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Experimental Management of Japanese Knotweed (*Fallopia japonica*) on the Batavia Kill, Greene County, New York


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by

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Report to

Greene County Soil and Water Conservation District
and
New York City Department of Environmental Protection

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INTRODUCTION

Hudsonia Ltd. was asked by the Greene County Soil and Water Conservation District (GCSWCD) and the New York City Department of Environmental Protection (NYCDEP) to test management techniques that could be used by landowners to effectively control Japanese knotweed (Polygonaceae: *Fallopia japonica* [*Polygonum cuspidatum*], hereinafter "knotweed") on a local scale. 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 (NYC) water supply system. There is a high level of concern about the potential impacts of knotweed on water quality in streams in the NYC water supply watershed (Talmage and Kiviat 2004). Our study focused on three management techniques – partial replacement of knotweed with woody plantings, herbicide injection into uncut stems, and frequent cutting – at a study site on the banks of the Batavia Kill. This report presents the results of these studies and recommendations for management of knotweed. The GCSWCD and NYCDEP intend to use this study to develop guidance for property owners who wish to manage knotweed on their own lands.

Hudsonia Ltd. is an independent, non-advocacy, non-profit institute for research and education in the environmental sciences. We conduct studies to assess biological resources and make recommendations for ecologically sound land management. Hudsonia does not support or oppose land use projects; rather we provide scientific information, analyses, and recommendations impartially for use by parties involved in environmental planning and environmental management.

Metric units of measurement are used in this report. English equivalents are:
1 mm (millimeter) = 0.04 inch
1 cm (centimeter) = 0.39 inch
1 m (meter) = 3.28 feet
1 mL (milliliter) = 0.03 ounces

JAPANESE KNOTWEED

Knotweed was probably introduced to North America in the late 1800s (Seiger 1997, Child and Wade 2000), and is now widespread and invasive especially in riparian environments and on human-disturbed soils where it can form dense stands with a depauperate (species-poor) ground flora. Knotweed is native to Japan, northern China, Korea, and Taiwan (Child & Wade 2000). It is usually considered herbaceous and has annual aerial stems that die back to near ground level in autumn, and long-lived perennial root systems. Knotweed grows to 1-3 or more meters high. It has broadly egg-shaped, alternate leaves and greenish-white flowers arranged in clusters in the leaf axils.

Knotweed appears to root more shallowly than native riparian trees and shrubs, although more deeply than the local grasses. Streambanks dominated by knotweed, therefore, may be less stable and more prone to slumping and erosion than banks with trees or shrubs (Rene VanSchaack, personal communication). 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 and more likely to harbor pathogens, knotweed is a concern for the NYC water supply system. Populations of knotweed have also been reported on other streams of the Catskill Mountain component of the NYC water supply watershed, and these populations might also affect water quality. Rigorous scientific study of the relationship of knotweed to bank stability and water quality has not been conducted, as far as we know.

In addition to the potential effects of knotweed on water quality, the plant could also 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. Geographically and taxonomically wide ranging natural history study in the northeastern states and adjacent Canada indicate a complex biota of native and introduced species of animals, plants, and fungi associated with stands of knotweed (Kiviat, unpublished data). However, methodologically sound quantitative research on knotweed effects on the fitness and population dynamics of a broad range of native species remains to be conducted.

STUDY AREA

Figure 1 illustrates the study area. Four plot types (control, woody planting, herbicide injection, and frequent cutting) were located on the south bank of the Batavia Kill in the Town of Ashland in the northern Catskill Mountains in Greene County, New York, ca. 60 km southwest of Albany, New York (U.S. Geological Survey, 1945 Ashland 7.5 minute topographic map sheet). The study site was ca. 400 m west (downstream) of County Route 17. At this location, the Batavia Kill is classified as a class C trout stream (NYSDEC 2009). Soils are Barbour loam, a very deep, well-drained soil that formed in alluvial deposits (Day 2003). Soils are underlain by the Oneonta shale, sandstone, and conglomerate formation. Topography at the site is nearly level except where the bank slopes steeply to the creek. Land uses surrounding the study site were primarily agricultural; fields next to the plots were planted with corn during the study.

METHODS

Plot location

Nine 5 x 5 m plots were permanently marked on the floodplain of the Batavia Kill. (Ten additional plots were originally established on a nearby site; however, the additional plots were compromised due to the activities of a landowner.) Plots were randomly spaced 3-7 m apart to avoid potential impacts from neighboring treatment plots and to allow equipment access between plots. The four treatments (control, woody planting, herbicide injection, and frequent cutting) were assigned randomly. Plots were at least 1 m inside the stand edge, to avoid the weedy grasses and forbs associated with the stand edges. All plots were in stands in which knotweed was highly dominant, with the streamside plot edge 0-16 m ($\bar{x}$ = 10 m) from the top of the stream bank. We did not locate plots beneath substantial crown cover of tall woody plants. Knotweed is dioecous; in our plots all shoots examined were female.

Pre-treatment surveys
The vegetation on the plots was sampled 21 August to 5 September 2003, and the soils were sampled 16-26 September 2003, before treatments were initiated. For each whole plot, we visually estimated percent knotweed canopy cover, percent litter cover (all species), percent bryophyte cover on the soil, and percent insect damage to knotweed leaves. We identified all other vascular plants and visually estimated the percent cover of each species and its maximum height (cm). Because the garlic-mustard (*Alliaria petiolata*) senesced during the period of sampling, cover was estimated as if the associated species were in full summer condition. We recorded the maximum height of the knotweed canopy over three of the plot corners (excluding the first corner established for each plot) with a telescoping tree measuring pole. We measured basal diameter (10 cm above the soil, in mm) of all knotweed stems in 1 x 1 m subplots within the same three corners of the plot using a diameter tape.

Soil characteristics were observed in a soil pit in the middle of the western boundary of each 5 x 5 m plot. We avoided digging inside the plots because of their intended use for management experiments. Pits were dug with a shovel to a depth of ca. 1 m, and deeper characteristics were examined using a Dutch auger to the lower boundary of the C horizon when possible. For each soil horizon, observations on horizon thickness, color, pH, root distribution, and percent rock fragments were recorded (see Shoeneberger et al. 2002). Color was determined by comparison with a Munsell soil color chart (Kollmorgen Corp., Newburgh, New York). pH was estimated with the Cornell pH test kit with an accuracy of 0.2 to 0.4 pH unit.

GCSWCD and NYCDEP staff marked, trenched, and treated the plots. Larry Day (Delaware County Soil and Water Conservation District) performed the soil study.

Treatment techniques
<u>Site preparation</u>: To prevent the subsurface incursion of knotweed from outside the plots, trenches 0.6 m wide by 0.6 m deep were excavated adjoining the periphery of each plot. Each trench was then lined with 2 layers of silt fence material (filter fabric) and backfilled with clean soil when available, or with excavated material cleansed of knotweed clumps. Plots were prepared 21-23 September 2004.

<u>Woody planting plots</u>: Five woody plants were placed in each plot – a silver maple (*Acer saccharinum*), a box elder (*Acer negundo*), a red maple (*Acer rubrum*), a green ash (*Fraxinus pennsylvanica*), and a black cherry (*Prunus serotina*). Knotweed was grubbed from a 1 m diameter circle and the soil was excavated deep enough to accommodate the root ball of the planting stock. Each tree was then placed within a circle, and the area backfilled with knotweed-free soil. Two layers of 1 m diameter porous weed mat were placed around the planted tree. Each species was planted in the same location (the four corners and the center) on each plot. Plantings took place 2-4 May 2005. Planted trees were at least 1.2 m tall. Three plots received this treatment.

<u>Frequent cutting plots</u>: In 2005 and 2006, knotweed stems were cut to 20-25 cm above the ground using a metal-bladed Stihl SS250 Weed Eater approximately every other week (8 and 7 times, respectively) during the growing season (from late May to late August). In 2007, plots were cut every other week (3 times) from late May to late June. Cut

knotweed stalks were removed from the site, dried, and burned. Two plots received this treatment.

Herbicide injection plots: In mid-August 2005, an opening was cut just below the first or second node above ground-level of all stems greater than 10 mm diameter. The opening was cut using a Japanese knotweed probe (JK International, www.jkinjectiontools.com). Five mL of the herbicide glyphosate (Aqua-Master, www.monsanto.com) was then injected into the opening. Methods were adopted from Crockett et al. 2004. Two plots received this treatment. Herbicide injections were repeated in mid-August 2008.

Post-treatment surveys

All vegetation variables sampled pre-treatment (2003) were sampled post-treatment 21 August 2006, and 26-28 August and 7 September 2009. Bryophyte cover was not estimated in 2006 but was in 2009. In 2006 we collected bryophytes from frequently cut plots and in 2009 we collected bryophytes from all plots where they occurred, for later determination. In 2009 litter depths were also measured, to the nearest cm.

For consistency, Erik Kiviat and Jennifer Grieser sampled the vegetation in all three years. Vascular plant scientific names used in the report are based on the New York Flora Atlas (www.newyork.plantatlas.usf.edu). Vascular plants that could not be identified with confidence in the field were collected and the specimens identified by James (Spider) Barbour of Hudsonia. Mosses were identified by Sue Williams (Dalton, Massachusetts).

Data analysis

To compare variables by treatment and year, we created box plots. Because we only had two data points for control, frequent cutting, and herbicide injection treatments, and three points for woody planting treatments, we assigned the middle point as the median and the boxes as the minimum and maximum for each plot type. In the text, we present means and 95% confidence intervals (CI) for selected variables. Aboveground biomass was estimated from basal shoot diameters, using a regression equation derived from live basal diameter and shoot dry weight of approximately 100 untreated stems representing a wide range of size collected opportunistically from the Batavia Kill (Kiviat et al. 2004). To determine the importance of associated native and introduced plants, we multiplied percent cover by maximum height for each species and then summed the products to create indices of native and introduced plant vigor. For all calculations, < 1% cover was arbitrarily considered 0.1%. Because the differences from 2003 to 2006 and 2009 were dramatic, we believe our approach to data analysis is appropriate.

RESULTS

Pre-treatment (2003), knotweed in all plots was tall ($\bar{x}$ = 2.9 m, 95% CI = 2.6-3.1 m) with a high percent canopy cover ($\bar{x}$ = 85%, 95% CI = 80-90%). Average basal area was 3571 mm^2/m^2 (95% CI = 1773-5368 mm^2/m^2), and average aboveground biomass was 866 g/m^2 (95% CI = 327-1405 g/m^2). Knotweed basal stem diameter averaged 16 mm, and ranged from 11 mm to 23 mm. Litter cover was high ($\bar{x}$ = 79%; 95% CI = 70-87%) and bryophyte cover was virtually absent; only one species was found in one plot. Average leaf tissue loss to grazing insects was minimal ($\bar{x}$ = 1%), though maximum leaf tissue loss was high in a few instances (range = 15-60%). The number of associated vascular plant species in each plot was low ($\bar{x}$ = 4; range = 1-10; Table 1). Other introduced plants made up most of the associated species cover (native to introduced index ratio = 1:26).

Post-treatment, in the ***woody planting plots***, by 2006 all woody plantings appeared dead apart from one unthrifty green ash. By 2009, all woody plantings were dead except for one 3 m silver maple. Knotweed cover was consistently high throughout the study (Figure 2), and knotweed stem density, basal area, and biomass also remained consistent (Figures 3-5). The number of associated species remained consistently low, as did the vigor of both native and introduced plants (Figures 6-8). Mean canopy height decreased slightly in woody planting plots in 2009 (Figure 9). Percent litter cover increased slightly during the course of the study (Figure 10). Results were similar in the ***control*** plots, though associated introduced species had somewhat more vigor in 2003 (Figures 2-10). Leaf tissue loss was low in all treatment plots throughout the study (Figure 11).

In ***herbicide injection plots***, knotweed cover decreased in 2006 (post-treatment) and remained low in 2009. Stem count, canopy height, basal area, and biomass all decreased dramatically in 2006; by 2009, the knotweed had recovered, but not appreciably (Figures 3-5, 9). Litter cover decreased post-treatment, but not substantially (Figure 10). The number of associated species increased dramatically post-treatment, and remained high in 2009 (Figure 6; Tables 2 and 3). By 2009, native plant vigor was high compared with other treatments (Figure 7). Introduced plant vigor decreased immediately post-treatment, but increased to greater than pre-treatment levels by 2009 (Figure 8).

In ***frequent cutting plots***, knotweed and litter cover were greatly reduced in 2006 (during treatment; Figure 2). However, by 2009 (two years post-treatment), knotweed and litter cover were almost as high as pre-treatment cover (Figures 2 and 10). Canopy heights were also greater in 2009, though they had not recovered to pre-treatment heights (Figure 9). However, basal area and biomass both remained low post-treatment (Figures 4 and 5). Stem counts increased during treatment, but then dropped to pre-treatment counts (Figure 3). The number of associated species steadily increased from pre-treatment levels during the study (Figure 6; Tables 2 and 3). Species richness was higher in the cutting plots compared to the control and herbicide plots pre-treatment (Table 1) but we feel the great increase in species numbers post-treatment was clearly due to treatment. Neither introduced nor native plants had increased vigor; in fact, the vigor of introduced plants decreased from pre-treatment levels.

On 13 November 2007, five trees were planted in each frequent cutting plot. Species planted were box elder, red maple, black cherry, and sugar maple (*Acer saccharum*). The intention was to replant the woody planting plots with faster growing and larger trees using stock grown from the "root production method" (RPM) (RPM Ecosystems, www.**rpmecosystems**.com); however the landscapers could not locate the woody planting plots and planted them in the cut plots instead. Several of these plantings survived in 2009; a 3 m box elder, a 0.5 m red maple, and a 1.4 m red maple in one plot and a 1.8 m box elder and a 2.4 m box elder in the second plot.

In 2009, litter depths were lower in herbicide injection and frequent cutting plots than in control and woody planting plots (Figure 12). By 2009, mosses in the cutting and herbicide injection plots were quite diverse, particularly in the herbicide plots (Table 4). Although we did not record percent cover of bryophytes in 2006, it was clearly < 1%; however species richness of mosses was much greater than in 2003.

Species duration did not show any consistent patterns during the study (Table 5). Biennials tended to increase in herbicide injection and frequent cuttings plots, and perennials increased rather strongly in both treatment types. Woody species and annuals did not exhibit consistent patterns. However, with the small number of plots, these patterns are not strong enough to indicate relationships between duration and treatment type or duration and length of time post-treatment.

Some of the plant species that appeared in treated plots (Tables 2-3) were ecologically interesting. One species, *Eupatorium altissimum*, has previously not been found north of southern Ulster County (James Barbour, personal communication); this may indicate that the clearings created by treatment in the knotweed stands have warm microclimates. There were several wetland species (e.g., *Mimulus ringens, Polygonum punctatum, Polygonum sagittatum, Ludwigia palustris*) that may reflect low spots on the floodplain combined with a very wet growing season in 2009.

We found few relationships of soil characteristics to knotweed characteristics (Kiviat et al. 2004). This suggests that the floodplain soils of the study area were not limiting to the development of knotweed stands.

DISCUSSION AND RECOMMENDATIONS

In collaboration with GCSWCD and NYCDEP, we performed experimental management of Japanese knotweed on 5 x 5 meter plots using four different treatments: control, woody planting, herbicide injection, and frequent cutting. The woody planting treatment constituted five 1 m diameter circles grubbed free of knotweed in each plot with nursery stock of native trees planted one per circle. Most of the plantings died; however, taller (> 3 m instead of 1 m) or faster growing stock may have a greater chance of success.

The other two treatments consisted of herbicide injection into live stems 10 mm or greater in basal diameter and cutting several times during the growing season with removal of cut material. These treatments were successful at creating openings in the knotweed stands that were quickly colonized by diverse native and introduced herbaceous species and native mosses. Dense knotweed cover and litter apparently excludes most bryophytes and vascular plants. Once the knotweed is removed, vascular plants increase and mosses flourish on soil and decaying knotweed root crowns. Some live knotweed material persisted despite multiple years of treatment. As with most invasive plant management, treated areas need to be monitored and maintained in the long term. If treatments had continued, the vigor of remaining knotweed plants would probably have continued to decline with death resulting eventually.

Based on our results, both herbicide injection and frequent cutting have the potential to successfully manage knotweed stands on a small scale. These treatments may also have the potential to contain larger areas if used around the edges of the patches. Cutting, however, may require more maintenance or a longer treatment period than herbicide injection; several measures of knotweed vigor (cover, stem count) indicated a return to near pre-treatment levels in the cut plots by 2009 (following cutting during 2005-June 2007). Others (biomass and basal area), however, indicated continued reduced vigor. If the cutting were continued for several more years, or if cutting were combined with other mechanical methods (e.g. shading; Seiger 1991), knotweed vigor in the cut plots may be reduced to levels equivalent to those in the herbicide plots. A greenhouse study demonstrated that cutting more than once had a significant impact on the belowground biomass of knotweed, but cutting alone did not eliminate the knotweed (Seiger & Merchant 1997). The Vermont Chapter of the Nature Conservancy reduced the height of knotweed shoots by cutting or hand-pulling knotweed four times a year for four years (Catey Ritchie, personal communication, 2002-2003). In the United Kingdom, Baker (1988) greatly reduced knotweed by cutting semimonthly during the growing season for two years.

In herbicide plots, most measures of knotweed vigor remained low, although a slight increase in certain measures (e.g., canopy height, basal area) in 2009 suggests the need for continued maintenance in these plots as well. Another study of glyphosate injection into knotweed stems also determined that complete knotweed elimination may require numerous applications over several years (Hagen and Dunwiddie 2008). Hagen and Dunwiddie (2008) also noted that stems smaller than 2 cm diameter could not receive a precise application; therefore, as knotweed stems become smaller in subsequent application seasons, the proportion of stems that can be accurately treated decreases.

In the woody planting plots, the planted trees did not survive and therefore were not successful in shading knotweed stems. We believe the plants did not thrive because they were too small to compete with the knotweed. Planting larger or faster growing trees and shrubs, or cutting larger areas of knotweed before planting, may allow woody plants to thrive in, and eventually shade out, knotweed patches.

While both cutting and herbicide injection treatments allowed species richness in the plots to increase, introduced and native plant vigor and moss diversity were higher in the herbicide plots – likely due to the lack of frequent cutting disturbance. Therefore, if primary management goals are to increase plant diversity, herbicide injection may be the better management technique of the two. Hagen and Dunwiddie (2008) found that nontarget vegetation was not affected by glyphosate injection. In addition, herbicide injection may be less expensive than cutting due to high labor costs associated with cutting (J. Grieser, unpublished data). The NYCDEP has a strong preference to avoid chemical treatment, because of the potential for chemical contamination of the water supply. If herbicides are used, they should first be tried on a limited basis with monitoring for herbicide residues and toxic breakdown products. In addition, smaller amounts of glyphosate may be used; Hagen and Dunwiddie (2008) found no difference in knotweed control between 3 ml and 5 ml glyphosate applications. However, if primary management goals are to stabilize stream banks, cutting, possibly combined with woody plantings, may be the better alternative because it alleviates concerns about chemical contamination of the water supply and replaces knotweed with deep-rooted species.

Given that the treatment methods we used require intensive effort and lengthy maintenance to achieve success in reducing knotweed and facilitating colonization by alternate flora, a strategy other than large scale eradication of knotweed may be appropriate. Such a strategy could include removal of small patches of knotweed (e.g., < 10 m diameter), containment of large patches where expansion would threaten important resources, the creation of openings or corridors of alternate vegetation to promote the colonization of alternate vascular flora and mosses and provide access to the stream for fishing, and the planting of fast-growing, tall, deeply rooted native trees to stabilize stream banks. Effort and maintenance would still be required, but goals could be achieved without massive investment of resources to eradicate large knotweed stands. Remaining knotweed would potentially continue to emit vegetative propagules (stem or rhizome fragments) capable of initiating new stands when dispersed by water, ice, or machinery.

Recommendations for further study include:

-Installing saplings that are substantially taller than the knotweed in the woody plantings plots and then monitoring these plantings to determine whether this method alone can be successful in reducing knotweed stands or at least in stabilizing the stream banks.

-Mowing for an extended period of time in the frequent cutting plots to determine whether knotweed can be eliminated by mowing alone.

-Creating plots with combined treatments, e.g. cutting and woody plantings or cutting and an alternative shading technique.

-Trying a rake-out-the-litter treatment (without anything else) experimentally to see if it encourages plant diversity under the knotweed.

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Table 1. Vascular species associated with *Fallopia japonica* in the four plot types (control, woody planting, herbicide injection, and frequent cutting) in 2003, before treatments. Scientific names follow the New York Flora Atlas (www.newyork.plantatlas.usf.edu); names in brackets = names used by researchers during this study. N = Native, I = Introduced (in New York State). Numbers indicate the number of plots a species was found in for each treatment type (maximum plots = 2 for Control, 3 for Woody Planting [Plant], 2 for Herbicide Injection [Herb], and 2 for Frequent Cutting [Cut] plots).

			2003			
Scientific Name	**Common Name**	**N/I**	**Control**	**Plant**	**Herb**	**Cut**
Alliaria petiolata	Garlic mustard	I	2	3	2	2
Arctium lappa	Greater burdock	I	1			
Calystegia sepium	Hedge bindweed	I				2
Echinocystis lobata	Wild cucumber	N			1	
Erigeron annuus	Daisy fleabane	N				1
Fraxinus americana	White ash	N		1		
Glechoma hederacea	Ground ivy	I	1			1
Hemerocallis	Daylily	I				1
Lonicera X bella	Bell's honeysuckle	I				1
Lysimachia ciliata	Fringed loosestrife	N			1	
Parthenocissus quinquefolia	Virginia creeper	N	1		1	2
Phalaris arundinacea	Reed canary grass	N				1
Prunus	Cherry		1	1	2	1
Saponaria officinalis	Bouncing-bet	I				1
Sambucus nigra L. ssp. *canadensis* [*Sambucus canadensis*]	Common elderberry	N				1
Taraxacum officinale	Common dandelion	I	2		1	
Thalictrum	Meadow-rue	N				1
Viola sororia	Common violet	N			1	
Vitis	Grape					1
Zizia aurea	Common Alexanders	N				2
Total number of species			6	3	7	14

Table 2. Vascular species associated with *Fallopia japonica* in the four plot types (control, woody planting, herbicide injection, and frequent cutting) in 2006, post-treatment for woody planting and herbicide injection plots and during treatment for frequent cutting plots. Scientific names follow the New York Flora Atlas (www.newyork.plantatlas.usf.edu); names in brackets = names used by researchers during this study. N = Native, I = Introduced (in New York State). Numbers indicate the number of plots a species was found in for each treatment type (maximum plots = 2 for Control, 3 for Woody Planting [Plant], 2 for Herbicide Injection [Herb], and 2 for Frequent Cutting [Cut] plots).

			2006			
Scientific Name	**Common Name**	**N/I**	**Control**	**Plant**	**Herb**	**Cut**
Acer negundo	Box elder	N				1
Agrostis hyemalis	Winter bentgrass	N			2	
Alliaria petiolata	Garlic mustard	I	2	3	2	1
Allium vineale	Wild garlic	I			1	
Amaranthus	Amaranth				1	
Brassicaceae	Mustard				1	1
Carex	Sedge				2	
Centaurea stoebe L. *ssp. micranthos* [*Centaurea maculosa*]	Spotted knapweed	I			1	
Chenopodium album	Lamb’s-quarters	I			1	
Cyperus	Flatsedge				1	
Daucus carota	Wild carrot	I			1	1
Digitaria ischaemum	Smooth crabgrass	I			1	
Digitaria sanguinalis	Hairy crabgrass	I				1
Echinochloa crus-galli	Barnyard grass	I			1	
Echinocystis lobata	Wild cucumber	N			1	
Epilobium coloratum	Eastern willow-herb	N			2	
Erechtites hieraciifolius	Fireweed	N			1	
Eupatorium altissimum	Tall boneset	I			1	1
Eupatorium perfoliatum	Common boneset	N			1	
Euthamia graminifolia	Grass-leaved goldenrod	N			1	
Galium	Bedstraw				1	
Galium mollugo	White bedstraw	I				2
Geum aleppicum	Yellow avens	N				1
Gnaphalium uliginosum	Low cudweed	I			1	
Hemerocallis	Daylily	I				1
Hypericum mutilum	Dwarf St. John's-wort	N			1	1
Hypericum perforatum	Common St. John's-wort	I			1	
Impatiens capensis	Spotted jewelweed	N			2	
Juglans cinerea	Butternut	N			1	
Juncus tenuis	Path rush	N			1	
Lapsana communis	Common nipplewort	I			1	
Leersia virginica	Virginia cutgrass	N			1	

Table 2 cont.

Scientific Name	Common Name	N/I	Control	Plant	Herb	Cut
Leonurus marrubiastrum	Lion's tail	I			1	
Linaria	Toadflax	I			1	
Ludwigia palustris	Water purslane	N			1	
Lycopus	Bugleweed				1	
Lysimachia ciliata	Fringed loosestrife	N				1
Lysimachia nummularia	Moneywort	I				1
Mimulus ringens	Square-stemmed monkey-flower	N			1	
Oenothera biennis	Common evening-primrose	N				1
Oxalis stricta	Wood-sorrel	N			2	2
Panicum capillare	Old witch panic-grass	N			1	
Panicum flexile	Wiry panic-grass	N			1	1
Parthenocissus quinquefolia	Virginia creeper	N			1	1
Phalaris arundinacea	Reed canary grass	N			2	1
Plantago lanceolata	English plantain	I			1	1
Plantago major	Common plantain	I			1	1
Poa annua	Annual bluegrass	I				1
Poaceae	Grass				1	1
Polygonum sect. Avicularia	Knotweed					1
Persicaria pensylvanica [*Polygonum pensylvanicum*]	Pennsylvania smartweed	N			1	
Persicaria punctata [*Polygonum punctatum*]	Dotted smartweed	N			1	
Persicaria sagittata [*Polygonum sagittatum*]	Arrowleaf tearthumb	N			1	
Potentilla simplex	Common cinquefoil	N				1
Prunus	Cherry				1	
Prunella vulgaris	Self-heal	I				1
Rhus typhina	Staghorn sumac	N			1	
Rubus allegheniensis	Allegheny blackberry	N			1	
Rumex	Dock				1	
Setaria	Foxtail					1
Solanum dulcamara	Bittersweet nightshade	I			2	
Sonchus asper	Spiny-leaf sowthistle	I			1	
Stellaria	Chickweed	I			1	2
Taraxacum officinale	Common dandelion	I	1		1	2
Trifolium repens	White clover	I				2
Unidentified					2	1

Scientific Name	Common Name	N/I	Control	Plant	Herb	Cut
Verbena hastata	Swamp verbena	N			1	
Verbascum thapsus	Common mullein	I			2	
Veronica	Speedwell	I			1	2
Viola	Violet				2	
Vitis	Grape				1	
Total number of species			2	1	57	30

Table 3. Vascular species associated with *Fallopia japonica* in the four plot types (control, woody planting, herbicide injection, and frequent cutting) in 2009, post-treatment for all plots Scientific names follow the New York Flora Atlas (www.newyork.plantatlas.usf.edu); names in brackets = names used by researchers during this study.. N = Native, I = Introduced (in New York State). Numbers indicate the number of plots a species was found in for each treatment type (maximum plots = 2 for Control, 3 for Woody Planting [Plant], 2 for Herbicide Injection [Herb], and 2 for Frequent Cutting [Cut] plots).

			2009			
Scientific Name	**Common Name**	**N/I**	**Control**	**Plant**	**Herb**	**Cut**
Acer rubrum	Red maple	N			1	
Aegopodium podagraria	Bishops goutweed	I				1
Agrostis hyemalis	Winter bentgrass	N			2	2
Alliaria petiolata	Garlic mustard	I	1		2	2
Arctium lappa	Greater burdock	I			1	1
Berteroa incana	Hoary alyssum	I				1
Bromus inermis	Awnless brome	I				1
Carex	Sedge					2
Clematis virginiana	Virgin’s-bower	N				1
Cornus racemosa	Gray dogwood	N			1	
Echinocystis lobata	Wild cucumber	N	1	1	2	
Elymus riparius	River wild-rye	N				1
Epilobium	Willow-herb	N				1
Epilobium coloratum	Eastern willow-herb	N			2	
Erigeron annuus	Daisy fleabane	N			1	
Eupatorium altissimum	Tall boneset	I			1	
Eupatorium purpureum	Joe-pye weed	N			1	
Euthamia graminifolia	Grass-leaved goldenrod	N			2	
Galium mollugo	White bedstraw	I				1
Galium triflorum	Fragrant bedstraw	N			2	
Geum aleppicum	Yellow avens	N				2
Glechoma hederacea	Ground ivy	I				1
Hemerocallis	Daylily	I				1
Hypericum mutilum	Dwarf St. John's-wort	N			2	
Hypericum perforatum	Common St. John's-wort	I				1
Impatiens capensis	Spotted jewelweed	N			2	1
Juncus effusus	Common rush	N			1	1

Table 3 cont.

Scientific Name	**Common Name**	**N/I**	**Control**	**Plant**	**Herb**	**Cut**
Juncus tenuis	Path rush	N			1	1
Lamiaceae	Mint family				1	
Lamium maculatum	White Nancy	I			1	
Lapsana communis	Common nipplewort	I			1	
Leonurus cardiaca	Mother-wort	I				1
Leonurus marrubiastrum	Lion's tail	I			2	
Lepidium	Pepperweed					1
Linaria	Toadflax	I				1
Lysimachia ciliata	Fringed loosestrife	N				2
Lysimachia nummularia	Moneywort	I				1
Mentha arvensis	Wild mint	I				1
Oenothera biennis	Common evening-primrose	N			1	1
Oxalis stricta	Wood-sorrel	N			2	2
Parthenocissus quinquefolia	Virginia creeper	N			2	1
Pastinaca sativa	Wild parsnip	I			2	
Phalaris arundinacea	Reed canary grass	N			1	2
Poaceae	Grass				2	2
Persicaria lapathifolia [*Polygonum lapathifolium X persicaria*]	Dock-leaved smartweed	I			1	
Persicaria punctata [*Polygonum punctatum*]	Dotted smartweed	N			1	1
Persicaria sagittata [*Polygonum sagittatum*]	Arrowleaf tearthumb	N			1	
Potentilla simplex	Common cinquefoil	N				1
Prunus	Cherry				1	1
Prunus serotina	Black cherry	N			1	1
Rosa multiflora	Multiflora rose	I			1	
Rubus occidentalis	Black raspberry	N			2	
Rumex	Dock				1	1
Rumex obtusifolius	Broad-leaf dock	I				1
Sambucus nigra L. ssp. *canadensis* [*Sambucus canadensis*]	Common elderberry	N			1	
Scrophularia marilandica	Carpenter's square	N			1	
Secale cereale	Cereal rye	I				1
Solanum dulcamara	Bittersweet nightshade	I			2	
Solidago	Goldenrod	N			1	2
Sonchus arvensis	Field sowthistle	I			1	
Stellaria	Chickweed	I			1	1
Taraxacum officinale	Common dandelion	I	1		2	2

Scientific Name	Common Name	N/I	Control	Plant	Herb	Cut
Unidentified					1	1
Veronica	Speedwell	I			2	1
Verbascum thapsus	Common mullein	I			1	1
Vitis	Grape				1	
Total number of species			3	1	45	42

Table 4. Bryophyte species in *Fallopia japonica* treatment plots, 2006 and 2009. Numbers indicate the number of plots a species was found in for each treatment type (maximum plots = 2).

Scientific Name	2006 Cutting	2009 Herbicide	2009 Cutting
Amblystegium varium			1
Aphanorrhegma serratum	2?		
Atrichum altecristatum		1	2
Barbula unguiculata	1?		1
Brachythecium reflexum		1	
Brachythecium salebrosum		1	1
Bryhnia novae-angliae		2	2
Bryum cf. *bicolor*		1	
Bryum capillare		1	
Bryum cf. *pseudotriquetrum*	1	1	
Bryum cf. *radiculosum*		1	
Bryum		1	
Campylium hispidulum		1	
Campylium radicale		1	
Ceratodon purpureus		2	1
Dicranella heteromalla	1	1	
Ditrichum pusillum		1	
Ditrichum			1
Drepanocladus fluitans		2	1
Ephemerum crassinervium		1	
Eurhynchium pulchellum		1	
Hypnum lindbergii		1	2
Hypnum pallescens	1		
Leptobryum pyriforme		1	
Leptodictyum riparium		1	
Plagiomnium cuspidatum		1	2
Pohlia			1
Polytrichum cf. *formosum*	1		
Thuidium delicatulum		1	
Weissia controversa		2	
Total number of species	6	23	11

Table 5. Duration of plants in *Fallopia japonica* treatment plots by year.

Plot/Year	Treatment	Annual	Biennial	Perennial Herb	Woody
L1 2003	*Control*	0	1	2	1
2006		0	1	1	0
2009		1	0	1	0
L6 2003	*Control*	0	2	1	1
2006		0	1	0	0
2009		0	1	0	0
L2 2003	*Woody planting*	0	1	1	1
2006		0	1	0	0
2009		1	0	0	0
L4 2003	*Woody planting*	0	1	0	0
2006		0	1	0	0
2009		0	0	0	0
L5 2003	*Woody planting*	0	1	0	0
2006		0	1	0	0
2009		0	0	0	0
L3 2003	*Herbicide injection*	0	1	2	1
2006		4	3	12	5
2009		4	5	14	7
L8 2003	*Herbicide injection*	1	1	1	2
2006		8	5	20	0
2009		3	4	16	3
L7 2003	*Frequent cutting*	1	1	4	2
2006		4	2	14	0
2009		2	5	25	0
L9 2003	*Frequent cutting*	0	1	5	4
2006		0	1	5	1
2009		0	1	13	5

Figure 1. Japanese knotweed study area,
Town of Ashland, Greene County, New York

Figure 2. Box plots of percent aerial cover *Fallopia japonica* by treatment type and year

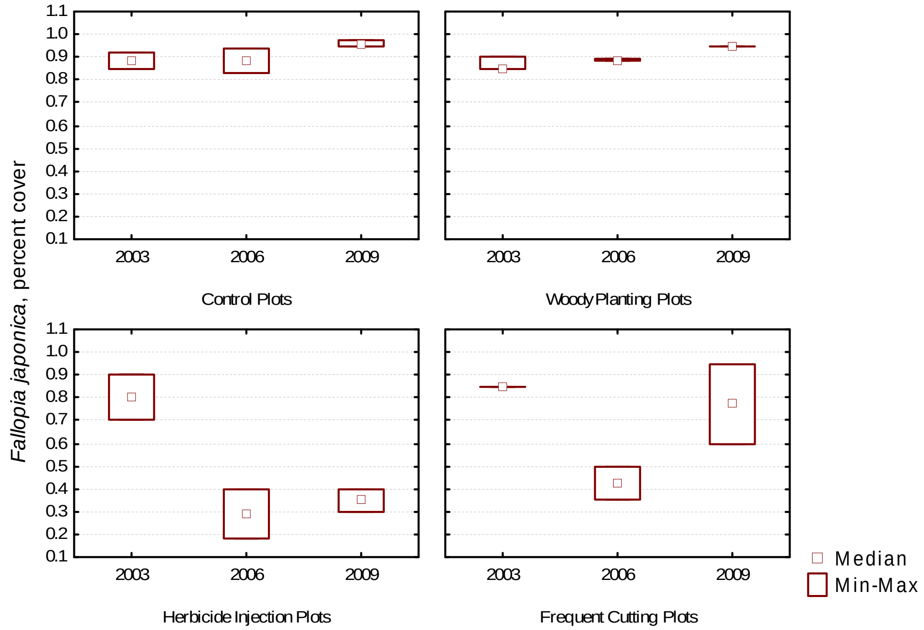


Figure 3. Box plots of average number of *Fallopia japonica* stems by treatment type and year

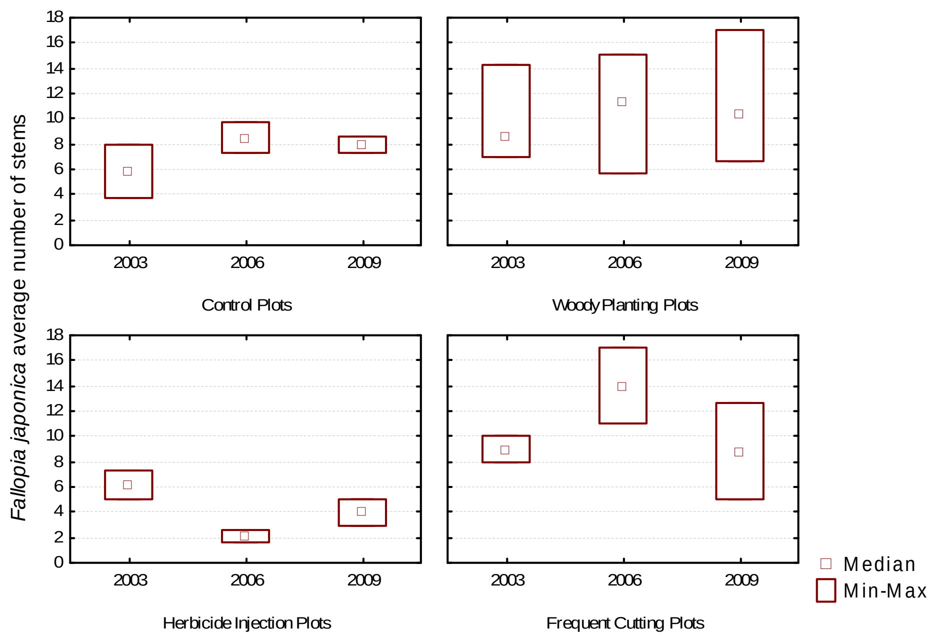


Figure 4. Box plots of average basal area of *Fallopia japonica* by treatment type and year

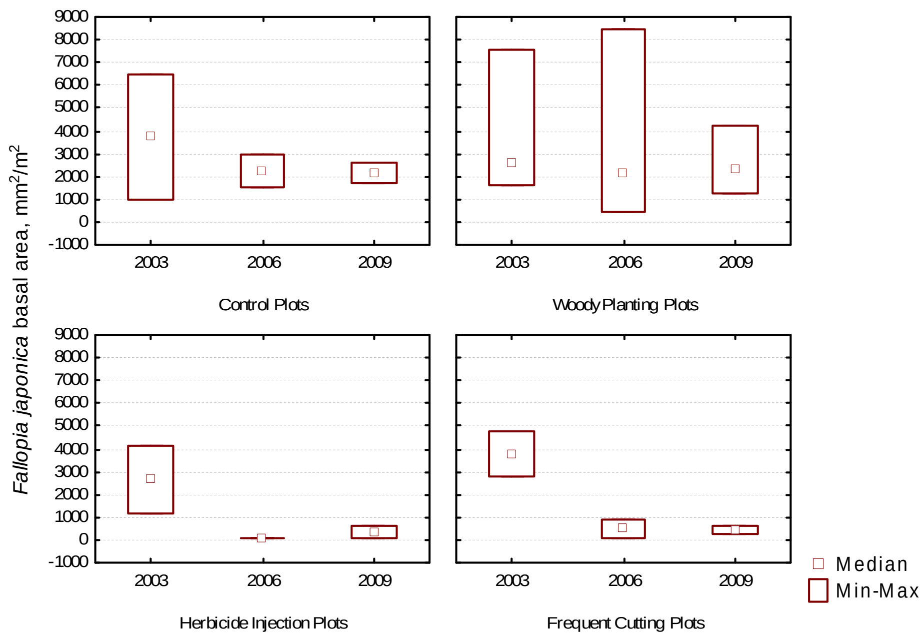
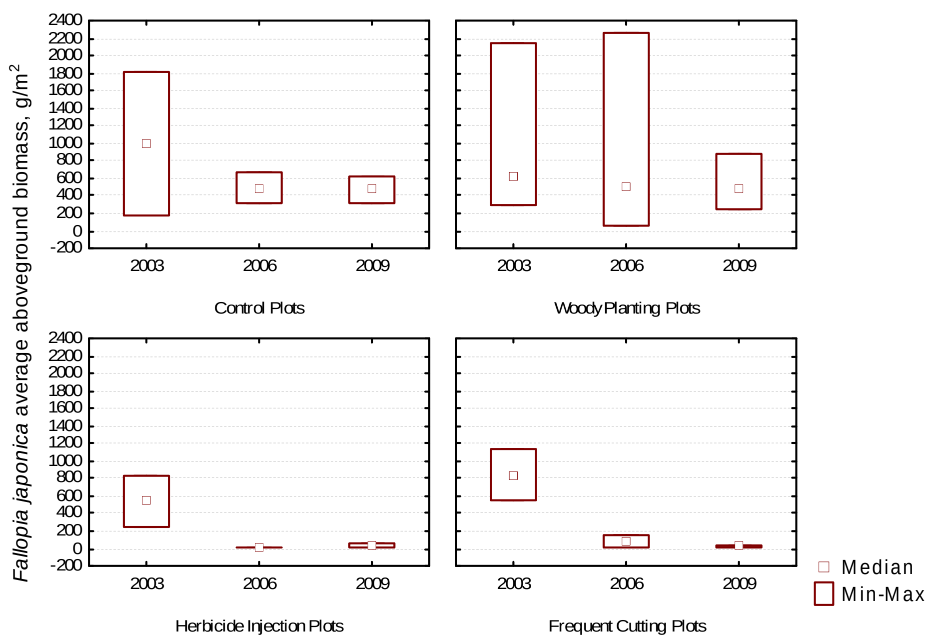


Figure 5. Box plots of average aboveground biomass (g/m^2) of *Fallopia japonica*, determined by regression of basal stem diameters



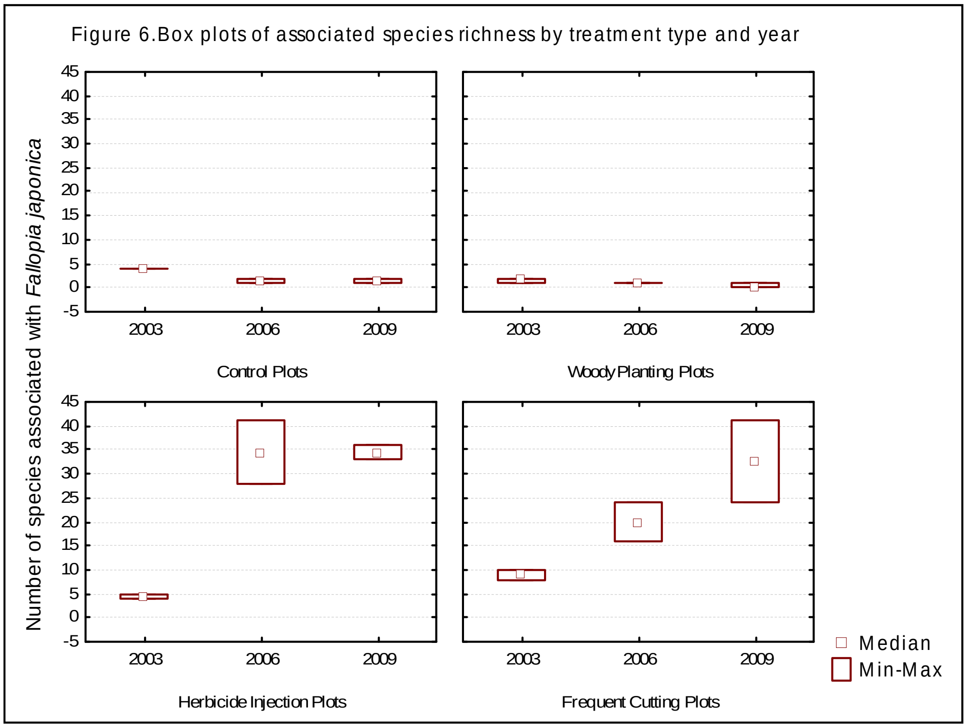


Figure 6.Box plots of associated species richness by treatment type and year
Number of species associated with *Fallopia japonica*
45
40
35
30
25
20
15
10
5
0
-5
2003
2006
2009
Control Plots
Woody Planting Plots
Herbicide Injection Plots
Frequent Cutting Plots
Median
Min-Max

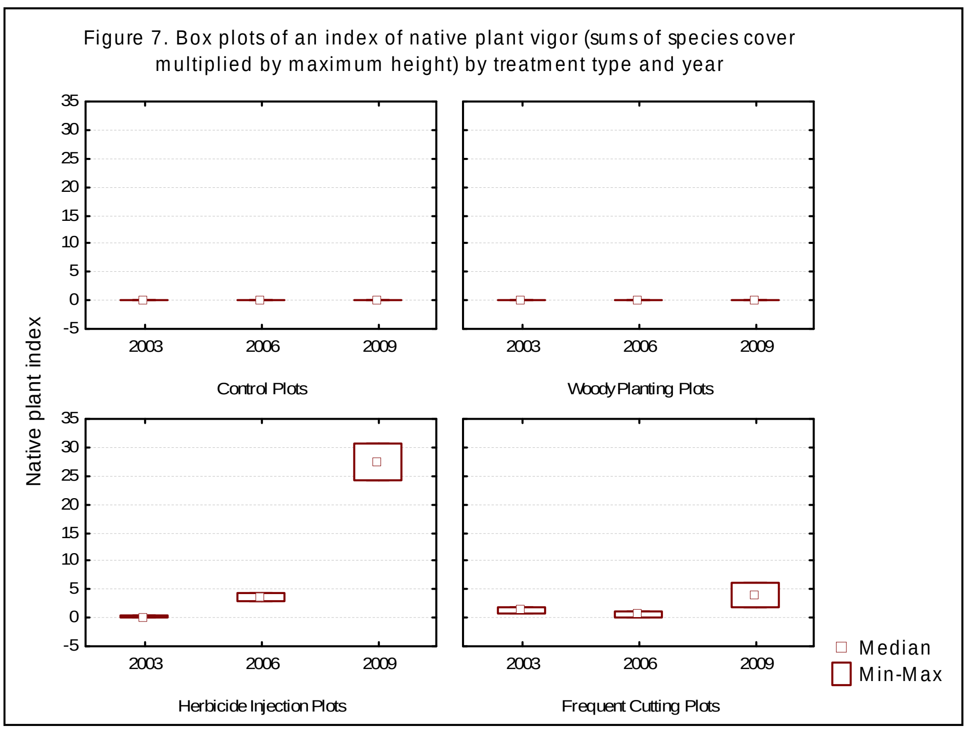


Figure 7. Box plots of an index of native plant vigor (sums of species cover multiplied by maximum height) by treatment type and year
Native plant index
35
30
25
20
15
10
5
0
-5
2003
2006
2009
Control Plots
Woody Planting Plots
Herbicide Injection Plots
Frequent Cutting Plots
Median
Min-Max

Figure 8. Box plots of an index of introduced plant vigor (sums of species cover multiplied by maximum height) by treatment type and year

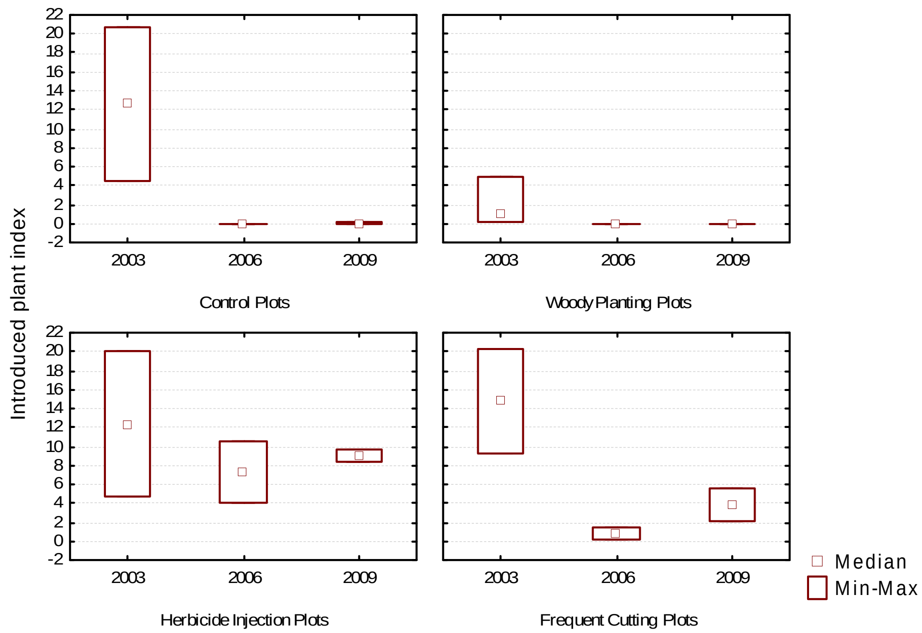


Figure 9. Box plots of average canoy height of *Fallopia japonica* (cm) by treatment type and year

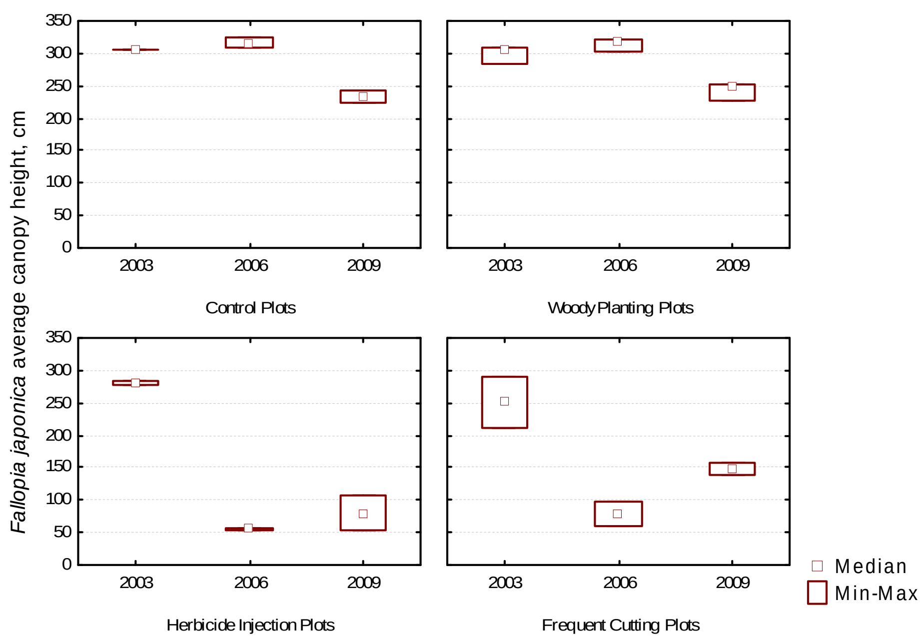


Figure 10. Box plots of percent litter cover (all species) by treatment type and year.

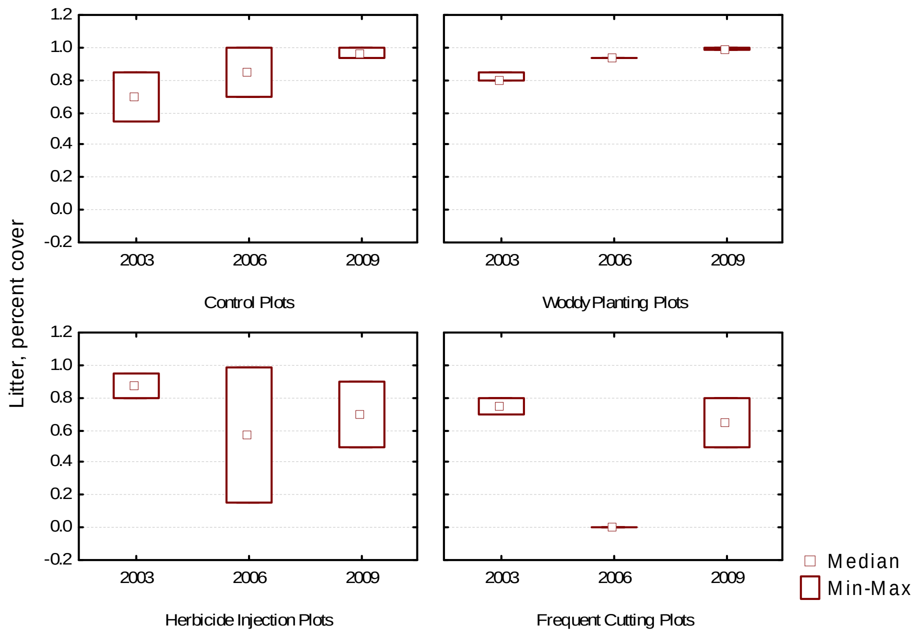


Figure 11. Box plots of average loss of leaf tissue to grazing by treatment type and year

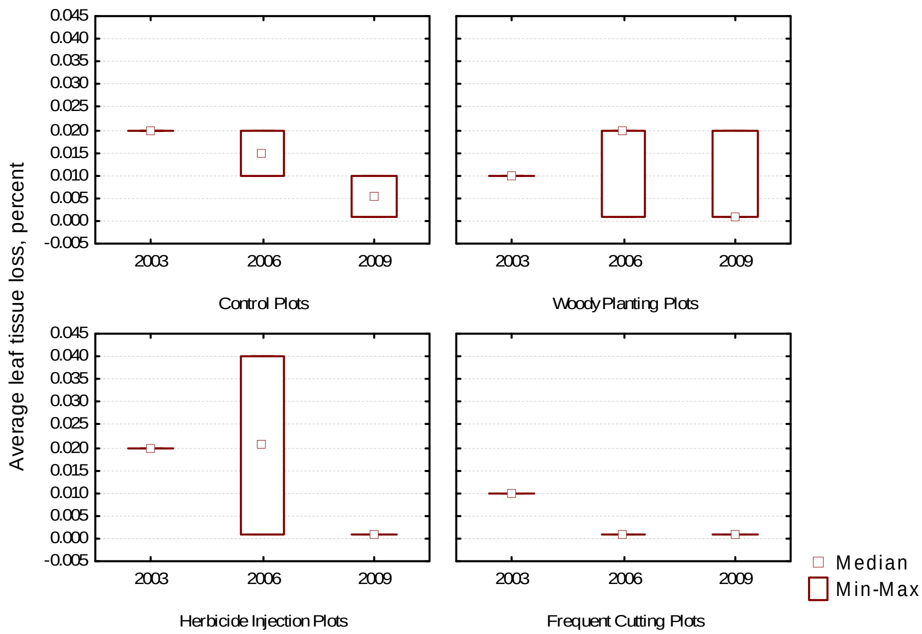


Figure 12. Box plot of average litter depth (all species, cm) in each treatment type in 2009.