Japanese Knotweed and Water Quality on the Batavia Kill in Greene County, New York: Background Information and Literature Review

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Introduction

This study was undertaken by Hudsonia Ltd. at the request of the Greene County Soil and Water Conservation District (GCSWCD) and the New York City Department of Environmental Protection (NYCDEP). Japanese knotweed stands are widespread, and in many places extensive, on the banks and floodplain of the Batavia Kill in Greene County, New York. The Batavia Kill flows into Schoharie Creek which feeds Schoharie Reservoir, part of the New York City water supply system. There is a high level of concern about the impacts of Japanese knotweed on water quality in the Batavia Kill.

Japanese knotweed appears to root more shallowly than desirable native riparian trees and shrubs, although more deeply than the local grasses. Banks dominated by Japanese knotweed, therefore, may be less stable and more prone to slumping and erosion than banks with trees or shrubs. This is believed to increase suspended sediment loads and turbidity, and thus degrade water quality in the Batavia Kill. Because more turbid water is more expensive to treat, Japanese knotweed is a concern for the New York City water supply system. Populations of Japanese knotweed have also been reported on other streams of the Catskill Mountain component of the New York City water supply watershed, and these populations might also affect water quality.

In addition to the potential effects of Japanese knotweed on water quality, the plant could also potentially affect fisheries. This could occur via alteration of the detritus (dead plant matter) based food web that supports trout and other stream fishes, as well as via interference with human access to stream banks for angling. Because riparian zones are a critical component of the environment for many other animal and plant species, physical, chemical, and biological changes to the riparian zones caused by a large-scale plant invasion could also change habitat functions, including habitat for plants, and food, shelter, and nesting sites for animals.

The following report includes a review of the literature on Japanese knotweed, information obtained from telephone interviews and site visits with persons conducting management of Japanese knotweed in other areas, and preliminary observations on the plant along the Batavia Kill in 2002-2003. This review of information on Japanese knotweed is a necessary first step in addressing the GCSWCD and NYCDEP concerns about Japanese knotweed impacts. Our review addresses the basic ecology of Japanese knotweed and methods that have been used for managing it in other regions. Because much of the information on the ecology and management of invasive plants has not been published in the formal scientific literature, in addition to searching the formal literature we also used the Internet, the “gray” literature (e.g., agency reports and theses), and oral reports from naturalists, environmental practitioners, and others who have experience with Japanese knotweed.

Introduction to Japanese Knotweed

Nomenclature

Japanese knotweed (*Fallopia japonica* [Houtt.] Ronse Decraene) has various other common names including Japanese fleece flower, mountain fleece flower, Mexican bamboo, Japanese bamboo, and crimson beauty. In recent years, Japanese knotweed has been classified in three different genera: *Polygonum*, *Reynoutria*, and *Fallopia*. Houttuyn originally described *Reynoutria japonica* based on specimens collected in Japan in 1777. In 1846, additional specimens were brought from Japan, and the plant was named *Polygonum cuspidatum* by Siebold and Zuccarini (Beerling et al. 1994). In 1901, a third scientist realized the two names referred to the same species (Beerling et al. 1994). The name *Fallopia japonica* is most commonly used now (see Bailey & Conolly 2000, Child & Wade 2000) although some biologists still use *Polygonum cuspidatum*. Recently retired New York State Botanist Richard Mitchell (personal communication, 2002), an expert on the genus *Polygonum*, recognises no morphological or anatomical reason to segregate *Fallopia* from *Polygonum*. In this report we use the names *Fallopia japonica* and Japanese knotweed because these appear most often in the English-language technical and popular literature of the last few years.

Japanese knotweed belongs to the buckwheat or smartweed family Polygonaceae. This family comprises a wide range of herbs, shrubs, vines, and a few trees. Most North American Polygonaceae are annual or perennial herbs: smartweeds, knotweeds, docks, sorrels, and buckwheat (Mitchell & Dean 1978). Several species of smartweeds are important components of marsh vegetation and very important foods for wildlife (especially ducks and rails). For those botanists who segregate *Fallopia*, along with Japanese knotweed the genus includes the giant knotweed *Fallopia sachalinensis* and the silver lace vine *Fallopia baldschuanica*, both Asian species introduced to the U.S. *Fallopia* also includes three native and introduced herbaceous vines, *Fallopia scandens*, *Fallopia convolvulus*, and *Fallopia cilinode*. All these plants were formerly included in *Polygonum* by American botanists.

Morphology and Phenology

Japanese knotweed is usually considered herbaceous (non-woody). The plant has annual aerial stems that die back to near ground level in autumn, and long-lived perennial root crown, main roots, and rhizomes (underground stems). Japanese knotweed has been referred to as “gynodioecious” (Beerling et al. 1994), “functionally dioecious” (Cronk & Fuller 1995, Child & Wade 2000) or “subdioecious” (Forman 2003). Dioecious means that male and female flowers are borne on separate individual plants. Forman (2003) explained “subdioecious” as “male and female flowers on separate plants and males that sometimes set seed,” although she did not explain how seeds were produced by male plants. The mating system of Japanese knotweed appears to be evolving, with an incomplete separation of male and female functions (Jennifer Forman, personal communication, 2003). Batavia Kill plants appear to have either stamens (male flower parts), or both pistils (female parts) and apparently nonfunctional stamens (Kiviat, personal observation 2003). Child & Wade (2000) and Forman & Kesseli (2003) noted that both male and female plants are found in the U.S. although some countries have unisexual populations.

Japanese knotweed grows in clumps 1-3+ m high. Occasional plants on poor soils are stunted and no taller than 0.3 m. Japanese knotweed stems are superficially bamboo-like, hollow, with a diaphragm at each node, and extend erect or arching from the root crown. The dead stems typically remain upright through the winter. The broadly ovate (egg-shaped in outline) leaves have rounded sides and a pointed tip, and are nearly straight across (truncate) or shallowly wedge-shaped at the base. Leaves are alternate, 5-15+ cm long and 5-12 cm wide, with 1-3 cm long petioles (leaf-stalks). Illustrations of Japanese knotweed are in Child & Wade (2000) and many flora manuals, field guides, and gardening books.

Japanese knotweed flowers from July through September in New York (Mitchell & Dean 1978), August-September on the Batavia Kill. The greenish-white flowers are densely arranged in axillary panicled racemes (Seiger 1993). Male flowers are erect and female flowers are drooping or decumbent (Seiger 1993).

Rhizomes are as long as 5-7 m, and roots to almost 2 m (Seiger 1993). Rhizome fragments have been found to sprout even when buried up to 1 m deep (Seiger 1993). The deep root system of Japanese knotweed enables it to obtain nutrients and water in a wide range of soil conditions. The plant is able to store photosynthate in the underground parts through the winter, and the stored material is used during the rapid growth period the following spring. The rapid spring growth fueled by stored food gives Japanese knotweed a competitive advantage over smaller plants that grow more slowly in spring.

Despite the report of a 2 m rooting depth cited above, our preliminary observations on the Batavia Kill suggest that Japanese knotweed binds soil to a depth of ca. 0.5 m. In certain places, we have seen Japanese knotweed root systems eroding out of near-vertical banks. René VanSchaack (personal communication) has observed that Japanese knotweed does not root deeply enough to stabilize high banks (1.2 m or more) that are subject to high shear stress from water flowing in the stream bed.

Native Range and Habitat

Japanese knotweed is native to Japan, northern China, and Taiwan (Child & Wade 2000). In its native range in Japan, Japanese knotweed is often a pioneer species. The plant is frequently found on sunny bare ground, slopes, volcanic deserts, and along railroads and roads. It is often the dominant colonizer in volcanic deserts, especially on Mt. Fuji (Adachi et al. 1995). It is an important primary colonizer of volcanic slopes, where soil sulphur levels are high and pH is low. Japanese knotweed plays a critical role in the development of vegetation on bare volcanic slopes, because of its ability to serve as a nutrient reservoir and to stabilize the soil surface. The upper elevation limit is 2500-2600 m; beyond that, the plants appear to be limited by insufficient photosynthetic activity resulting in the inability to produce viable seeds. This is most likely due to the shorter growing season relative to lower elevations (Maruta 1983). In its native range, plant height is 0.5-1.5 m, considerably smaller than in its introduced range (Seiger 1993). Japanese knotweed flowers from July to October in Japan (Seiger 1991).

Introduced Range and Habitat

In 1848, Japanese knotweed was first commercially available in Britain, but probably was introduced earlier (Bailey & Conolly 2000). Cronk & Fuller (1995) stated that Japanese knotweed was introduced to Britain in 1825. The plant was most likely introduced from Britain to the northeastern United States in the late 1800s (Seiger 1991, Child & Wade 2000). Japanese knotweed is naturalized in a number of other countries including the Czech Republic, Germany, France, Russia, New Zealand, and Canada (Child & Wade 2000).

Japanese knotweed in the eastern U.S. is predominantly a plant of urban and suburban yards and vacant lots, roadsides, and riparian areas. Although Shaw & Seiger (2002) refer to Japanese knotweed invading wetlands, it seems to be much more closely associated with moist or seasonally wet, well drained soils on stream banks and floodplains (Kiviat, personal observations). We have seen Japanese knotweed at wetland edges but not in wetland interiors. In the freshwater tidal mouth of Stockport Creek (Hudson River, Columbia County, New York), Japanese knotweed grows above the level of the average high tides on alluvial islands (Kiviat, personal observation). On the Saw Mill River in Westchester County, New York, Japanese knotweed grows on the banks as well as the backswamps of the floodplain, and possibly occupies hydric soils in some areas (Kiviat, personal observation).

Japanese Knotweed as an Invasive Species

Introduction to Invasive Plants

An “invasive” plant is a native or introduced species that spreads and displaces native plant communities. Invasive plants may alter habitat quality for other biota, vegetation structure, biogeochemical cycling, fire regimes, soil characteristics, or other aspects of the habitat and ecosystem. Most invasive plants appear to take advantage of human alterations and natural disturbances to soil and vegetation such as nutrient or salt additions, soil erosion and siltation, removal of vegetation, overgrazing, or disturbance by animals such as muskrat, beaver, or deer. Any change in an ecosystem can have positive as well as negative impacts depending on the local situation and the management goals. Riparian areas are often prone to plant invasions due to the disturbance of soil and vegetation by flooding, ice, farming, and other natural processes and human activities, as well as transport of propagules by streamflow and flooding.

Japanese Knotweed in the United Kingdom

History

Japanese knotweed was introduced beyond its native range as a garden ornamental. It was so highly prized that it was awarded a gold medal in 1847, by the Society of Agriculture and Horticulture at Utrecht, for being the most interesting new ornamental plant of the year (Bailey & Conolly 2000). Naturalized populations were first noted in 1886 (Conolly 1977, Seiger 1993). Japanese knotweed has since spread throughout the United Kingdom, and is found in stands ranging from individual stems to colonies covering more than 500 square meters (Seiger 1991). Japanese knotweed spreads readily and negative impacts were characterized as follows:

> …damage to paving and tarmac areas; damage to flood defense structures; damage to archaeological sites; reduction of biodiversity through out-shading native vegetation; restriction of access to riverbanks for anglers, bank inspection and amenity use; reduction in land values; increased risk of flooding through dead stems washed into river and stream channels; increased risk of soil erosion and bank instability following removal of established stands in riparian areas; accumulation of litter in well established stands; aesthetically displeasing; and expensive to treat (Japanese Knotweed Alliance 1999).

In Britain, under the Wildlife and Countryside Act of 1981: "it is an offence to plant or otherwise cause the species to grow in the wild" (Child & Wade 2000).

Japanese Knotweed in North America

History

In North America, Japanese knotweed occurs on a variety of soils. The plant is often found along roads and riverbanks, and in overgrown gardens and other disturbed areas. It is rarely found in forests, but can be found in the forest edge or in open-canopy woodlands. It is widely distributed in the eastern U.S. In western Pennsylvania it occupies hundreds of hectares of wetlands, stream banks, and hillsides. In addition to occurring throughout the eastern states, Japanese knotweed is also prevalent in Washington and Oregon (Seiger 1993). Japanese knotweed has been found in 38 states (excluding Arizona, Florida, Hawaii, Nevada, New Mexico, North Dakota, South Dakota, Texas, or Wyoming) and 6 Canadian provinces (Shaw & Seiger 2002). The plant is found in Canada as far north as Newfoundland, and is most abundant in the Atlantic Provinces, on roadsides and in disturbed habitats.

Of the 35 states that have official noxious weed lists, California, Oregon, and Washington have included Japanese knotweed (as *Polygonum cuspidatum*) in this category. Many other states have listed Japanese knotweed as a problem weed. According to the Federal Noxious Weed Act of 1974, noxious is a more serious designation and is:

> …any living stage (including seeds and reproductive parts) of a parasitic or other plant of a kind which is of foreign origin, is new to or not widely prevalent in the U.S., and can directly or indirectly injure crops, other useful plants, livestock, poultry or other interests of agriculture, including irrigation, navigation, fish and wildlife resources, or the public health (Federal Noxious Weed Act 1974).

In New York, it is listed by the Invasive Plants Council (IPC) as 1 of the top 20 invasive plants in the state. Japanese knotweed is found throughout the state; it is one of the most common invasive plants in the Adirondacks where it is most often found along roadways, and in forest edges, old gardens, and a variety of riparian habitats (IPC 2002).

Reproduction of Japanese Knotweed

Japanese knotweed reproduces by seeds, rhizome fragments, and stem fragments. In its native range, Japanese knotweed appears to reproduce mainly by seed and the plant is capable of high seed production (Seiger 1991). In its introduced range the primary mode of reproduction is vegetative. Local spread occurs by lateral extension of rhizomes, and longer-distance dispersal occurs by rhizome or stem fragments. Dispersal of rhizome and stem fragments occurs via waterways, or by humans transporting soil containing the fragments (Seiger 1991).

Seeds

Seiger (1993) studied viability of seeds from a stand of Japanese knotweed in Rock Creek Park, Washington, DC. Seeds were collected in 1986 and stored for 2 years. No seedlings were observed in the wild, and all of the 400 young shoots that Seiger excavated were attached to older rhizomes. Three seedlings from the 1986 collection were planted (presumably in the laboratory; Seiger did not state where or when). The plants that developed appeared to be hybrids between *Fallopia japonica* and *F. baldschuanica* (silver lace vine), a cross previously described in Britain (Seiger 1993).

Forman & Kesseli (2003) studied seeds from 29 field sites in Massachusetts. They found that Japanese knotweed produced large amounts of seed with high germinability. Seeds germinated immediately after collection or after various treatments over the winter. Most importantly, Forman & Kesseli found seedlings at several sites and some seedlings survived one winter (information on further survival is not available). Seedlings appear in spring (Jennifer Forman, personal communication, 2003). Forman & Kesseli (2003) concluded that vegetative reproduction is the predominant means of spread of Japanese knotweed in the U.S. but that reproduction by seed potentially contributes to the spread and invasiveness of this species.

Vegetative Reproduction

In the U.K., only female Japanese knotweed plants with male-sterile flowers have been recorded, and the species appears to reproduce solely by vegetative means (Bailey 1994). The primary means of reproduction is rhizome fragments, but viability of tissue of aerial stems has been demonstrated, and even regeneration from fallen leaves has been reported (Brabec 1997, de Waal 2001). The potential regeneration of rhizome and stem tissue was estimated at 2100 propagules per square meter of a stand (de Waal 2001). Rhizomes can regenerate when buried 1 m deep in the soil. They have also been observed growing through two inches of asphalt, and in other harsh conditions such as cinder dumps and railway ballast (Seiger 1991, Child et al. 1992). The commonest mode of dispersal in both the U.K. and North America is by water transportation of plant fragments. Thus, if cutting or excavation is used as a means of control, it is important to dispose of the cut material safely.

Clonal Plants

To determine if the British population of Japanese knotweed was multiclonal, genetic diversity was studied. One hundred fifty samples from the U.K. and 16 samples from other introduced populations were collected (time period not stated) and genotyped using

RAPD (randomly amplified polymorphic DNA). The molecular data generated in that study:

> …coupled with the absence of male fertile individuals provide strong evidence to support the hypothesis that the entire British population of Japanese Knotweed consists of a single clone. Furthermore, the identical RAPD profile detected in samples of this taxon from France, Germany, the Czech Republic and the U.S.A indicates that its distribution is not limited to Britain (Hollingsworth 2000).

As this clone occupies thousands of hectares in Britain and is also in continental Europe and North America, in total biomass it might be the largest female organism in the world (Japanese Knotweed Alliance 1999).

Many plant species that constitute aerial shoots connected by underground stems (rhizomes) are able to share water and other materials among different parts of the colony by transport through the rhizomes. This phenomenon is called clonal integration and allows a portion of the colony growing in favorable environmental conditions to subsidize a portion growing in unfavorable conditions. The degree of clonal integration has implications for establishment, persistence, and management of Japanese knotweed. Although the underground structure of knotweed suggests clonal integration, there is little information in the literature on this subject. Clonal integration with regard to nitrogen was demonstrated in Japanese knotweed growing in nitrogen-poor volcanic soils in Japan; nitrogen moved from central to peripheral portions of knotweed colonies, facilitating peripheral expansion of the colony (Adachi et al. 1996).

Environmental Physiology

Certain environmental conditions, such as human-altered environments or natural disturbances, facilitate the success of many invasive plants. Like many other invasive plants, Japanese knotweed does better in such disturbed areas. There are certain other factors that can influence its growth including available light, incidence of frost, soil type, and land use.

Disturbed areas are often areas with a high availability of light at the soil surface. Lack of light, due to a dense canopy, may inhibit invasions (Seiger 1993). In a greenhouse study of plants from Rock Creek Park, Washington, DC, there was a significant difference between Japanese knotweed plants grown in low light versus plants grown in high light. Differences were found in the basal diameter of aerial stems, belowground biomass, leaf size, and plant height (Seiger 1993). The differences in available light can affect growth in the field and may help explain why Japanese knotweed does better on open stream banks than beneath a forest canopy (Seiger 1993).

In Britain, Japanese knotweed was present with increasing abundance in: natural or semi-natural communities, grazed grasslands, closed canopy woodlands, open canopy woodlands, waste ground or colliery spoil (coal mine waste), and land drainage works (land recently disturbed for "flood prevention and channel alignment"). Although the plant was found in closed canopy woodlands its abundance and growth were depressed, supporting the hypothesis that low levels of sunlight can negatively influence growth (Beerling 1991).

In the U.K., it appears that Japanese knotweed stands are most vigorous and abundant along rivers and canals, and in coastal locations. Knotweed may be more abundant at these locations due to the lower incidence of frost and the increased humidity (Beerling et al. 1994). Both late frosts and summer droughts can limit the knotweed spread in both southerly and northerly directions by reducing the ability of the plant to build sufficient reserves to survive the winter (Beerling et al. 1994). Japanese knotweed is very sensitive to late spring or early fall frosts that kill the growing tips (René VanSchaack, personal communication). We think that flood disturbance is an important factor in the invasibility of riparian areas by Japanese knotweed. Floods transport plant fragments downstream (Beerling et al. 1994) and presumably cause some of the fragmentation, as well as creating suitable habitats for fragment establishment in erosional and depositional environments (see Pyšek & Prach 1994).

Japanese knotweed is able to grow on a variety of soils "from colliery spoil [coal mine waste] through alluvial soils, clays and loams to shingles and free-draining mineral soils and peats" (Beerling et al. 1994:964). Analyses of soils from 17 stands in Wales showed no correlation of stand size and vigor with soil characteristics. The study documented the range soil characteristics the plant could tolerate: pH 4.2-8.5, soil organic matter 2.3-24.6%, and wide ranges of potassium, sodium, calcium, magnesium, and phosphorus (Palmer 1994). Inasmuch as the average soil organic matter of agricultural soils worldwide is about 1%, the soils studied by Palmer were probably enriched in organic matter by the Japanese knotweed itself.

In Japan, higher nitrate concentrations were found beneath a patch of Japanese knotweed relative to bare volcanic soil (Hirose & Tateno 1984). A similar study in the U.K. found higher nitrate concentrations under clumps of Japanese knotweed, although only 3 of 9 were significantly higher (Beerling et al. 1994). Higher nitrate beneath Japanese knotweed was attributed to low nitrate-absorbing capacity of Japanese knotweed roots. Neither of these studies, however, examined the soils before Japanese knotweed establishment and it is possible that knotweed established preferentially on more nitrate-rich soil. Beerling et al. (1994) stated that knotweed is characteristic of nutrient-rich soil, and also that it is favored by high rainfall and humidity, a long growing season, shelter from wind, and coastal locations.

Two studies (Kubota et al. 1988, Beerling et al. 1994) demonstrated tolerance of Japanese knotweed to soils with high concentrations of heavy metals, and accumulation of the metals in the cell wall fraction of the roots. Knotweed tolerance of heavy metals may explain why the plant is so successful in mines and other metal-rich habitats (Nishizono et al. 1989).

Ecological Relationships

Japanese knotweed has large aerial stems (up to 3+ m tall, up to 40+ mm in basal diameter on the Batavia Kill; Kiviat, personal observation). The stems are hard and apparently rich in lignin, although hollow. During the growing season, multiple generations of stems are visible in the Batavia Kill stands: live stems of the current year, mostly-standing dead stems of the previous year, and fallen rotting stems of one or more earlier years that may be on the soil surface or supported above the soil by the base of the stem "clump" and root crown (Kiviat, personal observation 2003). This accumulation of dead stem material is greater than that of many other herbaceous plants but not necessarily greater than litter and woody debris accumulation beneath shrubs or trees. In its size, accumulated litter, and decomposition rate, Japanese knotweed appears to be intermediate between typical herbaceous plants and many woody plants.

Because Japanese knotweed forms dense stands with large amounts of live and dead material, typically few plant species grow beneath the knotweed canopy. Some early-flowering species can take advantage of the sunlight penetrating the canopy in spring and also tolerate the accumulated stem litter (Beerling et al. 1994), and knotweed may provide habitat for some of those species on derelict land (Child et al. 1992). In Britain, some of the species that grow beneath knotweed are mugwort (*Artemisia vulgaris*), cleavers (*Galium aparine*), broad-leaved dock (*Rumex obtusifolius*), common nettles (*Urtica dioica*), hogweed (*Heracleum spondylium*), and bramble (*Rubus fruticosus*) (at least the first four of these species also occur in the northeastern U.S. although not necessarily in knotweed stands). Additional species associated with knotweed were listed by Beerling et al. (1994) and Palmer (1994). In Britain, Japanese knotweed plants were found growing below a canopy of elder (*Sambucus nigra*) and Norway maple (*Acer pseudoplatanus*) (Beerling et al. 1994).

There is little documentation of fauna that benefit from, or even use, Japanese knotweed. Along riverbanks in Britain, stands of Japanese knotweed can provide resting places for otters and cover for certain birds (Child et al. 1992). In 1991, in Leicester, U.K., a flock of (native) house sparrows, *Passer domesticus*, ate almost an entire year's seed production (Beerling et al. 1994). Some invertebrates take advantage of the late flowering of the plant, but overall the significance of the nectar supply to insects is unknown (Ferrazzi et al. 1990, Palmer 1994). In the U.K., species of Hemiptera, Lepidoptera and Coleoptera have been found to feed on Japanese knotweed (Beerling et al. 1994). In Vermont, two thrush (species unidentified) nests were found in a stand of Japanese knotweed (Paul 2000). Nonetheless, an employee of The Nature Conservancy who has worked in stands of knotweed in Washington State and Vermont, has never noticed nests or signs of knotweed being grazed, except for one grazed clump in a cattle pasture (Catey Ritchie, personal communication, 2002). Unpublished data suggest that green frogs (*Rana clamitans*) find less prey in Japanese knotweed stands compared to old field vegetation without knotweed (Maerz & Blossey 2003). Although one might infer from this information that Japanese knotweed in its introduced range receives little use by animals, in fact many species of invertebrates and vertebrates can be found in knotweed stands in New York, New Jersey, and Massachusetts (Kiviat, personal observations). Virtually nothing is known, however, about the relative values of knotweed and non-knotweed habitats for native animals.

Human Uses of Japanese Knotweed

Japanese knotweed has various medicinal attributes (Spainhour 1977). The plant has been used as a laxative. Japanese knotweed extracts can reduce gastric secretions and protect the gastric membranes against stress ulcers. Roots contain aromatic hydrocarbons called stilbenes; one stilbene, resveratrol, is anti-microbial, antioxidant, anti-mutagen, and anti-inflammatory (Spainhour 1997). The plant has also been found to promote healing of burns by enhancing immune function and cardiac function (Spainhour 1997).
Japanese knotweed, along with a number of other knotweed species, is listed as a famine food. Shoots and leaves of Japanese knotweed are eaten in China; we do not know if this refers to cultivated plants. Young shoots in spring can be baked or cooked with less-tart fruits and vegetables, much like rhubarb. Japanese knotweed is high in vitamin C, stimulates digestion and helps digest dietary fat (Young 2002). The young knotweed shoots, up to 30 cm, can be treated like asparagus and can be steamed or boiled for 4- 5 minutes with a little sugar added, to reduce the tartness (Peterson & McKenny 1968). The older stems can also be used to make rhubarb-like jam (Peterson & McKenny 1968). A wild plants cookbook has recipes that use Japanese knotweed to make sherbet, soup, pie, and other dishes (Brill 2002).

Because of its high productivity, Japanese knotweed has been studied as a possible source of renewable energy (Beerling et al. 1994, Callaghan 1984). Annual production is potentially as high as 12 metric tons per hectare (Callaghan 1984) or 1200 grams per square meter (probably aboveground dry weight).

Potential Effects on Habitats and Biota

Japanese knotweed might have the following ecological effects:

On other flora- Knotweed appears to exclude many native plants from beneath the knotweed canopy. This is presumably due to shade, competition for nutrients and water, litter mass, and allelopathy. Knotweed could have a negative impact on rare plants of river and stream banks in the Hudson Valley such as winged monkeyflower (*Mimulus alatus*) or green dragon (*Arisaema dracontium*) (see discussion of rare species of riparian habitats in Kiviat & Stevens [2001]). We do not yet know which, if any, rare plants occur on or near the Batavia Kill.

On vegetation- On extensive reaches of the Batavia Kill (e.g., generally in the Windham to Ashland section), Japanese knotweed covers extensive areas of the banks and the floodplain as well as smaller patches in the streambed. Knotweed has altered the distribution and development of riparian plant communities.

On litter- A large, productive herb growing in dense stands, like knotweed, typically produces deep litter, and this is true of knotweed in the study area. This litter provides microhabitats for many small animals (invertebrates and their predators), within and between the old hollow stalks (Kiviat, personal observations). The litter could also exclude many plants and animals.

On herbivores- Knotweed could be providing a new food source for herbivorous invertebrates and vertebrates, or replacing more valuable food plants. There seemed to be minor insect grazing (approximately 1-2% loss of leaf area in late summer; Kiviat et al., unpublished data). With the exception of beaver cutting, we did not observe obvious vertebrate grazing on knotweed in the study area.

On detritus-feeding animals- The food quality of knotweed detritus for terrestrial and aquatic invertebrates is unknown. Many invertebrates, especially aquatic insects, have "preferences" for particular species of woody plant leaves, and could be affected by knotweed invasion.

On stream water quality- The potential impacts of knotweed on sedimentation processes are mentioned elsewhere in this report; it is not well understood in what situations knotweed increases or decreases bank erosion thus affecting turbidity and other parameters of stream water quality. Knotweed presumably is intercepting nutrients and fine sediment from the agricultural fields uphill at some Batavia Kill locations; we do not know how this function compares to alternate plant communities such as riparian tree and shrub stands, or grassy areas. We have not found information on other potential impacts on stream water quality e.g., temperature, pH, alkalinity, dissolved oxygen, dissolved and particulate organic matter, or algal communities.

On fisheries- Knotweed stands may make it harder for anglers to reach, and fish from, stream banks (see Child et al. 1992)). Knotweed shades the stream more than lower-growing herbaceous vegetation such as most grasses, but less than trees. Different plant species produce detritus with different food quality for detritivorous aquatic invertebrates (e.g., Sweeney 1993). Knotweed leaf and stem detritus probably has different palatability and nutritional value for aquatic insects (compared to native woody plants) thus might affect the food base for trout and other stream fishes. Japanese knotweed is believed to cause "over-widening" of the stream channel and less suitable habitat for fish (NYCDEP, personal communication 2003).

On fire regimes- Some invasive plants produce highly combustible material that increases intensity and frequency of vegetation fires. (Common reed and eucalyptus have both been considered fire hazards, although there seem to be few hard data bearing on this subject.) We have seen no information on the fuel and fire characteristics of knotweed stands.

On other habitat functions- There is virtually no information available on invertebrate or vertebrate use of knotweed in North America. Knotweed could provide habitat or replace plant communities more valuable as habitat for particular species.

On agriculture- Child & Wade (2000) reported that Japanese knotweed is not a significant weed of agriculture in the U.K.. Along the Batavia Kill, however, one farmer reported knotweed spreading from the bank of the Batavia Kill into hay fields. Small amounts of knotweed were cut and baled with hay at the field edge. The farmer said that he occasionally used a bulldozer to push the knotweed back over the stream bank.

Knotweed also formed small colonies (ca. 1-5 m^2) in the interior of a hay field where it appeared to have been treated with herbicide in 2003 (Kiviat and Jennifer Hanink, personal observations, 2003). Possibly rhizome or stem fragments were transported accidentally by farm equipment and provided the propagules for these investations.

On amenity values- Knotweed could obscure the view of the stream channel at certain locations. Also, some persons might consider the dead standing canes unattractive during the dormant season. One landowner complained that knotweed was invading a lawn near the Batavia Kill and the available mowing equipment was ineffective at cutting the knotweed (however, the following year this knotweed stand was cut mechanically during summer).

Although many of these considerations are not directly relevant to the issues of most concern to GCSWCD and NYCDEP (water quality and the trout fishery), additional issues will need consideration if a major knotweed management campaign is to be initiated on the Batavia Kill. Invasive exotic plants can have positive impacts, and their removal can have negative impacts, on native biota and ecological processes, in particular situations (Kiviat, in press). Thus a variety of aspects of knotweed ecology may need to be assessed in order to design a management plan for the Batavia Kill knotweed population.

Riparian Habitats

Rivers can disperse many invasive species, including Japanese knotweed. In addition, flooding causes periodic disturbances (scouring, sediment deposition) and some invasive plants are adapted to colonize disturbed areas. Japanese knotweed can form dense stands on riverbanks and in intermittently wet areas. These stands can displace native vegetation, and make access to the riverbank more difficult for angling and other activities. Japanese knotweed is believed to exacerbate flooding by clogging river and stream channels with its large (presumably both live and dead) stalks thus decreasing water flow through the channels (Child et al. 1992, Seiger 1996; Trevor Renals, personal communication, 2002). The sparse winter canopy cover of knotweed and the few associated plants leaves bare soil exposed and vulnerable to erosion (Child et al. 1992). Knotweed, however, was planted for erosion control in Connecticut (Peter Picone, Connecticut Department of Environmental Protection, presentation 29 March 2003, Cornwall, CT).

When a large flood occurred on the St. Austell River in Cornwall, U.K., it was noticed that the largest Japanese knotweed infestations along that river were where the most scouring and the most deposition had occurred (Trevor Renals, personal communication, 2002). It is unclear, however, whether scoured areas provided favorable habitat for knotweed colonization or knotweed-colonized areas eroded faster. Scoured areas might collect vegetative propagules of knotweed during floods. Continual erosion might also stimulate rhizomes, resulting in prolific knotweed growth. Large knotweed canes in a highly scoured area tend to be washed out and deposited in areas of fine substrate, ideal for growth, or in other highly scoured areas. Knotweed growth could also increase deposition by trapping sediment during overbank floods. At the same time knotweed can increase the severity of a flood event because the litter can be swept downstream and block flood channels. By increasing flood severity, knotweed may increase, as viable canes are spread farther (Trevor Renals, personal communication, 2002). Knotweed thus might alter sedimentation patterns in a river by increasing or decreasing either erosion or deposition (Trevor Renals, personal communication, 2002).

Description of the Batavia Kill

Watershed

The headwaters of the Batavia Kill are in the Blackhead range, above Maplecrest and CD Lane park. The Batavia Kill flows into Schoharie Creek, which in turn flows into Schoharie Reservoir. Sediment is the most common problem with water supplies from the Catskill District (Ashokan and Schoharie Reservoir basins in the eastern Catskills) (NYCDEP, personal communication, 2003).

All waters in the state of New York are classified by the New York State Department of Conservation (NYSDEC) based on the best usage of the water. Classifications range from AA (suitable for consumption) to D (suitable for fishing). If a stream has the classification of C or higher, it can also have a sub-classification of t (supports trout populations), or ts (supports trout spawning). The classification of the mainstem Batavia Kill ranges from A(t) and A(ts) (13 km) to C(t) and C(ts) (22.1 km) (Greene County Soil and Water Conservation District 2002).

Japanese Knotweed along the Batavia Kill

In 2002, Japanese knotweed occurred in numerous locations along the Batavia Kill. The farthest upstream occurrence was just above CD Lane Park (René VanSchaack, personal communication, 2002). The plant was more abundant downstream, and generally appeared to be more closely associated with agriculture and landscaping. Japanese knotweed was abundant around Maplecrest, an old resort community well upstream. At that location, knotweed was widespread around abandoned buildings, and also occurred locally between the resort and the river, and on the banks of the river. The knotweed stands at Maplecrest may have provided propagules (e.g., rhizome fragments) for colonization of the riverbanks downstream, and may do so in the future.

On 16 May 2002, Talmage visited several locations on the Batavia Kill with Karen Moore; Talmage and Kiviat both visited the river on 25 June 2002. Areas along the bank that were primarily gravel or cobbles had no, or sparse, knotweed. In one location (along Route 17), on 25 June, there were at least 20 other herb species growing in a gravelly area between knotweed stands at the base of the stream bank. We found a few herb species growing beneath the knotweed. On that day, we did not see vertebrates in the knotweed stands, but we found a fairly diverse insect fauna. Two apparently common insects on knotweed leaves were a scarabaeid beetle and a tephritid fly.There was a small amount of insect damage to the leaves (visually estimated at <1% of leaf tissue). The damage consisted of parallel large holes or tiny holes in the leaf blades, or large pieces missing from the leaf margins. These types of damage could have been caused by, respectively, weevils, flea beetles, and grasshoppers. (Many additional observations on animal use of Japanese knotweed were made by Kiviat et al. in 2003 and will be summarized in the Hudsonia report on the 2003 knotweed mapping and sampling studies.)

At one site (Route 17), we excavated the underground parts of a single robust clump of knotweed. The plant was firmly rooted. The surface soil around the plant was dominated by reddish-brown sand, and pebbles were common below the surface. The underground parts appeared to include large more-or-less vertical storage roots and smaller horizontal "rhizomes." There was a limited amount of knotweed litter, but the aerial stems of the previous year were obvious. We found places where knotweed clumps were apparently eroding out of the sides of steep banks, as well as places where knotweed was growing on more gently sloping banks without evidence of exposed root systems.

NYCDEP questioned whether Japanese knotweed is a pioneer or a climax species along the Batavia Kill. Knotweed is a pioneer species in respect of its colonization of bare soils on bars and probably bank levees and floodplain. A climax species, in the classical sense, is a plant that dominates vegetation and continues to reproduce indefinitely in its own shelter. Vegetation, however, is by nature unstable and plant communities change on short and long time scales, whether due to exogenous factors (such as flood-caused scouring and deposition) or endogenous factors (such as production of organic matter by plants and its accumulation in soil). Many of the knotweed stands on the Batavia Kill seem to have had their origin within the past 10-20 years. It is not known whether, for example, knotweed stands on the Batavia Kill, if left alone, would eventually be invaded, and partly or entirely replaced, by woody plants, or whether older portions of knotweed rhizomes would die, creating space for other plants at the edge or center of existing knotweed stands. Given the apparent ease of establishment of knotweed propagules, however, and the likelihood that stands can survive for decades or longer, we might consider Japanese knotweed stable on the scale of human stream management and water supply activities.

Bank Erosion and Turbidity

"The soils in the Batavia Kill watershed have a moderate to severe risk of erosion. Approximately 88% of the watershed soils are characterized as having a moderate erosion hazard or worse, with 54% classified as severe to very severe. As would be expected, the erosion hazard is directly related to soils with steeper slopes" (Greene County Soil and Water Conservation District 2002). Turbidity is a measure of fine suspended particles, most of which normally originate as material eroded from soils. Sediment must be removed from drinking water, in part because pathogens such as *Giardia* and *Cryptosporidium* attach to suspended particles. An increase in turbidity can interfere with effective disinfection of water, and therefore lead to an increased concentration of pathogens in the water and a greater health risk to the public (Karen Moore, personal communication, 2002). This may require filtration or disinfection at the water treatment plant. Determining causes of turbidity and preventing its increase can be very cost effective.

The concept of Japanese knotweed effects on soils along the Batavia Kill comprises two ideas: 1. The rooting pattern of knotweed holds the streambank more effectively than grass (e.g., hay or lawn) but less effectively than native riparian woody plants, and subjects the banks to undercutting and slumping; and 2. The limited aerial cover and unstable litter cover of knotweed does not protect floodplain soils which wash out during overbank floods (Greene County Soil and Water Conservation District, personal communications, 2002-2003). Because the economic and ecological costs of active management of knotweed will be substantial, it is important to analyze all negative and positive impacts of knotweed in consideration of the costs of reducing or removing knotweed and replacing it successfully and permanently with more desirable plant communities.

Because research on an invasive plant species often focuses on one or a few impacts (e.g., aesthetics, birds, fish, rare flora), and because invasion ecology and management goals vary geographically, biologists and managers working with Japanese knotweed may not have adequately considered the impacts of knotweed on soil stability and water quality. If Japanese knotweed does increase bank erosion, and therefore turbidity in the water, its potential impacts on water quality and cost of water treatment could be high. As yet we have found no quantitative data relating Japanese knotweed to an increase in bank erosion and turbidity (Larry McCormick, personal communication; Trevor Renals, personal communication, 2002; Catey Ritchie, personal communication, 2002). Some practitioners believe that Japanese knotweed stabilizes banks and reduces erosion (Paul 2000; Dan Spada, personal communication, 2002; Richard Mitchell, personal communication, 2003). Catey Ritchie (personal communication 2003) has seen segments of the Connecticut River in Vermont where undercutting and slumping seem to be occurring at knotweed stands. Neither hypothesis (knotweed increases erosion or knotweed reduces erosion) has been examined rigorously, as far as we know. Hard data are needed on the impact of Japanese knotweed on erosion and deposition processes.

Management of Japanese Knotweed

There has been considerable research on the control of Japanese knotweed. Most of the techniques reported in the literature are summarized in Table 3. The most successful treatments seem to combine mechanical and chemical controls (Child & Wade 2000). It is important, irrespective of technique, to treat at the correct season(s) and frequencies, and to monitor for regrowth or reinvasion.

Manual and Mechanical Control

Hand-pulling is recommended in the U.K. for controlling small infestations especially where biological sensitivity (e.g., rare plants) prevents the use of other methods. Hand-pulling must remove as much underground material as possible when the aboveground material is at peak standing crop (August), and pulling must continue for at least three years, or until no aerial shoots are detected. Hand-pulling is well-suited to control of new infestations before they spread (Child & Wade 2000). (It should be noted that control of new infestations and small colonies is generally considered an especially important part of the strategy to control any invasive plant.)

In a U.K. study knotweed was pulled instead of cut. Mature stems were pulled at the end of the growing season; care was taken to remove as much of the rhizomes as possible. Pulling was effective if continued for three years (Baker 1988, Child et al. 1992). Pulling is suitable for small stands but it is laborious and soils surrounding the knotweed stand may be damaged by trampling and digging. Hand-pulling should be considered for control of recently established, small stands.

A greenhouse study demonstrated that cutting more than once had a significant impact on the belowground biomass of Japanese knotweed (Seiger & Merchant 1997). The timing of the cuts was not as important as the frequency, but cutting alone did not eliminate knotweed. As soon as the cutting stopped, the plant returned. Cutting will reduce the vigor of the stand, and this can perhaps increase the efficacy of other treatments, or allow time for other plants to move in to the area.

The Vermont Chapter of the Nature Conservancy is currently using mechanical control to reduce the vigor of Japanese knotweed stands in three preserves where knotweed is a threat to two forested floodplain habitats and a calcareous seep habitat. Mechanical control was chosen instead of chemical control because of concern about impacts on nontarget flora. The knotweed is cut with hand clippers or hand-pulled 4x/year, and after 4 years the knotweed shoots were only 0.5 m high (Catey Ritchie, personal communications, 2002-2003). Baker (1988), in the U.K., greatly reduced vigor of Japanese knotweed by cutting semimonthly during the growing season for two years.

As mentioned above, belowground and aboveground knotweed material that has been cut or pulled may be viable, and disposal must be fastidious. Harvested material can be dried, burned or deeply buried. Where knotweed is managed by cutting or pulling at Nature Conservancy preserves on the Connecticut River in Vermont, the knotweed material is hung in bunches on tree branches and left permanently (Catey Ritchie, personal communication, 2003). Options for treating soil that contains fragments of Japanese knotweed include sterilization, freezing, burning, and sieving (Child & Wade 2000). In addition to concern about vegetative propagation, cut material should be removed from the stand to reduce accumulation of litter which seems to play a role in the dominance of Japanese knotweed. We have seen no reports of composting knotweed and it is unclear if knotweed allelochemicals would persist in the final product. Child & Wade (2000:83) recommended against composting, perhaps because of the potential for knotweed propagules to sprout from compost piles.

A further concern with hand-pulling or excavation (manual or mechanical) of knotweed is the resulting bare soil. The disturbed soil must be stabilized and planted with competitive native species, to prevent erosion or rapid reinvasion of knotweed (or another undesirable species).

Chemical Control

Japanese knotweed has been characterized as "fairly resistent to herbicides" (Cronk & Fuller 1995); however, certain herbicides are effective (Table 1). Some herbicides have been approved for use near water whereas others have not. Other factors to consider in choice of herbicide include: size of infestation, presence of other flora, and cost.

The NYCDEP has a strong preference to avoid chemical treatment, because of the potential for chemical contamination of the water supply. Controlled use of small amounts of herbicide, e.g., by clip-and-drip or injection, might be acceptable (if these treatments are used they should first be tried on a limited basis with monitoring for herbicide residues and any toxic breakdown products).

Although 5-10% solutions of acetic acid in water (essentially vinegar at the lower concentration) have been used to control a variety of weeds, this technique would appear ineffective for Japanese knotweed. Acetic acid kills aboveground parts but not belowground parts of weeds, thus would have to be reapplied many times (Bill Quarles, Bio-Integral Research Center, personal communication 2003).

Harvest for Livestock Fodder

In the U.S.S.R., Japanese knotweed was reported to provide good forage fresh and ensiled (Bobrov et al. 1970:535), presumably for cattle. Bobrov et al. (1970:536) also stated that the closely related giant knotweed was readily eaten by horses and cows and was suitable for silage. Both sheep and cattle can significantly reduce shoot density within stands of Japanese knotweed (Beerling 1990). Horses, donkeys and goats also eat Japanese knotweed. The animals tend to eat the young shoots in the spring and are less likely to eat the older plants as they become woodier. The previous year's plants (dead shoots) deter most livestock from grazing, and must be cut to allow livestock access to the young shoots (Child & Wade 2000). It might be possible to treat small stands using livestock confined by temporary or portable fences as has been done with common reed. NYCDEP, however, is concerned about erosion and compaction of soils caused by livestock treading.

It might be feasible to harvest Japanese knotweed to feed it to livestock. In summer 2003, E. Kiviat and Jennifer Hanink observed small amounts of Japanese knotweed being cut and baled with grass hay on the Batavia Kill at Route 17. Richard Mitchell (personal communication, 2002) mentioned "rare reports of livestock foundering after eating [Japanese knotweed] in quantity."

We have not found any information on the potential of wild mammals (e.g., deer, beaver, muskrat) to affect knotweed stands. Japanese knotweed is unpalatable to white-tailed deer (Bryon Shissler, Pennsylvania Game Commission, presentation at conference 6 July 2003, Philadelphia). There were many deer trails in knotweed stands on the Batavia Kill in 2003 but no evidence of grazing (E. Kiviat & J. Hanink, personal observation). In 2003, beaver were cutting Japanese knotweed for dam construction on the Batavia Kill (M. Folsom & G. Stevens, personal communication), and this behavior has also been reported from other locations in the northeastern states by Jennifer Hanink (personal communication 2003), Mary Beth Deller (personal communication 2003) and Ken Soltesz (personal communication 2003).

Biological Control

"Classical" biological control establishes species-specific herbivorous insects or microorganisms introduced from the native range of an invasive plant. The genetic uniformity of Japanese knotweed makes it a good candidate for biocontrol (Seiger 1991). Early work on biocontrol in the U.K. and U.S. has yielded promising results (Richard Shaw, personal communication, 2002). Some pathogenic fungi have been identified. Herbivorous insects are also under consideration as potential biocontrol agents (Shaw & Seiger 2002). "Augmentative" or "inundative" biocontrol may be a viable alternative to classical biocontrol; this would involve local introduction of a native (or already-established exotic) grazer or pathogen to reduce knotweed biomass on a site-specific basis, without bringing new organisms in from Asia. We do not know of any research on applying this technique to Japanese knotweed.

Other Methods

Shading, perhaps combined with cutting, may be a somewhat effective means of control (Seiger 1991). Prescribed fire could have the same result as cutting, by reducing food storage in rhizomes. One individual who has attempted to control knotweed for years has suggested electrocution (*fide* Lori Quillen, personal communication, 2002). Competitive planting (i.e., planting fast-growing, competitive, native woody riparian species such as certain willows, alders, or aspens; see Seiger 1993) needs study; Jon Petrillo (KleinSchmidt Associates, personal communication, 2003) is initiating experiments in Connecticut. Small experimental plots could be used to establish the safety and efficacy of prospective techniques on a small scale, and then larger scale experiments could be conducted with concomitant monitoring.

Prevention of establishment and spread into new areas is an important part of a management program. This should include avoidance of transporting knotweed-infested soils and knotweed propagules themselves (e.g., on highway improvement projects and construction projects), and not facilitating the movement of propagules into streams (e.g., by not bulldozing knotweed into streams, leaving cut knotweed material where it can wash or blow into streams, or causing erosion in existing knotweed stands).

In developing a plan to manage Japanese knotweed on the Batavia Kill, both negative and positive impacts of knotweed, and negative and positive impacts of its management (reduction or removal), must be considered. Impacts encompass both economic impacts (costs of initial management and maintenance of the desired condition; benefits to water quality, fisheries, wildlife, etc.), and ecological impacts. Negative ecological impacts of managing knotweed potentially include: 1. Erosion of soil exposed by removing knotweed, or erosion of soil stabilized by knotweed, unless and until the knotweed can be permanently replaced by desirable vegetation that is a more effective soil binder; 2. Compaction of soils by heavy equipment; 3. Chemical contamination by herbicides (including their breakdown products) used for knotweed control, or by agricultural chemicals remobilized from disturbed soil; and 4. Changes in habitat on the floodplain or in the stream that may result in reduced density, productivity, fitness, or health of desirable biota such as trout, native birds, and native insect pollinators. Positive impacts of managing knotweed potentially include: 1. Reduced soil erosion such that suspended sediment is less over the long term; 2. Improvements to habitat; and 3. Reduced nuisance related to visual amenity, managing ornamental vegetation (e.g., lawns) and hay that is invasible by knotweed, and access to stream banks for fishing. As part of the economic cost-benefit equation, the need for periodic maintenance of managed areas must be considered, because knotweed is likely to be incompletely removed or to reinvade. It is unclear whether a management solution can be found that will create plant communities not significantly invasible by knotweed (e.g., closed-canopy forest of native trees that suppresses the establishment and vigor of knotweed).

Further Study

We recommend the following field studies of Japanese knotweed in the Batavia Kill corridor.

Mapping

Map existing stands from recent stereophotography with appropriate ground-truthing (see Hudsonia report, in preparation). Analyze distribution of knotweed in relation to land use and recreation. If possible study older aerial photos and ground photos to understand history and rates of spread of knotweed. Determine which habitats are at risk of invasion. Use existing GCSWCD and NYCDEP data to analyze the relationship of knotweed stands to different geomorphic habitats and features, and the temporal changes in the stands.

Table 1. Methods for management of Japanese knotweed (from Baker 1988, Beerling 1990, Seiger 1991, 1996; Child et al. 1992, Child & Wade 2000, de Waal 2000; Catey Ritchie, personal communication, 2002; Richard Shaw, personal communication, 2002). Table format and certain entries modified from Child and Wade (2000).

Objectives	Technique	Season	Frequency	Advantages	Disadvantages
Removal of dead stems prior to chemical treatment	***Cutting with a metal blade***	Autumn-winter	Annually	Can increase efficacy of chemical control	Labor intensive
Preventing spread of Japanese knotweed into lawn, hay, or	***Mowing or grazing***	Growing season	Mow every 2 weeks. Graze livestock graze throughout growing season	No herbicides; for riparian and sensitive habitats	Can be labor intensive; potential soil compaction

pasture					
Reducing Japanese knotweed vigor	***Cutting, mowing, grazing***	March-October	Mow every 2 weeks. Graze livestock graze throughout growing season	No herbicides; for riparian and sensitive habitats	Will suppress but not eradicate; potential soil compaction
Removing Japanese knotweed from mixed vegetation	***Hand-pulling***	Growing season	As new shoots appear, or at the end of the growing season	No herbicides; for riparian and sensitive habitats	Labor intensive
Cutting knotweed shoots back before chemical treatment	***Cutting***	March-August	As required	Can increase efficacy of chemical control	Labor intensive; potential for soil compaction
Reducing stand vigor	***Shading or solarization with commercial weed control fabric or plastic sheet***	Growing season	As new shoots arise – most effective combined with cutting	No herbicides; for riparian and sensitive habitats	Only suitable for small stands
Elimination of the stand	***Digging 5-7 m laterally and at least 2 m down***	All year except when ground frozen		No herbicides; for riparian and sensitive habitats	Labor intensive; must dispose of fill carefully or can increase spread; difficult to remove all belowground material; potential for soil damage
Removal of knotweed or reduction in vigor	***Picloram (Tordon, Grazon)***	When plants are a minimum of 1 m high	1x/year; chemical persistent in soil for up to 2 years	May be used on paving, hard surfaces, or other areas without wildlife value	Can not use near water; selective herbicide and persistent in soil
Removal of knotweed or reduction in vigor	***Imazapyr (Arsenal)***	Growing season	Maximum of 1x/ year		Can not use near water; persistent in soil and non-selective
Removal of knotweed or reduction in vigor	***Triclopyr (Garlon A, Garlon 4, Turflon)***	During active growth when foliage is well developed (June-July)	No more than 2x/ year	May be used on paving, hard surfaces or other areas	Selective herbicide affects broad-leafed species but not grasses

				without wildlife value	
Removal of knotweed or reduction in vigor	***Glyphosate (Roundup, Rodeo, etc.)***	May and July	2x/year	Certain formulations can be used near water	Non-selective and can kill beneficial species; surfactant in Roundup is toxic to fish and other aquatic organisms
Removal of knotweed or reduction in vigor	***2,4-D amine (Weedone, Weed-b-Gon, Weeder)***	May and July (additional application in September for complete control)	2-3x/year	Can use near water	Kills broadleaf weeds, and woody plants. They can damage other nearby desirable broadleaf plants; cotton, grapes and tomatoes are particularly sensitive
Reduction in biomass	***Biocontrol***		In development, primarily in Britain	Potentially very effective, due to genetic uniformity	Potential for host-switching by biocontrol organisms; may be ineffective on Japanese knotweed
Disposal of knotweed material	***Burying knotweed fragments in 10 m of soil***	As needed			Need to watch carefully, to make sure no spread occurs
Disposal of knotweed material	***Separation of rhizome material and burning***	As needed			Need to watch carefully, to make sure no spread occurs
Disposal of knotweed material	***Legal regulation of planting and disposal of plant materials***[1]	As needed			
Disposal of knotweed material	***Drying of plant cuttings***	As needed			Need to watch carefully, to make sure no spread occurs
Prevention of spread	***Education***	As needed			

[1]In Britain it is illegal to plant Japanese knotweed (Wildlife and Countryside Act 1981) and it is classified as a 'controlled waste' and must be disposed of safely at a licensed landfill site (Environmental Protection Act 1990).

Water Quality

Examine rooting structures and soil structure (and possibly subfossil knotweed material) within and between knotweed stands in depositing and eroding bank habitats to better understand how knotweed affects erosion and deposition. Make direct measurements of erosion of stream banks and the floodplain surface in different plant communities.

Impacts on Other Biota

Establish permanent plots in knotweed stands and adjoining stands of native vegetation. Sample vegetation to document knotweed characteristics (e.g., height, biomass) and other flora growing beneath the knotweed (see Hudsonia report, in preparation).

Sample arthropods associated with knotweed leaves and flowers using, e.g., sweep net and visual observation. Sample invertebrates associated with knotweed litter using Berlese funnel separation. Samples from knotweed stands should be compared with samples from native woody plant communities and herbaceous communities in nearby similar habitats. Sample invertebrate drift in stream to determine the relative composition by knotweed and non-knotweed arthropods.

Conduct studies (e.g., using litterbags) to compare aquatic macroinvertebrate use of knotweed detritus and native woody plant detritus. Examine trout food habits relative to both food chains.

Sample use of knotweed stands by terrestrial vertebrates (birds, mammals, reptiles, amphibians) for foraging, nesting, and shelter. Study the density, behavior, health, and fitness of selected species in knotweed compared to alternate plant communities.

Human Concerns

Interview residents and visitors concerning possible sources of knotweed propagules (e.g., yard waste), attitudes towards knotweed, and impacts of knotweed on angling or other use and enjoyment of the Batavia Kill. Educate the public about knotweed and how its spread can be reduced. Develop an educational brochure about Japanese knotweed, its impacts, and how landowners can contribute to an effective integrated management program.

Integrated Management Program

Information from the recommended studies should allow determination of the impacts on Japanese knotweed on water quality, the trout fishery, and other components of the Batavia Kill landscape. GCSWCD, NYCDEP, Hudsonia, and other “stakeholders” can then decide where management should aim to eliminate knotweed stands, reduce the vigor of stands and alter their architecture (to change habitat functions and geomorphic impacts), or simply prevent further spread. Then we will be able to experiment with various management techniques. After suitable experiments are conducted and appropriately monitored, a Batavia Kill-specific management approach can be designed based on the integrated pest management (IPM) model.

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