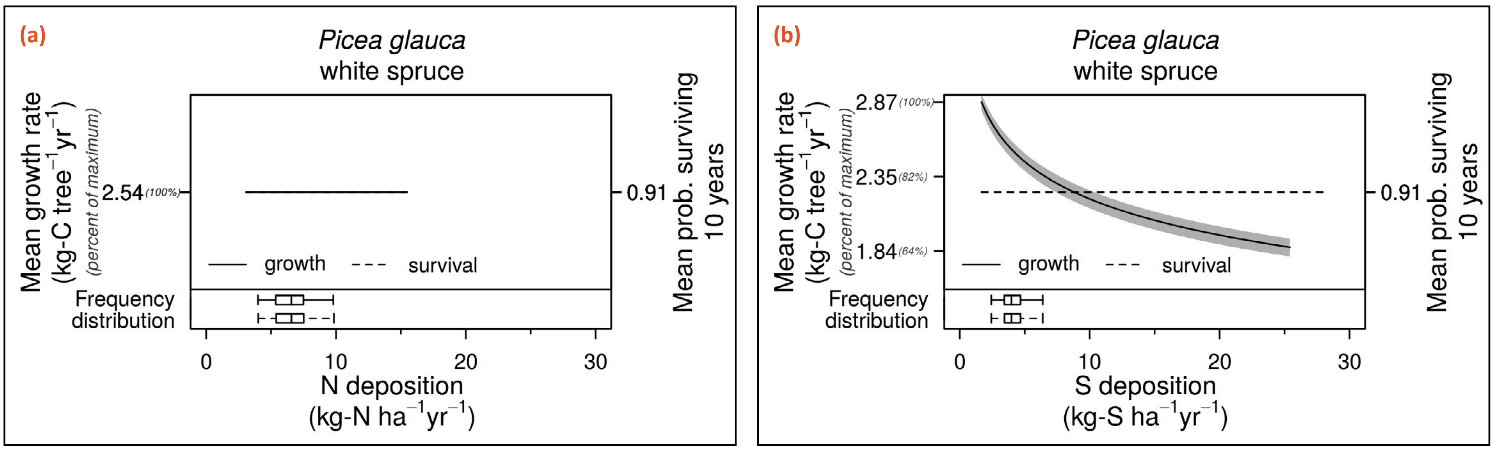
Ecosystem Services

This is one of the most important commercial species in North American boreal forests. The lightweight, straight-grained, resilient wood is used primarily for pulpwood and as lumber. White spruce is useful for long-term revegetation of coal- mine overburden and borrow pits.

The Abnaki, Algonquin, Shuswap, and others used the bark to cover dwellings and smoke hides; the roots to lash baskets and canoes; the boughs for bedding; and the pitch for medicines.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of white spruce has no relationship to N deposition and decreases with increasing S deposition. Survival has no relationship to N or S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are correlated for many species, so inferring causality to a single stressor can be difficult. See Appendix Table 4 and the Introduction for more information.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	**Shade Tolerance**	**Leaf Type**	**Mammal Uses**	**Bird Uses**
	Medium	Coniferous Evergreen	Yes	Yes

Wood products				**Traditional uses**	**Ornamental uses**	**Fuelwood**
Paper	**Unfinished wood products**	**Building material**	**Finished wood products**			
X	X	X		X		

Protection			**Rehabilitation**	**Food products**	**Oils and other**	**General services**
Erosion	**Wind**	**Erosion and wind**				
			X			X

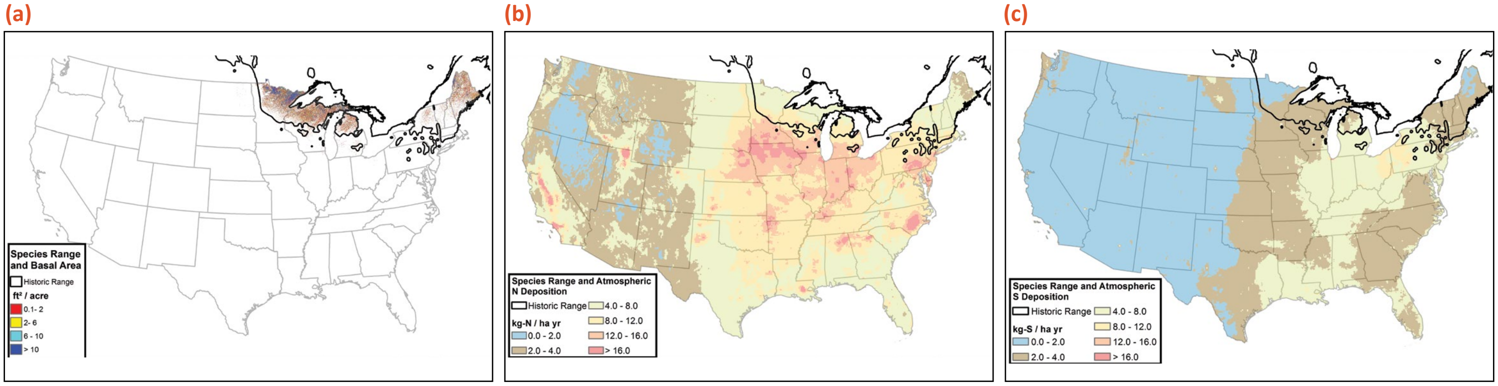
A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

Primary Sources

Abrahamson, Ilana. 2015. *Picea glauca*, white spruce. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/plants/tree/picgla/all.html. (3 March 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Picea mariana (black spruce)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Black spruce, a conifer, grows as a medium- to small-sized tree or as a shrub. Throughout its distribution, mature trees range from 30 to 50 feet (9–15 m) tall and 6 to 10 inches (15–25 cm) in diameter. It generally has a moderate lifespan, although individuals at arctic treeline may be long-lived. The trees have a straight bole with little taper and short, compact, drooping branches with upturned ends. Its primary method of reproduction is establishing a stand from seed within 10 years of a stand-replacing fire. Cones form dense clusters in the upper part of the tree. Seeds support a long, thin wing that is relatively large compared to seed size. Vegetative reproduction occurs via layering and usually is initiated when mosses or litter cover the tree's lower branches. Generally, black spruce density increases with decreasing latitude and is higher on permafrost than non-permafrost sites. It occurs mostly on cold sites, including wet lowlands and drier uplands; it is prevalent on organic soils and is particularly common in swamps, bogs, and at arctic and elevational treelines underlain with permafrost. Most succession in black spruce communities is set back by fire, but the species is found in all stages of boreal forest succession. It has intermediate shade tolerance. Many factors affect postfire trajectories in black spruce ecosystems, including prefire plant community composition, fire severity, presence of permafrost, and postfire weather.

Wildlife Uses

Wild ungulates and livestock rarely browse the species. Moose occasionally browse saplings, but white-tailed deer browse black spruce only under starvation conditions. Barren-ground caribou use black spruce/lichen woodlands and black spruce/shrub forests as winter rangeland. Woodland caribou use late-seral black spruce communities as winter habitat and forage on arboreal lichens draping on black spruce branches. Red squirrels harvest the cones and eat the seeds within. Mice, voles, shrews, and chipmunks consume seeds off the ground. Chickadees, nuthatches, crossbills, grosbeaks, and the pine siskin extract seeds from open spruce cones and eat seeds off the ground. Mammals using black spruce communities as habitat include moose, caribou, American martens, and American minks. A variety of bird species use black spruce communities, including woodpecker and sparrow species, great grey owls, and northern hawk owls. Many wildlife species are adapted to particular successional stages in black spruce communities. For example, moose, snowshoe hares, black-backed woodpeckers, and other woodpeckers use early postfire stages. American martens use mid-seral and late-seral black spruce communities. Some wildlife species move between and use different-aged black spruce stands. For example, woodland caribou use open burns when migrating and as predator escape routes. Canada lynx also might use late-seral black spruce stands during denning and when snowshoe hare numbers are low. The ruby-crowned kinglet,

Stand of *Picea mariana.* Photo by Steven Katovich, USDA Forest Service, Bugwood.org, 5506076.

Bark of *Picea mariana.* Photo by Wendy VanDyk Evans, Bugwood.org, 5443735.

magnolia warbler, Cape May warbler, and ovenbird commonly nest in black spruces.

Ecosystem Services

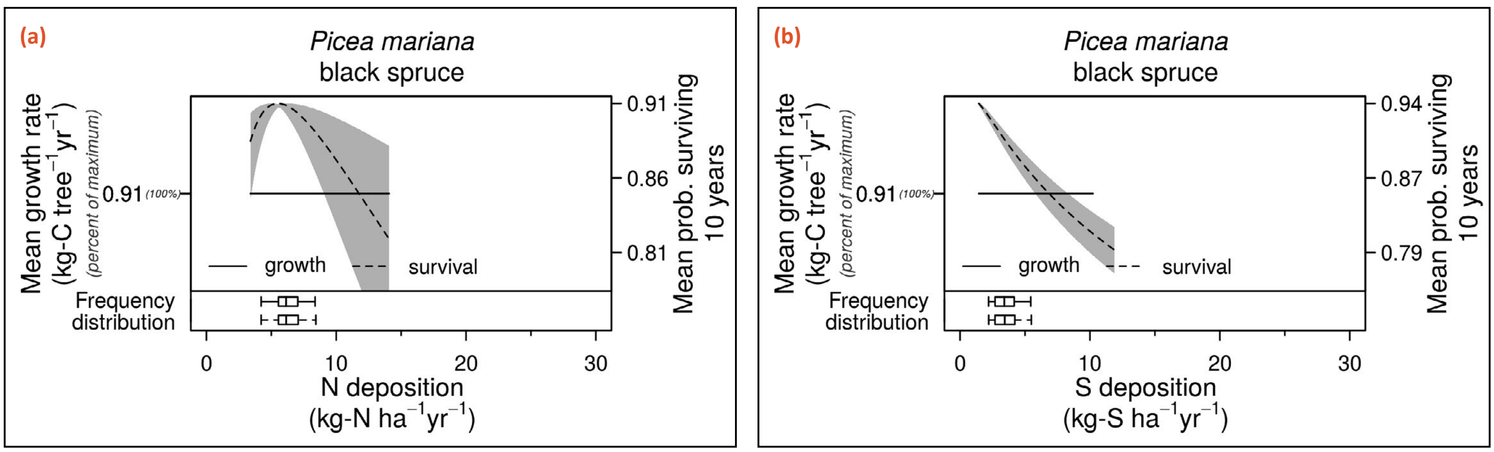
The wood is relatively lightweight but strong and is used as lumber and pulpwood. Black spruce trees are also harvested for Christmas trees.

The Algonquin, Cree, Iroquois, and others traditionally made healing salves from the gum, antiscorbutic and diuretic beverages from twigs and needles, and rope from the roots.

Black spruce is recommended for revegetating disturbed sites in boreal regions. It can be used for revegetating seismic lines, borrow pits, abandoned roads, and construction and well sites.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of black spruce has no relationship to N or S deposition. Survival has a hump-shaped relationship with increasing N deposition and decreases with increasing S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X		X		

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
			X		X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

Primary Sources

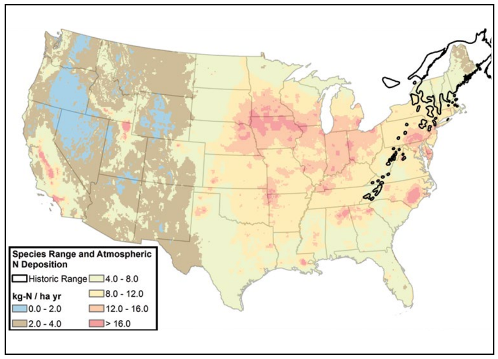
Fryer, Janet L. 2014. *Picea mariana*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (3 March 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

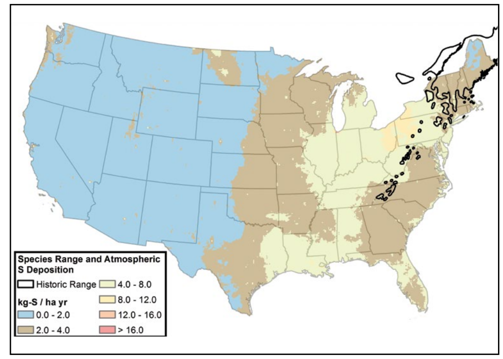
Picea rubens (red spruce)

(a)

(b)



(c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

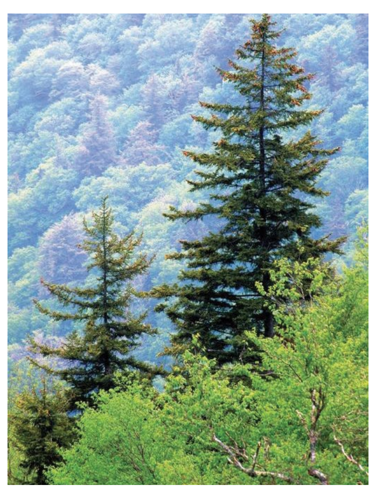
Red spruce is a native, evergreen conifer. It is a medium-sized tree, with average mature heights reaching 60 to 75 feet (18–23 m). This long-lived tree often achieves ages greater than 350 years. Red spruce reproduces exclusively by seed; the first cone crop is usually produced when the crown first reaches direct light. It grows in climates with cool, moist summers and cold winters. Most of the soils on which red spruce occurs are developed from glacial deposits; the most productive soils are derived from parent materials of unsorted glacial drift and till deposited on the midslopes of hills and mountains. The soils on these sites are usually acidic with thick mor humus and a well-defined A2 horizon. Red spruce is often found on sites that are unfavorable for other species, such as organic soils overlying rocks in mountainous locales, on steep rocky slopes with thin soils, and in wet bottomlands. The species is shade-tolerant, but growth tends to be suppressed, and it responds to canopy removal even after many years of suppression. On shallow, acidic, glacial-till soils, red spruce is considered climax. It is usually subclimax on fertile, well-drained slopes and on abandoned fields and pastures, where it is replaced by shade-tolerant hardwoods such as sugar maple and beech. Red spruce and red spruce-fir cover types are self-maintaining without disturbance. Its thin bark, shallow roots, flammable needles, lack of self-pruning mean that it is killed by fire. Throughout its range, growth rates of red spruce have declined and mortality has increased—the situation is apparently more severe at higher elevations, in older stands, and on more exposed sites. The combination of climatic stress and atmospheric pollution is probably the major cause of this decline.

Wildlife Uses

Spruce grouse browse the leaves and twigs of red spruce. Mice and voles consume and store significant amounts of spruce seeds. Birds (particularly crossbills or grosbeaks) will clip the terminal buds of young spruce, as will porcupines, bears, snowshoe hares, and, rarely, deer. Red squirrels clip twigs and terminal buds and also eat reproductive and vegetative buds. In the southern part of its range, red spruce forests are used by only a few wildlife species. Many of these species—such as snowshoe hare, wood warblers and other songbirds, rodents, and salamanders—are usually only found farther north. Red spruce provides thermal and loafing cover for spruce grouse in winter.

Ecosystem Services

One of the more important timber species in the northeastern United States, its wood is lightweight, straight-grained, and



Specimens of *Picea rubens.* Photo by USDA Forest Service, Southern Research Station, Bugwood.org, 5487683.

Trunk of *Picea rubens*. Photo by Georgette Smith, Canadian Forest Service, Bugwood.org, 5137061.

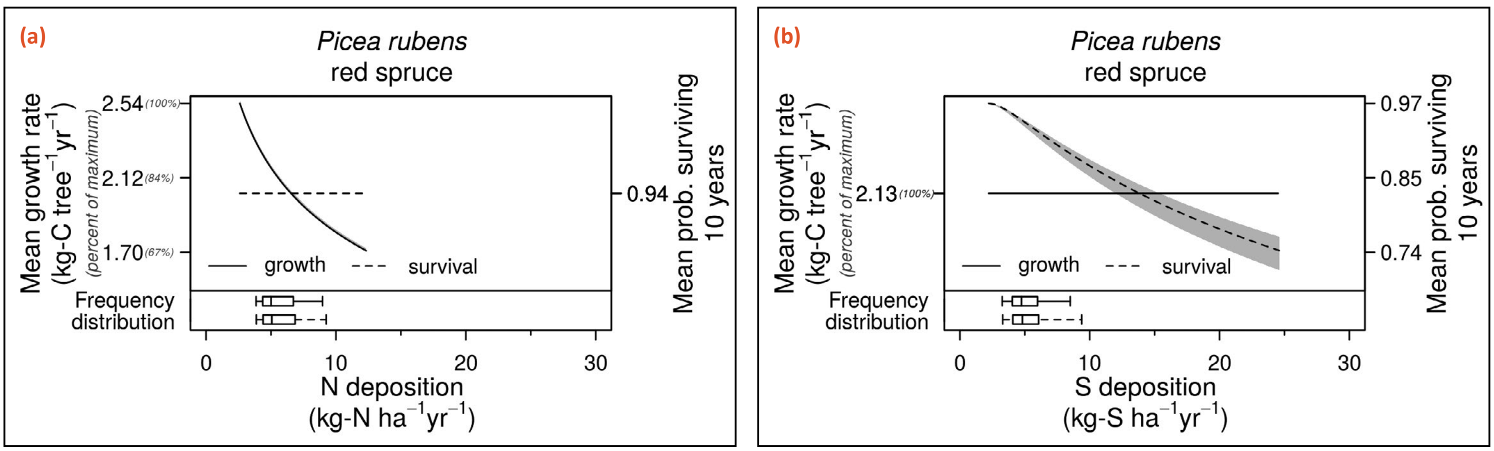
resilient. It is used for paper, construction lumber, and is highly preferred for musical instruments. In the past, red spruce gum was formerly collected and processed for chewing gum.

The Cherokee and Montagnais made an infusion from the boughs to treat colds and sore throats, and the Ojibwa used the leaves to make a beverage.

Red spruce is occasionally used for revegetation of coal-mine sites in West Virginia, primarily at high elevations, but it is of limited value for this purpose.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of red spruce decreases with increasing N deposition and has no relationship to S deposition. Survival has no relationship to N deposition and decreases with increasing S deposition. Confidence in these relationships is low based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for additional guidance on these topics.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	High	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X		X	X	X		

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
			X	X		X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

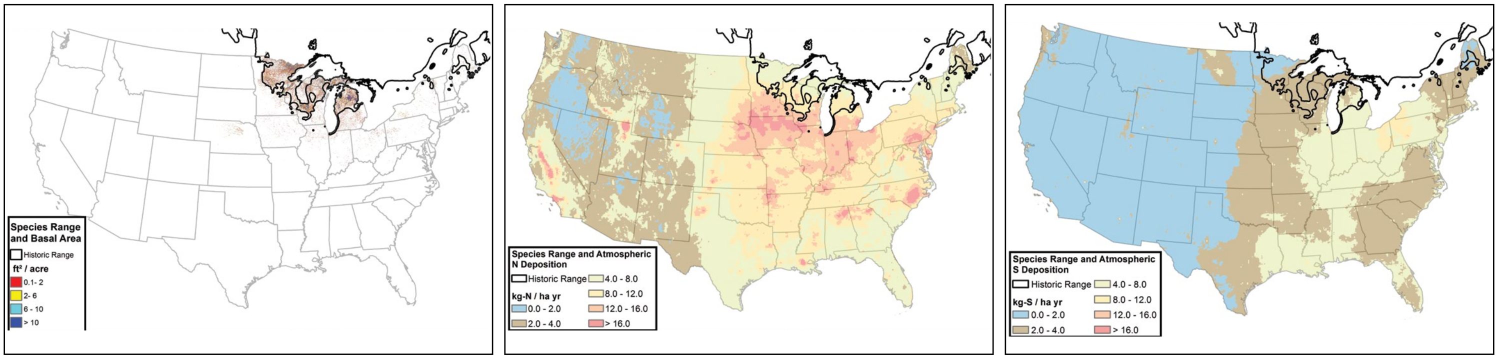
Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

Sullivan, Janet. 1993. *Picea rubens*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (3 March 2016).

Pinus banksiana (jack pine)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Jack pine is a small- to medium-sized, native, coniferous, evergreen tree with needles 0.75 to 2.0 inches (2–5 cm) long. Mature jack pine are usually 55 to 65 feet (17–20 m) tall and 8 to 10 inches (20–25 cm) in diameter. On extremely harsh, sandy sites, jack pines are small and bushy. Individual trees can have nonserotinous cones or a combination of serotinous and nonserotinous cones. Gravity and wind disperse the winged seeds—the smallest of the native North American pines. Jack pine does not reproduce vegetatively, and usually only occurs in even-aged stands that regenerate from seed after fire. It grows on level to gently rolling sand plains of glacial outwash, fluvial, or lacustrine origin, and on eskers, sand dunes, rock outcrops, bald rock ridges, and lake shores. Jack pine usually grows in dry, acidic sandy soils, but also in loamy soil, thin soil over bedrock, peat, and soil over permafrost. The species invades areas where mineral soil has been exposed by major disturbance such as fire. During its first 20 years, jack pine is one of the fastest growing conifers in its native range but also one of the most shade-intolerant trees. In the absence of fire, more shade-tolerant species usually succeed it, but on the driest, harshest sites, jack pine may persist and form an edaphic climax. Of all boreal forest conifers, jack pine is best adapted to fire.

Wildlife Uses

White-tailed deer, caribou, and snowshoe hare browse jack pine. Woodland and barren-ground caribou eat lichens growing on the ground and on tree bark in jack pine stands. A variety of birds and rodents, including red-backed voles, eat the seeds. Jack pine stands provide cover to mammals such as moose and snowshoe hares. Debris and seedlings in burned stands provide cover for smaller mammals such as red-backed voles. The federally endangered Kirtland's warbler is endemic to jack pine barrens; its nests are located on the ground, near or at the edge of fairly dense young jack pine stands.

Ecosystem Services

The moderately hard and heavy wood produces pulpwood, lumber, telephone poles, fence posts, mine timbers, and railroad ties. Jack pine is planted for Christmas trees and is intensively managed for lumber in the Lake States.

The Cree, Menominee, Ojibwa, and Potawatomi traditionally used the plant as caulk and sewing material for waterproofing seams, and medicinally for reviving fainted or comatose individuals.

Jack pine is adapted to acidic, dry, and sandy disturbed sites with a lower pH limit of 4.0 and has been planted in mined oil sands.

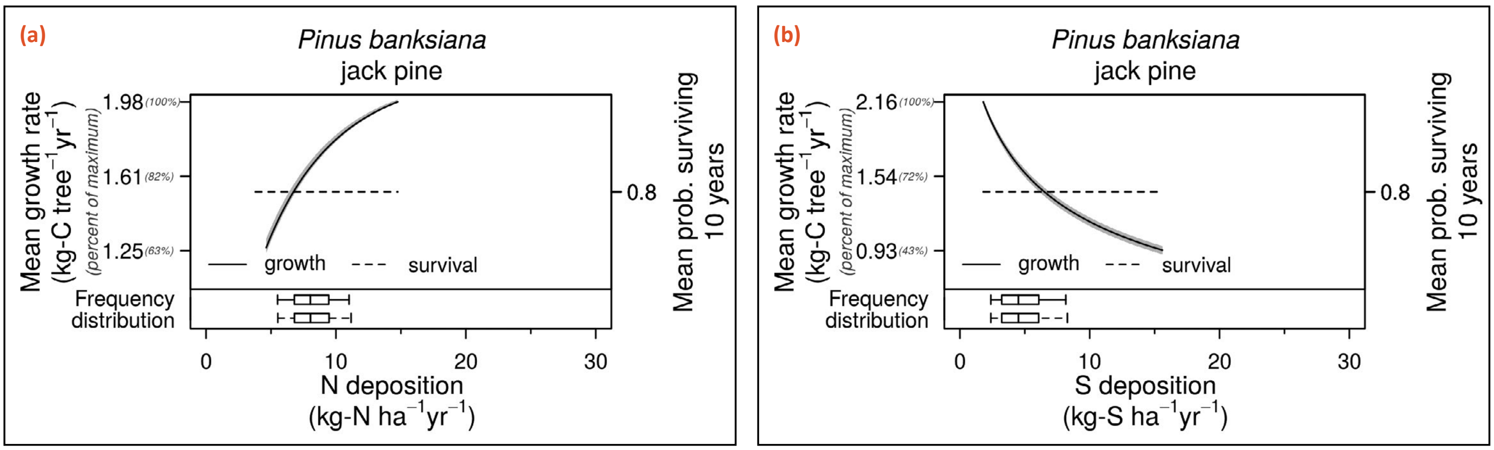
Specimen of *Pinus banksiana*. Photo by Richard Webb, Bugwood.org, 1480703. Specimen of Pinus banksiana.

Flowers of *Pinus banksiana.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008126.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of jack pine increases with increasing N deposition and decreases with increasing S deposition. Survival has no relationship to N or S deposition. Confidence in these relationships is medium low based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Foliage and young cone of *Pinus banksiana.* Photo by Bill Cook, Michigan State University, Bugwood.org, 1218036.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Low	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X		X		

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
			X			X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

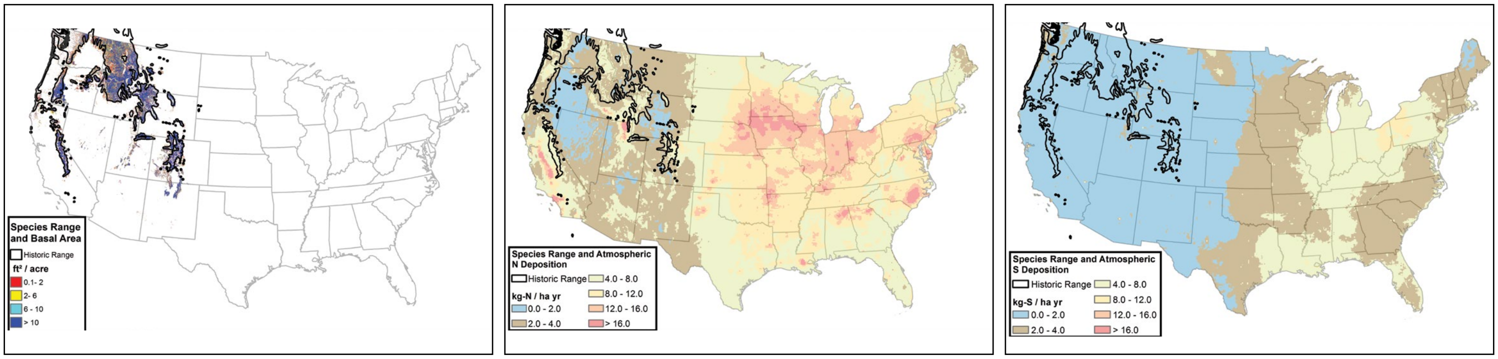
Primary Sources

Carey, Jennifer H. 1993. *Pinus banksiana*. In: Fire Effects Information System, [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. Available: http://www.fs.fed.us/database/feis/. (2016, March 3).

Native American Ethnobotany Database. http://naeb.brit.org.

Pinus contorta (lodgepole pine)

(a) (b) (c)



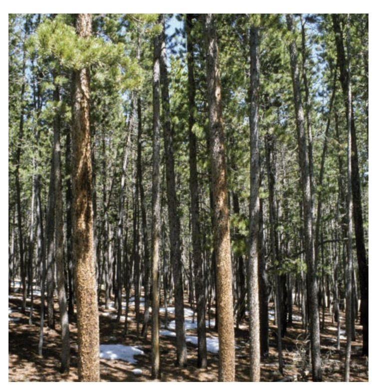
Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Rocky Mountain lodgepole is the most widely distributed of the lodgepole pine varieties. This pine grows 45 to 150 feet (13–45 m) tall with diameters exceeding 30 inches (76 cm). The average lifespan is 150 to 200 years. The tree grows rapidly where competition is limited. It develops a thin, narrow crown with a moderately low and open branch habit. Its cones are hard and heavy. The degree of serotiny can affect the age distribution in the stands. Wind-dispersed seed from open-coned trees produces uneven-aged stands, where seedlings establish over a period of years. Closed-cone trees generally produce even-aged stands, developing from the flush of seedlings that follows fire-induced seed release. Rocky Mountain lodgepole pine grows in a wide range of ecological conditions; from low to high elevations, dry to wet conditions, warm to cold temperatures, and on nearly every soil condition found in Western North America. It is limited by a lack of water at lower elevations and short growing seasons at higher elevations. It grows well on nutrient-poor soils, though increased nutrient availability can increase productivity. The tree has moderate drought tolerance and moderate to high frost tolerance. However, the species is primarily an aggressive pioneer on disturbed sites, with its occurrence due largely to fire. Postfire tree regeneration depends on the severity and uniformity of fire behavior, the relative availability of open and closed cones, and postfire moisture conditions. Overall the successional status of Rocky Mountain lodgepole pine is complicated because it depends on environmental conditions, disturbance history and pattern, and competition from associated species. Typically, the species is seral, but sometimes climax stands of lodgepole pine persist without fire maintenance. Recently, mountain pine beetle infestations have hastened the succession from Rocky Mountain lodgepole pine-dominated stands to more shade-tolerant species.

Wildlife Uses

Mule deer, moose, and elk may browse the tree, generally when other food is scarce. Small mammals, including snowshoe hares, pocket gophers, voles, and squirrels, feed on the cambium, as do porcupines and black bears. The seeds provide an important food source for red crossbills year-round. Blue grouse and spruce grouse eat both the seeds and the needles. In late summer and fall, seeds are important for small mammals, especially red squirrels. The dense stands are preferred foraging habitat for Canada lynx due to abundant populations of snowshoe hares. Mountain pine beetle larvae harbored by the tree are an important food source for woodpeckers. Rocky Mountain lodgepole pine forests provide summer range for big game animals and habitat for a variety of nongame birds, and the stands offer valuable cover for big game animals, upland game birds, small nongame birds, and small mammals throughout the year. Ruffed grouse use the tree for roosting cover and a variety of birds, including the northern goshawk, use it as a nesting site. Downed Rocky Mountain lodgepole pine provides drumming sites for ruffed grouse. The mountain pine beetle is the most serious



Stand of *Pinus contorta*. USDA Forest Service photo, Region 2, Rocky Mountain Region, Bugwood.org, 1442150.

Cones of *Pinus contorta.* Photo by Rob Routledge, Sault College, Bugwood.org, 5454125.

insect pest in mature Rocky Mountain lodgepole pine stands, periodically killing most of the large-diameter trees in a stand.

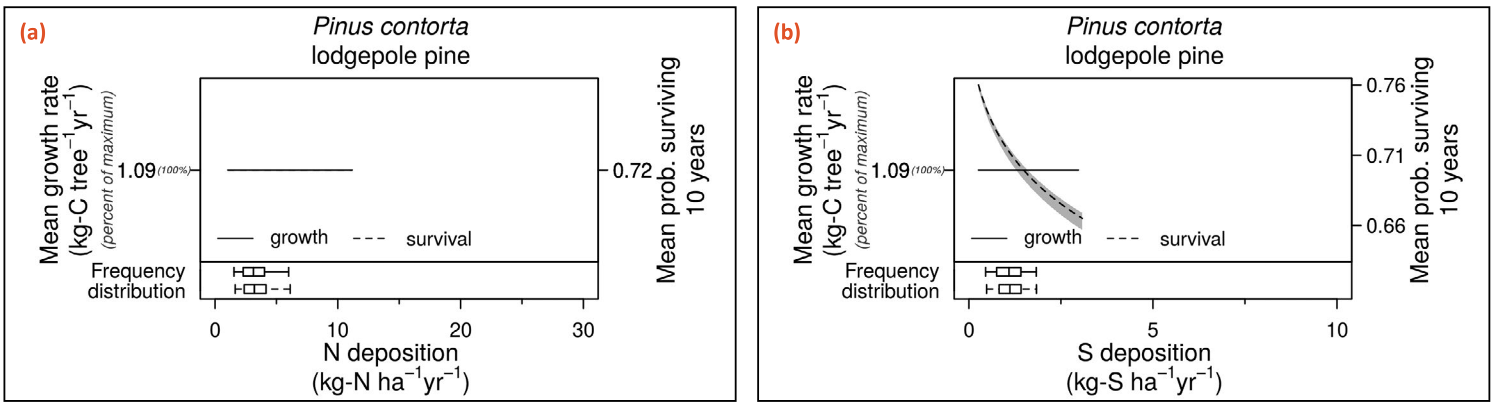
Ecosystem Services

Rocky Mountain lodgepole pine is harvested for sawtimber, paneling, floor joists, poles, pulpwood, firewood, fenceposts, and fence rails. It is also important in plywood, fiberboard, and composite/laminate products. Rocky Mountain lodgepole pine is frequently employed in reforestation efforts and is successfully used to revegetate mine sites.

Indigenous peoples use the tree for tipi poles and traditionally boiled the inner bark for food. The Bella Coola, Blackfoot, Inuit and Yupik used various parts of the tree to treat ulcers, sore throats, colds, tuberculosis, boils, blemishes, and other ailments.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of lodgepole pine has no relationship to N or S deposition. Survival has no relationship to N deposition and decreases with increasing S deposition. Confidence in these relationships is low based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are correlated for many species, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X		X		X

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
			X			X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

Primary Sources

Anderson, Michelle D. 2003. *Pinus contorta* var. *latifolia*. In: Fire Effects Information System [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (2 March 2016).

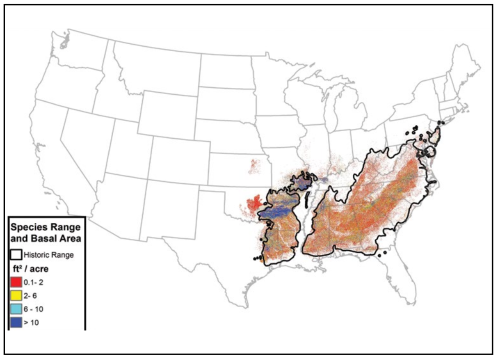
Cope, Amy B. 1993. *Pinus contorta* var. *contorta*. In: Fire Effects Information System [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (2 March 2016).

Cope, Amy B. 1993. *Pinus contorta* var. *murrayana*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (2 March 2016).

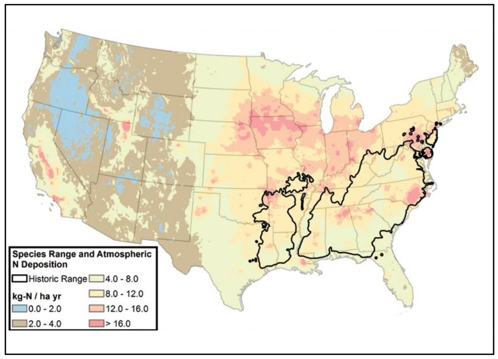
Native American Ethnobotany Database. http://naeb.brit.org.

Pinus echinata (shortleaf pine)

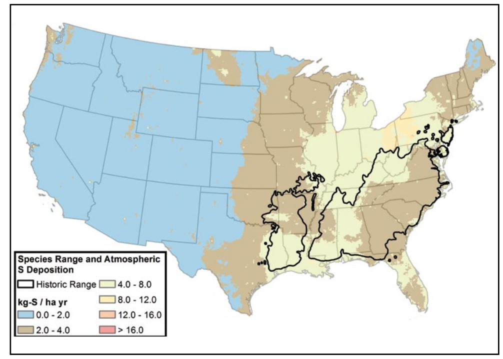
(a)



(b)



(c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Shortleaf pine is a medium-sized, evergreen conifer with relatively short needles and thin, flaky, black bark that becomes reddish brown with age. Shortleaf pine attains a height of 100 feet (30 m) and a diameter of 24 to 36 inches (61–91 cm). Individuals generally grow straight and have conical crowns. Cones yield 25 to 38 seeds, which are equipped with wings and get dispersed as far as 200 to 300 feet (61–91 m), although most fall close to the source tree. If the crown is damaged or killed in younger trees, it is capable of reproducing vegetatively through sprouting from the root crown and dormant buds at nodes in the bole. Shortleaf pine is common in the Atlantic and Gulf coastal plains, the upper and lower Piedmont, and on floodplains. It usually grows on south- or west-facing slopes and is commonly found on old agricultural fields. Shortleaf pine has great adaptability, but grows best on moist, well-drained, deep, sandy or silty loam. It best competes, however, on drier, coarser, less acidic, and infertile sites. It is considered a pioneer species, commonly growing in even-aged stands. Shortleaf pine is classified as fire-resistant and depends on fire to diminish understory competition. This is because shortleaf pine is shade-intolerant and eventually will be suppressed by hardwood competition in the absence of fire. Acid rain is suspected of causing an abnormal decrease in growth of shortleaf pine in the past 25 years. Ozone concentrations two and a half times the ambient ozone concentration also cause decreased growth.

Wildlife Uses

Deer browse on the seedlings. Stands of seedlings and saplings provide cover for bobwhite quail and wild turkey. The seeds make up an important food source for birds and small mammals. Old-growth shortleaf pine provides habitat for multiple cavity dwellers—in particular, the federally endangered red-cockaded woodpecker, which lives in old-growth shortleaf pine with decayed heartwood. The decline of the tree has resulted in a decline in population of that woodpecker. The southern pine beetle is currently driving the death of old-growth shortleaf pine.

Ecosystem Services

Shortleaf pine, an important commercial species, ranks second to loblolly pine in total softwood volume harvested in the southeastern United States. The strong wood is used for lumber, plywood, structural material, and pulpwood. The tree is also planted as an ornamental.

The Choctaw, Nanticoke, Rappahannock, and Cherokee traditionally used the wood to make canoes; they made decoctions from the bark and branches to treat swelling, and used tar pellets to treat soreness.

Specimen of *Pinus echinata*. Photo by Chris Evans, University of Illinois, Bugwood.org, 1380361.

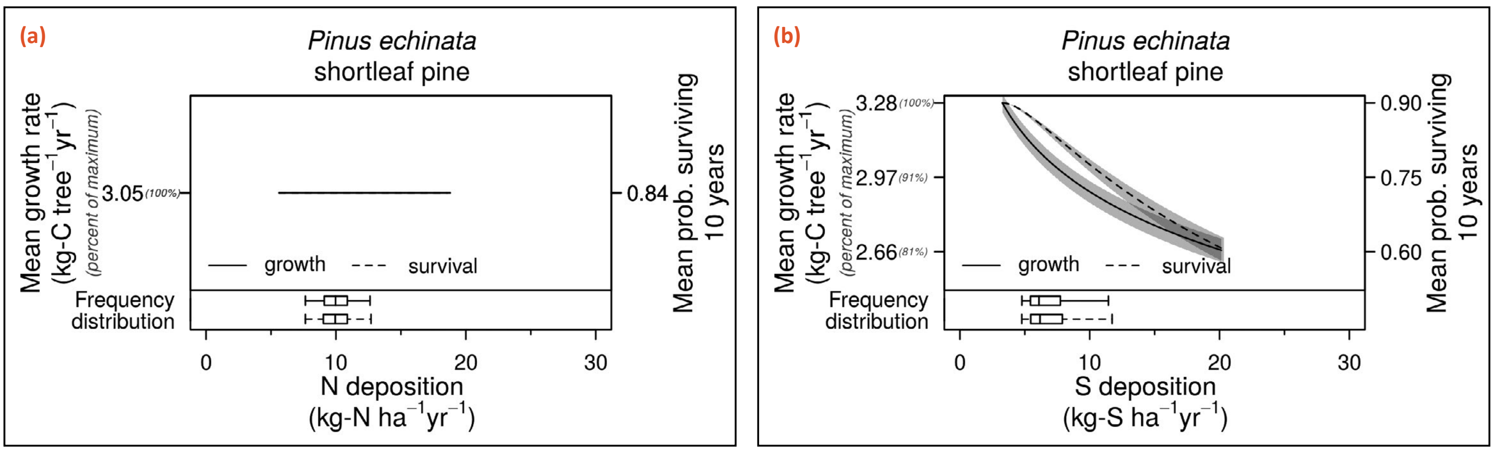
Bark of *Pinus echinata.* Photo by Chris Evans, University of Illinois, Bugwood.org, 1380363.

Because of its adaptability, shortleaf pine has potential for rehabilitating eroded areas and mine sites.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth and survival of shortleaf pine has no relationship to N or S deposition. Growth and survival both decrease with increasing S deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Immature cone of *Pinus echinata*. Photo by Franklin Bonner (retired), USDA Forest Service, Bugwood.org, 5423980.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Low	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X		X	X	

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
X			X			X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

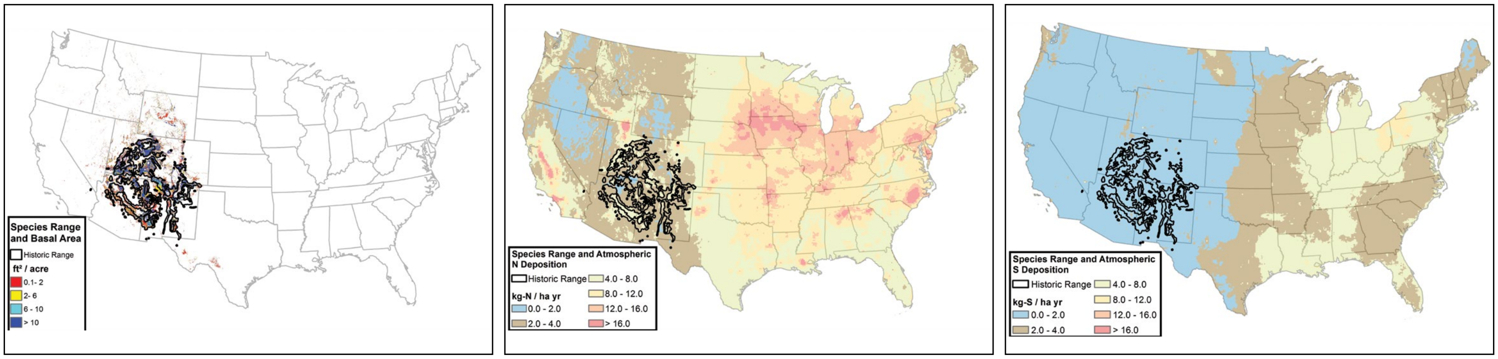
Primary Sources

Carey, Jennifer H. 1992. *Pinus echinata*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (2 March 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Pinus edulis (Colorado pinyon)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Colorado pinyon often grows as a low, bushy tree with an irregularly rounded, spreading crown. Crowns of young trees are broadly conical, and those of old trees are spreading or flat-topped. The trunk is generally short and crooked, with several large, crooked branches. It may grow to 40 inches (1 m) in diameter. Height is typically 26 to 56 feet (8–17 m). The average cone contains 10 to 20 soft-shelled seeds. Colorado pinyon is a slow-growing, long-lived tree that can survive more than 500 years and may reach 800 to 1,000 years of age. The density of Colorado pinyon in woodland communities ranges from none or few to several hundred stems per hectare. The natural reproduction is limited due to unfavorable climate, infertility of the seed, rapidly declining germination of seed produced, and loss of seed to vertebrates and insects. Birds and small mammals, primarily squirrels and chipmunks, disperse the wingless seeds. The species is found on level or gently rolling uplands to moderately steep and very steep slopes (27–75 percent), and it may also occur in riparian areas. Distribution of the sites may be limited because the species lacks tolerance for water stress and is unable to withstand cold temperature or compete with ponderosa pine at higher elevations. Colorado pinyon occurs on a wide range of soil types. Soils of these communities may be shallow to moderately deep and are often rocky, well drained, and low in fertility. Soils under well-developed pinyon-juniper stands are completely occupied by tree roots, limiting understory growth through competition and possibly allelopathy. Pinyon-juniper stands have slow succession rates, and Colorado pinyon occurs as an early- to late-seral or climax species. Thus, the eventual suppression of grasses and shrubs by mature trees after fire may take up to 100 years and climax stands may require 300 years to develop. The tree is shade-intolerant in all but the seedling stage of its growth; "nurse plants" are required during this stage to protect the seedlings from excessive drying and heating. Overall, fire opens pinyon-juniper stands, increases diversity and productivity in understory species, and creates a mosaic of stands of different sizes and ages across the landscape. In addition, fire maintains the boundaries between the woodlands and adjacent shrub or grasslands.

Wildlife Uses

Livestock grazing is an important use of pinyon-juniper woodlands. Pinyon-juniper communities provide food for deer, elk, pronghorn, wild horses, small mammals, and both game and nongame bird species. Colorado pinyon provides browse for mule deer, though it is not substantially utilized. The seeds provide an important food for small mammals, primarily chipmunks and squirrels, and for birds, particularly Clark's nutcracker, scrub jays, and pinyon jays. It also provides habitat for coyotes, mountain lions, and bobcats, and important winter habitat for goshawks.

Stand of *Pinus edulis*. Photo by Dave Powell (retired), USDA Forest Service, Bugwood.org, 1213045.

Cones of *Pinus edulis*. Photo by Dave Powell (retired), USDA Forest Service, Bugwood.org, 0806049.

Pinyon-juniper woodlands are important winter ranges for mule deer, providing cover, shelter, and understory forage. Colorado pinyon provides good cover for elk, mule deer, white-tailed deer, pronghorn, upland game birds, small nongame birds, and small mammals.

Ecosystem Services

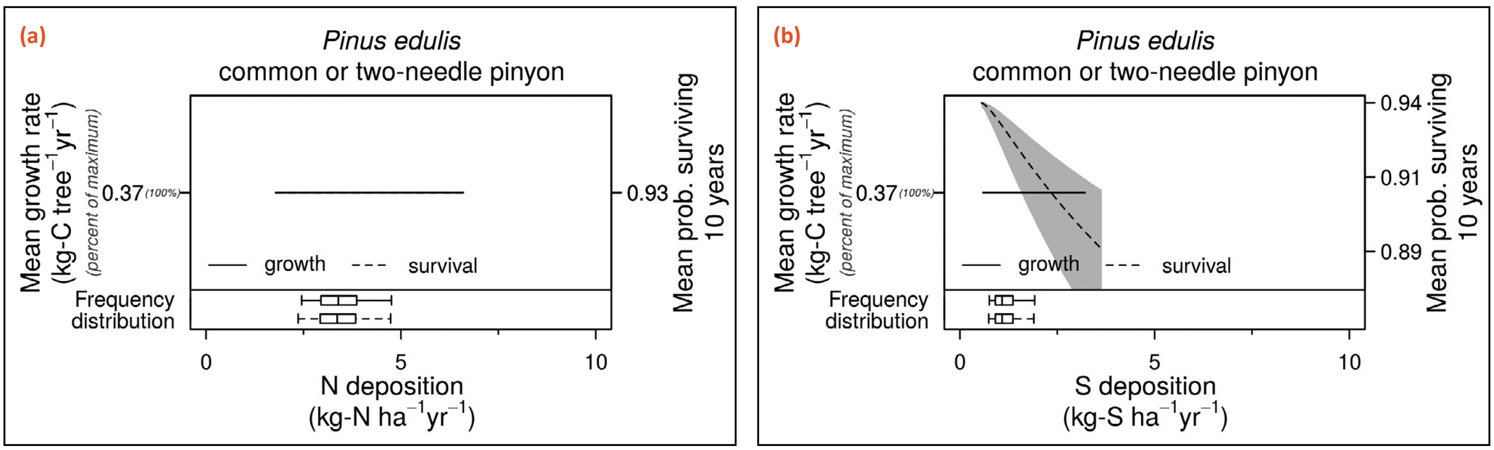
Wood products from Colorado pinyon include fuelwood, charcoal, mine timbers, railroad crossties, lumber, fenceposts, and pulpwood. The tree is also planted for Christmas trees and landscaping. The edible seeds are marketed commercially as pine nuts.

Traditionally, these seeds served as an important dietary supplement for indigenous peoples of the Southwest. The pitch was used for medicinal purposes and for waterproofing baskets and clay water bottles.

Colorado pinyon is used to rehabilitate mined areas and critical habitats that have been damaged by fire.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

Growth of Colorado pinyon has no relationship to N or S deposition. Survival has no relationship to N deposition and decreases with increasing S deposition. Confidence in these relationships is low based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X		X	X	X

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
			X	X	X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

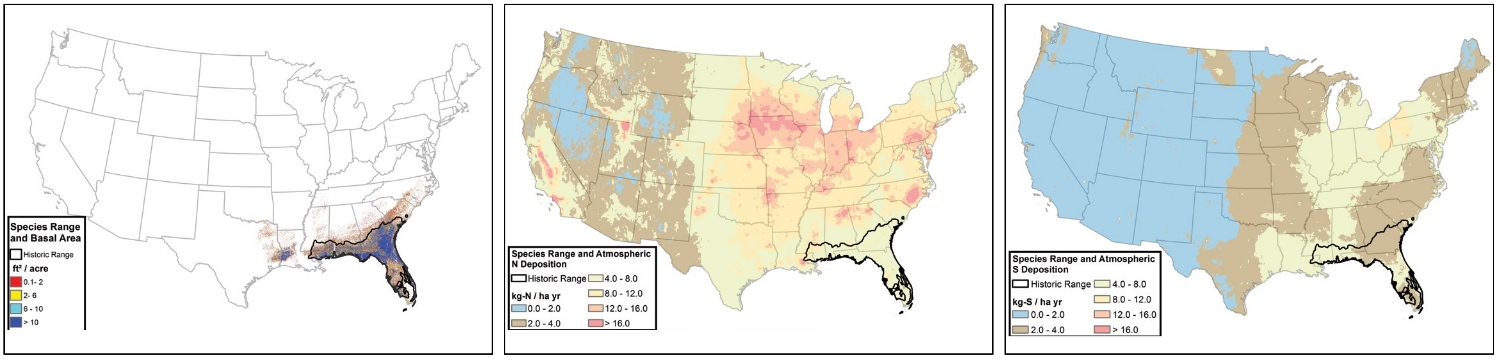
Primary Sources

Anderson, Michelle D. 2002. *Pinus edulis*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (2 March 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Pinus elliottii (slash pine)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Slash pine is a native evergreen conifer with thick, platy bark and relatively long needles. Mature trees vary in height from 60 to 100 feet (18–30.5 m) and average 24 inches (61 cm) in diameter. It grows rapidly and lives approximately 200 years. The typical variety has a straight bole and a narrow crown. Wind disperses most of the light, winged seeds from cones. Slash pine grows in a warm, humid climate, and grows best on mesic flatwood sites and on pond or stream margins where soil moisture is ample but not excessive and drainage is poor. Established stands grow well on flooded sites, but flooding restricts seedling establishment. Slash pine's native range was probably more restricted by frequent fire than by soil types or soil moisture. Young trees are susceptible to fire, but mature trees are fire-resistant. With fire suppression, slash pine has spread to drier sites. The species is relatively intolerant of competition and shade and is often replaced by southern mixed-hardwood forests. It will reproduce in small openings and invade open longleaf pine stands, but growth is reduced by competition and partial shade. Slash pine invades fallow agricultural fields and disturbed areas.

Wildlife Uses

Birds and small mammals eat the seeds. Cattle grazing is extensive on pine flatwoods in the Southeast, and both cattle and deer occasionally browse seedlings. The dense foliage of slash pine provides cover and shelter for wildlife. The endangered red-cockaded woodpecker is known to nest in slash pine, although it is not this cavity-dweller's preferred species. Large slash pine provide nest sites for bald eagles. More than 15 species of herbs are endemic to the Miami Rock Ridge pinelands of southern Florida where slash pine dominates.

Ecosystem Services

Slash pine is an important timber species in the southeastern United States. Its strong, heavy wood is excellent for construction, with a high resin content that makes the wood useful for railroad ties, poles, and piling. Slash pine is the preferred naval stores species and its resin produces gum turpentine and rosin.

The Seminole used various parts of the slash pine to make baskets, torches, medicinal decoctions, furniture, tanning compounds, and ball poles (for children).

Because of slash pine's rapid growth, it is used to stabilize soil and rehabilitate mine spoils.

Stand of *Pinus elliottii*. Photo by William M. Ciesla, Forest Health Management International, Bugwood.org, 3943007.

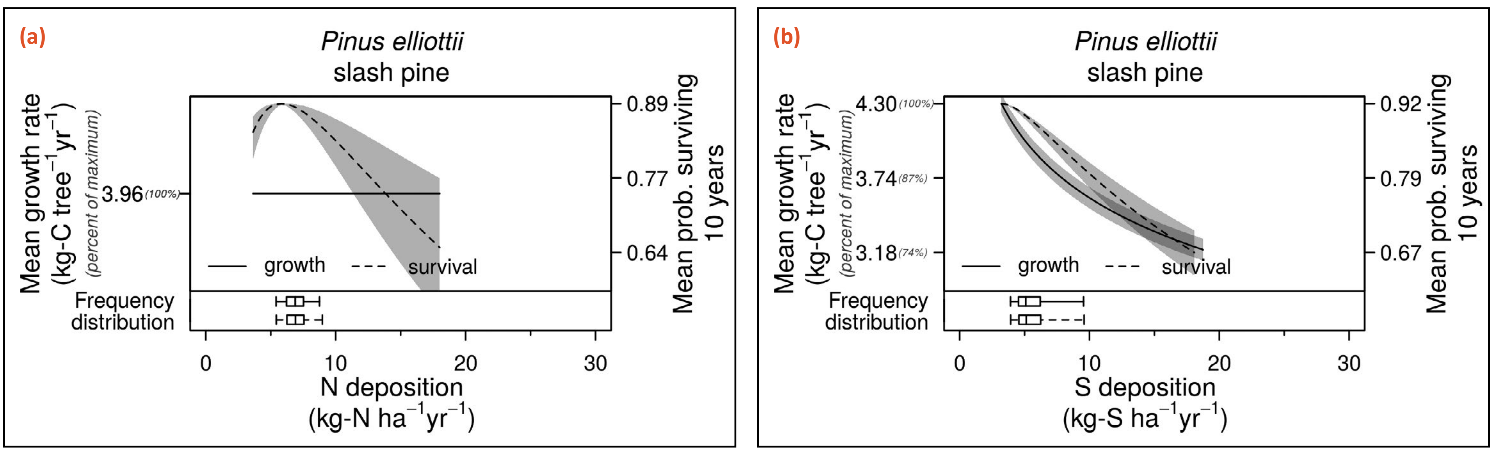
Bark of *Pinus elliottii.* Photo by Chris Evans, University of Illinois, Bugwood.org, 1380370.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of slash pine has no relationship to N deposition and decreases with increasing S deposition. Survival has a hump-shaped relationship to N deposition and decreases with increasing S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Cone of *Pinus elliottii.* Photo by Chris Evans, University of Illinois, Bugwood.org, 1119378.

Flowers of *Pinus elliottii.* Photo by Chris Evans, University of Illinois, Bugwood.org, 1373014.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Low	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
	X	X		X		

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
X			X		X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

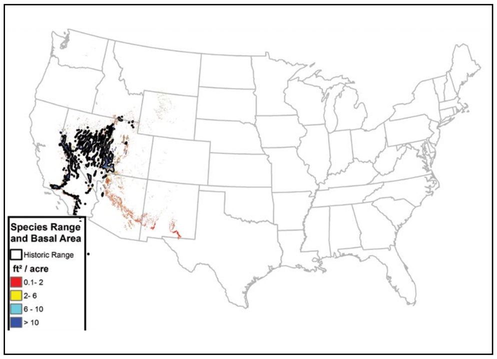
Primary Sources

Carey, Jennifer H. 1992. *Pinus elliottii*. In: Fire Effects Information System, [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (2 March 2016).

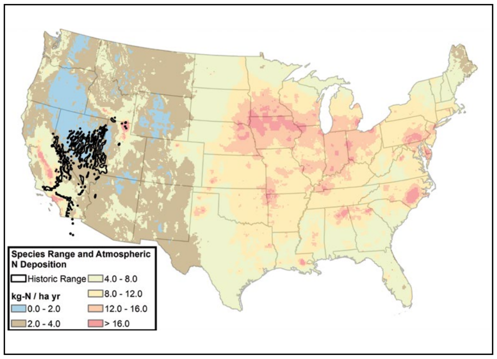
Native American Ethnobotany Database. http://naeb.brit.org.

Pinus monophylla (singleleaf pinyon)

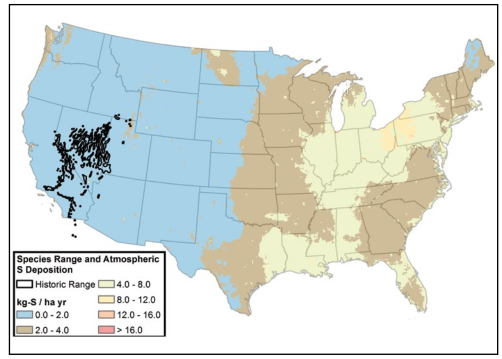
(a)



(b)



(c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Mature singleleaf pinyon is typically a short (20–40 feet (6–12 m) tall), yet long-lived tree, with a rounded to flat-topped crown and multiple, upswept branches due to lack of self-pruning. Singleleaf pinyon has an extensive lateral root system, giving it the ability to penetrate into open areas between tree canopies and extract water and nutrients. The long-lived needles of singleleaf pinyon are solitary, rigid, and 1 to 1.4 inches (2.5–3.5 cm) long. The single needle (leaf) is unique among pines of the world. Reproduction in singleleaf pinyon is by seed and does not occur naturally by vegetative means. Singleleaf pinyon generally begins bearing cones at about 35 years of age, begins producing good seed crops at about 75 to 100 years, and reaches maximum production at about 160 to 200 years. Because singleleaf pinyon seeds are totally wingless, seed dispersal is dependent on vertebrate dispersers that store seeds in food caches, where unconsumed seeds germinate. Singleleaf pinyon is adapted to a wide variety of sites, but the tree is the most xeric pine in the United States. It usually grows on pediments, dry rocky slopes, ridges, and alluvial fans and is rarely found on valley floors. It is frost resistant, tolerant of drought, and requires full sunlight for maximum growth. Old-growth or climax stands of singleleaf pinyon often occupy rocky hillslopes where the sparse understory will not carry fire. At the northern end of its range, singleleaf pinyon is found primarily on south-facing slopes and outcrops of decomposed granite. At the southern end of its range, it occurs only on north-facing slopes. Singleleaf pinyon typically grows on shallow, well-drained, low fertility soils, although it has been found on more productive soils as well. The pinyon-juniper woodland is generally a climax vegetation type throughout its range, reaching climax about 300 years after disturbance, with an ongoing trend toward increased tree density and canopy cover and a decline in understory species over time.

Wildlife Uses

Pinyon-juniper woodlands provide shelter and forage for numerous species of wildlife, some of which may be obligate to these woodlands such as pinyon mice and woodrats. These forests have value as habitat for several large mammals such as mule deer, white-tailed deer, pronghorn, desert bighorn sheep, elk, wild horses, mountain lions, and bears. Gray foxes, bobcats, coyotes, weasels, skunks, badgers, and ringtails search for prey here. Many species of birds and reptiles find food and shelter here. Pinyon-juniper forests are important wintering areas for Clark's nutcrackers. The quantity and variety of species using the pinyon-juniper woodlands changes with succession. Singleleaf pinyon provides cover and shelter for numerous birds and animals. Game animals favor areas where pinyon-juniper woodlands form mosaics with browse shrubs.

Specimens of *Pinus monophylla.* Photo by Brytten Steed, USDA Forest Service, Bugwood.org, 2143061.

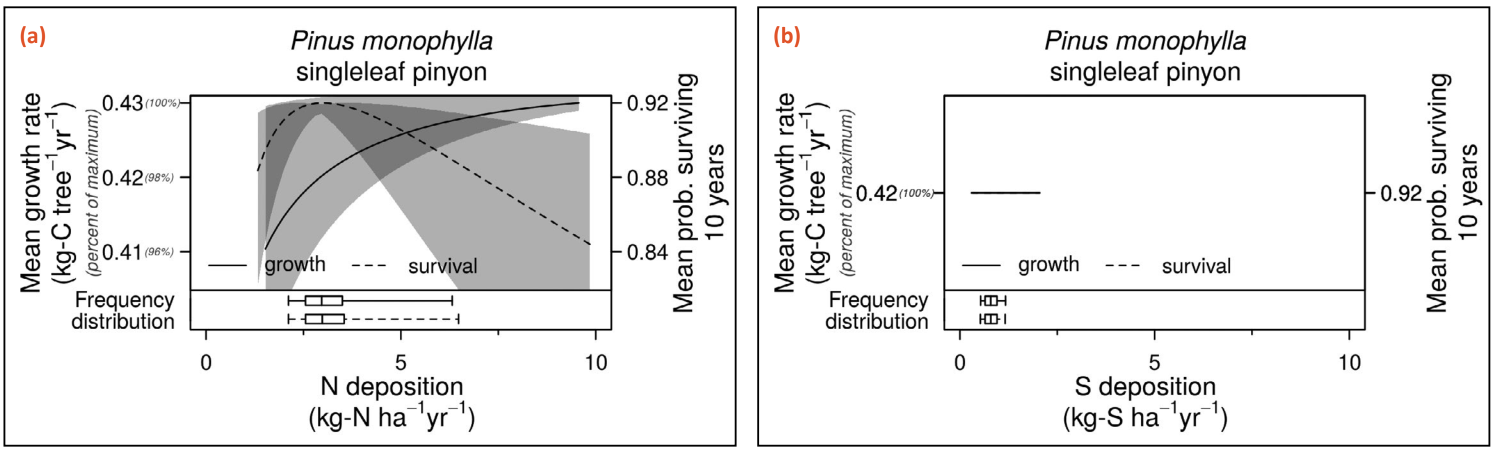
Cones of *Pinus monophylla.* Photo by Brytten Steed, USDA Forest Service, Bugwood.org, 2143060.

Ecosystem Services

Wood of singleleaf pinyon is used primarily for fuel wood and fence posts. It may be used for particle board and cement board. The old wood burns hot and served as an important fuel source for railroads and a major charcoal source for silver smelters in the late 1800s. Pinyon-juniper ecosystems have had subsistence, cultural, spiritual, economic, aesthetic, and medicinal value to indigenous peoples for centuries, and singleleaf pinyon has provided food, fuel, medicine, and shelter to the Apache, Cahuilla, Hopi, Kawaiisu and others. The pitch of singleleaf pinyon has been used as an adhesive, caulking material, and a paint binder. It may also be used medicinally and chewed like gum. Pinyon seeds are a valuable food source for people, and a valuable commercial crop. Singleleaf pinyon has not been regarded historically as a species to be used for rehabilitation of disturbed sites, but more often as a disturbance agent and an invasive species. Some literature recommends rehabilitating pinyon-juniper sites by managing for old-growth structure with an emphasis on pine nut production.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

Growth increases with increasing N deposition and has no relationship to S deposition. Survival has a hump-shaped relationship with increasing N deposition and no relationship to S deposition. Confidence in these relationships is medium high based on the correlation with deposition across the species' range and the variance inflation factors. Nitrogen and S deposition are correlated for many species, so inferring causality can be difficult. See also Appendix Table 4 and the Introduction for more information.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
	X	X		X		X

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
				X	X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

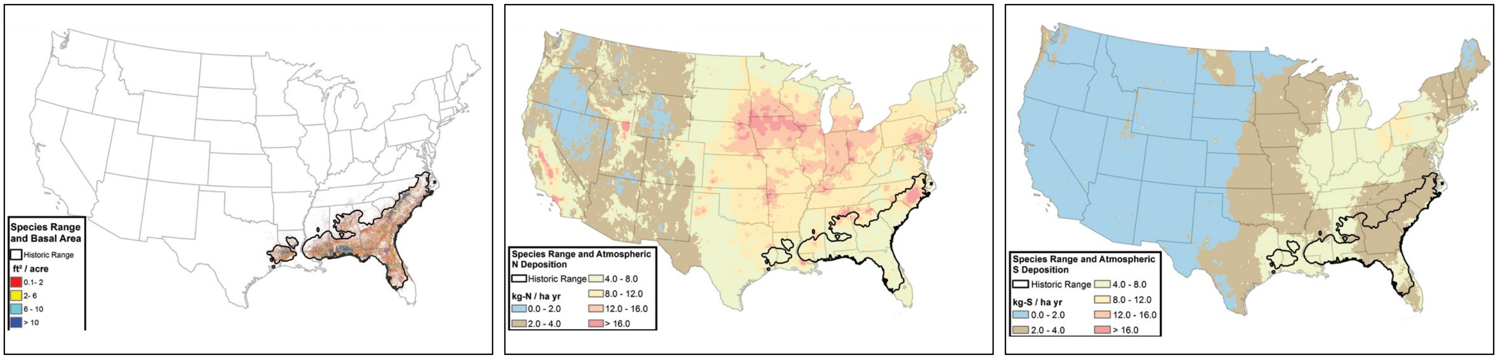
Primary Source

Native American Ethnobotany Database. http://naeb.brit.org.

Zouhar, Kristin L. 2001. *Pinus monophylla*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/plants/tree/pinmon/all.html. (2017, May 16).

Pinus palustris (longleaf pine)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Longleaf pine is a long-lived, native, evergreen, cone-bearing conifer with scaly bark and needles that are 8 to 18 inches (20–46 cm) long. Mature trees attain a height of 100 to 120 feet (30.5–36.6 m) and have the potential of living 400 to 500 years. The seed is the largest of all southern pines. The tree masts every 7 to 10 years, but healthy trees will produce a fair to good seed crop every 3 to 4 years. The winged seeds are primarily dispersed a short distance by wind. If grass-stage seedlings are top-killed, they can also sprout from the root collar. The species occupies a wide variety of upland and flatwood sites, but is most common on sandy, infertile, well-drained soils. This pine grows in a warm, wet, temperate climate with an annual precipitation of 43 to 69 inches (109–175 cm). Longleaf pine is intolerant of shade and competition. With frequent fire, uneven-aged pure stands form park-like savannahs. Because the tree regenerates in openings created by the death of mature trees, small clusters of trees of the same age are dispersed throughout the stand. In the absence of frequent fire, longleaf pine is replaced by hardwoods and other southern pines. The species is classified as a fire subclimax. Lightning, which historically ignited the frequent fires, is a component of a long-term climatic pattern; as long as there is lightning, longleaf pine can perpetuate itself indefinitely on a site.

Wildlife Uses

Birds, mice, squirrels, and other small mammals, as well as domestic hogs, eat the large seeds. Ants eat germinating seeds, and razorback hogs eat the roots of seedlings. Natural regeneration of longleaf pine is limited because of high seed and seedling predation by animals. Cattle grazing is also common in longleaf pine savannahs. Longleaf pine forests provide excellent habitat for bobwhite quail, white-tailed deer, wild turkey, and fox squirrel. Sixty-eight species of birds utilize these forests. The old-growth stands also provide nesting habitat for the endangered red-cockaded woodpecker.

Ecosystem Services

In the past, longleaf pine was used extensively for timber and ship building. Most virgin stands have now been harvested, and because longleaf pine is not as easy to regenerate as other southern pine timber species, it is not used as extensively as it once was. The needles can be used for mulch, and the naval stores industry produces gum turpentine and rosin from the resin.

Longleaf pine is recommended for reforestation of dry, infertile, deep sands in the southeastern United States.

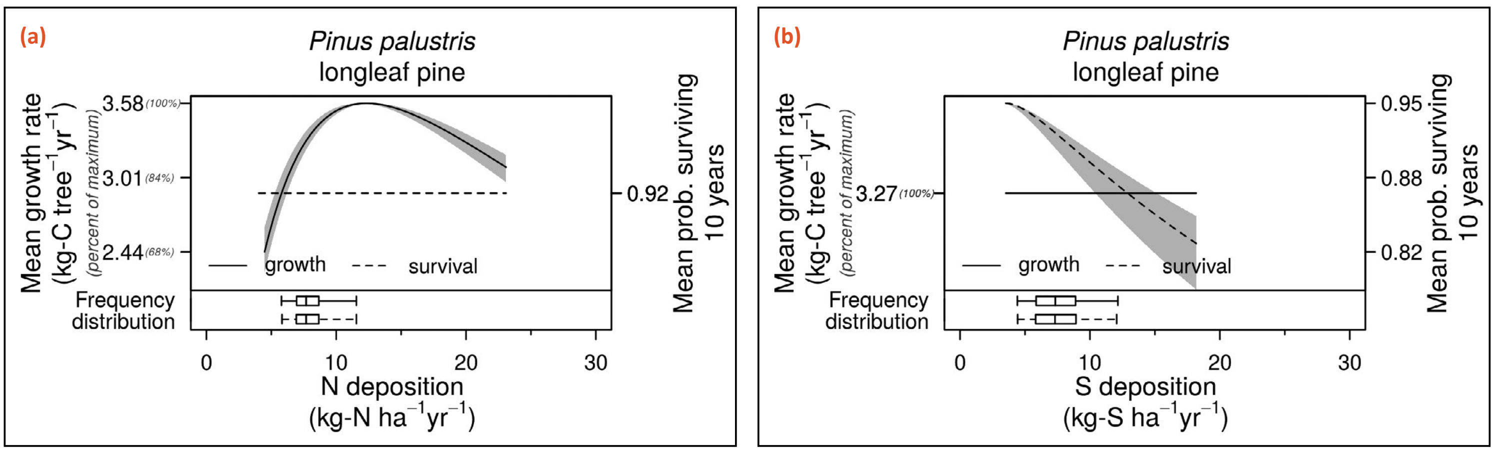
Stand of *Pinus palustris.* Photo by Chuck Bargeron, University of Georgia, Bugwood.org, 1150076.

Young specimen of *Pinus palustris.* Photo by Chuck Bargeron, University of Georgia, Bugwood.org, 1150062.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of longleaf pine has a hump-shaped relationship with increasing N deposition and no relationship to S deposition. Survival has no relationship to N deposition and decreases with increasing S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Cone of *Pinus palustris.* Photo by David J. Moorhead, University of Georgia, Bugwood.org, 0908004.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Low	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
	X	X				

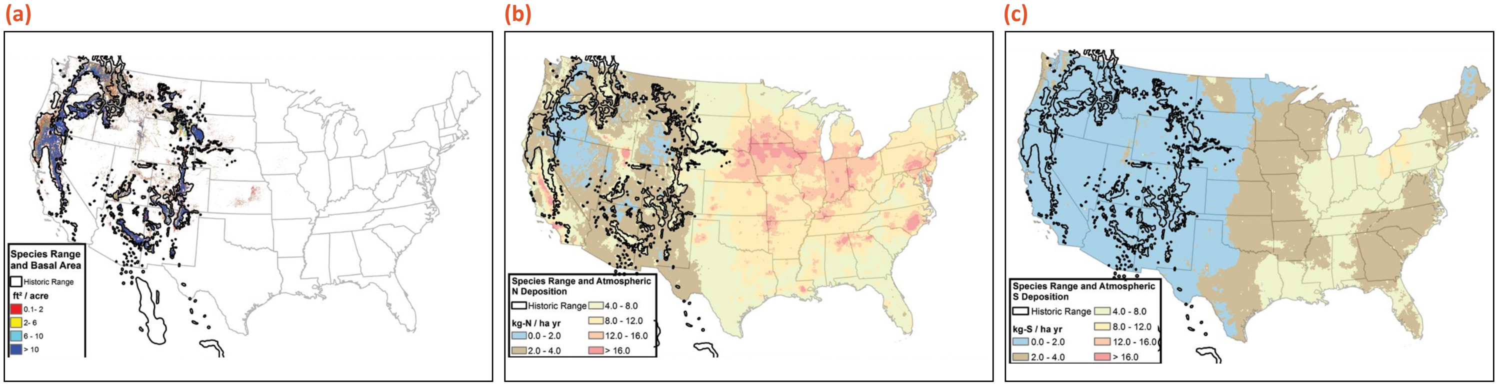
Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
			X		X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

Primary Source

Carey, Jennifer H. 1992. *Pinus palustris*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (2 March 2016).

Pinus ponderosa (ponderosa pine)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Ponderosa pine may achieve large dimensions. Diameters of 30 to 50 inches (76–127 cm) and heights of 90 to 130 feet (27.4–39.6 m) are common throughout its range. Trees often reach ages of 300 to 600 years. The crown is conical and composed of stout branches. The tree reproduces sexually and produces cones. Wind and bird species such as Clark's nutcrackers disperse the seeds. Ponderosa pine is typically found on warm, dry sites and occurs on a wide variety of soils ranging from glacial till, glacio-fluvial sand and gravel, dune, basaltic rubble, colluvium, to deep loess and volcanic ash. Historically, fire has played the greatest role in the successional status of ponderosa pines. This tree species is shade-intolerant, and grows most rapidly in near-full sunlight. Climax pine stands generally tend to be even-aged in small groups rather than being truly uneven-aged. The successional status of ponderosa pine ranges from seral to climax depending on specific site conditions. It plays a climax role on sites toward the extreme limits of its environmental range and becomes increasingly seral with more favorable conditions. On sites with favorable moisture, pines encounter greater competition and must establish opportunistically. On moist sites, it is usually seral to Douglas-fir and firs like grand and white fir. On severe sites, it is climax by default because other species cannot establish; on such sites, establishment depends largely on the cyclical nature of large seed crops and favorable weather.

Wildlife Uses

Ponderosa pine needles, cones, buds, pollen, twigs, seeds, and associated fungi and insects provide food for many species of birds and mammals. Small mammals that eat stems and roots include deer mice, chipmunks, shrews, voles, and tree and ground squirrels. Large browse mammals include elk, deer, porcupines, hares, rabbits, cattle, domestic sheep, and occasionally horses, domestic goats, and hogs. Many birds, such as junco, Cassin's finch, pine siskin, evening grosbeak, varied thrush, Clark's nutcracker, sparrows, chickadees, and other passerines, eat the seeds. At each morphological stage, ponderosa pines provide numerous species of birds and mammals with shelter. As seedlings they offer low ground cover for small birds and mammals. Upon reaching pole size, stands provide good windbreaks and thickets and serve as hiding and thermal cover for larger mammals such as elk and deer. Mature trees and standing snags house arboreal species, and fallen logs and stumps provide many cavities for species such as cottontails, small rodents, and reptiles. Species using this tree for nests include the bald eagle, wild turkey, and band-tailed pigeon; and squirrels, hawks, and owls use the tree for roosts. Primary and secondary cavity-nesting birds, such as the acorn woodpecker and mountain chickadee use both live and dead pine trees.

Ecosystem Services

Old-growth ponderosa pine produces clear, high-grade lumber, although young trees are typically lumbered because natural pruning develops slowly. A large percentage of small, low-grade trees is processed into dimensional lumber and other products for the construction market. High-grade lumber is an important raw material for molding, millwork, cabinets, doors, and windows. Ponderosa pine stands offer year-round recreation and aesthetic scenery.

Stand of *Pinus ponderosa.* Photo by Chris Schnepf, University of Idaho, Bugwood.org, 1171044.

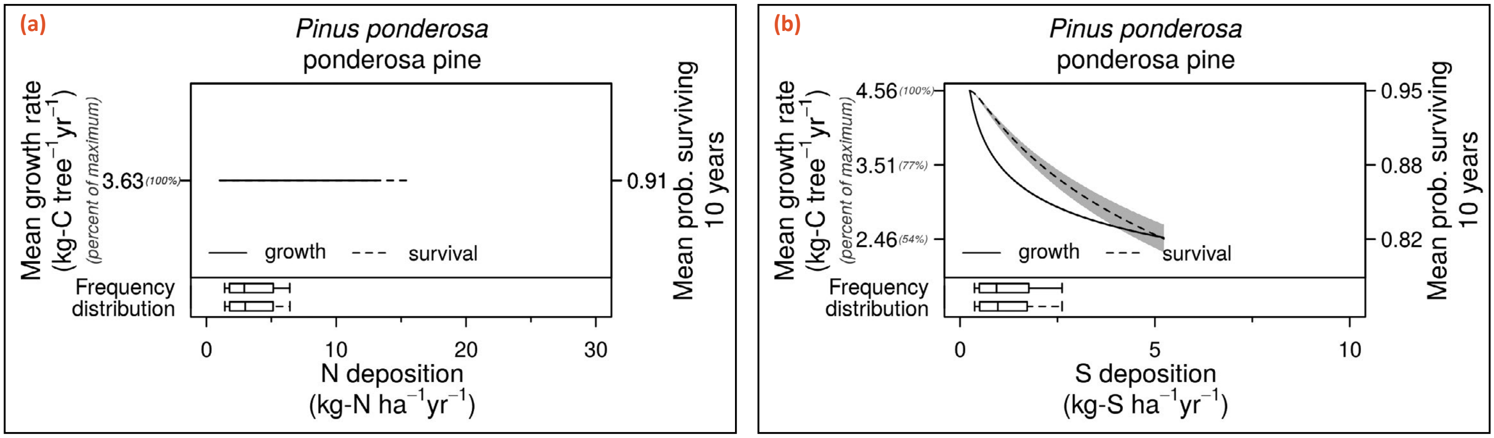
Cones of *Pinus ponderosa.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008260.

Indigenous peoples of the Pacific Northwest used the inner cambial layer, bark, cones, nuts, and seeds as food. They also converted the resin into medicinal salve for rheumatism, backaches, and dandruff.

Ponderosa pine is widely used for soil stabilization and watershed protection and is occasionally planted on mine-spoils.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth and survival of ponderosa pine has no relationship to N deposition. Growth and survival decreases with increasing S deposition. Confidence in these relationships is low based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.



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Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Low	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
	X	X	X	X	X	
Protection			**Rehabilitation**	**Food products**	**Oils and other**	**General services**
Erosion	Wind	Erosion and wind				
X			X			X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

Primary Sources

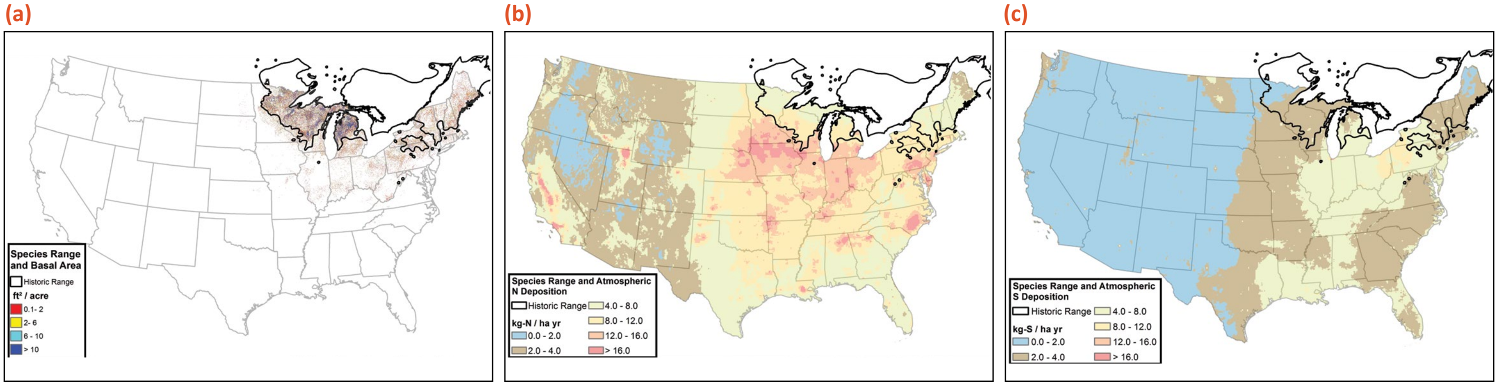
Esser, Lora L. 1993. *Pinus ponderosa* var. *washoensis*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/plants/tree/pinponw/all.html (2 March 2016).

Habeck, R. J. 1992. *Pinus ponderosa* var. *benthamiana*, P. p. var. *ponderosa*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/plants/tree/pinponp.all.html. (2 March 2016).

Howard, Janet L. 2003. *Pinus ponderosa* var. *brachyptera*, P. p. var. *scopulorum*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/plants/tree/pinpons/all.html. (2 March 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Pinus resinosa (red pine)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Red pine is a long-lived (200–400 years) coniferous tree. It has an average height of 75 feet (23 m) and an average diameter of 10 to 20 inches (30–60 cm). It has a straight trunk with little taper, few branches occurring below the canopy. The bark is furrowed and cross-checked into irregular rectangular, scaly plates up to 2 inches (6 cm) thick. Male and female cones generally occur on different branches of the same tree. Red pine is most common on level or gently rolling sand plains or low ridges adjacent to lakes and swamps. It may also grow on rocky and open habitats and on poorly drained, dry, windswept slopes. Red pine, while having a wide geographic distribution, has very low genetic diversity. Red pine grows best on well-drained, aerated sandy to loamy soils, typically of glacial outwash origin. Mature red pine is drought tolerant, but needles may turn reddish brown when very dry conditions persist over several growing seasons. The tree is shade-intolerant but it often succeeds its less shade-tolerant and shorter lived associates such as jack pine, paper birch, and aspens. The species is succeeded by more shade-tolerant species such as eastern white pine, white spruce, and balsam fir. Red pine is often an early successional species throughout its range. Since red pine depends on fire to create the conditions necessary for establishment, it occurs as a postfire pioneer species. Red pine-eastern white pine forests have greatly constricted due to fire suppression and aggressive logging. In 1850, these forests comprised 97,703,000 acres (39,539,000 ha); in 1995, red pine-eastern white pine forests were found on only 20,500,000 acres (8,310,000 ha).

Wildlife Uses

Red squirrels, eastern gray squirrels, white-footed mice, and meadow voles, among other wildlife, eat the seeds of red pine. Deer and moose browse the tree, and snowshoe hare browse both bark and seedlings. Kirtland's warbler and pine warbler are found exclusively in eastern white pine/jack pine/red pine stands, bald eagles and osprey nest in the trees and colonies of great blue heron use red pines along waterways. Gray wolves, red squirrels, a variety of bats, prairie sharp-tailed grouse, barred owls, ruffed grouse, and eastern gray squirrels often use red pine for cover. More than 200 insect species exploit red pine.

Ecosystem Services

Red pine is used for lumber, pilings, poles, cabin logs, railway ties, posts, mine timbers, box boards, pulpwood, and fuel. It is also planted as an ornamental.

The Algonquin, Ojibwa, and Potawami used the bark, cones, and leaves for medicinal purposes—to relieve headache, treat a cold, and revive a comatose patient. The Ojibwa also used the resin to make a waterproof pitch for canoes and buildings.

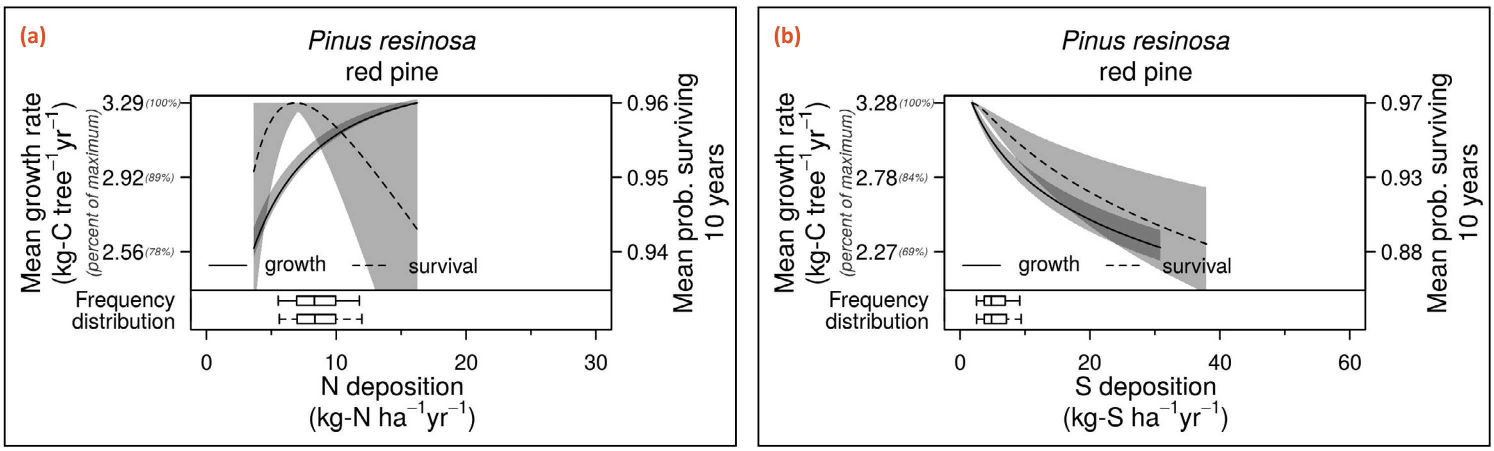
Trunk of *Pinus resinosa.* Photo by Bill Cook, Michigan State University, Bugwood.org, 1218045.

Cone of *Pinus resinosa.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008261.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of red pine increases with increasing N deposition and decreases with increasing S deposition. Survival has a hump-shaped relationship with increasing N deposition and decreases with increasing S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Flowers of *Pinus resinosa.* Photo by Joseph O'Brien, USDA Forest Service, Bugwood.org, 5031004.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X		X	X	X

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
						X

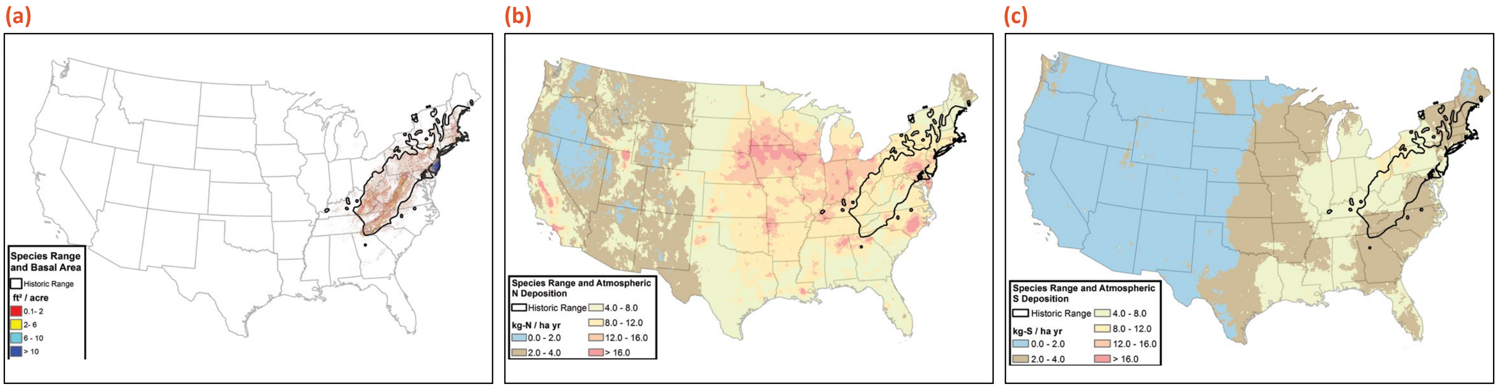
A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

Primary Sources

Hauser, A. Scott. 2008. *Pinus resinosa*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (2 March 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Pinus rigida (pitch pine)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Pitch pine is a hard pine with highly variable growth forms. As a tree, it is medium-sized and rarely grows beyond 82 feet (25 m) tall and 3 feet (1 m) in diameter. Branching is often irregular; branches can be twisted or gnarled, and self-pruning is poor. The cones produce smooth, winged seeds. Pitch pine occupies a wide variety of harsh sites that include dry sand plains, rocky ridges, and swamps. Soils are often dry, thin, infertile, and sandy or gravelly in texture, and the tree tolerates soils ranging from rapidly draining to swampy. Pitch pine is considered tolerant of cold, drought, and salt spray. While it persists in a variety of climates, it prefers humid climates with well-distributed rainfall. It is an early seral species that is replaced by hardwoods in the absence of fires that expose mineral soil and allow light to the reach the forest floor. In some very harsh habitats, pitch pine may represent a climax forest species. The tree is generally considered shade-intolerant and is well adapted to postfire regeneration through asexual and sexual means.

Wildlife Uses

Pitch pine provides habitat and food for a large number of wildlife species, including many that are rare and endangered. Deer browse seedlings and new sprouts, and small mammals, such as squirrels, and birds, including eastern towhees, pine warblers, and numerous others, feed on the seeds. Pine snakes, a variety of insects, wild turkey, red-cockaded woodpeckers, other woodpeckers, pine warblers, and other rare bird species find shelter and nesting sites in the tree.

Ecosystem Services

The coarse-grained and resinous wood provides an excellent source of turpentine.

The Iroquois used the pitch to treat rheumatism, burns, cuts, and boils, and as a laxative. Both the Iroquois and the Shinnecock made pitch pine poultices to open boils and to treat abscesses. The Cherokee used the wood in canoe construction and for decorative carvings.

Pitch pine has survived planting on and naturally colonized coal mines, anthracite mines, and landfill sites, and therefore may be useful for site reclamation.

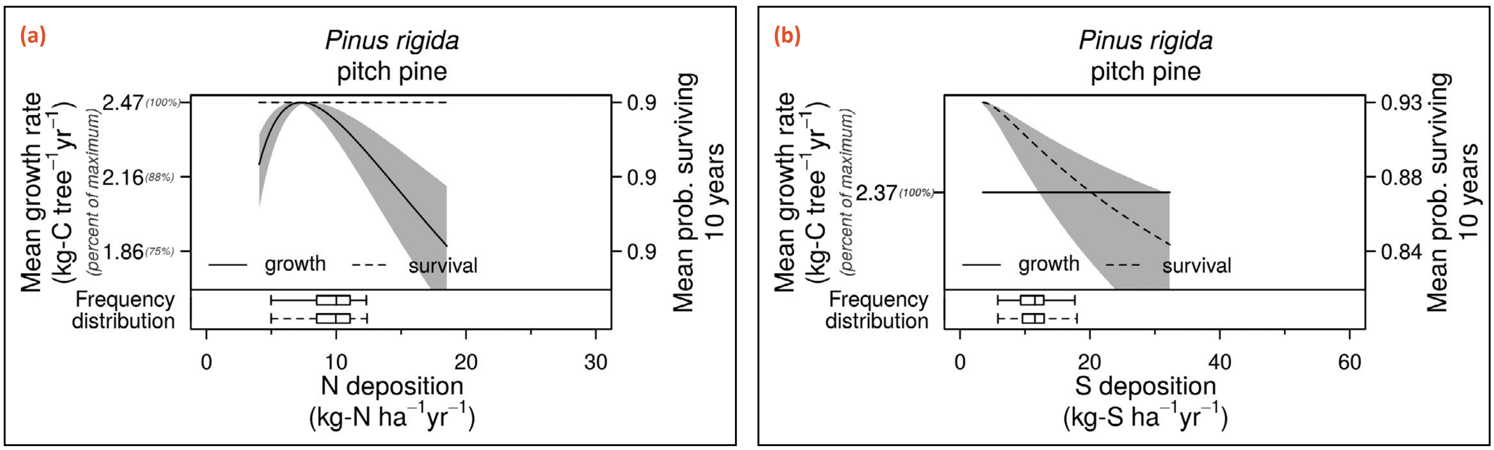
Specimen of *Pinus rigida.* Photo by T. Davis Sydnor, The Ohio State University, Bugwood.org, 5527494.

Cone of *Pinus rigida*. Photo by T. Davis Sydnor, The Ohio State University, Bugwood.org, 5349080.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of pitch pine has a humped-shape relationship with increasing N deposition and no relationship to S deposition. Survival has no relationship to N deposition and decreases with increasing S deposition. Confidence in these relationships is medium low based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Flowers of Pinus rigida. Photo by T. Davis Sydnor, The Ohio State University, Bugwood.org, 5527492.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	**Shade Tolerance**	**Leaf Type**	**Mammal Uses**	**Bird Uses**
	Low	Coniferous Evergreen	Yes	Yes

Wood products				**Traditional uses**	**Ornamental uses**	**Fuelwood**
Paper	**Unfinished wood products**	**Building material**	**Finished wood products**			
				X		

Protection			**Rehabilitation**	**Food products**	**Oils and other**	**General services**
Erosion	**Wind**	**Erosion and wind**				
			X		X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

Primary Sources

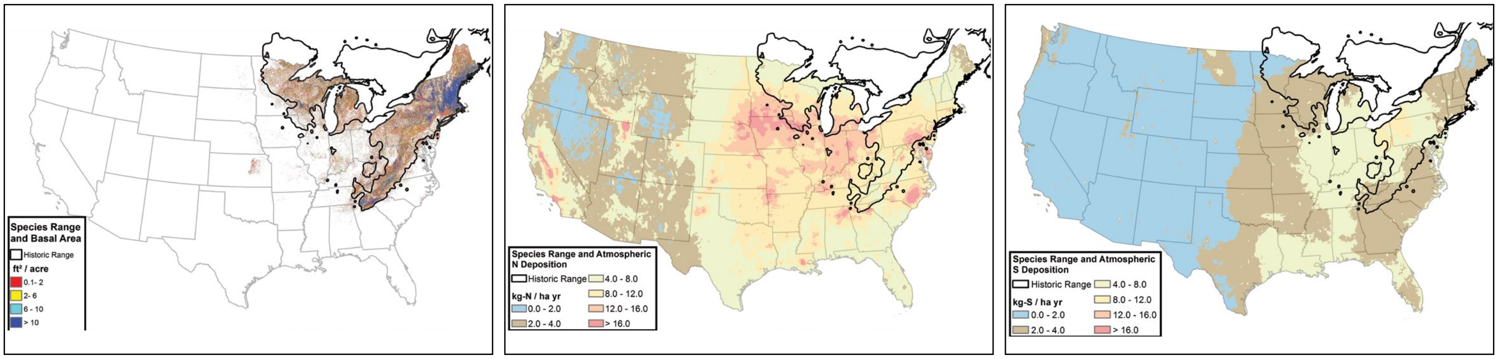
Gucker, Corey L. 2007. *Pinus rigida*. In: Fire Effects Information System.[Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (26 January 2016).

18 July 2013: DeGraaf, Richard M.; Rudis, Deborah D. 2001 citation corrected to DeGraaf, Richard M.; Yamasaki, Mariko. 2001.

Native American Ethnobotany Database. http://naeb.brit.org.

Pinus strobus (eastern white pine)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Eastern white pine is a large, native, evergreen conifer. It grows rapidly yet is a rather long-lived species, and reaches heights of 60 to 150 feet (18.3–46 m) tall. In closed stands, boles are free of branches for over two-thirds of their length. Wind and animal caching, primarily, disperse the seeds, which come from cones. The tree occurs on nearly all soil types and is found along the full moisture gradient from wet bogs and moist stream bottoms to xeric sand plains and rocky ridges. It is most competitive on fairly infertile sandy soils, steep slopes, and ridge tops, where it often becomes a climax species. Eastern white pine is intermediate in shade tolerance and is present in all successional stages. It appears in lower frequency in today's forests than in presettlement forests. The tree was heavily logged in the 1800s in the North Central United States. Regeneration after the early logging was poor because of the lack of seed trees and the fact it does not reproduce vegetatively.

Wildlife Uses

Songbirds and small mammals eat eastern white pine seeds. Snowshoe hares, white-tailed deer, and cottontails browse the foliage; various mammals consume the bark. Pocket gophers graze the roots of seedlings and young trees. Young black bear cubs use large eastern white pine to climb to safety. Northeastern pine forests can support a rich community of breeding birds. Bald eagles build nests in living trees, usually at a main branch located below the crown top. Eastern white pine, especially those with broken tops, provide valuable habitat for cavity-nesting wildlife.

Ecosystem Services

Eastern white pine is a valuable timber species in the eastern United States and Canada for the manufacture of doors, moldings, trim, siding, paneling, cabinet work, and furniture.

The Ojibwa, Abnaki, Delaware, Ontario, Iroquois, and other eastern North American indigenous peoples traditionally used the species for medicinal applications, such as making bark decoctions, poultice from the pitch, salve from the resin, and inhalant from the leaves to treat coughs, boils, burns, and headaches. They constructed canoes from the logs, harvested the catkins for food, and waterproofed buildings with the pitch.

For site reclamation, eastern white pine is used extensively for stabilizing strip-mine spoils, especially in northern Appalachian coal fields.

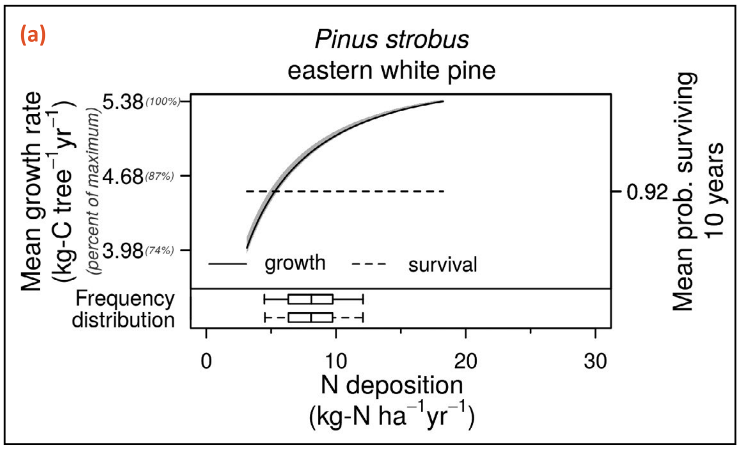
Foliage of *Pinus strobus.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008414.

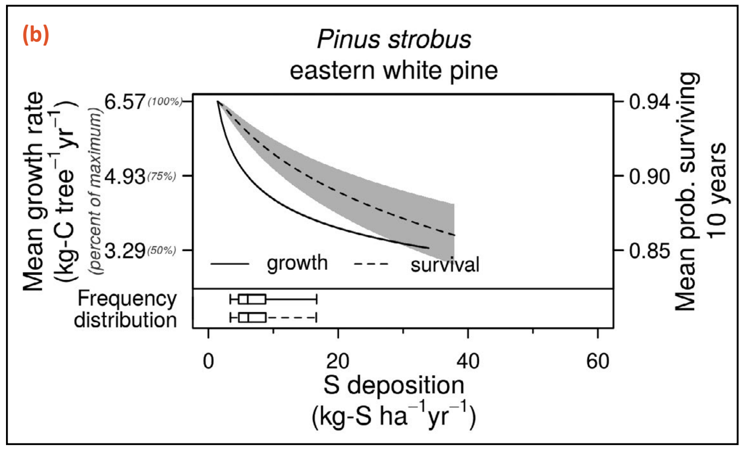
Cones of *Pinus strobus.* Photo by Keith Kanoti, Maine Forest Service, Bugwood.org, 5350005.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of eastern white pine increases with increasing N deposition and decreases with increasing S deposition. Survival has no relationship to N deposition and decreases with increasing S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Foliage and new growth of *Pinus strobus.* Photo by Bruce Watt, University of Maine, Bugwood.org, 5533040.





Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
	X	X	X	X		

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
			X			X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

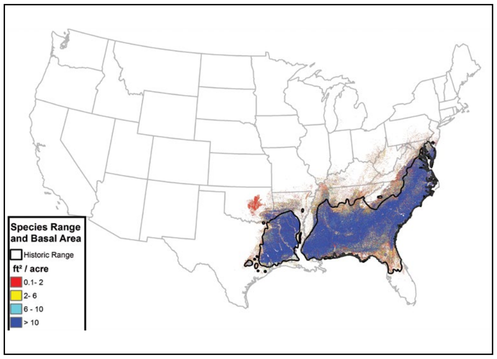
Primary Sources

Carey, Jennifer H. 1993. *Pinus strobus*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (26 January 2016).

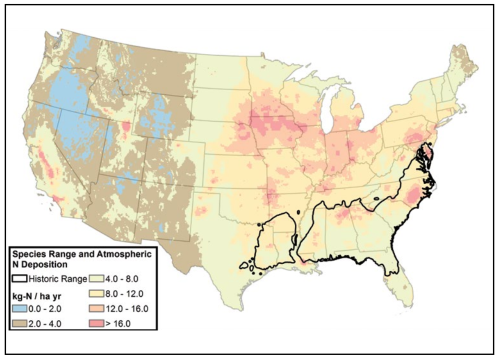
Native American Ethnobotany Database. http://naeb.brit.org.

Pinus taeda (loblolly pine)

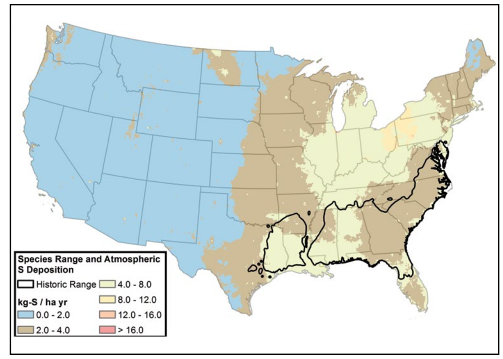
(a)



(b)



(c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Loblolly pine is a medium- to large-sized native, evergreen conifer with a long, straight, cylindrical bole. A medium-lived tree, it grows rapidly, and is 90 to 110 feet (27–34 m) tall and 24 to 30 inches (61–76 cm) in diameter at maturity. Seed dispersal from cones begins in the fall and wind disperses the winged seeds 200 to 300 feet (61–91 m). Loblolly pine grows best on moderately acidic soils with imperfect to poor surface drainage, thick, medium-textured surface layers, and fine-textured subsoils. The tree thrives in areas with 40 to 50 inches (1,020–1,270 mm) of annual precipitation and 6 to 10 frost-free months. Low temperatures limit its northern range and low rainfall limits its western range. It is moderately tolerant of shade when young but becomes intolerant with age. It invades old fields, clearcuts, and other disturbed sites. Loblolly pine's rapid growth allows it to dominate a site early. In the absence of fire, loblolly pine is replaced by climax hardwood forests.

Wildlife Uses

Loblolly pine seeds provide an important food source for birds and small mammals—more than 20 songbirds feed on the seeds, and the seeds make up more than half the diet of the red crossbill. Deer and rabbit browse seedlings. Loblolly pine stands provide cover and habitat for white-tailed deer, northern bobwhite, wild turkey, and grey and fox squirrels. Old-growth trees provide nesting habitat for the endangered red-cockaded woodpecker; trees older than 75 years are most likely to develop the heart rot necessary for cavity excavation. Kudzu vine (*Pueraria lobate*), an introduced species, will engulf, choke, weigh down, and eventually kill even large loblolly pine.

Ecosystem Services

Loblolly pine is the leading commercial timber species in the southeastern United States. Three-quarters of a million acres (300,000 ha) are harvested each year for lumber and pulpwood. Most harvested pines are under 50 years old. The tree is also planted for shade and as a wind and noise barrier.

The Cherokee used loblolly pine to make 30- to 40-foot canoes and valued the wood for carving.

Because of its fast growth and good litter production, loblolly pine is used for soil stabilization and can also be used for surface-mine reclamation.

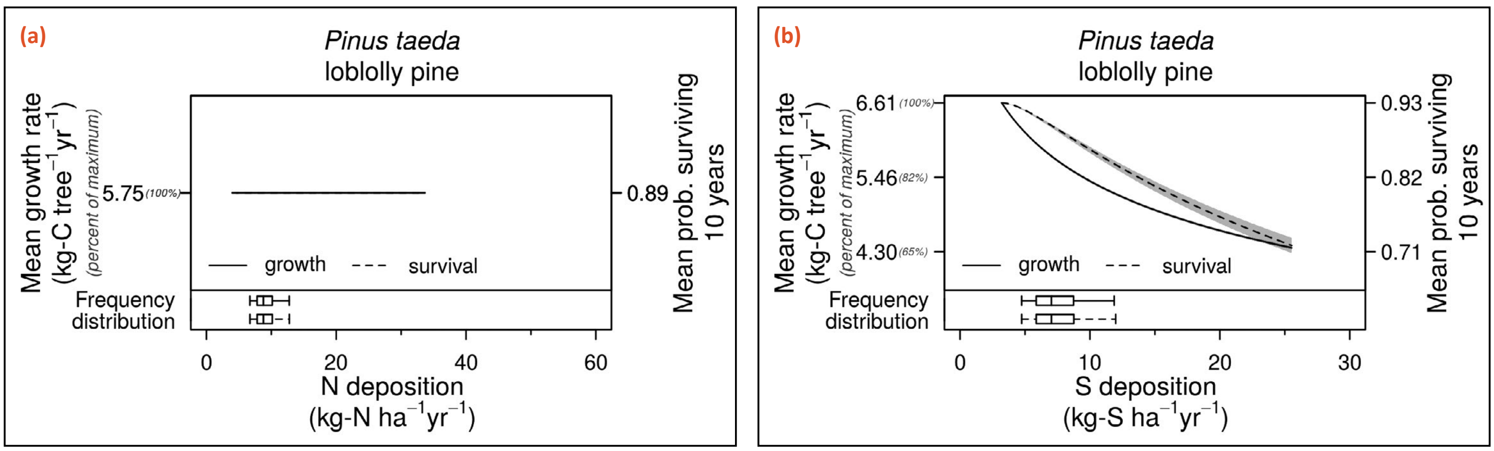
Bark of *Pinus taeda.* Photo by Paul Bolstad, University of Minnesota, Bugwood.org, 1437098.

Emerging growth and flowers of *Pinus taeda.* Photo by Erich G. Vallery, USDA Forest Service, SRS-4552, Bugwood. org, 5433043.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth and survival of loblolly pine has no relationship to N deposition. Growth and survival decreases with increasing S deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for additional information.

Stand of *Pinus taeda.* Photo by David Stephens, Bugwood.org, 5472472.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X		X	X	

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
		X	X			X

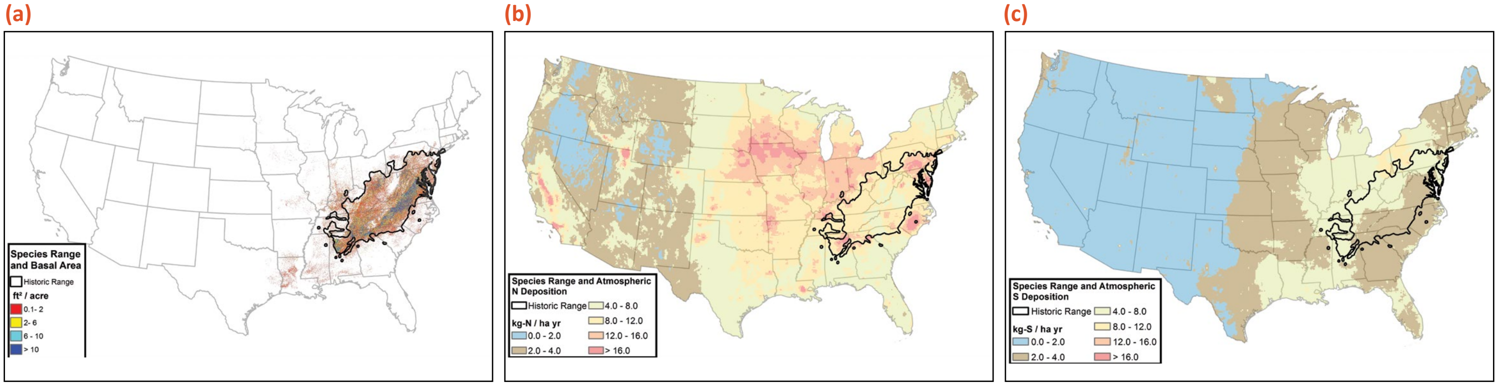
A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

Primary Sources

Carey, Jennifer H. 1992. *Pinus taeda*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (26 January 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Pinus virginiana (Virginia pine)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Virginia pine is a native, medium-sized, two-needle pine. Average height at maturity (50 years) is 50 to 75 feet (15–23 m) on better sites. Its long horizontal branches are irregularly spaced; the trunk is relatively short, with an open, flat-topped crown. With this relatively short-lived species, senescence usually occurs around 65 to 90 years. The tree produces an abundance of seeds. The cones open in the fall, and most seeds are dispersed within 100 feet (approximately 30 m) of the parent. Virginia pine grows on sandy and weakly acidic soils derived from marine deposits, crystalline rocks, sandstones and shales, and to a lesser extent, limestone. It is intolerant of shade, and is usually quickly replaced by tolerant hardwoods such as oaks and hickories. Virginia pine is an aggressive invader of burned sites.

Wildlife Uses

The seeds provide an important food source for many small mammals and birds, including northern bobwhites, and the tree serves as high-choice browse for white-tailed deer, and probably for other animals as well. With a preponderance of softened wood, the older trees offer good nesting sites for woodpeckers. Young Virginia pine stands with an extensive shrub layer provide good habitat for rabbits, northern bobwhite, and many nongame birds.

Ecosystem Services

Virginia pine currently has little importance as lumber, but it is becoming more important as a pulpwood species, especially through the reforestation of abandoned agricultural lands, cutover, and mined sites. In the past, it was used only for mine props, railroad ties, rough lumber, fuel, tar, and charcoal. It is also planted for Christmas trees.

Various indigenous peoples in the East used Virginia pine to treat worms, scent soap, and alleviate swelling.

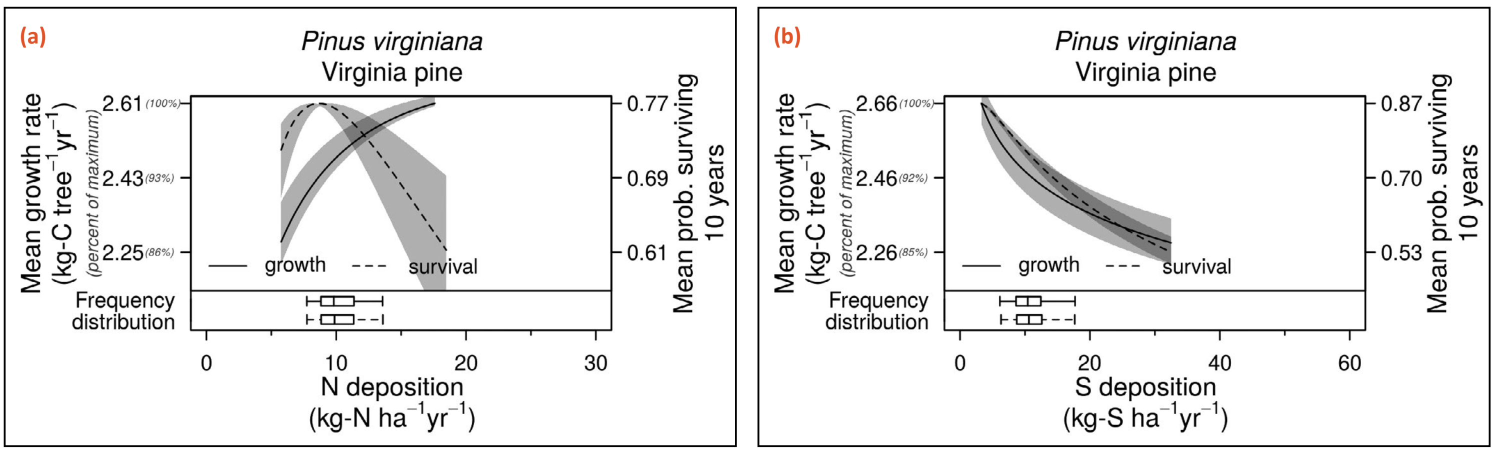
Stand of *Pinus virginiana.* Photo by Chris Evans, University of Illinois, Bugwood.org, 1342130.

Bark of *Pinus virginiana.* Photo by Vern Wilkins, Indiana University, Bugwood.org, 5491864.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of Virginia pine increases with increasing N deposition and decreases with increasing S deposition. Survival has a hump-shaped relationship with increasing N deposition and decreases with increasing S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Cones of *Pinus virginiana.* Photo by Franklin Bonner (retired), USDA Forest Service, Bugwood.org, 5423982.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Low	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X		X		X

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
			X		X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

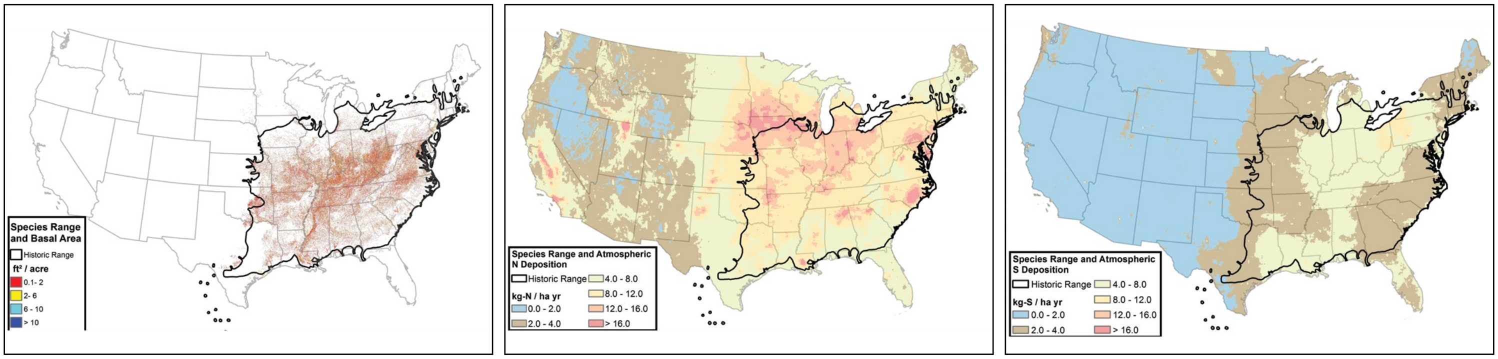
Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

Sullivan, Janet. 1993. *Pinus virginiana*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (26 January 2016).

Platanus occidentalis (American sycamore)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

The American sycamore is a native, deciduous tree and is among the tallest trees of eastern deciduous forests. It is characterized by rapid growth throughout its life; but it is also long lived (over 250 years). Mature heights range from 60 to 120 feet (18–37 m) and reported diameters range from 2 to 6.6 feet (0.6–2 m). Sycamore flowers appear in spring and bear a ball-shaped fruiting head. Because spring floods disperse most of the seeds, sycamore grows primarily on alluvial soils along streams and in bottomlands, but occurs occasionally as a pioneer on drier upland slopes if seeds are disseminated by wind. A wide variety of soils, including both sands and clays, support the species, which grows best with a reliable source of ground water. Sycamore is rated as moderately tolerant of flooding. The seedlings require direct sunlight for good growth and establishment, and the species is shade-intolerant. Sycamore occurs in forest types that are pioneer, transitional, subclimax, and climax. It will pioneer on sand and gravel bars and other newly formed land, often persisting alongside the emergence of sugar maple (*Acer saccharum*)-bitternut hickory (*Carya cordiformis*) series, particularly on wet sites.

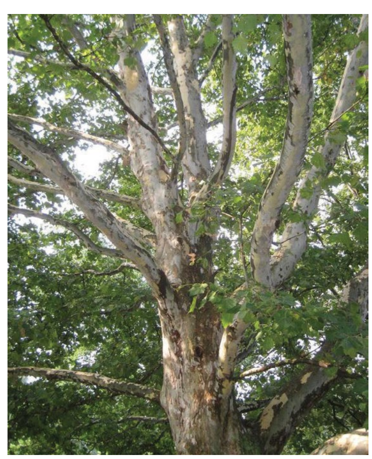
Wildlife Uses

American sycamore does not provide much food for wildlife, although some birds and animals—including purple finch, goldfinch, chickadees, and dark-eyed junco, and muskrat, beaver, and squirrels—eat the seeds. The species is rated as medium in suitability for waterfowl habitat. As sycamores age, they may develop hollow trunks which provide shelter for a number of wildlife species; some large, old individual trees have formed cavities large enough to be used as dens by black bear. Birds nesting in the cavities include the barred owl, eastern screech-owl, great crested flycatcher, and chimney swift. Wood duck use sycamores as nest trees. The bottomland forests in which sycamore occurs are very important wildlife habitat, sheltering numerous animal species, such as wood duck, other waterfowl, upland game birds, and deer. In Indiana, riparian forests in which sycamore occurs are important habitat for the endangered Indiana bat, which uses these areas for nursery colonies.

Ecosystem Services

Sycamore is a valuable timber tree; although the wood is not very strong, it is hard, with a twisted and coarse grain, suitable for furniture, interior trim, boxes, fuelwood, pulpwood, and particle and fiber board. Sycamore is also planted in short-rotation intensive culture systems for fuel or pulp. Sycamore is planted as a street tree, although it is highly susceptible to ozone damage and is susceptible to foliar injury and reduced growth when exposed to salt spray. It has been planted in shelterbelts.

The Cherokee, Delaware, and others traditionally used sycamore in various decoctions and infusions to treat dysentery, discomfort



Trunk of *Platanus occidentalis.* Photo by Rob Routledge, Sault College, Bugwood.org, 5445788.

Bark of *Platanus occidentalis.* Photo by Karan A. Rawlins, University of Georgia, Bugwood.org, 5434125.

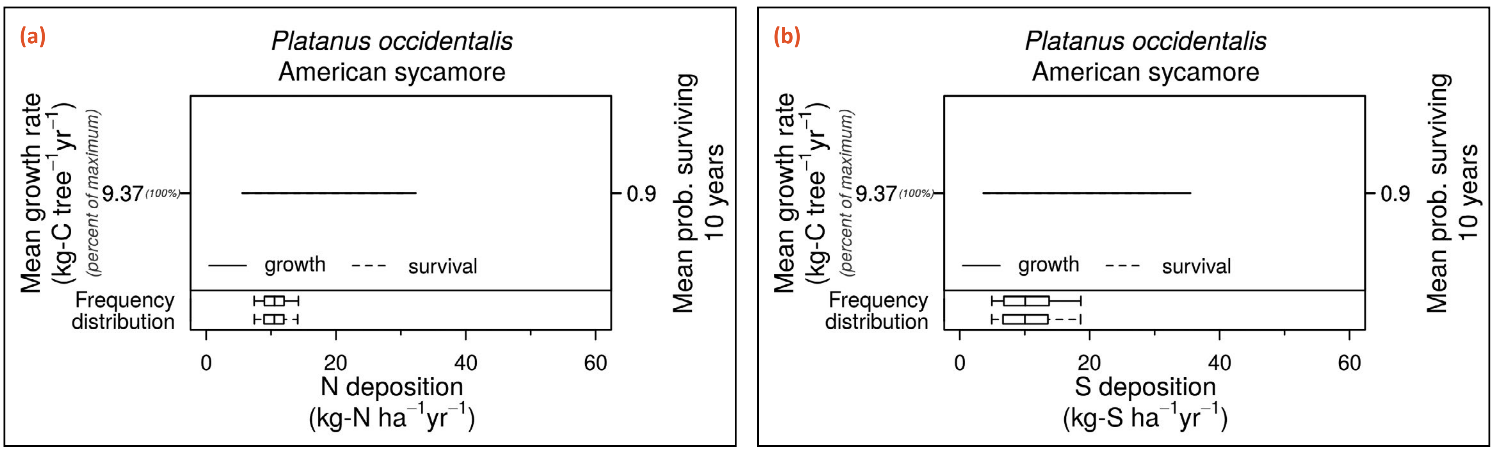
during menses, lung troubles, and cough. The Cherokee made buttons from the wood.

Sycamore occurs naturally on disturbed sites like quarries and surface mines if there is sufficient moisture for seedling establishment.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth and survival of American sycamore has no relationship to N or S deposition. Confidence in the absence of these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Fruits of *Platanus occidentalis*. Photo by Allen Bridgman, South Carolina Department of Natural Resources, Bugwood.org, 5191080.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Low	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X	X	X	X	X

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
	X		X			X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

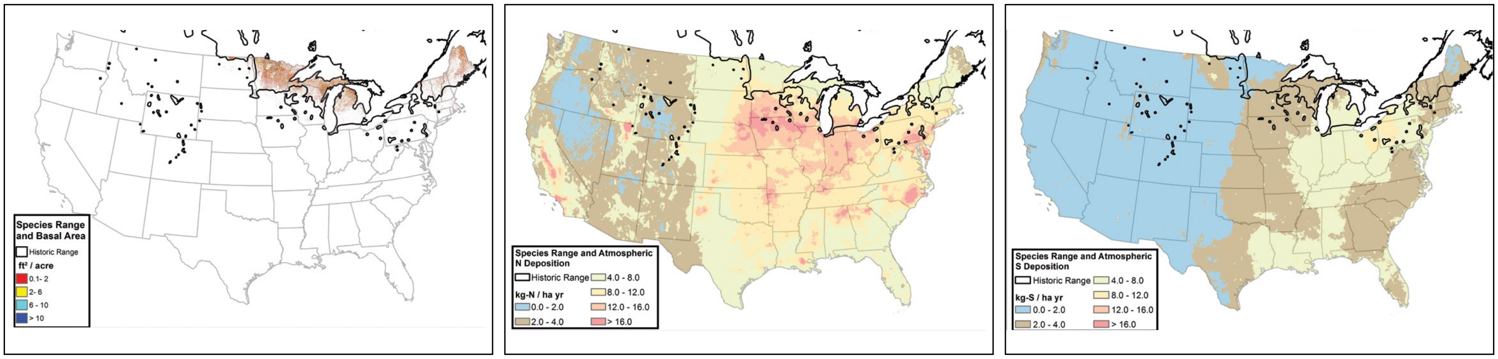
Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

Sullivan, Janet. 1994. *Platanus occidentalis*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (25 January 2016).

Populus balsamifera (balsam poplar)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Balsam poplar is a medium to large native deciduous tree. Heights of mature trees range from 30 to 100 feet (9–30 m) and trunk diameters from 4 inches to 2 feet (10–60 cm). The trunk is straight and cylindrical with an open crown of a few stout ascending branches. The flowers bloom and seeds disperse before leaves completely emerge in late spring. Balsam poplar generally occurs on moist sites, such as river floodplains, stream and lake shores, moist depressions, and swamps, but will also grow on drier sites once established. It commonly grows in moist forests of the boreal zone, and is found in the forest-tundra transition zone in Canada. The tree has high nutrient requirements and cannot tolerate infertile, acidic soils. Climates in which balsam poplars grow range from arctic to temperate but most commonly are boreal. It is a pioneer species which invades disturbed wet sites by seeding or suckering and is one of the fastest growing trees in temperate latitudes. Stands of balsam poplar are often polyclonal, with several genotypes and their sprouts making up a stand.

Wildlife Uses

Boreal forests containing balsam poplar support a wide variety of wildlife, including moose, elk, Stone's sheep, mountain goat, mountain caribou, mule deer, wolf, coyote, black bear, grizzly bear, lynx, snowshoe hare, wolverine, pine marten, and beaver. Moose, deer, voles, and snowshoe hare eat balsam poplar to a small extent. Beavers use the tree for food and building materials; and their activity creates additional habitat for birds and other aquatic furbearers. It provides valuable cover for upland game birds, larger ungulates, small birds, and small mammals.

Ecosystem Services

Balsam poplar is used for pulpwood, lumber, and veneer and to make high-grade paper and particleboard, as well as boxes and crates.

The Algonquin, Quebec, Karok, Haisla, Kutenai, Shuswap, and others traditionally used balsam poplar in a variety of ways, including making salves from spring buds, constructing fasteners from buds, smoking buckskin with the wood, and treating bleeding wounds with poultice of chewed green roots.

For remediation purposes, balsam poplar is also an important riparian species that stabilizes river banks and maintains river islands.

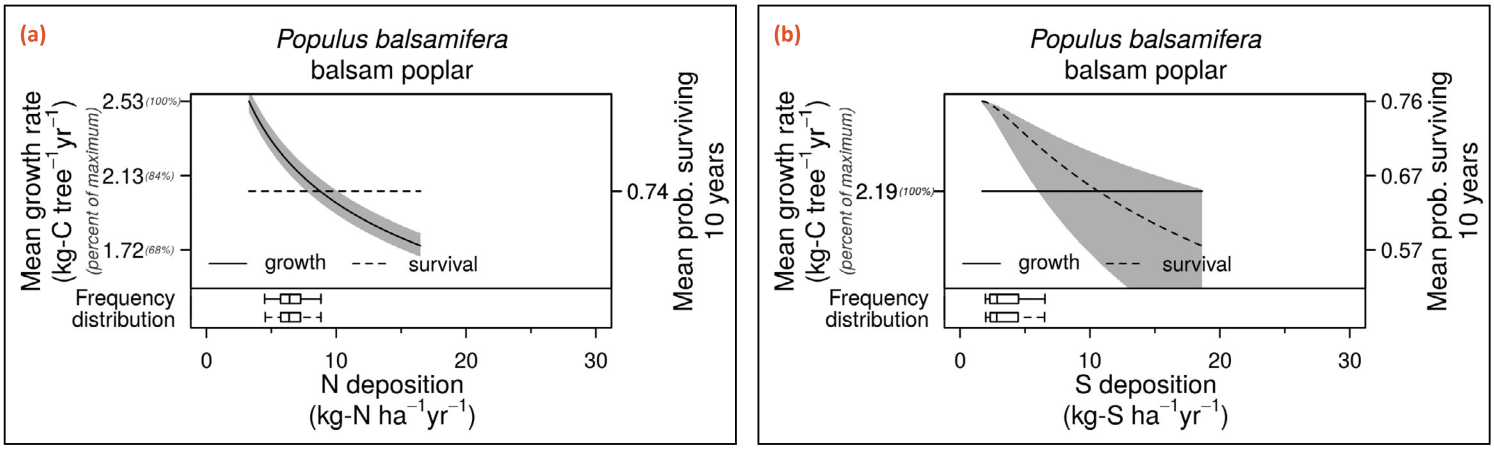
Stand of *Populus balsamifera.* Photo by Dave Powell (retired), USDA Forest Service, Bugwood.org, 1213055.

Fruits of *Populus balsamifera.* Photo by Bill Cook, Michigan State University, Bugwood.org, 1219167.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of balsam poplar decreases with increasing N deposition and has no relationship to S deposition. Survival has no relationship to N deposition and decreases with increasing S deposition. Confidence in these relationships is medium low based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for additional guidance on these topics.

Foliage of *Populus balsamifera.* Photo by Mary Ellen (Mel) Harte, Bugwood.org, 5001055.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Low	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X		X		

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
X			X			X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

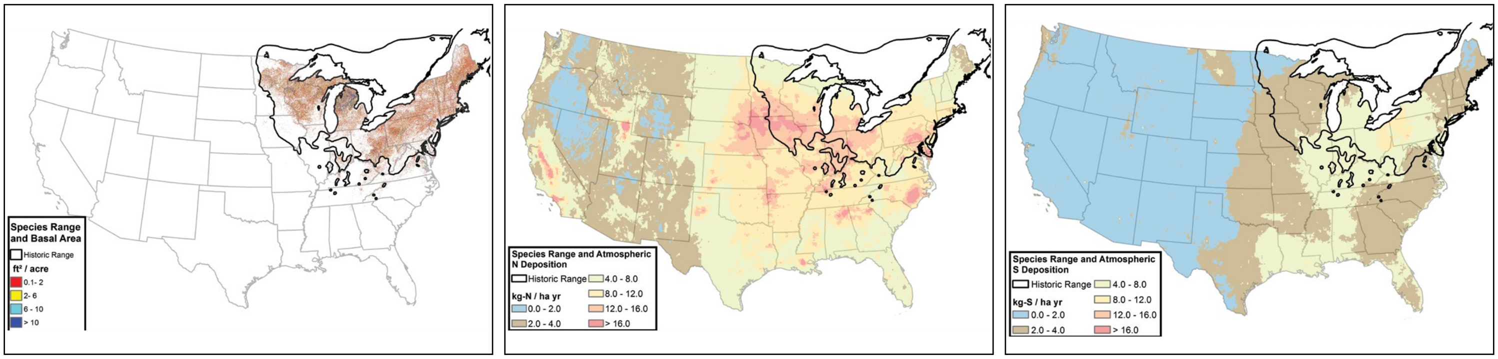
Primary Sources

Harris, Holly T. 1990. *Populus balsamifera* subsp. *balsamifera*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (25 January 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Populus grandidentata (bigtooth aspen)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Bigtooth aspen is a medium-sized, deciduous tree with a straight trunk and gently ascending branches. A short-lived and rapidly growing tree, at maturity, it attains heights of 60 to 80 feet (18–24 m) and diameters of 8 to 10 inches (20–25 cm). Bigtooth aspen is a clonal species that forms small groves, but is also a prolific seed producer. Wind disperses the lightweight seeds over long distances. The species most commonly occurs on floodplains, gently rolling terrain, and the lower slopes of uplands. Large stands grow on sands, loamy sands, and light sandy loams but individuals have been recorded on almost any type of soil. It is very shade-intolerant, but this pioneer species is capable of dominating disturbed sites due to vigorous growth and tenacious sprouting of clones from its lateral roots. Bigtooth aspen stands begin to deteriorate after 50 to 70 years on good sites, and are replaced by stands of conifers and other hardwoods in the absence of disturbance.

Wildlife Uses

Moose and white-tailed deer browse bigtooth aspen. Beaver eat bark, leaves, twigs, and branches. Ruffed grouse feed on the leaves in the summer, staminate flower buds in the winter, and catkins prior to the breeding season. It provides the basic habitat for ruffed grouse over much of its range. In addition, approximately 116 nongame bird species breed in aspen-birch forests. Cavity-nesters use bigtooth aspen, and this species can account for a large proportion of cavities in certain forests.

Ecosystem Services

The wood is light-colored, straight-grained, finely textured, and soft, used primarily for pulp, but also for particleboard and structural panels. Minor uses include log homes, pallets, boxes, match splints, chopsticks, hockey stick components, and ladders. Bigtooth aspen bark is pelletized for fuel and supplemental cattle feed.

The Cree traditionally used an infusion of the bark to ease and lessen menses. The Ojibwa used the cambium layer for creating a dish similar to eggs.

Bigtooth aspen regenerates naturally on barren, acidic, metal-contaminated soil, making it a possible candidate species for site reclamation and rehabilitation.

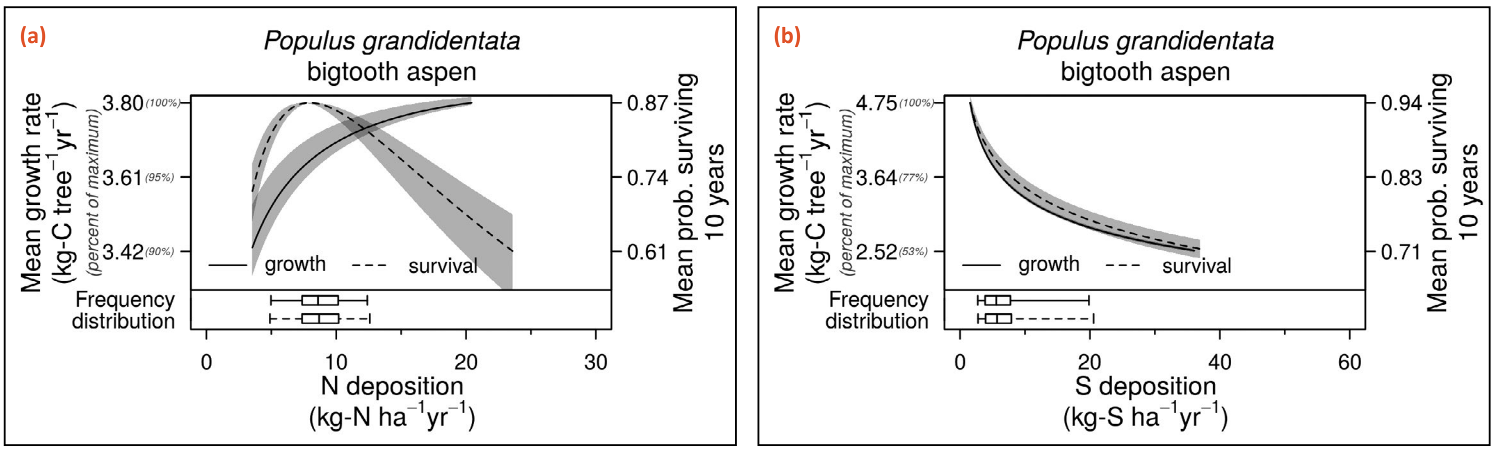
Stand of *Populus grandidentata.* Photo by Bill Cook, Michigan State University, Bugwood.org, 1219171.

Bark of *Populus grandidentata.* Photo by Vern Wilkins, Indiana University, Bugwood.org, 5448917.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of bigtooth aspen increases with increasing N deposition an decreases with increasing S deposition. Survival has a hump-shaped relationship with N deposition and decreases with increasing S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Foliage of *Populus grandidentata*. Photo by Paul Wray, Iowa State University, Bugwood.org, 0008293.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Low	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X	X	X		X

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
			X	X		X

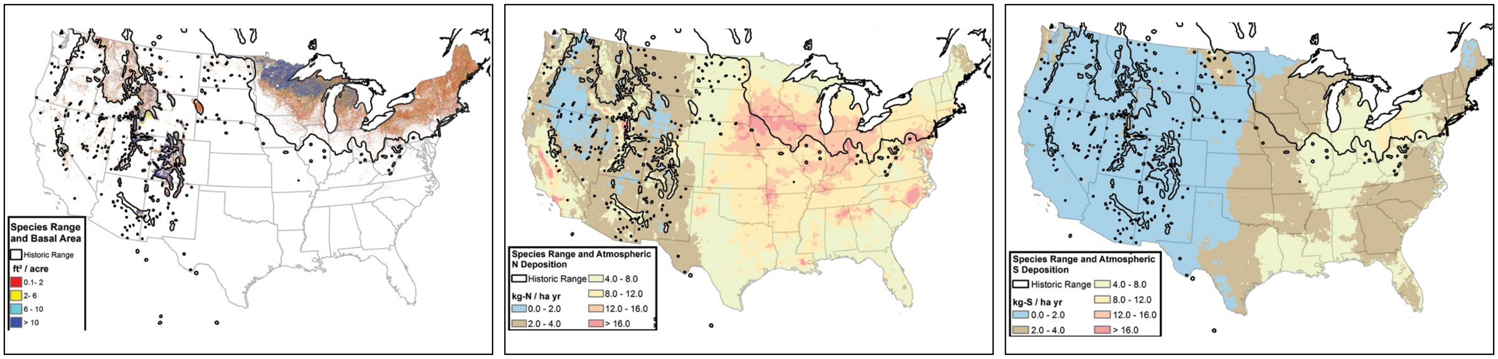
A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

Primary Sources

Carey, Jennifer H. 1994. *Populus grandidentata*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (25 January 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Populus tremuloides (quaking aspen)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

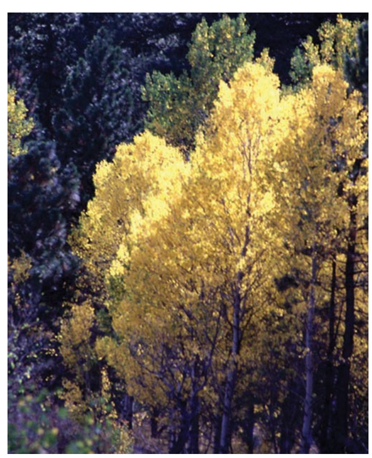
Quaking aspen is a native deciduous tree, small- to medium-sized, typically less than 48 feet (15 m) in height and 16 inches (40 cm) in diameter. It has spreading branches and a pyramidal or rounded crown. Its catkins elongate before the leaves expand, and female trees generally flower and leaf out before male trees. It often reproduces through sprouting, but sprouts usually die unless they occur in a canopy gap. Quaking aspen occurs on a wide variety of sites, including moist upland woods, dry mountainsides, high plateaus, mesas, avalanche chutes, talus, parklands, gentle slopes near valley bottoms, alluvial terraces, and along watercourses. It grows on soils ranging from shallow and rocky to deep loamy sands and heavy clays. It does not tolerate long-term flooding or waterlogged soils. Quaking aspen is not shade-tolerant; it persists through most successional stages, and readily colonizes after fire, clear-cutting, or other disturbance.

Wildlife Uses

Most classes of domestic livestock use quaking aspen for forage. Although many wild animals—including elk, mule deer, white-tailed deer, moose, bison, rabbits and hare, pikas, different species of rodents and shrews, beaver, porcupine, and ruffed grouse—browse on many parts of quaking aspen year-round, it is especially valuable during fall and winter, when protein levels are high relative to other browse species. Black and grizzly bears feed on forbs and berries in the understory of quaking aspen forests and black bear find excellent denning and foraging sites there. The tree hosts a variety of insects that are food for woodpeckers and sapsuckers. Bird species using the tree for hiding, roosting, and nesting habitat include sandhill crane, western wood pewee, six species of ducks, grouse (blue, ruffed, and sharp-tailed), band-tailed pigeon, mourning dove, wild turkey, red-breasted nuthatch, pine siskin and many others. Wild and domestic ungulates use quaking aspen for summer shade. Seral communities of quaking aspen provide some hiding and thermal cover for ungulates and small mammals in winter.

Ecosystem Services

Quaking aspen is one of the most important timber trees in the East. Its wood is used primarily for particleboard, especially waferboard and oriented strandboard, fine paper, and for pulp. The tree also provides lumber for boxes, crates, pallets, studs, and furniture, as well as specialty products such as excelsior, matchsticks, and tongue depressors. The wood pellets are used for fuel. A popular ornamental, quaking aspen is valued for its aesthetic qualities year-round, but its yellow, orange, and red autumn foliage particularly enhances the recreational value of quaking aspen sites.



Specimens of *Populus tremuloides.* Photo by Terry Spivey, USDA Forest Service, Bugwood.org, 1375340.

Stand of *Populus tremuloides.* Photo by Terry Spivey, USDA Forest Service, Bugwood.org, 1375331.

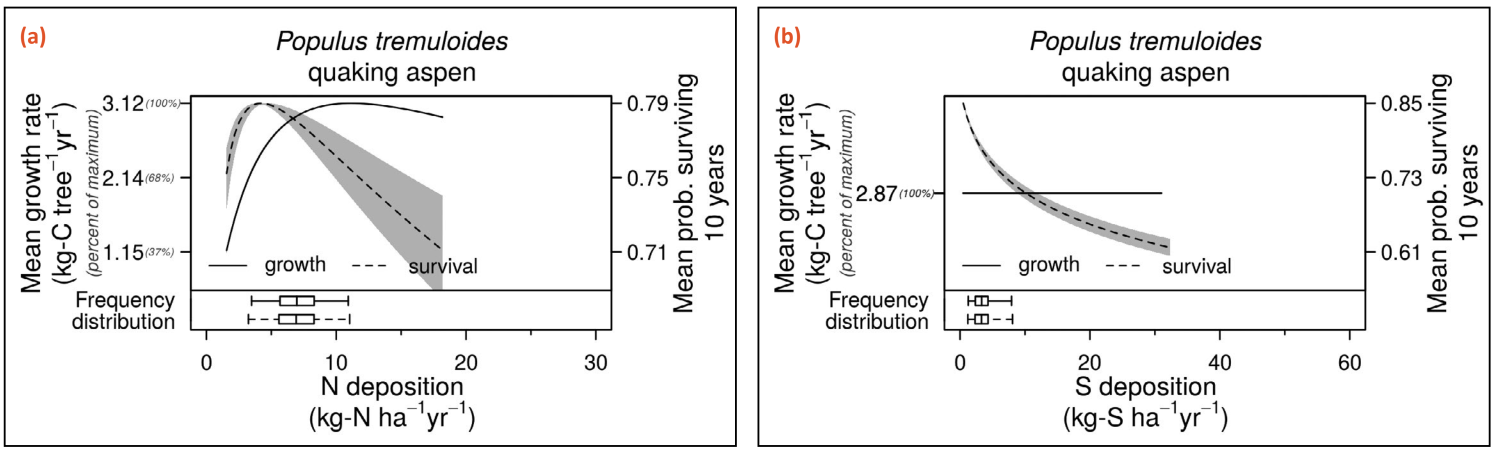
The Abnaki, Algonquin, Bella Coola, Blackfoot, and others created a quaking aspen bark infusion to treat heartburn, a root decoction to treat gonorrhea, and salve for colds and coughs. Logs were used to make lodges.

Quaking aspen is widely used in site reclamation and watershed management.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of quaking aspen has a hump-shaped relationship with increasing N deposition and no relationship to S deposition. Survival has a hump-shaped relationship to increasing N deposition and decreases with increasing S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Foliage of *Populus tremuloides.* Photo by Mary Ellen (Mel) Harte, Bugwood.org, 5001059.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X	X	X	X	X
Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
X			X			X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

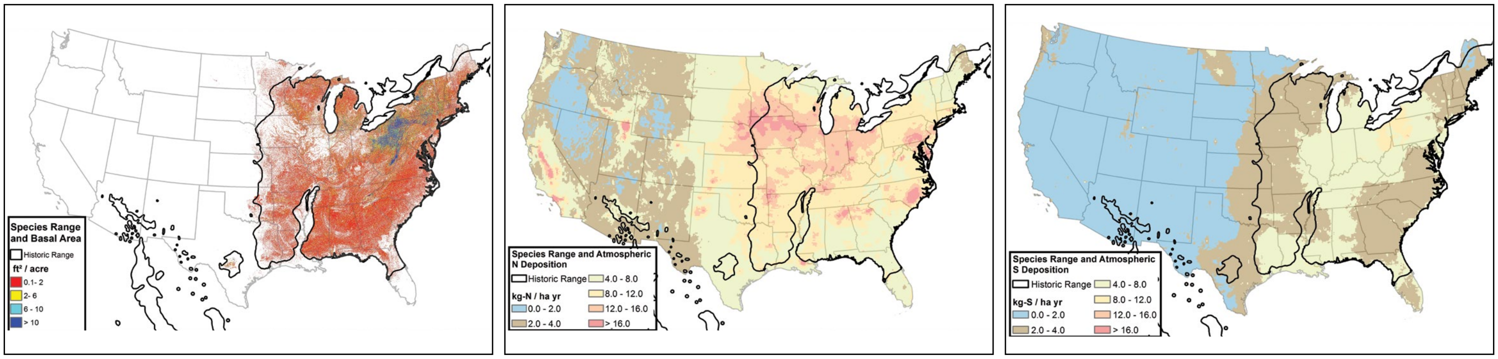
Primary Sources

Howard, Janet L. 1996. *Populus tremuloides*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (24 January 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Prunus serotina (black cherry)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Black cherry is a deciduous, single-stemmed, medium- to large-sized tree, growing to heights of 30 to 125 feet (9–38 m). In a forest, it typically has a large, straight, branch-free bole with a narrow crown. An understory of tiny black cherry seedlings is common in numerous mixed deciduous forests; these grow vigorously following gap formation. It also sprouts vigorously from the stump following cutting or fire. Black cherry occurs in numerous mesic woods and second-growth hardwood forests in the eastern United States and Canada. It grows on a variety of soil types, textures, and drainages but is most abundant on mesic sites. Sites include canyons, cove forests, valleys, and rich bottom lands, and gentle slopes, and it is also common in old fields and along fence rows. Black cherry rarely occurs in the canopy of late-successional deciduous forests, but buried seed and seedlings are often present in the understory. Seeds not dispersed by animals generally land near the parent tree. Because of animal dispersal, however, black cherry seedlings are often abundant in stands with no or few seed-producing black cherry trees.

Wildlife Uses

Black cherry leaves, twigs, bark, and seeds are poisonous to livestock. However, some ungulates, such as white-tailed deer, eat the leaves and twigs without harm and browse small to moderate amounts of seedlings and saplings. The fruits provide an important food source for numerous species of mammals and birds—including the American robin, brown thrasher, mockingbird, eastern bluebird, European starling, gray catbird, blue jay, willow flycatcher, northern cardinal, common crow, waxwings, thrushes, woodpeckers, grackles, grosbeaks, sparrows, and vireos, among passerine birds, as well as numerous songbirds that feed on the fruit as they migrate south in the fall. Black cherries are important in the summer and fall diets of the ruffed grouse, sharp-tailed grouse, wild turkey, northern bobwhite, and greater and lesser prairie chicken. Red fox, raccoon, opossum, and squirrels and rabbits also eat the fruit, and they have been described as a favorite food of black bears.

Ecosystem Services

Black cherry is an important commercial tree because it works well and finishes smoothly, making it one of the most valued cabinet and furniture woods in North America. Products made with the wood also include paneling, interior trim, veneers, handles, crafts, toys, and scientific instruments. Pitted fruits are eaten raw, used in wine and jelly, and to flavor rum and brandy. Historically, black cherry bark was used in the Appalachians as a cough remedy, tonic, and sedative.

The Cherokee, Penobscot, Rappahannock, and others treated coughs and colds with adjuvants and tonics made with black cherry.

Black cherry is planted for surface mine-spoil reclamation in the East.

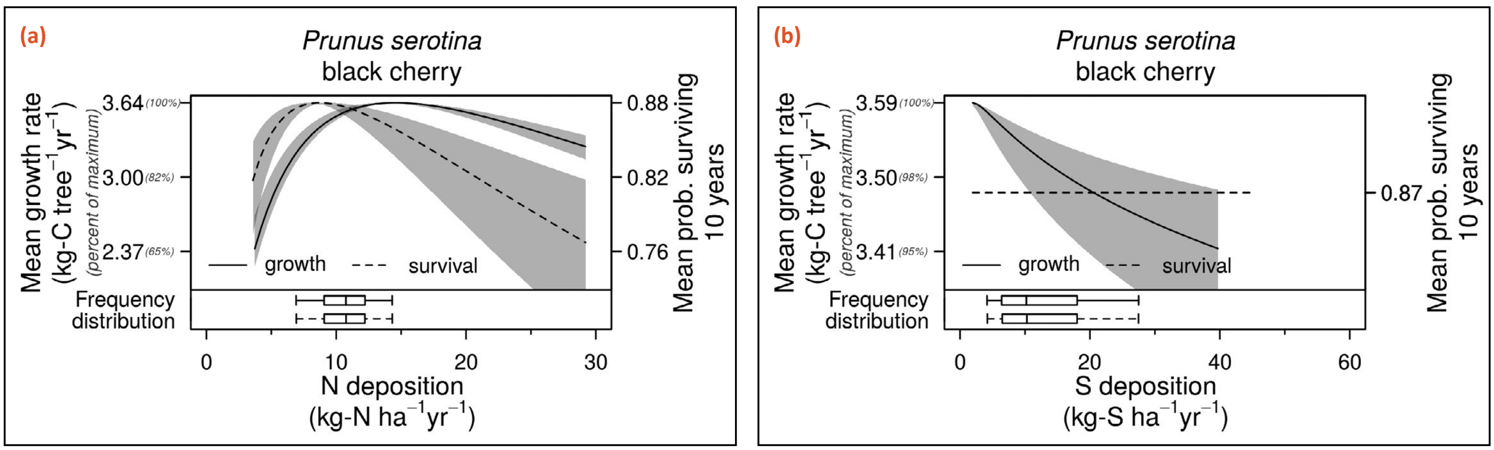
Foliage and fruit of *Prunus serotina.* Photo by Brian Lockhart, USDA Forest Service, Bugwood.org, 1219177.

Bark of *Prunus serotina.* Photo by Brian Lockhart, USDA Forest Service, Bugwood.org, 1118024.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of black cherry has a hump-shaped relationship with increasing N deposition and decreases with increasing S deposition. Survival has a hump-shaped relationship with increasing N deposition and no relationship to S deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Bark of lateral stem of *Prunus serotina.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008010.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Low	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
		X	X	X		

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
			X	X	X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

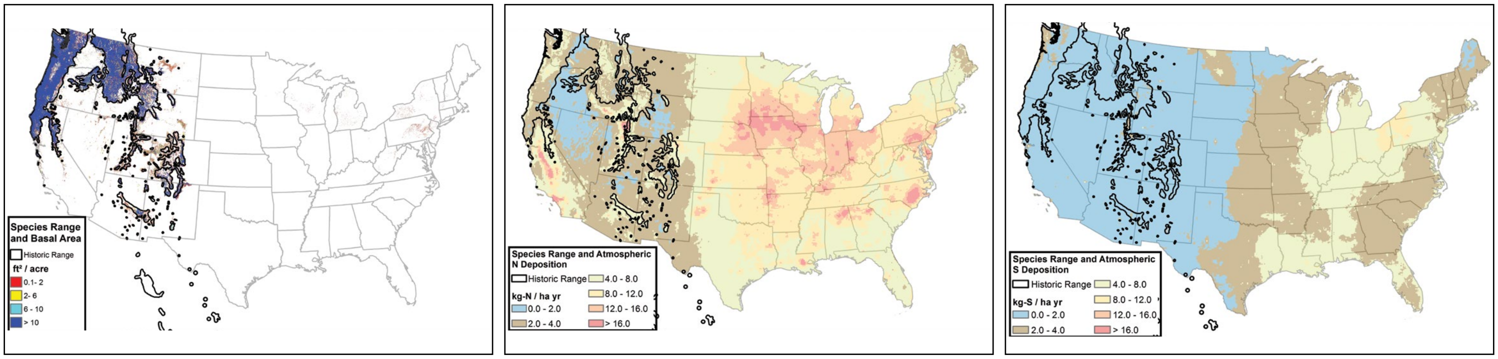
Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

Uchytil, Ronald J. 1991. *Prunus serotina*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (24 January 2016).

Pseudotsuga menziesii (Douglas-fir)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

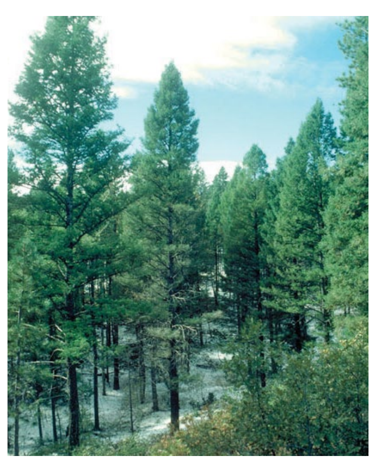
Douglas-fir is a long-lived coniferous, evergreen tree. Open-growing trees often have branches over the length of the bole, while trees in dense stands lack lower limbs. The main differences between the coastal and Rocky Mountain subspecies are growth rates and cold tolerance—the coastal subspecies grow faster and the inland subspecies possess greater cold tolerance. Douglas-fir rely on wind dispersal to distribute pollen from cones in the spring. Coast Douglas-fir exhibits a strong preference for moist mineral soil, while Rocky Mountain Douglas-fir establishes in mineral soil and organic seedbeds. Both subspecies prefer fertile sites with high base cation availability. The species grows at sea level on the Pacific coast and at lower elevations adjacent to and within bunchgrass communities, and is also found in upper elevation subalpine forests. It tends to be most abundant in low- and middle-elevation forests, where it grows over a wide range of aspects, slopes, landforms, and soils. Douglas-fir is a shade-tolerant climax species in dry-to-moist lower and middle-elevation forests but is shade-intolerant in wetter forests. In the absence of disturbance, it tends to replace interior ponderosa pine, lodgepole pine, limber pine, quaking aspen, and western larch in the northern Rockies. On moist sites west of the Continental Divide, western redcedar, western hemlock, spruces, and true firs replace Douglas-fir if disturbance does not occur.

Wildlife Uses

While black-tailed deer, livestock, and elk do not prefer Douglas-fir browse, it can be an important food source for these animals during the winter when other preferred forages are lacking. Drier, more open stands, however, afford these large mammals access to many nutritious herbaceous and shrub species. Blue grouse relies on Douglas-fir needles for forage in the winter. The seeds are an extremely important food for insects and small mammals including white-footed deer mice, creeping voles, chipmunks, and shrews. The Douglas squirrel harvests and caches great quantities of Douglas-fir cones for later use. The seeds are also important in the diets of the winter wren, pine siskin, song sparrow, golden-crowned sparrow, white-crowned sparrow, red crossbill, dark-eyed junco, and purple finch. In the winter, porcupines primarily eat the inner bark of young conifers, especially Douglas-fir. Low-elevation Douglas-fir sites are often important winter ranges for moose, white-tailed deer, and mule deer. Mature or old-growth coast Douglas-fir is the primary habitat of the red tree vole and the spotted owl. The snags are abundant in forests older than 110 years and provide cavity-nesting habitat for numerous forest birds. Merriam's turkeys use tall, high-canopy coverage Rocky Mountain Douglas-fir for roosts. Due to the diversity of plant and insect species, raptors often inhabit Douglas-fir-dominated stands.

Ecosystem Services

Douglas-fir is one of the world's best timber producers and yields more timber than any other tree in North America. The wood is used for dimensional lumber, railroad ties, veneer, pulp,



Stand of *Pseudotsuga menziesii.* Photo by Dave Powell (retired), USDA Forest Service, Bugwood.org, 1210046.

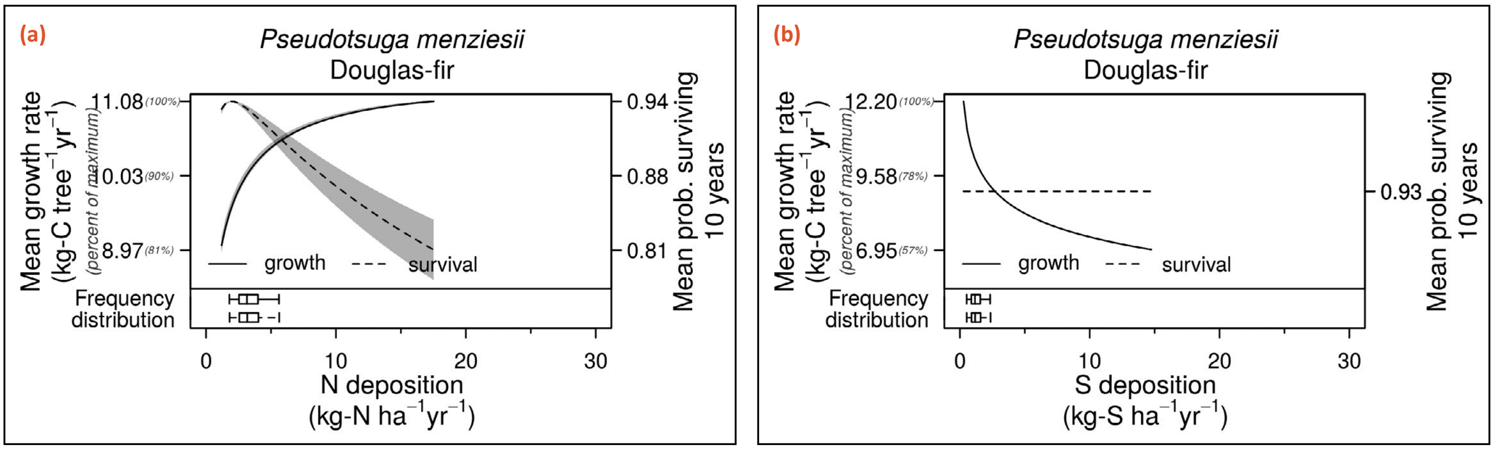
Cones of *Pseudotsuga menziesii.* Photo by Mary Ellen (Mel) Harte, Bugwood.org, 5001061.

furniture, log cabins timbers, pilings, and plywood. Marine structures are constructed with creosote-soaked pilings and decking. Coast Douglas-fir is used extensively in landscaping, planted as a specimen tree or in mass screenings. It is also a popular Christmas tree.

Indigenous peoples of western North America, including the Apache, Hanaksiala, Skagit, and Karok, used Douglas-fir for ceremonial purposes, hunting implements, fuelwood, mouth fresheners, and decoctions for venereal diseases. The Quinault and Skagit also used the wood for the shafts of their harpoons for salmon fishing.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of Douglas-fir increases with increasing N deposition and decreases with increasing S deposition. Survival decreases with increasing N deposition and has no relationship to S deposition. Confidence in these relationships is medium low based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated, so inferring causality to one or the other stressor can be difficult. See also Appendix Table 4 and the Introduction for more information.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X	X	X	X	X

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
	X				X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

Primary Sources

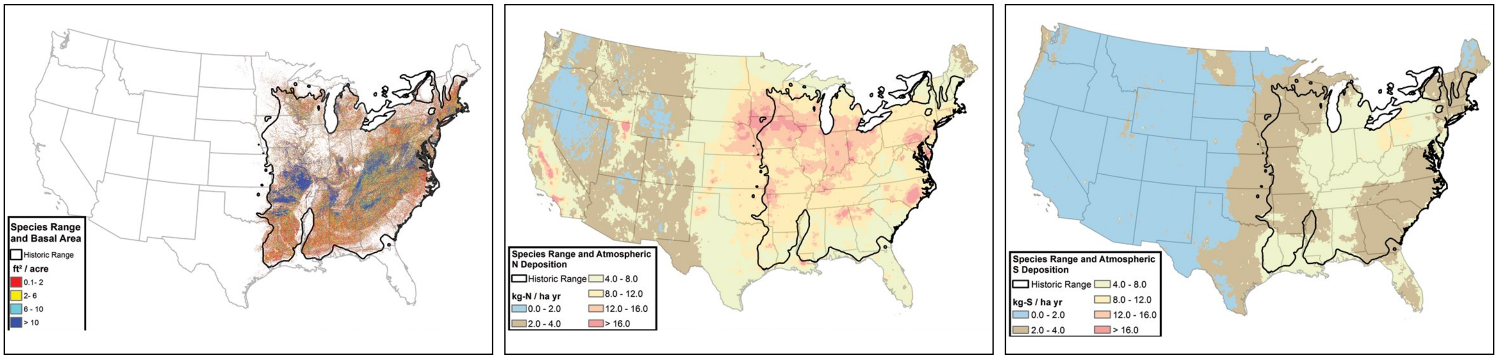
Native American Ethnobotany Database. http://naeb.brit.org.

Steinberg, Peter D. 2002. *Pseudotsuga menziesii* var. *glauca*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (24 January 2016).

Uchytil, Ronald J. 1991. *Pseudotsuga menziesii* var. *menziesii*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/ (24 January 2016).

Quercus alba (white oak)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

White oak is a medium to large, spreading, deciduous tree, which commonly reaches 60 to 80 feet (18–24 m) in height. It is slow-growing and long-lived (up to 600 years). The short-stalked acorns are tan to brown and generally borne in pairs. The tree reproduces through seed and by vegetative means. In years of poor acorn production, the entire seed crop may be eaten. Wind, gravity, birds, and animals disperse any acorns that are not eaten on site. White oak grows in rich uplands, moist bottomlands, along streams, on hammocks, sinks, sandy plains, and on dry, gravelly slopes. It occurs on all upland aspects, and slope positions. It is absent on ridgetops with shallow soil, on poorly drained flats, and on very wet bottomlands. The tree grows on a wide variety of soils derived from many types of parent materials; it grows on silty loam, clay loam, silty clay loam, fine sand, and loamy clay but grows best on deep, well-drained loamy soils. White oak readily regenerates after disturbances such as fire or logging and often assumes prominence in mid to late seral stages. In the North, white oak is commonly seral to sugar maple and other species characteristic of mixed mesophytic stands. In much of its range, it is succeeded by beech and other shade-tolerant species on well-drained stream bottoms and in protected coves. White oak is unable to regenerate beneath the shade of parent trees and relies on periodic fires for its perpetuation. The exclusion of fire has inhibited white oak regeneration through much of its range.

Wildlife Uses

Deer, rabbits, and livestock readily consume the young shoots of many eastern oak species. White-tailed deer occasionally eat dried oak leaves in the fall or winter. Rabbits often browse twigs and can girdle stems. Porcupine feed on the bark, and beavers eat the twigs. Acorns of white oak are considered choice food for many wildlife species, including the white-footed mouse, fox squirrel, black bear, pine mouse, red squirrel, and cottontail rabbits. Many birds, including the blue jay, northern bobwhite, mallard, ring-necked pheasant, greater prairie chicken, ruffed grouse, and wild turkey, also eat the acorns. Oak leaves often persist longer than many other plant associates and, in some areas, young oaks may represent the only brushy winter cover in dense pole stands. Oaks frequently serve as perching or nesting sites for various songbirds. The well-developed crowns provide shelter and hiding cover for small mammals such as tree squirrels. Many birds and mammals use twigs and leaves as nesting materials. Large oaks provide denning sites for a variety of mammals.

Ecosystem Services

White oak is the most important timber oak and is commercially important throughout much of the South and East. Wood products include furniture, veneer, paneling, and flooring. It has been used to make railroad ties, fenceposts, mine timbers, ships,

Canopy of *Quercus alba.* Photo by Richard Webb, Bugwood.org, 1480390.

Bark of *Quercus alba.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008037.

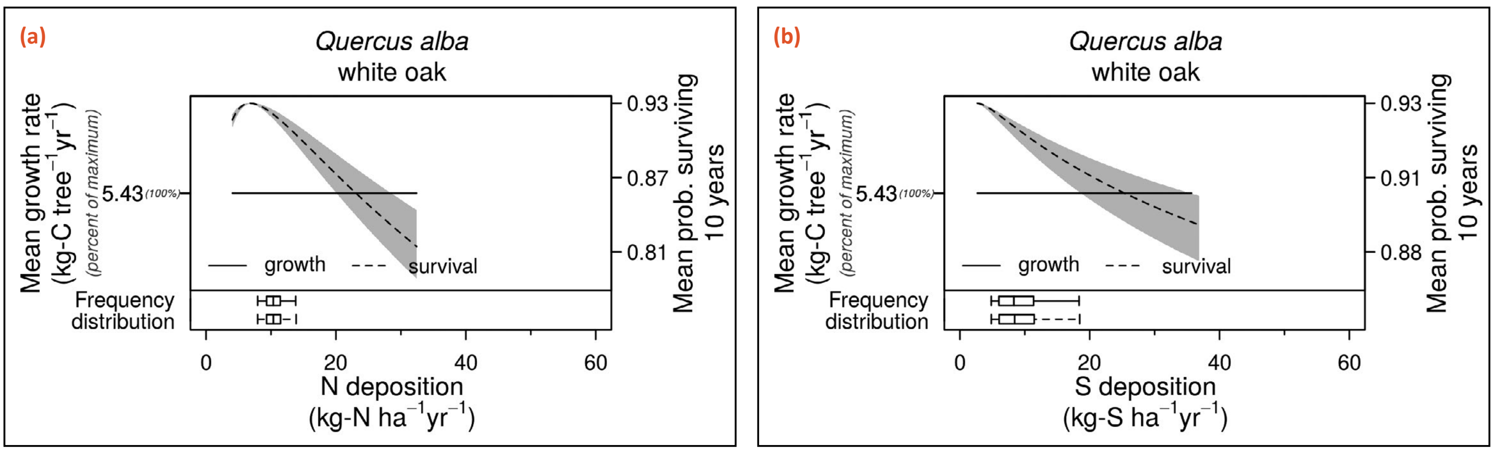
and caskets, as well as clapboard shingles and woven baskets. White oak has long been used in cooperage and is currently the major source of wood for whiskey barrels. Its high fuel value makes it an attractive firewood. White oak is commonly used in landscaping and is often planted as a shade tree or ornamental. Its colorful purplish-red to violet-purple foliage in autumn enhances its ornamental value.

The sweet and edible acorns of white oak were traditionally an important food source for many indigenous peoples including the Cherokee, Delaware, Oklahoma, and Mohegan. The acorns were often boiled to remove tannins and offset some bitterness. Oils obtained from pressed acorns were used to alleviate pain in the joints. In addition, various decoctions and infusions from the bark were traditionally used to treat indigestion, fever, and asthma.

White oak is potentially valuable for use in reforestation projects and appears to have potential for use on other types of disturbed sites such as strip-mined lands.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of white oak has no relationship to N or S deposition. Survival mostly decreases with increasing N deposition and decreases with increasing S deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	**Shade Tolerance**	**Leaf Type**	**Mammal Uses**	**Bird Uses**
	Medium	Broadleaf Deciduous	Yes	Yes

Wood products				**Traditional uses**	**Ornamental uses**	**Fuelwood**
Paper	**Unfinished wood products**	**Building material**	**Finished wood products**			
	X	X	X	X	X	X
Protection			**Rehabilitation**	**Food products**	**Oils and other**	**General services**
Erosion	**Wind**	**Erosion and wind**				
			X			X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

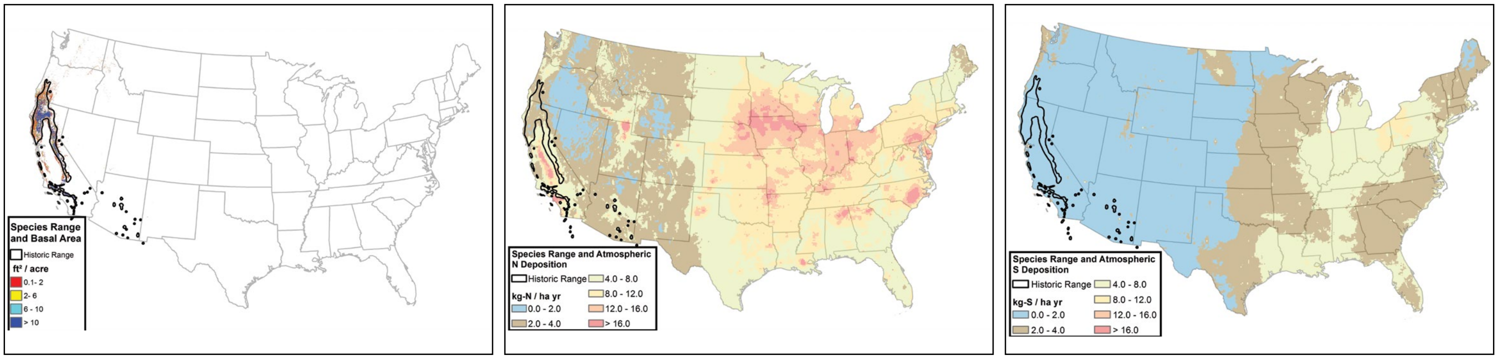
Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

Tirmenstein, D. A. 1991. *Quercus alba*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (1 March 2016).

Quercus chrysolepis (canyon live oak)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Canyon live oak is one of the most morphologically variable oaks in North America. It is a spreading, perennial, sclerophyllous evergreen that ranges from less than 15 feet to 100 feet (5–30 m) tall and up to 10.7 feet (3.3 m) in diameter. It grows as a shrub and may form dense thickets on mountain slopes and ridgetops and it grows as a tree in sheltered, moist canyons. The bark is smooth to flaky. Canyon oak is a prolific yet irregular seed producer, but also reproduces vegetatively through sprouting. On steep canyon slopes, acorns may roll downhill a long distance. Small mammals and birds that cache the acorns are also effective dispersal agents. Canyon live oak occurs on a wide variety of sites ranging from canyon bottoms to ridgetops. It grows under more variable conditions than any other oak in California. It is commonly found on steep, rocky, exposed ridges, rock crevices, and canyon slopes and also grows in riparian areas, sheltered coves, and deep, moist, shady ravines and canyons. It grows in a wide variety of soils—within deep, rich canyon bottoms to rocky, shallow, infertile soils. Canyon live oak is shade-tolerant and long lived. Shade tolerance and its phenotypic plasticity enable the species to persist in a variety of late seral and climax communities including old-growth mixed-evergreen, mixed-conifer, and hardwood forests. Canyon live oak is also an important component of many early seral communities, primarily because of rapid, prolific sprouting that enables it to grow much faster after disturbance than conifers that reproduce only by seed. Its ability to assume multiple growth forms allows it to dominate early-seral, late-seral, and climax stages in some communities.

Wildlife Uses

Canyon live oak has limited food value for livestock. However, the tree is a valuable food source for many species of wildlife. Deer feed on the foliage and twigs throughout the year in California and Arizona. Sprouting canyon live oak provide browse for wildlife following wildfires. The acorns are a primary food source for acorn woodpeckers and an important food source for western scrub jays, Steller's jays, band-tailed pigeons, wild turkeys, mountain quail, ground squirrels, western gray squirrels, woodrats, common crows, gophers, American black bears, and mule deer. Canyon live oak forests and woodlands provide habitat for a variety of large mammals including American black bears, deer, coyotes, mountain lions, bobcats, and American badgers, and small mammals, including red tree voles, deer mice, white-footed mice, pinyon mice, California pocket mice, California voles, Botta's pocket gophers, and broad-footed mice. A variety of birds forage in canyon live oak forests and woodlands, including Nuttall's woodpeckers, acorn woodpeckers, white-breasted nuthatches, plain titmice, black-headed grosbeaks, and Baltimore orioles. The tree provides nesting habitat for California spotted owls, raptors, and ravens. There are also several associated reptiles and amphibians found with canyon live oak woodlands, including San Bernardino Mountain kingsnakes, San Gabriel Mountain slender salamanders, large-blotched salamanders, black-bellied slender salamanders, California slender salamanders, Gilbert's skinks, yellow-blotched salamanders, foothill yellow-legged frogs, western fence lizards, and southern alligator lizards. Canyon live oak is host to at least 39 cynipid gall wasp species in California.

Ecosystem Services

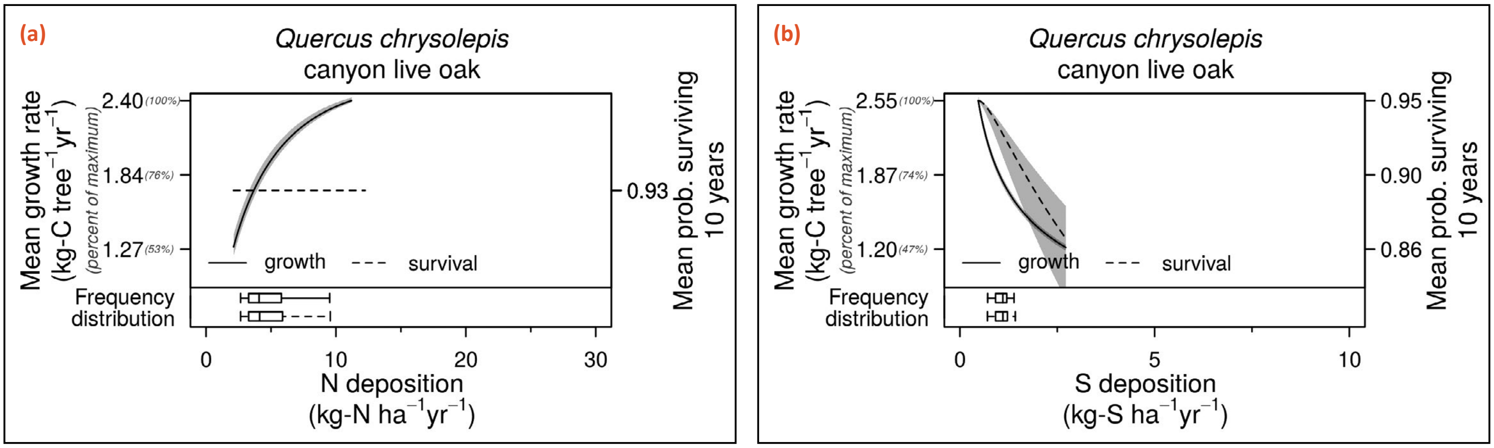
Canyon live oak wood is the highest quality of all western oaks. Because the wood is particularly hard—sometimes referred to as "rock oak" or "maul oak"—it has been used for axles, tool handles, mauls, wagon tongues, plow beams, ship frames, and wheels. Wedges made from canyon live oak were used to split redwood into railroad ties. Today, its commercial value is limited by the small quantities available. Canyon live oak is an attractive landscaping tree and an important source of firewood in southern California.

Indigenous peoples of the Sierra Nevada and southern California, including the Chuilla, Diegueno, and Karok, ground the acorns into a fine meal and flour. The acorns may be poisonous if eaten raw.

Canyon live oak's deep root system and its ability to grow on rocky, unstable sites make it useful for soil stabilization on steep slopes.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of canyon live oak increases with N deposition and decreases with increasing S deposition. Survival has no relationship to N deposition and decreases with increasing S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	High	Broadleaf Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
			X	X	X	X

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
X			X			X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

Primary Sources

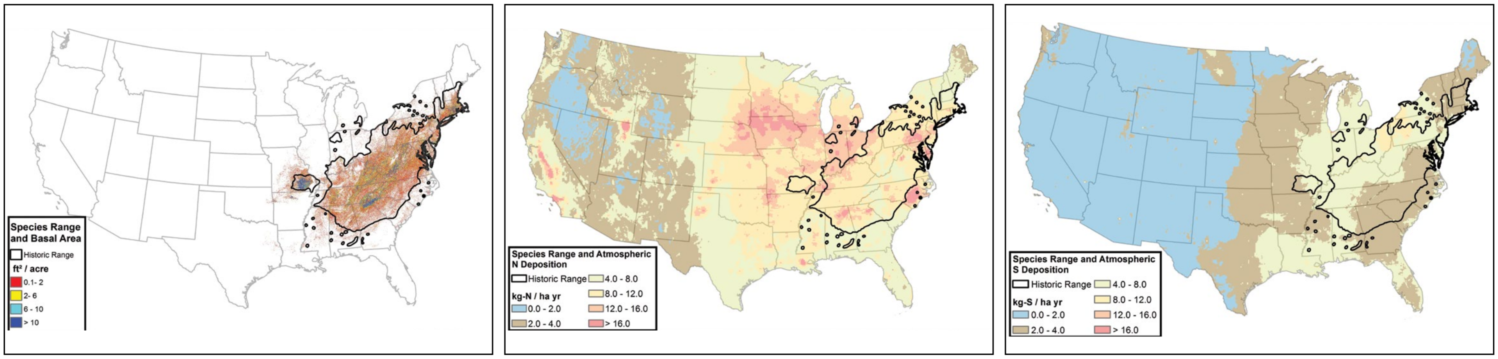
Native American Ethnobotany Database. http://naeb.brit.org.

Tollefson, Jennifer E. 2008. *Quercus chrysolepis*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (1 March 2016).

U.S. Department of Agriculture, Natural Resources Conservation Service. 2016. The PLANTS Database. National Plant Data Team, Greensboro, NC 27401–4901 USA. http://plants.usda.gov. (1 March 2016).

Quercus coccinea (scarlet oak)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Scarlet oak is a medium-sized deciduous tree with an open, rounded crown. At maturity, the tree is usually 60 to 80 feet (18–24 m) tall and 24 to 36 inches (61–91 cm) in diameter. It is one of the fastest growing upland oak species and is short-lived (less than 150 years). Acorn production is irregular and unpredictable. Scarlet oak, an upland xerophytic species, commonly occurs on ridges and slopes in hilly to mountainous terrain. It occurs up to 5,000 feet (1,520 m) in the southern Appalachian Mountains but is most common below 3,000 feet (910 m). The species grows in a wide variety of soils, but especially in dry sandy or gravelly soils. It is most common on lower quality sites. It is shade-intolerant and usually found in dominant and codominant positions, since suppressed individuals eventually die. Scarlet oak tends to be better represented in forests with a history of disturbance such as fire, logging, grazing, or disease. In the absence of disturbance, codominant scarlet oak declines in importance in mixed oak stands. It may be climax on dry sites with adequate light because of its drought tolerance, but it has a low fire resistance.

Wildlife Uses

Scarlet oak acorns provide an important food source for numerous upland wildlife species, including squirrels, chipmunks, mice, wild turkeys, white-tailed deer, blue jays, and woodpeckers. White-tailed deer occasionally browse young oak sprouts. The deer only take the top few inches of the sprout unless it is extremely succulent or other food is scarce. Small mammals and birds use scarlet oak for nesting sites, both in the canopy and in cavities.

Ecosystem Services

Although scarlet oak wood is of inferior grade, it is cut and used with other red oaks as red oak lumber. With its brilliant red foliage in autumn, it is widely planted in the United States and Europe as a shade tree and ornamental. When managing forests for cavity-nesting species, scarlet oak is preferred due to its high number of cavities.

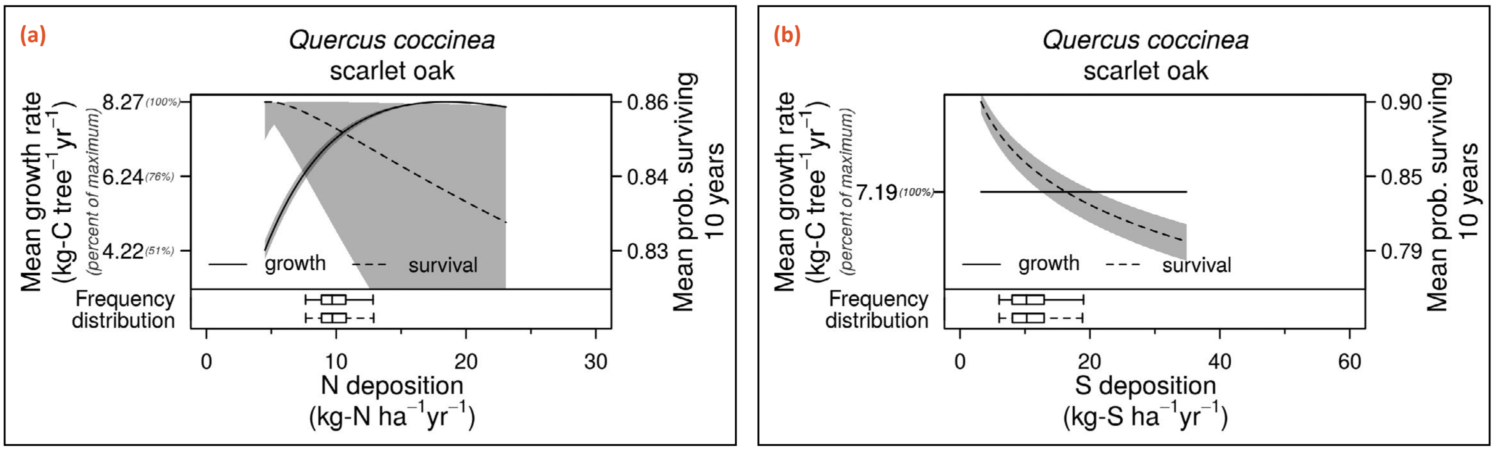
Specimen of *Quercus coccinea*. Photo by Chris Evans, University of Illinois, Bugwood.org, 2150011.

Leaf of *Quercus coccinea.* Photo by J.S. Peterson, hosted by the USDA-NRCS PLANTS Database.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of scarlet oak mostly increases with N deposition, and has no relationship to S deposition. Survival decreases with increasing N deposition and decreases with S deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Acorns of *Quercus coccinea.* Photo by Steve Hurst, hosted by the USDA-NRCS PLANTS Database.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Low	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
		X			X	

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
						X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

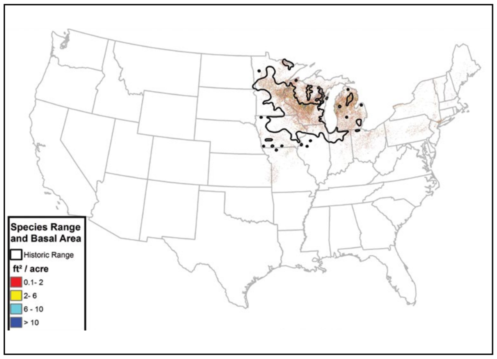
Primary Source

Carey, Jennifer H. 1992. *Quercus coccinea*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (1 March 2016).

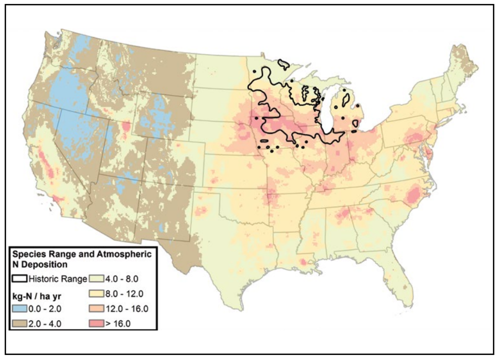
U.S. Department of Agriculture, Natural Resources Conservation Service. 2016. The PLANTS Database. National Plant Data Team, Greensboro, NC 27401–4901 USA. http://plants.usda.gov. (1 March 2016).

Quercus ellipsoidalis (northern pin oak)

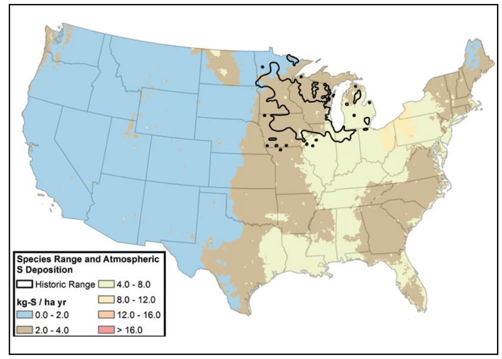
(a)



(b)



(c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Northern pin oak is a small to medium-sized, native deciduous tree, typically reaching heights to 70 feet (21 m). It has an irregularly shaped crown and low-hanging branches that persist for long periods as dead stubs, giving a ragged appearance to the trunks. Seed production begins when the tree is about 20 years old, and acorns take two years to ripen. Squirrels, blue jays, and gravity handle seed dissemination. Northern pin oak is an upland xeric species that commonly grows on dry, acid, sandy soils with a very thin organic layer. It most often occurs on sandy plains and sandstone hills and develops into extensive pure populations only on such sites. Northern pin oak is the most drought tolerant of all black oaks. It is very shade-intolerant and does not reproduce under its own shade. The other oaks with which it is commonly associated are less light demanding and thus tend to succeed it. Succession is toward white oak/black oak/northern red oak and bur oak communities. After a disturbance, northern pin oak sprouts from the root collar or stump if top-killed or cut. In addition, the tree is well adapted to fire—the thermal insulating properties of the bark of mature trees allow it to survive even annual burning.

Wildlife Uses

Northern pin oak acorns provide food for a variety of wildlife species including gray squirrels, white-tailed deer, and blue jays. During off years of acorn production, many of the acorns are destroyed by weevils. Wood ducks, eastern kingbirds, and the federally endangered Kirtland's warbler use trunk cavities as nesting sites.

Ecosystem Services

Like several other oaks, northern pin oak can be used to make furniture, flooring, and interior finishing.

The Menominee traditionally roasted the acorns to make a coffee-like beverage and used a decoction of the inner bark to suppress menses.

Northern pin oak is useful for rehabilitating disturbed sites because of its ability to withstand droughts and persist on nutrient-poor soils.

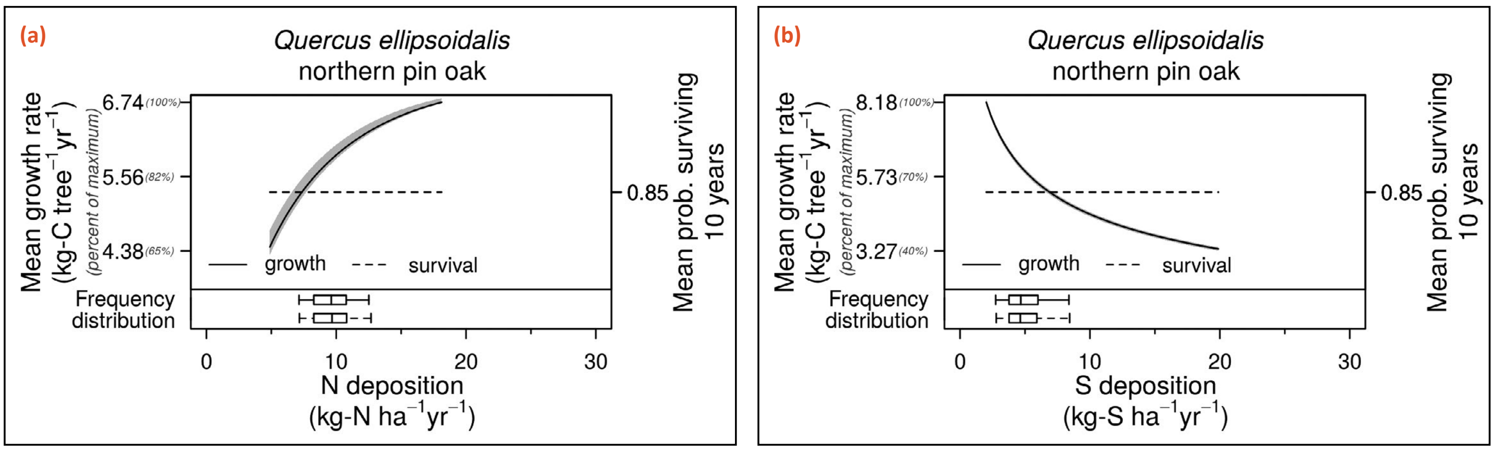
Stand of *Quercus ellipsoidalis.* Photo by Bill Cook, Michigan State University, Bugwood.org, 1219191.

Acorns of *Quercus ellipsoidalis.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008235.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of northern pin oak increases with increasing N deposition, and decreases with increasing S deposition. Survival has no relationship to N or S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Foliage of *Quercus ellipsoidalis*. Photo by Paul Wray, Iowa State University, Bugwood.org, 0008391.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Low	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
		X	X	X		

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
			X			X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

Primary Sources

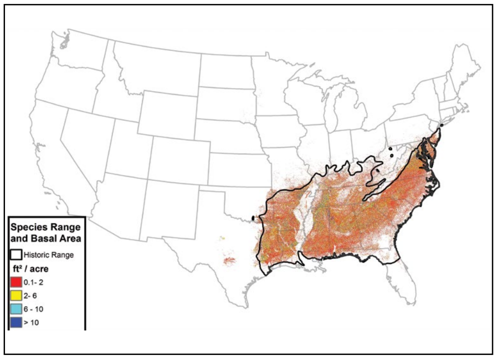
Coladonato, Milo. 1993. *Quercus ellipsoidalis*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (1 March 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

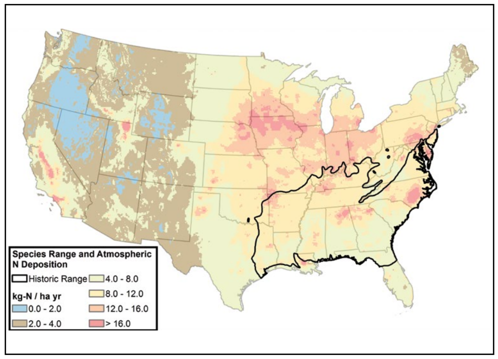
U.S. Department of Agriculture, Natural Resources Conservation Service. 2016. The PLANTS Database. National Plant Data Team, Greensboro, NC 27401–4901 USA. http://plants.usda.gov. (1 March 2016).

Quercus falcata (southern red oak)

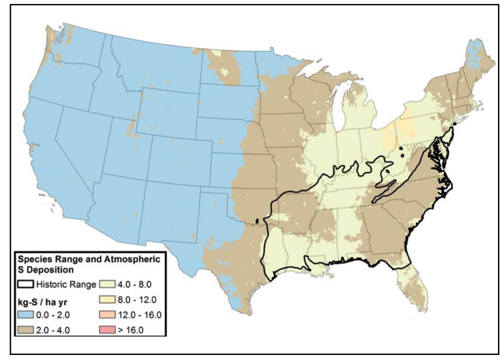
(a)



(b)



(c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Southern red oak is a medium- to large-sized, native deciduous tree with a long, straight trunk and upward-reaching branches that form a high rounded crown. It is usually 70 to 80 feet (20–25m) tall and 24 to 36 inches (60–90 cm) in diameter, but it can be larger on good sites. It is one of the hardiest and fastest growing oaks, and lives to about 150 years. Squirrels and blue jays, which transport and cache acorns, are responsible for most of the seed dissemination, but gravity is also important because the tree often grows on steep slopes. Southern red oak occurs on dry, upland sites to about 2,000 feet (610 m) in elevation. It is often found on south- and west-facing slopes or on dry ridgetops and grows on sandy, loamy, or clay soils. Southern red oak is mid-tolerant to intolerant of shade. It is common in transitional pine-hardwood and early hardwood communities. In the absence of fire, it replaces pine on drier upland sites. It is occasionally encountered as a codominant in climax or near climax southern mixed hardwood communities and oak-hickory climax forests. The tree's thin bark makes it susceptible to fire.

Wildlife Uses

The acorns are an important food source for wildlife, including waterfowl, wild turkey, blue jay, red-headed and red-bellied woodpeckers, white-breasted nuthatch, common grackle, raccoon, white-tailed deer, and squirrels. Acorns of the red oak group are an especially important food source in the winter because those of the white oak group germinate soon after falling and, therefore, are unavailable. Southern red oak also provides cover and nesting sites for birds and mammals.

Ecosystem Services

Wood from the southern red oak is strong and heavy, but tends to be rough, coarse-grained, and have insect and stain damage; it is used mainly for factory lumber, railroad ties, and timbers. Acorns are collected for foodstuffs, and southern red oak is also often planted as a shade tree.

The Cherokee traditionally used the bark of southern red oak to create decoctions and infusions or tonics to treat fevers, chronic dysentery, mouth sores, and laryngitis.

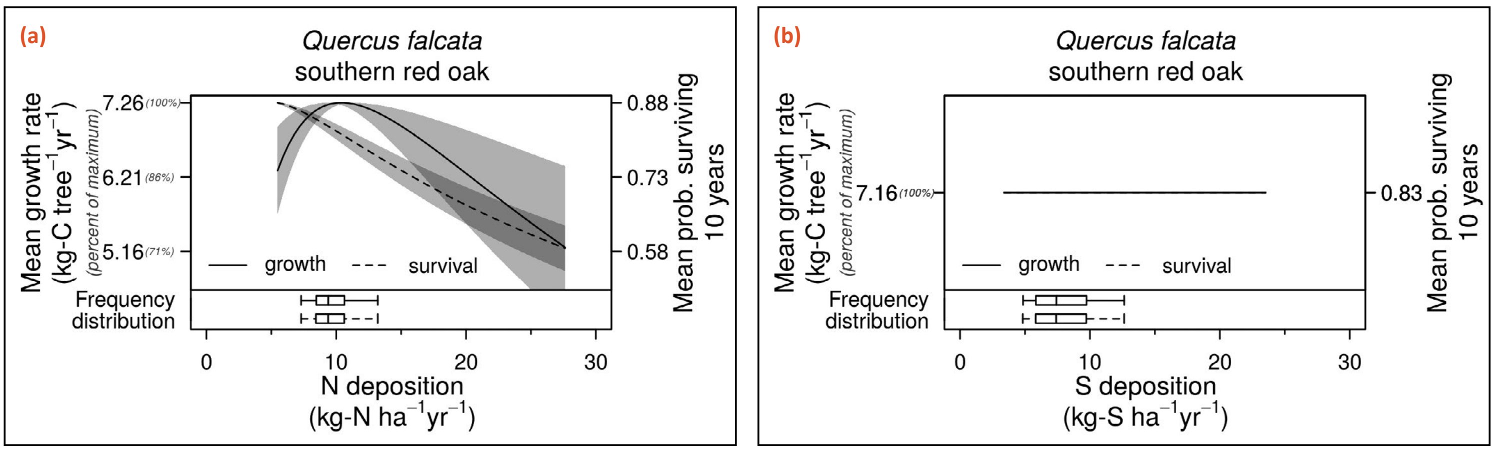
Specimen of *Quercus falcata.* Photo by Chris Evans, University of Illinois, Bugwood.org, 2151023.

Foliage of *Quercus falcata.* Photo by Chris Evans, University of Illinois, Bugwood.org, 1380389.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of southern red oak has a hump-shaped relationship with increasing N deposition and has no relationship to S deposition. Survival decreases with increasing N deposition and has no relationship to S deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Twigs/shoots of *Quercus falcata.* Photo by Chris Evans, University of Illinois, Bugwood.org, 1380390.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
	X	X		X	X	

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
				X		X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

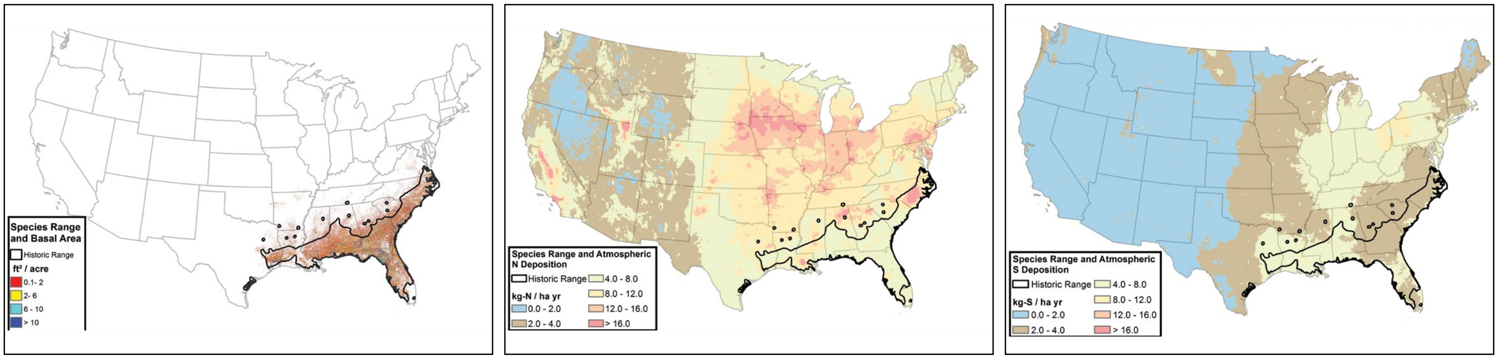
Primary Sources

Carey, Jennifer H. 1992. *Quercus falcata*, Q. *pagoda*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (1 March 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Quercus laurifolia (swamp laurel oak)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Swamp laurel oak is a rapidly growing, short-lived, semi-evergreen tree. It can reach 148 feet (45 m) in height and 6.6 feet (2 m) in diameter. It produces abundant flowers almost every year and is a prolific seed bearer. It sustains high leaf-fall production from October to March, and flowers in February or March, at the same time that the last of the previous year's leaves are shed. Dissemination of the heavy acorns is mainly by squirrels, but gravity and water also play a role. Swamp laurel oak is considered a bottomland or facultative wetland species. It generally grows in soils that are better drained than soils where water oak and willow oak grow but can also be found in very wet sites. It commonly grows on alluvial flood plains and sandy soils near rivers, swamps, and hammocks, and is moderately tolerant of flooding. In addition to bottomland forests, swamp laurel oak is found in bay swamps, mixed hardwood swamps, river swamps, hydric hammocks, and cypress ponds and strands. It also grows on barrier islands off the Atlantic Coast. Swamp laurel oak is shade-tolerant and often becomes established under and grows up through a dense canopy. However, the species is also an early invader on some sites. It will invade early seral wetlands if a seed source is nearby and will dominate if fire is suppressed—swamp laurel oak is fire intolerant.

Wildlife Uses

The consistent and abundant acorn crops of these oaks are an important food source for many animals, including white-tailed deer, raccoon, squirrels, wild turkey, ducks, quail, smaller birds, and rodents. It also provides good deer browse.

Ecosystem Services

Although swamp laurel oak has hard, heavy, and strong wood, it is not good quality lumber. It is marketed for pulpwood and used for firewood. The tree has attractive leaves and is often planted as an ornamental.

The Choctaw traditionally boiled the bark to make paint.

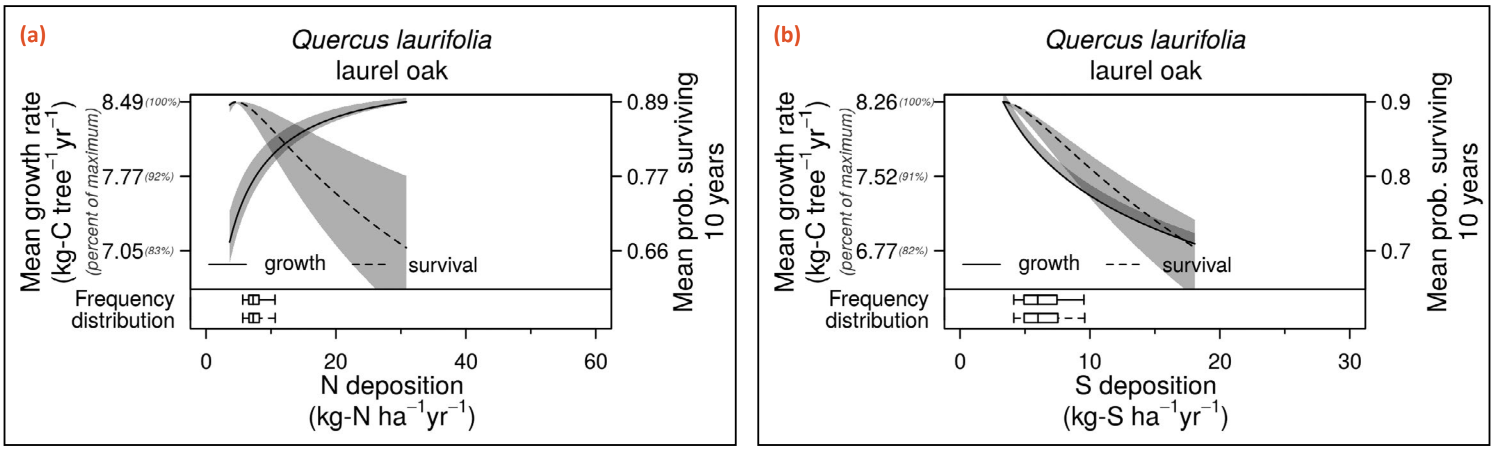
Crown of *Quercus laurifolia.* Photo by Douglas Goldman, USDA.

Bark of *Quercus laurifolia.* Photo by Douglas Goldman, USDA.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of swamp laurel oak increases with increasing N deposition and decreases with increasing S deposition. Survival mostly decreases with increasing N deposition and decreases with increasing S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Acorns of *Quercus laurifolia.* Photo by Steve Hurst, hosted by the USDA-NRCS PLANTS Database.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	High	Broadleaf Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X				X	X	X

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
						X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

Primary Sources

Carey, Jennifer H. 1992. *Quercus hemisphaerica*, Q. *laurifolia*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (29 February 2016).

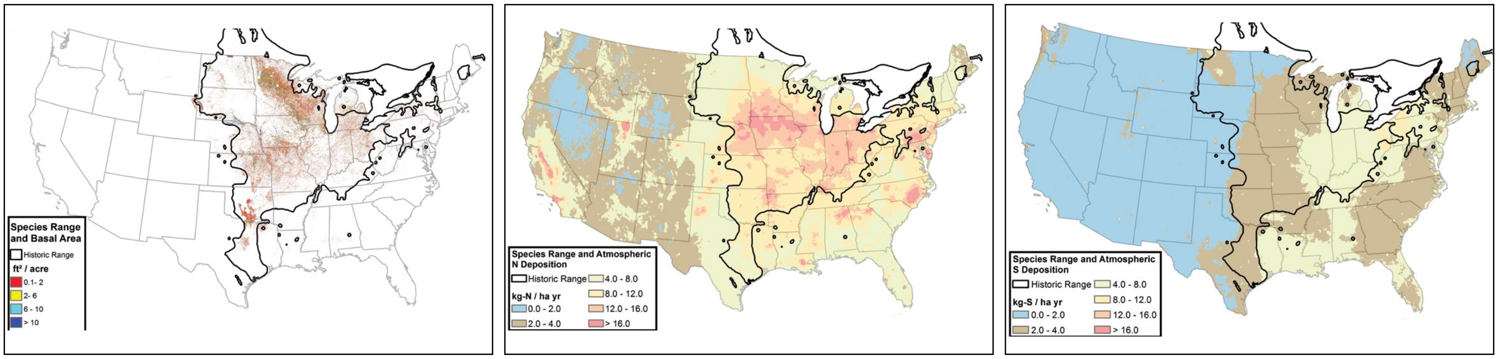
Native American Ethnobotany Database. http://naeb.brit.org.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2016. The PLANTS Database. National Plant Data Team, Greensboro, NC 27401–4901 USA. http://plants.usda.gov. (1 March 2016).

Weller, Rebecca (creator). 2017. Trees for Me. http://www.treesforme.com. (March 17, 2017).

Quercus macrocarpa (bur oak)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Bur oak typically grows as a large, spreading tree up to 130 feet (40 m) tall; however, growth form and size can vary by site. Branches in the upper portion of the crown are ascending; in the lower crown, branches are larger and horizontal. The trunks of mature trees have thick, deeply grooved bark. In the western part of its range on exposed, harsh sites, bur oak grows as a small tree or shrub and may produce crooked, gnarled branches. Bur oak is a long-lived tree. Generally, leaves are deeply lobed and large, up to 12 inches (30 cm) long and about half as wide. The acorns are usually one-seeded with a large cup. Bur oak occupies habitats ranging from moist woodlands and bottomland forests to prairies and sandhills. While it tolerates harsh soil conditions, including poor, dry soils and wet, poorly drained or inundated soils, bur oak distribution is not necessarily dictated by soil characteristics. Bur oak is one of the most cold-tolerant of the North American oak species. In most areas, it is a shade-intolerant, early-seral species that is replaced by shade-tolerant deciduous species in the absence of large-scale disturbances. Capable of sprouting, bur oak communities are described as persistent vegetation maintained by frequent fire.

Wildlife Uses

The acorns provide an important food source for a variety of livestock, ungulates, birds, and small mammals. Black bears, red squirrel, deer, cattle, goats, cottontails, wild turkey, squirrels, white-footed mice, and other rodents all eat the acorns. Bur oaks also provide cavity-nesting sites for mountain bluebirds, white-breasted nuthatches, and northern flickers.

Ecosystem Services

Bur oak wood is used for railroad ties, cabinetry, and tight cooperage, as well as hardwood flooring, and fence posts.

Both indigenous peoples and early European settlers ate the acorns. The Cheyenne of Montana traditionally ate the acorns in a mush mixed with buffalo fat. Others, including the Iroquois, Menominee, Dakota, and Winnebago, used various wood and bark decoctions to treat pin worms, lung and heart ailments, and cramps.

Survival and persistence of bur oak have been reported on revegetated mine sites, making them a candidate species for site reclamation.

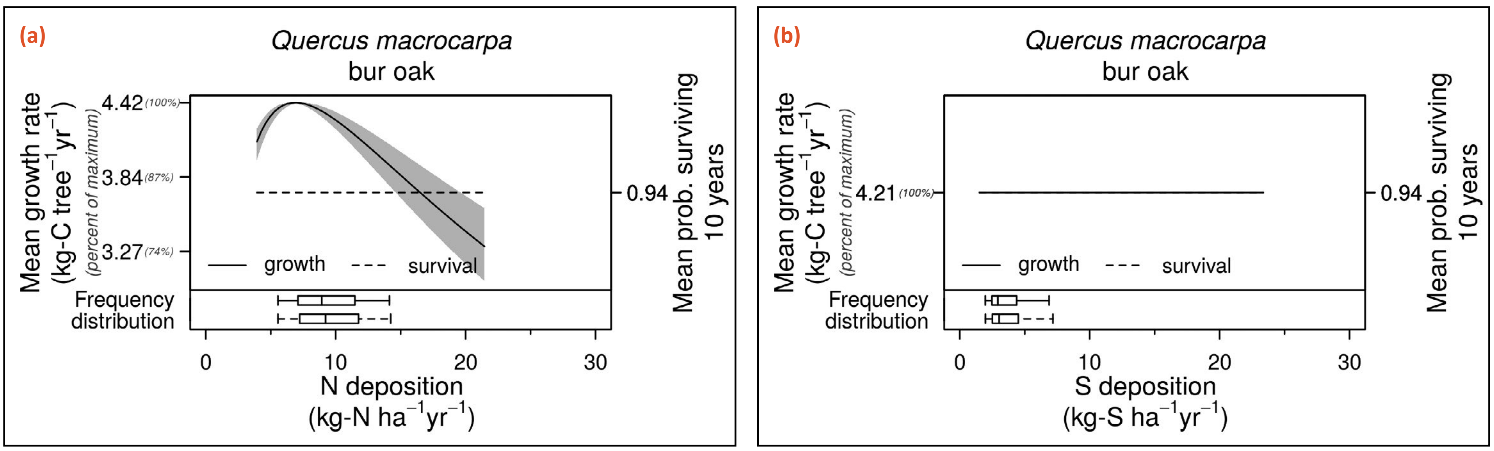
Specimen of *Quercus macrocarpa.* Photo by T. Davis Sydnor, The Ohio State University, Bugwood.org, 5529805.

Bark of *Quercus macrocarpa.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008028.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of bur oak has a hump-shaped relationship with N deposition and no relationship to S deposition. Survival has no relationship to N or S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Acorn of *Quercus macrocarpa.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008232.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Low	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
	X	X	X	X		

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
			X	X		X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

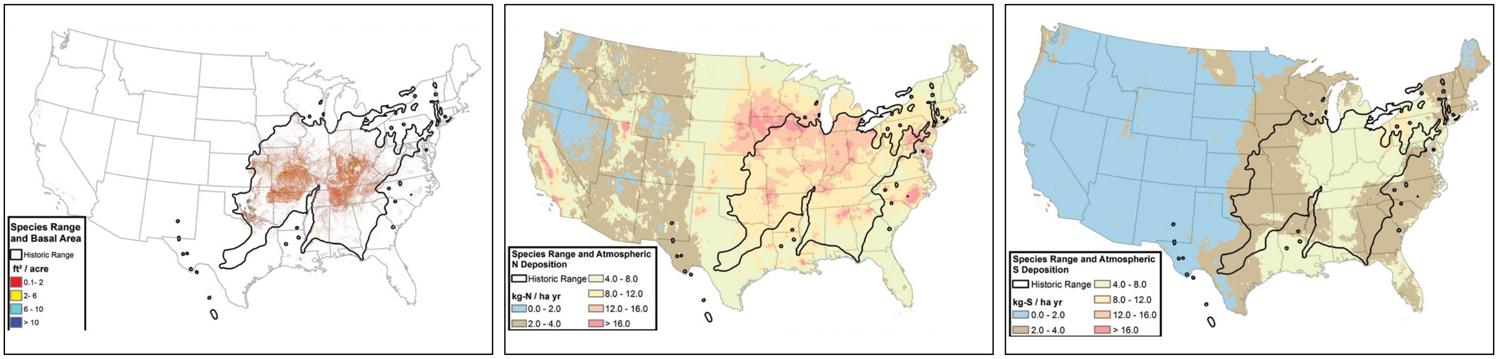
Primary Sources

Gucker, Corey L. 2011. *Quercus macrocarpa*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (29 February 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Quercus muehlenbergii (chinkapin oak)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Chinkapin oak is a spreading, medium to large, deciduous tree which generally reaches 16 to 52 feet (5–16 m) tall. In closed forest stands, it develops a straight, columnar trunk, a dense rounded crown, and fairly small branches. The thin bark is light gray to silvery and rough or scaly. Acorns are borne singly or in pairs, are dark brown to nearly black, and about half of the nut is enclosed by the cup. Chinkapin oak grows on dry, rocky sites, such as calcareous bluffs, rocky hillsides, and protected slopes and canyons. It also occurs in glades and valleys and along rocky stream banks. In parts of the Midwest, it grows in rich forests and on stabilized dunes. It is particularly common near forest margins. It grows on deep, well-drained soils of river and creek bottoms and on limestone outcrops. Soils are often of low fertility and deficient in nutrients such as phosphorus. It is fairly tolerant of shade and drought. Chinkapin oak is a climax tree on dry soils, particularly those of limestone origin. It is seral on more moist sites, generally being replaced by more shade-tolerant species. In the case of stem mortality, chinkapin oak sprouts readily from roots after disturbance.

Wildlife Uses

Browse and acorns of chinkapin oak are important to a wide variety of livestock and wildlife. Deer and rabbits eat the browse; rabbits sometimes girdle small trees. Beaver feed on the bark and twigs, and porcupines consume the bark. Mice, squirrels, voles, other small mammals, and white-tailed deer feed on the acorns, which are also an especially important fall food item for the black bear. A large variety of birds feed on the acorns—among them the ruffed grouse, sharp-tailed grouse, ring-necked pheasant, wild turkey, common crow, northern flicker, grackle, blue jay, brown thrasher, tufted titmouse, starling, lesser prairie chicken, chickadees, nuthatches, and waterfowl—and they are a particularly important food item for the red-headed woodpecker, red-bellied woodpecker, northern bobwhite, and blue jay. Although effective dispersal agents, birds and mammals also consume many seeds. In some areas, 90 to 100 percent of the annual acorn crop may be lost to seed predators. Leaves often persist longer than those of many other plant associates, and in some areas, young oaks may represent the only brushy winter cover in dense pole stands. Many species of birds and mammals use twigs and leaves as nesting material. Large oaks provide denning sites for a variety of mammals.

Specimen of *Quercus muehlenbergii.* Photo by T. Davis Sydnor, The Ohio State University, Bugwood.org, 5529813.

Flower of *Quercus muehlenbergii.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008113.

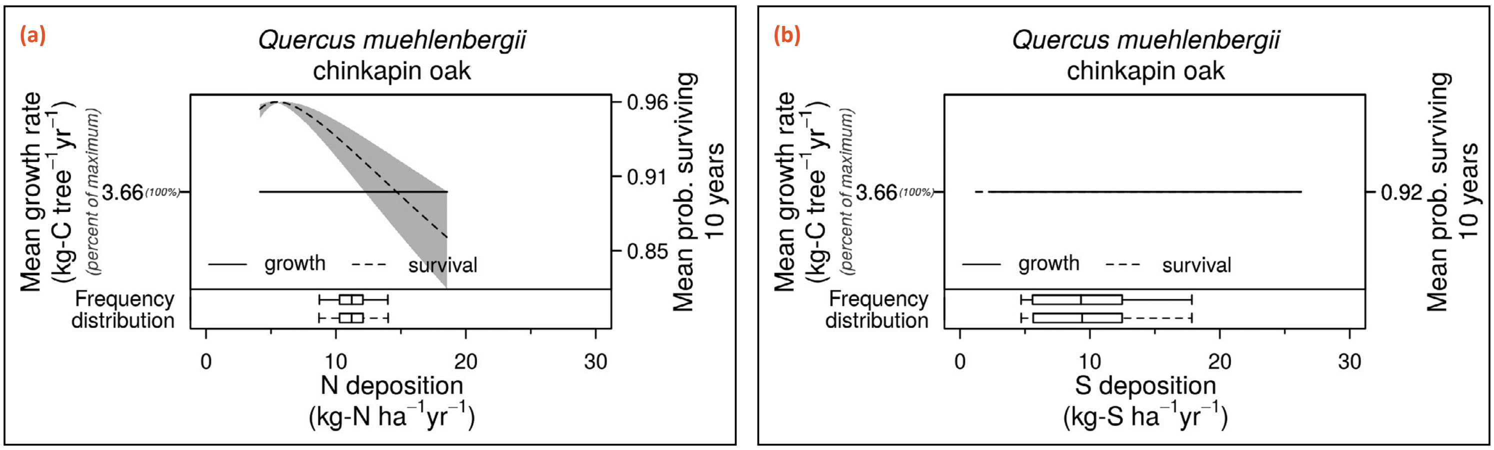
Ecosystem Services

Wood of chinkapin oak is hard, heavy, strong, and durable. It is commonly used as sawtimber and is considered a member of the select white oak group widely used for cabinets, furniture, pallets, and containers. Oak wood was traditionally used for railroad ties and is commonly cut for firewood. Chinkapin oak is an attractive shade tree; it was first cultivated in 1822.

The acorns of chinkapin oak are sweet and edible when roasted, and acorns were an important food source for indigenous peoples. The Delaware and Ontario used an infusion of the bark to treat vomiting.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of chinkapin oak has no relationship to N or S deposition. Survival mostly decreases with increasing N deposition and has no relationship to S deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
	X	X	X	X	X	X

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
				X		X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

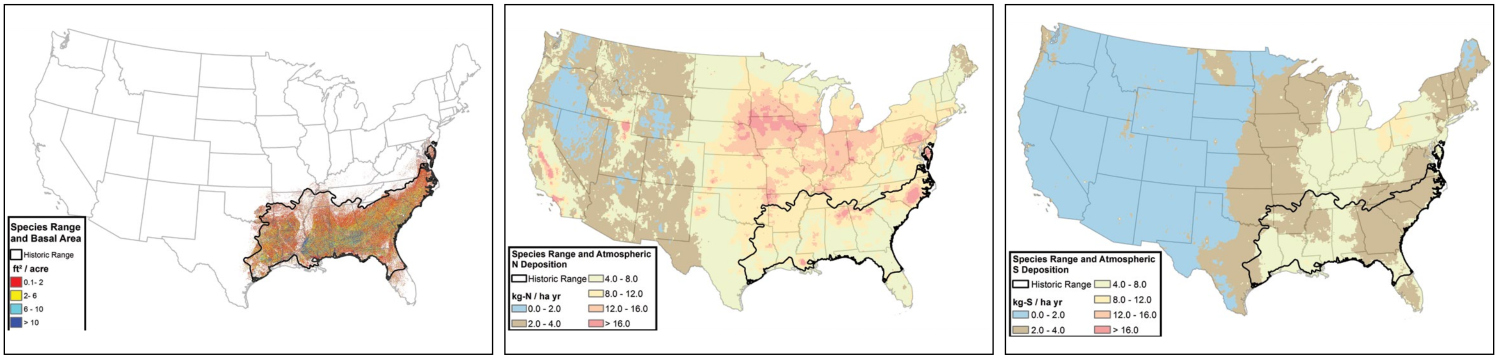
Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

Tirmenstein, D. A. 1991. *Quercus muehlenbergii*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (29 February 2016).

Quercus nigra (water oak)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Water oak is a medium-sized tree with glabrous twigs, membranous leaves, and a straight, slender trunk. On a good site, water oak can reach 105 feet (32 m) in height and attain 6.5 feet (2 m) in diameter. It is semi-evergreen in warmer parts of its range but completely deciduous in other areas. The heavy acorns are disseminated by gravity, water, and animals such as blue jays and ground squirrels, which cache acorns in the soil. Water oak grows on levees, high ridges, and elevated margins of swamps, rivers, and hydric hammocks that flood deeply and frequently but drain rapidly because of relief. It will also grow on uplands to about 1,000 feet (300 m) in elevation where soils remain moist. It grows well on better-drained silty clay or loamy soils and poorly on poorly drained clay soils. It can survive up to several months of flooded soil, but mortality is high if this is a yearly occurrence. Water oak is intolerant to semi-intolerant of shade; it germinates in shade but requires moderate light for development. Because of slow early growth, water oak does not compete well. It is a frequent early hardwood invader. The species is also responsive to disturbance through efficient sprouting from the root crown. In the absence of fire, it invades and eventually succeeds pine forests. Water oak is very susceptible to disease and insect attack when growing on impervious or dry terrace soils. It is also highly susceptible to air pollution, especially sulfur dioxide. Flowers are easily killed by late frosts.

Wildlife Uses

Water oak provides cover, food, and habitat for wildlife. Many animals, including squirrels, chipmunks, waterfowl, blue jay, wild turkey, and northern bobwhite, consume the acorns. Blue jays and squirrels cache acorns in the fall and return to eat them in the winter. Acorns of the black oak group are an especially important food source in the winter because those of the white oak group germinate soon after falling and, therefore, are unavailable. Deer browse water oak. Cavity-nesters such as the red-bellied woodpecker, great crested flycatcher, and hairy woodpecker nest in water oak snags. A tall mid-story of water oak within a pine forest provides habitat for the southern flying squirrel.

Ecosystem Services

On good sites, water oak produces moderate-quality factory lumber, but on poor sites the wood is knotty, mineral stained, and often insect damaged. The veneer is used as plywood for fruit and vegetable containers.

The Kiowa traditionally used the water oak in their peyote ceremonies, and both the Choctaw and Kiowa used the acorns for food and beverages.

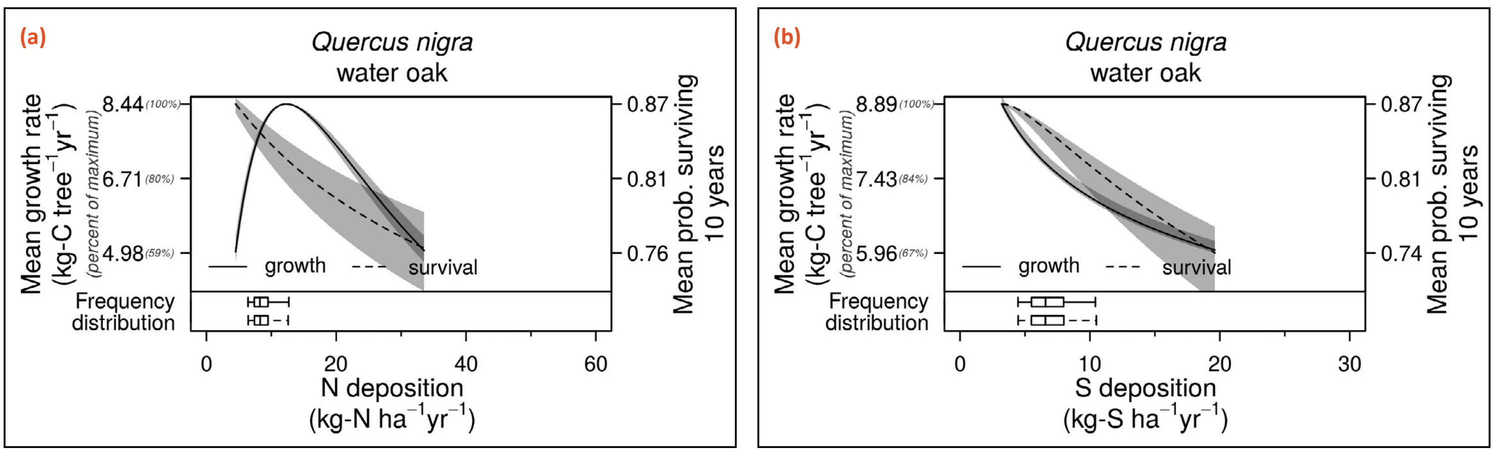
Flowers of *Quercus nigra.* Photo by Chris Evans, University of Illinois, Bugwood.org, 1119446.

Bark of *Quercus nigra.* Photo by Chris Evans, University of Illinois, Bugwood.org, 1119028.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of water oak has a hump-shaped relationship with increasing N deposition and decreases with increasing S deposition. Survival decreases with increasing N deposition and decreases with increasing S deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Foliage of *Quercus nigra.* Photo by Amy Gilliss, Arundel Tree Service, Bugwood.org, 5538633.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Broadleaf Evergreen, Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
	X	X		X		

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
						X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

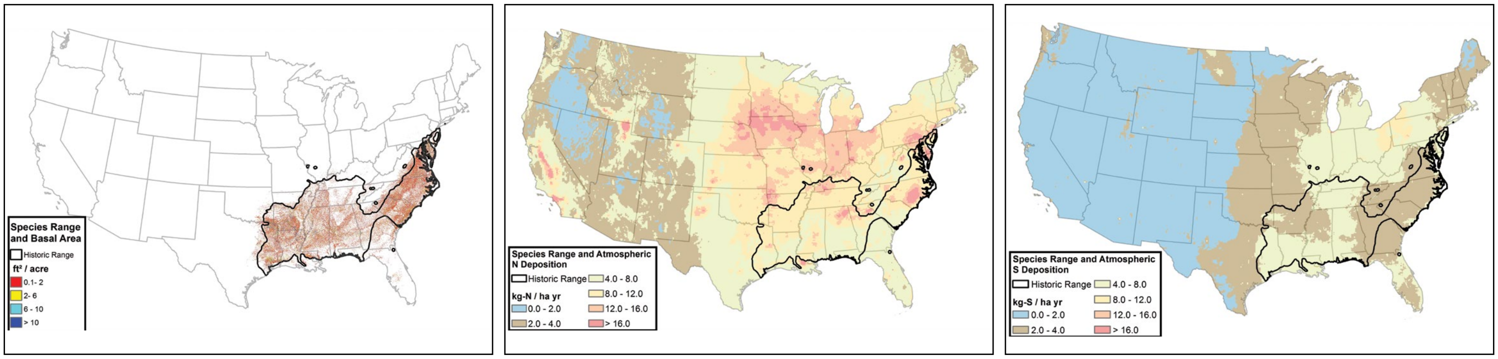
Primary Sources

Carey, Jennifer H. 1992. *Quercus nigra*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (29 February 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Quercus phellos (willow oak)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Willow oak is a large, deciduous, graceful tree with a straight, tall, slender trunk and willow-like leaves. This species is long-lived and shows moderately rapid growth on good sites. It reaches 80 to 120 feet (24–37 m) in height and 40 or more inches (100+ cm) in diameter. Acorn production begins when the tree is about 20 years old. This species produces a good acorn crop nearly every year. Animals and water disseminate the acorns. Willow oak grows primarily on floodplain sites that are commonly flooded in the winter and spring but only briefly flooded during the growing season. This species usually grows on ridges and high flats surrounded by swamps and major rivers that flood deeply and frequently but drain rapidly because of relief. It grows best in moist alluvial soils that are deep, uncompacted, and relatively undisturbed. The best soil is medium-textured, silty, or loamy. The willow oak/water oak/laurel oak forest cover type may represent a topographic or edaphic climax on terrace flats and poorly drained flatwoods. Willow oak sprouts readily from stumps of smaller trees.

Wildlife Uses

The consistent and abundant acorn crops of willow oak are an important food source for wildlife, including waterfowl, wild turkey, blue jays, red-headed and red-bellied woodpeckers, flickers, grackles, white-tailed deer, fox and gray squirrels, and other small rodents. Blue jays transport and cache acorns up to several kilometers from the collection tree. It is considered good browse for white-tailed deer.

Ecosystem Services

Willow oak is an important source of lumber and pulp. This species is also used widely as a shade tree and ornamental. It is often planted to provide habitat and food for wintering waterfowl in managed bottomland forests.

The Seminole traditionally used willow oak for ceremonial purposes, as a cleaning agent (lye), and as a hemorrhoid remedy.

It is a good species to plant along margins of fluctuating-level reservoirs due to its ability to withstand seasonal flooding.

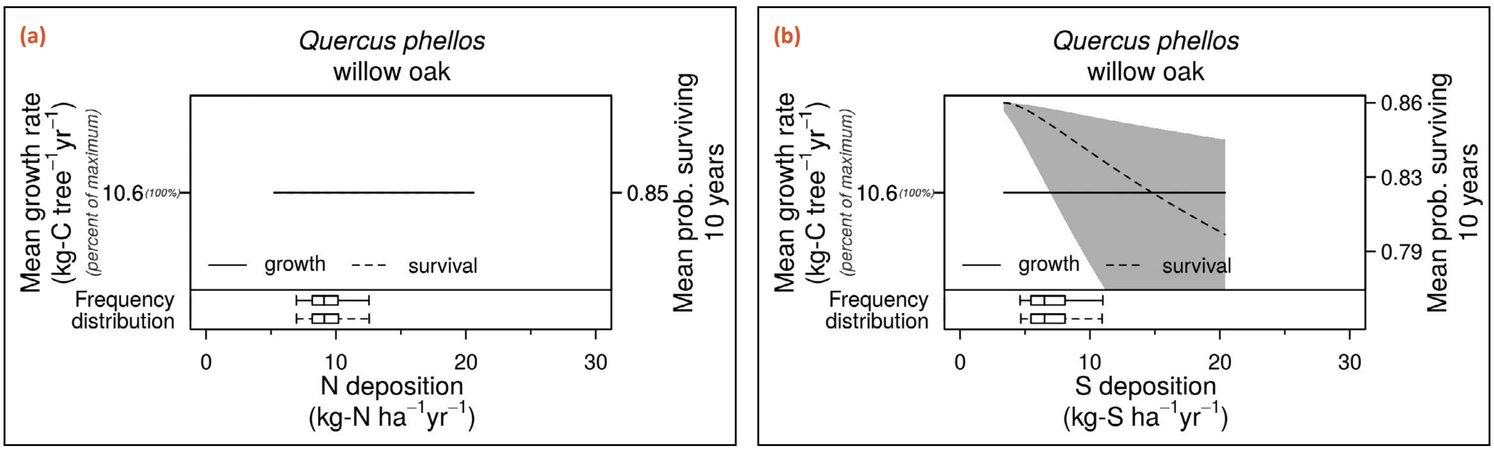
Specimen of *Quercus phellos*. Photo by David Stephens, Bugwood.org, 5521718.

Acorn of *Quercus phellos*. Photo by David Stephens, Bugwood.org, 5521714.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of willow oak has no relationship to N or S deposition. Survival has no relationship to N deposition and decreases with increasing S deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Foliage of *Quercus phellos*. Photo by David Stephens, Bugwood.org, 5521715.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X		X	X	X	X	

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
X			X			X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

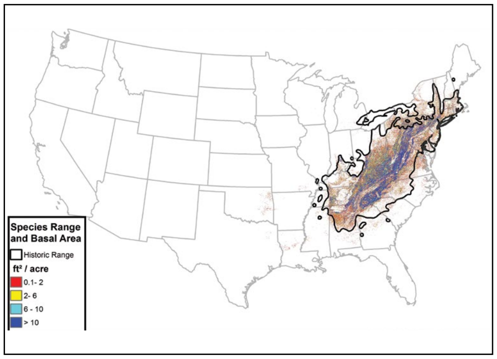
Primary Sources

Carey, Jennifer H. 1992. *Quercus phellos*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (2016, February 29).

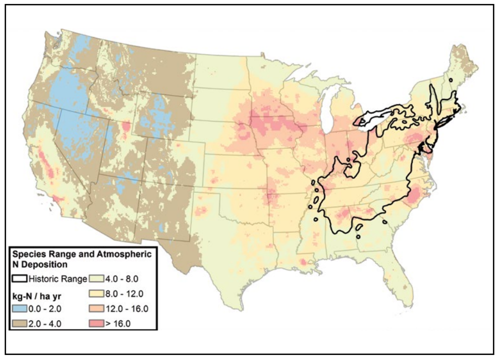
Native American Ethnobotany Database. http://naeb.brit.org.

Quercus prinus (chestnut oak)

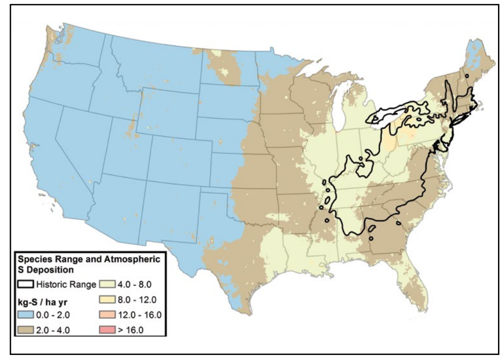
(a)



(b)



(c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Chestnut oak is a medium-sized, native, deciduous tree. Like many other oaks, it is long-lived and slow-growing. At maturity, it is usually 65 to 80 feet (20–24 m) tall and 20 to 30 inches (51–76 cm) in diameter. Acorns mature in one growing season and drop in late summer or early fall before other oaks drop their acorns. Gravity and squirrels disseminate the acorns, which germinate in the fall. Chestnut oak, an upland xerophytic species, commonly occurs on ridgetops and upper slopes. It is usually found on dry, rocky, infertile soil with a low moisture-holding capacity with deep litter layers, although it grows best in rich, well-drained soils along streams. Pure and almost-pure stands of chestnut oak have sparse ground vegetation. The species is intermediate in shade tolerance but will die after a few years under a closed canopy. Thus, it is excluded from mesic sites by more rapidly growing species. On some poor sites in the Appalachian Mountains, chestnut oak stands are considered a physiographic climax species. In more fertile sites, it will be succeeded by more shade-tolerant species in the absence of disturbance. If top-killed, chestnut oaks sprout vigorously from dormant buds at the root crown. Sprouts grow faster than seedlings and likely vegetative sprouting makes up the majority of reproduction.

Wildlife Uses

Good crops of chestnut oak acorns are infrequent, but when available, white-tailed deer, squirrels, chipmunks, mice, and wild turkeys are among the upland wildlife species that feed on the acorns. White-tailed deer occasionally browse young chestnut oak sprouts. Small birds and mammals, as well as insects such as bees, use chestnut oak cavities for nesting. Gypsy moth defoliation of the overstory canopy in recent decades has led to chestnut oak decline in some areas but releases in other.

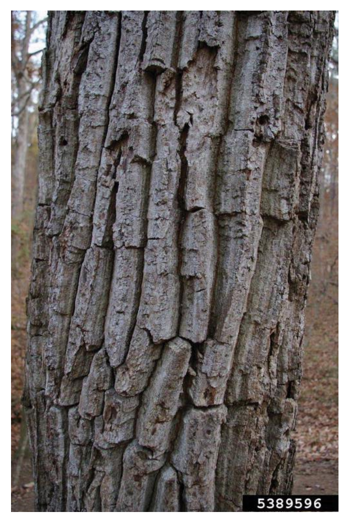
Ecosystem Services

Chestnut oak wood is cut and used as white oak lumber for cabinetry, construction, rail ties, furniture, and other uses.

The Cherokee traditionally used the bark to make a brown dye.

Chestnut oak shows a 7- to 10-day delay in budbreak and leaf flush on sites that have heavy metal (copper, zinc, and lead) enrichment of the soil, so this retarded leaf flush may be used in geobotanical remote-sensing techniques for mineral detection.

Acorn of *Querus prinus*. Photo by David Stephens, Bugwood.org, 5521714.

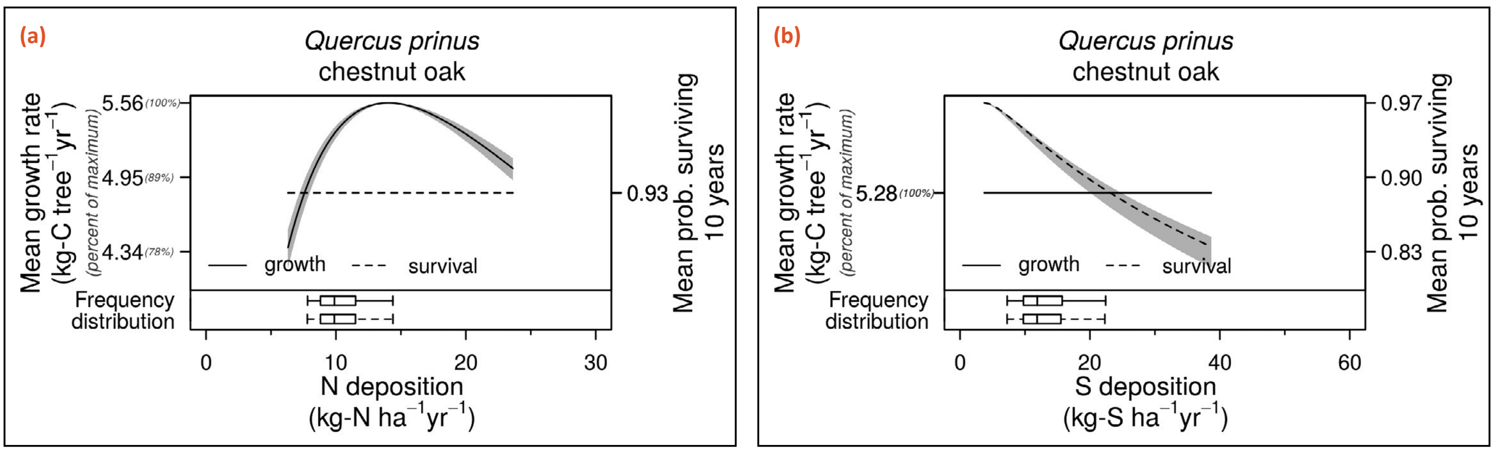


Bark of *Querus prinus*. Photo by David Stephens, Bugwood.org, 5521718.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of chestnut oak has a hump-shaped relationship with increasing N deposition and no relationship to S deposition. Survival has no relationship to N deposition and decreases with increasing S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Foliage of *Quercus prinus.* Photo by David Stephens, Bugwood.org, 5521715.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	**Shade Tolerance**	**Leaf Type**	**Mammal Uses**	**Bird Uses**
	Medium	Broadleaf Deciduous	Yes	Yes

Wood products				**Traditional uses**	**Ornamental uses**	**Fuelwood**
Paper	**Unfinished wood products**	**Building material**	**Finished wood products**			
	X	X	X	X		
Protection			**Rehabilitation**	**Food products**	**Oils and other**	**General services**
Erosion	**Wind**	**Erosion and wind**				
						X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

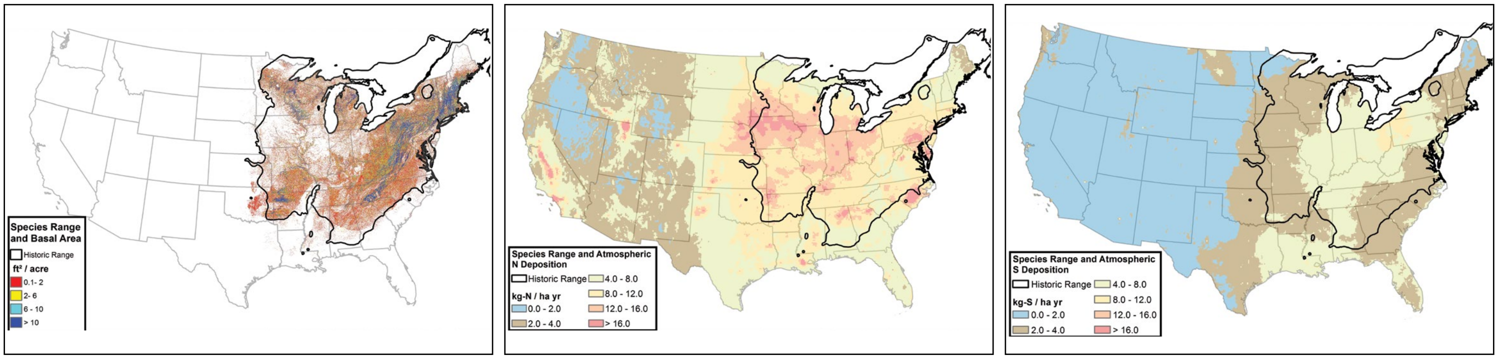
Primary Sources

Carey, Jennifer H. 1992. *Quercus prinus*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (2016, January 23).

Native American Ethnobotany Database. http://naeb.brit.org.

Quercus rubra (northern red oak)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Northern red oak is a medium to large, variable deciduous tree. It is one of the tallest and most rapidly growing of the oaks and commonly reaches 65 to 98 feet (20–30 m) in height and 2 to 3 feet (61–91 m) in diameter. It grows primarily in the Northeast on clay, loam, and sandy or gravelly soils derived from a wide variety of parent material. Plants generally exhibit best growth on deep, fertile, well-drained, finely textured soils with a relatively high water table. Northern red oak is most common on north- and east-facing slopes. It typically grows on lower and middle slopes, in coves, ravines, and on valley floors. It is intermediate in shade tolerance. Even-aged stands are common; the species is unable to establish beneath its own canopy. Most trees do not produce acorns until 50 years of age, and bear good acorn crops every two to five years. Seeds of northern red oak are primarily dispersed by birds and mammals. Scatter-hoarders such as the gray squirrel are particularly important dispersal agents in some areas.

Wildlife Uses

Many species of mammal, insect, and bird rely on the red oak for forage and habitat. White-tailed deer, elk, and other animals browse leaves and young seedlings, and pocket gophers occasionally feed on the roots of seedlings. Many animals, among them the white-footed mouse, black bear, eastern chipmunk, fox squirrel, gray squirrel, red squirrel, white-tailed deer, flying squirrels, and deer mice, consume the acorns. Domestic hogs also eat large quantities of northern red oak acorns where available. Birds relying on the acorns include the bobwhite, red-headed woodpecker, red-bellied woodpecker, blue jay, tufted titmouse, grackle, white-breasted nuthatch, sapsuckers, quail, and ruffed grouse. The acorns represent an important food sources for various waterfowl such as the golden-eye, gadwall, wood duck, hooded merganser, mallard, American pintail, black duck, redhead, and green-winged teal, and are particularly important for the wild turkey. Northern red oak provides good cover for a wide variety of birds and mammals throughout the year. Oaks frequently serve as perching or nesting sites for various songbirds. Many cavity-nesters, such as the red-bellied and hairy woodpecker, nest in northern red oak. The well-developed crowns of oaks provide shelter and hiding cover for tree squirrels and other small mammals. Many birds and mammals use twigs and leaves as nesting materials. Large oaks provide denning sites for a variety of mammals.

Ecosystem Services

Northern red oak is an important source of hardwood lumber. The wood has been used to make railroad ties, fence posts, veneer, furniture, cabinets, paneling, flooring, caskets, and pulpwood. It has a high fuel value and is an excellent firewood. Northern red oak was first cultivated in 1724 and is a popular ornamental shade tree in eastern North America and in parts of Europe.

Flowers of *Quercus rubra.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008115.

Bark of *Quercus rubra.* Photo by Chris Evans, University of Illinois, Bugwood.org, 1380244.

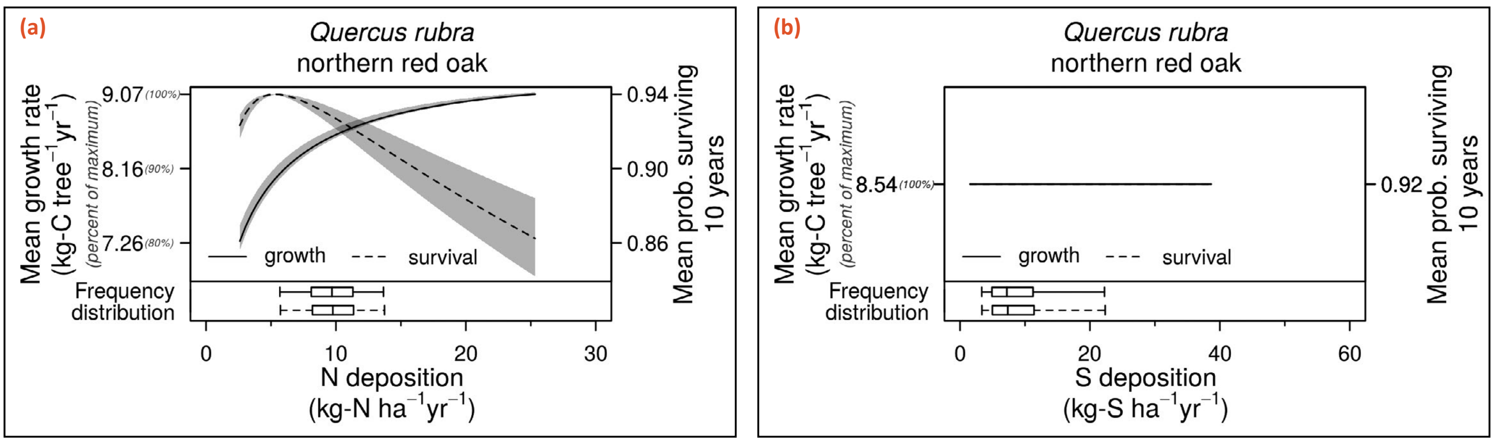
The Cherokee, Objibwa, and others used northern red oak for antidiarrheal drugs, dermatological aids, disinfectants, and food. Oak (Quercus species) acorns were an important traditional food source for indigenous peoples of North America. Acorns of red oak were leached with ashes to remove bitter tannins and used in foods. Bark preparations were used to treat bowel problems.

Northern red oak has been successfully planted onto coal mine spoils, thus the species has been demonstrated to be useful for rehabilitation of disturbed sites.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of northern red oak increases with increasing N deposition and has no relationship to S deposition. Survival has a hump-shaped relationship with increasing N deposition and no relationship to S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are correlated for many species, so inferring causality to either stressor can be difficult. See also Appendix Table 4 and the Introduction for more information.

Acorns of *Quercus rubra.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008245.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Broadleaf Deciduous	Yes	Yes

Wood products: Paper	Wood products: Unfinished wood products	Wood products: Building material	Wood products: Finished wood products	Traditional uses	Ornamental uses	Fuelwood
X	X	X	X	X	X	X

Protection: Erosion	Protection: Wind	Protection: Erosion and wind	Rehabilitation	Food products	Oils and other	General services
			X			X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

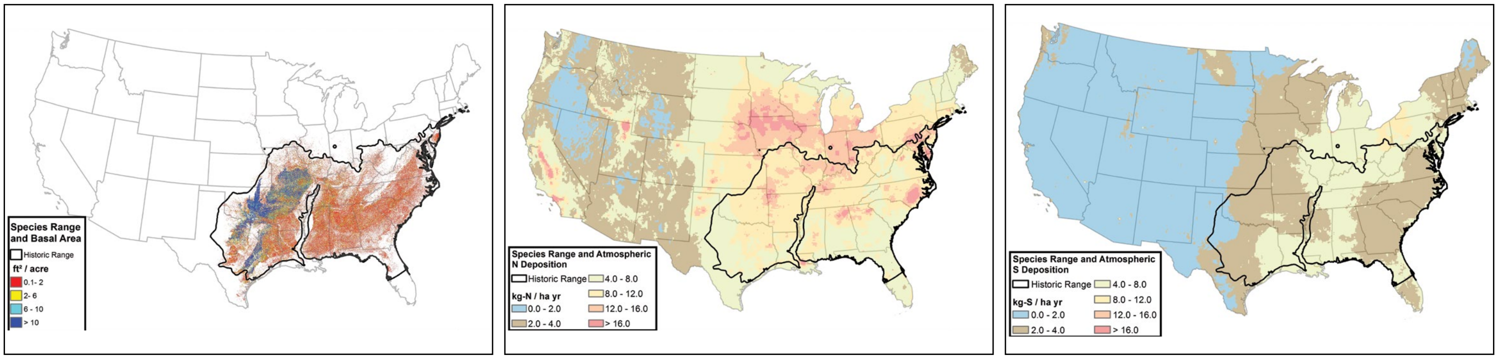
Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

Tirmenstein, D. A. 1991. *Quercus rubra*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (23 February 2016).

Quercus stellata (post oak)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Post oak is a long-lived, native, deciduous tree with a crown of horizontal branches. The typical variety usually grows 50 to 60 feet (15.2–18.3 m) in height and 12 to 24 inches (30–61 cm) in diameter. It grows slowly and lives 300 to 400 years. Height and diameter growth are typically slow for this species. Flowers and leaves appear sometime in the spring, and acorns ripen and drop by mid-fall. Post oak occurs in soils that are usually shallow, well-drained, coarse-textured, dry, and deficient in nutrients and organic matter. It commonly grows in serpentine soils. It is often restricted to sites where an impermeable heavy clay subsurface or bedrock layer is within 1 to 3 feet (0.6–0.9 m) of the surface. It is intolerant of shade and competition. Because of slow growth it is often overtopped by other species, including most oaks. It persists and becomes dominant on poor sites because of its drought resistance. Generally, excessive soil moisture and inundation cause high mortality or severe stress to post oak. One exception is the delta post oak variety, which occurs in rich, moist bottomlands. Post oak is common in the understory of pine (Pinus spp.)–hardwood forests. In the absence of fire, post oak may become dominant depending on site conditions and competition from associated species.

Wildlife Uses

The acorns are an important food source for wildlife including white-tailed deer, wild turkey, and squirrels and other rodents. The tannin in leaves, buds, and acorns is toxic to sheep, cattle, and goats. Post oak gives cover and habitat for a variety of birds and mammals. Cavities also provide nest and den sites, and leaves are used for nest construction.

Ecosystem Services

Post oak is not a preferred timber species because of its susceptibility to insect damage and slow growth. The wood itself is very durable and resistant to decay, so it is used for railroad ties, mine timbers, flooring, siding, lathing, planks, construction timbers, and fence posts. It is planted as a shade tree and its bark is used for decorative and protective mulch in landscaping.

The Cherokee, Creek, and Kiowa traditionally used infusions and decoctions from the post oak to create astringents and antiseptics that treated dysentery, asthma, and skin issues. The Kiowa also made a coffee-like beverage from the acorns.

In sites needing rehabilitation, post oak is planted for soil stabilization on dry, sloping, stony sites that are unsuitable for other species.

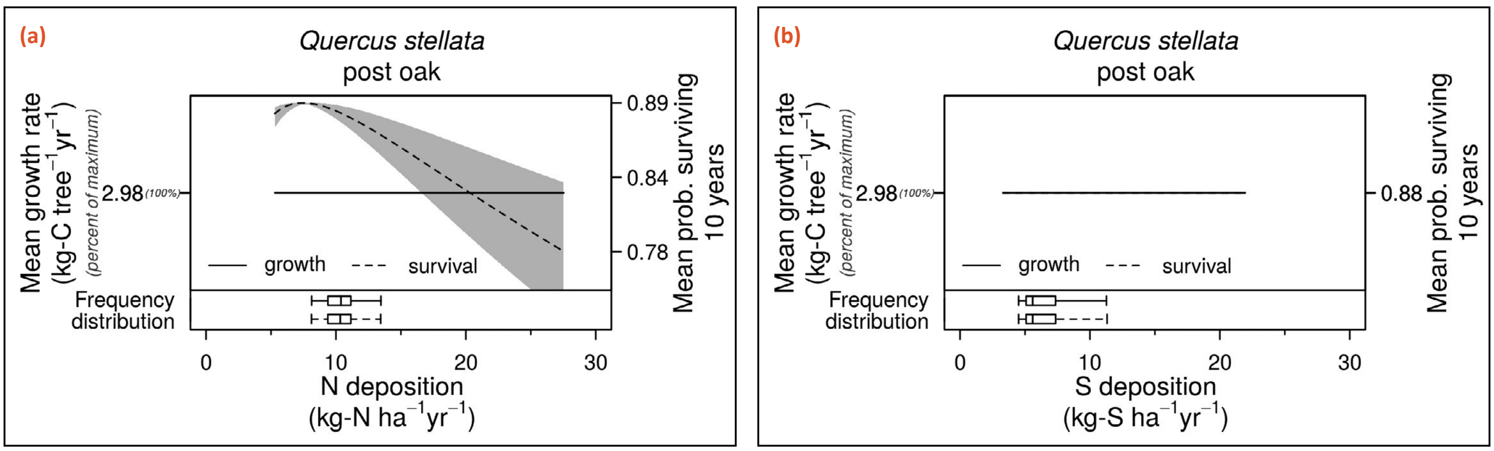
Foliage of *Quercus stellata.* Photo by Vern Wilkins, Indiana University, Bugwood.org, 5503999.

Bark of *Quercus stellata.* Photo by David Stephens, Bugwood.org, 5492599.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of post oak has no relationship to N or S deposition. Survival mostly decreases with increasing N deposition and has no relationship to S deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Acorn of *Quercus stellata*. Photo by Paul Wray, Iowa State University, Bugwood.org, 0008241.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	**Shade Tolerance**	**Leaf Type**	**Mammal Uses**	**Bird Uses**
	High	Broadleaf Deciduous	Yes	Yes

Wood products				**Traditional uses**	**Ornamental uses**	**Fuelwood**
Paper	**Unfinished wood products**	**Building material**	**Finished wood products**			
	X	X		X	X	
Protection			**Rehabilitation**	**Food products**	**Oils and other**	**General services**
Erosion	**Wind**	**Erosion and wind**				
X			X		X	X

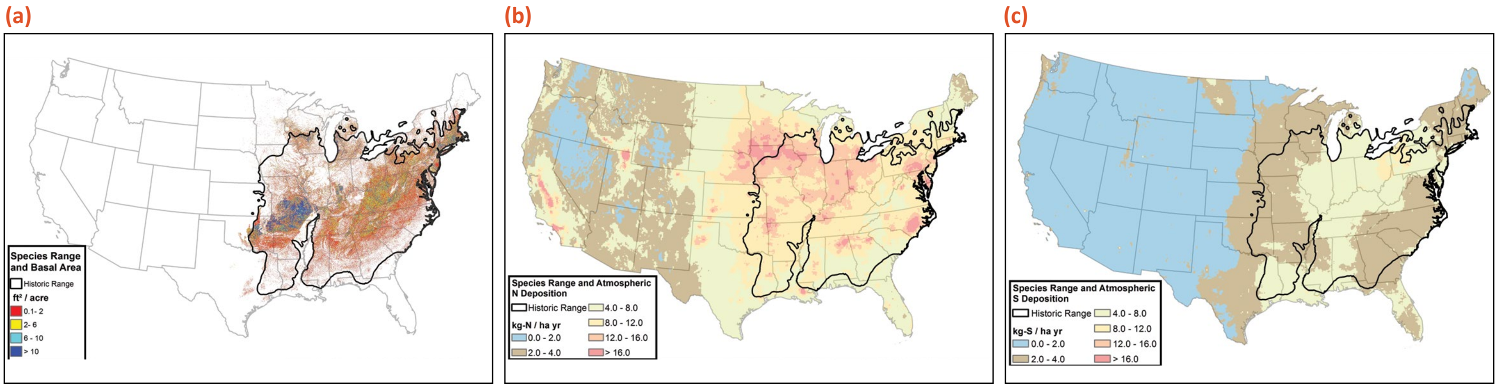
A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

Primary Sources

Carey, Jennifer H. 1992. *Quercus stellata*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (23 January 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Quercus velutina (black oak)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Black oak is a medium- to large-sized, native, deciduous tree with an irregularly rounded crown. Individuals may live 150 to 200 years, and trees typically reach 60 to 80 feet (18–24 m) tall and 24 to 36 inches (61–91 cm) in diameter. Catkins emerge before or at the same time as the current year's leaves, usually in April or May. Acorns mature and ripen over the course of two growing season, drop in the fall, and germinate in the spring. Squirrels, mice, blue jays, and other animals, and gravity disseminate the seeds. Seedlings colonize open patches subsequent to invasion of herbaceous vegetation. Seedling growth is slow, but seedlings are capable of surviving drought conditions. This oak is an upland xerophytic species and can occur on all aspects and slope positions but tends to be more abundant on the drier southerly and westerly aspects and on upper slopes and ridges due to drought tolerance and limited competition. Seedlings eventually die under a closed-canopy forest. Although it grows best on moist, rich, well-drained sites, it is sensitive to competition on these sites and is more often found on dry, nutrient-poor, coarse-textured soils. Black oak is intermediate in shade tolerance so light is required to recruit black oak seedlings into the sapling stage. It sprouts from the root collar if top-killed or cut.

Wildlife Uses

Black oak acorns provide food for numerous wildlife species such as various types of squirrels, mice, blue jays, bear, and white-tailed deer. It has a high cavity value for wildlife such as the northern flicker. Gypsy moth (*Lymantria dispar*), an introduced species, defoliates black oak, and two or three successive defoliations can kill a tree. It is potentially the most destructive insect to black oak.

Ecosystem Services

The wood of black oak, which is light brown with a nearly white sapwood, is sold as "red oak" and used for furniture, flooring, and interior finishing. It is also used for barrels and railroad ties. The bark contains enough tannin to make commercial extraction worthwhile. A yellow dye, suitable for coloring natural fibers, can be obtained by boiling the inner bark.

The Cherokee, Delaware, Ojibwa, and others traditionally used black oak for dye making. They also ate the acorns and made preparations to treat throat and respiratory problems.

Black oak naturally regenerates on abandoned lead-zinc mine sites, making it a candidate species for land rehabilitation.

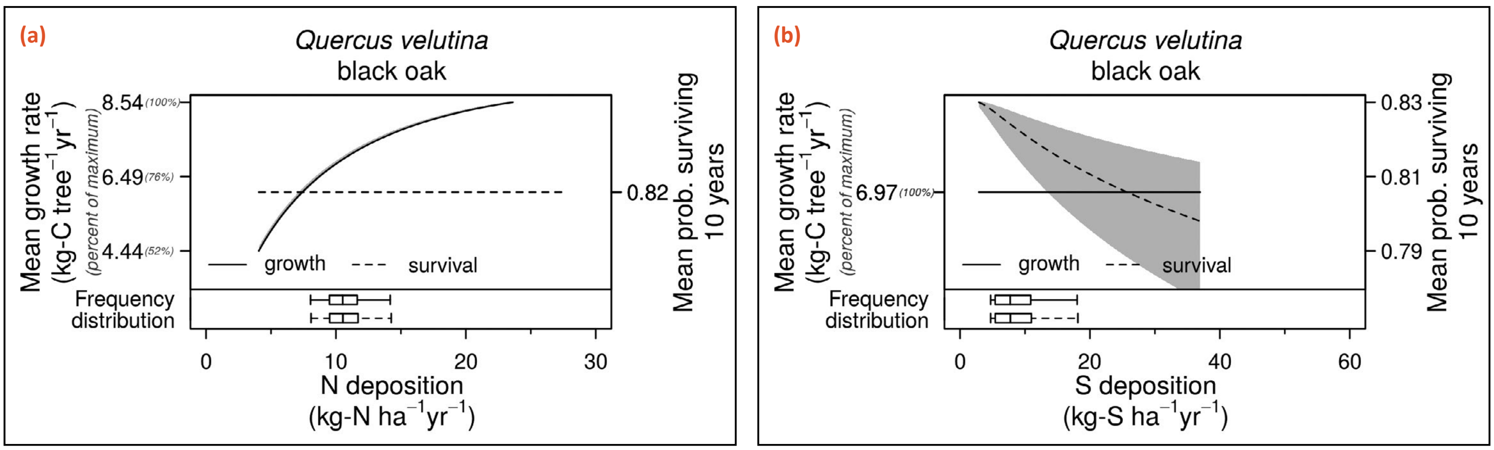
Acorn of *Quercus velutina.* Photo by David Stephens, Bugwood.org, 5520759.

Bark of *Quercus velutina.* Photo by Vern Wilkins, Indiana University, Bugwood.org, 5470002.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of black oak increases with increasing N deposition and has no relationship to S deposition. Survival has no relationship to N deposition and decreases with increasing S deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Foliage of *Quercus velutina.* Photo by Chris Evans, University of Illinois, Bugwood.org, 2118080.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
	X	X	X	X		

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
			X		X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

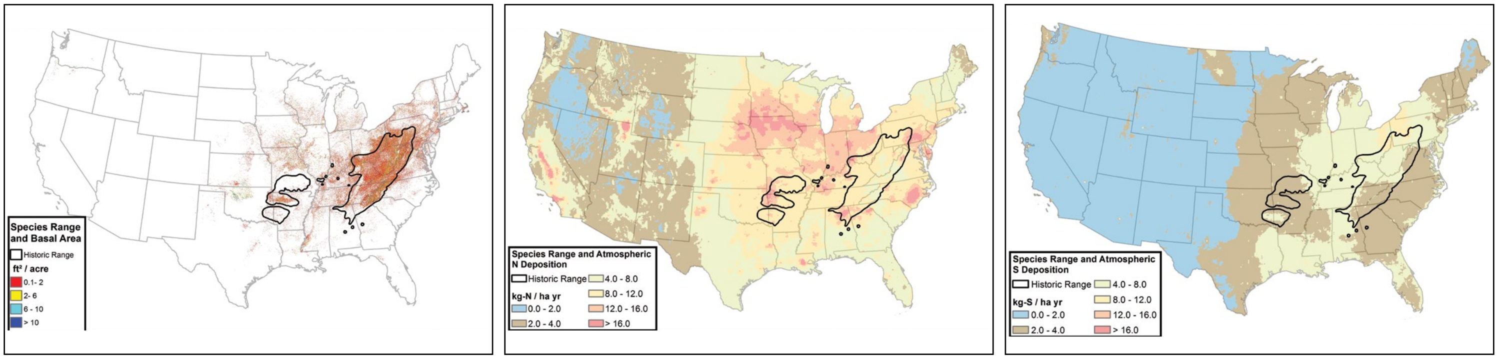
Primary Sources

Carey, Jennifer H. 1992. *Quercus velutina*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (23 January 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Robinia pseudoacacia (black locust)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Black locust is a fast-growing, N-fixing, short-lived medium-sized tree, generally 40 to 60 feet (12–18 m) in height and 12 to 30 inches (30–76 cm) in diameter. Young trees are thorny but as trees age, the bark becomes thick, deeply furrowed, scaly, and dark brown. The flowers are showy, white, and fragrant, in drooping clusters and attract insects and hummingbirds for pollination. The seeds often make up a large proportion of the underlying seed bank. Black locust occurs in a variety of soil types within its native range but is sensitive to soil conditions that produce either minimal or excessive aeration or drainage. It is a shade-intolerant species; thus, it generally occurs at low density within the forest interior but establishes well in forest openings, edges, and other early-successional habitats. It is highly susceptible to frost and cold-weather damage, which may ultimately limit its range. It is thought that black locust, a pioneer species, facilitates late-successional plant species because of its ability to fix nitrogen and stabilize soils.

Wildlife Uses

White-tailed deer, rabbits, ruffed grouse, and mule deer browse black locust leaves and stems. Squirrels, doves, California quail, northern bobwhite, chukar, pheasants, ruffed grouse, and other game birds eat the nutritious seeds. A multitude of invertebrate species also consume black locust. The tree is an important cover species for wildlife, providing nesting, roosting, loafing spots, and thermal cover for species such as grey squirrels, red-eyed vireo, screech owl, and rufous-sided towhee. The persistent nature of black locust stems after tree death makes it an important resource for cavity-dependent wildlife species including long-eared bats, Indiana bat, northern bats, hairy woodpecker, down woodpecker, northern flicker, red-bellied woodpecker, and screech owls.

Ecosystem Services

The wood is valuable for a variety of uses, such as fenceposts, railroad ties, insulator pins, mine timbers, shipbuilding, furniture, handles, barrel staves, boxes and crates, pulp, and fuelwood. It is also a popular timber plantation tree. Black locust is poisonous to humans—sometimes fatal, although some people eat the flowers fried or cooked and brew tea from them. The species has been widely planted for windbreaks and shelterbelts, as woody biomass for energy production, and as a street or ornamental tree. It has also been widely planted for honey production. The nitrogen-fixing abilities of black locust have prompted its planting in nurseries and plantations to assist the growth of other desired trees.

The Cherokee, Mendocino, and Wailaki Tribes traditionally used black locust for various purposes, including using the wood for bows and blowgun darts and chewing the bark as an emetic.

Black locust is also a favored tree for restoration or rehabilitation for sites such as surface mine sites and logged areas because

Specimen of *Robinia pseudoacacia.* Photo by Chris Evans, University of Illinois, Bugwood.org, 2188045.

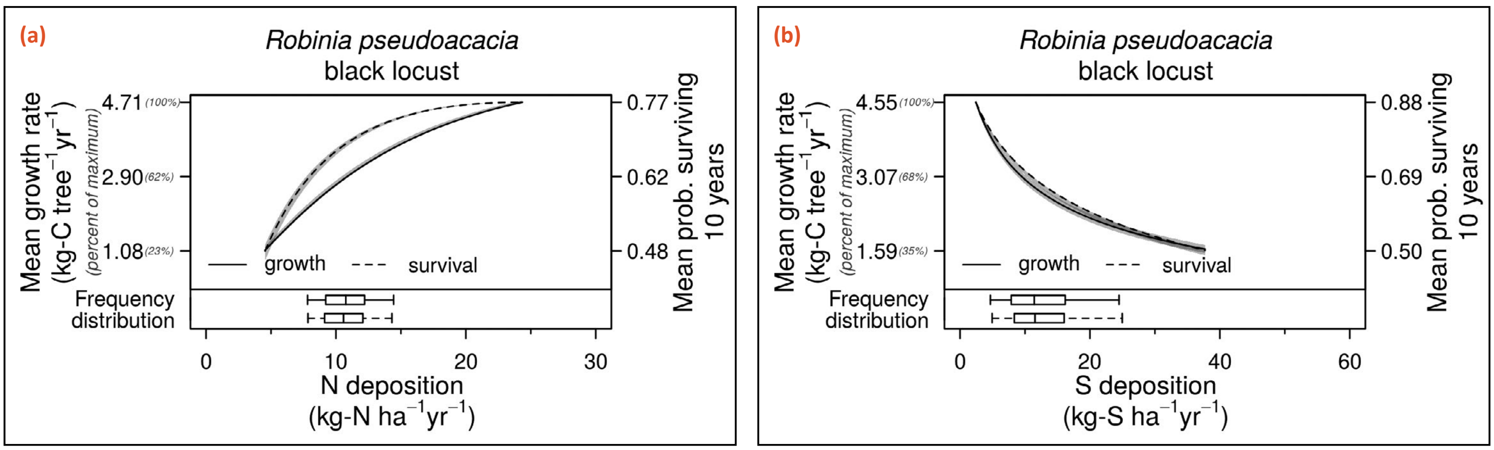
Flowers of *Robinia pseudoacacia.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008098.

its extensive root system holds and stabilizes the soil surface, it sprouts vigorously and prolifically, it increases soil fertility through nitrogen fixation, and it forms a leaf litter that protects the soil.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth and survival of black locust increase with increasing N deposition. Growth and survival decrease with increasing S. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Foliage of *Robinia pseudoacacia.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008365.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Low	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X		X	X	X	X

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
		X	X	X	X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

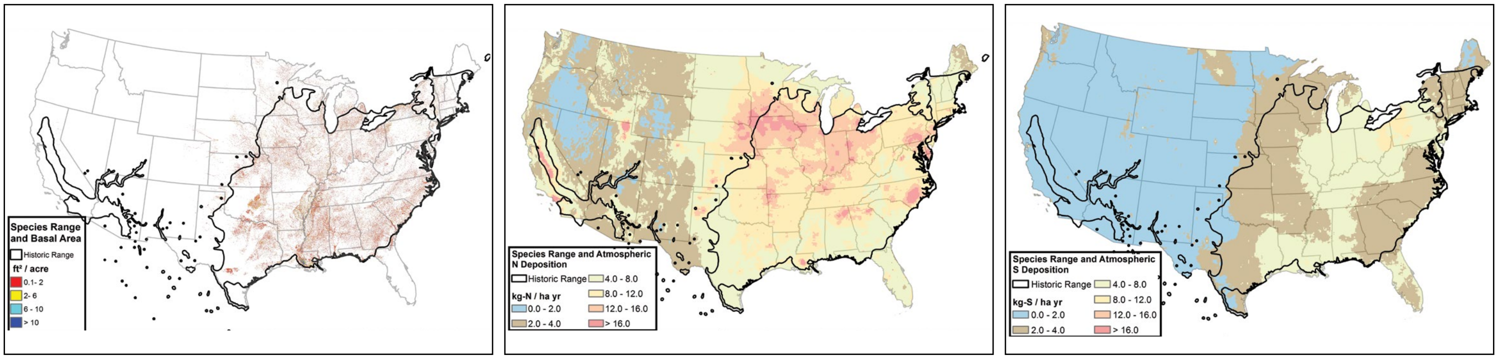
Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

Stone, Katharine R. 2009. *Robinia pseudoacacia*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (23 January 2016).

Salix nigra (black willow)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Black willow is a small (sometimes shrublike) to large, short-lived, deciduous tree. It is fast growing and may reach maturity within 30 years. This tree usually obtains a height of 66 feet (20 m). The massive trunks are usually leaning and are often divided. Black willow roots are shallow and laterally extensive. Black willow can reproduce sexually and vegetatively. Seeds ripen 45 to 60 days after catkins are pollinated by insects or wind. As the seeds fall, the long silky hairs act as wings to carry the seeds long distances. The seeds are also disseminated by water. Black willow is most common on river margins where it occupies the lower, wetter, and often less sandy sites. It is also common in swamps, sloughs, swales, gullies, and drainage ditches, growing anywhere light and moisture conditions are favorable. Black willow grows on a variety of soils but develops best in fine silt or clay in relatively stagnant water. It thrives in saturated or poorly drained soil from which other hardwoods are excluded. Black willow is a pioneer or early seral species commonly found along the edges of rivers and streams, mud flats, and floodplains. This tree is very shade intolerant and usually grows in dense, even-aged stands. Black willow stands periodically stagnate and are eventually replaced by more shade-tolerant trees such as American elm (*Ulmus americana*), sycamore (*Platanus* spp.), ash (*Fraxinus* spp.), boxelder (*Acer negundo*), and sweet gum (*Liquidambar styraciflua*).

Wildlife Uses

Birds eat the buds and flowering catkins of black willow; deer and livestock eat the twigs and leaves; and rodents eat the bark and buds. The yellow-bellied sapsucker feeds on the sap. Black willow is somewhat tolerant of grazing and browsing. Black willow/cottonwood stands are also commonly used as nesting habitat by some small nongame bird species.

Ecosystem Services

Black willow is the largest and only commercially important willow in North America. The wood was once used extensively for artificial limbs because it is lightweight, does not splinter easily, and holds its shape well. It is still used for making boxes and crates, furniture core stock, turned pieces, table tops, wooden novelties, doors, cabinets, polo balls, and toys. Black willow is also used for pulp. Ancient pharmacopoeia recognized the bark and leaves of willow as useful in the treatment of rheumatism. European settlers boiled the bark of black willow for its purgative and vermin-destroying powers. In 1829, the natural glucoside, salicin, which is closely related chemically to aspirin, was isolated from willow. Black willow was once used as a source of charcoal for gunpowder.

Traditional uses among the Cherokee, Iriquois, Koassati, and others include decoctions for treating colds and dyspepsia. Fibers from black willow are used for basketry.

Stand of *Salix nigra.* Photo by Brian Lockhart, USDA Forest Service, Bugwood.org, 1118014.

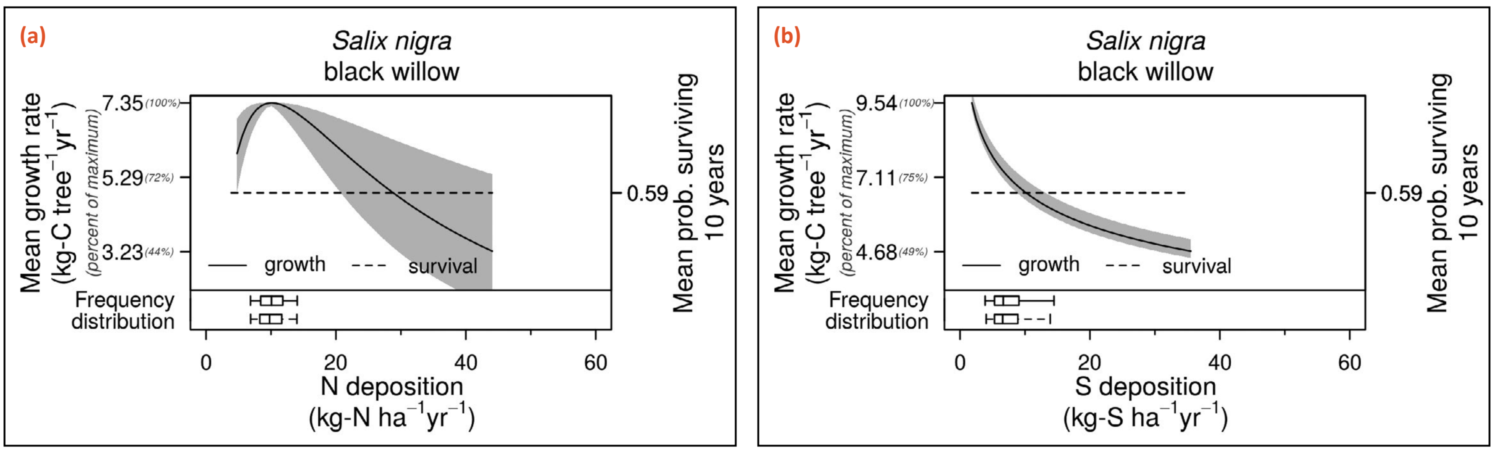
Foliage of *Salix nigra.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008450.

Black willow is commonly used in soil stabilization projects in early efforts at erosion control. Its flood tolerance and the ease with which it establishes from cuttings continue to make it an excellent species for reducing erosion of stream banks, bars, and islands.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of black willow has a hump-shaped relationship with increasing N deposition and decreases with increasing S deposition. Survival has no relationship to N or S deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Flowers of *Salix nigra.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008153.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Low	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X	X	X		

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
X			X		X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

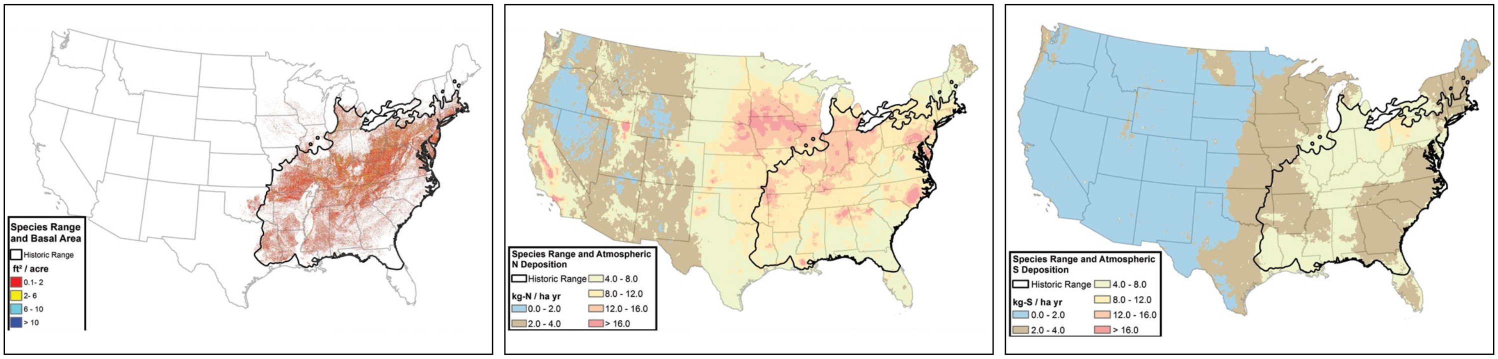
Primary Source

Native American Ethnobotany Database. http://naeb.brit.org.

Tesky, Julie L. 1992. *Salix nigra*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/. (2017, May 16).

Sassafras albidum (sassafras)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Sassafras is a native, deciduous, aromatic tree or large shrub, with a flattened, oblong crown with heights ranging from 40 to 98 feet (12–30m). It flowers in the spring and its fruit, a drupe, ripens by late summer. Birds, water, and small mammals disperse the seeds. Sassafras occurs on nearly all soil types within its range, but is best developed on moist, well-drained sandy loams in open woodlands. The persistence of sassafras into later series and climax stands may be a result of gap capture and its prolific ability to sprout in the understory. The species functions as the dominant shrub in many forests. It releases terpenoid allelopathic substances that inhibit germination and establishment of neighboring trees and shrubs. Sassafras is extremely sensitive to ozone.

Wildlife Uses

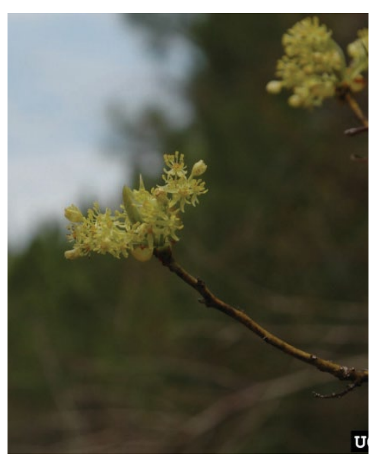
White-tailed deer, woodchucks, marsh rabbits, and black bears consume sassafras leaves and twigs. Rabbits also eat the bark in winter and beavers cut stems. Small mammals and birds including northern bobwhites, eastern kingbirds, great crested flycatchers, phoebes, wild turkeys, catbirds, flickers, pileated woodpeckers, downy woodpeckers, thrushes, vireos, and mockingbirds eat the lipid-rich sassafras fruits.

Ecosystem Services

Sassafras wood is soft, brittle, light, and has limited commercial value. It is used for cooperage, buckets, fence posts, rails, cabinets, interior finish, and furniture, and is considered good firewood. Sassafras oil is extracted from the root bark for use by the perfume industry, primarily for scenting soaps. It is also used as a flavoring agent and an antiseptic. However, large doses of the oil may have narcotic effects. Root bark is also used to make tea, which in weak infusions is a pleasant beverage, but in strong infusions induces sweating. The leaves can be used to flavor and thicken soups. The mucilaginous pith of the root is used in preparations to soothe eye irritations.

The Cherokee, Mohegan, Rappahannock, and Seminole traditionally used sassafras to treat diarrhea, vomiting, and other digestive disturbances. Because of its durability, it was also used for dugout canoes.

Sassafras is used for restoring depleted soils in old fields and can persist in sites severely contaminated with heavy metals.



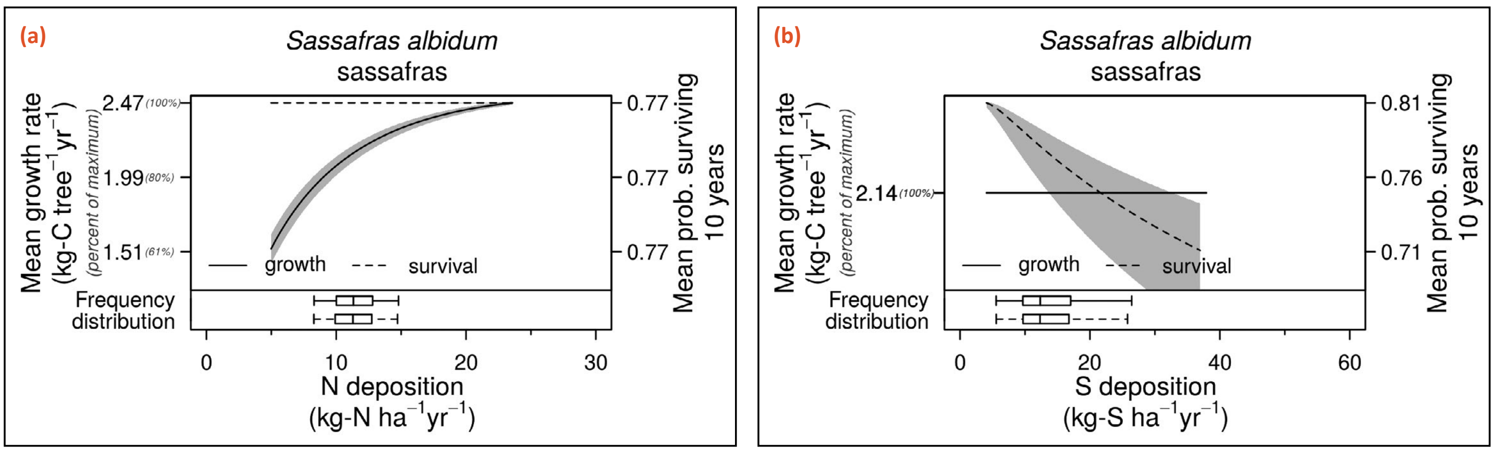
Flowers of *Sassafras albidum.* Photo by Chris Evans, University of Illinois, Bugwood.org, 2189099.

Bark of *Sassafras albidum.* Photo by Chris Evans, University of Illinois, Bugwood.org, 2150008.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of sassafras increases with increasing N deposition and has no relationship to S deposition. Survival has no relationship to N deposition and decreases with increasing S deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Foliage of *Sassafras albidum.* Photo by Chris Evans, University of Illinois, Bugwood.org, 1380356.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	High	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
	X		X	X		X
Protection			**Rehabilitation**	**Food products**	**Oils and other**	**General services**
Erosion	Wind	Erosion and wind				
			X	X	X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

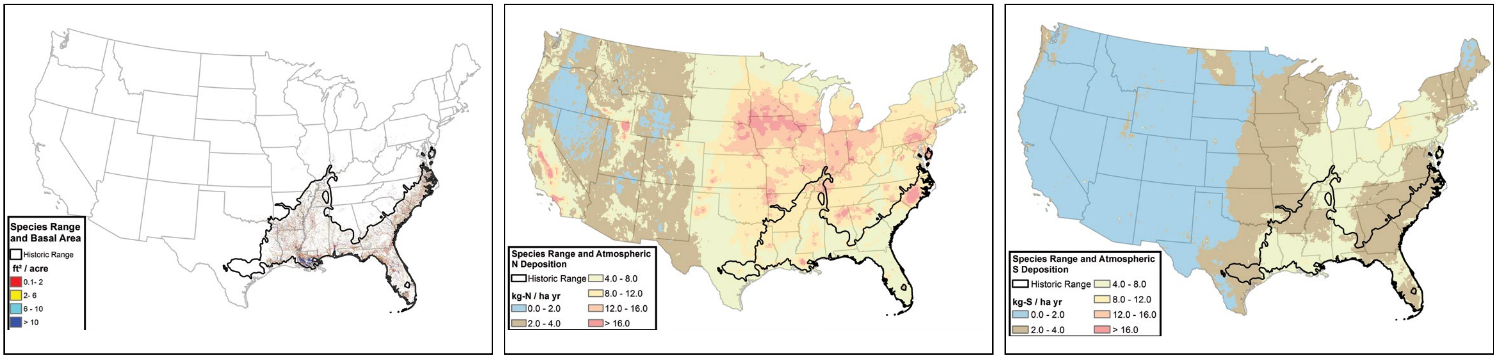
Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

Sullivan, Janet. 1993. *Sassafras albidum*. In: Fire Effects Information System, [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (23 January 2016).

Taxodium distichum (baldcypress)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Cypress is a large-sized, native, deciduous conifer, frequently growing to 100 to 120 feet (30–37 m) in height. In the forest, baldcypress typically has a broad, irregular crown, often draped in curtains and streams of gray Spanish moss. The trunks of older trees are massive and tapering, particularly when growing in swamps, and are buttressed at the base by protruding horizontal roots called knees. It is slow-growing and very long-lived. Flood waters do most of the dispersal of the seeds, which are produced every year. Cypress is usually restricted to very wet soils consisting of muck, clay, or fine sand where moisture is abundant and fairly permanent. More than 90 percent of the natural cypress stands are found on flat or nearly flat topography at elevations less than 100 feet (30 m) above sea level. Best growth occurs under a high degree of overhead light, but the tree persists under partial shade. Baldcypress also reproduces vegetatively by sprouting from the stumps of young trees. The tree develops a taproot as well as broad horizontal roots that lie just below the surface.

Wildlife Uses

Wild turkey, wood ducks, evening grosbeak, wading birds, other waterfowl, and squirrels eat the baldcypress seeds. Yellow-throated warblers forage in the Spanish moss often found hanging on the branches of old cypress trees. Cypress domes provide watering places for a variety of birds, mammals, and reptiles of the surrounding pinelands. The tops of cypress trees provide nesting sites for bald eagles and ospreys. Warblers use the old decaying knees for nesting cavities, and catfish spawn below cypress logs. Cypress domes provide breeding sites for a number of frogs, toads, and salamanders and nesting sites for herons and egrets.

Ecosystem Services

Baldcypress wood is highly resistant to decay, making it valuable for building construction, fence posts, planking in boats, doors, blinds, flooring, shingles, caskets, interior trim, and cabinetry. It has been planted as a water-tolerant tree species for shading and canopy closure, while helping reduce populations of the Anopheles mosquito. Baldcypress has been successfully planted throughout its range as an ornamental and along roadsides.

The Choctaw traditionally used the bark to make cordage.

Cypress swamps help to maintain high regional water tables and can provide advanced wastewater treatment for small communities. Research has shown that cypress domes can serve as tertiary sewage treatment facilities for improving water quality and recharging groundwater.

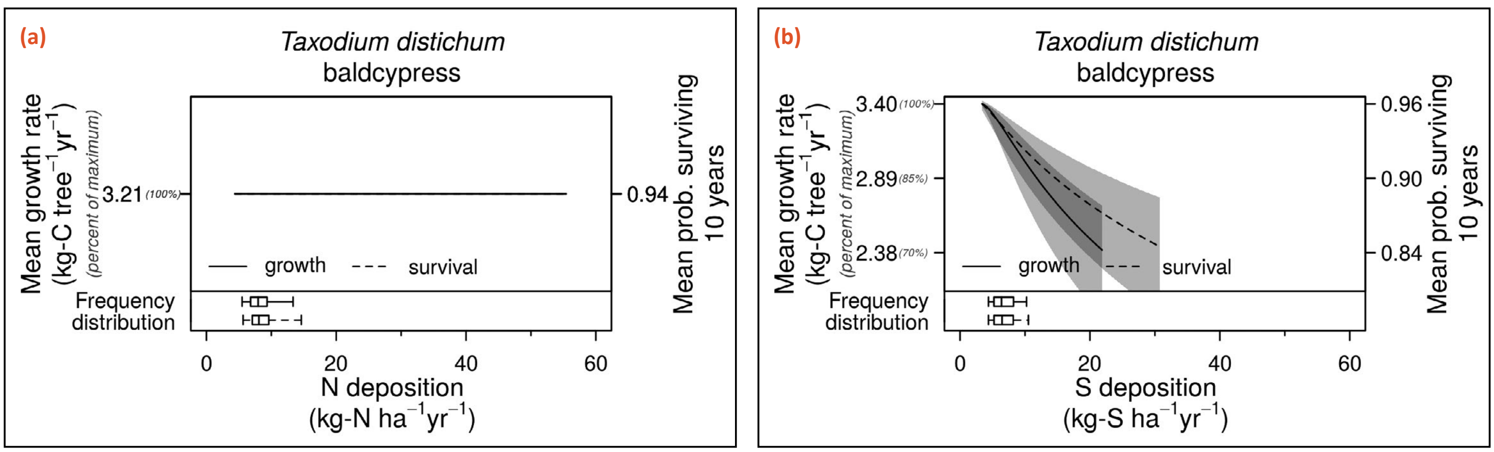
Stand of *Taxodium distichum.* Photo by Gerald J. Lenhard, Louisiana State University, Bugwood.org, 0014155.

Bark of *Taxodium distichum.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008020.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of baldcypress has no relationship to N deposition and decreases with increasing S deposition. Survival has no relationship to N deposition and decreases with increasing S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Foliage of *Taxodium distichum.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008296.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Coniferous Deciduous	Yes	Yes

Wood products: Paper	Wood products: Unfinished wood products	Wood products: Building material	Wood products: Finished wood products	Traditional uses	Ornamental uses	Fuelwood
	X	X	X	X	X	

Protection: Erosion	Protection: Wind	Protection: Erosion and wind	Rehabilitation	Food products	Oils and other	General services
			X		X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

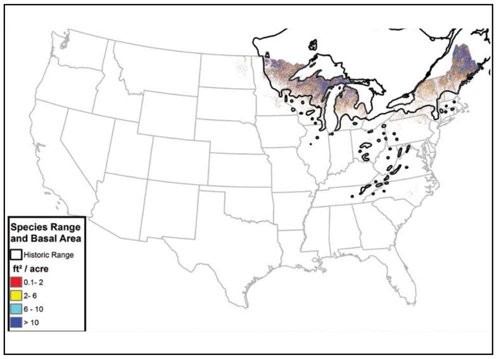
Primary Sources

Coladonato, Milo 1992. *Taxodium distichum*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (23 January 2016).

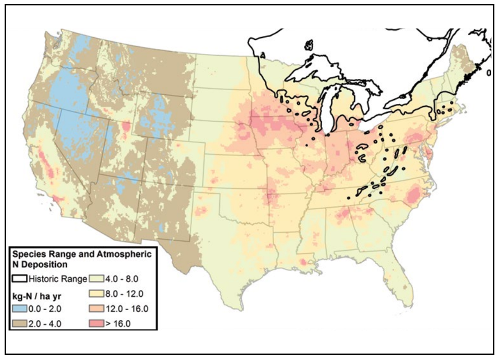
Native American Ethnobotany Database. http://naeb.brit.org.

Thuja occidentalis (northern white-cedar)

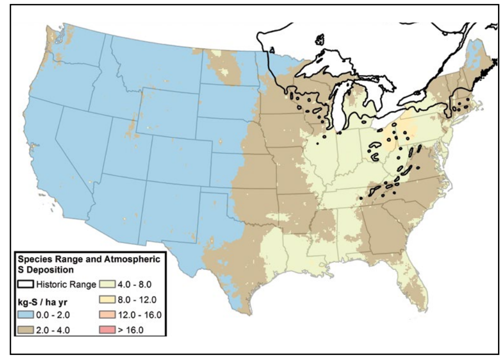
(a)



(b)



(c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Northern white-cedar is a native, evergreen tree with a narrow, almost columnar crown that typically reaches 40 to 50 feet (12–15 m) in height. Branches on open-grown trees extend to the ground. It has scale-like foliage and fibrous, sometimes shredding, bark. The species is extremely long-lived, with ages reaching in excess of 800 years. This cone bearing tree occurs on both uplands and lowlands. The uplands are primarily seepage areas, old fields, and limestone cliffs and boulder fields. The lowland sites include swamps, streambanks, and lakeshores. On lowland sites, northern white-cedar generally grows where there is a strong flow of moderately mineral-rich soil water of near neutral pH. On upland sites, it grows primarily in calcareous soils including calcareous clays and shallow loam overlying broken limestone. The tree is extremely shade-tolerant and can survive suppression for several years. Its extreme longevity and ability to vegetatively reproduce through layering makes it present in many forest climax communities. It is also considered a pioneer species for its ability to become established in old fields and limestone cliffs.

Wildlife Uses

White-tailed deer, snowshoe hares, moose, and porcupines heavily browse the nutritious foliage, especially during the winter. Pileated woodpeckers feed on carpenter ants that, in turn, nest in and feed on the heartwood of northern white-cedar. The stands provide thermal cover for white-tailed deer, moose, and black bear. Other birds that are especially abundant in northern white-cedar forests include white-throated sparrows, golden-crowned kinglets, yellow-bellied flycatchers, ovenbirds, northern parulas, winter wrens, Swainson's thrushes, and numerous warblers. Blackburnian warblers, Cape May warblers, ovenbirds, and golden-crowned kinglets also breed in the densest stands.

Ecosystem Services

The wood of northern white-cedar resists decay, so it is used for products that come in contact with water and soil, such as fence posts, shingles, paneling, log cabins, and boats. It is also used for kraft pulp and particleboard. It is widely planted as an ornamental. The leaf oil is distilled from boughs and used for perfume and medicines.

Indigenous peoples and early European explorers of northeastern North America used the foliage—rich in vitamin C—to treat scurvy. The Abnaki, Algonquin, and Micmac also used the inner bark and gum to treat headaches, burns, and fevers.

Because of its long lifespan, northern white-cedar is also a valuable species for dendroclimatic research.

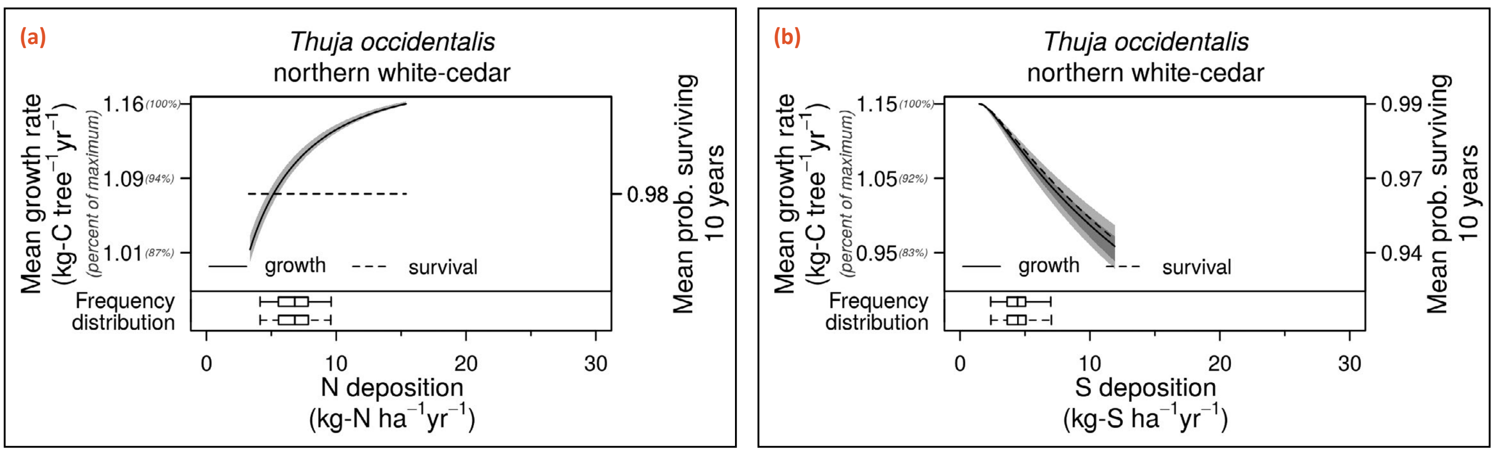
Specimen of *Thuja occidentalis.* Photo by Steven Katovich, USDA Forest Service, Bugwood.org, 1388012.

Bark of *Thuja occidentalis.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008011.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of northern white-cedar increases with increasing N deposition and decreases with increasing S deposition. Survival has no relationship to N deposition and decreases with increasing S deposition. Confidence in these relationships is medium low based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Foliage and cones of *Thuja occidentalis.* Photo by Richard Webb, Bugwood.org, 1480753.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	High	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X	X	X	X	

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
					X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

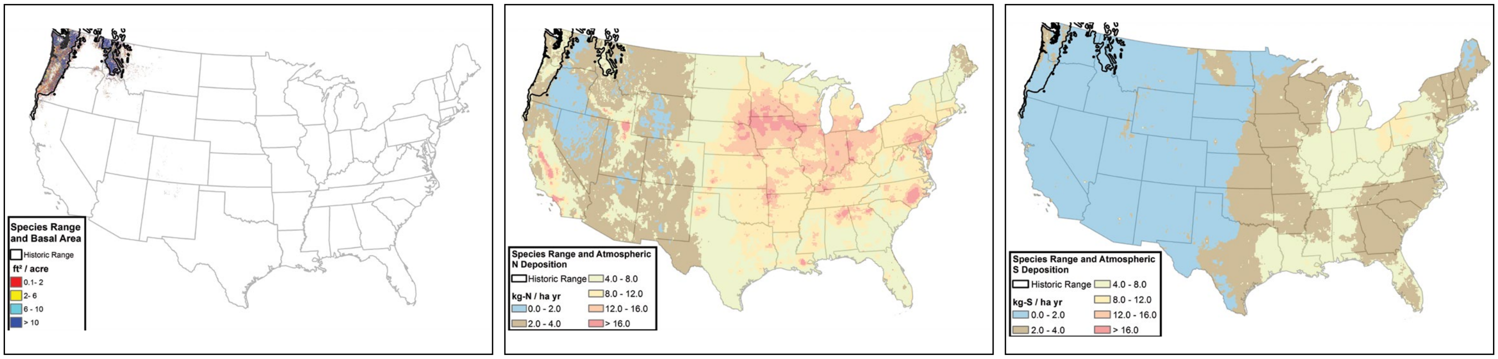
Primary Sources

Carey, Jennifer H. 1993. *Thuja occidentalis*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (22 January 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Thuja plicata (western redcedar)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Western redcedar is a large, native, long-lived, evergreen tree. At maturity it is generally 70 to 100 feet (21–30 m) tall, sometimes 130 feet (40 m), with a tapering trunk 2 to 4 feet (0.6–1.2 m) in diameter. The leaves are scalelike, flattened and 0.05 to 0.1 inches (1.5–3 mm) long. The twigs are flattened, in fanlike sprays and slightly drooping. The bark is thin, fibrous, and stringy or shreddy. Western redcedar roots are extensive, but taproots are poorly defined. Western redcedar reproduces from seeds more readily in open, disturbed areas, such as clearcuts, than in undisturbed stands. Cones bear small seeds that are dispersed primarily by wind. Western redcedar is also capable of reproducing vegetatively if moisture conditions are optimal. Western redcedar grows best in maritime climates with cool, cloudy summers and wet, mild winters. In drier areas west of the Cascades, western redcedar becomes abundant only on wet sites such as ravines, along streams, or on poorly drained bottomlands. When sufficient precipitation is present, low temperatures appear to limit western redcedar's range. Western redcedar can tolerate a wide range of soil. It grows well on shallow soils over chalk and can tolerate both acid and alkaline soils conditions. It is able to survive and grow on soils that are low in nutrients and is found on such soils over much of its natural range. Western redcedar is very shade tolerant. It is usually considered a climax or near climax species, but it can be found in all stages of forest succession. It invades disturbed areas as widely distributed seeds but regenerates vegetatively in undisturbed areas, tolerating competition in both.

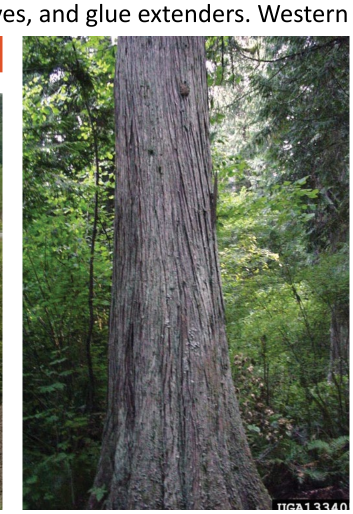
Wildlife Uses

Black-tailed deer, cattle, sheep, Roosevelt elk, and other big game browse western redcedar seedlings, saplings, and foliage. Black bears also remove western redcedar bark and feed on the exposed sapwood. Seeds of this conifer were only occasionally taken by field mice in caged tests. Old-growth stands of western redcedar provide hiding and thermal cover for several wildlife species. Bears, raccoons, skunks, and other animals use cavities in western redcedar for dens. Western redcedar is used as nest trees by cavity nesting bird species such as yellow-bellied sapsuckers, hairy woodpeckers, tree swallows, chestnut-backed chickadees, and Vaux's swifts.

Ecosystem Services

Western redcedar is an important commercial species throughout much of its natural range. The wood is best suited for use as exposed building material such as shingles, shakes, and exterior siding. Hand-split western redcedar shakes sell for several times the price of asphalt shingles but will last 100 years on a roof. Western redcedar wood is also used for utility poles, fence posts, light construction, pulp, clothes closets and chests, boats, canoes, fish trap floats, caskets, crates, and boxes. Perfumes, insecticides, medicinal preparations, veterinary soaps, shoe polishes, and deodorants are made from western redcedar leaf oil. Western redcedar extractives and residues are used in lead refining, boiler-water additives, and glue extenders. Western

Specimens of *Thuja plicata.* Photo by Karan A. Rawlins, University of Georgia, Bugwood.org, 5473261.



Bark of *Thuja plicata.* Photo by Chris Evans, University of Illinois, Bugwood.org, 1334055.

redcedar's drooping branches, thin fibrous bark, and flat sprays of scalelike leaves make it an attractive ornamental. Properly trimmed, western redcedar is an excellent hedge.

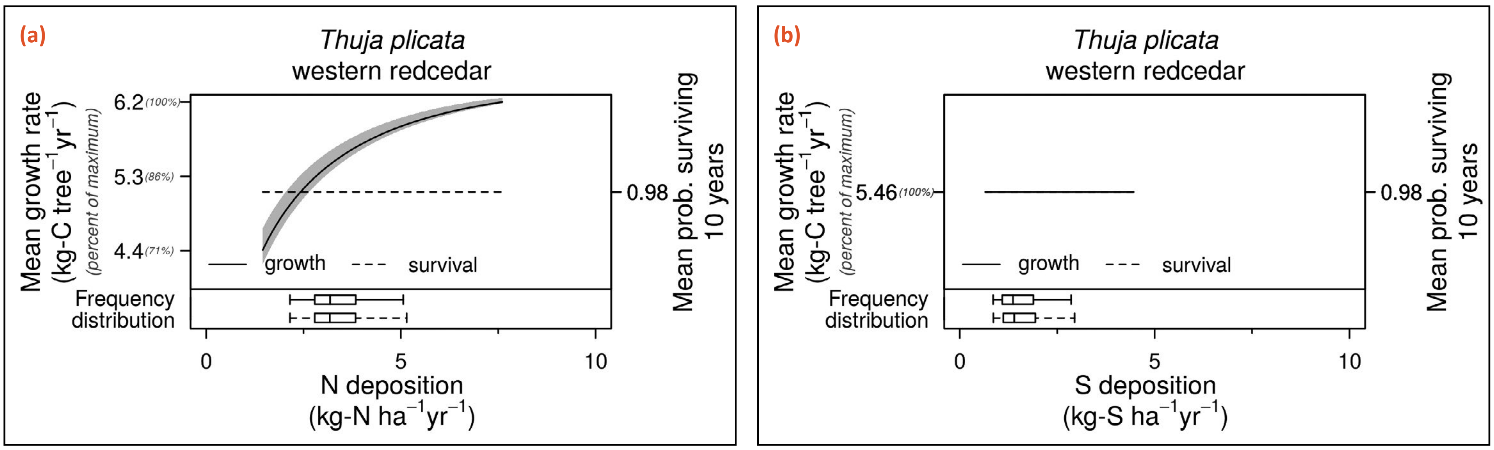
Western redcedar is an extremely valuable tree to indigenous peoples of the Northwest Coast, providing materials for shelter, clothing, dugout canoes, and fishing nets. The inner layer of bark was finely shredded for diapers and cradle padding.

Western redcedar can be planted on disturbed sites within its natural range for erosion control and long-term vegetation.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of western redcedar increases with increasing N deposition and has no relationship with S deposition. Survival has no relationship to N or S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Foliage of *Thuja plicata* in Alaska. Photo by Karen Dillman, USDA Forest Service



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	High	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X	X	X	X	

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
X			X		X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

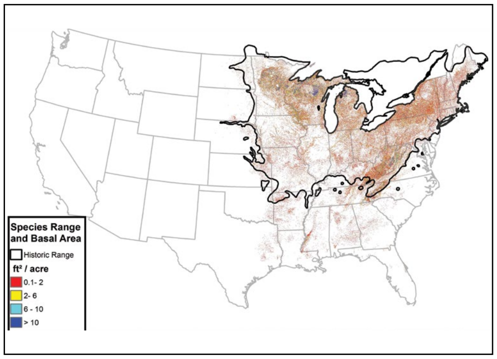
Primary Source

Native American Ethnobotany Database. http://naeb.brit.org.

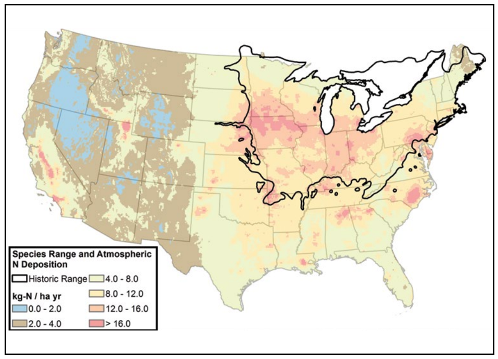
Tesky, Julie L. 1992. *Thuja plicata*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/plants/tree/thupli/all.html. (2017 May 17).

Tilia americana (American basswood)

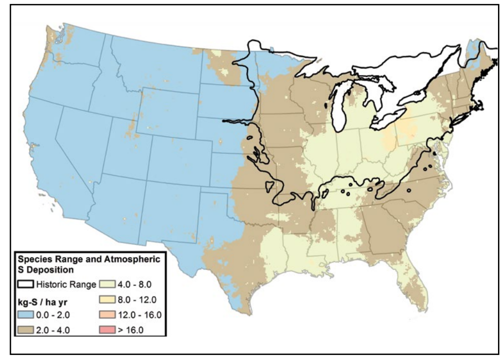
(a)



(b)



(c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

American basswood is a native deciduous tree that reaches heights ranging from 75 to 130 feet (23–40 m) with diameter ranging from 36 to 48 inches (91–122 cm). The tree crown is usually broad and rounded, but in close stands is more columnar, made up of small, weak branches. The bark is furrowed into narrow, flat-topped, firm ridges with characteristic horizontal cracks on mature trees. Maximum longevity is approximately 200 years. American basswood usually flowers in late spring; bees and flies typically pollinate these flowers. Seed dispersal occurs in the fall via dry, hard fruit. The species is moderately tolerant of shade, and shade actually enhances establishment and initial survival. The species is characteristically found in rich, moister uplands on mid-slopes in mixed deciduous forests, flood plains, and swamps. American basswood is generally confined to sandy loams, loams, or silt loams; it seems to thrive on finer-textured soils in mesic sites. Because the species is nitrogen-demanding, it grows poorly on nitrogen-deficient soils. Patchy or large-scale disturbance may favor American basswood because of its sprouting ability and persistent presence in the understory, thus making it a climax species in many forest communities.

Wildlife Uses

American basswood is preferred browse for white-tailed deer, and the flowers provide valuable nectar for honeybees. The easily decayed wood produces a disproportionate number of cavities which are used by cavity-nesting animals including wood ducks, pileated woodpeckers, other birds, and small mammals.

Ecosystem Services

The wood is soft and light, so, it is valued for hand carving and has many other uses including cooperage, boxes, veneer, excelsior, and pulp. It is economically important for timber and the stump sprouts can be managed for sawtimber. American basswood is also planted as a shade tree or ornamental.

The Algonquin, Cherokee, Iroquois, and Potawatomi use basswood for wood carving, and basket making. The fibrous inner bark ("bast") has traditional uses as a source of fiber for rope, mats, fishnets, and woven baskets. Other traditional uses included using an infusion of the leaves as an eyewash and decoctions to treat dysentery and cough.

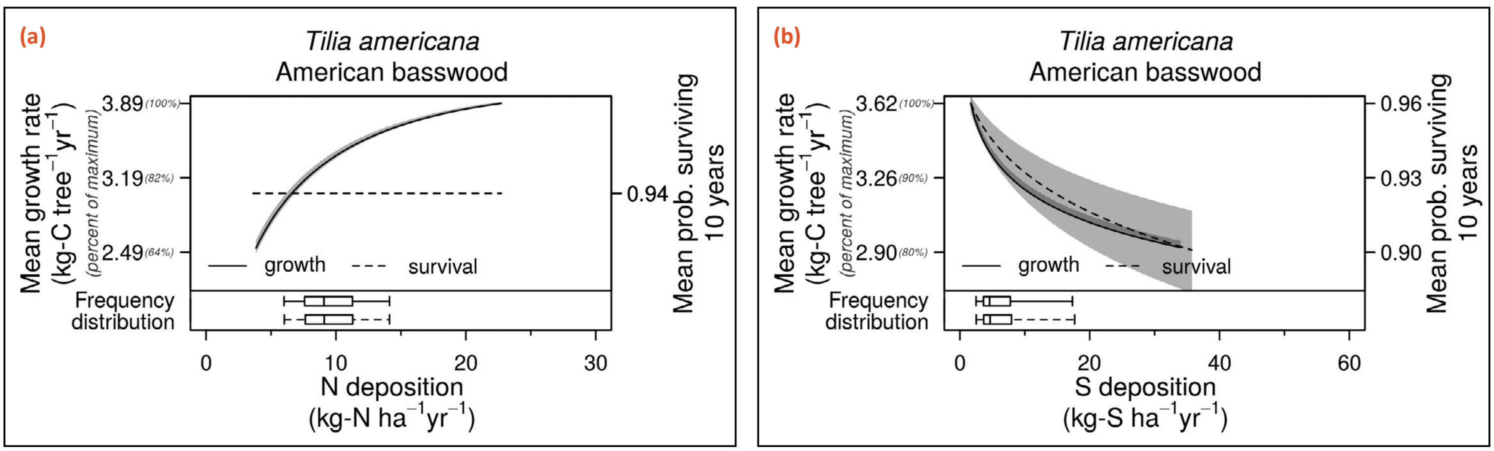
Trunks of *Tilia Americana.* Photo by Rob Routledge, Sault College, Bugwood.org, 5454122.

Flower of *Tilia Americana.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008060.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of American basswood increases with increasing N deposition and decreases with increasing S deposition. Survival has no relationship to N deposition and decreases with increasing S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Foliage of *Tilia Americana.* Photo by Paul Wray, Iowa State University, Bugwood. org, 0008299.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	**Shade Tolerance**	**Leaf Type**	**Mammal Uses**	**Bird Uses**
	Medium	Broadleaf Deciduous	Yes	Yes

Wood products				**Traditional uses**	**Ornamental uses**	**Fuelwood**
Paper	**Unfinished wood products**	**Building material**	**Finished wood products**			
X	X		X	X	X	

Protection			**Rehabilitation**	**Food products**	**Oils and other**	**General services**
Erosion	**Wind**	**Erosion and wind**				
						X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

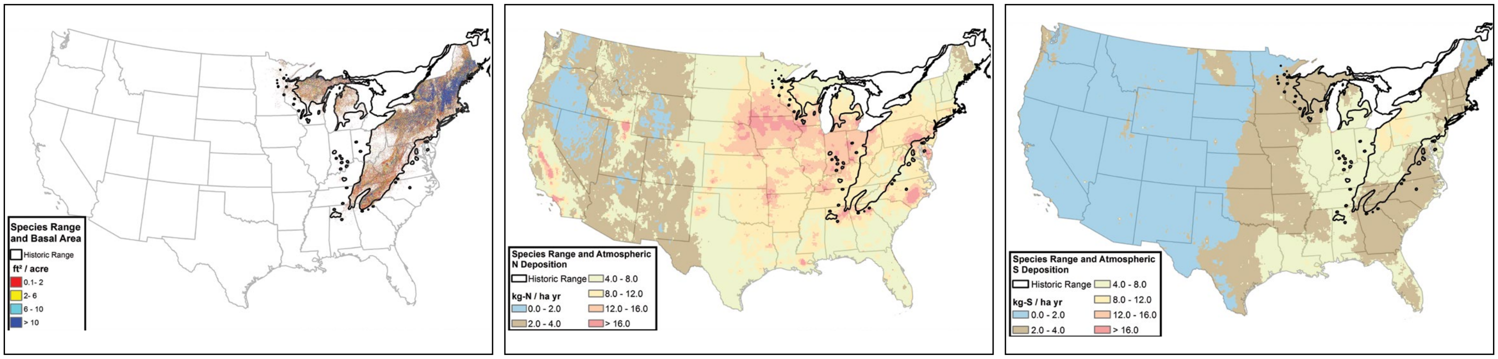
Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

Sullivan, Janet. 1994. *Tilia americana*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (22 January 2016).

Tsuga canadensis (eastern hemlock)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Eastern hemlock is a native, evergreen conifer with dense foliage on the branches. At maturity, it is commonly 60 to 70 feet (18–21 m) tall and 24 to 48 inches (61–122 cm) in diameter. At its western and southern limits, it is confined to moist, cool valleys, swamp edges, moist flats, northern and eastern slopes, coves, benches, and ravines. In the northern part of its range, it tolerates drier and warmer sites. Eastern hemlock grows in a wide variety of acidic soils; textures include sandy loams, loamy sands, and silty loams with gravel of glacial origin in the upper profile. Seedlings grow slowly and cannot tolerate full sunlight until fully established. Regeneration in dense stands is typically limited due to intense root competition, dry acidic litter, and extreme shading. Individual trees are able to survive several hundred years of suppression, however, and many show numerous growth releases and suppressions. Understory plant associates are scarce because of acidic infertile humus, low light, and cool conditions. Eastern hemlock is in general decline due to damage from the hemlock woolly adelgid and over-browsing from high deer populations.

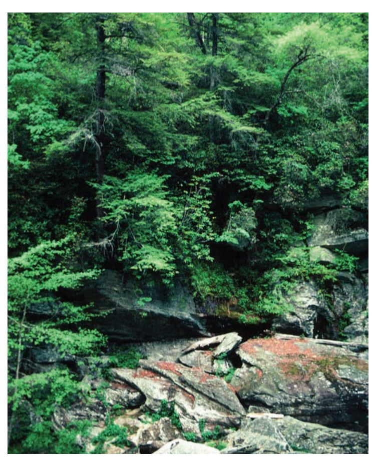
Wildlife Uses

Birds and mammals eat the seeds, and in the winter, white-tailed deer, moose, and snowshoe hares browse the foliage. The dense stands of eastern hemlock afford excellent wildlife habitat for bears, birds, and small mammals due to the high cavity values and large number of hollow trees. Cove forests in the southern Appalachian Mountains provide nesting habitat for many species of birds including the black-throated blue warbler, black-throated green warbler, and Blackburnian warbler. Eastern hemlock also gives cover to ruffed grouse, wild turkey, fishers, and other wildlife. It provides excellent thermal protection and snowfall interception for moose and white-tailed deer in the winter.

Ecosystem Services

The wood is of low value because of brittleness and abundant knots. It is used for pulp, light framing, sheathing, roofing, sub-flooring, and boxes and crates. From 1880 to 1930, eastern hemlock was extensively harvested for its bark, which is a source of tannin. The tree is also commonly planted as an ornamental.

The Abnaki, Algonquin, Iroquois, and Cherokee peoples created various infusions of the roots, bark, and leaves to treat rheumatism, arthritis, kidney issues, and colds. The Maliseet made a dark red dye by boiling down the bark.



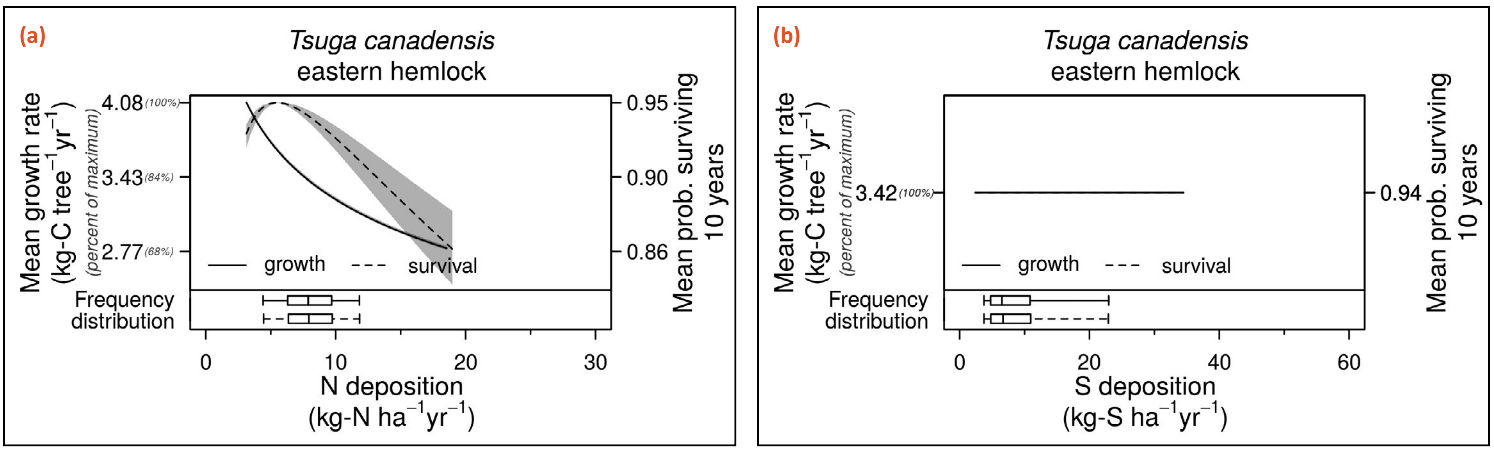
Stand of *Tsuga canadensis.* Photo by Paul Bolstad, University of Minnesota, Bugwood.org, 1437049.

Bark of *Tsuga canadensis.* Photo by Bill Cook, Michigan State University, Bugwood.org, 1218066.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of eastern hemlock decreases with increasing N deposition and has no relationship to S deposition. Survival has a humped-shape relationship with increasing N deposition and no relationship to S deposition. Confidence in these relationships is low based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Cone and foliage of *Tsuga canadensis*. Photo by Paul Wray, Iowa State University, Bugwood.org, 0008209.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	High	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X		X	X	

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
					X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

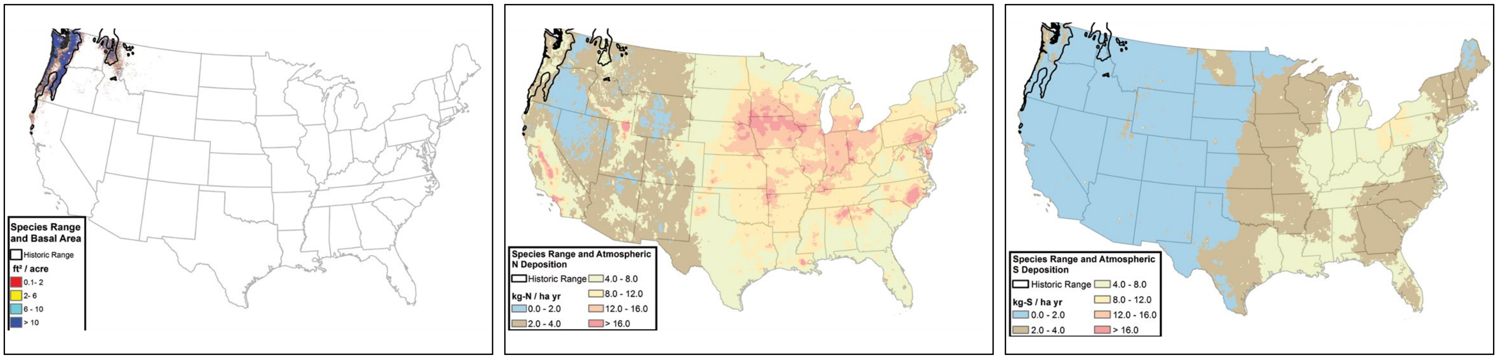
Primary Sources

Carey, Jennifer H. 1993. *Tsuga canadensis*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (22 January 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Tsuga heterophylla (western hemlock or Pacific hemlock)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Western hemlock is a large, native, evergreen tree and typically grows to heights of 100 to 150 feet (30–46 m) tall with a 2- to 4-foot (0.6–1.2 m) diameter. It is long-lived tree with maximum ages typically over 400 years old. Scaly thin bark develops on young trees, but as the tree ages, the thin bark becomes hard with furrows separating flat ridges. Western hemlock is generally a good cone and seed producer. The seeds have large wings so that wind distributes the seeds over long distances. Western hemlock thrives in humid areas of the Pacific Coast and northern Rocky Mountains. It grows best in mild, humid climates where frequent fog and precipitation occur during the growing season. It grows on soils derived from all bedrock types (except serpentines) within its range and is found on most soil textures. The species is extremely shade-tolerant and is considered to be a climax species, but it is also an aggressive pioneer because of its quick growth in full overhead light, vegetative layering, and ability to survive on a wide variety of seedbed conditions. Western hemlock is one of the conifers most sensitive to damage by sulfur dioxide.

Wildlife Uses

Snowshoe hare, rabbit, deer, elk, black bears, and beavers all browse western hemlock. Old-growth and mature western hemlock stands provide hiding and thermal coverage for many wildlife species such as the red tree vole, northern flying squirrel, northern spotted owl, barred owls, yellow-bellied sapsucker, and northern three-toed woodpecker.

Ecosystem Services

In terms of biomass production, western hemlock forests are among the most productive forests in the world. The wood is recognized as an all-purpose raw material for paper, paper board, rayon, cellophane, and many plastics. Lumber can be used for general construction and industrial activities, and the wood is suited for interior finished, boxes, kitchen cabinets, flooring, plywood, and many other uses. Young western hemlock saplings can be sheared to make excellent hedges for ornamental plantings.

The Bella Coola, Chehalis, Quinault, and other indigenous peoples of the Pacific Northwest traditionally used the inner bark to create poultices and the gum to treat tuberculosis, burns, coughs, and swelling. Other northwestern indigenous peoples made coarse bread from the inner bark and used the cambium as a sweetener.

For rehabilitation of disturbed or degraded sites, western hemlock is suitable for planting in moist areas.

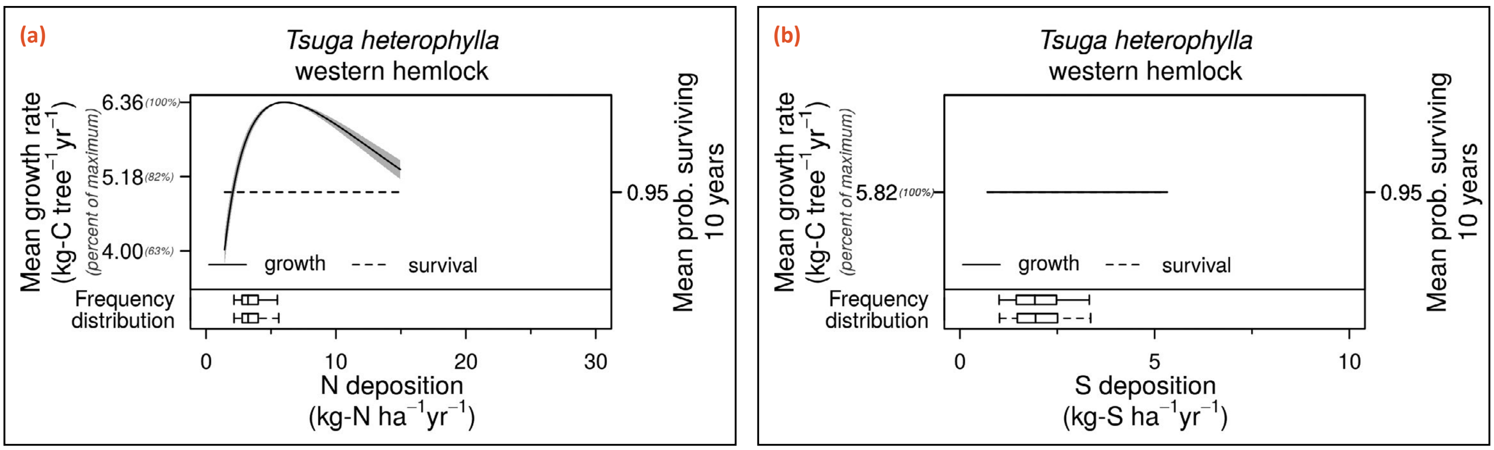
Specimens of *Tsuga heterophylla.* Photo by Chris Schnepf, University of Idaho, Bugwood.org, 1169002.

Bark of *Tsuga heterophylla.* Photo by J.S. Peterson, hosted by the USDA-NRCS PLANTS Database.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of western hemlock has a humped-shaped relationship with increasing N deposition and no relationship to S deposition. Survival of western hemlock has no relationship to or S deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Cones of *Tsuga heterophylla*. Lyndon Photography, Dried Botanical ID, USDA APHIS ITP, Bugwood.org, 5471070.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	High	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X	X	X	X	

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
			X		X	X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

Primary Sources

Native American Ethnobotany Database. http://naeb.brit.org.

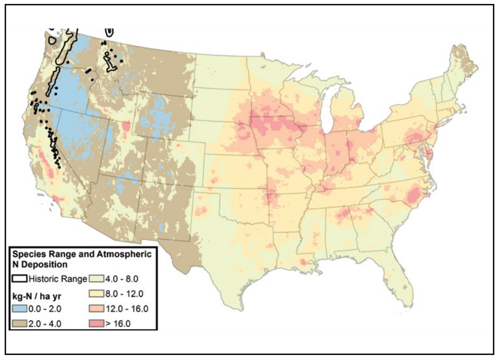
Tesky, Julie L. 1992. *Tsuga heterophylla*. In: Fire Effects Information System [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (22 January 2016).

U.S. Department of Agriculture, Natural Resources Conservation Service. 2016. The PLANTS Database. National Plant Data Team, Greensboro, NC 27401–4901 USA. http://plants.usda.gov. (1 March 2016).

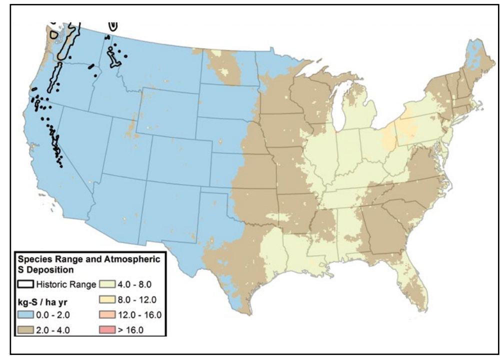
Tsuga mertensiana (mountain hemlock)

(a)

(b)



(c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Mountain hemlock is a native, slow-growing, coniferous, evergreen tree usually 75 to 100 feet (23–30 m) tall and 2.5 to 3.5 feet (0.8–1 m) in diameter. However, it takes on a variety of growth forms to adapt to subalpine conditions. Below 4,000 feet (1219 m) in the Coast Ranges, it grows in dense stands reaching diameters of 3 to 4 feet (0.8–0.9 m) and heights up to 150 feet (46 m). On exposed ridges at high elevations, it often grows as a low-spreading shrub or small tree. The needles are crowded on all sides of short twigs and curved upward. The bark is thick and deeply furrowed into scaly plates on old trees. Mountain hemlock begins producing seed at about age 20. Cones average about 70 to 100 seeds. Mountain hemlock's winged seeds are dispersed primarily by wind. Mountain hemlock is commonly found on cold, snowy subalpine or boreal sites where it grows slowly, sometimes reaching more than 800 years of age. Mountain hemlock generally occurs on sites with mild to cold winters; short, warm to cool growing seasons; and moderate to high precipitation. Mountain hemlock grows on soils derived from a wide variety of parent materials; however, it is rare and stunted on soils derived from calcareous parent materials. Mountain hemlock is shade tolerant. It is considered a major or minor climax species over most of its habitat; however, it is also a pioneer on glacial moraines in British Columbia and Alaska. Mountain hemlock is considered a coclimax species with subalpine fir where they occur together.

Wildlife Uses

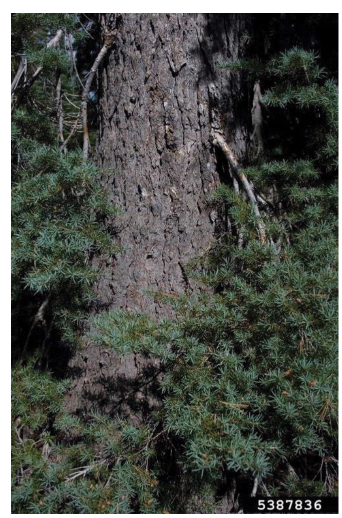
Mountain hemlock stands provide good hiding and thermal cover for many wildlife species. Sites dominated by mountain hemlock provide important summer range for deer in Alaska and Vancouver Island because of abundant nutrient-rich forbs available in the understory. In Montana, mountain hemlock habitat types provide summer range for mule deer, elk, and bear. Mountain hemlock seeds have been found in the stomachs of crows and grouse.

Ecosystem Services

Mountain hemlock is largely inaccessible because of the high altitudes at which it occurs and is unimportant as commercial timber. The wood is moderately strong and light colored and is most often used for small-dimension lumber and pulp. The wood is also used for railway ties, mine timbers, interior finishes, crates, kitchen cabinets, and flooring and ceilings. Nearly pure stands of mountain hemlock have also been logged for pulp. Mountain hemlock is often used as an ornamental for landscaping in the Pacific Northwest and throughout Great Britain. Its dense, compact foliage coupled with its slow growth make it ideal as a garden evergreen.

Hemlock (*Tsuga* spp.) objects played a supernatural role in the mythology of the Nlaka'pamux and Lillooet Interior Salish of

Specimen of *Tsuga mertensiana.* Photo by Donald Owen, California Department of Forestry and Fire Protection, Bugwood.org, 5387834.



Bark of *Tsuga mertensiana.* Photo by Donald Owen, California Department of Forestry and Fire Protection, Bugwood.org, 5387836.

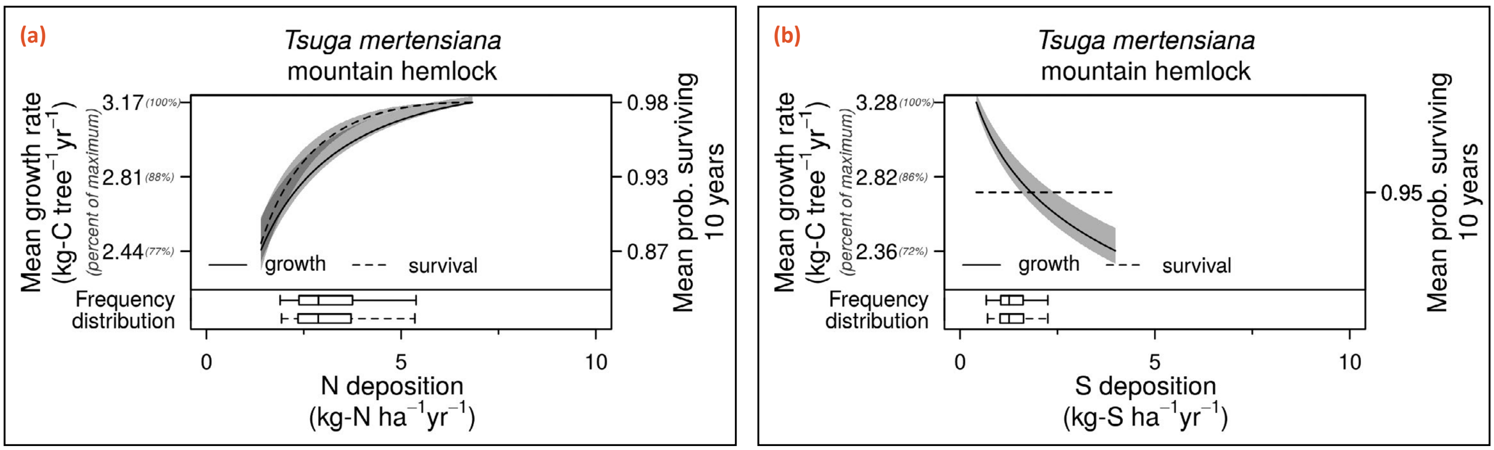
British Columbia. Its bark has also been used for tanning hides by the Hoh.

Mountain hemlock is important for watershed protection. The mountain hemlock/blueberry (*Vaccinium* spp.)–copperbush (*Cladothamnus pyrolaeflorus*)/deer cabbage (*Fauria crista-galli*) association in Alaska captures runoff from snowmelt. Planted stock of mountain hemlock does not perform well, so reliance on natural regeneration may be preferred.

Foliage of *Tsuga mertensiana.* Photo by Donald Owen, California Department of Forestry and Fire Protection, Bugwood.org, 5387835.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of mountain hemlock increases with increasing N deposition and decreases with increasing S deposition. Survival increases with increasing N deposition and has no relationship to S deposition. Confidence in these relationships is medium high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See also Appendix Table 4 and the Introduction for more information.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	High	Coniferous Evergreen	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
X	X	X		X	X	

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
X						X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

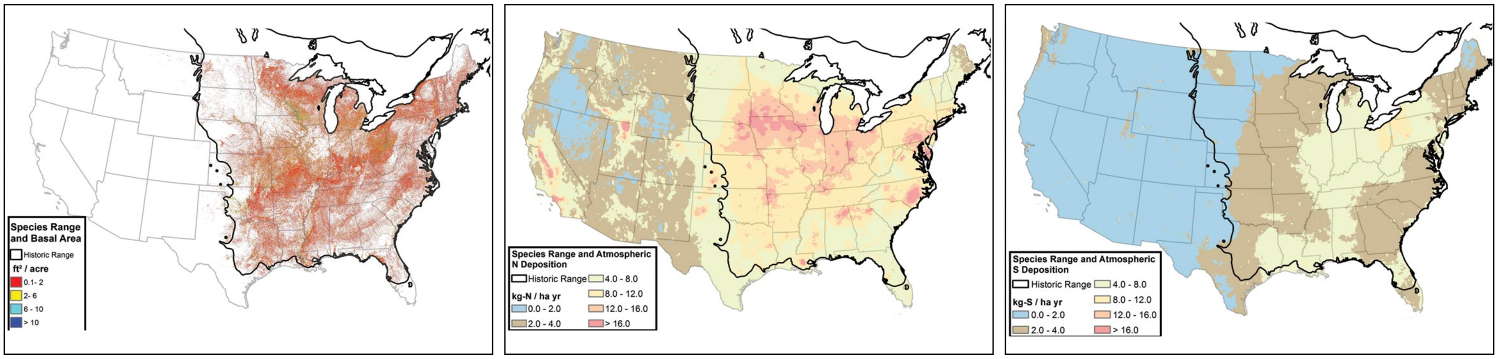
Primary Source

Native American Ethnobotany Database. http://naeb.brit.org.

Tesky, Julie L. 1992. *Tsuga mertensiana*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/. (2017, May 17).

Ulmus americana (American elm)

(a) (b) (c)



Map (c) showing range overlaid with sulfur (S) deposition

Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

American elm is a deciduous, fast-growing, long-lived tree that may reach 100 to 200 feet (30–36 m) in height and 48 to 60 inches (122–152 cm) in diameter. In the forest, it often develops a clear bole 50 to 60 feet (15–18m) in length and tends to form an arching crown in open conditions. The flowers are borne in dense clusters and the fruit is surrounded by a membranous wing that is dispersed with wind and gravity. The tree also reproduces vegetatively from stump sprouts and root suckering. American elm is commonly found on wet flats, bottomlands, and riparian areas along streams but can also be found in the plains and moraines. It has been found to grow best in rich, well-drained loams, with growth decreasing in drier and coarser soils. The species is intermediate in shade tolerance and tends to respond well to release from light limitation. If release does not occur, American elms are typically replaced by sugar maple (Acer saccharum) or beech (Fagus grandifolia). If American elm becomes dominant in a mixed hardwood stand, it is seldom overtaken by other species, thus making it a common associated species in climax types of moist sites.

Wildlife Uses

Deer, rabbits, and hares will occasionally browse the leaves and twigs but do not treat American elm as a preferred browse. A number of small birds eat the seeds and birds and small mammals consume the flower buds, flowers, and fruit. American elm provides thermal cover and nesting sites for a variety of primary and secondary cavity-nesters.

Ecosystem Services

The wood is coarse-grained, heavy, and strong; but it lacks durability during processing. It is used in the manufacture of boxes, baskets, crates, barrels, furniture, agricultural implements, and caskets. Elm veneer is used for furniture and decorative panels. The tree is also used for fuel wood. American elm can be planted for erosion protection and as a windbreak. Its shallow and wide-spreading roots make it fairly wind-firm. American elm was once prized as a street ornamental in many cities in North America, but Dutch elm disease has eliminated many mature trees throughout the continent.

The Cheyenne, Choctaw, Delaware, Iroquois, Mohegan, and many others brewed decoctions from the inner bark to treat severe coughs, menstrual cramps, and colds. The bard was used as building material for lodges.

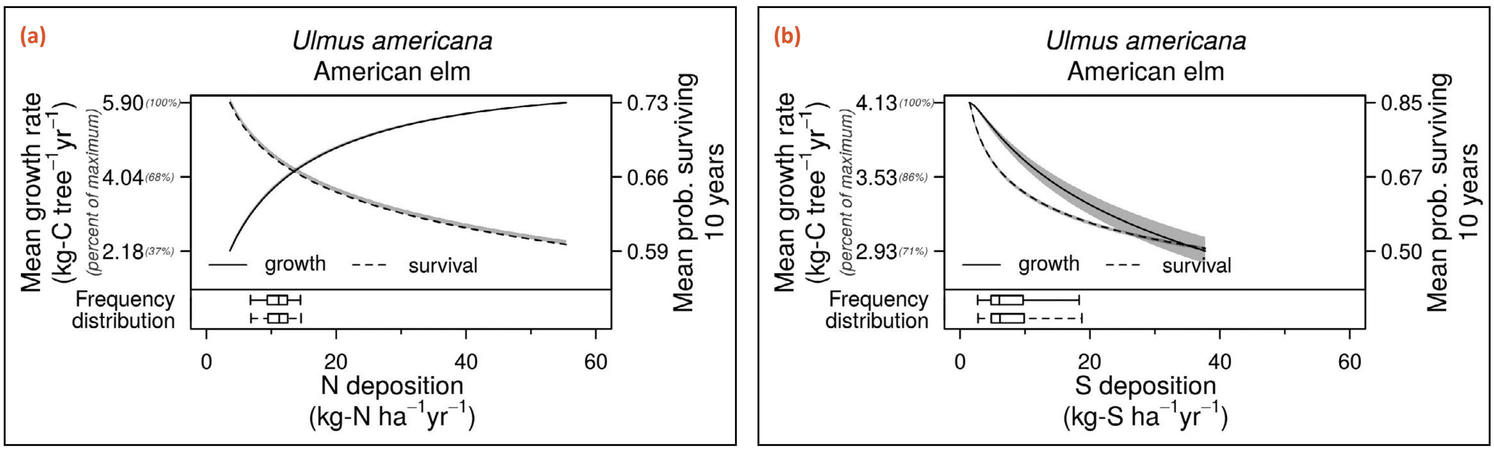
Specimen of *Ulmus americana*. Photo by Richard Webb, Bugwood.org, 1480517.

Bark of *Ulmus americana*. Photo by Keith Kanoti, Maine Forest Service, Bugwood.org, 5350067.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of American elm increases with increasing N deposition and decreases with increasing S deposition. Survival decreases with increasing N deposition and decreases with increasing S deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are often correlated across species' geographic distributions, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Flowers of *Ulmus americana.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008077.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	Medium	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
	X		X	X	X	X

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
		X				X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

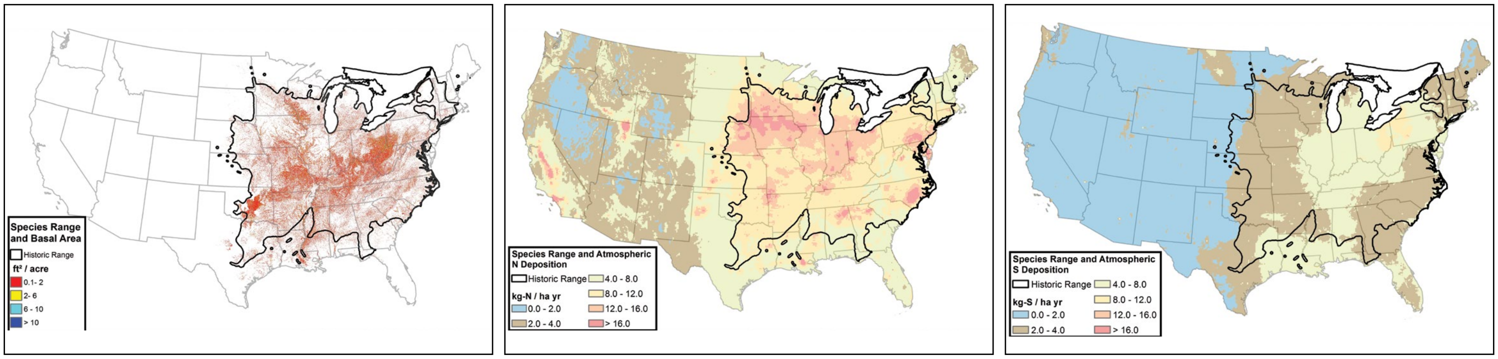
Primary Sources

Coladonato, Milo. 1992. *Ulmus americana*. In: Fire Effects Information System, [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (21 January 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

Ulmus rubra (slippery elm)

(a) (b) (c)



Species range and abundance (a), range overlaid with either nitrogen (N) deposition (b), or sulfur (S) deposition (c). In (a) black outlines indicate the historical range from USGS (1999), and the colored pixels show the abundances in square feet per acre from Wilson and others (2013). In (b) and (c), the average annual deposition of total N and total S, respectively, are shown for 2012–2014 from Schwede and Lear (2014), with species historic range from USGS (1999) repeated for reference. See Chapter 1 for more information on the species response summary and on the maps. Ft = feet, ha = hectare, kg = kilograms.

Species Characteristics and Habitat

Slippery elm is a native, medium-sized, deciduous tree typically reaching 60 to 70 feet (18–21 m) in height with a straight bole and a shallow, widespread root system. Flowers form dense-packed clusters and bloom prior to leaf out in the spring. After the seeds ripen, gravity and wind disperse them, and germinated seedlings can become established in both mineral soil and forest litter. The tree also readily sprouts from the stump or root crown and can reproduce through layering. Slippery elm can be found in moist, rich soils of lower slopes, streambanks, river terraces, floodplains, and bottomlands, but can also be found on much drier sites. It is a shade-tolerant species and is frequently found in the sub-canopy.

Wildlife Uses

Birds, deer, and small mammals browse and eat the seeds and twigs. The tree also provides thermal cover and nesting sites for a variety of primary and secondary cavity-nesters.

Ecosystem Services

Slippery elm is not an important lumber tree, but it has been used to manufacture boxes, baskets, crates, and barrels. The bark has been used—traditionally and currently—as a treatment for coughs and diarrhea. The tree has been planted as a street ornamental tree in many localities, but its recent use has been limited following the introduction of Dutch elm disease.

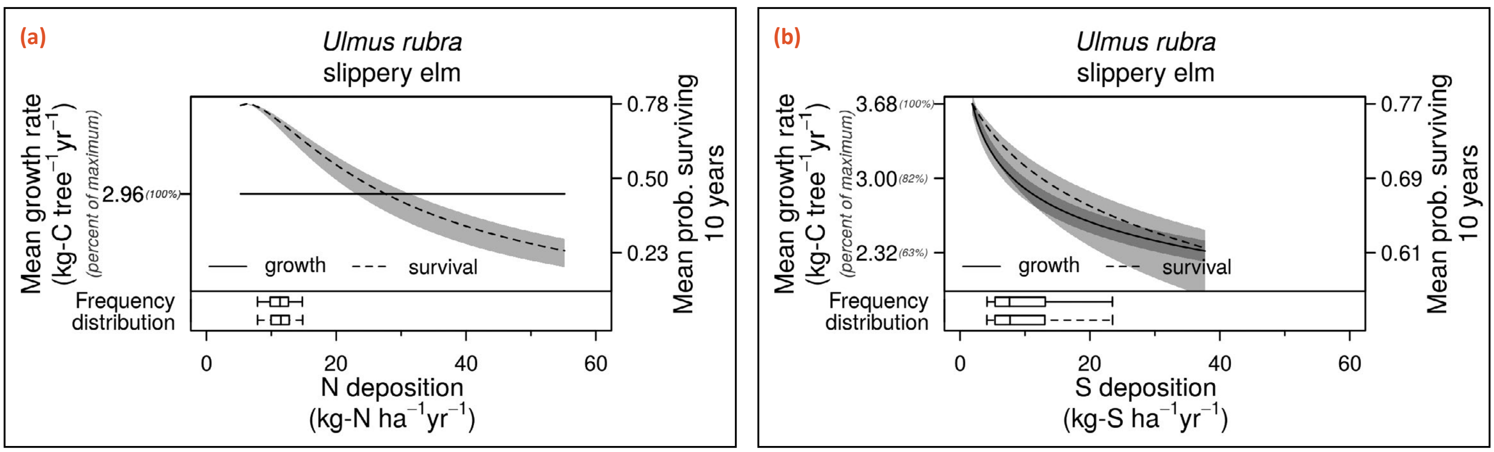
Foliage of *Ulmus rubra.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008331.

Bark of *Ulmus rubra.* Photo by Rob Routledge, Sault College, Bugwood.org, 5473626.

Survival and Growth Responses to Nitrogen and Sulfur Deposition

The growth of slippery elm has no relationship to N deposition and decreases with increasing S deposition. Survival mostly decreases with increasing N deposition and decreases with increasing S deposition. Confidence in these relationships is high based on the correlation between atmospheric N and S deposition across the species range and the variance inflation factors. Nitrogen and S deposition are correlated for many species, and uncorrelated for others, so inferring causality to one or the other stressor can be difficult. See Appendix Table 4 and the Introduction for more information.

Leaf scars and buds of *Ulmus rubra.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008490.



Functional response curves for the association of (a) nitrogen (N) and (b) sulfur (S) deposition with annual growth rate (solid lines, left axes) and probability of survival over 10 years (dash lines, right axes). Gray shadings indicate the error in the estimate of the curve (2.5th–97.5th confidence interval), and the box-and-whisker plots below the functional response curves show the distribution of individual trees along the gradient. Values on the y-axes are shown in absolute units (black) and in relative units as the percent of maximum (gray italics). See Chapter 1 for more information. C = carbon, ha = hectare, kg = kilograms, yr = year.

Species Summary	Shade Tolerance	Leaf Type	Mammal Uses	Bird Uses
	High	Broadleaf Deciduous	Yes	Yes

Wood products				Traditional uses	Ornamental uses	Fuelwood
Paper	Unfinished wood products	Building material	Finished wood products			
	X			X	X	

Protection			Rehabilitation	Food products	Oils and other	General services
Erosion	Wind	Erosion and wind				
						X

A summary of the ecological characteristics (green) and ecosystem services (blue) of this species. Four ecological characteristics are highlighted: (1) shade tolerance, (2) leaf type, (3) mammal uses, and (4) bird uses. Nine ecosystem services are highlighted: (1) wood products, (2) traditional uses, (3) ornamental uses, (4) fuelwood, (5) protection, (6) rehabilitation of land, (7) food products, (8) oils and other (nontimber and nonfood products), and (9) general services. An "X" in the ecosystem service cell indicates that the species is reported to provide the specified service in the USDA Forest Service Fire Effects Information System. For more details on these ecological characteristics and ecosystem services, see Chapter 1 and primary sources below.

Primary Source

Coladonato, Milo. 1993. *Ulmus rubra*. In: Fire Effects Information System, [Online]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (21 January 2016).

Native American Ethnobotany Database. http://naeb.brit.org.

APPENDIX TABLE 1

Genus	Species	Common name	Ecologic attribute	N deposition Growth	N deposition Survival	S deposition Growth	S deposition Survival
Abies	amabilis	Pacific silver fir	S-E-EM	hump-shaped	flat	decreasing	flat
Abies	balsamea	balsam fir	S-E-EM	decreasing	flat	decreasing	decreasing
Abies	concolor	white fir	S-E-EM	flat	flat	decreasing	decreasing
Abies	grandis	grand fir	S-E-EM	increasing	increasing	decreasing	decreasing
Abies	lasiocarpa	subalpine fir	S-E-EM	increasing	flat	flat	flat
Acer	negundo	boxelder	H-D-AM	hump-shaped	flat	flat	flat
Acer	rubrum	red maple	H-D-AM	increasing	hump-shaped	decreasing	flat
Acer	saccharinum	silver maple	H-D-AM	flat	hump-shaped	decreasing	decreasing
Acer	saccharum	sugar maple	H-D-AM	flat	flat	decreasing	flat
Betula	alleghaniensis	yellow birch	H-D-EM	decreasing	flat	flat	flat
Betula	lenta	sweet birch	H-D-EM	increasing	flat	flat	flat
Betula	papyrifera	paper birch	H-D-EM	increasing	flat	flat	flat
Calocedrus	decurrens	incense cedar	S-E-AM	decreasing	hump-shaped	decreasing	decreasing
Carpinus	caroliniana	American hornbeam, musclewood	H-D-EM	flat	flat	decreasing	flat
Carya	alba	mockernut hickory	H-D-EM	flat	hump-shaped	flat	decreasing
Carya	cordiformis	bitternut hickory	H-D-EM	decreasing	flat	flat	decreasing
Carya	glabra	pignut hickory	H-D-EM	increasing	flat	decreasing	flat
Carya	ovata	shagbark hickory	H-D-EM	flat	flat	flat	decreasing
Carya	texana	black hickory	H-D-EM	flat	flat	flat	decreasing
Celtis	laevigata	sugarberry	H-D-AM	flat	flat	decreasing	decreasing
Celtis	occidentalis	hackberry	H-D-AM	flat	hump-shaped	decreasing	decreasing
Fagus	grandifolia	American beech	H-D-EM	hump-shaped	flat	flat	decreasing
Fraxinus	americana	white ash	H-D-AM	flat	flat	decreasing	decreasing
Fraxinus	nigra	black ash	H-D-AM	increasing	hump-shaped	decreasing	decreasing
Fraxinus	pennsylvanica	green ash	H-D-AM	hump-shaped	increasing	flat	decreasing
Gleditsia	triacanthos	honeylocust	H-D-AM	increasing	flat	decreasing	decreasing
Juglans	nigra	black walnut	H-D-AM	flat	flat	decreasing	decreasing
Juniperus	monosperma	oneseed juniper	S-E-AM	increasing	hump-shaped	decreasing	decreasing
Juniperus	occidentalis	western juniper	S-E-AM	increasing	hump-shaped	flat	flat
Juniperus	osteosperma	Utah juniper	S-E-AM	increasing	hump-shaped	decreasing	flat
Juniperus	virginiana	eastern redcedar	S-E-AM	flat	flat	decreasing	decreasing
Larix	laricina	tamarack (native)	S-E-EM	increasing	flat	flat	flat
Larix	occidentalis	western larch	S-D-EM	increasing	flat	decreasing	decreasing
Liquidambar	styraciflua	sweetgum	H-D-AM	increasing	flat	flat	flat
Liriodendron	tulipifera	yellow-poplar	H-D-AM	decreasing	hump-shaped	flat	flat
Lithocarpus	densiflorus	tanoak	H-D-EM	hump-shaped	flat	flat	flat
Maclura	pomifera	Osage-orange	H-D-AM	increasing	increasing	decreasing	flat
Magnolia	virginiana	sweetbay	H-E/D-AM	flat	flat	decreasing	decreasing
Nyssa	aquatica	water tupelo	H-D-AM	increasing	hump-shaped	decreasing	decreasing
Nyssa	biflora	swamp tupelo	H-D-AM	increasing	increasing	decreasing	flat
Nyssa	sylvatica	blackgum	H-D-AM	flat	flat	flat	decreasing
Ostrya	virginiana	eastern hophornbeam	H-D-EM	decreasing	increasing	flat	decreasing

APPENDIX TABLE 1 continued

Oxydendrum	arboreum	sourwood	H-D-EM	flat	hump-shaped	decreasing	decreasing
Picea	engelmannii	Engelmann spruce	S-E-EM	flat	hump-shaped	decreasing	decreasing
Picea	glauca	white spruce	S-E-EM	flat	flat	decreasing	decreasing
Picea	mariana	black spruce	S-E-EM	flat	flat	flat	flat
Picea	rubens	red spruce	S-E-EM	flat	flat	flat	decreasing
Pinus	banksiana	jack pine	S-E-EM	flat	flat	flat	flat
Pinus	contorta	lodgepole pine	S-E-EM	increasing	flat	flat	flat
Pinus	echinata	shortleaf pine	S-E-EM	flat	decreasing	flat	flat
Pinus	edulis	Colorado pinyon	S-E-EM	flat	flat	flat	flat
Pinus	elliottii	slash pine	S-E-EM	hump-shaped	flat	flat	decreasing
Pinus	monophylla	singleleaf pinyon	S-E-EM	hump-shaped	hump-shaped	decreasing	decreasing
Pinus	palustris	longleaf pine	S-E-EM	increasing	hump-shaped	flat	flat
Pinus	ponderosa	ponderosa pine	S-E-EM	increasing	flat	decreasing	flat
Pinus	resinosa	red pine	S-E-EM	hump-shaped	hump-shaped	ddecreasing	decreasing
Pinus	rigida	pitch pine	S-E-EM	flat	flat	decreasing	flat
Pinus	strobus	eastern white pine	S-E-EM	increasing	hump-shaped	decreasing	flat
Pinus	taeda	loblolly pine	S-E-EM	increasing	hump-shaped	decreasing	decreasing
Pinus	virginiana	Virginia pine	S-E-EM	increasing	flat	flat	decreasing
Platanus	occidentalis	American sycamore	H-D-AM	hump-shaped	flat	flat	flat
Populus	balsamifera	balsam poplar	H-D-EM/AM	increasing	flat	decreasing	flat
Populus	grandidentata	bigtooth aspen	H-D-EM/AM	hump-shaped	hump-shaped	flat	decreasing
Populus	tremuloides	quaking aspen	H-D-EM/AM	flat	flat	decreasing	flat
Prunus	serotina	black cherry	H-D-AM	flat	hump-shaped	flat	flat
Pseudotsuga	menziesii	Douglas-fir	S-E-EM	hump-shaped	flat	flat	decreasing
Quercus	alba	white oak	H-D-EM	flat	flat	flat	decreasing
Quercus	chrysolepis	canyon live oak	H-D-EM	flat	hump-shaped	flat	decreasing
Quercus	coccinea	scarlet oak	H-D-EM	flat	flat	flat	flat
Quercus	ellipsoidalis	northern pin oak	H-D-EM	decreasing	flat	flat	decreasing
Quercus	falcata	southern red oak	H-D-EM	increasing	hump-shaped	decreasing	decreasing
Quercus	laurifolia	swamp laurel oak	H-D-EM	hump-shaped	hump-shaped	flat	decreasing
Quercus	macrocarpa	bur oak	H-D-EM	hump-shaped	hump-shaped	decreasing	flat
Quercus	muehlenbergii	chinkapin oak	H-D-EM	flat	hump-shaped	flat	decreasing
Quercus	nigra	water oak	H-D-EM	increasing	flat	decreasing	decreasing
Quercus	phellos	willow oak	H-D-EM	hump-shaped	decreasing	flat	decreasing
Quercus	prinus	chestnut oak	H-D-EM	increasing	flat	decreasing	flat
Quercus	rubra	northern red oak	H-D-EM	hump-shaped	decreasing	flat	flat
Quercus	stellata	post oak	H-D-EM	increasing	hump-shaped	decreasing	decreasing
Quercus	velutina	black oak	H-D-EM	hump-shaped	flat	flat	flat
Robinia	pseudoacacia	black locust	H-D-AM	flat	hump-shaped	flat	flat
Salix	nigra	black willow	H-D-AM	hump-shaped	decreasing	decreasing	decreasing
Sassafras	albidum	sassafras	H-D-AM	flat	flat	flat	decreasing
Taxodium	ascendens	pondcypress	S-E-AM	hump-shaped	flat	flat	decreasing
Taxodium	distichum	baldcypress	S-E-AM	increasing	hump-shaped	flat	flat
Thuja	occidentalis	northern white-cedar	S-E-AM	flat	hump-shaped	flat	flat
Thuja	plicata	western redcedar	S-E-AM	increasing	flat	flat	decreasing

APPENDIX TABLE 1 continued

Tilia	americana	American basswood	H-D-EM	increasing	increasing	decreasing	decreasing
Tsuga	canadensis	eastern hemlock	S-E-EM	hump-shaped	flat	decreasing	flat
Tsuga	heterophylla	western or Pacific hemlock	S-E-EM	increasing	increasing	flat	decreasing
Tsuga	mertensiana	mountain hemlock	S-E-EM	increasing	flat	decreasing	decreasing
Ulmus	alata	winged elm	H-D-AM	flat	decreasing	flat	flat
Ulmus	americana	American elm	H-D-AM	increasing	decreasing	decreasing	decreasing
Ulmus	rubra	slippery elm	H-D-AM	flat	hump-shaped	decreasing	decreasing

APPENDIX TABLE 2
SELECT ECOLOGICAL CHARACTERISTCS FOR EACH SPECIES.

Species	Shade Tolerance: Low (L), Medium (M), High (H)	Leaf Morphology (Broadleaf, B; Coniferous, C) and Phenology (Deciduous, D; Evergreen, E)	Mammal Uses	Bird Uses
Abies amabilis	H	CE	Yes	Yes
Abies balsamea	H	CE	Yes	Yes
Abies concolor	M	CE	Yes	Yes
Abies grandis	M,H	CE	Yes	Yes
Abies lasiocarpa	L	CE	Yes	Yes
Acer negundo	M	BD	Yes	Yes
Acer rubrum	M	BD	Yes	Yes
Acer saccharinum	M	BD	Yes	Yes
Acer saccharum	H	BD	Yes	Yes
Betula alleghaniensis	M	BD	Yes	Yes
Betula papyrifera	L	BD	Yes	Yes
Calocedrus decurrens	H	CE	Yes	Yes
Carpinus caroliniana	H	BD	Yes	Yes
Carya alba	L	BD	Yes	Yes
Carya cordiformis	L	BD	Yes	Yes
Carya glabra	M	BD	Yes	Yes
Carya ovata	M	BD	Yes	Yes
Celtis laevigata	H	BD	Yes	Yes
Celtis occidentalis	H	BD	Yes	Yes
Fagus grandifolia	H	BD	Yes	Yes
Fraxinus americana	M	BD	Yes	Yes
Fraxinus nigra	M	BD	Yes	Yes
Fraxinus pennsylvanica	M	BD	Yes	Yes
Juglans nigra	H	BD	Yes	Yes
Juniperus monosperma	M	CE	Yes	Yes
Juniperus occidentalis	L	CE	Yes	Yes
Juniperus osteosperma	L	CE	Yes	Yes
Juniperus virginiana	M	CE	Yes	Yes
Larix laricina	L	CD	Yes	Yes
Larix occidentalis	L	CD	Yes	Yes
Liquidambar styraciflua	M	BD	Yes	Yes
Liriodendron tulipifera	L	BD	Yes	Yes
Lithocarpus densiflorus	H	BE	Yes	Yes
Maclura pomifera	M	BD	Yes	Yes
Magnolia virginiana	M	BE	Yes	Yes
Nyssa sylvatica	H	BD	Yes	Yes
Ostrya virginiana	H	BD	Yes	Yes
Oxydendrum arboreum	H	BD	Yes	Yes
Picea engelmannii	H	CE	Yes	Yes
Picea glauca	M	CE	Yes	Yes
Picea mariana	M	CE	Yes	Yes

APPENDIX TABLE 2 continued

Picea rubens	H	CE	Yes	Yes
Pinus banksiana	L	CE	Yes	Yes
Pinus contorta	M	CE	Yes	Yes
Pinus echinata	L	CE	Yes	Yes
Pinus edulis	M	CE	Yes	Yes
Pinus elliottii	L	CE	Yes	Yes
Pinus monophylla	M	CE	Yes	Yes
Pinus palustris	L	CE	Yes	Yes
Pinus ponderosa	L	CE	Yes	Yes
Pinus resinosa	M	CE	Yes	Yes
Pinus rigida	L	CE	Yes	Yes
Pinus strobus	M	CE	Yes	Yes
Pinus taeda	M	CE	Yes	Yes
Pinus virginiana	L	CE	Yes	Yes
Platanus occidentalis	L	BD	Yes	Yes
Populus balsamifera	L	BD	Yes	Yes
Populus grandidentata	L	BD	Yes	Yes
Populus tremuloides	M	BD	Yes	Yes
Prunus serotina	L	BD	Yes	Yes
Pseudotsuga menziesii	M	CE	Yes	Yes
Quercus alba	M	BD	Yes	Yes
Quercus chrysolepis	H	BE	Yes	Yes
Quercus coccinea	L	BD	Yes	Yes
Quercus ellipsoidalis	L	BD	Yes	Yes
Quercus falcata	M	BD	Yes	Yes
Quercus laurifolia	H	BE	Yes	Yes
Quercus macrocarpa	L	BD	Yes	Yes
Quercus muehlenbergii	M	BD	Yes	Yes
Quercus nigra	M	BE, BD	Yes	Yes
Quercus phellos	M	BD	Yes	Yes
Quercus prinus	M	BD	Yes	Yes
Quercus rubra	M	BD	Yes	Yes
Quercus stellata	H	BD	Yes	Yes
Quercus velutina	M	BD	Yes	Yes
Robinia pseudoacacia	L	BD	Yes	Yes
Salix nigra	L	BD	Yes	Yes
Sassafras albidum	H	BD	Yes	Yes
Taxodium distichum	M	CD	Yes	Yes
Thuja occidentalis	H	CE	Yes	Yes
Thuja plicata	H	CE	Yes	Yes
Tilia americana	M	BD	Yes	Yes
Tsuga canadensis	H	CE	Yes	Yes
Tsuga heterophylla	H	CE	Yes	Yes
Tsuga mertensiana	H	CE	Yes	Yes
Ulmus americana	M	BD	Yes	Yes
Ulmus rubra	H	BD	Yes	Yes

APPENDIX TABLE 3
SELECT ECOSYSTEM SERVICES PROVIDED BY EACH SPECIES.

Species	Wood products: Paper (P), unfinished wood products (UP), building material (B), finished wood products (FP)				Traditional uses	Ornamental uses	Fuelwood	Protection against erosion (E), wind (W) or both (EW)			Rehabilitation	Food products	Oils and other non-timber and non-food products	General services
	P	UP	B	FP				E	W	EW				
Abies amabilis	X	X	X	X	X	X				X			X	X
Abies balsamea	X	X	X		X	X			X				X	X
Abies concolor	X	X	X		X	X	X	X			X			X
Abies grandis	X	X	X		X	X		X			X		X	X
Abies lasiocarpa	X	X	X	X	X	X			X		X		X	X
Acer negundo		X		X	X	X	X		X			X		X
Acer rubrum	X	X	X	X	X	X	X				X	X		X
Acer saccharinum		X	X	X	X	X		X			X	X		X
Acer saccharum			X	X	X	X	X		X		X	X		X
Betula alleghaniensis	X	X	X	X	X	X	X				X	X	X	X
Betula papyrifera	X		X	X	X	X	X	X			X	X	X	X
Calocedrus decurrens		X	X	X	X	X		X			X			X
Carpinus caroliniana		X		X	X							X	X	X
Carya alba	X	X	X	X			X	X				X		X
Carya cordiformis			X	X	X		X	X			X	X		X
Carya glabra				X	X		X				X	X		X
Carya ovata				X	X	X	X	X			X	X		X
Celtis laevigata		X		X	X	X	X					X	X	X
Celtis occidentalis				X	X	X	X				X		X	X
Fagus grandifolia		X	X	X	X		X					X	X	X
Fraxinus americana		X		X	X	X					X		X	X
Fraxinus nigra		X	X	X	X	X						X		X
Fraxinus pennsylvanica		X		X	X	X			X		X			X
Juglans nigra				X	X	X					X	X	X	X
Juniperus monosperma		X	X		X		X	X			X	X	X	X
Juniperus occidentalis		X	X		X	X		X			X	X	X	X
Juniperus osteosperma		X	X	X	X		X						X	X
Juniperus virginiana		X	X	X	X				X		X		X	X
Larix laricina	X	X	X	X	X		X				X		X	X
Larix occidentalis	X	X	X		X		X	X			X	X	X	X
Liquidambar styraciflua		X	X	X	X	X	X				X	X	X	X

APPENDIX TABLE 3 continued

Species	Wood products: Paper (P), unfinished wood products (UP), building material (B), finished wood products (FP)				Traditional uses	Ornamental uses	Fuelwood	Protection against erosion (E), wind (W) or both (EW)			Rehabilitation	Food products	Oils and other non-timber and non-food products	General services
	P	UP	B	FP				E	W	EW				
Liriodendron tulipifera	X	X	X	X	X	X	X				X	X	X	X
Lithocarpus densiflorus		X	X		X			X			X	X	X	X
Maclura pomifera		X			X	X				X	X	X	X	X
Magnolia virginiana		X		X	X						X			X
Nyssa sylvatica	X	X	X	X	X	X						X		X
Ostrya virginiana		X		X	X	X					X			X
Oxydendrum arboreum	X			X	X	X						X		X
Picea engelmannii	X	X	X	X	X	X			X		X			X
Picea glauca	X	X	X		X						X			X
Picea mariana	X	X	X		X						X		X	X
Picea rubens	X		X	X	X						X	X		X
Pinus banksiana	X	X	X		X						X			X
Pinus contorta	X	X	X		X		X				X			X
Pinus echinata	X	X	X		X	X		X			X			X
Pinus edulis	X	X	X		X	X	X				X	X	X	X
Pinus elliottii		X	X		X			X			X		X	X
Pinus monophylla		X	X		X		X					X	X	X
Pinus palustris		X	X								X		X	X
Pinus ponderosa		X	X	X	X	X		X			X			X
Pinus resinosa	X	X	X		X	X	X							X
Pinus rigida					X						X		X	X
Pinus strobus		X	X	X	X						X			X
Pinus taeda	X	X	X		X	X				X	X			X
Pinus virginiana	X	X	X		X		X				X		X	X
Platanus occidentalis	X	X	X	X	X	X	X		X		X			X
Populus balsamifera	X	X	X		X			X			X			X
Populus grandidentata	X	X	X	X	X		X				X	X		X
Populus tremuloides	X	X	X	X	X	X	X	X			X			X
Prunus serotina			X	X	X						X	X	X	X
Pseudotsuga menziesii	X	X	X	X	X	X	X		X				X	X
Quercus alba		X	X	X	X	X	X				X			X

APPENDIX TABLE 3 continued

Species	Wood products: Paper (P), unfinished wood products (UP), building material (B), finished wood products (FP)				Traditional uses	Ornamental uses	Fuelwood	Protection against erosion (E), wind (W) or both (EW)			Rehabilitation	Food products	Oils and other non-timber and non-food products	General services
	P	UP	B	FP				E	W	EW				
Quercus chrysolepis				X	X	X	X	X						X
Quercus coccinea			X			X								X
Quercus ellipsoidalis			X	X	X						X			X
Quercus falcata		X	X		X	X						X		X
Quercus laurifolia	X				X	X	X							X
Quercus macrocarpa		X	X	X	X						X	X		X
Quercus muehlenbergii		X	X	X	X	X	X					X		X
Quercus nigra		X	X		X									X
Quercus phellos	X		X	X	X	X		X						X
Quercus prinus		X	X	X	X									X
Quercus rubra	X	X	X	X	X	X	X				X			X
Quercus stellata		X	X		X	X		X			X		X	X
Quercus velutina		X	X	X	X						X		X	X
Robinia pseudoacacia	X	X		X	X	X	X			X	X	X	X	X
Salix nigra	X	X	X	X	X			X			X		X	X
Sassafras albidum		X		X	X		X				X	X	X	X
Taxodium distichum		X	X	X	X	X					X		X	X
Thuja occidentalis	X	X	X	X	X	X							X	X
Thuja plicata	X	X	X	X	X	X		X			X		X	X
Tilia americana	X	X		X	X	X								X
Tsuga canadensis	X	X	X		X	X							X	X
Tsuga heterophylla	X	X	X	X	X	X					X		X	X
Tsuga mertensiana	X	X	X		X	X		X						X
Ulmus americana		X		X	X	X	X			X				X
Ulmus rubra		X			X	X								X

APPENDIX TABLE 4 - CORRELATIONS AND VARIANCE INFLATION FACTORS FOR EACH SPECIES (SEE CHAPTER 1 FOR MORE INFORMATION).

Tree species	N & S correlation	ViF-N	ViF-S	Confidence
Abies amabilis	0.63	1.7	4.4	Medium Low
Abies balsamea	0.48	2.3	3.2	Medium High
Abies concolor	0.78	3.0	2.7	Low
Abies grandis	0.86	3.9	6.6	Low
Abies lasiocarpa	0.74	2.7	3.0	Low
Acer Negundo	0.14	1.1	1.4	High
Acer rubrum	0.60	1.8	1.7	Medium High
Acer saccharinum	0.27	1.1	1.4	High
Acer saccharum	0.67	2.4	2.3	Medium Low
Betula alleghaniensis	0.70	2.4	2.5	Medium Low
Betula papyrifera	0.42	1.8	2.0	Medium High
Calocedrus decurrens	0.83	7.5	10.3	Low
Carpinus caroliniana	0.23	1.1	1.8	High
Carya alba	0.14	1.0	1.4	High
Carya cordiformis	0.06	1.1	1.2	High
Carya glabra	0.40	1.2	1.5	Medium High
Carya ovata	0.07	1.2	1.1	High
Celtis laevigata	0.38	1.2	1.2	High
Celtis occidentalis	0.17	1.5	1.6	High
Fagus grandifolia	0.76	3.0	2.4	Low
Fraxinus americana	0.54	1.8	1.5	Medium High
Fraxinus nigra	0.62	2.2	3.0	Medium Low
Fraxinus pennsylvanica	0.45	1.3	1.6	Medium High
Juglans nigra	0.08	1.3	1.2	High
Juniperus monosperma	0.78	4.2	3.4	Low
Juniperus occidentalis	0.93	8.0	12.2	Low
Juniperus osteosperma	0.71	2.4	2.1	Low
Juniperus virginiana	0.30	1.3	1.4	High
Larix laricina	0.66	2.7	3.8	Medium Low
Larix occidentalis	0.90	6.2	6.2	Low
Liquidambar styraciflua	0.37	1.3	1.4	High
Liriodendron tulipifera	0.41	1.2	1.9	Medium High
Lithocarpus densiflorus	0.57	1.7	2.6	Medium High
Maclura pomifera	0.36	1.5	1.5	High
Magnolia virginiana	0.34	1.4	1.6	High
Nyssa sylvatica	0.43	1.3	1.9	Medium High
Ostrya virginiana	0.36	1.5	1.4	High
Oxydendrum arboreum	0.28	1.3	1.5	High
Picea engelmannii	0.84	3.4	3.5	Low
Picea glauca	0.43	2.0	1.8	Medium High
Picea mariana	0.55	2.7	4.0	Medium High
Picea rubens	0.84	3.8	3.6	Low

APPENDIX TABLE 4 continued

Pinus banksiana	0.61	3.5	2.5	Medium Low
Pinus contorta	0.76	2.4	3.2	Low
Pinus echinata	0.16	1.2	1.0	High
Pinus edulis	0.78	3.2	2.6	Low
Pinus elliottii	0.46	1.4	1.8	Medium High
Pinus monophylla	0.58	1.8	2.8	Medium High
Pinus palustris	0.45	1.8	1.8	Medium High
Pinus ponderosa	0.90	6.5	5.9	Low
Pinus resinosa	0.53	2.4	2.0	Medium High
Pinus rigida	0.66	2.3	2.2	Medium Low
Pinus strobus	0.59	2.2	1.8	Medium High
Pinus taeda	0.32	1.2	1.3	High
Pinus virginiana	0.44	1.4	1.6	Medium High
Platanus occidentalis	0.38	1.3	1.6	High
Populus balsamifera	0.62	2.6	4.3	Medium Low
Populus grandidentata	0.57	2.3	2.4	Medium High
Populus tremuloides	0.60	1.8	2.2	Medium High
Prunus serotina	0.33	1.2	1.3	High
Pseudotsuga menziesii	0.65	1.9	3.0	Medium Low
Quercus alba	0.16	1.0	1.1	High
Quercus chrysolepis	0.41	3.0	4.3	Medium High
Quercus coccinea	0.37	1.3	1.6	High
Quercus ellipsoidalis	0.41	2.1	2.5	Medium High
Quercus falcata	0.36	1.2	1.3	High
Quercus laurifolia	0.41	1.2	1.4	Medium High
Quercus macrocarpa	0.59	2.2	2.3	Medium High
Quercus muehlenbergii	0.31	1.1	1.6	High
Quercus nigra	0.26	1.2	1.2	High
Quercus phellos	0.37	1.2	1.3	High
Quercus prinus	0.45	1.3	1.9	Medium High
Quercus rubra	0.42	1.6	1.4	Medium High
Quercus stellata	0.13	1.2	1.1	High
Quercus velutina	0.13	1.1	1.1	High
Robina pseudoacacia	0.18	1.1	1.1	High
Salix nigra	0.29	1.3	1.3	High
Sassafras albidum	0.28	1.1	1.4	High
Taxodium distichum	0.54	1.4	1.6	Medium High
Thuja occidentalis	0.61	3.0	3.4	Medium Low
Thuja plicata	0.41	1.2	3.8	Medium High
Tilia americana	0.40	1.4	2.1	Medium High
Tsuga canadensis	0.78	2.9	2.6	Low
Tsuga heterophylla	0.34	1.2	2.9	High
Tsuga mertensiana	0.58	2.6	7.0	Medium High
Ulmus americana	0.25	1.1	1.3	High
Ulmus rubra	0.08	1.3	1.2	High

NOTES

Foliage of *Acer saccharum.* Photo by Paul Wray, Iowa State University, Bugwood.org, 0008379.

Flowers of *Pinus resinosa.* Photo by Joseph O'Brien, USDA Forest Service, Bugwood.org, 5031004.

Trees are integral for the continued health and survival of wildlife, plants, fungi, soil microbes, and invertebrates that constitute the biodiversity of a forest. Trees also provide the raw materials for many human uses, are enjoyed by visitors to the nation's many federal and state forests and parks, and protect our environment by contributing to air and water purification and climate regulation.

Air pollution from human activities can be harmful to trees. The deposition of nitrogen- and sulfur-containing acidifying and fertilizing air pollutants remains many times above pre-industrial levels in some parts of the United States. These pollutants can increase the vulnerability of trees to other stressors such as pest and disease outbreaks, drought, and freezing weather. Additionally, changes in soil chemistry and damage to essential mycorrhizal communities from air pollution can alter or diminish the growth and survival rates of trees.

This report summarizes the habitats, wildlife uses, ecosystem services, and potential impacts from air pollution on 94 tree species from across the contiguous United States. Landowners, foresters, wildlife biologists, urban planners and others seeking information on these topics can refer to this guide for reforestation, afforestation or other restoration activities.

This report is the first of a three-volume series concerning air pollution impacts to trees (Volume 1), lichens (Volume 2) and herbaceous understory species (Volume 3).