Ailanthus altissima

INTRODUCTORY

Photo courtesy of David J. Moorehead, Forestry Images

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FEIS ABBREVIATION:
AILALT

NRCS PLANT CODE [302]:
AIAL

COMMON NAMES:
tree-of-heaven
tree of heaven
stink tree
Chinese sumac

TAXONOMY:
The scientific name of tree-of-heaven is *Ailanthus altissima* (Mill.) Swingle. It is in quassia (Simaroubaceae) [71,104,105,114,136,137,158,199,214,250,280,317,323,324], a family of mostly tropical woody plants [285].

SYNONYMS:
Ailanthus altissima forma *erythrocarpa* (Carr.) Schneider [267]
Ailanthus glandulosa Desf. [153]

LIFE FORM:
Tree

DISTRIBUTION AND OCCURRENCE

SPECIES: Ailanthus altissima

GENERAL DISTRIBUTION:
Tree-of-heaven is native to Taiwan and central China, where it occurs from 22° to 34° N in latitude [304]. It is nonnative in North America, where it is distributed from British Columbia, southern Ontario and Quebec, and Maine south to Florida, Texas, southern California, and Mexico [105,158,208,297,328]. Tree-of-heaven spread in North America apparently followed 3 introductions from China. It was 1st imported to Pennsylvania in 1784 as an ornamental [71,93,139,287,288,312]. A 2nd introduction occurred in New York in 1820, where tree-of-heaven was again planted as an ornamental [62]. Both eastern introductions were from English stock imported from China. Tree-of-heaven was commercially available in eastern nurseries by 1840. The 3rd introduction was in California during the Gold Rush of the mid-1800s. Chinese immigrating to work in the gold fields and in construction of the transcontinental railroad brought tree-of-heaven to California, probably because of the tree's medicinal and cultural importance in their homeland (see Other Uses) [139,288]. Tree-of-heaven was first planted in Hawaii in 1924 [321]. Plants database provides a map of tree-of-heaven's distribution in the United States.

A century after the North American introductions, tree-of-heaven is still most common in its initial centers of distribution: the Northeast and California. In the eastern United States, it is most invasive from New England south to the mid-Atlantic states [93,233]. Tree-of-heaven is frequently found in the upper Midwest. It is weakly invasive in the middle and southern Great Plains [114,258]. It is uncommon south of North Carolina in the Southeast and in the South [82,233,324], but it is spreading in the South. By a 2008 estimate, tree-of-heaven was present in over 214,000 acres (86,600 ha) of southern forests [208]. In the West, tree-of-heaven is common throughout much of California and is locally common in Oregon and Washington [93,137]. In California, it is invasive in the Bay Area, the Central Valley, and in foothill counties with a history of gold mining [139,153]. It grows along waterways in the Pacific Northwest, including banks of the Snake and Columbia rivers [137]. In the Southwest it invades riparian zones and mesic canyons [287].

Tree-of-heaven has established in temperate climates throughout the world. Its earliest introductions may have been in Japan and Korea, where it is probably not native [191]. It was introduced in Europe in the 1700s and has become widespread there [86,163,288]. Using seed from European trees, introductions in Argentina, Australia, and Africa followed [139,140]. Kowarik [172] views human settlements as centers of distribution for tree-of-heaven, with roads providing the migration routes.

HABITAT TYPES AND PLANT COMMUNITIES:
Tree-of-heaven is most common in urban areas [141]. It varies from a minor to important component of wildland vegetation in its North American range. Because of its scattered and disjunct distribution in North America, tree-of-heaven occurrence is not well documented for all plant communities where it may occur [211]. The following descriptions are not restrictive, but they include plant communities where tree-of-heaven is a known invader.

In wildlands of the **East** and **Midwest**, tree-of-heaven is a common component in oak-hickory (*Quercus*-*Carya* spp.) and maple-birch-beech (*Acer*-*Betula*-*Fagus* spp.) forests [286]. It has infested hundreds of acres of oak-hickory forest in Shenandoah National Park, Virginia [195,303]. In eastern oak-hickory forests, tree-of-heaven is frequently associated with native black locust (*Robinia pseudoacacia*), an early-successional species, and nonnative Norway maple (*Acer platanoides*) and princesstree (*Paulownia tomentosa*) [45,46,117,227,249,314]. Other early-seral associates are black cherry (*Prunus serotina*), gray birch (*Betula populifolia*), sweetgum (*Liquidambar styraciflua*), and eastern redcedar (*Juniperus virginiana*) [117]. In oak-hickory woodlands of Gettysburg National Military Park, Pennsylvania, tree-of-heaven is associated with overstory with black oak (*Q. velutina*), red oak (*Q. rubra*), scarlet oak (*Q. coccinea*), mockernut hickory (*C. tomentosa*), and bitternut hickory (*C. cordiformis*). Nonnative invasives other than tree-of-heaven include the understory species Japanese barberry (*Berberis thunbergii*) and multiflora rose (*Rosa multiflora*). Late-successional native understory species include white ash (*Fraxinus americana*), black cherry, sassafras (*Sassafras albidum*), and boxelder (*Acer negundo*) [91]. In silver maple (*Acer saccharinum*)-white oak-red oak forests of Ohio, tree-of-heaven occurs with American elm (*Ulmus americana*), hickory, black locust, black walnut (*Juglans nigra*), and black cherry [67]. Tree-of-heaven stands have been observed in estuaries and freshwater marshes on the Atlantic seaboard. Tree-of-heaven dominated the overstory of the estuary at Jug Bay Wetlands Sanctuary, Maryland [164].

On the **Georgia piedmont**, tree-of-heaven is an important species in early-successional loblolly pine (*Pinus taeda*)-black oak-white oak forests. Native flowering dogwood (*Cornus florida*) and yellow-poplar (*Liriodendron tulipifera*) and nonnative Chinese privet (*Ligustrum sinense*) and winged elm (*U. alata*) are common associated species [55].

Tree-of-heaven is most common in riparian, valley, and foothill communities of **California**. In riparian areas of southern California, tree-of-heaven frequently associates with Fremont cottonwood (*Populus fremontii*), California sycamore (*Platanus racemosa*), mule-fat (*Baccharis salicifolia*), and poison-oak (*Toxicodendron diversilobum*). A 1990 to 1992 survey in Chino Hills State Park showed 15% frequency for tree-of-heaven, with its geographic range and "vigor" increasing over the study period [162].

Tree-of-heaven is invasive in riparian zones of the **Southwest** [135,266,273,281]. In the middle Rio Grande Basin of New Mexico, it occurs in Fremont cottonwood-Rio Grande cottonwood-sandbar willow (*P. deltoides* var. *wislizenii*-*Salix exigua*) bosques along with nonnative, invasive Siberian elm (*U. pumila*) and white mulberry (*Morus alba*) [97]. Tree-of-heaven has invaded arroyos of the Sandia National Laboratory, New Mexico; nonnative Siberian elm and saltcedar (*Tamarix ramosissima*) and native Apache plume (*Fallugia paradoxa*) and fourwing saltbush (*Atriplex canescens*) are common associated species. On upland sites it occurs in Colorado pinyon-oneseed juniper (*Pinus edulis*-*Juniperus monosperma*) stands with Gambel oak (*Quercus gambelii*) and Siberian elm [203].

The following vegetation classifications describe plant communities in which tree-of-heaven is a dominant or indicator species:

Appalachians and Northeast

- tree-of-heaven forest alliance. Occurs in the Appalachians, the Piedmont, the Interior Low Plateau, eastern Kentucky, the Ozark and Ouachita mountains, and probably other areas in the northeastern United States. Common in disturbed areas, along roadsides, urban abandoned lands, and on limestone clifftops [223].

California

- locally dominant in riparian woodlands [204]

North Carolina

- dominant and indicator species in edge communities developing on logged sites near oak-loblolly pine forest [205]

Pennsylvania

- eastern white pine (*Pinus strobiformis*)-gray birch-tree-of-heaven shale scree slopes in the Delaware Water Gap National Recreation Area [241]
- occasional codominant in the black cherry-yellow-poplar-red maple (*Acer rubrum*)-white ash forest alliance of Valley Forge National Historical Park [246]
- modified successional forest at Allegheny Portage Railroad National Historic Site; this forest is dominated by "weedy, early successional species" [243]

Tennessee

- tree-of-heaven forest alliance in Great Smoky Mountains National Park [290]

Virginia

- successional mixed shrublands on the Petersburg National Battlefield [237] and in Richmond National Battlefield Park; sweetgum may codominate [238]
- locally dominant on disturbed calcareous forest on the Petersburg National Battlefield [237]
- successional tree-of-heaven forest in Colonial National Historical Park [236] and Appomattox Court House National Historical Park [234]

BOTANICAL AND ECOLOGICAL CHARACTERISTICS

SPECIES: Ailanthus altissima

GENERAL BOTANICAL CHARACTERISTICS:

Botanical description: The following description of tree-of-heaven provides characteristics that may be relevant to fire ecology and is not meant for identification. Keys for identification are available (for example, [71,104,105,135,199,317,324]). Billings and others [28] provide a key for identifying tree-of-heaven and other eastern trees in winter.

Tree-of-heaven is deciduous. It may reach 60 to 70 feet (18-21 m) in height, 80 feet (24 m) in crown width, and 20 feet (6 m) in trunk diameter at maturity [8,71,105,308]. The champion tree as of 2010 was in Virginia; it reached 55 feet (17 m) in height, 48 feet (15 m) in spread, and 20 feet in diameter [8]. Tree-of-heaven may be shrubby when suppressed beneath the canopy or pruned regularly [104]. It has smooth, thin bark and a straight bole. Branches are brittle and self-pruning [71,104,105,308]. There are 2 branch types: long and short shoots. Long shoots are sterile and may extend 18 feet (5 m), while short shoots bear flowers and rarely reach more than 18 inches (46 cm) long [63]. The large, malodorous leaves are pinnately compound, with prominent glands on the back of each leaflet. Leaflets range from 15 to 41 in number, and total leaf length may reach 3 feet (1 m) [71,104,105,308]. Leaf stipules have nectaries that excrete sugars [30].

Most flowers are unisexual, but some trees may have perfect flowers [328]. The inflorescence is a 4- to 7-inch (10-20 cm) long panicle with 6- to 8-mm long flowers. Staminate flowers have a strong odor that is objectionable to humans. Fruits are one-seeded, dry schizocarps with wings. They are 1 to 2 inches (2.5-5 cm) long and propeller-shaped, resembling maple (*Acer* spp.) fruits [71,104,135,136,147,149,250,317]. The fruits grow in clusters; a fruit cluster may contain hundreds of seeds [163]. Seeds average 0.2 × 1.0 inch (0.6 × 0.25 cm) in area [9] and 27 mg in mass [201].

Roots are shallow and wide-spread [211]. Young trees have a taproot and several large lateral roots [230,248,249], although the taproot may diminish with age [211]. Ramets do not have taproots. In dry, rocky soil or beneath pavement, tree-of-heaven grows long, horizontal roots that do not branch until reaching a more favorable substrate [230,248,249]. Roots near the trunk thicken with age, serving as storage organs. Deep roots send out smaller roots that grow near the soil surface; stem shoots generally sprout from these shallow roots. Most roots occur in the upper 18 inches (46 cm) of soil [211].**Stand structure:** Tree-of-heaven typically occurs in clumps, although it may form rows along streams, roads, and fences, and occasionally it grows as widely spaced, single stems. Clumping can result from an even-aged seedling establishment or from clonal expansion through root sprouting [249]. Open-grown colonies may eventually become dense by sprouting. Davis [61] observed a half-acre (0.2 ha) stand in Kentucky that had 32 stems. Stands subject to infrequent control measures may develop into even-aged thickets [77,151]. Untreated stands self-thin, so the stand tends to become even-aged over time. Two years after tree-of-heaven harvest in Pennsylvania, density of tree-of-heaven sprouts averaged 17,860 two-year-old sprouts/acre (mean height=9 feet (3 m)), with 10,019 one-year-old sprouts/acre (mean height=2 feet (0.6 m)). After 3 years many of the sprouts had died, so dead stems were more common than live stems [151]. Sprouts volunteering in closed-canopy understories remain suppressed and few in number. For example, Hunter [148] reported scattered, single-stemmed trees-of-heaven—rather than thickets—in the understory of a mixed-evergreen forest in northern California. On the Jefferson National Forest, Virginia, tree-of-heaven had a clumped distribution on low-leave shelterwood sites and a random distribution on clearcuts and high-leave shelterwood sites [47].

Over- and understory trees-of-heaven. Photo © John M. Randall, The Nature Conservancy.

There are few clues as to tree-of-heaven's original growth habit in China, where it is native. As valued ornamentals, mature trees-of-heaven in China are often pruned to aesthetically pleasing, single-stemmed forms, with sprouts harvested for firewood and medicinal uses [140,249].

Life span: Tree-of-heaven is typically short-lived, with life spans ranging from 30 to 70 years [85,163,211]. Cloning from root sprouts can extend ramet life hundreds of years [148]. Sprouts from the first tree-of-heaven in North America, planted in Philadelphia's Bartram Botanical Garden 1784, still existed at the turn of the 21st century [45].

Physiology: Tree-of-heaven has several physiological adaptations that probably aid in its establishment and spread. It appears to be allelopathic [64,184,190,206,209,217]. Chemical extracts from the leaves, bark, roots, and seeds have inhibited germination and growth of other plant species in the laboratory [129,130,131,184]. Allelopathic chemicals (ailanthone and other compounds identified in these sources: [9,10,64,206]) are concentrated in roots and in young trees, with young ramets producing more toxins than older trees [129,184].

Open-grown trees-of-heaven are highly efficient at photosynthesis [30,33,34,122,194,207] and store large quantities of photosynthate in stems and roots [30,33,34,194,207]. Foliar nectaries excrete photosynthates during growth and flower initiation [31]. A study in a Mediterranean region of Spain found that even after 5 years of once- or twice-yearly cuttings, leaves from new tree-of-heaven sprouts showed higher rates of stomatal conductance in spring than leaves of uncut trees-of-heaven. The authors conjectured that regulating stomatal conductance helps sprouting trees-of-heaven grow quickly [54].

Tree-of-heaven is drought tolerant [87]. In Nava-Constan and others' [54] experiment in Spain, trees-of-heaven showed more positive leaf water potentials than native flowering ashes (*Fraxinus ornus*). Conflicting information states tree-of-heaven is intolerant [108] or tolerant [18,87] of flooding. Further observations and field studies are needed to resolve this conflict.

Tree-of-heaven is highly tolerant of most industrial pollutants [207,253], although it is sensitive to ozone pollution [111]. In a highly polluted area of Armenia, tree-of-heaven showed the least damage and best growth of 8 urban tree species (Derojan 1958 cited in [93]).

Raunkiaer [254] **life form:**
Phanerophyte
Geophyte

SEASONAL DEVELOPMENT:
Leaf expansion typically begins in early spring, with trees-of-heaven flowering and dispersing pollen in late spring [148,211]. Tree-of-heaven's seasonal development may sometimes be slower than associated woody species. On Nantucket Island, Massachusetts, tree-of-heaven was noted in a 1912 publication as "nearly naked" in early June, when other tree species had already leafed out [26]. Seed ripening begins in late summer and continues through fall. Schizocarps usually persist on female trees through winter [198,211], but they may disperse anytime from October through the next spring [211]. In New York, schizocarp clusters usually broke off in fall, while individual schizocarps often persisted until spring [230].

Tree-of-heaven phenology by state and region		
Area	Event	Time
Arkansas	flowers	April-May
	fruits	September-spring [147]
California	flowers	May
	seeds ripen	September-October [149]
Carolinas	flowers	late May-early June
	fruits	July-October [250]
Florida	flowers	spring [324]
Illinois	flowers	June-July [214]
New Jersey	seeds disperse	October-early April; about half disperse October-November [181]
New Mexico	flowers	June-July [199]
New York	seeds germinate	June
	seeds disperse	October-April [249]
Texas	flowers	April-May
	fruits	September-October[308]
West Virginia	flowers	June-July [280]
	fruits	late October-early April; most dispersal October-November [180]
Great Plains	flowers	mid-May-June [114]
New England	fruits	mid-August-mid-October [267]
Pacific Northwest	flowers	June-July [137]
Southeast	flowers	May-July [82]

Seasonally, tree-of-heaven's allelopathic toxins are greatest in spring and decline as the growing season progresses [311]. See Impacts and Control for more information on allelopathy.

REGENERATION PROCESSES:
Tree-of-heaven reproduces by sprouting and from seed [71,135,312]. Both methods are important to tree-of-heaven's reproductive success and invasiveness [87,249].

Vegetative regeneration: Tree-of-heaven sprouts from the roots, root crown, and bole [93,145,163,185,211,275]. Although reproduction from seed is not rare, sprouting is its most common method of regeneration [163]. In Ithaca, New York, 58% of 1-year-old, excavated tree-of-heaven stems were root sprouts and 42% were seedlings [230]. Young trees that are cut to the root crown before bark becomes thick and corky often sprout from both the root crown and roots [163,275]. Bole damage promotes root, root crown, and bole sprouting [148,163]. Death or injury of the main stem usually results in prolific root sprouting [211]. Top-growth damage is not necessary for root sprouting to occur, however. Even as seedlings, trees-of-heaven produce horizontal roots capable of sprouting [45]. Except in the rose (Rosacea) [96,269] and willow (Salicaceae) (review by [327]) families, root sprouting without top damage is uncommon in woody species (reviews by [65,120]), but it is a powerful regeneration strategy for species employing it. Roots have more nutrient- and photosynthate-storing capacity than rhizomes, conferring better protection from aboveground disturbances such as fire [159,160] and show a stronger sprouting response after top-kill [65,120]. Tree-of-heaven sprouts are more likely to persist in low-light conditions, such as within a subcanopy, than are seedlings [85].

With tree-of-heaven's spreading root system, root sprouts may appear as far as 50 to 90 feet (15-27 m) from the parent stem [151,163,275]. During drought, tree-of-heaven translocates stem water into roots and begins stem die-back. Die-back may be extensive during extended droughts, but tree-of-heaven typically survives drought by sprouting from the roots when there is sufficient water to support new growth. Sprouting after frost die-back is common in tree-of-heaven's northern limits [93].

On the Himalayan foothills of India, trees-of-heaven with root crown girths between 12 and 16 inches (30 and 40 cm) showed greatest root sprout production following road construction. Trees in the largest-diameter class did not produce sprouts [179].

Breeding system: Tree-of-heaven is mostly dioecious. Rarely, either bisexual trees or trees with both bisexual and unisexual flowers are found [71,104,148,211,328].

As with most species with wind-dispersed seed, tree-of-heaven appears to have a relatively uniform genetic system, with most diversity occurring among rather than within populations [94,249]. Because most North American tree-of-heaven populations originated from 3 introductions [71,139,288,312] (see General Distribution), they may be less genetically diverse than native Asian populations. A comparison of tree-of-heaven seedlings germinated from seed collections from 5 locations across the United States and 5 locations across China showed significant differences in height growth (*P*=0.01), root:shoot ratios (*P*=0.05), and leaf area (*P*=0.05) among seedlings from the United States and Chinese seedlings. Populations from the United States were taller, allocated relatively less biomass to roots than stems, and had greater leaf areas than Chinese populations [94]. In a common garden study comparing seedlings of populations within the United States, Feret and others [95] found California populations were significantly taller than eastern populations (P=0.01). Seed width and biomass were correlated with latitude (t=0.96), with northern populations having the widest, heaviest seeds. Feret [93] found some tree-of-heaven seed and seedling growth characteristics of provenances from the eastern United States and California appeared random, and they were not correlated (nor appeared best adapted) to site or geographic location. He reported significant differences between North American and Chinese tree-of-heaven provenances for seed and seedling characteristics. Contrary to expectations, there was no evidence of inbreeding depression in North American provenances compared to native Chinese provenances [93].

Pollination: A variety of nectar- and pollen-feeding insects pollinate tree-of-heaven [5,227]. Although disagreeable to humans, the strong odor of the flowers attracts honey bees, flies, beetles, and other insects [5,211]. A study in suburban Chicago found large bee species were the primary pollinators; the bees visited both male and female trees. Flies, especially those attracted to fetid-smelling flowers, visited female trees-of-heaven often but were probably less efficient pollinators than the bees [5].

Seed production: Tree-of-heaven produces many small, light seeds [77,92]. In a mixed-hardwood forest in Connecticut, tree-of-heaven averaged 4.84 inches (12.3 cm) DBH in size at first seed production. It had greatest average seed production of 10 overstory trees across 2 years; its seed production was 40 times that of the next highest-producing species. For parent trees of 12 inches (30 cm) DBH, tree-of-heaven produced means of 400,000 seeds in 1994 and 2 million seeds in 1995. Tree-of-heaven and white ash had the longest seed dispersal distances of the 10 trees, but most tree-of-heaven seeds fell within 20 feet (5 m) of the parent trunk. Tree-of-heaven seed rain spiked at 2,500 seeds/m^2/12-inch DBH parent tree, showing greatest seed output of all 10 tree species. The authors concluded that tree-of-heaven is "exceptionally fecund even in competitive, closed-canopy forest stands" [198].

Flower, fruit, and seed production begins early in development. Six-week-old seedlings have flowered in the greenhouse [92], and 1-year-old seedlings and 2-year-old root sprouts have been observed in the field with fruit [148,163,275]. Trees in California produce viable seed by 10 years of age [148]. Heaviest seed production is from 12 to 20 years of age [211]. In France, which has a climate similar to California, 1.6- to 3.3-foot long (0.5-1 m) root sprouts produced seeds [30].

Mature female trees may produce several hundred flower clusters in a year. Hunter [148] reports that over 5 years, production of a female tree in Martinez, California, averaged 150, 183, 219, 439, and 56 clusters/year. An individual flower contains hundreds of seeds, so individual trees may produce >325,000 seeds/year [30,148]. Illick and Brouse [151] estimated that a small, 12-inch-diameter (30 cm) tree in Pennsylvania produced over a million seeds in 1 year. Most seeds are viable, even those that overwinter on the tree and disperse in spring [148,328]. Repeated top-kill reduces seed production [211].

Seed dispersal: The winged schizocarps are easily and widely dispersed by wind [53,82,163,170,180,181,261]. Entire schizocarp clusters may break off and disperse as a unit. In Ithaca, New York, tree-of-heaven schizocarp clusters often fell and dispersed in clumps in fall, resulting in patches of closely related seedlings. Over the winter, seeds dispersed individually as the fruit clusters disintegrated [230]. A New Jersey study found large, heavy tree-of-heaven seeds traveled as far as light tree-of-heaven seeds [181]. In Seoul, South Korea, tree-of-heaven seed traveled a maximum of 7.5 times the width of the parent crown [53]. On Staten Island, New York, tree-of-heaven seedlings volunteered on a restored landfill site planted to native woody species. A year after restoration plantings, tree-of-heaven count on fifty 10 × 30 meter plots totaled 65 seedlings, the 6th highest among 32 taxa that regenerated on the site. Distance to the nearest seed-bearing tree-of-heaven was 299 feet (70 m) [257]. In West Virginia, seeds from trees on steep slopes dispersed farther downhill than seeds on gentle or flat sites (P<0.001) [157]. Matlack [201] reported the following dispersal patterns for tree-of-heaven schizocarps collected in Delaware:

Dispersal characteristics for tree-of-heaven schizocarps in the laboratory. Data are means (SD) [201].		
Rate of descent	Lateral movement in still air	Lateral distance in a 10 km/hr breeze (estimated)

0.56 m/sec (0.09)	0.87 m (0.10)	111.6 m

Distance traveled was significantly greater than that of fruits or seeds of 37 other wind-dispersed species ($P<0.05$) [201].

Water [174,232,261] and machinery [232] also disperse tree-of-heaven schizocarp clusters and seeds. A study in Germany found that for cities with rivers, the rivers were a secondary dispersal agent that moved wind-dispersed tree-of-heaven seed that landed in rivers from urban to distant rural areas [261]. Tree-of-heaven seeds dispersed in and along the Monogahela River of West Virginia showed germination rates similar to those of seeds on land (94% germination, $P=0.006$). Seeds from trees growing near water were most likely to land in and be transported directly by water; water-borne seeds stayed buoyant about 1.5 days [157]. In a pine-oak community in West Virginia, Marsh [196] observed that tree-of-heaven established near roads and on tree harvest sites; machinery may have helped disperse seeds onto these sites.

Seed banking: Seeds retain dormancy for less than a year, so tree-of-heaven does not build up a persistent seed bank [87,149,176]. Tree-of-heaven establishes transient soil seed banks from on- and off-site parent sources [328]. Dobberpuhl [75] found viable tree-of-heaven seed in a soil seed bank in Tennessee, although there were no trees-of-heaven in the mixed-oak overstory [75]. A West Virginia field study showed tree-of-heaven's seed bank averaged 48.5 seeds/m² in soils of rural woodlands and grasslands [180]. In soils from a New York City park, tree-of-heaven establishment in the greenhouse averaged 27.7 emergents/m² in soils collected at 0- to 2-inch (5 cm) depths and 14.3 emergents/m² in soils collected at 2- to 4-inch (5-10 cm) depths [168].

Germination and seedling establishment: Tree-of-heaven does not have exacting germination requirements, although germination may proceed slowly. Tree-of-heaven embryos are dormant, and stratification improves germination rates [19,112,148,211]. Seeds dispersed in the field likely overwinter before germinating. Hunter [148] reported a 30% germination rate for seeds that overwintered on parent trees and dispersed in spring. A study in Spain found tree-of-heaven schizocarp size was not correlated with rates of either germination or seedling establishment [66].

Substrate is seemingly not important for successful tree-of-heaven germination. Seed can germinate and establish in highly compacted soil [249] and in pavement cracks [291]. The seed is salt tolerant. Studies of several eastern hardwood species found roadside salt did not appreciably affect tree-of-heaven germination; native oak and birch seeds were far more adversely affected by road salt [27].

Immersion, light intensity, and presence of litter affect tree-of-heaven germination rates. Short immersion in water may enhance tree-of-heaven germination. A German study showed 87% mean germination for tree-of-heaven seed lots soaked for 3 days, 53% germination for unsoaked seed lots, and 32% germination for seed lots soaked for 20 days [174]. Tree-of-heaven may germinate in low light, but resulting emergents are unlikely to establish [85]. Litter has both negative and positive effects on germination. In eastern deciduous forests, oak (*Quercus* spp.) leaf litter delayed tree-of-heaven germination and increased seedling mortality, but it did not affect subsequent biomass of surviving tree-of-heaven seedlings [89]. Litter may have positive effects on tree-of-heaven germination and establishment by reducing interference from herbaceous species [90].

Although seed production is prolific, tree-of-heaven seedling establishment is infrequent on many sites [148,198,232]. Despite tree-of-heaven's large seed output in a Connecticut site (see Seed production) [198], seedling establishment was low. The authors concluded that tree-of-heaven required canopy gaps to establish in otherwise closed-canopy forests [198]. Dry climate may limit tree-of-heaven recruitment in the Great Plains and the western United States [93,232]. Even so, tree-of-heaven has successfully expanded its range through seed spread and seedling establishment [166,245,257,262], and establishment from seed appears more common than generally indicated in the literature [163,275]. In a root excavation study in New York, Knapp and Canham [166] found initial tree-of-heaven recruitment in gaps in an eastern hemlock (*Tsuga canadensis*) forest was from off-site seed, not root sprouts. In the Black Rock Forest of New York, tree-of-heaven likely established from seed after a blowdown and subsequent logging and herbicide spraying in the 1960s. By the early 2000s, an oak-hickory forest had redeveloped; tree-of-heaven was present but not reproducing under the canopy [17]. Tree-of-heaven also established from seed on harvested oak forests on the Jefferson National Forest, Virginia [47].

Kostel-Hughes and others [169] surmised that tree-of-heaven is best adapted to establishment in early succession, when litter layers are lacking or shallow. In the greenhouse, tree-of-heaven seeds showed no significant differences in germination rate when placed on top of the litter, buried shallowly (0.4-0.8 inch (1-2 cm)), or buried deeply (2 inches (5 cm)). However, seedling height ($P<0.001$), aboveground biomass ($P<0.03$), and root:shoot ratio ($P<0.001$) decreased with increasing burial depth of seeds. The authors noted that some oak seedlings lifted up and hence reduced litter as they emerged, and some tree-of-heaven seedlings emerged from those reduced-litter microsites. Based on studies by Facelli and Pickett [90], they conjectured that a portion of tree-of-heaven's invasive success may be due to its ability to allocate more biomass to shoots than roots when emerging in deep litter. Although less root biomass means less ability to absorb water and nutrients, tree-of-heaven may compensate by allocating more resources to roots later in the growing season [169].

Two studies show tree-of-heaven germinated more slowly but had greater total emergence than native tree species. In the greenhouse, tree-of-heaven germinated later than native sweetgum, American sycamore, and nonnative princesstree [215,216]. In West Virginia field experiments in mixed-hardwood communities, stratified tree-of-heaven seeds showed better emergence across several sites compared to yellow-poplar seeds ($P<0.0001$). Tree-of-heaven showed no preference for north- vs. south-facing slopes, while yellow-poplar establishment was better on north slopes. Comparing tree-of-heaven germination across sites, there was no significant difference in emergence on clearcut and selective-cut sites (~80%), but tree-of-heaven emergence was significantly lower in intact forest (<20%) compared to logged sites ($P=0.001$) [171].

In Seoul, South Korea, tree-of-heaven seedlings established south of parent plants due to seed dispersal by prevailing northwest winds. The tree is nonnative there and is considered an urban weed because of its prolific seedling establishment and spread [53].

Growth: The tree-of-heaven embryo is well equipped for rapid growth. Although it lacks an endosperm, it has 2 large cotyledons with stored oils that provide energy for emergence and early growth [104,175,197,211,328]. Whether initial regeneration is accomplished from seed or by cloning, tree-of-heaven usually grows quickly on favorable sites. It is among the fastest-growing trees in North America [166,244,259]. Both the common name (tree-of-heaven) and the scientific name (*Ailanthus*, sky-tree) refer to the species' ability to attain height quickly [71,308]. In the eastern United States, tree-of-heaven's annual growth rate averaged 6 feet (1.8 m) for bole sprouts, 2.7 feet (0.8 m) for root sprouts, and 1.3 feet (6.5 m) for seedlings [151]. Root sprouts in California may exceed 3.5 feet (1 m) in their 1st year [148]. Tree-of-heaven sprouts generally grow faster than seedlings, although seedlings often grow 3.3 to 6.6 feet (1-2 m) in their 1st year [211]. A fact sheet states that tree-of-heaven may reach 80 feet (20 m) tall and 6 feet (2 m) in diameter in 10 years [87]. Two years after planting in a New York City common garden, height growth of tree-of-heaven seedlings was at least 3 times that of native sweetgum (*Liquidambar styraciflua*) and nonnative Norway maple seedlings [230].

Mean seedling stem and root growth of 3 tree species after 3 years in a common garden [230]

Species	Stem length (cm)		Lateral root length (cm)	
	Mean	Minimum/ maximum	Mean	Minimum/ maximum
tree-of-heaven	82.2	31/ 172	114.4	53/ 200
sweetgum	51.0	12/ 77	23.8	2/ 46
Norway maple	36.1	23/ 49	33.2	14/ 66

Even with its rapid height growth, tree-of-heaven may concentrate early growth in roots. A greenhouse study showed tree-of-heaven seedlings had higher root:shoot ratios than native sweetgum, American sycamore (*Platanus* *occidentalis*), and nonnative princesstree seedlings; this was true whether tree-of-heaven was grown in disturbed soils that lacked organic matter or in soils collected from mixed-hardwood forests left undisturbed for ≥50 years [215,216].

Tree-of-heaven saplings may average 3 feet (1 m) of height growth per year for at least 4 years [1]. Relatively rapid growth continued into the pole size class in New York: pole-sized trees-of-heaven growing in canopy gaps gained 2 to 4 mm of radial growth annually, the highest rate of 6 tree species measured (the other 5 species were native) [166]. In a New England survey, trees-of-heaven reached 33 to 49 feet (10-15 m) in height and 3.7 to 4.3 inches (9-11 cm) DBH in 30 years [1], and a 55-year-old tree on the George Washington National Forest, West Virginia, had a DBH of 15 inches (37 cm) [247]. In North America, growth is usually fastest for trees-of-heaven in California's mediterranean climate. Trees in the Central Valley have an 8-month growing season, so those trees may be 35 to 63 feet (10-20 m) tall by 12 to 20 years of age [149]. In Pennsylvania, growth slowed greatly after age 20 to 25, with height increases of 3 inches (7.6 cm) or less per year [151].

Once established, tree-of-heaven density increases by root sprouting. One ramet may occupy over 1 acre (0.4 ha). Sprout growth slows to several centimeters per year if sprouts become shaded [149]. In West Virginia, Kowarik [173] reported an average growth rate of 0.36 foot/year (0.11 m) for tree-of-heaven sprouts suppressed in the understory of an oak (*Quercus* spp.)-sugar maple forest.

Browsing and/or unfavorable site conditions can reduce tree-of-heaven growth. Cattle, deer, and small rodent browsing may slow tree-of-heaven establishment and growth [229]. Browsing effects may vary with animal density and by site. In a New York oak-hickory woodland, Forgione [99] found no significant differences in tree-of-heaven seedling establishment on open plots and plots with white-tailed deer exclosures. On Mediterranean islands of Spain, France, and Greece, tree-of-heaven clones on intermittent streams were significantly smaller than those on old fields and roadsides (P=0.022), and clones at relatively high elevations were larger than those at low elevations (P=0.004) [292].

SITE CHARACTERISTICS:

Tree-of-heaven occurs on a variety of sites in North America, ranging from very poor to very productive. In Ithaca, New York, it was positively correlated with urban sites where rooting space was limited and other species could not establish (P=0.05) [230,248]. In contrast, soils in the Central Valley of California, where tree-of-heaven is also common, are nutrient-rich and productive [128]. Little information is available on tree-of-heaven's original habitats in China; it is common there as a cultivated tree [139,140,249].

Tree-of-heaven has been characterized as "the most adaptable and pollution tolerant tree available" for urban plantings [74]. Highly tolerant of industrial gases, dust, and smoke, it is common on disturbed urban sites, especially alleyways, roadsides, and fence rows [71,105,114,214,324]. It is generally more common in urban, suburban, and rural than wild environments [57,181]. In wildlands, tree-of-heaven occurs on floodplains and other disturbed sites, riparian areas, open woodlands and forests, and rock outcrops [41,114,137,164,280,312]. After Hurricane Camille, tree-of-heaven was positively associated with debris avalanche chutes in Virginia [145]. It was most frequent on roadsides in an oak-hickory forest in West Virginia [141]:

Tree-of-heaven frequency on different sites within a West Virginian oak-hickory forest [141]	
Habitat	Frequency (%)
roadsides	26
streams	19
mature forest	13
open forest	7
railroad rights-of-way	6
residential	6
trails	3

old fields	0
other	20

Tree-of-heaven has invaded rare sugar maple-sweet birch (*Betula lenta*) rock outcrop communities in High Mountain Park Preserve, New Jersey [76]. In the Southwest, it invades canyons, arroyos, and riparian zones, including the banks of the Rio Grande [6,203].

Soils and topography: Tree-of-heaven tolerates a wide range of soil moisture conditions [82,211]. In oak-hickory woodland of Sussex County, New Jersey, it grows in permanently swampy, ridgebottom soils of an abandoned Boy Scout camp [18]. At the other extreme, tree-of-heaven tolerates dry, rocky soils and extended drought, aided by its large, water-storing roots. Even seedlings show drought tolerance, often volunteering in pavement cracks and other dry sites [113,293]. In Kansas, mature trees-of-heaven and eastern redcedars showed better survivorship during the "Dust Bowl" drought of 1934 than associated tree species [278].

Tree-of-heaven also tolerates a wide range of soil nutrient levels and other soil conditions. Best growth occurs on nutrient-rich, loamy soils, but tree-of-heaven establishes in nutrient-poor soils [93,163,211,328]. Tree-of-heaven tolerates all soil textures [216]. It often establishes on disturbed sites lacking topsoil [164]. In the Appalachians and the Northeast, the tree-of-heaven alliance occurs on limestone clifftops and on calcareous soils [223,237]. On reclamation sites, trees-of-heaven tolerated acid mine spoils better than calcareous spoils and grew on low-phosphorus soils [211]. Tree-of-heaven can grow on soils as low as 4.1 pH, in soluble salt concentrations of 0.25 mmhos/cm, and in soils with phosphorus levels as low as 1.8 ppm [245]. In a mixed-deciduous forest on Staten Island, New York, tree-of-heaven had the highest importance value and relative density of all tree species on neutral soils but was absent on acidic soils (pH ≤5.1) [186]. It tolerates compacted soils [230].

Topography on tree-of-heaven sites may be flat, rolling, or very steep, with tree-of-heaven potentially occurring on all aspects. Tree-of-heaven's spreading root system permits establishment and growth on steep inclines and cliff faces [7]. In Massachusetts, tree-of-heaven is reported on upland, interior wetland, and coastal areas [200]. On the floodplain of the Raitan River, New Jersey, tree-of-heaven was not important on low floodplains (<11 feet (3.3 m) above sea level), but it ranked in the top one-third of species' importance values on upper floodplains [101]. In a slippery elm-white ash woodlot in Ohio, tree-of-heaven presence on forest-roadside edges was similar on north- and south-facing exposures [85]. In Inwood Hill Park, a mixed-hardwood wildland site in Manhattan, tree-of-heaven was most common on west-facing ridges [98]:

Density of tree-of-heaven seedlings and saplings in a wildland park in New York City [98]		
	Seedlings (<2 cm DBH)	Saplings (2-10 cm DBH)
Valley forest	55	9
East ridge	113	38
Ridgetops	0	50
West ridge	363	211

Climate: Tree-of-heaven is most common in temperate climates, in both North America and its native China. It tolerates minimum temperatures of -38 °F (-39 °C) and maximum temperatures of 110 °F (45 °C). Mean annual precipitation ranges from 0.55 to 158 inches (14-4,010 mm) across tree-of-heaven's North American and Chinese distributions. Tree-of-heaven tolerates drought of several month's duration [3].

Climate within tree-of-heaven's North American distribution ranges from subtropical and wet in Florida; arid in the Great Plains and western United States; to cold and wet in the Northeast. It occurs in USDA hardiness zones 4 to 8 [144]. Annual mean maximum and minimum temperatures within its North American range are 15^{o} F and 97 ^{o}F (-9 ^{o}C and 36 ^{o}C). It tolerates as much as 90 inches (2,290 mm) of mean annual precipitation in the Appalachian

Mountains as little as 14 inches (360 mm) of annual precipitation and 8 months of drought in the western United States. Large, water-storing roots confer drought tolerance [140], although tree-of-heaven may not reach maximum growth on dry sites. On an "extremely dry" site on the George Washington National Forest, Pomp [247] observed that trees-of-heaven in an oak-pine forest only reached the canopy in riparian areas and on logged sites. Because seedlings are not cold resistant, extreme cold and prolonged snow cover restrict its occurrence to lower slopes in mountainous regions. Tree-of-heaven may be able to colonize in cold regions that experience several successive years of mild climate [211]. It is the only species in its genus that tolerates cold climates [140].

Elevation: Tree-of-heaven is reported from the following elevations in the western United States:

Elevational range of tree-of-heaven in 3 western states	
State	Elevation
California	<6,600 feet [135,149]
New Mexico	4,500-7,000 feet [199]
Utah	790-5,900 feet [317]

It grows from 4,900 to 5,900 feet (1,500-1,800 m) elevation in China [304].

SUCCESSIONAL STATUS:
Tree-of-heaven is mostly an early-successional species in forest ecosystems [257], and it is most common on disturbed sites throughout its North American range. Starting with a few stems along roadsides or woodland edges, tree-of-heaven may encroach into meadows, woodlands, and open forests [163,250,275]. In invades open eastern hardwood forests, sometimes sharing the canopy with native hardwoods into late succession [280]. In 1986, tree-of-heaven and princesstree were classified as the 2 most successful nonnative trees invading hardwood forests in the Northeast [227], where they often established after tree harvest or other disturbances [211,257]. Huebner [141] found tree-of-heaven was positively associated with either highly disturbed or urban counties in West Virginia ($P<0.05$). In mixed oak-pine forests on the Cumberland Plateau of Tennessee, tree-of-heaven occurred on early-seral sites disturbed by tornados or construction, on prescribed burns, and along roads, pipelines, and ditches [20]. It is an early-seral, subcanopy or canopy species characteristic of the black cherry-yellow-poplar-red maple-white ash forest association in the Delaware Water Gap National Recreation Area, Pennsylvania [242]. It sometimes codominates in successional black cherry-yellow-poplar-red maple-American ash forests in Valley Forge National Historical Park, North Carolina [246]. Tree-of-heaven is associated with eastern white pine/rhododendron (*Rhododendron* spp.) second growth on the Carl Sandberg Home National Historic Site, North Carolina [318].

Tree-of-heaven often establishes after logging [247]. It was most common on logged sites in oak-hickory forests on the Jefferson National Forest, especially on skid trails [47]. In another study in oak-hickory on the Jefferson National Forest, tree-of-heaven was most common on clearcut plots; less common on low-leave shelterwood plots; and least common on high-leave shelterwood plots, respectively [46]. On the George Washington National Forest, 71% of the sites where tree-of-heaven was found had previously been logged; the other sites were along roads [247]. Tree-of-heaven density was much greater in recently logged mixed-hardwood stands than mature forest stands in south-central Virginia; only yellow-poplar was more abundant on logged sites [49].

Tree-of-heaven density (stems/ha) in mixed-hardwood in Virginia [49]		
	Recently logged stands	Mature stands
Seedlings	10,138 (6,692)*	320 (147)
Saplings	318 (112)*	244 (212)
*Significant difference between logged and mature stands ($P\leq0.05$)). Seedlings are <0.5 m tall; saplings are ≥0.5 m tall but <10 cm DBH.		

Tree-of-heaven may also establish in early-seral shrubfields [238] and old fields. In Rock Creek, Washington, DC, tree-of-heaven is a common component in an Allegheny blackberry-multiflora rose (*Rubus allegheniensis-Rose multiflora*) shrubland [289]. In Maryland, it grew with black locust and princesstree on a farm abandoned 14 years previously [21]. A review of studies conducted in the Hutcheson Memorial Forest Center, New Jersey—which has the largest set of old-field permanent plots established for the longest time in the United States—determined that tree-of-heaven typically established 2 to 4 years after field abandonment [221]. Tree-of-heaven may also occur in middle old-field succession. It was not reported in initial old-field succession in Pennsylvania, but was found in old fields that were abandoned approximately 20 years before. In year 20, hardwoods were forming a 23- to 39-foot (7-12 m) canopy over the herbs. Tree-of-heaven was common in these young hardwood stands [161].

Capacity for rapid growth, mycorrhizal associations [143], and—in eastern hardwood forests with dense white-tailed deer populations—relative unpalatability compared to associated hardwood species [99,166] may confer advantages to tree-of-heaven during early succession. A West Virginia study found mycorrhizal colonization of tree-of-heaven seedling roots was significantly greater on a steep, barren slope (62%) compared to a forest site adjacent to a stream (38%) ($P<0.002$). The authors suggested that tree-of-heaven established more successfully on open sites due to this trend [143].

Tree-of-heaven is moderately shade tolerant [16,47,108,196] and may persist into late forest succession, typically at low levels in the subcanopy until a canopy gap allows further invasion or expansion [47,166,173,328]. In urban oak-hickory woodlots of central Massachusetts, tree-of-heaven was present only on disturbed sites and did not invade intact woodlands [25]. Gaps created by storms [145,325], hemlock woolly adelgid [228] or gypsy moth defoliation, windstorms [145], or possibly fire [20] may facilitate tree-of-heaven invasion. In Nelson County, Virginia, tree-of-heaven occurred in 2 of 4 avalanche debris chutes surveyed 10 years after Hurricane Camille, but it did not occur in adjacent, undisturbed hardwood forest [145]. Xi and others [325] found tree-of-heaven was invasive following hurricanes in mixed oak-sweetgum piedmont forests of Duke Forest, North Carolina.

Once established in a gap, tree-of-heaven may grow into the forest canopy [166]. It occurs in mature upland hardwood forests of northern New Jersey (review by [60]). It also occurs in upland, mature mixed oak-pignut hickory (*Carya glabra*) forest in the Black Rock Forest of New York. However, it is most common on disturbed sites, especially near reservoirs [17]. On the Cumberland Plateau of Tennessee, tree-of-heaven was a minor species in gaps within a sugar maple-red maple-yellow-poplar forest. Tree-of-heaven density averaged 4.7 saplings/ha, which represented <0.1 % relative density of tree species in forest gaps [127]. In Ohio, tree-of-heaven apparently invaded canopy gaps in an old-growth slippery elm-white ash woodlot from adjacent secondary stands. Its density was similar in secondary and old-growth stands, although density decreased with distance from roads. In a 2002 survey, tree-of-heaven had increased in all size classes compared to a 1980 survey. Density of trees-of-heaven in the canopy had increased threefold, but subcanopy and smaller trees had the largest increases. Survivorship of sprouts from 2001 to 2002 averaged 42% [85].

Tree-of-heaven does not regenerate from seed under its own canopy [17,85,173]. The seedlings are intolerant of deep shade [34,99,118,119,173], and tree-of-heaven does not photosynthesize efficiently in shade [33,34] at any age. A West Virginia survey found 100% mortality of seedlings in the understory of an oak (*Quercus* spp.)-sugar maple forest [170]. Seed plantings in New Jersey showed best tree-of-heaven establishment in an open-grown herbaceous community, intermediate establishment in an eastern redcedar/little bluestem (*Schizachyrium scoparium*) woodland, and least establishment in a closed-canopy oak-hickory forest. Mortality rate was over 90% for tree-of-heaven seed planted under a closed-canopy oak-hickory forest [99]. In the Black Rock Forest of New York, tree-of-heaven likely established from seed after a blowdown and subsequent logging and herbicide spraying in the 1960s. By the early 2000s, an oak-hickory forest had redeveloped; tree-of-heaven was present but not reproducing under the canopy [17].

Tree-of-heaven is generally uncommon in closed-canopy, late-successional hardwood forests lacking gaps [25,34,328]. However, trees-of-heaven on forest edges may spread into the surrounding understory by root sprouts, which may grow slowly but persist with shade [132,148,173]. Without canopy-opening disturbance, under-canopy sprouts remain suppressed and grow slowly [118,148,173]. Tree-of-heaven was scarce in a midsuccessional, mixed oak-hickory forest in southern Illinois, with 2.5 stems/ha, relative dominance of 0.1%, and a low importance value of 0.4% [188].

Little information was available on successional patterns of tree-of-heaven where it is native. A study on coal mine spoils in Shanxi, China, found tree-of-heaven dominated late stages of spoil recovery, after the grassland and shrubland stages had succeeded to a tree-of-heaven woodland [189].

FIRE EFFECTS AND MANAGEMENT

SPECIES: Ailanthus altissima

FIRE EFFECTS:

Immediate fire effect on plant: Fire top-kills tree-of-heaven [185,274,299]. Because tree-of-heaven has thin bark [71,104,105,308], live tissues beneath the bark probably scorch easily.

Postfire regeneration strategy [277]:
Tree with root suckers, a sprouting root crown, and adventitious buds
Geophyte, growing points deep in soil
Initial off-site colonizer (off site, initial community)
Secondary colonizer (on- or off-site seed sources)

Fire adaptations and plant response to fire:
Tree-of-heaven sprouts after top-kill by fire [103,274,299]. It sprouts from the roots, root crown, and/or bole after other aboveground damage (see Vegetative regeneration); so any of these sprouting strategies may occur after top-kill by fire, with root sprouting most likely. Anecdotal accounts suggest that tree-of-heaven is "able to sprout vigorously when...burnt" [185] and persists in some areas "despite...burning" [309]. The fire studies below provide other evidence of tree-of-heaven's ability to survive fire. It is likely—given its large, extended root system [211,230,248,249] and its ability to root sprout and show increased growth rates under fertilization [124]—that tree-of-heaven can flourish in postfire environments. As one of the fastest-growing trees in North America [166,244,259], tree-of-heaven may outcompete native woody species for the open spaces and flush of nutrients that often occur after fire. Further studies on the fire ecology of tree-of-heaven are needed.

Tree-of-heaven can also establish from seed after fire. Although this was documented in only 1 study as of 2010 [196], the potential for postfire tree-of-heaven seedling establishment seems high. Its seed disperses easily by wind [82,163,275], and tree-of-heaven is known to establish from seed in early-successional, disturbed environments other than burns [34,163,166,228] (see Successional Status).

Fire studies: Tree-of-heaven sprouted after the Chavez and Rio Grande Complex wildfires in Rio Grande cottonwood (*Populus deltoides* subsp. *wislizeni*) communities along the Middle Rio Grande, New Mexico [299]. It also sprouted after top-kill following 2 separate automobile-ignited fires at the same location in San Diego County, California. It was the only green vegetation in the burned area in postfire year 1 [103]. In mixed oak-pine forests of the Cooper State Forest and Wildlife Management Area, Tennessee, tree-of-heaven grew on sites burned under prescription [20].

Studies on the George Washington National Forest, West Virginia [196,247], and Tar Hollow State Forest, Ohio

[11,39,150] show that prescribed burning or thinning and burning may increase tree-of-heaven abundance over prefire or pretreatment levels.

One year after late March prescribed fires on the George Washington National Forest, tree-of-heaven increased on 2 of 3 study sites compared to prefire abundance; these increases were not considered significant except on the upper portion of 1 site, where tree-of-heaven increased exponentially. All postfire tree-of-heaven regeneration was from seedling establishment. The community was a Table Mountain pine-pitch pine-chestnut oak-scarlet oak/mountain-laurel (*Pinus pungens*-*P. rigida*-*Quercus prinus*-*Q. coccinea/Kalmia latifolia*) forest [196] where fire had been excluded for 81 years. Elevation ranged from 1,880 to 2,782 feet (573-848 m) [247]. Plots on the 3 study sites (Heavener Mountain, Dunkle Knob, and Brushy Knob) were distinguished by aspect and elevation (above or below 2,400 feet (732 m)) [196]. Fire management objectives were to reduce fuel loads, reduce understory shrubs and trees, and increase wildlife forage in groundlayer vegetation. Fire conditions were [196]:

Fire weather conditions for prescribed March fires in a pine-oak forest on the George Washington National Forest [196]		
	Heavener Mountain	Dunkle Knob
Date	25 March 2009	29 March 2009
Air temperature	18-27 °C	11-21 °C
Relative humidity	32-50%	29-76%
Wind direction	mostly SW; SE in late afternoon	NW and SE
Windspeed	1.6-9 km/h	2-10 km/h

Tree-of-heaven was not present on Brushy Knob sites either before fire or in postfire year 1. It increased significantly in density (*P*=0.032) and importance value (*P*=0.007) on the upper-northeast section of Heavener Mountain compared to adjacent unburned areas. In postfire year 1, tree-of-heaven seedlings also established on unburned portions of Heavener Mountain and on burned, southwest aspects of Heavener Mountain and on Dunkle Knob. Seedling establishment in the upper-northeast section of Dunkle Knob was about 4.5 times greater than that of the other sites combined [196].

Tree-of-heaven abundance before and after the prescribed March fires [196]						
Site	Density (stems/ha)		Importance value*		Basal area (m^2/ha)	
	prefire	postfire year 1	prefire	postfire year 1	prefire	postfire year 1
Heavener Mountain, lower-northeast section, seedlings	0.00	0.00	0.00	0.00		
Heavener Mountain, upper-northeast section, seedlings	0.00	277.78	0.00	0.93		
Dunkle Knob, lower-southwest section, seedlings	0.00	277.78	0.00	0.56		
Dunkle Knob, upper-southwest section, seedlings	0.00	833.33	0.00	2.04		
Dunkle Knob, upper-southwest section, overstory	2.22	2.22	0.56	0.56	0.09	0.09
Dunkle Knob, upper-northeast section, seedlings	277.78	6,388.89**	0.23	14.78**		
*Importance value=(relative density + relative basal area)/2						

**Significant difference between years (P<0.05). Cells are blank where information is not available.

Since tree-of-heaven seedlings occurred on both burned and unburned areas of Heavener Mountain, Marsh [196] suggested that tree-of-heaven increases on burned sites were not due to fire alone. Increases were not correlated with aspect or elevation, so those factors apparently did not affect tree-of-heaven establishment. Tree-of-heaven was the only nonnative tree species on the site. Overall, the prescribed fires did not significantly increase abundance of nonnative invasive shrubs or herbs. Fuel loads were significantly less in postfire year 1 compared to prefire loads (P=0.0052). Shrub density was reduced 19% to 21%. Forbs and ferns were more abundant after than before fire on sites where fire behavior was "most severe" [196].

In a follow-up study on Dunkle Knob, Pomp [247] found that on most sites, tree-of heaven had returned to prefire levels by postfire year 3. Tree-of-heaven seedlings were producing root sprouts, suggesting that tree-of-heaven density would soon increase beyond prefire levels. Dunkle Knob is an "extremely dry" site. Tree-of-heaven abundance was positively correlated with either moist areas where fire severity was low, areas with a history of logging, or with an open canopy. Outside of riparian zones, tree-of-heaven abundance in postfire year 3 was not significantly associated with fire severity. In contrast to Marsh's [196] earlier findings, Pomp [247] found tree-of-heaven abundance was positively correlated with increasing elevation (R^2=0.37).

In a mixed-oak forest in Tar Hollow State Forest, thin-and-burn treatments apparently promoted tree-of-heaven compared to thin-only and burn-only treatments, although the results could be due to pretreatment vegetation composition. Plots were thinned in fall and winter to a density of 19.5 m^2/ha; burning was conducted the following March and April [39]. All plots were in white-tailed deer exclosures [11,39]. The following summer, tree-of-heaven was the 4th most common species among 26 woody plants in thin-and-burn treatments [11]. It did not occur on thin-only or burn-only plots [39]. By postfire year 3, tree-of-heaven was "widely distributed" on thin-and-burn plots, with mean density of 17.1 stems/100 m^2 compared to 5.8 stems/100 m^2 in thin-only plots and 0.6 stem/100 m^2 in burn-only plots. Seedling establishment was the assumed method of postfire establishment due to the scarcity of trees-of-heaven before fire [150]. Hutchinson and others [150] concluded that tree-of-heaven's high posttreatment occurrence on thin-and-burn plots was due to its higher pretreatment density on thin-and-burn units (18 trees/100 m^2) compared to thin-only (8 trees/100 m^2) and burn-only (1 tree/100 m^2) units.

FUELS AND FIRE REGIMES:

- **Fuels**
- **Fire regimes**

Fuels: Few quantitative measurements of tree-of-heaven litter, aboveground biomass, or leaf area indices were available as of 2010, so the ability of tree-of-heaven to alter fuel loads of native ecosystems is unclear. Fuel studies are needed on tree-of-heaven.

Although tree-of-heaven has large, finely divided leaves [71,104,105,250,308], its leaves may not contribute more to total leaf litter load than the leaves of many associated tree species in deciduous forests. In Connecticut, mean depth of tree-of-heaven litter alone was similar to litter depth averages under most associated tree species in the mixed-deciduous forest (about 0.8 inch (2 cm)). Oaks contributed most biomass to the litter layer, which was sampled in July and August [167]. Tree-of-heaven litter may decay more rapidly than litter of many associated deciduous trees. In Spain, tree-of-heaven litter decayed faster than native English elm (*Ulmus minor*) (P=0.01) [50]. A study in Maryland found that in first-order streams, litter of native trees contained more lignin and decayed more than twice as slowly as tree-of-heaven litter (P<0.0001) [284].

Tree-of-heaven may contribute important amounts of woody debris to fuel loads in invaded areas. It frequently sheds broken branches in all size classes. The brittle branches break easily even when green, and branch die-back from drought or frost is common [148,151]. In riparian areas by the Middle Rio Grande in New Mexico, tree-of-heaven and other nonnative, invasive woody species were implicated as the main source of heavy fuel loads, with altered hydrologic regimes likely partially responsible for nonnative invasions. The author states "excess woody materials consisting of exotic species and dead and downed fuels of all species are the primary fuels of catastrophic fires" in riparian bosques on the Middle Rio Grande. The community was a Rio Grande cottonwood bosque before nonnative invasions. Contributions to total fuel load were not broken down by species, but saltcedar and Russian-olive (*Elaeagnus angustifolia*) apparently contributed more woody fuels than tree-of-heaven [152].

Flammability of tree-of-heaven was not reported in the literature as of 2010. Its growth habit and stand structure suggest that once ignited, tree-of-heaven stands probably burn easily. The large, finely divided leaves provide a surface-to-volume ratio favorable for ignition and burning. Dibble and others [69] conducted laboratory tests comparing fuel characteristics of nonnative invasive species with those of cooccurring native species. They found no significant difference between tree-of-heaven and quaking aspen in either total heat release or effective heat of combustion of leaves and twigs [69].

Fire regimes: The fire ecology of tree-of-heaven in its native China was not available in English-language literature as of this writing (2010). Tree-of-heaven is common in long-settled, densely populated regions of China. Although its pharmacological use is mentioned in early Chinese writings, Hu [140] reported that Chinese-language references to its historical ecology were lacking as of 1979. Tree-of-heaven's ability to sprout from photosynthate-storing roots and establish from off-site, wind-dispersed seed; its extraordinarily rapid growth rate; early age of seed production; and its appearance in early successional plant communities in North America (see Botanical and Ecological Characteristics) all suggest that tree-of-heaven has been subject to evolutionary pressures of frequent, stand-replacement disturbances. Whatever fire regimes tree-of-heaven's native ecosystems were subject to in the past, tree-of-heaven's ability to establish on disturbed sites and persist into late succession suggests that it is well-adapted to survive under a wide range of fire regimes. See the Fire Regime Table for information on fire regimes of North American plant communities in which tree-of-heaven may occur.

In North America, tree-of-heaven has invaded ecosystems where, for the most part, historic fire regimes are no longer functional (for example, see [12,239,313,322]). Dodge [76] speculates that fire exclusion in rare sugar maple-sweet birch communities of High Mountain Park Preserve, New Jersey, may have fostered establishment of tree-of-heaven. However, only a few fire studies have been conducted on tree-of-heaven to date (2010), so it is impossible to assess how—or whether—tree-of-heaven has altered historic fire regimes in North America.

FIRE MANAGEMENT CONSIDERATIONS:
Due to its ability to sprout from the roots, fire is not recommended for tree-of-heaven control [147,163,275]. Limited fire studies [11,20,39,150,196,247] and anecdotal information [185] suggest that fire may increase tree-of-heaven density. Tree-of-heaven is capable of rapid growth even under adverse conditions, and it grows best with increased nutrient and open canopy conditions [14,34,124,163,166,173,228], which fire can create. Pomp [247] recommends removing tree-of-heaven from the understory prior to prescribed burning or logging.

Whenever there is a nearby tree-of-heaven seed source, disturbed sites require monitoring and follow-up treatments to prevent tree-of-heaven invasion and spread. Roadways, skid trails, and other disturbed grounds are corridors for tree-of-heaven invasion [40,46]. By disturbing soil, fire suppression efforts may lead to postfire establishment if there are trees-of-heaven nearby. Fire-fighting machinery can also disperse tree-of-heaven seed. Washing equipment before it enters fire suppression zones can help prevent tree-of-heaven invasion on burned sites. Postfire monitoring and treatment of skid trails is also advised [232].

Preventing invasive plants from establishing in weed-free burned areas is the most effective and least costly management method. This may be accomplished through early detection and eradication, careful monitoring and follow-up, and limiting dispersal of invasive plant propagules into burned areas. General recommendations for preventing postfire establishment and spread of invasive plants include:

- Incorporate cost of weed prevention and management into fire rehabilitation plans
- Acquire restoration funding
- Include weed prevention education in fire training
- Minimize soil disturbance and vegetation removal during fire suppression and rehabilitation activities
- Minimize the use of retardants that may alter soil nutrient availability, such as those containing nitrogen and phosphorus

- Avoid areas dominated by high priority invasive plants when locating firelines, monitoring camps, staging areas, and helibases
- Clean equipment and vehicles prior to entering burned areas
- Regulate or prevent human and livestock entry into burned areas until desirable site vegetation has recovered sufficiently to resist invasion by undesirable vegetation
- Monitor burned areas and areas of significant disturbance or traffic from management activity
- Detect weeds early and eradicate before vegetative spread and/or seed dispersal
- Eradicate small patches and contain or control large infestations within or adjacent to the burned area
- Reestablish vegetation on bare ground as soon as possible
- Avoid use of fertilizers in postfire rehabilitation and restoration
- Use only certified weed-free seed mixes when revegetation is necessary

For more detailed information on these topics, see the following publications: [13,37,109,301].

MANAGEMENT CONSIDERATIONS

SPECIES: Ailanthus altissima

- FEDERAL LEGAL STATUS
- OTHER STATUS
- IMPORTANCE TO WILDLIFE AND LIVESTOCK
- OTHER USES
- IMPACTS AND CONTROL

FEDERAL LEGAL STATUS:
No special status

OTHER STATUS:
Tree-of-heaven is classified as a noxious or invasive plant on National Forest System lands [298,300] and in many states. Information on state-level noxious weed status of plants in the United States is available at Plants Database.

IMPORTANCE TO WILDLIFE AND LIVESTOCK:
There are few reports of either wildlife or domestic animal use of tree-of-heaven. White-tailed deer and domestic goats browse the foliage [35,147,308], but tree-of-heaven browse is apparently not preferred. In mixed-hardwood stands of Virginia, white-tailed deer browsed 0.4% of available tree-of-heaven seedlings and 12.6% of tree-of-heaven saplings in recently logged forests but preferred black tupelo (*Nyssa sylvatica*). Browsing pressure on tree-of-heaven was greater in mature stands—where other browse was less available—with white-tailed deer utilizing 33.3% of tree-of-heaven seedlings and 41.7% of saplings. Across tree species, browsing pressure was significantly greater in mature than logged stands (P=0.02) [49]. Meadow voles also browse tree-of-heaven [43]. An old-field study in New York showed meadow voles preferred tree-of-heaven seedlings over eastern white pine seedlings, but white-footed mice preferred eastern white pine, sugar maple, and white ash seedlings over tree-of-heaven seedlings [229].

Wildlife consumption of tree-of-heaven seeds is apparently light. A few birds, including pine grosbeak and crossbills, eat the seeds [147]. A New Jersey study found granivorous rodents ignored tree-of-heaven seeds in an old field [193].

Invertebrates use tree-of-heaven; the few studies available as of 2010 suggested tree-of-heaven is important in the diet of some invertebrate species. In a mixed-hardwood forest in New York, invertebrates browsed tree-of-heaven seedlings preferentially [43]. Tree-of-heaven nectaries attract ants, which may defend trees-of-heaven against other insects, including potential pollinators. Ants sometimes colonize hollow boles of fungus-infested trees-of-heaven [5]. A study in Maryland found detritus-feeding, aquatic isopods and caddisflies preferred tree-of-heaven litter to litter of 6 native species, possibly because tree-of-heaven litter decayed more rapidly than that of native species [284]. A greenhouse study found nonnative earthworms (*Lumbricus terrestris*) preferred tree-of-heaven litter to that of native yellow-poplar [22].

Palatability and nutritional value: Tree-of-heaven is unpalatable to ungulates [99]. The bark and leaves contain saponins, quassinoids, and other bitter compounds that discourage consumption [10,131,190,308].

Tree-of-heaven is a fairly good source of protein, especially early in the growing season [15].

Nutritional content (%) of tree-of-heaven browse in Pakistan [15]								
	Digestible matter	Crude protein	Neutral-detergent fiber	Acid-detergent fiber	Hemi-cellulose	Acid-detergent lignin	Ash	Dry matter digestibility*
Spring	65.3	27.2	22.3	17.9	4.4	4.8	9.4	78.56
Winter	66.3	10.5	26.0	18.3	7.7	2.6	13.5	67.26
*For domestic goats.								

The seeds are a good source of fatty oils [32,156]. Seed collected in the United States had 56% fatty oil and 23% protein content [10].

Cover value: No information is available on this topic.

OTHER USES:
Tree-of-heaven has been widely planted as an ornamental because it grows quickly, can be trained into an attractive shape, and has attractive foliage and fruits. It was once widely cultivated in North America [312,324] and is still available as a horticultural plant [126]. It is planted less frequently now [312,324] because of its disagreeable odor and strong tendency to spread into areas where it is not wanted. It is occasionally used for shelterbelts and urban plantings [211,328].

Tree-of-heaven's tolerance to pollution has management uses. It is a bioindicator of ozone pollution, to which it is sensitive. When subjected to heavy ozone concentrations, the leaves show spotting damage and drop off [111]. Conversely, tree-of-heaven tolerates high levels of sulfur and mercury pollution, concentrating mercury in its leaves (review by [175]). It has been used to rehabilitate mine spoils in the eastern United States. Tolerant of saline soils and low pH, tree-of-heaven shows better growth on mine spoils than many native species [245]. Due to its tendency to spread on disturbed sites, however, it is not generally recommended for rehabilitation [147,178].

Tree-of-heaven provides shade, medicine, wood, clothing, and food for humans. The species has a long history of folk medicine and cultural use in Asia [140]. It is used as an astringent, antispasmodic, anthelmintic, and parasiticide. Fresh stem bark is used to treat diarrhea and dysentery; root bark is used for heat ailments, epilepsy, and asthma. The fruits are used to regulate menstruation and treat ophthalmic diseases. Leaves are an astringent and used in lotions for seborrhea and scabies [9,140]. Laboratory studies show tree-of-heaven has a potential role in modern medicine. Tree-of-heaven extracts have antibacterial, antioxidant [251], and antiinflammatory [154] properties. Pharmacological research is focusing on possible use of tree-of-heaven extracts for treating cancer, malaria, and HIV-1 infection [9,36,52,226]. In China, tree-of-heaven is grown commercially as a host for *Attacus cynthia*, a silkworm that produces coarse, durable silk [140,308]. Tree-of-heaven is a food for honeybees worldwide. Initially bad-tasting, tree-of-heaven honey ages to a high-quality, flavorful product [59,211].

Putative allelopathic tree-of-heaven extracts have potential use as herbicides [64,131,190].

Wood Products: Tree-of-heaven wood resembles ash (*Fraxinus* spp.) wood in appearance and quality. It is easily worked with tools and glue, and takes a finish well. Alden [4] and Moslemi and Bhagwat [219] summarize manufacturing properties of tree-of-heaven wood. Berchem and others [23] and Adamik and Brauns [1] provide information on properties and potential uses of tree-of-heaven wood fiber.

Tree-of-heaven is an important timber and fuelwood tree in China, and is planted for timber and afforestation in New Zealand, the Middle East, eastern Europe, and South America [14,140,268,304,328]. Zasada and Little [328] provide information on tree-of-heaven cultivation.

IMPACTS AND CONTROL:

Impacts: Tree-of-heaven is invasive in many regions of the United States. It can have detrimental effects on ecosystem processes, damage structures, and poses risk to human health.

Invasiveness: Tree-of-heaven's preference for disturbed, early-seral habitats, ability to spread from root sprouts, prodigious seed production, and rapid growth make it an "aggressive" invader [47]. Hammerlynck [122] speculated that tree-of-heaven invasiveness may be due in part to its unusually high capacity to photosynthesize and its high water-use efficiency. These abilities, coupled with pollution [207,253] and drought [87] tolerance, make tree-of-heaven especially successful in urban environments and may also help it invade wildlands [122]. Although it is more common in populated areas (see Site Characteristics), it may spread from developed areas to wildlands [146], especially those disturbed by logging [181] or other canopy-opening events. Tree-of-heaven is most invasive in eastern deciduous forests [34,161,163,166,173,228]. It has invaded the Wayne National Forest, Ohio [79], and is common in white oak-red oak-chestnut oak-Carolina basswood/eastern hophornbeam (*Quercus alba-Q. rubra-Q. prinus-Tilia americana var. caroliniana/Ostrya virginiana*) forest alliances of the Uwharrie National Forest, North Carolina [224]. In 2007, the Alabama Invasive Plant Council determined there were "extensive and dense" tree-of-heaven infestations in Alabama's managed forests and wildlands [2]. In California, tree-of-heaven is most invasive in riparian zones [44,81] but also invades oak woodlands and valley grasslands [44]. Tellman [287] states tree-of-heaven is "rapidly becoming a problem species" in the Southwest, where it invades riparian zones and other moist areas.

Tree-of-heaven has been rated a threat or potential threat in many areas of the United States. It is rated a potential invader in low-montane areas of the Cascade Range, the Sierra Nevada, and the Middle Rocky Mountains [231]; a high threat to northeastern deciduous and riparian forests and a potentially high threat to northeastern coniferous and mixed forests, grasslands, and fresh and tidal wetlands [70]; and a high threat to oak-hickory forests of the Southeast [279]. Other ratings of tree-of-heaven invasiveness as of 2010 include:

Ratings of tree-of-heaven's invasiveness by state		
Rating	Area	Affected ecosystems
West		
Potentially high threat	coastal southern Oregon and coastal California	mixed-evergreen, coniferous, and riparian forests, grasslands, chaparral, and wetlands [165]
very invasive, especially on disturbed sites	Willamette Valley, Oregon	Oregon prairie and white oak woodlands [222]
Hawaii		
Large potential threat	throughout	native Hawaiian plant communities [272,321]
Northeast		
1 of the top 10 most invasive weeds	Bronx River Parkway Reservation, New York	riparian and urban forests [100]
Appalachians		
Low threat	Oak Ridge National Environmental Research Park, Tennessee	oak-hickory [78]
Southeast		

Highly invasive	Savage Neck Dunes Natural Area Preserve on the Delmarva Peninsula, Virginia	Chesapeake Bay beach, dune, and maritime forest communities [225]
Highly invasive	Petersburg National Battlefield and Colonial National Historical Park, Virginia	oak-gum-cypress, loblolly-shortleaf pine, oak-hickory [237] and oak-hickory, oak-gum-cypress, maple-beech-birch, old-field, fresh wetland, and saltmarsh [236] communities, respectively
Most invasive and rapidly spreading nonnative species on site	Booker T. Washington National Monument, Virginia	oak-hickory, maple-beech-birch, and old-field communities [235]

There is some controversy about tree-of-heaven's ability to invade intact ecosystems. Some authors note that although tree-of-heaven established in North America over 100 years ago, it has not spread to many sites that appear to be good habitat for the species [219]. Hunter [148] considers it "only potentially invasive, and also potentially eradicable" in California. Huebner's [142] model predicts that in wildlands, tree-of-heaven will mostly spread along nonforested corridors and invade forests slowly. Tree-of-heaven may not invade closed-canopy forests [93,148]. It was ranked the least invasive of 18 nonnative, invasive species on the Oak Ridge National Environmental Research Park, Tennessee [78]. Long-distance seed dispersal, however, may enable tree-of-heaven to quickly invade disturbed openings in forest interiors [142]. Merriam [210] estimated a 4.76% increase in tree-of-heaven's rate of spread per year in North Carolina. Further information and research are needed to recognize undisturbed sites at risk for tree-of-heaven invasion [139].

Effects on ecosystem processes: As an early-seral species favoring disturbed sites (see Successional Status), tree-of-heaven grows extremely rapidly and interferes with growth of native species. The large, interconnected roots effectively occupy underground space and crowd out native species. Tree-of-heaven sometimes forms large thickets, displacing native vegetation [172,173]. It may affect natural successional trajectories, in part from competition for light and nutrients in early-successional environments, and possibly from allelopathy [129,130,131,140,184]. Tree-of-heaven and Amur honeysuckle (*Lonicera maackii*) were the most abundant and ubiquitous woody species in disturbed urban areas of Ohio. The authors speculate that these exotic species invasions have the potential to modify forest composition and ecological function of urban riparian systems [240].

Allelopathic species may alter stand structure and alter key ecosystem processes [314]. Tree-of-heaven's reputed allelopathy may slow succession in plant communities where it is invasive [129,163]. It is apparently toxic to other plants, rodents, and microbes. In an abstract of their laboratory work, Greer and Aldrich [116] report higher toxicity in leaves of young (≤2 years) trees-of-heaven than in leaves of older trees; they also found that minor injury to tree-of-heaven increases toxin production. Concentration of allelopathic chemicals is highest in young tree-of-heaven stands [45,184]; allelopathy may help tree-of-heaven seedlings establish [184] and clones to spread [209]. Seasonally, toxins are greatest in spring and decline as the growing season progresses. Allelopathic chemicals are present in all portions of the tree, but they are most concentrated in roots. The litter is also likely allelopathic. In the greenhouse, slash (*Pinus elliottii*) and Monterey pine (*P. radiata*) seed germination was inhibited by fresh tree-of-heaven litter. Allelopathy of tree-of-heaven litter was highest during pine's spring germination period and dwindled through the growing season [311]. In a red maple-sugar maple-northern red oak forest in northwestern Connecticut, tree-of-heaven did not inhibit emergence or survival of either red maple, sugar maple, or northern red oak seedlings beneath tree-of-heaven canopies, but tree-of-heaven significantly reduced seedling growth of red maple (R^2=0.33), sugar maple (R^2=0.31), and northern red oak (R^2=0.49) compared to seedling growth on control sites. Activated carbon was added to the soil on control sites to neutralize the effects of tree-of-heaven's allelopathic chemicals. Allelopathic effects in the soil were positively related to nearness of tree-of-heaven trunks, and soils lost their allelopathic effects about 20 feet (5 m) from the trunks. Cumulative allelopathic effects were proportional to tree-of-heaven density, regardless of tree-of-heaven size [107].

Tree-of-heaven may alter litter layer depth and increase available soil nitrogen in native plant communities. In Spain, tree-of-heaven litter decayed faster than litter of native English elm (*P*=0.01), and nitrogen release was greater beneath trees-of-heaven than beneath English elms (*P*=0.005). Soils beneath trees-of-heaven were not higher in nitrogen, however; the authors speculated this may be due to quick nitrogen uptake by nearby plants [50]. Studies on Mediterranean islands of Spain, France, Italy, and Greece found tree-of-heaven presence significantly decreased soil carbon:nitrogen ratios and reduced diversity of native species compared to uninvaded plots (*P*<0.05 for both variables) [307]. In aquatic ecosystems, preference of invertebrate detritus-feeders for tree-of-heaven litter over litter of native trees (see Palatability) may alter decay rates of native species [284]. Relative palatability of tree-of-heaven litter may affect successional trajectories and increase invasibility of mixed-hardwood communities. In a greenhouse study, earthworms consumed or buried nearly 100% of tree-of-heaven litter; in turn, this increased establishment and growth of nonnative tall fescue (*Schedonorus arundinaceus*), which had been seeded onto mesocosms (soil-filled tubs) with litter, soil, and earthworms. Tall fescue recruitment was less in mesocosms with native American chestnut (*Castanea dentata*), northern red oak, or yellow-popular litter than in mesocosms with tree-of-heaven litter [22]. A study in a sugar maple-white ash-northern red oak forest in Connecticut found significantly greater total soil nitrogen, calcium, and nutrient- cycling rates on sites with tree-of-heaven compared to sites without it. This effect increased in soil samples nearer to tree-of-heaven and with increasing tree-of-heaven DBH [106].

Socioeconomic factors: In developed areas, tree-of-heaven roots can damage buildings, foundations, and water facilities [140]. The rapidly growing, extensive root system also allows the tree to establish on steep to vertical structures including roofs and cracked walls, which are damaged if seedlings are not promptly killed [7,262]. Tree-of-heaven has damaged archeological sites in Europe. A study in Mediterranean Italy found it was the only nonnative tree species establishing in and damaging archeological remains [51]. In Portugal, tree-of-heaven roots damaged the walls and roof of the 800-year-old Sé Velha of Coimbra Cathedral after establishing in the wall mortar and clay roof tiles [7]. The water-seeking roots can stop up sewer lines and invade wells and cisterns, damaging infrastructures and giving potable water an unpleasant taste [62,140].

Tree-of-heaven poses human health risks. The pollen can cause an allergic reaction [68]. The sap causes a dermatitis reaction in some people [68,319], and prolonged exposure of broken skin to sap can have serious consequences. For at least one tree remover, exposure to tree-of-heaven sap on rope burns resulted in an elevated heart rate and chest pain that was severe enough to require hospitalization for several days [29].

Control: In all cases where invasive species are targeted for control, the potential for other invasive species to fill their void must be considered no matter what method is employed [38]. Control of biotic invasions is most effective when it employs a long-term, ecosystem-wide strategy rather than a tactical approach focused on battling individual invaders [192].

Prevention: It is commonly argued that the most cost-efficient and effective method of managing invasive species is to prevent their establishment and spread by maintaining "healthy" natural communities [192,270] (e.g., avoid road building in wildlands [296]) and by monitoring several times each year [155]. Managing to maintain the integrity of the native plant community and mitigate the factors enhancing ecosystem invasibility is likely to be more effective than managing solely to control the invader [138]. Weed prevention and control can be incorporated into many types of management plans, including those for logging and site preparation, grazing allotments, recreation management, research projects, road building and maintenance, and fire management [301]. See the Guide to noxious weed prevention practices [301] for specific guidelines in preventing the spread of weed seeds and propagules under different management conditions. The Center for Invasive Plant Management provides an online guide to noxious weed prevention practices. Nursery businesses can reduce tree-of-heaven introductions by not stocking tree-of-heaven and discouraging its use [126]. Gonzalez and Christoffersen [108] give suggestions for alternative landscaping species that are native in the Southeast and Southwest.

Posttreatment monitoring and retreatment are essential for this root-sprouting, rapidly growing species (see Regeneration Processes). Monitoring efforts are best concentrated on the most disturbed areas in a site, particularly along potential pathways for tree-of-heaven invasion: roadsides, trails, parking lots, fencelines, trails, and waterways [40,46,141]. In a West Virginia study, tree-of-heaven occurrence was heaviest along interstate freeways I-68 and I-79 [141]. Fortunately, tree-of-heaven's pattern of roadside and trail invasion makes accessibility, early detection, and treatment relatively easy on many sites [40]. Treated areas need checking once or twice a year, with any new sprouts or seedlings retreated as soon as possible so that plants do not have time to build up carbohydrate reserves and grow larger [139]. Whenever there is a nearby tree-of-heaven seed source, disturbed sites require monitoring and follow-up treatments to prevent tree-of-heaven invasion. Initial summer treatment impacts trees when their root reserves are low. Targeting female trees-of-heaven for control helps slow seed dissemination [139]. Monitoring is most effective when continued for at least a year after tree-of-heaven sprouting appears controlled [149]. Tree-of-heaven may show up on sites where treatments for other invasive weeds have created open, disturbed conditions. For example, tree-of-heaven and Norway maple seedlings invaded a New Jersey site after Norway maple removal treatments (cutting mature trees and hand-pulling Norway maple seedlings). Tree-of-heaven was not present on study plots prior to Norway maple removal [315].

Fire: Prescribed fire is not recommended to control tree-of-heaven due to tree-of-heaven's ability to establish from root sprouts and seed after disturbance [87,149] (see Fire Management Considerations). Nava-Constan and others' [54] experiment in Spain (see Physical and/or mechanical treatment) demonstrates tree-of-heaven's ability to increase by sprouting after top-kill. However, fire may be used as the initial top-kill treatment for tree-of-heaven control or for spot treatment. Instead of using mechanical or chemical methods to top-kill stems, a flame thrower or weed burner can heat-girdle tree-of-heaven boles [56]. As with all top-kill methods, tree-of-heaven sprouts after heat girdling [56,87], so follow-up treatments are needed to control sprouts.

Cultural: Maintaining a healthy overstory can help minimize invasive potential for tree-of-heaven [270]. Establishing a thick cover of native trees or grass helps shade out tree-of-heaven and discourages tree-of-heaven regrowth [139]. Broadcasting seed of native tree species may help slow tree-of-heaven establishment on some disturbed sites. In West Virginia, seedling establishment experiments in a harvested mixed-hardwood community showed yellow-poplar seedling survivorship 2 years after sowing was higher than that of tree-of-heaven seedlings (80% vs. 28%, $P<0.01$) on selection cuts. However, tree-of-heaven survivorship was higher than that of yellow-poplar on clearcut and unharvested control sites [171]. Moore and Lacey [216] found sweetgum and American sycamore germinated and established more quickly in the greenhouse than nonnative trees, including tree-of-heaven ($P<0.001$); they suggested establishing native tree seedlings on disturbed sites to help reduce invasion of nonnative tree species such as tree-of-heaven [216]. If artificial regeneration of native trees is indicated, it is important to establish the native seedlings quickly. With one of the fastest growth rates of any tree in North America [166], young trees-of-heaven may grow faster than and overtop young native tree species [149,166,173].

Physical and/or mechanical: Mechanical treatments, including cutting or girdling, are a good first step in controlling tree-of-heaven. Mechanical treatment alone encourages both stump and root sprouts, so follow-up treatments are required [149,316]. Cutting stems before flowering prevents seed spread, and cutting at ground level prevents bole sprouts [149]. Root and root crown sprouts can be controlled by further cutting treatments or herbicides [139,149,178], although herbicides are more effective (see Chemical control). Unless the treatment area is heavily shaded, it usually takes at least 5 years of follow-up mechanical treatment to control sprouts [58,139]. Removing the roots eliminates sprouting [58,87] but is impractical on most sites. Cutting without further treatment is not recommended because it promotes tree-of-heaven sprouting [58] and may increase tree-of-heaven abundance. A study in a Mediterranean ecosystem of Spain found that after tree-of-heaven was cut twice a year for 5 years, its density and leaf area index were greater on cut than on uncut plots ($P<0.05$) [54].

In small areas, seedlings can be controlled by hand pulling. Seedlings quickly develop extensive root systems, so the entire root needs to be removed to prevent sprouting [178]. Seedling and root sprout top-growth looks similar, but root sprouts are connected by large lateral roots. Tree-of-heaven seedlings can sometimes be compared to the variable number of leaflets and thicker stems of sprouts [149]. Grubbing roots may be effective for saplings [294]. Except for small infestations, grubbing for mature trees or well-established tree-of-heaven colonies. The root systems are extensive and nearly impossible to entirely remove, and even a small root fragment can produce root sprouts [139,149].

Biological: Biological control of invasive species has a long history that indicates many factors must be considered before using biological controls. Refer to these sources: [305,320] and the Weed control methods handbook [294] for background information and important considerations for developing and implementing biological control programs.

As of this writing (2010), there were no biological control agents approved for tree-of-heaven [134,260,294]. *Eucryptorrhynchus brandti* and *E. chinensis*, weevils native to China, are apparently host-specific tree-of-heaven feeders [72,134,260]. As of 2009, they were being tested as possible control agents for tree-of-heaven [134,260]. A wilt fungus (*Verticullum albo-atrum*) is also being tested for tree-of-heaven control [265]. Ding and others [73] provide a review of these and other biological control agents being tested for tree-of-heaven as of 2006.

Chemical: Herbicides are effective in gaining initial control of a new invasion or a severe infestation, but they are rarely a complete or long-term solution to weed management [42]. See the Weed control methods handbook [294] large infestations when incorporated into long-term management plans that include replacement of weeds with desirable species, careful land use management, and prevention of new infestations. Control with herbicides is temporary, as it does not change conditions that allow infestations to occur in the first place (for example, [326]).

Systemic herbicides that kill roots (for example, triclopyr and glyphosate) currently provide the best chemical control for tree-of-heaven. Dicamba, imazapyr, and methsulfuron methyl have also provided control [83,84,139,178,275]. See The Nature Conservancy's Weed control methods handbook for considerations on the use of herbicides in Natural Areas and detailed information on specific chemicals. See these sources for information pertaining to chemical of tree-of-heaven in particular: [83,139,145,178,199,212,275,276,294,294,304,311,312,317].

Several studies indicate that herbicides control tree-of-heaven better than cutting [40,54,208], and probably better than prescribed fire (see Fire studies). In oak-hickory communities of Shenandoah National Park, low-volume basal application of herbicides (triclopyr, picloram, imazapyr, and combinations) gave better tree-of-heaven control than cutting. At posttreatment year 2, a shift toward native herbs had occurred on plots where tree-of-heaven was controlled, while nonnative herbs including garlic mustard (*Alliaria petiolata*) and burdock (*Arctium minus*) were more prevalent on plots where tree-of-heaven density remained high [40].

Mean tree-of-heaven density 2 years after control treatments in Shenandoah National Park [40]

Treatment	Stems/acre
cutting	5,645
imazapyr	363
picloram + triclopyr*	81

*Several herbicide combinations and application rates were used. See Burch and Zedaker [40] for details.

Herbicides meant for tree-of-heaven may kill nontarget trees, even when injected into tree-of-heaven stems. Spraying may be indicated when there are large thickets without nontarget species or as a follow-up treatment to other control methods, but in mixed stands herbicides will probably have a greater impact on nontarget species that lack tree-of-heaven's ability to root sprout than on tree-of-heaven [139,178,275,294]. Tree-of-heaven roots may exude herbicides, so caution is recommended when treating trees-of-heaven growing next to high-value trees [83]. In southeastern Ohio, 17.5% of native hardwoods within 10 feet (3 m) of trees-of-heaven injected with imazapyr were also killed. The authors surmised that root grafts and/or shared mycorrhizae translocated imazapyr from tree-of-heaven to native hardwood roots [187].

Chemical control programs targeting herbaceous species may unintentionally increase tree-of-heaven, depending upon the herbicides used. In West Virginia, diuron, simazine, and terbacil treatments for rough pigweed (*Amaranthus retroflexus*), barnyard grass (*Echinochloa crus-galli*), and other herbaceous weeds in a commercial apple (*Malus sylvestris*) orchard successfully reduced most herbaceous weeds; however, tree-of-heaven and nonnative tall fescue (*Schedonorus arundinaceus*) dominated the ground layer of plots treated with diuron and simazine. Terbacil gave best control of tree-of-heaven [295].

Integrated management: A combination of complementary control methods may be helpful for rapid and effective control of tree-of-heaven. Integrated management includes not only killing the target plant, but establishing desirable species and discouraging nonnative, invasive species over the long term. In a black oak community in Rondeau Provincial Park, Ontario, cutting and applying glyphosate to tree-of-heaven stumps best controlled trees-of-heaven for

2 years, while cutting alone increased tree-of-heaven density over pretreatment levels. Hand-pulling and mulching was done on seedlings that had not yet developed taproots and on juveniles (<20 inches (60 cm) tall)); juveniles were extracted by the roots to prevent sprouting [208]:

Tree-of-heaven density (shoots/m²) after control treatments in Rondeau Provincial Park [208]					
	Juveniles			Control	Mature trees
Treatment	Hand-pulling & mulch	Cut stump & glyphosate	Cut stump	Untreated	Glyphosate-injected
Pretreatment	12.7a	11.8a	12.8a	13.4a	14.2a
Posttreatment year 1	1.7b	0.8b	9.2a	10.6a	9.8a
Posttreatment year 2	5.8b	1.0c	20.9d	10.9a	8.9a
Within rows, means followed by different letters are significantly different (*P*=0.05). Means of juvenile trees on experimental plots are compared only with means of juvenile trees on control plots, and means of mature trees on experimental plots are compared only with means of mature trees on control plots.					

In an experiment in the Mediterranean region of Spain (see Physical and/or mechanical control), a single stump cutting followed by glyphosate treatment significantly reduced tree-of-heaven biomass, density, and leaf area index compared to single cutting, twice-yearly cutting, and control treatments ($P<0.05$) [54].

APPENDIX: FIRE REGIME TABLE

SPECIES: Ailanthus altissima

The following table provides fire regime information that may be relevant to tree-of-heaven habitats. Follow the links in the table to documents that provide more detailed information on these fire regimes.

Fire regime information on vegetation communities in which xxxx may occur. This information is taken from the LANDFIRE Rapid Assessment Vegetation Models [183], which were developed by local experts using available literature, local data, and/or expert opinion. This table summarizes fire regime characteristics for each plant community listed. The PDF file linked from each plant community name describes the model and synthesizes the knowledge available on vegetation composition, structure, and dynamics in that community. Cells are blank where information is not available in the Rapid Assessment Vegetation Model.				
Pacific Northwest	California	Southwest	Great Basin	Northern and Central Rockies
Northern Great Plains	Great Lakes	Northeast	South-central US	Southern Appalachians
Southeast				

Pacific Northwest

- Northwest Shrubland
- Northwest Woodland
- Northwest Forested

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
Northwest Shrubland					
Mountain big sagebrush (cool sagebrush)	Replacement	100%	20	10	40
Northwest Woodland					
Western juniper (pumice)	Replacement	33%	>1,000		
	Mixed	67%	500		
Oregon white oak-ponderosa pine	Replacement	16%	125	100	300
	Mixed	2%	900	50	
	Surface or low	81%	25	5	30
Ponderosa pine	Replacement	5%	200		
	Mixed	17%	60		
	Surface or low	78%	13		
Oregon white oak	Replacement	3%	275		
	Mixed	19%	50		
	Surface or low	78%	12.5		
Northwest Forested					
Douglas-fir (Willamette Valley foothills)	Replacement	18%	150	100	400
	Mixed	29%	90	40	150
	Surface or low	53%	50	20	80
Oregon coastal tanoak	Replacement	10%	250		
	Mixed	90%	28	15	40

Ponderosa pine (xeric)	Replacement	37%	130		
	Mixed	48%	100		
	Surface or low	16%	300		
Dry ponderosa pine (mesic)	Replacement	5%	125		
	Mixed	13%	50		
	Surface or low	82%	8		
Mixed conifer (southwestern Oregon)	Replacement	4%	400		
	Mixed	29%	50		
	Surface or low	67%	22		
California mixed evergreen (northern California and southern Oregon)	Replacement	6%	150	100	200
	Mixed	29%	33	15	50
	Surface or low	64%	15	5	30
Mixed conifer (eastside dry)	Replacement	14%	115	70	200
	Mixed	21%	75	70	175
	Surface or low	64%	25	20	25
Mixed conifer (eastside mesic)	Replacement	35%	200		
	Mixed	47%	150		
	Surface or low	18%	400		

California

- California Grassland
- California Shrubland
- California Woodland
- California Forested

		Fire regime characteristics

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
California Grassland					
California grassland	Replacement	100%	2	1	3
Herbaceous wetland	Replacement	70%	15		
	Mixed	30%	35		
California Shrubland					
Coastal sage scrub	Replacement	100%	50	20	150
Coastal sage scrub-coastal prairie	Replacement	8%	40	8	900
	Mixed	31%	10	1	900
	Surface or low	62%	5	1	6
Chaparral	Replacement	100%	50	30	125
Montane chaparral	Replacement	34%	95		
	Mixed	66%	50		
California Woodland					
California oak woodlands	Replacement	8%	120		
	Mixed	2%	500		
	Surface or low	91%	10		
Ponderosa pine	Replacement	5%	200		
	Mixed	17%	60		
	Surface or low	78%	13		

California Forested					
California mixed evergreen	Replacement	10%	140	65	700
	Mixed	58%	25	10	33
	Surface or low	32%	45	7	
Coast redwood	Replacement	2%	≥1,000		
	Surface or low	98%	20		
Mixed conifer (north slopes)	Replacement	5%	250		
	Mixed	7%	200		
	Surface or low	88%	15	10	40
Mixed conifer (south slopes)	Replacement	4%	200		
	Mixed	16%	50		
	Surface or low	80%	10		

Southwest

- Southwest Grassland
- Southwest Shrubland
- Southwest Woodland
- Southwest Forested

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
Southwest Grassland					
Shortgrass prairie	Replacement	87%	12	2	35
	Mixed	13%	80		
Shortgrass prairie with shrubs	Replacement	80%	15	2	35

	Mixed	20%	60		
Shortgrass prairie with trees	Replacement	80%	15	2	35
	Mixed	20%	60		
Southwest Shrubland					
Southwestern shrub steppe	Replacement	72%	14	8	15
	Mixed	13%	75	70	80
	Surface or low	15%	69	60	100
Southwestern shrub steppe with trees	Replacement	52%	17	10	25
	Mixed	22%	40	25	50
	Surface or low	25%	35	25	100
Interior Arizona chaparral	Replacement	100%	125	60	150
Mountain sagebrush (cool sage)	Replacement	75%	100		
	Mixed	25%	300		
Gambel oak	Replacement	75%	50		
	Mixed	25%	150		
Southwest Woodland					
Madrean oak-conifer woodland	Replacement	16%	65	25	
	Mixed	8%	140	5	
	Surface or low	76%	14	1	20
Pinyon-juniper (mixed fire regime)	Replacement	29%	430		
	Mixed	65%	192		
	Surface or low	6%	>1,000		

Pinyon-juniper (rare replacement fire regime)	Replacement	76%	526		
	Mixed	20%	>1,000		
	Surface or low	4%	>1,000		
Ponderosa pine/grassland (Southwest)	Replacement	3%	300		
	Surface or low	97%	10		
Southwest Forested					
Riparian forest with conifers	Replacement	100%	435	300	550
Riparian deciduous woodland	Replacement	50%	110	15	200
	Mixed	20%	275	25	
	Surface or low	30%	180	10	
Ponderosa pine-Gambel oak (southern Rockies and Southwest)	Replacement	8%	300		
	Surface or low	92%	25	10	30

Great Basin

- Great Basin Shrubland
- Great Basin Woodland
- Great Basin Forested

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
Great Basin Shrubland					
Basin big sagebrush	Replacement	80%	50	10	100
	Mixed	20%	200	50	300
	Replacement	86%	200	30	200

Wyoming big sagebrush semidesert	Mixed	9%	>1,000	20	>1,000
	Surface or low	5%	>1,000	20	>1,000
Wyoming big sagebrush semidesert with trees	Replacement	84%	137	30	200
	Mixed	11%	≥1,000	20	>1,000
	Surface or low	5%	>1,000	20	>1,000
Wyoming sagebrush steppe	Replacement	89%	92	30	120
	Mixed	11%	714	120	
Interior Arizona chaparral	Replacement	88%	46	25	100
	Mixed	12%	350		
Mountain big sagebrush	Replacement	100%	48	15	100
Mountain big sagebrush with conifers	Replacement	100%	49	15	100
Mountain sagebrush (cool sage)	Replacement	75%	100		
	Mixed	25%	300		
Montane chaparral	Replacement	37%	93		
	Mixed	63%	54		
Gambel oak	Replacement	75%	50		
	Mixed	25%	150		
Mountain shrubland with trees	Replacement	22%	105	100	200
	Mixed	78%	29	25	100
Great Basin Woodland					
Juniper and pinyon-juniper steppe woodland	Replacement	20%	333	100	≥1,000

	Mixed	31%	217	100	≥1,000
	Surface or low	49%	135	100	
Ponderosa pine	Replacement	5%	200		
	Mixed	17%	60		
	Surface or low	78%	13		
Great Basin Forested					
Interior ponderosa pine	Replacement	5%	161		800
	Mixed	10%	80	50	80
	Surface or low	86%	9	8	10
Ponderosa pine-Douglas-fir	Replacement	10%	250		≥1,000
	Mixed	51%	50	50	130
	Surface or low	39%	65	15	

Northern and Central Rockies

- Northern and Central Rockies Woodland
- Northern and Central Rockies Forested

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
Northern and Central Rockies Woodland					
Ancient juniper	Replacement	100%	750	200	≥1,000
Northern and Central Rockies Forested					
Ponderosa pine (Northern Great Plains)	Replacement	5%	300		
	Mixed	20%	75		
	Surface or	75%	20	10	40

	low				
[Ponderosa pine (Northern and Central Rockies)](#)	Replacement	4%	300	100	≥1,000
	Mixed	19%	60	50	200
	Surface or low	77%	15	3	30
[Ponderosa pine (Black Hills, low elevation)](#)	Replacement	7%	300	200	400
	Mixed	21%	100	50	400
	Surface or low	71%	30	5	50

Northern Great Plains

- Northern Plains Grassland
- Northern Plains Woodland

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
Northern Plains Grassland					
Southern mixed-grass prairie	Replacement	100%	9	1	10
Central tallgrass prairie	Replacement	75%	5	3	5
	Mixed	11%	34	1	100
	Surface or low	13%	28	1	50
Southern tallgrass prairie (East)	Replacement	96%	4	1	10
	Mixed	1%	277		
	Surface or low	3%	135		
Oak savanna	Replacement	7%	44		
	Mixed	17%	18		

	Surface or low	76%	4		
Northern Plains Woodland					
Oak woodland	Replacement	2%	450		
	Surface or low	98%	7.5		
Northern Great Plains wooded draws and ravines	Replacement	38%	45	30	100
	Mixed	18%	94		
	Surface or low	43%	40	10	
Great Plains floodplain	Replacement	100%	500		

Great Lakes

- Great Lakes Grassland
- Great Lakes Woodland
- Great Lakes Forested

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
Great Lakes Grassland					
Mosaic of bluestem prairie and oak-hickory	Replacement	79%	5	1	8
	Mixed	2%	260		
	Surface or low	20%	2		33
Great Lakes Woodland					
Northern oak savanna	Replacement	4%	110	50	500
	Mixed	9%	50	15	150
	Surface or low	87%	5	1	20
Great Lakes Forested					

Northern hardwood maple-beech-eastern hemlock	Replacement	60%	>1,000		
	Mixed	40%	>1,000		
Great Lakes floodplain forest	Mixed	7%	833		
	Surface or low	93%	61		
Great Lakes spruce-fir	Replacement	100%	85	50	200
Maple-basswood	Replacement	33%	≥1,000		
	Surface or low	67%	500		
Maple-basswood-oak-aspen	Replacement	4%	769		
	Mixed	7%	476		
	Surface or low	89%	35		
Northern hardwood-eastern hemlock forest (Great Lakes)	Replacement	99%	>1,000		
Oak-hickory	Replacement	13%	66	1	
	Mixed	11%	77	5	
	Surface or low	76%	11	2	25
Pine-oak	Replacement	19%	357		
	Surface or low	81%	85		

Northeast

- Northeast Grassland
- Northeast Woodland
- Northeast Forested

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			

		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
Northeast Grassland					
Northern coastal marsh	Replacement	97%	7	2	50
	Mixed	3%	265	20	
Northeast Woodland					
Eastern woodland mosaic	Replacement	2%	200	100	300
	Mixed	9%	40	20	60
	Surface or low	89%	4	1	7
Rocky outcrop pine (Northeast)	Replacement	16%	128		
	Mixed	32%	65		
	Surface or low	52%	40		
Pine barrens	Replacement	10%	78		
	Mixed	25%	32		
	Surface or low	65%	12		
Oak-pine (eastern dry-xeric)	Replacement	4%	185		
	Mixed	7%	110		
	Surface or low	90%	8		
Northeast Forested					
Northern hardwoods (Northeast)	Replacement	39%	≥1,000		
	Mixed	61%	650		
Eastern white pine-northern hardwood	Replacement	72%	475		
	Surface or low	28%	>1,000		

Northern hardwoods-eastern hemlock	Replacement	50%	≥1,000		
	Surface or low	50%	≥1,000		
Northern hardwoods-spruce	Replacement	100%	≥1,000	400	>1,000
Appalachian oak forest (dry-mesic)	Replacement	2%	625	500	≥1,000
	Mixed	6%	250	200	500
	Surface or low	92%	15	7	26
Beech-maple	Replacement	100%	>1,000		
Northeast spruce-fir forest	Replacement	100%	265	150	300
Southeastern red spruce-Fraser fir	Replacement	100%	500	300	≥1,000

South-central US

- South-central US Grassland
- South-central US Woodland
- South-central US Forested

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
South-central US Grassland					
Southern shortgrass or mixed-grass prairie	Replacement	100%	8	1	10
Southern tallgrass prairie	Replacement	91%	5		
	Mixed	9%	50		
Oak savanna	Replacement	3%	100	5	110
	Mixed	5%	60	5	250
	Surface or low	93%	3	1	4

South-central US Woodland					
Oak-hickory savanna (East Texas)	Replacement	1%	227		
	Surface or low	99%	3.2		
Interior Highlands dry oak/bluestem woodland and glade	Replacement	16%	25	10	100
	Mixed	4%	100	10	
	Surface or low	80%	5	2	7
Oak woodland-shrubland-grassland mosaic	Replacement	11%	50		
	Mixed	56%	10		
	Surface or low	33%	17		
Interior Highlands oak-hickory-pine	Replacement	3%	150	100	300
	Surface or low	97%	4	2	10
South-central US Forested					
Interior Highlands dry-mesic forest and woodland	Replacement	7%	250	50	300
	Mixed	18%	90	20	150
	Surface or low	75%	22	5	35

Southern Appalachians

- Southern Appalachians Grassland
- Southern Appalachians Woodland
- Southern Appalachians Forested

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
Southern Appalachians Grassland					

Bluestem-oak barrens	Replacement	46%	15		
	Mixed	10%	69		
	Surface or low	44%	16		
Eastern prairie-woodland mosaic	Replacement	50%	10		
	Mixed	1%	900		
	Surface or low	50%	10		
Southern Appalachians Woodland					
Appalachian shortleaf pine	Replacement	4%	125		
	Mixed	4%	155		
	Surface or low	92%	6		
Table Mountain-pitch pine	Replacement	5%	100		
	Mixed	3%	160		
	Surface or low	92%	5		
Oak-ash woodland	Replacement	23%	119		
	Mixed	28%	95		
	Surface or low	49%	55		
Southern Appalachians Forested					
Bottomland hardwood forest	Replacement	25%	435	200	≥1,000
	Mixed	24%	455	150	500
	Surface or low	51%	210	50	250
Mixed mesophytic hardwood	Replacement	11%	665		
	Mixed	10%	715		
	Surface or low	79%	90		

Appalachian oak-hickory-pine	Replacement	3%	180	30	500
	Mixed	8%	65	15	150
	Surface or low	89%	6	3	10
Eastern hemlock-eastern white pine-hardwood	Replacement	17%	≥1,000	500	>1,000
	Surface or low	83%	210	100	>1,000
Oak (eastern dry-xeric)	Replacement	6%	128	50	100
	Mixed	16%	50	20	30
	Surface or low	78%	10	1	10
Appalachian Virginia pine	Replacement	20%	110	25	125
	Mixed	15%	145		
	Surface or low	64%	35	10	40
Appalachian oak forest (dry-mesic)	Replacement	6%	220		
	Mixed	15%	90		
	Surface or low	79%	17		

Southeast

- Southeast Grassland
- Southeast Woodland
- Southeast Forested

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
Southeast Grassland					
Floodplain marsh	Replacement	100%	4	3	30

Pondcypress savanna	Replacement	17%	120		
	Mixed	27%	75		
	Surface or low	57%	35		
Southern tidal brackish to freshwater marsh	Replacement	100%	5		
Southeast Woodland					
Longleaf pine/bluestem	Replacement	3%	130		
	Surface or low	97%	4	1	5
Longleaf pine (mesic uplands)	Replacement	3%	110	40	200
	Surface or low	97%	3	1	5
Longleaf pine-Sandhills prairie	Replacement	3%	130	25	500
	Surface or low	97%	4	1	10
Pine rocklands	Mixed	1%	330		
	Surface or low	99%	3	1	5
Pond pine	Replacement	64%	7	5	500
	Mixed	25%	18	8	150
	Surface or low	10%	43	2	50
South Florida slash pine flatwoods	Replacement	6%	50	50	90
	Surface or low	94%	3	1	6
Atlantic wet pine savanna	Replacement	4%	100		
	Mixed	2%	175		

	Surface or low	94%	4		
Southeast Forested					
Sand pine scrub	Replacement	90%	45	10	100
	Mixed	10%	400	60	
Coastal Plain pine-oak-hickory	Replacement	4%	200		
	Mixed	7%	100		
	Surface or low	89%	8		
Atlantic white-cedar forest	Replacement	34%	200	25	350
	Mixed	8%	900	20	900
	Surface or low	59%	115	10	500
Maritime forest	Replacement	18%	40		500
	Mixed	2%	310	100	500
	Surface or low	80%	9	3	50
Mesic-dry flatwoods	Replacement	3%	65	5	150
	Surface or low	97%	2	1	8
Loess bluff and plain forest	Replacement	7%	476		
	Mixed	9%	385		
	Surface or low	85%	39		
Southern floodplain	Replacement	7%	900		
	Surface or low	93%	63		

*Fire Severities—
Replacement: Any fire that causes greater than 75% top removal of a vegetation-fuel type, resulting in general replacement of existing vegetation; may or may not cause a lethal effect on the plants.
Mixed: Any fire burning more than 5% of an area that does not qualify as a replacement, surface, or low-severity fire; includes mosaic and other fires that are intermediate in effects.
Surface or low: Any fire that causes less than 25% upper layer replacement and/or removal in a vegetation-fuel class but

burns 5% or more of the area [123,182].

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