12 Japanese Knotweed

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PEST STATUS OF WEED

Japanese knotweed (*Fallopia japonica* var. *japonica* [Houtt.] Ronse Decraene) (Fig.1) was introduced to North America in the late 19th century (Pridham and Bing, 1975; Patterson, 1976; Conolly, 1977). It rapidly spread to become a problem weed, mirroring its history in the United Kingdom and Europe where it has been present since the 1840s (Beerling *et al.*, 1994). *Fallopia japonica* is now officially regarded as the most pernicious weed in the United Kingdom (Mabey, 1998), and it is one of only two terrestrial weeds restricted under the Wildlife and Countryside Act 1981, making it illegal to plant it anywhere in the wild. *Fallopia japonica* is becoming widely recognized as a problem in the United States and some legislation to control it has been introduced in Washington state, where it is designated for mandatory control where not yet widespread. In Oregon, its planting is prohibited in at least one county (Washington State Department of Agriculture, 1999; Multnomah County, Oregon Land Use Planning Division, 1998). In other states, including Tennessee and Georgia, the recently established Exotic Pest Plant Councils list *F. japonica* as a species of concern and a "severe threat" (Tennessee Exotic Pest Plant Council, 1996; Murphy,

Figure 1. *Fallopia japonica.* (Photo by L. Seiger.)

2000). *Fallopia japonica* is extremely difficult and expensive to control and is regarded as a serious pest by the public and authorities alike, thanks to coverage by the popular press. There are few people who share the fondness for the plant displayed by its 19th century importers.

Nature of Damage

There is little quantitative information available for the United States, but extrapolation from United Kingdom figures will be indicative.

Economic damage. The costs of the Japanese knotweed invasion in the United Kingdom are likely to be in the tens of millions of dollars per year. The main quantifiable cost is that of herbicidal treatment, which is often quoted in the United Kingdom at around $1.60/m² for a year of repeated spraying of glyphosate (Hathaway, 1999). This does not include the costs of revegetation after herbicide treatment, which would be much greater. It has been estimated that the presence of Japanese knotweed on a development site adds 10% to the total budget, in order to cover removal and legal disposal of the topsoil contaminated with viable root material (T. Renals, pers. comm.). Further costs include repairs of flood control structures (Beerling, 1991a) and the replacement of cracked paving and asphalt through which the plant has grown. For example, one supermarket in the United Kingdom had to spend more than $600,000 to resurface a new parking lot through which knotweed was growing. As is often the case the social cost is impossible to quantify, but a knotweed invasion can affect regional redevelopment plans and damage the tourism industry through obstruction of roadside vistas and reduced access to rivers.

Costs in the United States are expected to be comparable. Again, costs include control, usually through application of herbicide, direct damage to structures, and indirect damage associated with in-

creased flooding and reduced amenity value of land occupied by Japanese knotweed. It has been estimated that about $500 million is spent each year on residential exotic weed control in the United States and double that amount is spent on golf courses (Pimentel *et al.*, 2000). To be effective, Japanese knotweed control probably will need to be undertaken on a watershed-wide basis, as is being done with the ecologically similar *Arundo donax* L. in California (D. Lawson, pers. comm.). Additionally, *F. japonica* has recently been found as a crop weed in Missouri, adding agricultural losses as a potential cost attributable to this weed (Fishel, 1999).

Ecological damage. Japanese knotweed spreads quickly to form dense thickets that exclude native species and are of little value to wildlife, leading to it being described as an environmental weed (Holzner, 1982). Beerling and Dawah (1993) point out that "…if maximizing phytophagous insect diversity is considered important on nature reserves then clearly *F. japonica* represents a threat to the aims of the conservationist." The extensive rhizome system of this weed can reach 15 to 20 m in length (Locandro, 1973) and enables the plant to achieve early emergence and great height, which combine to shade out other vegetation, and reduce native species diversity (Sukopp and Sukopp, 1988). At the end of the season, a mass of dead stems remains that further inhibits native plant regeneration and leaves river banks vulnerable to erosion as well as to flooding (Child *et al.,* 1992). Such flooding facilitates the further spread of propagules downstream in the form of fragments of stem and rhizome that rapidly colonize scoured banks and islands. Additionally, the fibrous stems are slow to decompose and may alter rates of decomposition (Seiger, 1997). Once established, *F. japonica* is very difficult to eradicate and removal efforts may have further adverse impacts on the soil or other plants. In arid areas of the United States, *F. japonica* has the potential to have significant detrimental effects in scarce and already stressed riparian systems (Seiger, 1997).

Extent of losses. The damage attributed to *F. japonica* in the United States has not been quantified, but is probably greater than generally recognized. Because this plant invades valuable wetland habitat (a significant portion of which has already been lost), it is of particular concern. Large stands have been noted in western Pennsylvania, in particular along the banks of the Ohio and Allegheny Rivers and on

the islands in these rivers where it occupies hundreds of acres of wetlands, stream banks, and hillsides (Wiegman, pers. comm.). It is present on at least two sites belonging to the Pennsylvania Chapter of The Nature Conservancy (Long Pond in the Poconos and Bristol Marsh, an urban preserve near Philadelphia) and has become a problem in creeks in suburban Philadelphia (Broaddus, pers. comm.). *Fallopia japonica* also is a serious problem in other eastern states, including New York, New Jersey, Maryland, and Virginia, where it spreads primarily along river banks, but also grows in wetlands, waste places, along roadways, and in other disturbed areas (Muenscher, 1955; Conolly, 1977; Beerling, 1990; Mehrhoff, 1997; Virginia Native Plant Society, 1999).

Geographical Distribution

Fallopia japonica has spread through most of North America (Fig. 2) and has been observed as far north as Alaska. Its southern distribution extends into Louisiana in the east and to central California in the west. Found throughout the midwestern and much of the western United States, it is particularly abundant in the eastern United States and in the coastal areas of Washington and Oregon (Patterson, 1976; Locandro, 1978; Pauly, 1986; Seiger, 1997; USDA, NRCS, 1999). Its Canadian distribution includes British Columbia and most of eastern Canada (Seiger, 1997; USDA, NRCS, 1999).
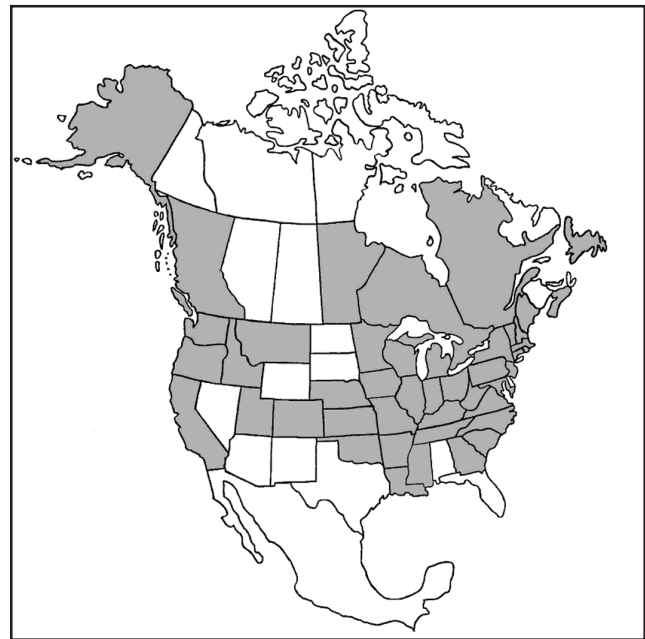
Figure 2. Current distribution of *Fallopia japonica* in North America. (L. Seiger.)

In the United Kingdom, *F. japonica* has spread widely, occurring in more than half of the 10 x 10 km quadrats in the national grid (Biological Records Centre, Monkswood). Stands range in size from individual plants to clumps of more than 500 m^2 (Palmer, 1990). It also is a concern in several other European countries including France, Germany, the Czech Republic and Norway. Its spread in Europe shows the typical exponential invasion pattern (Pysek and Prach, 1993).

BACKGROUND INFORMATION ON PEST PLANT

Taxonomy

Synonyms of *Fallopia japonica* var. *japonica* (Houtt.) Ronse Decraene include *Reynoutria japonica* Houtt. var. *japonica*, *Polygonum cuspidatum* Sieb. and Zucc., *Polygonum sieboldii* Vriese, and *Polygonum reynoutria* Makino. Common names include: Japanese knotweed, Japanese bamboo, Mexican bamboo, Japanese fleece flower, donkey rhubarb, Sally rhubarb, German sausage, and pea-shooter plant.

Japanese knotweed was independently classified as *Reynoutria japonica* by Houttuyn in 1777 and as *P. cuspidatum* by Siebold in 1846. It was not until the early part of the 20th century that these were discovered to be the same plant (Bailey, 1990), which is generally referred to as *Polygonum cuspidatum* by Japanese and American authors. Recent evidence vindicates Meissner's 1856 classification as *Fallopia japonica* var. *japonica* (Bailey, 1990). The two most common introduced varieties are *japonica* and *compacta*. I is the former that is the main problematic weed, and where this paper refers to *F. japonica* it implies *F. japonica* var. *japonica.*

Biology

In the United States, *F. japonica* has been observed growing in a variety of soil types, including silt, loam, and sand, and in soils with pH ranging from 4.5 to 7.4 (Locandro, 1973). In areas where *F. japonica* has been introduced, it is found primarily in moist, unshaded habitats. Distribution maps from the United Kingdom show that it is generally associated with regions of high precipitation (Conolly, 1977). However, Locandro (1973) reported it growing on xeric as well as hydric sites in the United States.

Fallopia japonica requires high light environments and competes effectively for light in such situations. It is found primarily in open sites, and its growth and abundance are depressed in shady sites (Beerling, 1991b; Seiger, 1993). Consequently, it is unable to invade forest (Beerling, 1991b, Seiger, 1993) but the species is present at many forest interior sites in New York, potentially a result of earlier plantings that survived the return of the forest (Blossey, pers. comm.)

After overwintering, shoots appear from underground rhizomes early in the spring around March and April. Rapid growth, which can exceed 8 cm per day (Locandro, 1973), means that full height, which can exceed 4 m, is attained by the early part of summer. Flowering occurs in late August or early September (Fernald, 1950; Muenscher, 1955), leaves senesce after reproduction, and the above-ground parts are killed off by the first frost but stems remain standing into the next growing season.

Although insect pollination, sexual reproduction, and wind dispersal of seed is the dominant method of reproduction and dissemination in its native range, introduced populations rely solely on vegetative means. Seeds can be found, but these rarely germinate in the wild. It has been shown that these populations originate from one male-sterile clone and any seed produced by it must therefore be of hybrid origin (Bailey *et al.*, 1996). These hybrids occur in the United Kingdom in the form of crosses between *F. japonica* and *Fallopia sachalinensis* (F. Schmidt ex. Maxim.) Ronse Decraene, which form the hybrid *Fallopia* x *bohemica* (Chrtek and Chrtková) J. Bailey (Bailey, 1990). *Fallopia japonica* also hybridizes with *Fallopia baldschuanica* (Regel) Holub. (Bailey, 1985, 1988, 1990, 1994). In the United States, hybrids morphologically similar to those between *F. japonica* and *F. baldschuanica* have been grown from seeds collected in the field, but seedling establishment has not been observed in the wild (Seiger, 1993). Fortunately, these crosses form a plant with reduced vigor rather than conferring the benefits of both parents, but backcrossing could result in *F. japonica* regaining the advantages of sexual reproduction.

Since plants can reliably regenerate from less than 5 g of root material, the rhizomes beneath a 1 m^2 stand of knotweed could produce 238 new shoots (Brock and Wade, 1992). Plants also have been observed to regenerate from internode tissue (Locandro, 1973). Such material can regenerate when buried up

to 1 m deep, and shoots have been observed growing through two inches of asphalt (Locandro, 1978; Pridham and Bing, 1975). Dispersal is limited to areas where rhizome fragments can be distributed from existing stands by being washed downstream, or when soil containing rhizomes is transported by humans. *Fallopia japonica* occurs over most of the United States and is increasingly recognized as a major weed.

ANALYSIS OF RELATED NATIVE PLANTS IN THE EASTERN UNITED STATES

Fallopia japonica belongs to the Polygonaceae family of which there are about 49 genera and 1,100 species worldwide. There are approximately 24 genera and 446 species in the United States and Canada, many of which are introduced. Most genera originate in northern temperate regions with only a few from subtropical and tropical areas. The most common genera in the United States are *Polygonum*, *Eriogonum*, and *Rumex* (Zomlefer, 1994). Genera of minor economic importance include *Rheum*, *Fagopyrum*, *Rumex*, and *Coccoloba* for their agricultural products, and a number of other genera used as ornamentals.

The phylogeny of the Polygonaceae is controversial and some of the genera continue to be disputed. However, a recent study indicates that *Fallopia* is among those genera that are distinct (Mondal, 1997). There are seven species of *Fallopia* recorded in the United States: *Fallopia aubertii* (Henry) Holub, *F. baldschuanica*, *Fallopia convolvulus* (L.) A. Löve, *F. japonica*, *F. sachalinensis*, *Fallopia cilinodis* (Michx.) Holub and *Fallopia scandens* (L.) Holub (Kartesz, 1994; USDA, NRCS, 1999). Only the last two are native species. As discussed elsewhere in this text, hybridization occurs between *F. japonica* and *F. sachalinensis,* and between *F. japonica* and *F. baldschuanica* in the United Kingdom and possibly in the United States.

Members of the Polygonaceae comprise a number of cosmopolitan species widely distributed throughout the eastern United States and elsewhere. Many of these species have important wildlife value. The plants and seeds of various species in the closely related genus *Polygonum* are used by birds and small mammals and, in particular, are an important source of food for ducks. Other species of *Polygonum* provide habitat for invertebrates on which ducks feed. Dense stands of *Polygonum* also are used as cover by various birds, small mammals such as muskrats, and deer. Native species that are particularly important to wildlife include the native species *Polygonum pensylvanicum* L., *Polygonum hydropiperoides* Michx., *Polygonum sagittatum* L., and *Polygonum arifolium* L. All grow as herbaceous plants in wetland habitats. The potential effects on these and other closely related species will have to be considered as part of any biological control program.

HISTORY OF BIOLOGICAL CONTROL EFFORTS IN THE EASTERN UNITED STATES

Area of Origin of Weed

Fallopia japonica is native to Japan, China, Korea, and Taiwan (Beerling *et al.,* 1994), while the form *japonica* comes solely from Japan. In Japan, where it is known by the name Itadori, meaning "heals the sick," where it can be found at up to 2,400 m on Mt. Fuji (Maruta, 1983). In the more southerly latitude of Taiwan, the plant grows at altitudes between 2,400 and 3,800 m. Although common on roadsides and riverbanks, it is a natural pioneer of volcanic fumaroles (Hirose and Katajima, 1986), where the soil conditions are extreme. At such sites, it is displaced by other vegetation after 50 years or so (Yoshioka, 1974).

Areas Surveyed for Natural Enemies

So far there have been no comprehensive surveys of natural enemies of Japanese knotweed in the area of origin. However some work has been carried out on groups of natural enemies such as the Lepidoptera (Yano and Teraoka, 1995), and ad hoc collections of fungal pathogens have been made by scientists of CAB International. Emery (1983) made some field observations on natural enemies in the United Kingdom and recorded damage inflicted by the green dock beetle, *Gastrophysa viridula* De Geer, but only after heavy skeletonization of neighboring *Rumex obtusifolius* L. plants. Regional surveys for potential natural enemies were begun in 2000 in the northeastern United States.

Natural Enemies Found

In contrast to the situation in the United Kingdom and United States, damage to *F. japonica* by foliage-feeding invertebrates and pathogens was high in some of the Japanese sites examined by Yano and co-workers in 1991 and 1992 (K. Yano, pers. comm.). At least 12 species of insect herbivores were commonly found on the plant at these sites and many more species of insect herbivores have been recorded on the plant. At least 39 of these are likely to be to be feeding on plant parts other than the flowers (Shaw, 1995).

Stem-mining Lepidoptera, found in the internodal sections of stems of the closely related *F. sachalinensis,* are so numerous that they are regularly used as fishing bait (Sukopp and Starfinger, 1995). Zwölfer (1973) reported complete skeletonization of this plant in the field in 1972, noting that the "apparently specific leaf-feeding chrysomelid beetle *Gallerucida nigromaculata* Baly (Fig. 3) seems to play a role in the natural control of *Polygonum* (*cuspidatum*) and may be a promising candidate for the biological control of *P. cuspidatum* in Europe."

Figure 3. Leaf feeding damage to *Fallopia* sp. in Japan 1999. (Photo by J. Bailey.)

In Japan, *F. japonica* also is attacked by a suite of fungal pathogens in the field, including *Puccinia polygoni-weyrichii* Miyabe, whose erupting uredinia are shown in Fig. 4. It is apparent that a combination of insect and fungal agents severely damages the plant in its native range, reducing it to an innocuous member of the flora in competition with the other members of the "giant herb" community common in Japan.

Figure 4. *Puccinia* sp. on *Fallopia japonica* in Japan showing urediniospores. (Photo by R. Shaw.)

Host Range Tests and Results

None have been reported to date.

Releases Made

None have been made to date.

BIOLOGY AND ECOLOGY OF KEY NATURAL ENEMIES

Natural enemy surveys have not yet been completed and thus no information is currently available on the biology of candidate natural enemies.

EVALUATION OF PROJECT OUTCOMES

The biological control of this weed has not yet been attempted, although projects in the United Kingdom and United States are being considered.

RECOMMENDATIONS FOR FUTURE WORK

A proposal by CAB International for a classical biological control research program to assess both arthropod and fungal natural enemies for use against *F. japonica* is currently under consideration by potential sponsors in both the United States and the United Kingdom. The United States funding consor-

tium is being coordinated by the Biological Control of Non-Indigenous Plant Species Program at Cornell University.

Initial surveys of natural enemies already present in the United States will run concurrent with a preliminary survey of natural enemies in Japan, in the area of origin, and establishment of collaborative agreements with suitable scientists in the most appropriate areas. An entomologist and pathologist will carry out this work and produce a report based on the findings. Further surveys and shipments of selected natural enemies to CABI's United Kingdom quarantine facilities for host specificity testing will then pursued, coupled with a long-term field study in the area of origin. Special attention will be paid to those species identified as promising in previous literature studies (Fowler *et al.,* 1991; Greaves and Shaw, 1997; Shaw 1995) and to rhizome feeders that may attack the large underground storage reserves. If release is appropriate, then long-term monitoring programs would be set up to monitor for control levels as well as non-target effects.

Apart from the environmental and financial costs associated with ineffective chemical-based control measures, perhaps the most important aspect of knotweed invasions is the displacement of native plants in riparian situations. These problems are common to several countries, so there are advantages to a collaborative approach to research, as well as the sharing of funding. The target plant in this case is believed to be clonal and, therefore, none of the usual problems associated with a variable target weed population will be experienced. However, since hybridization is already occurring, time is of the essence. The opportunity to investigate both arthropod and fungal agents from the outset rather than one following on from the other, as has often been the case, opens up the exciting field of insect-fungal interactions with regard to weed biological control. Japanese knotweed is certainly a plant for which classical biological control is the only long-term, sustainable solution.

REFERENCES

Bailey, J. P. 1985. Chromosome numbers of some alien *Reynoutria* species in the British Isles. *Watsonia* 15: 269-277.

Bailey, J. P. 1988. Putative *Reynoutria japonica* Houtt. x *Fallopia baldschuanica* (Regel) Holub. hybrids discovered in Britain. *Watsonia*, 17: 163-181.

Bailey, J. P. 1990. Breeding behavior and seed production in Alien Giant Knotweed in the British Isles. *In* Anon. *The Biology and Control of Invasive Plants*. Conference of September 20-21, 1990, organized by the Industrial Ecology Group of the British Ecological Society at the University of Wales, College of Cardiff.

Bailey, J. P. 1994. The reproductive biology and fertility of *Fallopia japonica* (Japanese knotweed) and its hybrids in the British Isles, pp. 141-158. *In* De Waal, L. C., L. E. Child, P. M. Wade, and J. H. Brock (eds.). *Ecology and Management of Invasive Riparian Plants*. John Wiley and Sons, Chichester, United Kingdom.

Bailey, J. P., L. E. Child, and A. P. Conolly. 1996. A survey of the distribution of *Fallopia x bohemica* (Chrtek and Chrtková) J. Bailey (Polygonaceae) in the British Isles. *Watsonia* 21: 187-198.

Beerling, D. J. 1990. The use of non-persistent herbicides, glyphosate and 2,4-D amine to control riparian stands of Japanese knotweed (*Reynoutria japonica* Houtt.). *Regulated Rivers, Research and Management* 5: 413-417.

Beerling, D. J. 1991a. The testing of concrete revetment blocks resistant to growths of *Reynoutria japonica* Houtt (Japanese knotweed). *Water Research Oxford* 25: 495-498.

Beerling, D. J. 1991b. The effect of riparian land use on occurrence and abundance of Japanese knotweed *Reynoutria japonica* on selected rivers in South Wales. *Biological- Conservation* 55: 329-337.

Beerling, D. J. and H. A. Dawah. 1993. Abundance and diversity of invertebrates associated with *Fallopia japonica* (Houtt. Ronse Decraene) and *Impatiens glandulifera* (Royle): two alien plant species in the British Isles. *The Entomologist* 112 (2): 127-139.

Beerling, D. J., J. P. Bailey, and A. P. Conolly. 1994. *Fallopia japonica* (Houtt.) Ronse Decraene, biological flora of the British Isles. *Journal of Ecology* 82: 959-979.

Brock, J. and M. Wade 1992. Regeneration of Japanese knotweed (*Fallopia japonica*) from rhizome and stems: Observations from greenhouse trials, pp. 85-93. *IX éme Colloque International Sur la Biologie des Mauvaise Herbes*. September 1992, Dijon, France. ANPP, Paris, France.

Child, L. E., L. C. de Waal, P. M. Wade, and J. P. Palmer. 1992. Control and management of *Reynoutria* species (Knotweed). *Aspects of Applied Biology* 29: 295-307.

Conolly, A. P. 1977. The distribution and history in the British Isles of some alien species of *Polygonum* and *Reynoutria*. *Watsonia* 11: 291-311.

Emery, M. J. 1983. The ecology of Japanese knotweed, its herbivores and pathogens and their potential as biological control agents. M. S. dissertation, University of Wales, United Kingdom.

Fernald, M. L. 1950. *Gray's Manual of Botany*, 8th ed. American Book Company, New York.

Fishel, F. 1999. Weeds of field crops and pastures. *Missouri Weeds.* http://www.psu.missouri.edu/fishel/field_crops.htm (accessed 17 April 2000).

Fowler, S. V., A. N. G. Holden, and D. Schroeder. 1991. The possibilities for classical biological control of weeds of industrial and amenity land in the United Kingdom using introduced insect herbivores or plant pathogens, pp. 1173-1190. *Proceedings of the Brighton Crop Protection Conference – Weeds 1991*. Organized by the British Crop Protection Council, Brighton, United Kingdom.

Greaves. M. P. and R. H. Shaw. 1997. *Biological Control of Weeds — A Scoping Study of the Feasibility of Biological Control of Aquatic and Riparian Weeds in the United Kingdom.* R and D Technical Report W105 (produced under R and D project W5-734). Long Ashton Research Centre for Aquatic Plant Management. U.K. Environment Agency Publication, Bristol, United Kingdom.

Hathaway, S. 1999. Costs for the control of Japanese knotweed. *In* The Biological Control of Japanese Knotweed: The Natural Alternative. A workshop held at CABI Bioscience, Silwood Park, Ascot , Berks, United Kingdom.

Hirose, T. and Katajima, K. 1986. Nitrogen uptake and plant growth effect on nitrogen removal on the growth of *Polygonum cuspidatum* on Mt. Fuji. *Oecologia* 61: 218-223.

Holzner, W. 1982. Concepts, categories and characteristics of weeds, pp. 3-20. *In* Holzner, W. and M. Numata (eds.). *Biology and Ecology of Weeds*. Dr. W. Junk, The Hague, Netherlands.

Kartesz, J. T. 1994. *A Synonymized Checklist of the Vascular Flora of the United States, Canada, and Greenland*, 2nd ed. Timber Press, Portland, Oregon, USA

Locandro, R. R. 1973. Reproduction ecology of *Polygonum cuspidatum*. Ph.D. dissertation, Rutgers University, New Brunswick, New Jersey, USA.

Locandro, R. R. 1978. Weed watch: Japanese bamboo – 1978. *Weeds Today* 9: 21-22.

Mabey, R. 1998. *Flora Britannica*: The Concise Edition. Chatto and Windus, London, United Kingdom.

Maruta, E. 1983. Growth and survival of current-year seedlings of *Polygonum cuspidatum* at the upper distributional limit on Mt. Fuji. *Oecologia* 60: 316-320.

Mehrhoff, L. J. 1997. Non-native invasive plant species occurring in Connecticut, University of Connecticut Center for Conservation and Biodiversity. http://darwin.eeb.uconn.edu/ccb/publications/publication-1.html (accessed 11 April 2000).

Mondal, M. S. 1997. *Pollen Morphology and Systematic Relationship of the Family Polygonaceae*. Botanical Survey of India, Vedams. Calcutta, India.

Muenscher, W. C. 1955. *Weeds*, 2nd edition. McMillan Press, New York.

Multnomah County, Oregon Land Use Planning Division. 1998. 11.15.6426 Criteria for approval of SEC-h permit wildlife habitat, Significant Environmental Concern. http://www.multnomah.lib.or.us/lup/zonordin/sec/11.15.6426.html (accessed 11 April 2000).

Murphy, T. R. 2000. Proposed Exotic Pest Plant Species for Georgia. http://gacaps.org/gaeppc/exotalk1.htm (accessed 11 April 2000).

Palmer, J. P. 1990. Japanese knotweed (*Reynoutria japonica*) in Wales. *In* Anon. *The Biology and Control of Invasive Plants.* Conference of September 20-21, 1990, organized by the Industrial Ecology Group of the British Ecological Society at the University of Wales, College of Cardiff, United Kingdom.

Patterson, D. T. 1976. The history and distribution of five exotic weeds in North Carolina. *Castanea* 41: 177-180.

Pauly, W. R. 1986. Summary of Mexican bamboo control methods (Wisconsin). *Restoration and Management Notes* 4(1): 37-38.

Pimentel, D., L. Lach, R. Zuniga, and D. Morrison. 2000. Environmental and economic costs associated with non-indigenous species in the United States. *Bioscience* 50: 53-65.

Pridham, A. M. S. and A. Bing. 1975. Japanese-bamboo plants. *Gardener* 31: 56-57.

Pysek, P. and K. Prach. 1993. Plant invasions and the role of riparian habitats: a comparison of four species alien to Central Europe. *Journal of Biogeography* 20: 413-420.

Seiger, L. A. 1993. The ecology and control of *Reynoutria japonica* (*Polygonum cuspidatum*). Ph.D. dissertation, George Washington University, Washington, D.C., USA.

Seiger, L. A. 1997. The status of *Fallopia japonica* (*Reynoutria japonica; Polygonum cuspidatum*) in North America, pp. 95-102. *In* Brock, J. H., M. Wade, P. Pysek, and D. Green (eds.). *Plant Invasions: Studies from North America and Europe*. Backhuys Publishers, Leiden, Netherlands.

Shaw, R. H. 1995. Towards the biological control of Japanese knotweed in the United Kingdom. M. S. thesis, University of London, London, United Kingdom.

Sukopp, H. and U. Starfinger. 1995. *Reynoutria sachalinensis* in Europe and in the Far East: A comparison of the species' ecology in its native and adventive distribution range, pp. 151-159. *In* Anon. *Plant Invasions: General Aspects and Social Problems*. Workshop of September 16-19, 1993, held at Kostelec nad Cernymi lesy, Czech Republic.

Sukopp, H. and U. Sukopp. 1988. *Reynoutria japonica* Houtt. in Japan und in Euröpa. *Veröffen Geobotanische Institut. ETH, Stiftung Rübel, Zürich* 98: 354-372.

Tennessee Exotic Pest Plant Council. 1997. Invasive Exotic Pest Plants in Tennessee. http://www.webriver.com/tn-eppc/exlist.htm (accessed 11 April 2000).

USDA, NRCS. 1999. United States Department of Agriculture, Natural Resources Conservation Service. PLANTS Database. http://plants.usda.gov/plants (accessed 19 April 2000).

Virginia Native Plant Society. 1999. Invasive Alien Plant Species of Virginia; Japanese knotweed (Polygonum cuspidatum). http://www.vnps.org/invasive/FSPOLYG.html (accessed 4 April 2000).

Washington State Department of Agriculture. 1999. State Weed Board proposes 2000 noxious weed list. http://www.wa.gov/agr/communications/1999/news9942.htm (accessed 11 April 2000).

Yano K. and M. Teraoka. 1995. Notes on Lepidoptera feeding on *Polygonum cuspidatum*. *Chugoku Kontyu* 9: 10-17.

Yoshioka, K. 1974. Volcanic vegetation, pp. 237-267. *In* Numata, M. (ed.). *The Present Flora: Its General Features and Regional Divisions. Flora and Vegetation of Japan*. Elsevier, Amsterdam, Netherlands.

Zomlefer, W. B. 1994. *Guide to Flowering Plant Families*. University of North Carolina Press, Chapel Hill, North Carolina, USA.

Zwölfer, H. 1973. Possibilities and limitations in biological control of weeds. *Bulletin of the European Plant Protection Organisation* 3: 19-30