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Source: *Invasive Plant Science and Management*, 7(1):84-92. 2014.

Published By: Weed Science Society of America

DOI: <http://dx.doi.org/10.1614/IPSM-D-13-00027.1>

URL: <http://www.bioone.org/doi/full/10.1614/IPSM-D-13-00027.1>

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In Situ Growth and Rapid Response Management of Flood-Dispersed Japanese Knotweed (*Fallopia japonica*)

Brian P. Colleran and Katherine E. Goodall*

The objective of this article is to identify growth patterns of Japanese knotweed propagules distributed by high-water events. Along four river systems, we collected and measured Japanese knotweed propagules that had been distributed by flooding approximately 1 yr earlier. Results indicate that the size of the emergent shoot may be determined by the extent of underground growth late in the growing season, although initially it is linked to the size of the propagule. Our results show that 70% of new plants originated from rhizome fragments, and 30% from stems. This proportion is similar to regeneration rates shown in laboratory studies. We suggest that the best way to prevent the spread of Japanese knotweed along rivers is to focus control efforts on those stands most susceptible to erosion and propagule dispersal. We also suggest that an early detection and rapid response management approach can be effectively utilized to eradicate these propagules, and effectively suppress the spread of Japanese knotweed. Our data-collection method also provides evidence that control of newly distributed propagules can be effectively accomplished without the use of herbicides or heavy mechanical tools.

Nomenclature: Knotweed *sensu lato*; Japanese knotweed; *Fallopia japonica* (Houtt.) Ronse Decr.; *Polygonum cuspidatum* Siebold & Zucc.; *Reynoutria japonica* Houtt.

Key words: Tropical Storm Irene, flooding, riparian invasives, early detection, rapid response, erosion, climate change, knotweed propagules, knotweed growth, knotweed spread, volunteer knotweed control.

The taxon of plants commonly known as knotweed, including Japanese knotweed (*Fallopia japonica* (Houtt.) Ronse Decr.; = *Polygonum cuspidatum* Siebold & Zucc.), giant knotweed (*Fallopia sachalinensis* (F. Schmidt ex Maxim.) Ronse Decr.; = *Polygonum sachalinense* F. Schmidt ex Maxim.), and their many hybrids, have a complicated history of identification. The confusion regarding the naming of these species and their hybrids is well documented (Beerling et al. 1994; Bram and McNair 2004; Weston et al. 2005). Previous research has shown distinguishing *F. japonica* from its hybrids with the use of morphological keys based on work in Europe or elsewhere in North America is unlikely to apply to populations in New England (Gammon et al. 2007). Although most knotweed plants in Vermont are believed to be *F. japonica*, we adhere to the suggestion of Bailey and Conolly (2000) to use the term

knotweed s.l. (*sensu lato*), allowing for the possibility that our sample may have included hybrid plant propagules.

The earliest known example of Japanese knotweed in the United States is a herbarium specimen of a cultivated plant from Yorkville, New York in 1873 (Barney 2006). It has since become invasive throughout many parts of the country, and is expected to continue expanding its range (Barney 2006; Barney et al. 2008; Bouchier and Van Hezewijk 2010). The potential economic impact of this plant can be seen in Great Britain, where control costs have been estimated at approximately U.S. \$250 million annually (Williams et al. 2010).

The threat of knotweed s.l. goes beyond a significant negative impact on plant biodiversity (Aguilera et al. 2009; Gerber et al. 2008); it may also have strong negative impacts on instream macroinvertebrate decomposers (Lecerf et al. 2007), gastropods (Stoll et al. 2012), and frogs (Maerz et al. 2005). Knotweed s.l. also increases the threat of erosion over the long term by locally eliminating the presence of groundcovers that hold topsoil in place during floods (Child et al. 1992; Mummigatti 2008), and inhibiting the regeneration of native species that provide critical structural support to river banks (Aguilera et al. 2009; Urgenson et al. 2009).

DOI: 10.1614/IPSM-D-13-00027.1

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Management Implications

Once established, stands of the invasive species knotweed s.l. requires several seasons of intensive effort to eliminate, often requiring the use of hand tools, heavy machinery, or herbicides. This is due to its ability to regenerate from very small pieces of stem or rhizome. Currently, management techniques focus on eliminating established stands, rather than new plants. After the flooding caused by tropical storm Irene in Vermont in 2011, land managers anticipated that knotweed would become widely distributed across floodplains throughout the state. A coordinator was hired for the summer of 2012 to arrange the removal of as many new plants as possible, by only manual labor. Over the course of the summer, 5,000 to 6,000 plants were eliminated over approximately 30 acres (12.1 ha). It was quickly recognized during initial removal efforts that a better understanding of the relationship between the sprout above ground and lateral underground growth could be a quick and simple assessment tool that would generate more efficient and site-specific strategies for eliminating new knotweed plants. Though our study does not reveal a consistent relationship between the sprout above ground and lateral underground growth for knotweed s.l., there may be a window of time during which such a relationship does exist. We also found that stem and rhizome fragments retained their ability to regenerate and grow up to 13 mo after tropical storm Irene. We also found that 86% of new plants were growing from propagules buried under less than 4 in. (10 cm) of sediment. Given this relatively shallow burial depth, we suggest that whole plants can be easily removed by hand within a year of the dispersal event. When properly integrated into a long-term management strategy, these techniques may significantly reduce the need for more costly, and potentially environmentally disruptive, treatments in the future. We suggest that every new knotweed dispersal event is an opportunity to use early detection and rapid response (EDRR) procedures that take advantage of the window of opportunity when manual labor is an effective means of knotweed control.

In its native Japan, knotweed s.l. is a primary colonizer of high-altitude volcanic deserts, often composed of basaltic gravel (Maruta 1976), and bare scoria fields (Adachi et al. 1996; Zhou et al. 2003). Successive pioneer species depend on biomass generated by knotweed s.l. patches and its subsequent decomposition to facilitate colonization (Adachi et al. 1996). Previously believed not to spread by seed in the United States (Adler 1993; Locandro 1973; Seiger 1993), it has been shown that knotweed s.l. does produce viable seeds in the wild in the northeastern United States, specifically in Massachusetts (Forman and Kesseli 2003; Gammon et al. 2010), though the geographic extent of populations reproducing sexually remains unknown. It has been suggested that only hybrid seeds are viable (Bailey 1994), and we were unable to find any references to viable, pure, and wild *F. japonica* or *F. sachalinensis* seeds outside their native range to dispute this assertion. This hybrid viability is particularly important in New England, because 84% of a sampled population in Massachusetts show some level of hybridization (Gammon et al. 2007), a situation

that may very well lead to more than one hybrid strain with seeds that are viable in the wild (Bailey et al. 2008). It is also well documented that pieces of stem or rhizome can successfully regenerate, even when the stem (Brock and Wade 1992; Brock et al. 1995; De Waal 2001) or rhizome (Child et al. 1992; Sásik and Pavol 2006) is exceptionally small, as long as the piece contains at least one node. These small pieces are buoyant and can be spread by rivers (Rouified et al. 2011) or tides (Bailey 1994). The plant tolerates a wide range of environments, significantly contributing to its invasiveness (Brock et al. 1995; Locandro 1973; Richards et al. 2008).

Methods for controlling well-established knotweed s.l. patches with the use of mechanical and chemical control techniques have been well studied (Child et al. 1992; Child and Wade 2000), as has the investigation of biocontrol options (Shaw et al. 2011; Wang et al. 2008). The few exceptions that recommend controlling newly established plants do so only in a general sense, without offering specific guidelines, management techniques, or expectations (Barney 2006; Brock et al. 1995; Welsh Development Agency [WDA] 2011).

In conjunction with predictions for more frequent (Armstrong et al. 2012) and more severe (Collins 2009) flooding events in the northeastern United States, we feel that there is significant potential for the development of a positive-feedback loop between an increased knotweed s.l. population, more common and severe flood events, erosion, and the dispersal of viable knotweed propagules. As knotweed has been documented to grow through structures (Elliott 2011) and roads (Locandro 1973; Nagel 2012), controlling the spread of this plant should begin as early in the life cycle of the plant as possible, and controlling this plant is of vital importance to effective floodplain management, specifically the protection of ecological integrity, and the built environment.

The objective of the research reported here is to identify growth patterns of in situ flood-dispersed knotweed propagules. Identifiable connections between aboveground and belowground growth would allow for reliable assessments of how difficult it would be to remove new plants whole, based only on a visual evaluation of potential project sites. Such a tool would help land managers prioritize the deployment of limited resources and most effectively remove new knotweed plants after dispersal events.

Materials and Methods

In the wake of tropical storm Irene on August 28, 2011, the State of Vermont hired a Japanese knotweed coordinator with the goal of finding and eliminating as many newly established knotweed s.l. plants as possible, utilizing only manual labor to accomplish this task. It was

this removal work that allowed for the collection of knotweed propagules. Plant samples were collected from three sites on the Green River in Guilford, VT between July 23 and July 25, 2012 (42°76'N, 72°66'W); one site on the West River in Weston, VT on July 26, 2012 (43°25'N, 72°79'W); one site on the Winhall River in Jamaica, VT on July 26 and July 27, 2012 (43°15'N, 72°83'W); and at one site on the New Haven River in Bristol, VT on July 30 and August 1, 2012 (44°10'N, 73°09'W). An additional collection was taken from one site on the Green River in Guilford, VT on September 16, 2012 (42°77'N, 72°66'W). No small dead stalks of knotweed s.l. were observed at any site, and all indications are that any propagule mortality took place before the propagule was able to generate photosynthetic material. Plants were removed by loosening the soil or flood debris surrounding each plant, taking care not to sever rhizomes. Once the surrounding material was sufficiently loose, care was taken to remove the whole plant without severing any underground parts. The plant was then visually checked to ensure it was fully intact. When belowground pieces did break, a reasonable effort was made to find them, and these efforts were usually successful. Crew members reported getting the whole plant out intact 75 to 80% of the time, and when the plant broke, were able to find and remove remaining underground pieces with similar success rates. Crew members then deposited all pieces removed from the ground into the nearest available trash bag. At the end of each workday, the coordinator randomly selected one of the garbage bags, and removed all the incomplete specimens. The remaining whole plants were then counted to ensure there were at least 30. When fewer than 30 plants were present, the smallest garbage bag from the days' work was treated the same way. During data collection, plants were randomly removed from the bag, and due to constant jostling during transit and the entangling effects of the stems, no size class became distinctly separate from the rest of the sample plants. All nonsample plants were destroyed in burn piles soon after removal from field sites, and all sample plants were destroyed in the same fashion after data collection was complete. For each plant, the following data were collected: Height of the tallest live sprout, measured from its base below ground at the propagule to the base of its highest leaf, which we define as sprout total height. We divided sprout total height into the length of the sprout below ground, and the length of sprout above ground. Each knotweed propagule was measured to determine the fragment volume. Fragment volume for propagules with a cylindrical shape was determined by measuring length (L) and circumference (C) with the use of the following equation:

$$\left[\left(\frac{C_{\text{propagule}}}{2\pi} \right) * \left(\frac{C_{\text{propagule}}}{2\pi} \right) * L_{\text{propagule}} * \pi \right] \quad [1]$$

or $\pi * r_{\text{propagule}}^2 * L_{\text{propagule}}$.

Fragment volume for propagules of a cubic form was calculated using the following equation:

$$\text{length} \times \text{width} \times \text{height}. \quad [2]$$

The three longest horizontal rhizomes were measured, and mean longest rhizome was determined by averaging the three longest rhizome measurements. Finally, we identified flood debris propagules as rhizome fragments, stem fragments, or both, in those cases where the root crown washed downstream with pieces of stems and rhizomes still connected. Together, these classifications are herein referred to as original fragment types.

Statistical analyses of the data were performed with the use of SPSS (2011). For all analyses, quantitative variables were natural-log transformed to meet the assumption of normality. Data were analyzed for patterns across space and time. Patterns across space compared data across different river systems. Temporal analysis compared data between two different collection times along the Green River—the first in July, the second in September. Special attention was paid to how original fragment type influenced growth patterns across both space and time.

Spatial Analysis. ANOVA and Tukey's HSD post hoc tests were conducted to compare morphometric data of knotweed s.l. plants across the four river sites (SPSS 2011). Measurements included in this analysis were longest rhizome, mean longest rhizome, sprout below ground, sprout above ground, sprout total height, and fragment volume. ANCOVA was conducted to test whether sprout aboveground measurements were different across sites, when fragment volume was accounted for. Site was considered a fixed factor and fragment volume was considered a covariate. Site number by fragment volume was evaluated for an interaction. A bivariate correlation was used to investigate relationships between growth metrics further. A chi-square test was conducted to determine if there was a difference in the proportion of original fragment types across the four river systems. We used *t* tests to examine whether sprout aboveground, sprout belowground, and sprout total height differed between original fragment types.

Temporal Analysis. Sprout above ground. For the samples collected from the Green River in both July and September, ANOVAs were conducted to compare morphometric data of knotweed s.l. across samples. Measurements included in these analyses were longest rhizome, mean longest rhizome, sprout belowground, sprout aboveground, sprout total height, and fragment volume. A chi-square test was conducted to determine if there was a difference in the distribution of original fragment type between the two collection times. We used *t* tests to examine whether sprout aboveground, sprout below-

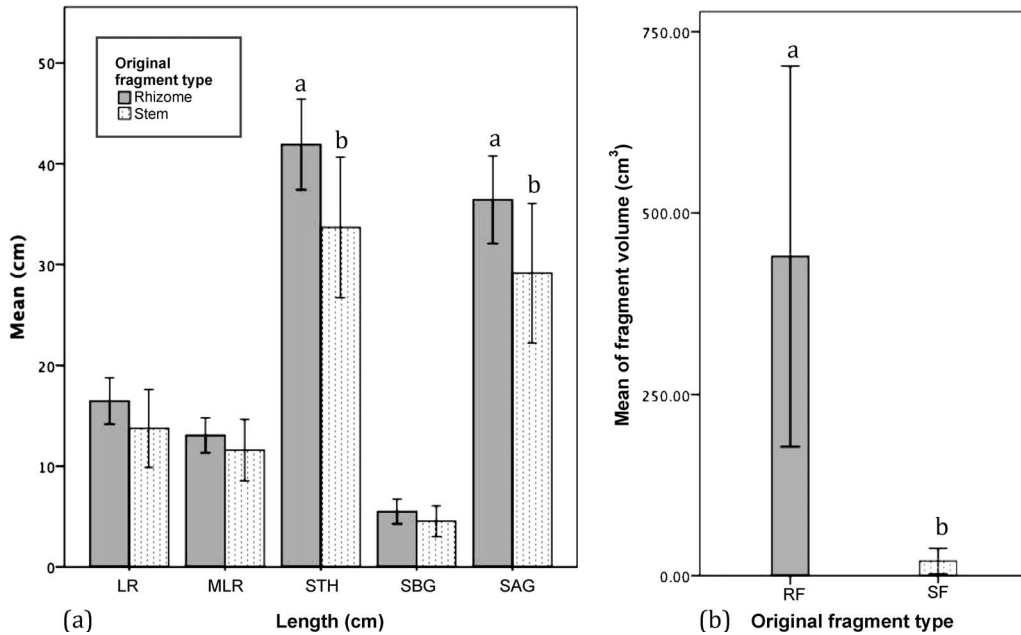


Figure 1. Morphometric comparison of plants originating from rhizome fragments and stem fragments of knotweed s.l. Measurements included (a) longest rhizome (LR), mean longest rhizome (MLR), sprout total height (STH), sprout below ground (SBG) and sprout above ground (SAG). Fragment volumes (b) were also compared; RF = root fragment and SF = shoot fragment. Error bars represent a 95% confidence interval.

ground, and sprout total height differed between original fragment type in the second collection. Linear regressions with sprout above ground as the dependent variable were conducted to identify which belowground variables predicted aboveground growth for each of the two collection times.

Results and Discussion

Comparing Original Fragment Types Across Rivers: Roots vs. Stems. The chi-square analysis revealed that there was no difference in the distribution of original fragment types across rivers ($\chi^2 = 5.941$, $df = 3$, $P = 0.115$). The general ratio was 70% rhizome fragments and 30% stem fragments. We used t tests to compare the morphometrics of stem fragments and rhizome fragments. The tests revealed that rhizome fragments have greater volume than stem fragments ($t = 5.316$, $df = 128$, $P < 0.000$) and they produce greater sprout aboveground ($t = 2.780$, $df = 130$, $P = 0.006$) and sprout total height ($t = 2.881$, $df = 130$, $P = 0.005$) (Figure 1).

Comparing Original Fragment Types Over Time. Chi-square analysis revealed no difference in the distribution of original fragment types across the two collection times ($\chi^2 = 0.117$, $df = 1$, $P = 0.831$), and that the general ratio was 70% rhizome fragments and 30% stem fragments. This ratio is consistent with the distribution we found

across rivers. We used t tests to compare the morphometrics of plants originating from rhizome fragments between the first and second collection. Significant differences occurred in all measurements (Figure 2). Belowground measurements are all higher in the second collection: longest rhizome ($t = -2.190$, $df = 70$, $P = 0.032$), mean longest rhizome ($t = -2.141$, $df = 70$, $P = 0.036$), and sprout below ground ($t = -2.607$, $df = 61$, $P = 0.011$). However, fragment volume ($t = 2.043$, $df = 70$, $P = 0.045$), and sprout above ground ($t = 10.817$, $df = 70$, $P < 0.001$) are higher in the first collection. Sprout total height was also higher in the first collection ($t = 7.496$, $df = 70$, $P < 0.001$). t tests to compare the morphometrics of plants originating from stem fragments between the first and second collection revealed no significant differences in mean longest rhizome ($t = 0.047$, $df = 29$, $P = 0.963$), longest rhizome ($t = -0.023$, $df = 29$, $P = 0.982$), nor sprout below ground ($t = -1.639$, $df = 27$, $P = 0.113$). On the other hand, fragment volume ($t = 3.437$, $df = 28$, $P = 0.002$), sprout above ground ($t = 7.200$, $df = 29$, $P < 0.001$), and sprout total height ($t = 5.990$, $df = 29$, $P < 0.001$) are all greater in the first collection time for plants originating from stem fragments (Figure 3).

The consistency of propagule proportions as 30% stem fragments and 70% rhizome fragments across both space and time closely matches previous findings that suggest rhizome fragments have about twice the regeneration success rate as stem fragments (Bímová et al. 2003), though we cannot know with certainty how many propagules were

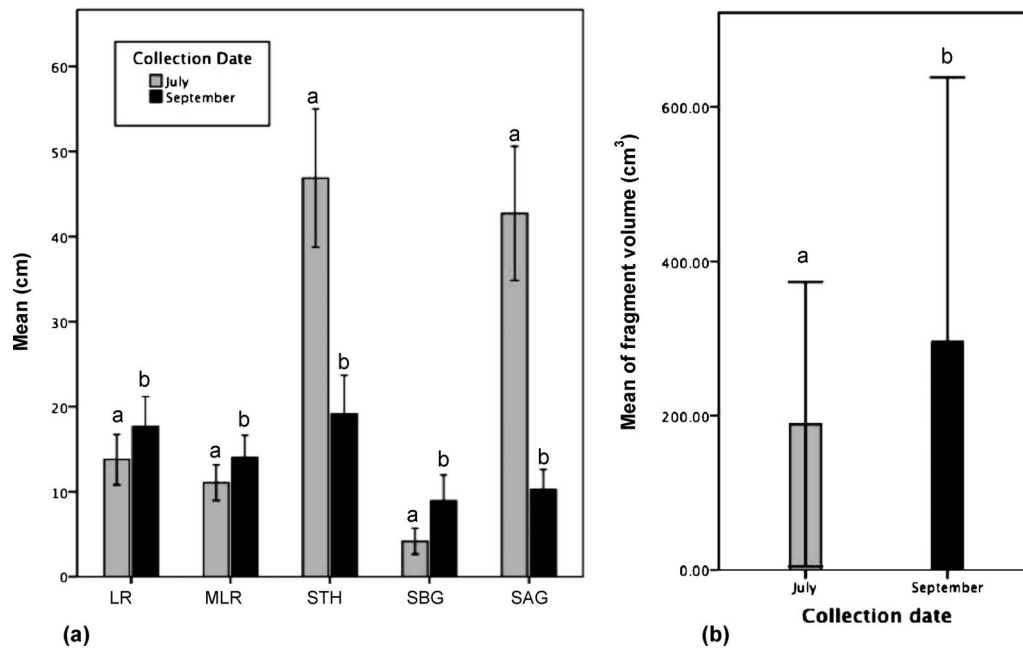


Figure 2. Morphometric comparisons of plants originating from rhizome fragments of knotweed s.l. collected 2 mo apart. Measurements included (a) longest rhizome (LR), mean longest rhizome (MLR), sprout total height (STH), sprout below ground (SBG), and sprout above ground (SAG). Fragment volumes (b) were also compared. Error bars represent a 95% confidence interval.

generated during tropical storm Irene, nor what percentage of them will regenerate. The relative success of rhizome fragments compared to stem fragments may be due to a greater store of resources within the rhizome fragments, which has been suggested as an important factor for success

(Francis et al. 2008). Differences in belowground growth between the first and second collection for rhizome fragments and not stem fragments along the Green River suggest that rhizome fragments are more effective at generating root mass over time, and take better advantage

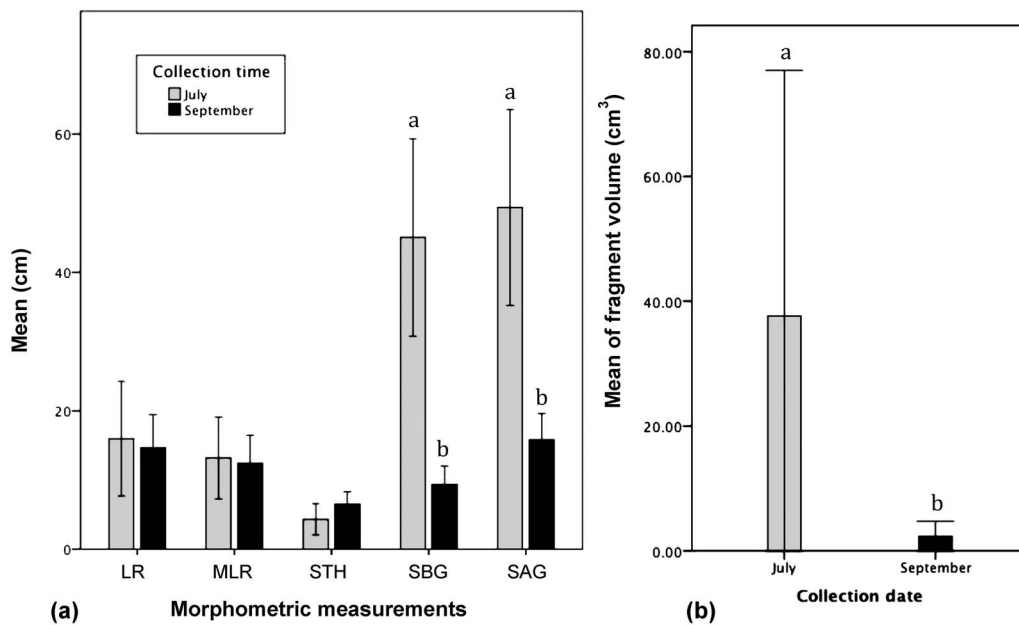


Figure 3. Morphometric comparisons of plants originating from stem fragments of knotweed s.l. collected 2 mo apart. Measurements included (a) longest rhizome (LR), mean longest rhizome (MLR), sprout total height (STH), sprout below ground (SBG), and sprout above ground (SAG). Fragment volumes (b) were also compared. Error bars represent a 95% confidence interval.

Table 1. ANOVA comparing plant growth variables across four river systems.

Variable	River	<i>n</i>	Mean \pm SD ^a	<i>F</i>	<i>P</i>
Fragment volume (cm ³) (FV)	Green	87	315.90 \pm 1452.00	0.659	0.578
	New Haven	30	232.46 \pm 518.54		
	West	26	1069.92 \pm 2139.20		
	Winhall	30	90.78 \pm 210.45		
Longest root/rhizome (cm) (LR)	Green	90	12.96 \pm 9.74 ab	17.82	< 0.001
	New Haven	30	29.22 \pm 22.17 c		
	West	27	8.87 \pm 6.22 a		
	Winhall	30	15.90 \pm 7.82 b		
Mean of longest roots (cm) (MLR)	Green	90	10.70 \pm 7.22 ab	17.72	< 0.001
	New Haven	30	22.39 \pm 11.27 c		
	West	27	7.92 \pm 5.45 a		
	Winhall	30	11.92 \pm 6.11 b		
Sprout below ground (cm) (SBG)	Green	60	3.80 \pm 4.34	2.53	0.061
	New Haven	30	6.00 \pm 6.37		
	West	27	5.09 \pm 5.20		
	Winhall	30	6.10 \pm 6.88		
Sprout above ground (cm) (SAG)	Green	60	43.92 \pm 24.56 a	6.93	< 0.001
	New Haven	30	31.40 \pm 18.86 b		
	West	27	25.19 \pm 15.96 b		
	Winhall	29	29.40 \pm 15.66 b		
Sprout total height (cm) (STH)	Green	90	42.41 \pm 25.59	1.65	0.180
	New Haven	30	37.40 \pm 21.39		
	West	27	30.28 \pm 16.27		
	Winhall	30	34.52 \pm 17.74		

^aMean (\pm SD) followed by the same letter are not significantly different by Tukey's HSD (*P* = 0.05).

of soil resources than stem fragments. Alternatively, the floods may have simply created more rhizome fragments than stem fragments. In any case, these results suggest that the spread of rhizome fragments are a major cause of knotweed s.l. establishment along river corridors.

Both sprout aboveground and fragment volume were larger for all original fragment types in the earlier sample set. Rhizome fragments with a larger fragment volume regenerate better (Sásik and Pavol 2006), and if sprout above ground can be used as an indicator of plant success, then we suggest that this is true for stem fragments as well.

The smaller sprout above ground in the second collection could be due to smaller fragment volumes for both original fragment types, and/or that the sprouts were unable to pierce the soil surface as quickly. This would be especially true for rhizome fragments, which had higher sprout belowground values. The smaller sprout above ground in the second collection also suggests that those plants sprouted later in the growing season. In conjunction with our observed fragment regeneration ratios 11 to 13 mo after propagule distribution, and evidence from 30-d lab experiments suggesting rhizome fragments regenerate about twice as well as stem fragments (Bímová et al. 2003), we suggest that the regenerative ability of propagules does not decrease over time. We also suggest that regenerative ability

is not impacted by the amount of sediment covering the propagule, though deeper burial makes it more difficult for new shoots to reach sunlight before the resources within the fragment are exhausted. We found that 86% of new plants were growing from propagules buried under less than 10 cm of sediment. Only three new plants emerged from propagules buried deeper than 20 cm (8 in.), and only one of those from deeper than 30 cm (12 in.).

Comparing Stands Across Rivers. Differences existed between river sites for longest rhizome, mean longest rhizome, and sprout above ground (Table 1). Tukey honestly significant difference post hoc analysis identified that the New Haven River was significantly higher than all other sites for belowground measurements of longest rhizome and mean longest rhizome (Table 1). For sprout above ground, the Green River had a significantly higher mean measurement (Table 1). Though sprout above ground is not significantly correlated with any belowground growth metrics, sprout above ground is positively correlated with fragment volume (Pearson's $r = 0.432$, $P < 0.001$) (Figure 4). The ANCOVA model revealed that approximately one-third of the variance in sprout above ground can be explained by fragment volume, when site is accounted for ($F = 16.042$, $P < 0.000$, $R^2 = 0.317$). Mechanistically, the influence of

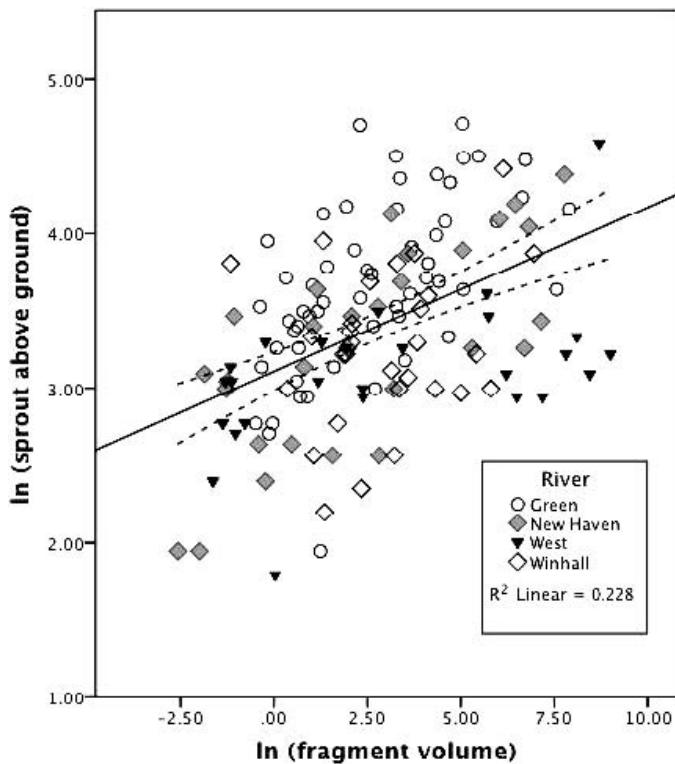


Figure 4. Correlation between sprout above ground and fragment volume of knotweed s.l. Dashed lines represent 95% confidence intervals.

fragment volume on sprout above ground may be at least partially explained by the number of nodes on the original fragment, as fragment volume is positively correlated with number of nodes (Pearson's $r = 0.26$, $n = 144$, $P = 0.002$).

Comparing Stands Over Time. Mean sprout belowground, sprout aboveground, sprout total height, longest rhizome, mean longest rhizome, and fragment volume of plants in the first and second collection times along the Green River were all significantly different between the two samples (Figure 5), though the direction of these differences was not consistent. Longest rhizome ($t = 2.593$, $df = 146$, $P = 0.010$), mean longest rhizome ($t = 2.551$, $df = 146$, $P = 0.012$), sprout total height ($t = 8.408$, $df = 146$, $P < 0.001$), and fragment volume ($t = 2.620$, $df = 103.8$, $P = 0.010$) were all higher in the first collection time. Sprout above ground ($t = 13.561$, $df = 116$, $P < 0.001$) and sprout below ground ($t = 3.070$, $df = 99$, $P = 0.003$) were both higher in the second collection time. Linear regressions revealed that in the first collection, the most parsimonious model was that which included fragment volume only ($F = 10.726$, $P = 0.002$). Fragment volume explained approximately 16% of sprout above ground ($R^2 = 0.161$, $\beta = 0.101$, $P = 0.002$). In the second collection, the strongest model was that which included sprout below ground and longest rhizome only ($F = 21.561$, $P < 0.001$).

Sprout below ground ($\beta = 0.241$, $P = 0.006$) and longest rhizome ($\beta = 0.411$, $P < 0.001$) significantly explained sprout above ground ($R^2 = 0.449$). These results suggest that early in the regeneration process, the size of the original fragment is most important for aboveground growth. As the season continues, however, root mass and underground growth determine aboveground growth. This difference may reflect prioritization of energy use in knotweed s.l., the influence of site-specific variables such as light and nutrient availability, or a combination of factors. If site factors are relevant, then certain riparian areas are more likely to be successfully colonized after flood events than others. It has been suggested that less disturbed habitats (Beerling 1991), and those with lower light availabilities (Beerling et al. 1994), are less susceptible to invasion. However, stem-fragment regeneration may benefit from shade (Brock et al. 1995), because of slower desiccation rates. Additionally, knotweed is especially efficient with nitrogen use and can grow well in low-nitrogen environments (Kovářová et al. 2011). Which species or hybrid the plant is can also influence how propagules respond to the soil (Bímová et al. 2003), as well as how plants respond to control efforts (Bímová et al. 2001). To best identify those areas most likely to be successfully invaded, the site factors that influence the overall success of propagules, as well as underground growth after the influence of fragment volume has waned, should be explored in future research. Identification of these factors would be key for land managers developing strategies and prioritizing potential invasion sites for monitoring, control, and removal of newly established knotweed s.l. Our results also suggest that further insight into how this plant spreads requires a more detailed understanding of mechanisms underlying the growth patterns we identify here, as well as a better understanding of site-specific variables.

For the purpose of controlling the spread of this invasive, we believe that the relatively long window of propagule viability, which is over a year after the flood event that produced and dispersed the propagules (B. P. Colleran, personal observation), creates an excellent opportunity for generating an early detection and rapid response (EDRR) – based management plan. For fragment volume, the mean for all samples was 331.24 cm^3 , which is just smaller than a 12-oz. soda can, with a standard deviation of 1243.18 cm^3 . The ease, speed, and low cost with which propagules of these sizes can be removed from the environment with only garden spades and bare hands, compared with the costly and time-consuming techniques required to eliminate well-established stands, is significant. It is also one of the few ways to involve volunteers in controlling knotweed s.l. that combines a genuine long-term impact with instant gratification for the volunteer. These factors lie at the heart of what EDRR represents, though the concept is usually applied to regions or ecosystems that have yet to be substantially colonized by an invasive species. We suggest

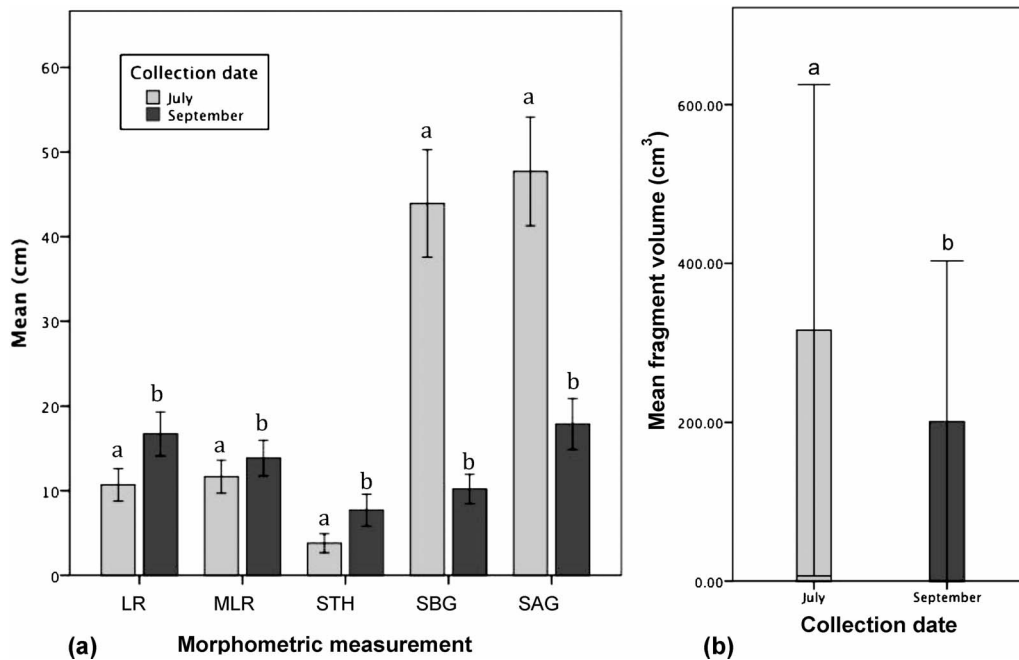


Figure 5. Morphometric differences across two collection times for all plants. Measurements included (a) longest rhizome (LR), mean longest rhizome (MLR), sprout total height (STH), sprout below ground (SBG), sprout above ground (SAG), and (b) fragment volume. Error bars represent a 95% confidence interval.

that in the case of knotweed s.l., such thinking would prevent managers from realizing that each new dispersal event is an opportunity to react quickly and effectively to prevent the spread of this invasive plant.

Acknowledgments

We would like to thank the Conservation Commission of Guilford, VT; the Vermont Youth Conservation Corps Conservation Program; and especially Laura DeMaria, Elizabeth Kelly, Anika Cartterfield, Rachel Keller, Ambur Cameron, Briana Yablonski, Delany Cargo, Shannon Choquette, Nicholas Prechel, Stacey Sexton, Ivan Crinic, Jr., Alyssa Wirkus, for their removal efforts that generated our samples. At the University of Vermont, Alan Howard provided helpful advice during the analysis phase, and Rachel Schattman and Sebastian Castro provided insight during the manuscript preparation.

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Received April 21, 2013, and approved October 9, 2013.