Polygonum sachalinense, P. cuspidatum, P. × bohemicum

INTRODUCTORY

Japanese knotweed in Alaska.
Photo by Tom Heutte, USDA Forest Service, Bugwood.org

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FEIS ABBREVIATION:
POLSAC
POLCUS
POLBOH

NRCS PLANT CODE [135]:
POSA4
POCU6
POBO10

COMMON NAMES:
giant knotweed
Sakhalin knotweed
Japanese bamboo

Japanese knotweed
crimson beauty
Mexican bamboo
Japanese fleeceflower

Bohemian knotweed

TAXONOMY:
The genus name for knotweeds is *Polygonum* L. (Polygonaceae). This review summarizes information on the following knotweed taxa:

Polygonum sachalinense F. Schmidt ex Maxim., giant knotweed
Polygonum cuspidatum Siebold & Zucc., Japanese knotweed [67]

and their hybrid:

Polygonum × *bohemicum* (Chrtek & Chrtková) Zika & Jacobson (*cuspidatum* × *sachalinense*), Bohemian knotweed [42,47]

In this review, species are referred to by their common names, and "3 knotweeds" refers to all 3 taxa.

Hybrids: Japanese and giant knotweed hybridize to form Bohemian knotweed. There is some concern that Bohemian knotweed may be more invasive than either of its parents due to its greater genetic diversity ([3], review by [46]), possibly allowing it to adapt to diverse habitat conditions and establish in plant communities where giant or Japanese knotweed have not established (review by [46]). Bohemian knotweed also backcrosses with giant and Japanese knotweed to produce viable seeds. This seed-producing ability is of concern because the majority of reproduction of the 3 knotweeds is currently (2010) thought to be vegetative [3] (see Regeneration Processes).

In Europe, Japanese knotweed also hybridizes with Bukhara fleeceflower (*Polygonum baldschuanicum* Regel). In the United States, hybrids morphologically similar to those between Japanese knotweed and Bukhara fleeceflower have been grown from field-collected seeds, but seedling establishment has not been observed in the wild (review by [104]).

Varieties: A dwarf variety of Japanese knotweed, *Polygonum cuspidatum* Siebold & Zucc. var. *compactum* (Hook f.) Bailey, occurs in North America [67]. One source suggests that this variety dominates Japanese knotweed populations in North America [46], though mention of this variety was encountered infrequently in the literature.

SYNONYMS:
for ***Polygonum sachalinense* F. Schmidt ex Maxim.**:
Fallopia sachalinense (F.Schmidt ex Maxim.) Dcne. [42,47,52,53,86]
Reynoutria sachalinense (F.Schmidt ex Maxim.) Nakai [128]

for ***Polygonum cuspidatum* Siebold & Zucc.**:
Fallopia japonica (Houtt.) Dcne. [11,42,47,97]
Reynoutria japonica Houtt. [146]

for ***Polygonum* × *bohemicum* (Chrtek & Chrtková) Zika & Jacobson**
Fallopia × *bohemica* (Chrtek & Chrtková) J. Bailey [11,47,97,107]

The scientific names used to identify giant and Japanese knotweed are not consistent, particularly in North American versus European literature. The citations listed above for synonyms include both floras that recognize the synonym and/or primary literature used in this review that used the synonym. For a review of genus-level taxonomy issues see the following source: [11].

LIFE FORM:
Forb
Forb-shrub

DISTRIBUTION AND OCCURRENCE

SPECIES: Polygonum sachalinense, P. cuspidatum, P. × bohemicum

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GENERAL DISTRIBUTION:

Distribution: Giant knotweed has a discontinuous distribution in North America. In eastern North America, giant knotweed occurs from Tennessee and North Carolina north into eastern Canada. Some states in the Great Lakes region (e.g., Indiana) and New England (e.g., New Hampshire) lack giant knotweed. Giant knotweed is also found in Louisiana. In western North America, giant knotweed occurs from California north to Alaska, with populations also in Idaho and Montana.

Japanese knotweed is more widely distributed than giant knotweed. The Plants Database reports Japanese knotweed occurring in almost all of the United States with the exceptions of Florida, Alabama, Texas, New Mexico, Arizona, Wyoming, and North Dakota. However, one source documented Japanese knotweed in Arizona [39]. Japanese knotweed occurs throughout Canada, with the exceptions of Labrador, Saskatchewan, Alberta, Northwest Territories, and Yukon. Plants Database provides distribution maps of giant and Japanese knotweed.

As of this writing (2010), the distribution of Bohemian knotweed in North America is not well known. The Plants Database reports Bohemian knotweed occurring in British Columbia, Ontario, and Quebec (2010). However, sources included in this profile have also documented Bohemian knotweed in New York [97,107] and Washington [31,109,111,153]. It is likely that the distribution of all 3 knotweeds is expanding in the United States.

Introduction to North America: Both giant [49,85,98,121] and Japanese [46,98] knotweed are native to Asia. During the late 19th century, giant [42] and Japanese [98] knotweed were introduced to North America as ornamental plants. Giant knotweed was also promoted as a soil binder [42] and fodder plant [136]. One source reports Japanese knotweed established from seeds released from ship ballast in New York [6]. Giant [98] and Japanese knotweed [6,49,51,85,142,146] escaped cultivation, with herbarium records indicating that Japanese knotweed escaped cultivation at least 115 times in North America prior to 2003 [6].

Rate of spread: There is some information available regarding the rate of spread of Japanese knotweed, though as of this writing (2010) information was limited for Bohemian knotweed and lacking for giant knotweed. After initial introductions, Japanese knotweed populations displayed a 50-year lag time prior to exponential population growth. As of 2006, spread rates in the United States were increasing rapidly, while those in Canada leveled off in the 1970s [6]. In Washington, Japanese knotweed was established in one county in 1960; by 2000, it was established in more than 50 counties [127]. Along the Hoh River in northwestern Washington, one Bohemian knotweed plant was transported downstream in a winter storm event. Approximately 4 years after this event, 9,600 stems were located within 20 river miles of where this plant established. Five years after the flooding event, 18,585 stems were mapped within the same 20 river miles [111].

Means of spread: The spread of all 3 knotweeds is linked to the ability of both aboveground and belowground parts to sprout when separated from the parent plant (see Vegetative regeneration). Humans spread the plants through dumping yard waste [31,40], roadside mowing or construction projects [40], or using fill dirt from riparian areas [8]. Plants of all 3 knotweeds that escape cultivation and establish in riparian areas may spread when plant parts are transported downstream ([2,93,112,136], review by [7]). Spread by seed is rare, though it has been suggested for Japanese knotweed [141,151], and seedlings of giant [87], Japanese [16,44,74], and Bohemian [115] knotweed have been observed.

HABITAT TYPES AND PLANT COMMUNITIES:
Giant, Japanese, and Bohemian knotweed establish most often in riparian plant communities, though some sources report them in forest understories, forest edges, or disturbed plant communities.

Giant knotweed: Giant knotweed is reported in riparian or wetland plant communities in Pennsylvania [87], California [22], Oregon [86], and the Pacific Northwest [52,115]. The few available descriptions of plant communities with giant knotweed are from the western United States. In California, giant knotweed occurred in riparian areas, with the most severe impacts in wetlands in the northwestern part of the state [22]. In northwestern Oregon, giant knotweed was reported as an "invader" of Pacific golden saxifrage (*Chrysosplenium glechomifolium*) plant communities occurring directly adjacent to riparian channels, in overflow channels, or in swamps. This plant community was typically herbaceous and open, though some overhanging cover was provided by salmonberry (*Rubus spectabilis*) and red elderberry (*Sambucus racemosa*). Sites were too frequently disturbed and under water too long to develop a stable tree and shrub component. Nonnative or "weedy" species were common [82]. In northwestern Washington, giant knotweed occurred on low terrace and floodplain forests adjacent to active stream channels. Floodplain forests were dominated by pioneer broadleaved trees, primarily red alder (*Alnus rubra*), willow (*Salix* spp.) and some black cottonwood (*Populus balsamifera* subsp. *trichocarpa*). Overstory conifers were less common but included western redcedar (*Thuja plicata*), Douglas-fir (*Pseudotsuga menziesii*), and western hemlock (*Tsuga heterophylla*) [136].

Japanese knotweed: Japanese knotweed is reported in riparian or wetland plant communities in Virginia [113], Maryland [119], Washington, DC [41,103], New Jersey [12,74,114], Pennsylvania [16,26,68,87], New York [32], Massachusetts [44], Vermont [139], Maine [8], New England [83], Wisconsin [96], Oregon [86,124], Washington [19,40], and the Pacific Northwest ([115], review by [88]). The following descriptions of plant communities with Japanese knotweed are organized by the eastern and western United States.

Eastern United States: Plant community descriptions are relatively detailed for the mid-Atlantic states and the Northeast, but are limited for the Southeast and the Great Lakes region.

In the mid-Atlantic states, Japanese knotweed commonly establishes in riparian, wetland, or lowland plant communities [26,37,41,68,74,103,104,114,119,144]. In Virginia, Japanese knotweed occurred on river bluffs [113]. It occurred in edge and riparian habitats in Washington, DC. Canopy dominants of riparian habitats included boxelder (*A. negundo*), red maple, yellow-poplar, and American sycamore (*Platanus occidentalis*) [41]. Near Washington, DC, Japanese knotweed occurred in a second-growth mixed-hardwood urban forest, establishing mostly along streambanks [103]. In Maryland, Japanese knotweed was a rare species in riverbank habitats in the Potomac River lowlands and creek floodplains. Forested areas were generally wet to mesic and contained a mixture of swamp white oak (*Quercus bicolor*), willow oak (*Q. phellos*), pin oak (*Q. palustris*), Shumard oak (*Q. shumardii*), sweetgum (*Liquidambar styraciflua*), and red maple [119]. In western Pennsylvania Japanese knotweed occupied hundreds of acres of wetlands, streambanks, and hillsides and spread along the banks of the Allegheny and Ohio Rivers, dominating the edges of many of the islands in these rivers (Wiegman personal communication cited by [104]). Japanese knotweed was an infrequent species in open habitats on 2 Allegheny River islands in northwestern Pennsylvania. Riparian forests on the islands were dominated by silver maple (*A. saccharinum*) and American sycamore [144]. Japanese knotweed was a dominant component (>25% cover) of herbaceous cover in floodplain forests along the Allegheny River in northeastern Pennsylvania. Dominant canopy trees included American sycamore and silver maple [26]. In southeastern Pennsylvania, Japanese knotweed established in streamside areas with American sycamore, boxelder, silver maple, red maple, black walnut, and yellow-poplar [68]. In southeastern Pennsylvania, Japanese knotweed comprised 15% of the herbaceous groundcover in lowland forests dominated by white ash, American sycamore, and black cherry [138]. In

New Jersey, Japanese knotweed occurred in urban wetlands [37], floodplains [74,114], open woods and thickets, meadows, successional fields, and on the margins of ponds and lakes [114].

Japanese knotweed also establishes in some upland areas in the mid-Atlantic states [108,113,114]. Japanese knotweed occurred in mixed mesophytic forests along the Cheat River, West Virginia. Codominants included sugar maple (*Acer saccharum*), basswood (*Tilia americana*), American beech (*Fagus grandifolia*), yellow-poplar (*Liriodendron tulipifera*), sweet birch (*Betula lenta*), eastern hemlock (*Tsuga canadensis*), black cherry (*Prunus serotina*), cucumber-tree (*Magnolia acuminata*), white ash (*Fraxinus americana*), red maple (*A. rubrum*), black walnut (*Juglans nigra*), shagbark hickory (*Carya ovata*), bitternut hickory (*C. cordiformis*), and slippery elm (*Ulmus rubra*) [108].

In the Northeast, Japanese knotweed commonly establishes in riparian areas or wetlands [8,32,34,44,83,96,97,139]. In New England, Japanese knotweed occurred in floodplain forests, forested wetlands, herbaceous wetlands, shrub wetlands, and wet meadows [83]. In Massachusetts, Japanese knotweed occurred in riparian [44], wetland, and coastal habitats [81]. On Staten Island, New York; Japanese knotweed established in disturbed areas within a deciduous swamp dominated by red maple, black willow (*Salix nigra*), northern spicebush (*Lindera benzoin*), and southern arrowwood (*Viburnum dentatum*) [34]. On Long Island, New York, Japanese knotweed established in salt marshes, often growing next to or on the terrestrial border of marshes dominated by common reed (*Phragmites australis*) [97]. Japanese knotweed established along streams and riparian areas in Vermont [139] and Maine, in areas surrounded by northern hardwood forests [8].

Japanese knotweed may also establish in upland areas in the Northeast [73,77,81,83,96,99]. Japanese knotweed was found in localized clumps in little bluestem (*Schizachyrium scoparium*) grasslands adjacent to a former airport near Brooklyn, New York. Other common plants included northern dewberry (*Rubus flagellaris*), red fescue (*Festuca rubra*), and rough-stemmed goldenrod (*Solidago rugosa*) [99]. In northern New York, Japanese knotweed spread from roadways into adjacent forests containing sugar maple, red maple, yellow birch, American beech, white ash, and black cherry [73]. In New England, Japanese knotweed occurred in abandoned fields, early successional forests, and edge habitat [83]. In Massachusetts, Japanese knotweed occurred in upland habitats [81].

In the Southeast, Japanese knotweed was listed as invading southeastern forests and their margins [84]. In South Carolina, Japanese knotweed was reported in mountain, piedmont, and coastal plain regions [117].

In Wisconsin, managers reported Japanese knotweed as a facultative wetland species, occurring in both forest and grassland habitats [96].

Western United States: Japanese knotweed establishes most commonly in riparian areas in the western United States [14,19,22,40,124], though there is some documentation of it occurring in upland plant communities [19,39,40]. In northern Idaho, Japanese knotweed established along a fourth-order stream dominated by gray alder (*Alnus incana*) and black cottonwood [14]. Japanese knotweed was infrequent on an Umpqua River island in the Oregon Coast Range. It was observed in a red alder-Oregon ash (*Fraxinus latifolia*)/Himalayan blackberry (*Rubus discolor*)/reed canarygrass (*Phalaris arundinacea*) plant community on an alluvial secondary floodplain terrace [124]. In southwestern Washington, Japanese knotweed established along waterways, though some populations established on upland sites. Riparian banks and ridges above waterways were heavily forested with western redcedar and other conifers [19]. In the central Cascades of Washington, Japanese knotweed established in riparian areas and along unpaved logging roads in Douglas-fir forests [40].

In California, Japanese knotweed occurred in riparian areas, wetlands, and forest edges, with the most severe impacts in wetlands in the northwestern part of the state [22]. Japanese knotweed occurred in pinyon-juniper (*Pinus*-*Juniperus* spp.) woodlands in central Arizona [39].

Bohemian knotweed: Bohemian knotweed is reported in riparian or wetland plant communities in New York [97,107], Oregon [86], Washington [31,109,111,153], and the Pacific Northwest [115]. Plant community descriptions for sites with Bohemian knotweed are available for a few locations in the Northeast and the Pacific Northwest. In New York, a =10 year-old homogenous stand of Bohemian knotweed occupied a floodplain. The stand was bordered by an old field dominated by goldenrods (*Solidago* spp.) and riparian cottonwood (*Populus* spp.) trees [107]. On Long

Island, New York, Bohemian knotweed established in salt marshes, often growing next to or on the terrestrial border of marshes dominated by common reed [97]. In Washington, Bohemian knotweed established on tidal wetlands that included a mixture of sloughs and palustrine emergent, scrub-shrub, and forested wetlands. Forested areas were dominated by Sitka spruce [31]. Along the Hoh River in northwestern Washington, Bohemian knotweed was found on mature Sitka spruce terraces, alder forest floodplains and willow thickets, and cobble and gravel river bars [109,111].

BOTANICAL AND ECOLOGICAL CHARACTERISTICS

SPECIES: Polygonum sachalinense, P. cuspidatum, P. × bohemicum

GENERAL BOTANICAL CHARACTERISTICS:

Botanical description: This description covers characteristics that may be relevant to fire ecology and is not meant for identification. Keys for identification of giant and Japanese knotweed are available (e.g., [49,58,78,85,98,142]). For information on differentiating between giant, Japanese, and Bohemian knotweed, see the following: [7,43,153]. These 3 knotweeds are commonly confused [7,16,43,153].

Giant knotweed is a stout, rhizomatous, perennial geophyte (review by [7]). Observations from the Czech Republic suggest that giant knotweed roots grow "deep" into the soil. Rhizomes have a diameter of 3 inches (8 cm) and may spread 50 to 65 feet (15-20 m) laterally [79]. Giant knotweed stems are generally clustered, erect [42], hollow, and up to 13 feet (4 m) tall. Leaves are alternate, oval to oblong, and large, frequently 12 inches (30 cm) long, with a cordate base [121]. Flowers are white [94] or greenish and borne on axial or terminal racemes or panicles. Seeds are triangular achenes [121] with 3-mm long nutlets [94].

Giant knotweed flowers.
Photo by Jan Samanak, State Phytosanitary Administration, Czechia, Bugwood.org

Japanese knotweed is a stout, rhizomatous, perennial geophyte. Rhizomes are dark brown, knotty, up to 3 inches (8 cm) in diameter (review by [7]), and may spread laterally 23 to 65 feet (7-20 m) [115]. Japanese knotweed has a deep central taproot (reviews by [7,11]). Adventitious roots are white, fine, and thread-like. Stems are 3 to 13 feet (1-4 m) tall, glaucous, erect, and hollow (review by [7]). Japanese knotweed plants are often shrubby or woody at the base [98]. Leaves are alternate and broadly ovate (3 to 6 inches (8-15 cm) by 2 to 5 inches (5-12 cm)) with a truncate base [94]. Flowers are borne on axial or terminal racemes or panicles 3 to 6 inches (8-15 cm) long. Flowers are creamy-white. Seeds are tri-winged achenes (review by [7]).

Bohemian knotweed exhibits botanical characteristics similar to those of giant and Japanese knotweed, though it is intermediate in leaf size ([153], review by [7]).

Raunkiaer [95] **life form:**
Geophyte

SEASONAL DEVELOPMENT:
In North America, giant knotweed flowers from July to October [42], with some regional variation [78,85,94,121,150]. In North and South Carolina, giant knotweed produces fruit from August to October [94]. In Pennsylvania, seeds are mature in September [87]. Giant knotweed overwinters via an underground woody rhizome (review by [7]). In the Pacific Northwest, giant knotweed growth begins in April and stems may grow 15 feet (4.5 m) by June [115].

Japanese knotweed flowers from June through August in Pennsylvania [16]; August to September in Illinois [85], the Great Plains [51], and New England [78]; and August to October in Kentucky [56]. In Pennsylvania, Japanese knotweed fruit begins to form in late August [16] and matures in September [87]. In the eastern United States, fruits generally remain on plants through the winter. Leaves are photosynthetically active until autumn frosts prompt senescence. Leaves drop throughout the winter months. Assimilation of resources shifts from shoots to roots near the end of the growing season, as the plant prepares for overwintering (review by [7]). Near Washington, DC, Japanese knotweed plants allocated most resources to aboveground growth until approximately 30 July. Through most of August, resources were allocated equally to both aboveground and belowground parts. After 28 August, most resources were allocated to belowground parts [103]. In the eastern United States, Japanese knotweed seedlings emerge in mid-spring (late March to May) depending on latitude and altitude. Rhizome sprouts emerge from late spring through mid-summer until the canopy closes (review by [7]).

As of this writing (2010) little information is available regarding the phenology of Bohemian knotweed. In the Pacific Northwest, Bohemian knotweed growth begins in April [115]. It probably flowers in the late summer and early fall like giant and Japanese knotweed, because seeds of all 3 species were mature in September in Pennsylvania [87]. Bohemian knotweed overwinters via an underground, woody rhizome (review by [7]).

REGENERATION PROCESSES:

It is generally accepted that asexual reproduction is the primary mode of reproduction in North America for these 3 knotweeds [74,103], though there are some reports of reproduction by seed (see Seedling establishment and growth). Near Washington, DC, 400 Japanese knotweed shoots were excavated at the periphery of stands, and all were attached to existing plants via rhizomes. No seedlings were found [103]. In Massachusetts, Japanese knotweed populations seemed to reproduce both sexually and asexually [53].

Vegetative regeneration: The ability for multiple plant parts to regenerate vegetatively plays an important role in the spread and establishment of the 3 knotweeds. Vegetative regeneration is possible from multiple plant parts, including rhizomes, aboveground stems, roots, and leaves.

Japanese knotweed rhizomes and roots.
Photo by John Cardina, The Ohio State University, Bugwood.org

Rhizomes: Giant [42,121,136], Japanese [11,49,94,103,142], and Bohemian [31] knotweed are rhizomatous. As much as two-thirds of a Japanese knotweed plant's biomass exists underground in rhizomes (review by [7]). This morphology facilitates early spring emergence and rapid growth (review by [102]) and provides sufficient reserves for plants to survive multiple losses of aboveground parts within a growing season [101]. Rhizomes of the 3 knotweeds are capable of extensive spread both horizontally and vertically. In the Pacific Northwest, the rhizomes of all 3 knotweeds penetrated at least 7 feet (2 m) into the soil and spread laterally 23 to 65 feet (7-20 m) [115]. In the Czech Republic giant knotweed rhizomes reached 50 to 65 feet (15-20 m) in length [79].

Fragment size, soil depth, and light availability impact sprouting from rhizomes. In a study of Japanese knotweed rhizome regeneration from the Slovak Republic, even 1-inch (2-cm) rhizome fragments regenerated, at a rate of 47% one year and 70% another year. Regeneration rate was higher for larger fragments than smaller fragments; 3-inch (8-cm) fragments had a 90% regeneration rate one year and 70% another year [100].

Japanese knotweed rhizomes can sprout from various soil depths; 1-inch (2-cm) depth is optimal, but rhizomes may sprout from as deep as 3 feet (1 m) (review by [7]). In New Jersey field experiments, larger Japanese knotweed rhizomes and those planted at shallower depths produced more shoots than smaller rhizomes or those planted at greater depths. One inch (2 cm) was the optimal depth for planting, though fragments left on the surface or planted as deep as 20 inches (50 cm) were able to produce shoots. Rhizome fragments could produce shoots in as little as 11 days when planted 1 inch (2 cm) deep, or 47 days for fragments planted 20 inches (50 cm) deep [74]. In the United Kingdom, 4-inch (10-cm) rhizome fragments of Japanese knotweed were buried at 2-inch (5-cm), 6-inch (15-cm), and 10-inch (25-cm) depths. By 19 days after burial, rhizome fragments at all depths sprouted, though not all shoots from rhizomes buried at the greater depths had broken the soil surface. All rhizome fragments produced adventitious roots. Although regeneration was not prevented at the depths tested, this study found poorer performance (e.g., number of shoots/shoot length) with deeper burial [45]. Both giant and Japanese knotweed regenerated vegetatively through 20-inch (50-cm) (Japanese) and 40-inch (100-cm) (giant) -thick accumulations of volcanic ash and pumice following the eruption of Mt. Usu in Japan [130].

Light may enhance the survival of sprouting rhizomes. Near Washington, DC, Japanese knotweed rhizome fragments placed on streambank sites had higher survivorship than those placed under adjacent vegetation ($P<0.05$). In their second year of growth, rhizomes planted on streambanks exhibited significantly greater stem growth ($P<0.001$), basal stem diameter ($P<0.001$), and stem height ($P<0.01$) than rhizomes planted in the understory. Streambank sites had significantly higher light levels than understory sites ($P<0.01$), though understory sites had more organic matter ($P<0.01$) [104].

Rhizomes may sprout immediately following damage but sprouting may also be delayed for years. In a study of

Japanese knotweed rhizome regeneration from the Slovak Republic, rhizome fragments sprouted as early as 1 week after planting for 3-inch (8-cm) long rhizomes and 4 weeks for 1-inch (2-cm) long rhizomes [100]. In riparian areas in northwestern Oregon, some sprouts of unidentified knotweeds did not emerge for 1 to 3 years following herbicide treatments that eliminated all aboveground growth. Field excavation of a plant that appeared to be dead revealed a 6-foot (2-m) long, 1-inch (3-cm) diameter living rhizome connected to the root crown 5 inches (13 cm) below the soil surface [116]. In New Jersey field experiments, season did not affect Japanese knotweed rhizome shoot production; shoots were produced in May, July, and September [74].

Other sources of vegetative regeneration: The 3 knotweeds may regenerate vegetatively from plant parts other than rhizomes. A review of Japanese knotweed biology reports that the most vigorous shoots arise in groups from perennating buds on the root crown (review by [11]). One manager from the Pacific Northwest reported that small sections of Bohemian knotweed root crowns are capable of regeneration [31].

In Pennsylvania field experiments, perennating buds formed at the base of giant knotweed seedling stems within the first growing season; these buds were the primary site of vegetative regeneration in this study, not rhizomes [87]. In the United Kingdom 4-inch (10-cm) and 12-inch (30-cm) stem fragments of Japanese knotweed were buried at 2-inch (5-cm), 6-inch (15-cm), and 10-inch (25-cm) depths. After 28 days, some of the 4-inch (10-cm) and more of the 12-inch (30-cm) stem fragments produced shoots. Although regeneration was not prevented at the depths tested, this study found poorer performance (e.g., number of shoots/shoot length) with deeper burial [45]. In the United Kingdom, cut Japanese knotweed stems floating in a canal produced axillary shoots (review by [11]). In the Pacific Northwest, Bohemian knotweed stems rooted from stem nodes [31]. Japanese knotweed cut stems may produce adventitious roots in a few days, which may be followed by axillary shoot production (review by [11]). In the Czech Republic an unidentified knotweed reportedly established from fallen leaves (Brabec 1997 as cited in [15]) though this trait has not been documented elsewhere in the literature (2010).

Root sprouting has been documented for giant knotweed. In Pennsylvania, giant knotweed seeds were planted in fields under various experimental conditions, including 3 shade levels (0%, 30%, and 63%), 2 leaf litter conditions (absent, present), and 2 seed sources. The emerging seedlings were clipped to examine their ability to sprout under the various conditions. Many of the clipped giant knotweed seedlings sprouted from the roots by June of the following year. Root sprouting was not influenced by shade treatment but failed in treatments with litter. Root sprouts grew an average of 21.2 inches (53.7 cm) in the year after clipping; the tallest was 56.7 inches (144.0 cm). Root sprouts also produced flowers and a few seeds by the end of their first growing season. The authors concluded that root reserves acquired within the first growing season were sufficient for perennial growth the next year [87].

Pollination and breeding system:

Pollination: The 3 knotweeds are insect-pollinated. In Pennsylvania they were pollinated by bees, ants, butterflies, and beetles [87]. Near Washington, DC, Japanese knotweed was pollinated by bees [103].

Breeding system: Reports of the breeding systems of the 3 knotweeds are conflicting. For a review of their breeding systems, see [46]. One review that considered plants and herbarium specimens from North America reports that Japanese knotweed is gynodioecious [7]. Another review reports that Japanese knotweed is functionally dioecious in the United States, while it is gynodioecious in the United Kingdom [87]. A third review describes the Japanese knotweed breeding system as "leaky" dioecious or subdioecious in North America because populations contain both male and female plants that maintain vestigial reproductive parts of the other sex [53]. A flora from the Pacific Northwest reports Japanese knotweed as generally monoecious [58]. Giant knotweed is reported as dioecious in the United States [58] or gynodioecious in the United Kingdom [3]. In Pennsylvania, the majority of plants from a population containing all 3 knotweeds had male-fertile and female-fertile flowers on separate plants and relatively few perfect flowers were found [87].

The sexual characteristics of a particular population have important implications for the viability of seeds. In Pennsylvania, viable seeds of the 3 knotweeds were not found when male-fertile plants were absent from the site, but many viable seeds were produced when both female and male-fertile plants were present [87]. In New Jersey, one researcher found Japanese knotweed populations of both sexes and other populations of just females; female-only populations produced seeds but they were not viable [74].

Seed production: Though seed production of the 3 knotweeds has been documented in North America, it is not clear how representative this information is for all populations. Even if seeds are produced, they may or may not be viable. In the Pacific Northwest, the seeds of giant and Japanese knotweed were largely infertile while Bohemian knotweed seeds were viable [115]. In New Jersey, Japanese knotweed populations produced seeds but they were not viable [74]. One review reports that though giant knotweed produces seeds, seeds do not mature in temperate zones [118].

In areas with all 3 knotweeds in Pennsylvania, single stems produced 50,000 to 150,000 seeds annually; millions of seeds were produced over a 108-ft² (10-m²) area in some locations [87]. Based on field observations in Pennsylvania, 1 Japanese knotweed stem was capable of producing over 127,000 seeds/year if all flowers were pollinated and seeds set. Consequently, a single seed-bearing plant with 10 stems/plant would be capable of producing more than a million seeds/year [16]. Giant knotweed seedlings from 2 field locations in Pennsylvania produced both flowers and seeds within 3 months of emergence [87].

Seed dispersal: Seeds of the 3 knotweeds may be dispersed by wind, birds, insects, or water. One review reports that the presence of a persistent, winged perianth and an abscission zone suggest wind-dispersal of Japanese knotweed seeds [11]. Giant knotweed seeds are wind-dispersed in its native range [129]. In Pennsylvania birds and insects consumed giant and Japanese knotweed seeds, which the author suggested may indicate potential dispersal mechanisms [87]. Near Washington, DC, Japanese knotweed seeds were washed downstream in floods [103]. In Belgium, the majority of Japanese knotweed seeds fell within the vicinity of the parent plant, though seedfall patterns indicated the potential for dispersal beyond 52 feet (16 m) for a small amount of seeds [126]. As of this writing (2010) no information was available regarding the dispersal of Bohemian knotweed seeds.

Seed banking: As of 2010, there was very little information related to seed banking of the 3 knotweeds. All available information was related to seed longevity of wild-collected Japanese knotweed seeds. Japanese knotweed seeds from Massachusetts retained up to 100% viability for 4 to 16 months after indoor storage [44], while those from New Jersey rarely germinated after 1 year of storage [74]. In established stands of Japanese knotweed in Pennsylvania, the emergence of high numbers of Japanese knotweed seedlings suggested seedlings originated from the soil seed bank [16]. See Germination for more details of this study.

Germination: Seeds collected from all 3 knotweeds in North America have germinated in laboratory settings [44,46,74,87]. Germination in nonexperimental settings is rare though it has been documented for giant [87], Japanese [16,44,74], and Bohemian [115] knotweed as evidenced by seedlings. The germination potential of seeds from the 3 knotweeds likely varies with characteristics (e.g., breeding system) of the population studied. Not all North American populations produce fertile seeds [74,87,115]. Pollen sources of studied populations are often unknown; one review reports that the seed source for several North American germination experiments could be any of the 3 knotweeds [148]. Consequently, the results of germination studies should be interpreted with caution and broad inferences may not be possible. The following information retains the names of knotweed taxa used by the authors.

Giant knotweed: Laboratory experiments in Massachusetts found that giant knotweed seeds took 16 to 37 days to germinate [46]. Giant knotweed seed germination is favored by moisture ([129], review by [118]) and disturbance [87,129]. In its native Japan, giant knotweed seed germination was high within rills in heavily eroded areas on volcanic deposits. Water content within the rills seemed to promote germination [129]. In Pennsylvania, thousands of giant knotweed seedlings emerged in areas disturbed by earth-moving equipment the previous year [87]. The Russian Agricultural Ministry suggested avoiding acidic soils, excessively damp soils, and loose sands when planting giant knotweed. It was recommended that seeds be moistened prior to planting (review by [118]).

Light may not influence giant knotweed germination, though only 1 study has addressed this topic as of 2010. In Pennsylvania, giant knotweed seeds were planted in fields under various experimental conditions, including 3 shade levels (0%, 30%, and 63%), 2 leaf litter conditions (absent, present), and 2 seed sources. Giant knotweed seeds germinated from all treatments. Sites with litter had lower germination than sites without litter across all 3 shade treatments (P=0.05). Low light availability did not result in decreased germination [87].

Japanese knotweed: Laboratory experiments in Massachusetts found that Japanese knotweed seeds took 5 to 55 days to germinate [46]. Laboratory germination of wild-collected Japanese knotweed seeds from New Jersey was not influenced by light, temperature, or moisture during storage. Pin-prick scarification tests suggested that scarification hindered germination. Germination was positively associated with cold treatment and negatively associated with storage period (P=0.01) [74].

Greenhouse experiments and field observations in Massachusetts suggest that Japanese knotweed germination may be high though seedling survival is limited. In a greenhouse, germination of wild-collected Japanese knotweed seed was highly variable, though some samples achieved 100% germination. Seeds did not require burial to germinate; those on the soil surface germinated several days before those that were buried 0.2 inches (0.5 cm). Seeds germinated after exposure to simulated New England weather conditions, though seedlings did not survive [44]. See Seedling establishment and growth for information on field germination and seedling survival from this study.

A series of field studies was conducted in Pennsylvania to assess the potential for Japanese knotweed to germinate under field conditions. In one experiment, Japanese knotweed seeds were collected in late October, dried, and planted in bags in late December in existing stands of Japanese knotweed. The bags were excavated in March and every 3 weeks afterward and the germinated seeds were counted. Germination rates ranged from 55% to 92% and averaged 82%. Roughly 30% of the seeds germinated before March 10, but germination date varied by location. In a second experiment, seeds that had overwintered were collected from stems in March. Seeds were planted in different microhabitats, including areas without previous Japanese knotweed establishment. Emerging seedlings were counted from April to August. Seeds germinated at several sites, including both riparian and wooded upland areas, though there was no way to identify if the emerging seedlings originated from the planted seeds or from the naturally occurring seed bank. Peak number of seedlings varied between microhabitats, and was greatest in plots in areas with established Japanese knotweed stands (P<0.000001), which the authors attributed to the germination of naturally occurring seeds in the soil seed bank. There was no difference in soil water content between microhabitats. For upland sites, where the authors assumed there were no naturally occurring Japanese knotweed seeds, germination rates ranged from 21% to 79%. Low germination rates in some of the upland sites was attributed to dense herbaceous cover that may have inhibited seed germination or increased early seedling mortality. The authors concluded that Japanese knotweed has the potential to establish from seed in field settings and it is not limited to riparian sites [16].

Bohemian knotweed: Bohemian knotweed seeds were collected in the Pacific Northwest and germinated in a laboratory [115], though details from this study are lacking. Laboratory experiments in Massachusetts found that Bohemian knotweed seeds took 11 to 55 days to germinate [46].

All 3 knotweeds: In Pennsylvania, wild-collected seeds from a population with all 3 knotweeds were stored varying lengths of time under 3 environmental conditions: warm (64 °F (18 °C))-dry , cold (37 °F (3 °C))-dry , and cold (37 °F (3 °C))-moist. Seed wings were removed from some seeds. Germination ranged from 60% to 100%, averaging 91%. There were significant differences in germination due to seed source, seed wing removal, and environmental conditions over time (P=0.05). Cold-moist storage yielded the highest germination, averaging 95%, though germination for the other environmental conditions was still high, averaging 89% [87].

Seedling establishment and growth: Documentation of seedlings of the 3 knotweeds is rare, and parentage of seedlings is often unclear [148]. Several sources report that seedling survivorship is poor in the field ([44,74,87], review by [102]), though there is the potential for seedlings to establish given the right conditions [44]. Light [44,74], moisture [44], litter levels [87], weather [44,80], and the presence of established vegetation [44,87,141,151] may all impact seedling survivorship.

At field sites in New Jersey, Japanese knotweed seedlings that germinated under the canopy of a parent plant rapidly declined in number after reaching the 3-leaf stage. No seedlings survived in the wild over 5 years of observation though early-season seedling densities were as high as 486 seedlings/0.5 m^2. In shading experiments, planted Japanese knotweed seedlings subjected to high light levels grew vigorously, stems were well-branched, and leaves were large, rich, and dark green. Seedlings grown at low light levels lacked vigor by the second week of the study. These seedlings had low growth and branching rates as well as small leaves that showed signs of chlorosis [74].

Observations from a second study suggest that both light and moisture may affect Japanese knotweed seedling survival. In Massachusetts, Japanese knotweed seedlings were observed at several field locations. At one site, seeds germinated but seedlings died after 1 month, which the authors attributed to the dense cover of Japanese knotweed sprouting from established rhizomes. At another site, seeds germinated but seedling growth was slow, which the authors attributed to dry local conditions. The seedlings ultimately died after the area was disturbed during a construction project. At another site, hundreds of seedlings emerged in an area lacking Japanese knotweed after a flowering stem from an uphill plant collapsed downslope. Despite shading from other plants, seedlings grew and developed through the season, with some individuals gaining as many as 5 true leaves. Though frost killed aboveground vegetation, surviving seedlings developed rhizomes in their first year. Few seedlings survived to the next year. The authors concluded that seedlings emerging underneath well-established stands of Japanese knotweed are not likely to survive because the rapid growth of vegetation from the rhizomes creates a canopy in early spring that blocks most sunlight. However, seedlings emerging in open areas have the potential to survive through the next growing season and establish successfully [44].

In Pennsylvania, tens of thousands of newly germinated seedlings were observed in populations with all 3 knotweeds. Differences in seedling survival were related to the proximity to mature plants; those seedlings that germinated under the canopy of parent plants and in the leaf litter did not survive. Thousands of seedlings did survive to the end of the first growing season, some reaching heights of >4 inches (10 cm). Second-year seedlings of giant knotweed were observed at some locations, with completely independent root systems and remnant stems from previous growth. In field experiments, giant knotweed seeds were planted and exposed to various treatments, including 3 shade levels (0%, 30%, and 63%), 2 leaf litter conditions (absent, present), and 2 seed sources. Litter had a significant negative impact on seedling biomass (P=0.05) while shade level did not. The author suggested that litter both physically prevented seedlings from reaching light and provided a habitat for slugs that ate the seedlings. The author also noted that seedlings not protected by shade experienced early frost damage, while those under shade grew into October [87].

In Japan, the ability of Japanese knotweed seedlings to survive overwintering is related to winter temperature and seedling size. One study compared seedling survival at elevations of 4,600 feet (1,400 m) or 8,200 feet (2,500 m). Japanese knotweed seedlings with a dry weight of <10 mg were unable to survive winter at either elevation, but 100% of seedlings with a dry weight of =40 mg survived. Seedling survival was higher at the lower elevation, a pattern attributed to the relatively long growing season and high winter temperatures at low elevations [80].

A guide for revegetating minespoils in the eastern United States reported that Japanese knotweed "spreads by seeds into gullies and over considerable distances on barren areas. However, it does not readily spread by seed into stands of established vegetation" [141]. Japanese knotweed reportedly spread by seed across minespoil sites in Pennsylvania. The highest number of seedlings was found under the cover of adult Japanese knotweed plants compared to areas where other plants were either established or had been planted. The authors concluded that high herbaceous plant and grass cover prevented Japanese knotweed seedling establishment [151].

Plant growth: Japanese knotweed exhibits rapid growth [98]. Over the New Jersey growing season of approximately 80 days, the average rate of Japanese knotweed growth was 3.28 inches (8.35 cm)/day [74]. In the Pacific Northwest, Japanese knotweed stems reached 10 feet (3 m) by June [115]. Giant knotweed also exhibits fast growth [136]. In the Czech Republic, early spring giant knotweed shoots grew an average of 1 inch (3 cm)/day for 20 days, then increased growth to approximately 2 inches (5 cm)/day [79]. In the Pacific Northwest, giant knotweed stems reached 15 feet (4.5 m) by June [115]. Several sources report that Japanese knotweed grows better in full sun than partial shade ([19,81,103], reviews by [11,38,102]). See Successional status for more information on this topic.

Populations of one or more of these 3 knotweeds may cover extensive areas. In Washington, DC, 2 streamside stands of Japanese knotweed extended 282 feet (86 m) and 190 feet (58 m), respectively [103]. Approximately 25% of individual Japanese and Bohemian knotweed plants surveyed in Belgium covered >0.02 acres (100 m²) [125].

Maximum stand size reported for 3 knotweed taxa		
Species	Location	Stand size (acres)
Bohemian	Washington	16 [31]
	New York	0.6 [107]
Japanese	Massachusetts	0.006 [44]
		>0.02 [53]
All 3	Oregon	1 [116]

In the United Kingdom, one Japanese knotweed plant occupied approximately 245 acres (100 ha) (S. Hatherway personal communication cited in [61]). This extensive growth plus the identification of all Japanese knotweed plants in the United Kingdom as genetically identical suggests that it might be one of the largest vascular plants on earth [61], prompting the newspaper headline: "Largest female on earth could strangle Britain" (review by [4]).

These 3 knotweeds grow in dense stands and often become the dominant vegetation ([73,87], review by [118]). Two- to 3-year-old giant knotweed plantings produced enough "root runners" that no vegetation of any kind could grow under their mat (review by [118]). Japanese knotweed stands in Colorado were characterized as "dense thickets of rank growth" [146]. In New York, vegetative cover of roadside Japanese knotweed was 81.3% in study plots with a total plant cover of 84.6% [73]. In Michigan, Japanese knotweed established in dense thickets >7 feet (2 m) tall [142]. In southwestern Washington, managers treated over 300,000 Japanese knotweed stems in 500 acres (200 ha) of treatments [19]. In northwestern Washington, giant knotweed stem density in low terrace and floodplain forests ranged from 0.0 to 8.8 stems/m² [136].

SITE CHARACTERISTICS:

Site description: Giant knotweed establishes in disturbed areas [42,78], including railroads [142], roadsides [78,142], and old homesites [142]. In Pennsylvania, giant knotweed established on abandoned fill and gravel and sand roadway materials [87]. A field guide reported that giant knotweed is likely to establish along streams or streambanks and in forests or woodlands of the Upper Midwest [28].

Japanese knotweed commonly establishes in disturbed areas ([53,65,78,83,98,114], review by [102]), including roadsides [8,32,40,51,56,73,78,98,114,142], along railroad tracks [6,56,74], in gravel pits, dumps [142], vacant lots [56,83], pastures [56], and abandoned fields [83] or gardens [51,56,83]. Japanese knotweed also occurs in woodland thickets [56] and borders [9], edge habitats [41], ravines [65], early successional forests, wetlands, wet meadows [83], floodplain forests [83,114], and the margins of ponds and lakes [114]. One source reports Japanese knotweed spreading from roadsides into adjacent forests in New York [73].

Descriptions of characteristics of sites with Bohemian knotweed are lacking in the literature (2010). One source reports it escaping cultivation and establishing on riverbanks, roadsides, garden dumps, and disturbed ground in western Washington [153].

Elevation: There is little information regarding the elevational limits of the 3 knotweeds in North America (2010). One flora reports that giant knotweed occurs from 0 to 1,800 feet (0-550 m) in North America [42]. Japanese knotweed was reported from 4,000 to 6,000 feet (1,220-1,830 m) in Utah [147] and at "low" elevations in Colorado [146]. In Japan, the upper elevation limit of Japanese knotweed is approximately 8,200 feet (2,500 m), with seedling survival decreasing as elevation increases [80].

Climate: The 3 knotweeds encounter a variety of climates throughout their North American distribution. In Washington where all 3 knotweeds occur, the average monthly maximum and minimum temperatures are 60 °F (15 °C) (August) and 40 °F (5 °C) (January). Annual precipitation averages 72 inches (1,820 mm), of which 27 inches (680 mm) falls as snow [136]. In the United States, Japanese knotweed appears to be established in all areas with more than 20 inches (>500 mm) mean annual precipitation (review by [102]).

Several sources suggest that the 3 knotweeds are limited by climate or weather events ([74,87], reviews by [7,11]). Aboveground shoots are highly susceptible to both late spring and early autumn frosts, which cause leaf drop, while the rhizome systems are able to survive in frozen soils. Early spring frosts often cause dieback, followed by regeneration from rhizomes (review by [7]). Short growing seasons and frosts that damage rhizomes also limit the ability of Japanese knotweed plants to store reserves for winter survival (review by [11]). However, one source reports that Japanese knotweed rhizome fragments dug from the ground and left out over winter were still able to regenerate [25]. At field experiment sites in Pennsylvania, giant knotweed seedlings not protected by experimental light barriers experienced early frost damage, while those under light barriers grew into October [87]. In Japan, Japanese knotweed seedlings with a dry weight of <10 mg were unable to survive a winter at either 4,600 feet (1,400 m) or 8,200 feet (2,500 m); seedlings exhibited 100% overwinter survival when dry weight was =40 mg. Survival was higher at 4,600 feet (1,400 m) where growing seasons were longer and winter temperatures were higher than at 8,200 feet (2,500 m) [80]. In the United Kingdom, Japanese knotweed plants were vulnerable to spring winds that damaged undeveloped leaves (review by [11]).

Some sources predict an expansion in the range of Japanese knotweed in Europe with the increasing temperatures expected from global climate change (review by [7]). Reports of recent high seed production by the 3 knotweeds in Europe could be partially due to warmer climate; as a late-season flowerer, seed production is reportedly limited by early-season frosts [3]. For information on how climate change might increase the invasiveness of Japanese knotweed in the United Kingdom see [10].

In North America, results from a Massachusetts study suggest that warming climates may allow additional Japanese knotweed seedling survival in places where cold temperatures currently limit survival. However, shade was found to be more limiting to seedling survival than climate in this study [44].

Soils: Japanese (reviews by [11,102]) and giant knotweed (review by [118]) are not limited by soil type. In its native range, Japanese knotweed commonly occurs on basaltic gravels [80]. In New Jersey, Japanese knotweed was found on sites with a range of soil textures, including silt, silt loam, and beach sand [74]. In the central Cascades of Washington, Japanese knotweed established on gravelly sandy loam [40]. Near Washington, DC, Japanese knotweed occurred on sandy loam, sand, and loamy sand [104].

Little information is available on soil nutrient preferences of the 3 knotweeds (2010). Japanese knotweed tolerated a range of soil nutrient levels in New Jersey [74]. In United Kingdom, Japanese knotweed established on relatively nutrient-rich soils (review by [11]).

Japanese knotweed can tolerate low soil pH; it is not clear if this pattern applies to giant or Bohemian knotweed. A guide for revegetating minespoils reports that Japanese knotweed tolerates extremely acidic soil, with a lower pH limit of 3.5 [141]. It grew in a range of soil pH in New Jersey (4.5 to 7.4) and was not limited by pH in the United Kingdom (review by [11]). Japanese knotweed had high survival (80%) 4 growing seasons after planting on acid surface-mine spoils in eastern Kentucky [91]. The Russian Agricultural Ministry suggests the avoidance of acidic soils when planting giant knotweed (review by [118]).

On Long Island, New York, Japanese and Bohemian knotweed have established in salt marshes. Greenhouse experiments demonstrated that individual plants varied in their response to different levels of salt exposure, suggesting that salt tolerance is not genetically predetermined but is determined by exposure [97]. In New Jersey it was noted that Japanese knotweed tolerated salt spray from the ocean [74].

The prevalence of the 3 knotweeds in riparian areas suggests tolerance of high soil moisture. Most herbarium specimens from North America documented Japanese knotweed in locations with high soil moisture (review by [7]). In New Jersey, Japanese knotweed often established near streams where soils were likely saturated with water through a majority of the growing season [74]. In New York, Japanese knotweed occurred on both dry and moist ruderal sites [35]. The occurrence of Japanese knotweed on dry ruderal sites suggests an ability to tolerate low soil moisture, though one study attributed slow seedling growth to dry local conditions [44]. The Russian Agricultural Ministry suggested avoiding excessively damp soils when planting giant knotweed (review by [118]). In the Czech Republic, it was reported that giant knotweed prefers sites with plenty of water [79].

SUCCESSIONAL STATUS:
The presence of giant [42,78,115], Japanese ([12,53,65,73,78,83,98,114,115], reviews by [11,88,102]), and Bohemian [115,153] knotweed in disturbed areas suggests a preference for early-successional sites. In their native ranges, giant [131] and Japanese ([131], review by [7]) knotweed are early-successional species, often among the first species to colonize recent lava flows. In the Pacific Northwest, all 3 knotweeds commonly established on freshly disturbed soils, like floodplains and cobble bars, following flooding [115]. One review listed plant communities where Japanese knotweed could establish in mountainous ecoregions of the northwestern United States. In all cases, disturbance was listed as a requirement for establishment [88]. Another review stated that Japanese knotweed is promoted by soil disturbance and high light environments in the southern United States; it does not appear to establish in undisturbed sites or forest interiors, though it may be able to establish in canopy gaps created by natural or human-made disturbance [38].

Some evidence suggests that giant [136] and Japanese ([19,81,103], reviews by [11,38,102]) knotweed grow better with more light. In Massachusetts, Japanese knotweed grew in full sun to full shade, but was considered "hardier" in full sun [81]. In growth chamber experiments, Japanese knotweed plants in high light had greater leaf area ($P<0.05$) and belowground biomass ($P<0.001$) than those in low light [103]. Two-year-old Japanese knotweed rhizomes planted on streambanks near Washington, DC, exhibited significantly higher survivorship ($P<0.05$) and greater stem growth ($P<0.001$), basal stem diameter ($P<0.001$), and stem height ($P<0.01$) than rhizomes planted in a forest understory. Streambank sites had significantly higher light levels than understory sites ($P<0.01$) [103]. Managers treating Japanese knotweed in southwestern Washington found smaller stems and plants in deeply shaded areas compared to more open areas [19]. Results from both field (full and 50% sun) and growth chamber (high and low light) experiments in North Carolina documented that giant knotweed plants grown in high-light conditions had higher photosynthetic rates than those grown in low-light conditions ($P<0.05$) [89].

Despite these findings, all 3 knotweeds have been documented growing in shady understories. One review reports giant knotweed growing well in semi-shaded places and along the edges of forests [118]. In northwestern Washington giant knotweed was found in low terrace and floodplain forests with an average canopy cover of 47.2% (range 2.5% to 85.0%) [136]. In Nova Scotia, Japanese knotweed did not appear to spread from shaded into open areas [98]. Along the Hoh River in northwestern Washington, Bohemian knotweed was found to grow slowly but persistently in the complete shade of red alder or willow, as well as under a dense, coniferous canopy [111].

Successional role: Changes in native plant cover or species richness in areas where the 3 knotweeds have established [13,48,57,77,136] suggest they could alter the successional trajectories of native plant communities (see Impacts). Some sources identify Japanese knotweed as a nursery plant in early successional communities, particularly in its native range, because it facilitates soil development and the establishment of later successional species (review by [7]).

FIRE EFFECTS AND MANAGEMENT

SPECIES: Polygonum sachalinense, P. cuspidatum, P. × bohemicum

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- FIRE EFFECTS
- FUELS AND FIRE REGIMES
- FIRE MANAGEMENT CONSIDERATIONS

FIRE EFFECTS:
Immediate fire effect on plant: As of 2010, little information was available regarding immediate fire effects on

these 3 knotweeds. Russian forestry officials who burned a stand of giant knotweed to test its potential to act as a fire break were not able to get more than a small percentage of the foliage to burn and concluded that the area with giant knotweed "suffers little from the effect of fire" (Russian Agricultural Ministry cited in [118]) (see Fuels for more information). Fire likely only top-kills the 3 knotweeds and does little damage to belowground parts (see Fire adaptations and plant response to fire). Seedlings may be killed by fire if they have not developed substantial underground reserves. As of 2010, no information was available on fire effects on or heat tolerance of seeds of the 3 knotweeds.

Postfire regeneration strategy [120]:

Rhizomatous herb, rhizome in soil
Initial off-site colonizer (off site, initial community)

Fire adaptations and plant response to fire:

Fire adaptations: As of 2010, there was no published information regarding fire adaptations of the 3 knotweeds. The information presented here is inferred from reported botanical traits.

The ability of the 3 knotweeds to sprout, particularly from rhizomes [45,74,100,116], roots [87], and root crowns ([31,121], review by [11]), suggests that top-killed plants are likely to regenerate vegetatively following fire (see Vegetative regeneration). The deep root penetration and lateral spread of rhizomes of giant [79,115], Japanese ([115], reviews by [7,11]), and Bohemian [115], knotweed (see Botanical description) likely improve their chances of surviving and sprouting following fire. Japanese knotweed rhizomes may sprout from as deep as 3 feet (1 m) (review by [7]). Rhizome sprouting may occur as soon as 1 week after fragmentation, as was seen in Japanese knotweed rhizomes from the Slovak Republic [100], or as long 1 to 3 years, as was reported following herbicide treatments of unidentified knotweeds in northwestern Oregon [116]. Some evidence suggests that Japanese knotweed rhizome sprouting may increase under high-light conditions [104] (see Vegetative regeneration), which are likely following fire. Fire season may not impact the ability of the 3 knotweeds to regenerate vegetatively; in New Jersey field experiments, planted Japanese knotweed rhizomes were able to sprout throughout the growing season [74]. However, fires occurring just prior to senescence in the fall could impact resource allocation to underground reserves; Japanese knotweed plants near Washington, DC, allocated most resources to belowground parts after 28 August [103].

Giant and Japanese knotweed exhibit rapid growth [79,98,115,136] (see Plant growth), which would facilitate recovery following top-kill. There is also some evidence to suggest that high-light conditions favor Japanese ([19,81,103], reviews by [11,38,102]) and giant [136] knotweed growth (see Successional status).

It is not clear whether postfire conditions would be conducive to germination or seedling establishment of these 3 knotweeds. Some studies suggest that giant knotweed seed germination is favored by disturbance [87,129] (see Germination). Seedling establishment is generally poor in the field ([44,74,87], review by [102]) but may be favored by the high-light conditions [44,74] and low cover of other vegetation [44,87,141,151] that may occur following fire. However, lack of moisture [44] may inhibit seedling survivorship (see Seedling establishment and growth). As of 2010 this topic has not been studied.

Giant [42,78,115], Japanese ([12,53,65,73,78,83,98,114,115], reviews by [11,88,102]), and Bohemian [115,153] knotweed commonly establish in disturbed areas (see Successional status) though it is not clear what characteristics of disturbed areas promote the 3 knotweeds or would be similar to postfire conditions.

Plant response to fire: As of 2010 no studies were available documenting the response of the 3 knotweeds to fire. The one report of burning giant knotweed stands in Russia concluded that giant knotweed "suffers little from the effect of fire" and no observations were made beyond immediate and minimal foliage damage (Russian Agricultural Ministry cited in [118]) (see Fuels for more information). It is known that plant parts may be destroyed by fire, as burning is an advocated method of disposing of removed Japanese knotweed parts ([27,32], review by [24]) or soil containing rhizome fragments (review by [73]).

FUELS AND FIRE REGIMES:

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

Fuels: It is not clear whether occurrence of the 3 knotweeds changes the fuel characteristics of invaded plant communities. Fuel characteristics of plant communities could potentially be altered in areas where the 3 knotweeds exhibit fuels traits (e.g., flammability, fuel loading, plant architecture), densities, and/or growth patterns differing from those of native vegetation.

Laboratory analyses suggest that Japanese knotweed foliage and stems are not particularly flammable [33]. Giant knotweed appears to exhibit similar characteristics. In the Czech Republic, the water content of spring giant knotweed stems reached values as high as 1,800% of dry mass. After 2 months, stem water content decreased and matched that of leaves, at 400% of dry mass [79]. In Russia, giant knotweed stems and leaves reportedly had an 82% moisture content. Consequently, Russian forestry officials investigated the use of 7-foot-tall stands of giant knotweed (referred to as Sakhalin buckwheat) as a live fire break to protect tree plantations. The testing occurred on a hot, dry day with a mild south wind. "The reaction of Sakhalin buckwheat thicket to forest fire was tested by igniting a brush fire in the wind direction 7 feet from the thicket edge. The incendiary fuel was brushwood, pine branches, drenched copiously with kerosene. Set ablaze on the buckwheat thicket side of the plantation, the brush fire whipped by wind burned fiercely for 30 minutes. The test established that buckwheat thickets minimize the effect of fire and at 8-inch depth localize it. The fire does not spread across the thicket to the tree plantation growing on the other side of the protective green zone. The zone itself suffers little from the effect of fire. Only 10% of the foliage embraced in flames, was curled up from burning. The thicket continued to stand upright. The commission concluded that thickets of Sakhalin buckwheat are a completely effective barrier against low forest fires and can be recommended for planting in fireproof zones and banks" (Russian Agricultural Ministry cited in [118]).

As of this writing (2010) no studies have documented fuel characteristics of litter of the 3 knotweeds. Litter accumulations can be high in some stands. In old fields in south-central New York, litter depth was higher in Japanese knotweed stands compared to outside the stands, though the litter material was almost all large, fibrous stems ($P<0.05$) [77]. In Pennsylvania it was noted that dense litter built up every autumn under riparian stands composed of all 3 knotweeds, though litter was generally washed away by summer [87]. In riparian forests of northwestern Washington, total mass of autumn litterfall did not differ between plots with and without established giant knotweed, though litter composition varied [136].

Occurrence of the 3 knotweeds may result in changes in aboveground vegetative structure that could impact fuel characteristics. Changes in vegetative architecture were observed in old fields in south-central New York. Vegetation height increased abruptly at the edge of Japanese knotweed stands, and average height of the first leaf was higher in Japanese knotweed stands compared to outside of stands [77]. In Belgium, plots with Japanese knotweed had higher aboveground biomass compared to plots with native vegetation (2.95 vs. 0.56 kg/m²) [29,30]. The 3 knotweeds often cover extensive areas [31,44,53,61,103,107,116,125] and may dominate local vegetation ([73,87], review by [118]) (see Plant growth).

Fire regimes: It is not known what type of fire regime the 3 knotweeds are best adapted to. They are common in riparian areas in many parts of North America, and fire regimes in riparian areas are often related to the fire regimes of adjacent upland communities. Thus fire regimes for plant communities with the 3 knotweeds could be quite variable. See the Fire Regime Table for further information on fire regimes of vegetation communities in which the 3 knotweeds may occur.

FIRE MANAGEMENT CONSIDERATIONS:

Preventing postfire establishment and spread: Because both seeds [103] (see Seed dispersal) and plant parts ([2,93,112,136], review by [7]) (see Vegetative regeneration) are often dispersed by water, it is possible that the 3 knotweeds may colonize burned areas adjacent to watercourses. Monitoring of burned riparian areas downstream from known populations of the 3 knotweeds is advised.

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 seed and 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: [2,17,50,134].

Use of prescribed fire as a control agent: As of this writing (2010), no information was available on the use of prescribed fire to control the 3 knotweeds. One review suggests that prescribed fire, like mechanical treatments, would kill aboveground material but not impact belowground plant parts [104]. Another source states that fire is "a poor control method, and seems not to affect the viability of the underground rhizomes" (G. Hendry personal communication cited in [11]). A third source reports that Japanese knotweed is "immune" to fire [5].

If fire were to be used as a control agent, it is likely that, as with other control options, managers would need multiple treatments within a single growing season [101,115,116] and/or several years of treatment ([103,109,115,116], review by [24]) to be effective (see Control).

MANAGEMENT CONSIDERATIONS

SPECIES: Polygonum sachalinense, P. cuspidatum, P. × bohemicum

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FEDERAL LEGAL STATUS:
None

OTHER STATUS:
Giant, Japanese, and Bohemian knotweed are listed as noxious in several states. Information on state-level noxious weed status of plants in the United States is available at Plants Database.

IMPORTANCE TO WILDLIFE AND LIVESTOCK:
Palatability and/or nutritional value: Giant and Japanese knotweed have some value as livestock fodder (review by [79]); however, rhizomes are toxic to some livestock (review by [11]). Giant knotweed is reportedly rich in protein, calcium, and albumin (review by [118]). In the United Kingdom, domestic sheep, cattle, and horses browse Japanese knotweed shoots (review by [11]). Experimental Japanese knotweed plants in New Jersey were eaten by wild rabbits, white-tailed deer, and woodchucks [74]. In its native range, giant knotweed is eaten by herbivorous animals including deer, roe buck, boars, and hares (review by [118]). In New Jersey, Japanese knotweed foliage was consumed by leaf-eating insects including Japanese beetles [74]. One author observed that Bohemian knotweed was essentially herbivore-free in North America, with the exception of the Japanese beetle [107].

House sparrows consumed Japanese knotweed seeds in Britain (review by [11]). In Pennsylvania, partial consumption of seeds of all 3 knotweeds was attributed to birds and terrestrial insects [87].

Cover value: There is little information to suggest that the 3 knotweeds provide suitable cover for wildlife and livestock. In the United Kingdom, an unidentified knotweed provided a resting spot for otters and vegetative cover for some birds (review by [24]).

OTHER USES:
The young shoots of Japanese knotweed are edible to humans and can be steamed and eaten like asparagus [36,56,69,78]. Tender parts of Japanese knotweed rhizomes may be peeled, boiled, and buttered like potatoes [36]. The leaves of Japanese knotweed were used as a substitute for tobacco by troops in World War II (review by [11]).

The knotweed genus (*Polygonum*) produces a wide variety of secondary compounds that have been evaluated for medicinal properties including cancer prevention and antifungal and antimicrobial activity (reviewed by [107]). The rhizomes of both Japanese and giant knotweed have been used to induce menstruation, as a cathartic, and as a laxative in China, and for painkilling and to reduce bleeding in Japan [69]. Japanese knotweed is made into "Itadori", or "well-being", tea in Asia because it contains high levels of the compound resveratrol, reported to reduce the risk of cancer, heart ailments, and health issues related to estrogen imbalance [20].

In the Pacific Northwest, Japanese and giant knotweed are valued for honey production. They provide a late-season flower source and the resulting honey is higher in antioxidants than honey made from other plants [90]. Laboratory experiments determined that extracts from giant knotweed may have the potential to be useful for restricting the fish pathogen pasteurellosis, preventing large economic losses in the aquaculture industry [69]. Giant and Japanese knotweed are also used for firewood and match sticks (review by [79]). In rehabilitation efforts, Japanese knotweed has been used as a sand dune stabilizer (review by [87]) and as a heavy metal accumulator on contaminated soil (review by [7]).

IMPACTS AND CONTROL:

Impacts: Studies in both North America and Europe have documented a decrease in native plant cover or species richness in areas where giant [13,57,136], Japanese [13,48,57,77], or Bohemian [13,57] knotweed have established. Mechanisms suggested for native plant exclusion include the accumulation of leaf and stem litter (review by [53]), nutrient (review by [52]) and light ([107], reviews by [52,53]) limitation, and allelopathy [107,143].

Stand of Bohemian knotweed in Washington.
Photo courtesy of 10,000 Years Institute,
www.10000yearsinstitute.org

Establishment of giant [136] and Japanese [72] knotweed may lead to changes in leaf litter dynamics. Japanese knotweed establishment may lead to high levels of some soil nutrients [29,30]. Studies in North America and Europe have documented changes in faunal communities, including a decrease in the diversity and abundance of invertebrates in areas with giant [66,128] and Japanese [48,72] knotweed, and a decrease in the abundance and fitness of green frogs in an area with Japanese knotweed [77]. Changes in fungal assemblages were reported in areas with Japanese knotweed [72]. In contrast, one study in Idaho found that instream leaf decomposition rates, microinvertebrate colonization, abundance, and species richness of some types of microinvertebrates did not differ in leaf litter containing Japanese knotweed compared to litter containing leaves of native gray alder and black cottonwood [14].

One study supported the assertion that giant knotweed displaces riparian species and has cascading effects on the structure and function of riparian systems. In northwestern Washington, riparian forests with higher giant knotweed stem density had lower juvenile conifer ($P<0.01$), juvenile red alder ($P<0.001$), juvenile broadleaved tree ($P<0.001$), and shrub ($P<0.01$) stem density; lower herb ($P<0.01$) and native herb ($P<0.001$) cover; and lower shrub ($P=0.001$), herb ($P<0.001$), and native herb ($P=0.002$) species richness compared to forests with lower giant knotweed stem density. Total mass of autumn litterfall did not differ between plots with and without established giant knotweed, but sites with giant knotweed had 70% loss in leaf litter mass of native species ($P<0.001$). Giant knotweed and native species differed greatly in C:N ratios in fresh and senescent leaves. Fresh giant knotweed leaves had 61% to 65% lower C:N ratios than red alder and willow leaves. In contrast, senescent giant knotweed leaves had 38% to 58% higher C:N ratios than leaves of native taxa. Estimates of nitrogen reabsorption prior to litterfall were high for giant knotweed (76%) and low for native species (red alder (5%) and willow (33%)). Consequently, areas dominated by giant knotweed had less nitrogen available for uptake by both terrestrial and aquatic organisms than areas dominated by native species. The authors suggested that changes in native species density and diversity and differences in litter quality resulting from giant knotweed establishment likely have cascading effects on the structure and function of riparian systems, though this hypothesis was not tested [136].

In old fields in south-central New York, one study examined how changes in plant diversity and stand structure resulting from Japanese knotweed establishment negatively impacted the foraging success of green frogs. Green frogs in areas with established Japanese knotweed failed to gain mass, while more than 50% of green frogs in areas without established Japanese knotweed gained mass. The authors suggested that the lower success of green frog foraging was due to declines in populations of invertebrate prey, though this hypothesis was not tested. The authors did document several changes in vegetative characteristics that could have influenced invertebrate populations and the ability of green frogs to forage. No native plants were found 33 feet (10 m) inside Japanese knotweed stands. Vegetation height increased abruptly at the edge of Japanese knotweed stands, from an average of 33 inches (84 cm) outside the stand to an average of 78 inches (198 cm) at the stand's edge. Average height to first leaves was higher in Japanese knotweed stands compared to vegetation outside of stands. Litter was deeper in Japanese knotweed stands, with most litter material consisting of large, fibrous stems [77].

Other ecological impacts of the 3 knotweeds include reduced recruitment of in-stream woody debris (review by [111]) and reduced habitat quality for wildlife (reviews by [52,87,111]). Establishment of these knotweeds may also increase the risk of streambank erosion [12] or flooding when decaying shoots are washed into rivers during high flows (reviews by [7,87]). Rhizomes and shoots may displace foundations, walls, pavement, and drainage works (review by [7]) or limit recreational access to riparian areas ([39], review by [52]). In the United Kingdom, lack of Japanese knotweed control in urban areas may lead to an increased risk of an area being "used as an illicit litter dump or as a refuge for vandals and muggers" [101].

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 control method is employed [18]. 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 [75]. Information presented in the following sections may not be comprehensive and is not intended to be prescriptive in nature. It is intended to help managers understand the ecology and control of the 3 knotweeds in the context of fire management. For more detailed information on the control of giant, Japanese, or Bohemian knotweed, consult the references cited here or local extension services. For a review of control recommendations for the 3 knotweeds in the Pacific Northwest, including commentary on hand cutting, mowing, digging, covering, goat browsing, and many methods of herbicide application, see [115]. For a review of control methods for Japanese knotweed in the United Kingdom plus information on preventing establishment, see [24].

Several sources suggest that the 3 knotweeds are difficult to eradicate [31,59,98,109,142] due to their extensive root and rhizome systems [115], the ability of multiple plant parts to regenerate vegetatively [31,115], sprouting immediately [115,116] or 1 to 3 years after treatment [116], and the large scale of stand establishment [115]. Control of the 3 knotweeds may require multiple treatments within a single growing season [101,115,116] or several years of treatment ([103,109,115,116], review by [24]) to be effective. Careful disposal of removed plant parts is important to prevent downstream transport [31] or reestablishment. Control and eradication efforts always face the potential for floods or high water to expose and/or transport buried rhizomes or propagules from upstream populations [109].

Fire: For information on the use of prescribed fire to control these species, see Fire Management Considerations.

Prevention: One way to minimize the establishment and spread of the 3 knotweeds is to avoid planting them. The Tennessee Exotic Pest Plant Council recommends the following native plant species as alternatives to Japanese knotweed in landscaping: goat's-beard (*Aruncus dioicus*), Culver's root (*Veronicastrum virginicum*), white snakeroot (*Ageratina altissima*), black cohosh (*Actaea racemosa*), coastal sweetpepperbush (*Clethra alnifolia*), and Virginia sweetspire (*Itea virginica*) [123]. Native alternatives to Japanese knotweed in the mid-Atlantic states include Virginia sweetspire, coastal sweetpepperbush, maleberry (*Lyonia ligustrina*), silky dogwood (*Cornus amomum*), fragrant sumac (*Rhus aromatica*), or flameleaf sumac (*R. copallinum*) [122].

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 [75,106] (e.g., avoid road building in wildlands [133]) and by monitoring several times each year [64]. 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 [59].

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 [134]. See the Guide to noxious weed prevention practices [134] for specific guidelines in preventing the spread of weed seeds and propagules under different management conditions.

Cultural control: No information was available as of this writing (2010).

Physical or mechanical control: For a review of mechanical control recommendations for the 3 knotweeds in the Pacific Northwest see [115]. Physical or mechanical control of the 3 knotweeds is complicated by extensive rhizome systems that allow plants to regenerate after single or multiple mechanical control attempts [101,103,115]. In the Pacific Northwest, the 3 knotweeds sprouted following cutting, mowing, and digging, sometimes within a week of mechanical treatments [115]. In the United Kingdom, cut Japanese knotweed stems produced new shoots from dormant buds on the "rootstock". Plants cut twice over 2 years had sufficient reserves in the rhizomes for "vigorous" regeneration [101]. Also in the United Kingdom, cutting Japanese knotweed stands increased both the lateral spread of clumps and stem density (review by [11]).

Hand-pulling was considered an ineffective means of Japanese knotweed control in the United Kingdom (review by [11]). In the United Kingdom, 3 years were needed to eradicate 2 small Japanese knotweed plants by hand pulling. In established riverbank stands, 10 years of hand pulling reduced Japanese knotweed cover but did not eliminate it. Two years of biweekly mowing in the growing season were considered effective at controlling Japanese knotweed [5]. In greenhouse studies near Washington, DC, grubbing was not an effective control strategy for Japanese knotweed; it did not remove all rhizome fragments and Japanese knotweed was able to regenerate. Grubbing also exposed large amounts of mineral soil, facilitating the establishment of other nonnative plants [103]. In the Czech Republic, mowing twice in the growing season and both high- and low-intensity grazing by domestic sheep and goats were effective at reducing the survival of planted rhizomes of all 3 knotweeds ($P<0.001$) [15].

In greenhouse studies near Washington, DC, cutting of Japanese knotweed stems originating from rhizome fragments led to a decrease in belowground biomass when the plants were cut between 5 June and 28 August ($P<0.05$). Multiple cuttings led to greater decreases in belowground biomass. In this experiment, 5 cuttings were needed to cause a net depletion of belowground biomass. The authors suggested that cutting should be done at least 8 weeks prior to senescence; otherwise the treatment would have no impact on underground reserves [103].

Covering or smothering the 3 knotweeds has had variable results. Field observations in New Jersey documented one Japanese knotweed plant emerging through 3 inches (8 cm) of asphalt [74]. A horticultural journal reports that giant and Japanese knotweed may push through 2 inches (5 cm) of asphalt but suggests that smothering giant and Japanese knotweed plants with several layers of black plastic topped with asphalt, gravel, or patio stones may be an effective control method [92]. One source from the Pacific Northwest reports that covering patches of the 3 knotweeds is not an effective control method [115].

Industrial composting methods kill all plant parts of Japanese knotweed, but home compost piles are not likely to reach lethal temperatures [32].

Biological control: Biological control of invasive species has a long history that indicates many factors must be considered before using biological controls. Refer to these sources: [137,149] and the Weed control methods handbook [132] for background information and important considerations for developing and implementing biological control programs.

Managers in the United Kingdom are actively pursuing biocontrol programs for Japanese knotweed [105]. Insects from its native range may be useful in controlling Japanese knotweed ([145], review by [24]). In North America, signs of insect herbivory are low for Japanese [23] and Bohemian [107] knotweed. One source identified a number of potential insect, slug, and snail biocontrol agents for "knotweeds" in North America, though field observations in New York, Oregon, and Washington suggested that herbivore damage was low [52].

Chemical control: 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 [21]. See the Weed control methods handbook [132] for considerations on the use of herbicides in natural areas and detailed information on specific chemicals.

Several sources suggest that herbicide application is the most effective means of controlling the 3 knotweeds in North America [31,73,109,111,112], though their establishment in riparian areas presents challenges to chemical control programs [73,111] and multiple years of treatment are needed [31,109,110]. For reviews of Japanese knotweed response to herbicides and other chemicals see the following sources: [7,11,101]. For information on intensive programs to chemically control the 3 knotweeds in North America, see the following sources: [31,40,73,109,110,111,112].

The 3 knotweeds may sprout in the growing season following some herbicide applications [31,110,115]. In Washington, numerous Bohemian knotweed root crowns sprouted the growing season following foliar herbicide application. Follow-up cut-stem treatments and stem injection treatments in the 2nd and 3rd season after initial treatment successfully killed plants, though some stems still survived into the 4th season [31].

Along the Hoh River in northwestern Washington, herbicide injection treatments reduced the number of Bohemian knotweed plants, but the resulting shift from large, multi-stemmed clumps of Bohemian knotweed to small, single-stem clumps made location of plants and subsequent control efforts difficult [112]. Effective management required large crews, intensive surveys and mapping, and multiyear efforts, all with the possibility that floods or high water might transport plants from upstream to control sites or expose buried rhizomes [109]. Managers also reported some concern that the injected herbicide could spread into adjacent soils and harm nearby native vegetation. Managers concluded that Bohemian knotweed eradication would likely take =10 years in this area [111].

Integrated management: Several sources report the use of integrated management techniques in the control of the 3 knotweeds. Along roadsides in New York, one author recommended management strategies that included both direct control of Japanese knotweed and the promotion of native vegetation [73]. In riparian areas in northwestern Oregon, managers used patch size, patch location, time of year, and landowner preference to determine control strategies for Japanese and giant knotweed. Integrated methods included foliar and stem herbicide application, spring stem cutting, and manual removal and digging of rhizomes. Adaptive management led to a 89.6% reduction in number of stems over 8 years of treatments. However, control efforts were not successful in eradicating any patch with >573 stems through the use of any treatment regime, even after up to 9 treatments [116]. Reports from Europe suggest that using a combination of mechanical digging and herbicide application led to a greater reduction in Japanese knotweed plant density, plant height, stem diameter, and number of leaves than either treatment alone [25].

APPENDIX: FIRE REGIME TABLE

SPECIES: Polygonum sachalinense, P. cuspidatum, P. ×bohemicum

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The following table provides fire regime information that may be relevant to giant, Japanese, and bohemian knotweed habitats. Follow the links in the table to documents that provide more detailed information on these fire regimes. Because the distribution of these species is likely expanding, published plant community descriptions are few, and fire regimes of riparian areas where they commonly establish may be closely related to fire regimes in adjacent upland communities, readers may want to review the complete FEIS Fire Regime Table.

Fire regime information on vegetation communities in which giant, Japanese, and bohemian knotweed may occur. This information is taken from the LANDFIRE Rapid Assessment Vegetation Models [71], 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	Northern Great Plains	Great Lakes
Northeast	South-central US	Southern Appalachians	Southeast	

Pacific Northwest

- Northwest Grassland
- 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 Grassland					
Marsh	Replacement	74%	7		
	Mixed	26%	20		
Northwest Forested					
Sitka spruce-western hemlock	Replacement	100%	700	300	>1,000
Douglas-fir-western hemlock (wet mesic)	Replacement	71%	400		
	Mixed	29%	>1,000		

California

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
California Grassland					
Herbaceous wetland	Replacement	70%	15		
	Mixed	30%	35		

Southwest

- Southwest Woodland
- Southwest Forested

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

				(years)	(years)
Southwest Woodland					
Pinyon-juniper (mixed fire regime)	Replacement	29%	430		
	Mixed	65%	192		
	Surface or low	6%	>1,000		
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	
Northern Great Plains					
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 Woodland					
Great Plains floodplain	Replacement	100%	500		
Great Lakes					
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 Forested					
Great Lakes floodplain forest	Mixed	7%	833		
	Surface or low	93%	61		
Northeast					
Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
Northeast Forested					
Northern hardwoods (Northeast)	Replacement	39%	≥1,000		
	Mixed	61%	650		
	Replacement	50%	≥1,000		

Northern hardwoods-eastern hemlock	Surface or low	50%	≥1,000		
Beech-maple	Replacement	100%	>1,000		

South-central US

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 Forested					
Southern floodplain	Replacement	42%	140		
	Surface or low	58%	100		
Southern floodplain (rare fire)	Replacement	42%	≥1,000		
	Surface or low	58%	714		

Southern Appalachians

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 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		

Southeast

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
Southeast Forested					
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 [55,70].

REFERENCES: Polygonum sachalinense, P. cuspidatum, P. × bohemicum

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