A review of literature and field practices focused on the management and control of invasive knotweed

(Polygonum cuspidatum, P. sachalinense, P. polystachyum and hybrids)

March 2006

J. Murray McHugh
The Nature Conservancy
Southern Lake Champlain Valley Program
West Haven, VT

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Preface

This document is a product of a cooperative agreement between The Nature Conservancy (TNC), U.S. Fish and Wildlife Service, and the New York State Council of Trout Unlimited. The goal of the cooperative agreement was to produce a report containing a literature review and synthesis on the ecology and control of invasive knotweed. The report was meant to:

> "…inform natural resource managers and policy makers, municipalities, conservation organizations, transportation specialists, and private landowners on the existing and potential threat of the spread of this plant to stream corridor areas and to improve control efforts throughout the Lake Champlain watershed and other impacted areas of the northeast and mid-west U. S".

In summary, a substantial amount of information on knotweed management exists, and several comprehensive summaries with at similar goals have been developed, on the invasive ecology and control of knotweed in the US. Two recently completed reports cover most of the ground that this report was originally to focus on.

The report written by Erin Talmage and Erik Kiviat of Hudsonia Ltd., *Japanese Knotweed and Water Quality on the Batavia Kill in Greene County, New York: Background Information and Literature Review*, provides a well-referenced and detailed description of the origin, growth habit, invasive history, potential ecological impacts, and management of Japanese knotweed.

Another report written by Jonathon Soll of the TNC Oregon Field Office, *Controlling Knotweed (Polygonum cuspidatum, P. sachalinense, P. polystachyum and hybrids) in the Pacific Northwest*, briefly describes the three species and their basic ecology, but then provides a detailed description of tested control methods and provides recommendations of Best Management Practices. The report is based on the experience gained from three years of active knotweed control effort and had the most complete and up-to-date descriptions of methodology.

Together, these documents provide a wealth of information on knotweed invasive ecology and control. To avoid duplicative effort in the writing of this report, little effort was spent on researching to describe the invasive ecology of knotweed, and the literature search was restricted to the period between 2004 and the present. Relevant new literature is reviewed in the section of this report it applies to. As for information on control methods, the report from Oregon TNC report forms the base of this report and new relevant information is provided at the end of each section.

Information summarized in this report comes from numerous different sources. Information was collected from grey literature, such as annual management reports, methodology recommendations and websites, and phone and email correspondence with practitioners. A substantial amount of information on control and management was often not systematically collected or recorded, and thus comes from recollected personal observations. Consideration of the subjective nature of such observations was used in presenting such information in this report.

Introduction

Non-native invasive knotweed species (hereafter referred to as "knotweed") have received much attention in recent years from many involved in ecological land management, including federal, state and local government, conservation organizations, watershed groups, state transportation departments, and private landowners. In most places, knotweed spreads across the landscape quickly and rapidly expands its footprint where it becomes established. It is quite visible and easy to identify (to the genus) for the botanist and layperson alike and its impacts on the landscape are often significant. The fast rate of spread in riparian systems and the degree to which it can impact water quality and riparian habitat have led to large scale efforts to control and eliminate knotweed.

Currently, the largest US-based efforts in knotweed control encountered were in the Pacific Northwest sates of Oregon and Washington in the Sandy River and xxxx watersheds. The large-scale Pacific Northwest knotweed invasion may have been initiated by a severe widespread flood event in 1996, which led to a lot of scouring and resultant bare substrates, and hence may have been a catalyst for the spread of knotweed in riparian systems (Dan Wallenmeyer, Noxious Weed Coordinator, Skamania County, Washington, personal communication). Nonetheless, much of the information on control methods currently originates from trials conducted in Oregon and Washington. Given the well-developed nature of these management projects, practitioners in the rest of the U.S. would be well advised to take advantage of the information networks that have formed in the Pacific Northwest to stay informed about the most recent control information. Whether the increased attention to knotweed is a response to possibly greater rates of invasion in the Pacific Northwest or simply due to a choice to focus on knotweed is beyond the scope of this report, but is still an interesting, and potentially ecologically significant, question.

Britain also has strong ongoing knotweed control efforts and is working on finding biological controls (http://www.cabi-bioscience.org/ISMIndex.asp).

Invasive Knotweed Species

Japanese knotweed (*Polygonum cuspidatum*), giant knotweed (*Polygonum sachalinense*) and their hybrid, Bohemian knotweed (*Polygonum x bohimicum*) are non-native herbaceous perennials that are invasive in many regions of the United States. All three knotweeds have been found in New England according to maps on the Invasive Plant Atlas of New England website (http://www.uconncgia.uconn.edu/ipane/ipane.maps.pl). Himalayan knotweed (*P. polystachyum*) is an invasive concern in the Pacific Northwest, but mention of occurrence and/or concern in the Northeast was not found. Japanese knotweed is the species that is nearly exclusively cited as the knotweed of invasive concern in the Northeast US, whereas all four species are considered major concerns in the Pacific Northwest. Growth and colonization characteristics of the four species do differ, but they are commonly lumped together in control information coming out of the Pacific Northwest. Reported differences between the three species and the hybrid that affect applicable control methods were not found.

Given the presence of multiple species in North America, managers in the Northeast should become familiar with the morphological features that separate the knotweed species to confirm that Japanese knotweed is in fact the predominant invasive species of the region.

To differentiate the species, look at leaves from the middle of a shoot, not the shoot tip leaves, which are highly variable. Leaves of Japanese knotweed are flat-based, with an acutely tapering tip, whereas leaves of giant knotweed have a deeply notched base with a more gradually tapering tip, and leaves of bohemian knotweed are intermediate between the other 2 species (Figures 1 & 3). Hairs on the midvein on the underside of the leaf are also diagnostic. To observe the hairs, use a 10X lens to view a backlit leaf bent over a finger. Hairs of giant knotweed are multicellular, kinky, and long, whereas hairs of bohemian knotweed are shorter and unicellular with a broad base, and hairs of Japanese knotweed are reduced to bumps (Figure 2) (http://www.fs.fed.us/r10/spf/fhp/invasive/Invasive%20Polygonaceae.pdf).

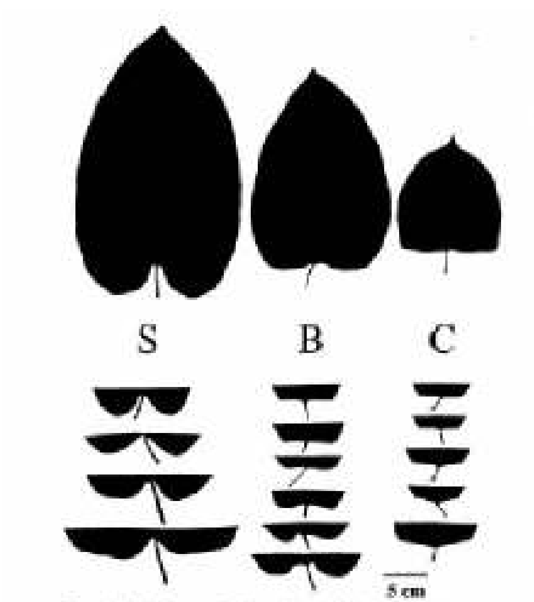
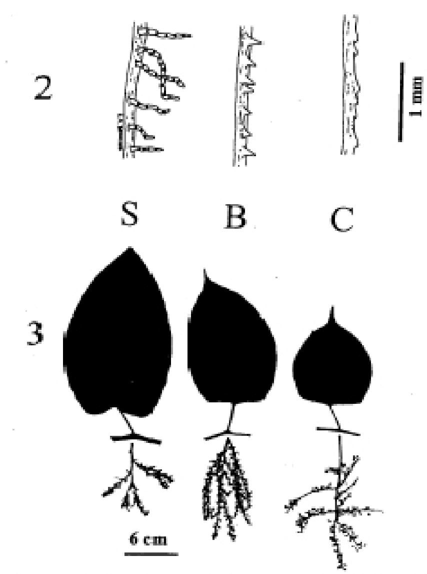


Figure 1. Leaf silhouettes for mid-stem leaves of *Polygonum*, showing variation in shape of leaf bases S = *P. sachalinense*. B = *P. x bohemicum*. C = *P. cuspidatum* (originally from Zika & Jacobson (2003); copied from http://www.nwcb.wa.gov/weed_info/Written_findings/Polygonum_bohemicum.doc).



Figures 2-3. *Polygonum* morphology. 2. Hairs on lower leaf surface. S = *P. sachalinense*, narrow-based long multicellular hairs. B = *P. x bohemicum*, broad-based stout single-celled hairs. C = *P. cuspidatum*, blunt broad-based scabers or knobs. 3. Relative length of inflorescence and subtending mid-branch leaf. S = *P. sachalinense*, inflorescence < leaf. B = *P. x bohemicum*, inflorescence variable, usually < leaf. C = *P. cuspidatum*, inflorescence ≥ subtending leaf (originally from Zika & Jacobson (2003); copied from http://www.nwcb.wa.gov/PNWKNOTWEED/images/knotweed_images.htm).

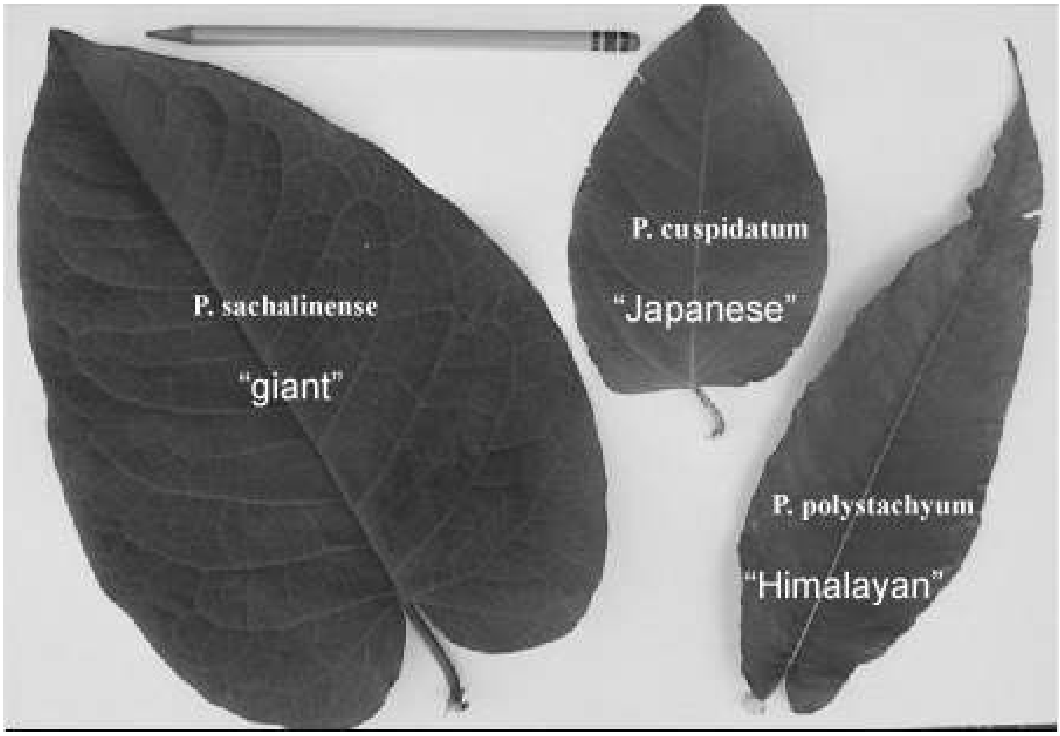


Figure 3. Leaves of *P. sachalinense*, *P. cuspidatum* and *P. polystachyum* (Oregon TNC)

Basic Knotweed Ecology *(from Soll, 2004)*

In the Pacific Northwest (PNW), at low elevation, knotweed typically starts growth in April, earlier in warm areas, and as late as June at higher elevations. Even at low elevation, stems from deeply buried roots may emerge as late as July or August. Knotweed grows extremely fast during the spring [Emergence reported in March and April in Pennsylvania (Gover, 2005) and flowering from July and September in New York (Mitchell & Dean, 1978)]. Giant knotweed can reach 15 feet (4.5 meters) by June (photograph 6). The slightly shorter Japanese knotweed reaches "only" 10 feet (3 meters) or so. The "dwarf" Himalayan variety is shorter still, typically reaching 4-6 feet (1.5 - 2 meters).

Knotweed is a creeping perennial. It dies back to the ground with the first hard frost, and returns each spring from the same root system. The term "creeping" refers to the extensive network of rhizomes (roots that can sprout) spreading at least 23 feet (7 meters), and possibly as far as 65 feet (20 meters) from the parent plant and penetrating at least 7 feet (2 meters) into the soil.

Knotweed can spread rapidly due to its ability to reproduce vegetatively. Root and stem fragments, as small as 1/2" (1cm) can form new plant colonies. Seasonal high water events and floods sweep plants into rivers and creeks, then fragment and disperse knotweed plant parts throughout the floodplains and cobble bars. The fast growing knotweed then takes advantage of the freshly disturbed soil to become established. Because it grows faster than most other plant species (including native species and most other weeds) it quickly outgrows and suppresses or kills them.

Roadside ditches, irrigation canals, and other water drainage systems can be colonized the same way. Cut or broken stems and roots will sprout if left on moist soil or put directly into water, or if moved by beavers (or earth moving equipment). Stem or root fragments can also be spread in contaminated fill material.

Although pure strains of Japanese, giant or Himalayan knotweed are not thought to produce fertile seed in the United States, the hybrid varieties (including the recently described hybrid of giant and Japanese knotweed — *Polygonum X bohemicum*) are able to produce fertile seeds. According to knowledgeable observers, unfortunately, many of the patches in the Pacific Northwest appear to be hybrids of Japanese and giant knotweed. The Nature Conservancy (TNC) has successfully germinated knotweed seeds in a laboratory setting and seedlings have been confirmed in at least one setting on the Sandy River during spring 2002. Should extensive sexual reproduction be confirmed in the field it would certainly alter the strategy for landscape level control projects.

Knotweed re-sprouts vigorously following cutting, mowing, digging and some herbicide treatments, especially early in the growing season, until at least August. Such treatments apparently stimulate the production of shoots from latent buds dispersed on the root crown or rhizomes.

Contrary to Soll (2004), two recent studies reported the potential for Japanese knotweed to spread by seed. Forman & Kesseli (2003) collected seed from 29 Japanese knotweed plants in Massachusetts field sites and found high germinability. They also found seedlings growing in the field and confirmed winter survival of some of the seedlings. Bramm and McNair (2004) showed the potential of seed germinability of Japanese knotweed in the areas of Philadelphia, PA. Of the three sites they studied for two consecutive years, they found consistent germination rates reaching 90% from two sites and from 40% to 50% from the third site. Germination occurred in the field both with planted seeds and naturally occurring seeds and occurred both within stands and in areas well removed from stands. They found that germinability of seed from two sites went from near 10% in seeds collected on September 11 to nearly 90% in seeds collected after 4 more weeks of ripening on the plant. They found that a typical stem at one of the sites was capable of producing over 127,000 seeds. Both studies show the potential for spread by seed and lead to the recommendation to remove female inflorescences before the formation of fruit.

Potential Impacts *(from Talmage and Kiviat, 2004)*

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*).

On vegetation- Japanese knotweed [can] cover extensive areas of [river] banks and floodplains 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 often true of knotweed. 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- 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 can presumably intercept nutrients and fine sediment from agricultural fields; 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 [in Greene County, NY], 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 m2) 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 infestations.

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.

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 leave 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).

Erik Kiviat supplied the following commentary on the above section when recently contacted (Erik Kiviat, Hudsonia, Ltd., personal communication, February 2006):

We have observed following floods (e.g. in 2005) that there is considerable deposition of fine sediment on the floodplain surface within Japanese knotweed stands in at least some areas. It is possible that sediment deposits among knotweed stems on the floodplain surface whereas streambanks dominated by knotweed eroded by

> undercutting and slumping. Measurements of deposition and erosion are needed on a large scale to establish the local and net effects of knotweed colonization on sedimentation processes in relation to alternate plant communities.
>
> There is a lot of speculation and hypotheses in the discussion above, and few quantitative data are available regarding knotweed impacts on other biota or on abiotic processes. Although there may be reasons to manage knotweed in certain ways (e.g., reducing dominance by an introduced species), hypothetical impacts on particular species or processes should not be used as a justification for a management approach until there are replicated quantitative studies pertaining to the species or processes of interest in the relevant geographic region and habitat type.

The only published experimental study found that investigates the comparative wildlife habitat quality of knotweed stands was completed by researchers in New York looking at green frogs foraging in Japanese knotweed. In the study, green frogs were allowed to forage in feeding buckets along transects that traversed ground from non-invaded to knotweed-dominated areas. They found that change in frog mass declined significantly along transects, with most frogs in non-invaded plots gaining mass and no frogs in invaded plots gaining mass. It was noted in the discussion that many factors would have been involved in the foraging activity of the frogs, but their results led them to the hypothesis that Japanese knotweed invasions degrade terrestrial habitat quality for frogs by indirectly reducing arthropod abundance. The study of vegetation structure and composition showed that diverse assemblages of native plants that covered non-invaded plots were absent from areas invaded by Japanese knotweed (Maerz et al., 2005).

Research on the impact of knotweed on stream bank erosion is being conducted at Cornell University led by Rebecca Schneider. Their research has focused on the plant and species levels of functioning. They have quantified and compared amounts and types of roots and resistance to erosive forces between knotweed, giant reed grass, purple loosestrife, and native cattails. They are looking for funding to expand the research to a larger scale, of whole stream banks and reaches (Directory of Participants, Regional Knotweed Mgrs Meeting, February 24, 2005, Kingston, NY). The larger scale study could provide evidence of the generally accepted belief that knotweed provides less protection from erosive forces than much of the vegetation that it displaces and excludes.

Control Planning

Knotweed invasion often occurs within riparian systems, and water seems to be a primary dispersal vector of knotweed propagules (Soll, 2004), be they seed or vegetative fragments. Thus whenever possible, control should be planned with water movement as a primary factor in deciding where to start working. Optimally, control planning would be done on a watershed scale, and control would begin at the headwaters and move downstream. Localized control efforts initiated in mid-reach stands downstream of infested areas would likely be susceptible to re-infestation from water borne propagules originating from upstream areas. Watershed scale strategies will likely pose the challenges of dealing with private landowners and access; and may not be able to be enacted as planned due to these constraints, but should nonetheless be the goal of landscape planning. That said, immediate control of specific downstream stands may be the priority for several reasons, including impacts to ecological conservation targets, restrictions to recreational access and line-of-site in transportation corridors.

Watershed planning for knotweed control involves two key factors: landowner participation and knotweed stand mapping. Landowner participation will in all likelihood require outreach and education, with a goal of landowners accepting that knotweed negatively impacts their watershed and that control in necessary. Permission to access property for mapping knotweed would be the minimum desired output; next would be permission to initiate control on their property; and the best outcome would be for landowners to initiate control themselves. Such efforts have proven successful on a watershed scale. The Nature Conservancy's effort in the Pacific Northwest successfully gained landowner permission from over 200 landowners to control 80% of knotweed occurances on the Sandy River (Tu & Soll, 2004).

Our review of collected information indicates that there are many factors that can influence the choice of the appropriate control method. In summary, site specific characteristics will influence the type of control methods that can be employed. The best control methods will likely vary according to site-specific characteristics. The following list includes thos most likely to influence management options.

- **Land ownership** – Landowners may not recognize the need to control knotweed on their property or may restrict access and/or the use of certain control methods.
- **Site accessibility** – Considerations such as the distance of the site from the base of operations and available modes of access, such as vehicular, boat and foot, can be important factors.
- **Knotweed stand metrics** – Stand size, shape, age and vigor, as well as stem diameters, could influence the efficiency of effort for specific control methods.
- **Funding** – Costs of equipment and materials will be dependant on method and can be front-loaded or spread over time. Workforce costs can vary with skills required, travel time, site accessibility and volunteer involvement.
- **Workforce –** The size, availability, skill level and dependability of the available workforce can influence methodology choice.
- **Herbicide restrictions** - The use of any herbicide, a specific herbicide and/or specific application methods and rates may be dictated by landowner preference or legal regulations specific to the site.
- **Non-target impacts** – Concern and potential for incidental impacts to other organisms and site processes could occur from both chemical and non-chemical methods and may be difficult to predict and model.

Approaching the suite of control methods available for knotweed control with a clear understanding of these factors for a given stand, or landscape, should facilitate the choice of appropriate methods.

Control and Eradication

Well-established knotweed is difficult to eradicate. Depending on the control strategy used and the vigor of the plants, successful control may entail managing a particular stand for several years of monitoring and repeated applications. Manual and mechanical controls will in nearly all cases require more site visits and control effort than will herbicide-based controls. For example, mowing is recommended to repeated every 2 weeks during the growing season and probably will not result in eradication (Talmage & Kiviat, 2004) whereas herbicide application through stem injection followed by a foliar spray of sprouts in the next growing season can result in eradication (Phil Burgess, Director, Clark County Weed Management, Washington, personal communication).

Even with the use of herbicide, knotweed has been found to be very difficult to eradicate in some circumstances. Practitioners have observed wide ranging results in control of different knotweed stands using the same control methods (Steven Flint, Invasive Field Steward, Adirondack TNC, personal communication; Tim Miller, Extension Weed Specialist, Washington State University, personal communication). The best approach may be to use a variety of methods, manual and/or chemical. For example, one control recommendation is to cut knotweed stems in the spring and apply a foliar spray to the sprouts during the early fall in the same year. This is an example of Integrated Vegetation Management (IVM) (Gover, 2005).

Control Methodology Summary*(from Soll 2004)*

> So you have knotweed and want to be rid of it? Good. It is possible, but not usually easy, especially at a landscape scale. Because of knotweed's incredibly extensive root system and sprouting ability, landscape level control must be thought of within the context of a program. Even on a patch by patch basis, successful eradication is likely to take more than one year, let alone one treatment in most cases. Finally, although there are potentially successful mechanical or manual control options for small patches, landscape level projects and large sites will almost certainly require integrating herbicide use into a control strategy.
>
> Although this document does not address it, a successful landscape level program will almost certainly involve outreach to private landowners and the broader community, as well as volunteer recruitment and coordination. You may need an outreach program to reach landowners that may have knotweed on their property. You almost certainly will need to educate those property owners and others so that they fully realize the threat knotweed poses. Fully understanding the devastating effects that knotweed can have on waterways and riparian ecological systems can only help motivate people to act.
>
> You may also want to work with volunteers and other organizations in your community to expand your ability to physically get the work done. Helping to create and protect free flowing waterways and noxious weed-free embankments provides the rewards that can inspire citizens to participate more fully in natural resource restoration projects.
>
> **Mechanical or Manual Control**
> **Variations: Cutting, mowing, pulling, digging, covering**
>
> The goal of mechanical control is to remove or starve the root system. In experiments conducted by The Nature Conservancy between June 2000 and June 2003 and as reported

in the literature, in the vast majority of cases, monthly cutting fails to eradicate even isolated and relatively small knotweed patches unless conducted for several years. However, The Japanese Knotweed Manual (Child and Wade 2000) reports successful control of an isolated and small patch after **three** consecutive years of uprooting the plants in August. TNC was able to control one small patch (25 stems) with 17 monthly cuttings over three field seasons. Child and Wade recommend against trying this technique for larger, more established patches.

So, unless you are prepared to cut knotweed patches TWICE A MONTH OR MORE - could we say it any stronger? - especially between April and August, and then once a month or more until the first frost, a program based on cutting alone is likely to be a recipe for frustration and failure. In some cases however, using manual / mechanical control may be the only viable option for legal or ethical reasons. For instance, if the knotweed is in a very environmentally sensitive area, if a particular landowner is opposed to pesticide use, on some federal lands and if labor costs are not an issue.

To be successful, one should plan for an aggressive mechanical control program (as described above and below) to be continued for at least two or three years if the patches are well established.

In the end, timely, thorough and persistent cutting over several years can eliminate knotweed, especially small, isolated patches. Because of the level of effort required, this approach is really best suited for individual landowners with easy access to their knotweed patches and a strong commitment to avoiding herbicides. Using a mower/weed-eater is an option if you can set it close to the ground. It is best to remove, rake or carefully dry all knotweed vegetation you cut or mow, because stems or stem fragments can sprout, and the area (or adjacent areas) may become re-infested. Do not allow cut, mowed or pulled vegetation to enter waterways.

Digging or pulling (uprooting) is a good option if your soil is soft. This will eliminate some portion of, but not all of the root system each time you do it. Be sure to carefully dry or dispose of the roots. Do not put them in a compost pile. In England, soil contaminated with knotweed roots is considered an environmental contaminant and needs to be buried 3 meters (10 feet) deep. You will need to follow up frequently as for cutting/mowing to catch re-sprouted stems. Be sure to search at least 20 feet (7 meters) away from the original patch center.

There are multiple anecdotal reports of control attempts using extended covering, but no reliable reports of successful knotweed control with covering. This includes those of the Lummi Nation in Washington, who combined digging, tilling and covering with several layers of cardboard on 2, ¼ acre patches. The results were poor however; they achieved only 80% reduction in stem number, at a cost of $32,000/acre. An effort to control knotweed by covering conducted by the USFS Mt Hood National Forest in Zig-Zag, Oregon, also failed, despite extensive pre-covering digging. TNC also failed to achieve good control covering a single large patch for about 6 weeks in the spring. Others have also reported that knotweed grows out from under the covering material. If you must try it, this method is likely to work better with isolated and smaller patches on open terrain. Plan to leave the covering material in place throughout the growing season and well into the next. As always, check the site through at least September the following year and again the year after.

Mechanical Control - How To:

Hand Cutting
Using a machete, loppers or pruning shears, cut the stems down to the ground surface as often as possible, but at least every 2-3 weeks from April (or as soon as the plant appears) through August. Sprouting slows after August, so you can reduce cutting frequency, but try and prevent the plants from ever exceeding six inches (15cm) in height. Pile the cut stems where they will quickly dry out.

Mowing
Using a weed-eater or mower, cut as low as possible and as often as possible, but at least every 2-3 weeks through August. Be sure you are not scattering stem or root fragments onto moist soil or into the water.

Goats are reported to eat knotweed and in some circumstances controlled goat grazing may be an option similar to intensive mowing. Be aware they will eat desirable vegetation as well.

Digging/Pulling
If the knotweed has established in soft soil, or better yet sand, try pulling the plant and major rhizomes up by the root crown to remove as much of the root system as you can. Although you will almost certainly not kill the plant in one treatment, you will reduce the root mass. Each time you see new sprouts (start looking a week after you pull and search at least 20 feet away from the original plant), uproot them as well, trying to pull out as much of the root as you can each time. This is probably only feasible with small patches. Be sure to carefully dispose of any root material.

Tilling
Used alone, tilling or otherwise physically disturbing the root system will not provide control and will create many sprouts. This approach may however offer some benefit in an integrated strategy, since it will increase the shoot to root ratio.

Covering
First cut stems down to ground surface (and possibly follow with tilling). Cover the area with thick black plastic or multiple layers of cardboard expanding beyond the plant base and stems at least 2 meters (and preferably 7 meters) beyond the outside stems. Weight down the covering material and watch the perimeters to be sure new stems are not popping up outside your cover material. Try this right at the beginning of the year or after you've cut the plant down a couple of times in the spring and reduced some of the rapid plant growth. It may be necessary to leave the plant covered through at least one entire growing season.

Comments on Manual Control and Combining Treatments
No matter which control method(s) is used, manual or mechanical control is going to be a lot of work. But, combining digging/pulling with cutting or even herbicides use, helps break up the root system and encourages the plant to send up new shoots. The more shoots there are per linear foot of root, the more likely you will be to be able to physically pull them out, exhaust them by depriving them of energy (i.e. by cutting the shoot off) or kill them with herbicides.

> If you do try and control knotweed manually, be sure you practice the four T's: be timely, tenacious, tough and thorough. And as always, carefully dispose of any stem or root material.

Additional Notes on Mechanical Control

There have been some promising results in using covering for control. Most trials continue to show problems with using plastic sheets. The plastic tends to disintegrate and tear within one growing season, allowing for sprouting and generally making a mess. Two examples were found in the Pacific Northwest in which geotextile fabrics are being used to smother knotweed on sites where using herbicides was not the first or possible choice for control. The use of geotextiles, coupled with frequent maintenance, has shown some promise. The materials are relatively expensive (fabric material costs ranging from $0.067 to $0.105 per sq ft plus delivery charges) and the method seems to require frequent maintenance, but covering with geotextiles might be considered where herbicides are discouraged and as part of a larger IVM strategy. In addition to the trials in the Pacific Northwest, a "root barrier" material is being tested for knotweed control in Germany and the United Kingdom. The material "…consists of a layer of a woven geotextile and a layer of non-woven geotextile sandwiching a copper foil sheet, all bonded together by needle-punching to create an environmentally friendly barrier that releases an inert chemical trace to roots and shoots of herbaceous and graminaceous plants" (http://www.recltd.co.uk/knotweedbarrier.htm).

The King County Noxious Weed Control Program and the Cedar River Municipal Watershed, both located in Washington State, have used geotextile fabrics with what to seem promising results so far. The TNC Oregon Coast Program similarly used geotextiles to successfully control the invasive saltmarsh grass, *Spartina patens* (Debbie Pickering, Oregon Coast Stewardship Ecologist, Oregon TNC, personal communication). What seems to be the key to the successes observed by these covering applications is the strength and longevity of the geotextile fabrics. In both programs in Washington State, the fabric was left covering the knotweed for two full seasons and is planned to be left for several more if necessary. The ability of covering to result in stand eradication has yet to be shown, but results seem promising so far.

Case Study: Cedar River Municipal Watershed, North Bend, WA

Because the watershed is a source of drinking water, the use of herbicides is restricted. The initial use of geotextiles was used on a 2000' x 10-20' area in conjunction with manual grubbing, mechanical excavation (to a depth of 16") and cutting. In 2004, geotextile fabric was laid over the knotweed after the cutting and secured with rocks and logs found on site. After two years little to no knotweed growth was observed under the fabric. Vigorous sprouting did occur along the edges of the fabric, which was controlled by repeated hand-pulling. As of the end of the 2005 field season, edge sprouting had significantly lessened and maintenance was being conducted on a 3 week schedule.

After the initial use, several applications using geotextiles were installed in the 2004 and 2005 field seasons. Two types of geotextiles were used; woven and non-woven. The source for the geotextiles was supplied by the local department of transportation office, as the fabrics are often used in road construction. The woven fabric generally allowed for less growth under the fabric, but was "stiff" and thus somewhat difficult to use except in straight runs. It is made of woven slit-film polypropylene (Layfield LP200, 4 oz/yd^2; www.layfieldgroup.com). The non-woven fabric was considerably easier to work with, especially when working around obstacles such as trees. It is made of UV-stabilized needle-punched non-woven polypropylene fibers (Layfield LP6 & LP8, 5.5 & 7.5 oz/yd^2; www.layfieldgroup.com).

Most of the applications were on forested or forest-edge sites. For the method used, timing of application did not matter. Stems were cut to the ground and piled where they were cut. The fabric was loosely laid over the cut stems and extended a minimum of 2' beyond the existing edge of the knotweed patch. Extension of the fabric was limited to 2' because the material was costly and because frequent monitoring allowed for needed addition of fabric to cover edge sprouting. The fabric was only secured with stakes on steep slopes, elsewhere rocks and logs from the site were used to hold the fabric down. Fabric was used on 3 streambanks. Rocks were used to secure the stream-side edge in water and no erosion problems were observed after 2 seasons. It was important to lay the fabric loosely over the cut stems. Taught fabric led to stems poking through the fabric. This was especially important when covering large old patches that tended to put up a lot of growth under the fabric. During monitoring visits, the stems growing under the fabric were crushed by walking and stomping on the fabric.

Each site was monitored every three weeks during the 2004 and 2005 growing seasons. The need for visits every 3 weeks will be re-evaluated for the 2006 season. In the 2006 season, the plan is to uncover selected areas and watch for knotweed growth. If no knotweed is found, the areas will be planted with native trees and shrubs. Having 2 seasons of experience, it is expected that knotweed eradication using the geotextiles with frequent monitoring will take from 3 to 6 years. It was suggested that smothering with geotextiles was applicable to long linear (10' – 20' wide) applications and to rectangular areas up to approximately 20' x 50'. For larger areas, it was suggested that material costs and maintenance requirements would be restrictive (Sally Nickelson, Wildlife Biologist/Watershed Ecologist, Cedar River Watershed, Washington, personal communication).

Case Study: Green/Duwamish River Upper Watershed, King County Noxious Weed Control Program, King County, WA

Control on roughly 7 acres of knotweed was initiated in 2004 using multiple methods including stem injection, foliar application, manual control, mowing and smothering with heavy grade geotextile fabric. Covering with a geotextile was a part of the control application in a county park, where herbicide use was discouraged. There were a number of knotweed stands within the park area that received the geotextile, the largest covering 10,000 square feet. A woven geotextile was used (Sunbelt, 2 oz/yd^2; DeWitt Company, Inc.). The first attempt at the site to cover was reported to be a failure, mainly due to a large degree of sprouting along the edges of the control area. It took some experience to develop the method that eventually proved to be successful. The method involved mowing the knotweed to the ground, covering the stand with the geotextile with a minimum 6" overlap at adjacent edges of fabric, staking the perimeter of the treatment area and securing crisscrossing cords over the fabric tied at the stakes. Some slack was left in the fabric with the concern that if it were too taught, stems may poke through. The fabric was spread one foot beyond the boundaries of existing knotweed root crowns.

Knotweed sprouted along the perimeter of the fabric and was spot treated with a glyphosate foliar spray one or two times during the growing season. No knotweed was found sprouting under the fabric by the end of the 2005 season. The next step in management of the covered stands is to experiment with sticking live stakes (living cuttings of tree and shrub species that typically root easily) through the fabric, thus allowing for soil stabilization prior to the removal of the fabric. The method was considered to be costly compared to what foliar application of herbicide for the area would have cost, but was proposed as a potentially useful technique as part of an IVM strategy for a large stand (personal communication, Sean MacDougall, Noxious Weed Specialist, King County, Washington).

Final thoughts on covering with geotextiles

The use of covering may be considered for sites where herbicide use is restricted or may pose non-target threats, but covering is not without potential non-target impacts itself. Any plants under the fabric are not likely to survive and there is the question as to the habitat value of the black fabric on the landscape for several years. If used on a stream bank, the installation must take into account the force of flooding water over the fabric and plans must be in place to stabilize what will probably turn out to be primarily bare soil after uncovering.

Success or failure in using geotextiles to cover and control knotweed seems to be dependant on good installation techniques and diligent monitoring. This method will almost inevitably involve supplemental mechanical and/or chemical control, but might be considered as part of an IVM strategy.

Chemical Control*(From Soll, 2004)*

Herbicides – General

> Many herbicides, herbicide combinations and application methods have been tried on knotweed, and work to a greater or lesser degree depending on many factors. But like any weed control method, herbicides will fail if used incorrectly. Because knotweed thrives in riparian areas, herbicide exposure to water, the susceptibility of surrounding desirable plants to the herbicide, and the potential impact of herbicides on aquatic organisms must be considered in choosing the most appropriate product for your particular weed control program.
>
> To successfully control knotweed with herbicide treatments, the active ingredient in an herbicide product must have a mode of action designed to move the chemical from the leaves into the root system (i.e. be translocated) at sufficient concentration to kill the root tissue. To achieve successful translocation at your site, it may be necessary to conduct some field trials to test the efficacy of different concentrations of spray solution. Some herbicides may need to be used at low concentrations in order to avoid damaging the above ground tissues of the plant before the herbicide is well dispersed in the root system.

Herbicides with an active ingredient of glyphosate (Rodeo, Aquamaster, Gly Star, Round-up among others), triclopyr (Garlon 3a and many "shrub-killers"), 2,4-D, picloram (Tordon) and Imazapyr (Arsenal) have shown to be variably effective in controlling knotweed either separately or in combinations. Each offers benefits and potential risks.

Although some glyphosate products demonstrate acceptable control with one or two treatments in some cases, they frequently allow survival of several badly mutated stems (so called epinastic growth) from a given clump. These stems appear likely to survive and recover if left untreated. Clark County (Washington) Weed Management reports getting good control from applications of 7-8% glyphosate (e.g. Aquamaster) on first year plants or sprouts from nodes, with some patches requiring additional treatments. However, inadequate control was observed with a different glyphosate product (e.g. Rodeo) applied at 7-8% concentration on established knotweed patches. Because both products used in this trial had the same concentration of active ingredient (53.8%) it was not clear as to why the difference in product performance was observed (total root mass is probably an issue).

TNC has heard reports of successful control using Garlon at rates as low as 3/4% (about 1 oz per gallon) in high volume application. In TNC's field experiments, both 3-5% Garlon 3a and 3-5% Rodeo with LI-700 eradicate about 50% of small patches after two to four treatments over two years. In controlled experiments comparing treatments on small patches (30-200 stems), Garlon 3a provided 90+ percent control in one year and 100% control within 2 years. Rodeo was slightly but consistently less effective, typically taking 3 years of treatment to achieve full control.

A note about adjuvants - Adjuvants (also referred to as surfactants, penetrants, activators or stickerspreaders) are agents added to the herbicide mix that help it stick to or penetrate into the leaf. They can make a significant difference on how well the herbicide treatment works. The surfactant LI-700 has been considered the most salmon safe and has been approved by the National Oceanic and Atmospheric Administration - Fisheries (formerly the National Marine Fisheries Service - see paragraph below). Where direct risks to aquatic organisms aren't involved other non-ionic surfactants such as R-11, Activator or various seed oil derivatives may work safely and most likely will be better than LI-700 for glyphosate based herbicides. Away from water, surfactants with silicone (Syltac by Wilbur-Ellis for instance) may be helpful. Please seek the advice of your pesticide dealer, consultant or university extension agent to determine which adjuvant is best for the herbicide you choose and in consideration if there is any potential exposure to waterways.

Herbicide: Foliar Spray

Whether using a small hand held, backpack, or large volume sprayer, spraying herbicide on the leaves is one way to apply herbicides. Spraying poses a relatively high risk of creating drift (allowing pesticide onto the soil, into water or on surrounding desirable plants) if precautions are not taken and care is not used. A basic rule to consider is that the faster the application method, the more likely it is to hit non-target areas. Contact your local Department of Environmental Quality for information on restrictions relating to proximity to surface waters. In any state, it is a requirement of federal and state law that the herbicide user follows the product label.

A standard mixing sequence for most herbicides that would be used in knotweed control would be to add half the total amount of water to your spray tank, add the measured amount of herbicide, any surfactant (and dye), then the rest of the water. Mix carefully, but thoroughly between steps. After mixing the herbicide solution, follow the directions for foliar applications on the label, which is usually to spray just enough solution to wet the leaves and stems while avoiding dripping. Try and spray the top surface of every leaf on the plant and the stems. The plant may take several weeks to show significant adverse effects. Do not worry or retreat, the best control happens slowly. Return later in the season and again the next season to determine if additional treatments will be necessary.

The right time to apply herbicides is greatly affected by herbicide choice. According to Oregon Department of Agriculture materials, the ideal time to spray most deep-rooted perennials is when they are in flower bud stage. However, because knotweed may be 15 feet tall when it begins to flower this is not always practical. The best time, from a practical standpoint, is when the patches are 1-2 meters tall. Shorter plants may not have adequate leaf surface to absorb, and translocate, enough chemical to be effective. However, young, rapidly growing plants do have a more efficient biological process to translocate chemicals. Spraying taller plants means creating more risk of pesticide drift and older plants may not be as efficient in chemical translocation. A spring spray or cutting will set back the plant so that it can be sprayed at an effective height and growth stage later in the year. Plants first encountered late in the year can be cut to 1.5 meters in height immediately before spraying, although control effectiveness is somewhat reduced. TNC field data analysis suggest treatment done in April or May is not as effective as those done in June or July.

Regardless of herbicide choice, rate or spray timing; large, established patches (hundreds or thousands of stems) will almost certainly require foliar treatments over two or more years. Just as when treating patches mechanically, be sure to search for new shoots at least as far as 20 feet away from the central patch after herbicide treatment begins

Herbicide: Wipe

This method relies on direct application of herbicide to plant tissue, typically using a sponge or brush of some sort. Although very slow, this approach greatly reduces or eliminates drift. This method may be useful in areas where plants are established in particularly sensitive areas or for landowners who are concerned about spraying. Unfortunately, control is generally mediocre without multiple repeat applications.

Wick (wipe-on) applicators - Use a sponge or wick on a long handle to wipe herbicide onto foliage and stems. Use of a wick eliminates the possibility of spray drift or droplets falling on non-target plants. However, herbicide can drip or dribble from some wicks.

- “Paint sticks” and “stain sticks” sold at local hardware stores have been used successfully for wick application. These sticks have a reservoir in the handle that can hold herbicide, which soaks a roller brush at the end of the handle. The brush is wiped or rolled across leaves and stems.
- The “glove of death” is a technique developed by TNC land stewards for applying herbicide in an otherwise high quality site. Herbicide is sprayed directly onto a heavy cotton glove worn over a thick rubber/latex (or nitrile) glove. The wearer of

> the glove can then apply the herbicide with total precision and little or no runoff (Tu et al., 2001).

In field trials in Southwestern Washington, it was found that when using wipe applications, better knotweed control was observed if the stems were first "topped" (cut) at approximately 3 feet tall than if plants were left intact. After topping the plants, the stems (few leaves or branches remained) were then wiped with a 33% glyphosate mix amended with LI-700. Control was comparable to that found with stem injection and wiping results in relatively less herbicide being put into the environment (Tim Miller, Extension Weed Specialist, Washington State University, personal communication).

Herbicide: Cut & Fill *(From Soll, 2004)*

> Although very slow, this approach also greatly reduces or eliminates drift. This method may be useful in areas where plants are established in particularly sensitive areas or for landowners that are concerned about spraying.
>
> After cutting the stem [just below the third node] above the ground, carefully pour or squirt approximately 5ml of undiluted herbicide into the stem cavity. [Also apply herbicide to the cross section of the cut stem. It is important to due this immediately after cutting as the plant cells will "seal" quickly, preventing the translocation of the herbicide (Steven Flint, Invasive Field Steward, Adirondack TNC, personal communication, January 2006)]. Different herbicides allow various concentrations of solution to be applied by this method, which will listed on the label.

Laboratory squirt bottles have been used to deliver the herbicide. Using a handheld a commercial-grade hand-held spray bottle to direct herbicide into the stem cavity as well as the cut surface has been shown to be an effective technique as well (Steven Flint, Invasive Field Steward, Adirondack TNC, personal communication). A follow-up foliar or wiping treatment will likely be needed to control new seedlings and sprouts.

In using this technique, it is very important to have a plan to deal with the cut stems. Because of the great propensity for knotweed to root from even very small pieces of stem tissue, it is important that the stems are managed in a way as not to provide propagules to start new plants at the control site or create a situation where the stems may be transported and set root in a new location. This has been accomplished in many ways, the most common being packing the stems into plastic garbage bags and transporting offsite and then make ineffective as propagules in many ways including rotting in the bags, drying out on racks or solid pavement, and burning. Managing the cut stems can end up being a significant part of the overall control effort.

Optimal timing for initial cut & fill applications for the Adirondack region in NY was reported as mid-July with a follow-up application in the early fall of the same season (Steven Flint, Invasive Field Steward, Adirondack TNC, personal communication, January 2006).

Herbicide: Stem Injection *(from Oregon TNC, 2005a&b)*

> Direct stem injection involves poking a small hole through both sides of a knotweed stem just below the 2nd or 3rd node and injecting 1 to 5 ml of undiluted glyphosate herbicide

into the hollow chamber of each stem of sufficient size in a knotweed patch. Stems with a large enough diameter (3/4" or larger) can be injected with 5ml of glyphosate, smaller stems will receive lesser amounts, depending on the capacity of the hollow chamber. Depending on the characteristics of a stand, many stems may be too small to accept glyphosate injection. [Wipe or foliar spray applications can be options for the stems too small to receive injection.]

Stem injection treatments were administered using a device acquired from JK International Injection Tools (www.jkinjectiontools.com). The injection tools can hold approximately 420 ml of glyphosate in the canister. A measured dose, between 1-7mls, can be delivered by pulling the trigger once the needle is inserted into the stem of a plant (Figure 2.0). For the most part we set our tools to deliver 5mls per injection, with the exception of sites where the amount of knotweed was so great that we would approach the legal limit of 7.5 liters per acre if the 5ml amount was used. In those cases we dropped the amount per stem down to 3ml, or utilized foliar spray as described above.

Figure 5. Stem injection (Oregon TNC, 2005b)

After two years of treatment in our controlled experiment, we found no statistically significant benefit to using 5ml vs. 3ml or 1.5 ml per stem, or to supplementing stem injection of 5ml with foliar applied glyphosate. That said, the 5ml+foliar spray had the highest level of control for every variable except for re-growth outside the main patch area. As a result, because living patches are a threat to downstream habitat we recommend that field control programs take a conservative approach and incorporate supplemental foliar spray into their control regimen whenever it is legal or feasible. Because we did not compare supplemental spraying of the three dose levels in the controlled portion of the experiment, we can not specifically address whether the lower levels will work as well as the 5ml treatment with supplemental spray. Landscape trials comparing 3ml+foliar spray vs. 5ml+ foliar spray, however, found similarly positive results after 1 year of treatments.

Because stem injection of knotweed requires a great deal more time and herbicide per treatment than foliar or integrated manual – foliar treatment, it may not be an appropriate choice for every knotweed occurrence. Injection does, however, save at least one site visit, making it particularly attractive for treatment of remote sites. The literature suggests biologically active glyphosate herbicide should not move within the soil. However, because we have observed some limited instances of damaged native vegetation (in the form of unusual growth patterns) within injection sites, because no data have been collected on levels of active glyphosate in the soil around injected patches, because the dose per patch level is quite high, and because many riparian habitat often include low levels of organic soil materials or a high water table, concerns remain that glyphosate may move from roots or stems of injected plants and affect biota in the surrounding area.

Comparison of stem injection vs. foliar treatment…indicated that stem injection delivers approximately the same level of control on a landscape basis as foliar spraying, while requiring one less field visit. Results from 2005 were somewhat better than those achieved previously, especially when patches treated for the first time were analyzed separately. Though still not close to the 90% and greater results gained in controlled experiments, the 83% average reduction in stem number on a landscape basis from a single treatment is substantially better than for previous treatment methods. However, given the additional time and relatively large volumes of herbicide required to perform stem injection, [it is recommended to] limit the use of stem injection to certain circumstances, specifically:

- Remote sites
- Patches encountered too late in the season for spring cut / fall spray treatment
- Landowners who insist on injection
- Patches near sensitive or highly desirable vegetation [see Non-Target Impacts section below]
- Patches overhanging water [see Non-Target Impacts section below]
- Patches with ~300 stems or less and a high percentage of injectable stems
- Large patches with convenient road access appear to be best treated with "traditional" methods.

There are reports of non-target symptomology and one report of glyphosate in river water resulting from stem injection applications, which are discussed in more detail below. It has been suggested that glyphosate may "leak-out" of knotweed roots/rhizomes and remain active in coarser sandy and gravelly soils, which have relatively fewer herbicide absorption sites than soils with finer particles and organic mater (Crockett, 2005; Oregon TNC, 2005a; Tim Miller, Extension Weed Specialist, Washington State University, personal communication). It would seem appropriate to consider this potential especially when working at sites with coarse soils and high water tables.

Integrated approaches (IVM)

Combining different control methods offers additional choices and provides flexibility in your weed control program. TNC has found little difference in control effectiveness of cutting the plant in the spring and spraying in the summer / early fall versus spraying both times. The spring cutting may reduce total herbicide load into your watershed and may be more labor efficient than spraying twice. Maximizing available labor and reducing program expenses allows more patches to be treated in a given season. Furthermore, cutting allows the use of volunteers, which is difficult or impossible with herbicide applications (Soll, 2004).

Foliar applications appear to be a reasonably efficient approach (1 to 4 treatments over two seasons) to obtain control over small and medium size knotweed patches. Larger patches will often require treatment over several years and combinations of manual and chemical control methods. Digging, pulling or tilling (if conditions warrant) before August and at least one month prior to spraying may also help by increasing the shoot to root ratio and reducing plant vigor and root mass, thereby increasing plant susceptibility to the herbicide.

Combined methods that have reported control success include:

- Spring cut – late summer/early fall foliar spray
- Repeated cutting and foliar spray
- Stem injection with supplemental foliar spray of small stems
- Grubbing and covering
- Covering and repeated pulling or foliar spray at the edges
- Cut-stem and covering

The following chart provides recommended timing for cutting and follow-up foliar spray application in Pennsylvania (Figure 4). Due to compressed growing seasons, timing may need to be adjusted somewhat for planning in northern locales.

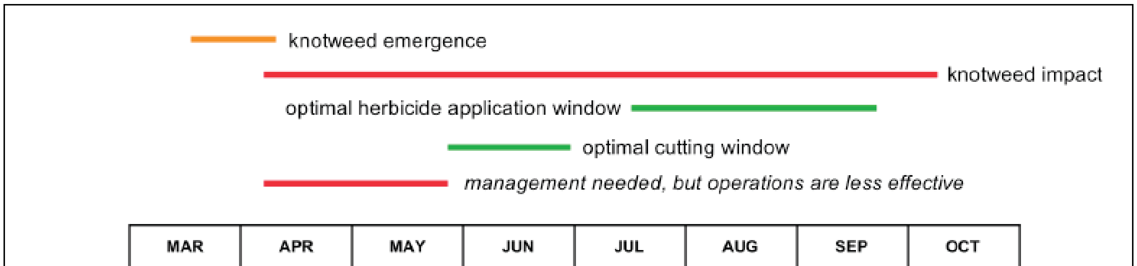


Figure 9. Our current view of the knotweed management calendar, based on its seasonal growth and response to control measures. In the roadside setting, the greatest concern is the period described as 'management needed, but operations are less effective', when knotweed is tall enough to impact sight distance, but mowing treatments will tend to result in tall regrowth and herbicide applications will only burn knotweed back, at best.

Figure 4. Seasonal growth and cutting and spraying timing recommendations for management of roadside knotweed in Pennsylvania (Gover, 2005)

Costs of Control

Few reports providing the direct costs of control were found.

Oregon TNC has managed knotweed on the Sandy River for six consecutive field seasons. Approximately 145 miles of waterways have been surveyed. Over 6,000 patches totaling over 176,000 initial stems (many of the patches were treated multiple times during the six field seasons and stem counts of re-treated patches are not included in the count) were treated. The gross area treated is estimated to be 400 acres. A 60% to 70% reduction in stem numbers after an initial injection + foliar spray or spring cut + fall foliar spray was typical. Many patches required multiple visits before no re-growth was observed. Staff for the project included a part time manager, three TNC staff at 90% and three AmeriCorps members at 90% for 10 months. The cost for the program over the six seasons has been approximately $165,000 annually, which included outreach, research, inventory, materials and staff.

Cathy Lucero, the Noxious Weed Control Coordinator for Clallam County, Washington, did collect information on costs of limited foliar spray and stem injection applications. Table 1 summarizes her results (Cathy Lucero, Noxious Weed Control Coordinator, Clallam County, Washington, personal communication).

Table 1. Knotweed control costs in Clallam County, Washington.

Method	stem injection	foliar spray
Stems Treated	14,520	3,630
Person-hours	232	24
Herbicide Qty	46 qts	3.1 qts
Total Cost	$7,018	$677

In a project in Skamania, Washington, workers were able to inject from 700 to 1200 stems per day (Dan Wallenmeyer, Noxious Weed Coordinator, Skamania County, Washington, personal communication).

Casey Gozart, a weed management project coordinator for Clark County, Washington, was able to provide some cost details for control work he managed from July of 2004 through June of 2005. A budget of approximately $80,000 included salary for the project coordinator, salary for a 4-person seasonal crew, truck rentals, landowner contact mailings, tools and herbicide. Approximately 30 miles of river were surveyed and approximately 124,000 knotweed stems at 247 sites were treated with foliar spray or stem injection (Gozart, 2004; Casey Gozart, Weed Management Project Coordinator, Clark County, Washington, personal communication).

Non-Target Impacts

Non-target impacts can occur through the use of any of the control methods listed above. Mechanical control through digging, grubbing and tilling can kill commingling plants and disturb the soil structure. A disturbed soil surface may be the perfect seedbed for additional invasive species. Covering will likely lead to mortality of any plant growing under the fabric and will likely result in areas of bare soil that will require erosion control planning and action. The potential effects on wildlife and soil biota of many years of black fabric in the landscape should be considered. Repeated cutting and mowing can impact woody regeneration and may negatively or positively herbaceous growth and regeneration.

Chemical application methods can also lead to non-target impacts and often method choice is made in an attempt to minimize such potential impacts. There are many state and federal regulations that govern the application of herbicides. Complying with these regulations is mandatory and should result in significantly moderating potential negative impacts to the applicator and environment. Understanding the way that herbicide reaches plant tissues, what happens to it after it has been absorbed by the plant and how it persists in the environment will all inform methodology choices.

Foliar spray applications can lead to non-target herbicide impacts from drift during spraying operations. Drifting herbicide can land on non-target plants, organisms and/or surface waters. Wipe, cut & fill and stem injection applications are much more likely to result in the herbicide only contracting target plant tissues during application, but post-application impacts have been reported.

Miller (2005) found incidence of non-target plant injury from injection treatments (5ml/stem, Aquamaster) of knotweed in Washington State. The injury was observed in shrubs such as salmonberry and snowberry and was not severe enough to result in plant death. It was suggested that the non-target symptomology resulted from root/rhizome leakage from injected knotweed plants, perhaps facilitated by gravely/sandy soil which contains far fewer herbicide absorption sites. Similar non-target symptomology was observed in shrubs in a greenhouse study from a leaf wiping application of glyphosate and also in cottonwood trees after a field foliar spray application (Tim Miller, Extension Weed Scientist, Washington State University, personal communication).

Oregon TNC observed evidence of herbicide impact on untreated plants during stem injection (5ml/stem, glyphosate) trials (Oregon TNC, 2005b). Whether the observed impact was to due to herbicide transport through connected roots or through the soil was not determined.

In Clallam County Washington, glyphosate was detected in river water following a stream bank stem injection application (3ml/stem, glyphosate). A high water event preceded the application by three days. Water samples were taken adjacent to the control site prior to and 24 hours after the herbicide application. Laboratory analysis confirmed the presence of glyphosate only in the post-application sample at 11 parts per billion, which is well below the current EPA drinking water standard of 700 parts per billion (Clallam County Noxious Weed Control Board, 2005).

A knotweed control report authored by Ron P. Crockett, a Technical Development Manager for Monsanto (the manufacturer of glyphosate-based herbicides) referred to observed non-target impacts:

> Observations made from limited applications in 2003 and 2004 indicated that under some unusually heavy rainfall conditions, non-target plants developed herbicide symptomology. In the situation where injury resulted, large numbers of plants had been treated outside labeling instruction, and soils became saturated with winter rain events. It is likely that glyphosate was released from treated root systems ('leaked-out' of roots that were breaking down) and became available to neighboring plant roots sharing the same space in the water saturated soil solution.
>
> In soils that are light in texture, such as sands, where fewer herbicide-binding sites exist to tie-up or bind the glyphosate to mineral soils making it herbicidal inactive; it is likely that these non-target plants accumulated enough glyphosate to show herbicide injury symptoms into the following year. These symptoms included, late leaf emergence and small misshaped leaves.
>
> These events would be predicted to occur in low organic matter soils, or in mineral soils with fewer binding sites.
>
> These conditions have not been seen in over 180,000 test site applications in Oregon and Washington, but this concern outlines the need for applicators to pay close attention to environmental concerns, as well as test site conditions. Adherence to labeling instruction, as well as safe herbicide use practices is always suggested for the safety of the applicator and the environment (Crockett, 2005).

It seems that each control method described here may potentially result in non-target impacts. The potential for root/rhizome leakage of herbicide, especially in coarse soils with a high water table, should be considered. The potential for impacts from any application method must be part of the decision process in planning control of knotweed.

Management Recommendations (Best Management Practices) *(from Soll, 2004)*

> As for all weeds, there is no single "best" control strategy for knotweed. The choices you make will hopefully be guided by understanding the ecology of the plant, your native system and the costs and effectiveness of the various treatment options discussed here, your project goals and your (or your organization's) capacity to execute them. That said, the following recommendations are made in an attempt to provide guidance based on combining financial, ecological, practical and legal considerations. Good luck.
>
> **When to use manual methods**
> If you have easy access to your site, [and you can commit to frequent periodic site visits for monitoring and action,] consider employing manual/mechanical methods. [Small stands may be the best candidates for manual control methods. Covering may hold potential for larger sites, but more information on long-term effectiveness is needed.] Be aware that repeated cutting tends to produce numerous small stems, which may make future treatment with stem injection more difficult. [Make sure that stem and root fragments are dealt with in a manner that prevents further knotweed spread.]

Patches outside the 100-year floodplain
Cut the patches in [late May through June], and then spray in [August through mid-June] with either glyphosate, triclopyr (Garlon 3a) or an herbicide mixture containing glyphosate and triclopyr at a 2:1 ratio or more of glyphosate to triclopyr. For example use a spray solution of 2% Rodeo, Aquamaster, Gly Star or Round-up and 3/4 - 1% Garlon 3a. Use R-11 or an equivalent surfactant at 1% volume (about 1 oz per gallon). Carefully follow the manufacturer's instructions for combining these two (or any) herbicides.

Alternatively, carefully spray the plants as soon as they reach 1-2 meters tall as above. Return late in the summer to check for sprouts. In some circumstances (i.e. isolated patches on cobble bars etc...) you may be able to spray plants that are in bud without an early season cutting. Spray tall plants very carefully, desirable plants hit with herbicide will be injured or killed.

Patches within the 100-year floodplain
Cut the patches in [late May through June], then, when they reach at least 1 -2 meters in height, and if doing spot treatment, spray with a 5-8% solution of herbicide containing glyphosate that is labeled for riparian, or better yet aquatic use (i.e. Rodeo, Aquamaster). For wider, broadcast use, the label specifies a 2% application rate. Use a surfactant that is appropriate and legal. As mentioned above NOAA-Fisheries has only approved LI-700, but many other surfactants are labeled for use in riparian areas. If a label that includes stem injection is approved in your state, consider using stem injection on all stems large enough to inject (~0.5-0.75" diameter minimum) and spot spraying small stems as above.

Patches overhanging water (revised with information from Oregon TNC 2005 Sandy River report)
It is probably a good idea to minimize herbicide water contact. Too little is known about sub-lethal effects of many herbicides on aquatic fauna to justify disregard. [Stem injection seems to be the optimal choice in this situation.] An integrated approach in which stems are cut, and then sprayed when they are short enough to prevent drift into water is probably the next best [method]. A [still] less attractive option is to use a wiping approach on the stems closest to the water. [See Non-Target Impacts section for discussion of potential herbicide root/rhizome leakage, especially in coarse soils with high water tables]

Conclusions

There are few methodical studies investigating the ecological impacts of knotweed infestations. There are a number of assumed negative impacts including, decreased native plant diversity, decreased habitat value, increased bank erosion and disrupted aquatic food webs. There is a need for measured studies to provide sound information to include in cost/benefit analysis of knotweed control. It would be best if practitioners could wait for more information to include in decision making, but the potential for knotweed to rapidly spread within riparian systems mayrequire action based on incomplete information. Without timely control, knotweed has the potential to spread and make any future control efforts immensely more resource intensive.

If knotweed is found to be spreading in a riparian system, planning should happen from a watershed perspective. Mapping knotweed stands and then strategically planning control based on potential for spread within the riparian system is logical. Mapping and eventual control applications will likely require private landowner permission. Permissions and participation may be greatly facilitated through a program of public outreach and education about knotweed and may be the best initial action step in a watershed-based control program. Regardless of the scale of the control operation, several years of active engagement will be required.

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Appendix A: Knotweed management project inventory

Location	**contact person**	**control method(s)**	**control scale/scope**	**written project details/monitoring results**
Sandy River Watershed, OR	Jonathon Soll, Willamete Basin Conservation Director, Oregon TNC	stem injection, foliar spray	watershed scale planning and action	(Oregon TNC, 2005)
Greene County, NY	Jennifer Grieser, New York City Department of Environmental Protection	formal experiment: stem injection, excavation/grubbing with tree planting and weed mat, mowing	single site	not yet available
Adirondack Region, NY	Steven Flint, Invasive Field Steward, Adirondack TNC	cut & fill, foliar spray, covering	multiple sites	unknown
Hancock, NY	Heather Jensen, Project Manager, US Army Corp of Engineers, Philadelphia District	formal experiment: cut & spray, covering, stem injection, sow grass seeds	single site	not yet available
Various locations, VT	Daniel Dietz, Conservation Steward, Vermont TNC	repeated cutting, cut & fill	multiple sites	unknown
Bouquet River Watershed, NY	Dillon Prime, Bouquet River Association	cut & fill, foliar spray, covering	multiple sites	(Boquet River Association, 2004)
Cedar River Watershed, WA	Sally Nickelson, Wildlife Biologist/Watershed Ecologist, Cedar River Watershed	grubbing, pulling, covering	multiple sites	unknown
Clallam County, WA	Cathy Lucero, Clallam County Noxious Weed Control Coordinator	stem injection, foliar spreay, wipe	multiple sites	(Clallam County Noxious Weed Board, 2005)

Appendix A: (continued)

Location	contact person	control method(s)	control scale/scope	written project details/monitoring results
Various locations, WA	Tim Miller, Weed Sceintist, Washington State University	stem injection, foliar spray	multiple sites	(Miller, 2005)
Lewis River Watershed, WA	Philip Brgess, Director, Clark County Weed Management	stem injection, foliar spray	watershed scale planning and action	(Burgess & Fuller, 2005)
King County, WA	Sean MacDougall, Noxious Weed Specialist, King County Noxious Weed Control Program	stem injection, foliar spray	watershed scale planning and action	unknown
Pacific Cascade Region, WA	Birdie Davenport, Natural Areas Manager, Washington State Department of Natural Resources	stem injection, cut & fill, foliar spray	single site	(Davenport, in press)
Washougal River Watershed, WA	Dan Wallenmeyer, Skamania County Weed Board	stem injection, foliar spray	watershed scale planning and action	unknown
Various locations, PA	Art Gover, Research Support Associate, Roadside Research Project, Pennsylvannia State University	cutting, foliar spray, granular herbicide soil application	multiple sites	(Gover, 2005)