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RESEARCH NOTE

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ABSTRACT: Japanese barberry (*Berberis thunbergii* DC) is a non-native shrub currently found in 31 states and four Canadian provinces. We examined the effectiveness of directed heating using 400,000 BTU backpack propane torches to control Japanese barberry infestations at two study areas in southern Connecticut. Each study area had eight 50-m x 50-m plots. Treatment combinations included a pre-leafout or post-leafout initial treatment with propane torches to reduce the size of established clumps and an early (late June), mid (early July), or late (late July) follow-up treatment to kill sprouts that developed from surviving root crowns. All treatment combinations were equally effective and reduced barberry abundance (a surrogate for cover) from 31% prior to treatment to only 0.5% the following autumn (i.e., a 98% reduction). All treatment combinations were also equally effective in reducing the size of surviving barberry to an average of only 11 cm compared with 74 cm for untreated clumps. Estimated labor costs using propane torches for both initial and follow-up treatment was 2.5 hr/ha for every 1% pretreatment abundance (e.g., 25 hr for a 1-ha stand with 10% abundance). Because timing of initial treatments (pre-leafout vs. post-leafout) and follow-up treatment (early, mid, late) were equally effective in reducing Japanese barberry abundance and height of surviving stems, initial treatments can be completed from March-June and follow-up treatments can be completed from June-August in southern New England. For habitat restoration projects on properties where herbicide use is restricted, directed heating with propane torches provides a non-chemical alternative that can effectively control invasive Japanese barberry.

Index terms: invasive shrub, mortality, non-chemical control, propane torch

INTRODUCTION

An increasingly common challenge for natural resources managers is controlling infestations of invasive shrubs in natural and managed landscapes (Ehrenfeld 1997; Tempel et al. 2004; Webster et al. 2006; Gubanyi et al. 2008; Honu et al. 2009). Dense thickets of invasive shrubs have developed throughout the deciduous forest in the eastern United States, especially where white-tailed deer (*Odocoileus virginianus* Zimmermann) populations are high (Ehrenfeld 1997; Silander and Klepeis 1999). One species of concern is Japanese barberry (*Berberis thunbergii* DC), now classified as invasive in 20 states and four Canadian provinces. It is also established in at least another 11 states (USDA, NRCS 2010). Throughout this paper, *Berberis thunbergii* will be referred as to Japanese barberry or just barberry.

Non-native shrubs, including Japanese barberry, can form dense thickets that inhibit forest regeneration and native herbaceous plant populations (Kourtev et al. 1998; Collier and Vankat 2002; Miller and Gorchov 2004). Barberry can alter soil biota and function by increasing soil nitrification and pH (Kourtev et al. 1999; Ehrenfeld et al. 2001). In addition, earthworm densities are greater and leaf litter is reduced in barberry infestations (Kourtev et al. 1999). Loss of leaf litter can cause increased soil erosion and sedimentation loads into adjacent streams as well as a loss of some herbaceous species (Hale et al. 2008). Barberry also has an indirect, adverse impact on human health by functioning as disease foci with enhanced levels of blacklegged ticks (*Ixodes scapularis* Say) infected with the Lyme disease-causing spirochete, *Borrelia burgdorferi* (Johnson, Schmidt, Hyde, Steigerwaldt & Brenner) (Williams et al. 2009).

Eradication or control of invasive species is often the crucial first step in restoration of natural areas (D'Antonio and Meyerson 2002). However, invasive control can be especially problematic on properties where herbicide use is restricted by regulations (e.g., parks, drinking water supply watersheds), deeds, or active public opposition. Biocontrols have shown promise for some invasive species such as *Ailanthus altissima* ((Mill.) Swingle) (Schall and Davis 2009), *Lythrum salicaria* (L.) (Wilson et al. 2004), and others (Hough-Goldstein et al. 2009). However, for most woody species, including barberry, non-chemical control is largely limited to root wrenching, repeated clipping (mowing), or prescribed fire. Root wrenching is labor extensive and exposes mineral soil that can be colonized again by invasive species (D'Antonio and Meyerson 2002). Repeated clipping or mowing may be effective for species that do not sprout; but less so for shade-tolerant species that sprout (Luken and Mattimiro 1991). Prescribed fire can be effective for controlling barberry (Richburg 2005; Ward et al. 2009), but is not an option on many properties.

A non-chemical treatment for smaller infestations (< 10 ha) is directed heating using portable propane torches. Directed heating with torches was reported effective for controlling a variety of hardwood species in New Hampshire (Cavanagh and Weyrick 1978), Cornish heath (*Erica vagans* L.) in Spain (Obeso and Vera 1996), and bellyache bush (*Jatropha gossypiifolia* L.) in Australia (Vitelli and Madigan 2004). Because barberry spreads by layering (in which an aerial stem can form adventitious roots and eventually become an independent plant) in forests with intact canopies (Ehrenfeld 1999; DeGasperis and Motzkin 2007) and has low seedling recruitment because of the lack of a seed bank (D'Appollonio 1997), eradication of established plants should lead to excellent long-term control.

Our earlier work found that propane torches can provide control of barberry for at least two years on small scale plots in Connecticut (Ward et al. 2010). The objective of this study was to examine the practicality and effectiveness of using backpack propane torches to control barberry at scales (2 ha) typical of smaller infestations, using 0.25 ha treatment plots. While earlier studies (Ward et al. 2009, 2010) examined the response of individual barberry clumps to treatment, this study examined how treatments reduced barberry abundance. If we assume that barberry abundance is an adequate surrogate for allocation of limited resources on a site (e.g., light, nutrients), then reducing barberry should allow for the use of released resources towards the re-establishment and spread of native tree seedlings and herbaceous plants.

METHODS

Study Areas

In 2008, two 2-ha study areas were established in southern Connecticut: one in North Branford, Conn., on South Central Connecticut Regional Water Authority property (Tommy Top) and one in Redding, Conn., on Centennial Watershed State Forest (Greenbush) cooperatively managed by Aquarion Water Company, The Nature Conservancy, and Connecticut Department of Environmental Protection.

Dominant forest trees were primarily sugar maple (*Acer saccharum* Marsh.) with mixed oak (*Quercus* spp.) at Tommy Top, and red maple (*Acer rubrum* L.), ash (*Fraxinus* spp.), and oak at Greenbush. Both study areas had extensive areas of barberry that were excluding desirable forest regeneration and native herbaceous vegetation (Figure 1). Study areas were agricultural fields or pastures abandoned in the early 1900s. Management was negligible at both plots except for salvage harvest of some eastern hemlock (*Tsuga canadensis* (L.) Carriere) in the early 1990s at Tommy Top.

Design and measurements - barberry

Each study area was divided into eight 50-m x 50-m (0.25 ha) plots, randomly assigned to one of eight treatments: control, a single treatment (mid-July); or 2 treatments, the first applied pre-leafout (March) or post-leafout (April) and the second applied early summer (late June), mid-summer (early July), or late summer (late July). Treatment consisted of directed heating with 400,000-BTU propane torches (BP 2512 SVC, Flame Engineering Inc., LaCrosse, Kan.). Initial treatments were applied to reduce the size of established barberry clumps, and follow-up treatments killed sprouts that developed from surviving root crowns.

Within each plot at each study area, twenty-five sample points were established on a 5-m x5-m grid with 8 m spacing between points. Sample points were permanently located with a wire flag and were at least 9 m from plot edges. Barberry height and abundance were estimated at each sample point. For this study, abundance was defined as the proportion of sixteen 17.7-cm x 17.7-cm cells within a 0.5 m^2 sampling frame, centered on the flagged point, that had at least one live barberry stem or leaf (Figure 2). For example, if barberry was observed in five cells, then abundance was 5/16 = 31%. This method, while biased to give slightly higher estimates than traditional cover estimates, especially for low density patches, is reproducible and can be used in both dormant (leaf-off)

Figure 1 - Dense, unmanaged Japanese barberry stand in Redding, Conn.

Figure 2 - Sampling frame used to estimate Japanese barberry abundance. Abundance was defined as the proportion of sixteen cells that had barberry, i.e., three cells with barberry would provide an estimated abundance of 3/16=19%.

and growing seasons. Occasionally, small stems buried under several inches of snow were missed during the dormant season field measurements. This resulted in a slight underestimation of abundance when sampled in the dormant season relative to growing season estimations.

For this study, frequency was the proportion of flagged points (not cells) that had at least one live barberry stem or leaf. At each point, average barberry height was concurrently estimated in 30-cm increments. Measurements were made in March (pre-treatment), late June prior to the follow-up treatments (2nd phase), and again in October.

We recorded fuel consumption by weighing propane tanks to the nearest 0.05 kg before and after treating each plot. Total treatment time and number of crew members was recorded for each plot.

Flame from the propane torches was applied to the base of a clump, at the root crown/soil interface, and across the top of the root crown where individual ramets (stems) emerged. Treatment continued until the individual ramets and the top of the root crown became carbonized and began to glow. This treatment simultaneously destroyed the cambial tissue of the ramets, effectively girdling them, and many of the dormant buds. Only leaf litter within several centimeters of treatment clumps was incidentally burned. Treatment times varied from 10 seconds for the smallest clumps to 40 seconds for the largest clumps. To reduce the risk of wildfire, all directed flame treatments were completed on days when the leaves were damp or wet and included some days of light to moderate rain showers.

Statistical analysis

A two-factor (study area, initial treatment) analysis of variance (ANOVA) with pretreatment abundance as a covariate was used to compare the influence of initial treatments on abundance in June 2008. All abundance values were arcsine transformed to stabilize the variance (Neter and Wasserman 1974). Tukey's HSD test was used to test for significant differences among initial treatments. Differences were judged significant at $p \leq 0.05$.

Timing (pre-leafout vs. post-leafout) of initial treatment did not have a significant effect on abundance values through late June (see Results). Therefore, initial treatment was not included as a factor in the analysis of follow-up treatments. A two-factor (study area, follow-up treatment) ANOVA with pretreatment abundance as a covariate was used to compare the influence of follow-up treatments on abundance in October. Again, all abundance values were arcsine transformed to stabilize the variance. Tukey's HSD test was used to test for significant differences among initial treatments. Differences were judged significant at $p \leq 0.05$.

Labor hours and fuel consumed were tracked for all initial and follow-up treatments. A two-factor (study area, initial treatment) ANOVA with pretreatment abundance as a covariate was used to compare initial treatment costs. Cost was defined as the number of hours per hectare to complete treatments. Tukey's HSD test was used to test for significant differences among initial treatments. Differences were judged significant at $p \leq 0.05$. Because costs did not vary among initial treatments, initial treatment cost was not included as a factor in the analysis of follow-up treatment costs. A two-factor (study area, initial treatment) ANOVA with pretreatment abundance as a covariate was used to compare follow-up treatment costs.

RESULTS

Prior to treatment, barberry abundance averaged 31% across all plots, ranging from 10%-55%. Pre-treatment abundance did not differ among study areas (F=0.93, df=1, p=0.360), initial treatment plots (F=0.080, df=2, p=0.924), or follow-up treatment plots (F=0.253, df=3, p=0.857). Directed heating significantly reduced barberry abundance to a mean of 6.3% (one treatment) or 0.7% (two treatments) (Figure 3).

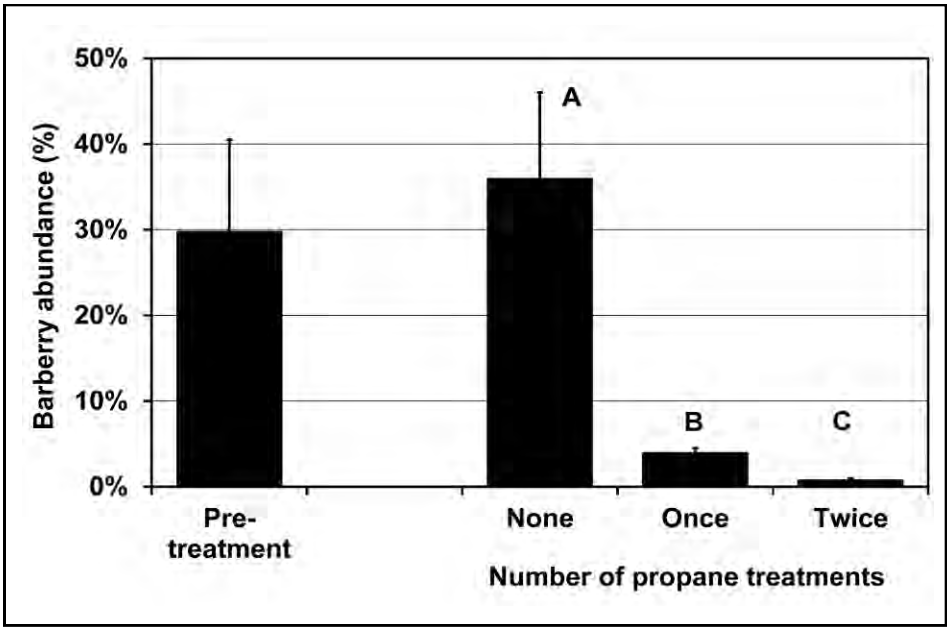

Figure 3 - Estimated barberry abundance before treatments and in following October by number of propane treatments: None (n=2), Once (n=2) and Twice (n=12). Abundance was an estimate of the proportion of area covered with barberry. Values with same letters above bars were not found significantly different using Tukey's HSD test at P < 0.05.

Timing of initial treatments (pre-leafout vs. post-leafout) had no effect on abundance estimates in June (F=2.262, df=1, p=0.163) or in October (F=0.093, df=1, p=0.769). Similarly, timing of follow-up treatments had no effect on final abundance estimates in October (F=1.663, df=2, p=0.262). The follow-up treatment resulted in barberry abundance of 0.5% compared with 3.9% on plots with only one treatment.

The number of directed heat treatments using propane torches did have an effect on barberry abundance in October (F=83.5, df=2, p<0.01). One treatment with propane torches reduced barberry abundance by an average of 83% and two treatments reduced barberry abundance by an average of 98%. Frequency, the proportion of sample points that had at least one barberry, averaged 52% prior to initial treatment (Figure 4). Directed heating using propane torches was highly effective in reducing barberry frequency. Initial treatments both before and after leafout were equally effective in reducing barberry frequencies. Barberry frequency in October differed by the number of directed heat treatments using propane torches (F=24.2, df=2, p<0.01). While the October survey found over 60% of points on untreated plots had at least one barberry, a single treatment reduced frequency to 18%. Two treatments reduced frequency to only 5%.

Average height of barberry was 78$\pm$4 cm in March prior to treatment and 74$\pm$4 cm in untreated plots in October. Directed heating using propane torches was highly effective in reducing the height of barberry (Figure 5). Barberry heights in October differed by number of directed heat treatments (F=16.4, df=2, p<0.01)–27$\pm$4 and 11$\pm$5 cm for once and twice treated barberry, respectively, compared with 74$\pm$4 cm for untreated barberry. Therefore, relative to untreated clumps in October, one directed heat treatment reduced the average size of barberry clumps by 64% and two treatments reduced the average size by 85%.

Labor costs (hours/ha) for both initial and follow-up treatments were correlated with pretreatment barberry abundance values, r^2=0.67 and r^2=0.60, respectively (Figure 6). For the initial treatments used to reduce the size of established barberry clumps, labor costs did not differ between the pre-leaf out and post-leaf out periods (F=0.006, df=1, p=0.942). Similarly, labor costs did not differ between the early, mid, and late summer treatment periods for the follow-up treatments used to kill new sprouts that developed from surviving root crowns, (F=0.74, df=2, p=0.510).

Labor costs for every 1% barberry abundance were estimated as 1.5 hr/ha for initial

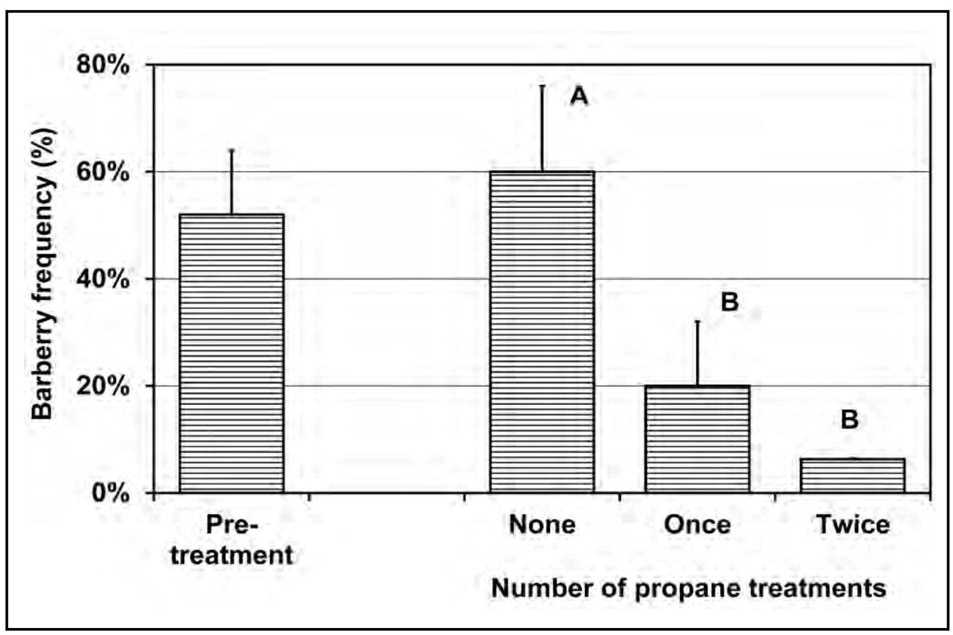

Figure 4 - Estimated barberry frequency (SE) before treatments and in following October by number of propane treatments. Frequency is the proportion of sample points that had at least one barberry stem. Values with same letters above bars were not found significantly different using Tukey's HSD test at P < 0.05. Note: Once and Twice treated were not significantly different at P=0.055.

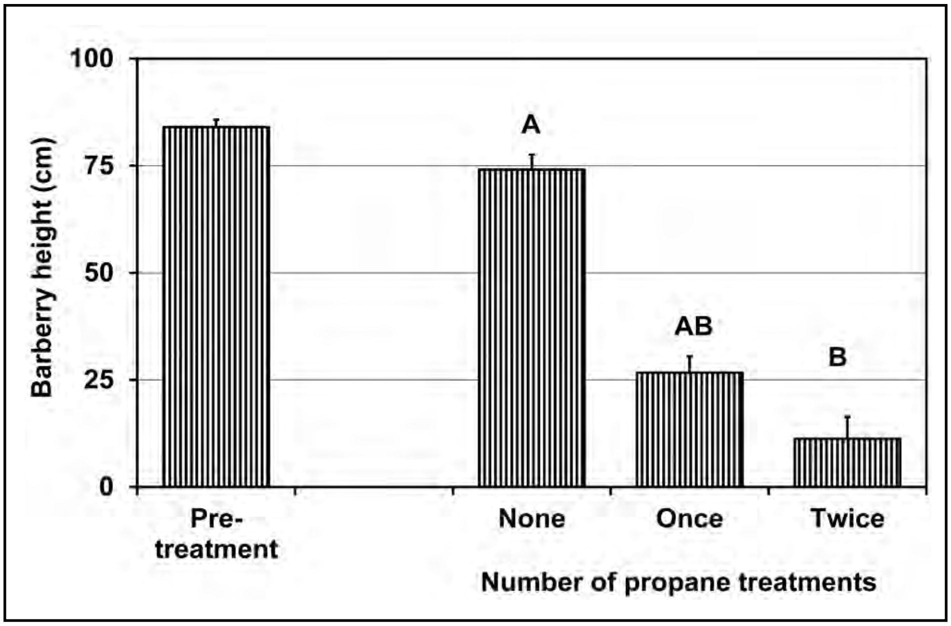

Figure 5 - Estimated Japanese barberry heights (SE) before treatments and in following October. Values with same letters above horizontal lines were not found significantly different using Tukey's HSD test at P < 0.05.

treatment and 1.0 hrs/ha for follow-up treatments. Thus, estimated labor costs using propane torches for both initial and follow-up treatment would be 2.5 hr/ha for every 1% abundance (e.g., 25 hr for a 1-ha stand with 10% barberry abundance). It should be noted that these estimates do not include time required for travel, refueling, and breaks.

The amount of propane used for the directed heating treatments was highly correlated (r^2=0.88) with the amount of time needed to treat barberry infestations. While there was a statistical difference between initial and follow-up treatments in the amount of propane used per hour (F=6.133, df=1, p=0.021), the actual difference, 0.28 kg/hr was of little practical difference relative to the 2.49 kg/hr average for both periods combined. Using the example above, a 1-ha stand with estimated 10% barberry abundance would require a total of 62 kg of propane for both the initial and follow-up treatments.

DISCUSSION

A two-step process of directed heating using propane torches can control barberry infestations. By every metric examined (abundance, frequency, height) in the current study, directed heating with propane torches was effective in reducing the amount of barberry in forest understories (Figures 3-5). An earlier report found that two directed heating treatments killed nearly 80% of clumps smaller than 180 cm and reduced the average size of surviving clumps to less than 50 cm (Ward et al. 2010). We anticipate that the reduction in barberry abundance and size will facilitate recruitment of native woody herbaceous species in forest understories, provided that deer populations are not too high.

Our results indicate that barberry can be effectively reduced using propane torches, with a first treatment applied anytime between six weeks before and one month after full leaf expansion, and a second treatment applied six weeks later. The importance of follow-up treatments can not be over-emphasized. While a single treatment reduced barberry abundance by 89% (Figure 3), an earlier study noted that 71% of clumps larger than 150 cm survived a single directed heating treatment compared with only 29% of similar clumps that were treated twice (Ward et al. 2010). Because barberry is able to replace carbohydrate reserves within one month of leafout (Richburg 2005), follow-up treatment is essential to reduce the capacity of this species to re-occupy the site after initiation of control measures. Surviving clumps can continue to grow in low light levels (Harrington et al. 2004) and then spread by layering (Ehrenfeld 1999; DeGasperis and Motzkin 2007).

Observations on our research plots suggest the propane torches might provide effective control for burningbush (*Euonymus alatus* (Thunb) Siebold) and Japanese stiltgrass (*Microstegium vimineum* (Trin) A. Camus), but not Asiatic bittersweet (*Celastrus orbiculatus* Thunb.), swallow-wort (**Cynanchum spp.**), or species that root sucker such as *Ailanthus*. We also observed directed heating, prescribed burning, and mechanical cutting were less effective for controlling barberry and other invasive species in large canopy gaps than in small gaps or under intact canopy.

Because propane torches produce a 1100 °C flame, they are inherently dangerous tools, like chainsaws, that must be treated with respect and operators should have safety training before use. We trained all personnel in safe and efficient operation, and ensured proper techniques were understood and followed before allowing independent use of equipment. At least two personnel were on site in case of an accident. The use of open flame in the forest has the risk of igniting a wildfire. We mitigated this risk by only using torches on days when the leaf litter was damp or wet, and had appropriate hand tools and backpack water pumps on hand for fire suppression. This provided an opportunity to conduct field work during inclement weather when other activities are restricted. Other safety concerns included, but are not limited to, tripping hazards and exposure to smoke, especially smoke from poison ivy (*Toxicodendron radicans* (L.) Kuntze).

High labor costs are another limitation of directed heating (Figure 6). This cost can be greatly reduced in areas where herbicides cannot be used by substituting mechanical cutting with a brush-saw as the initial treatment. Another alternative would be to use heavy equipment to smash or cut clumps, but care must be exercised to minimize damage to soil and native vegetation (Ward et al. 2009). The tradeoff is

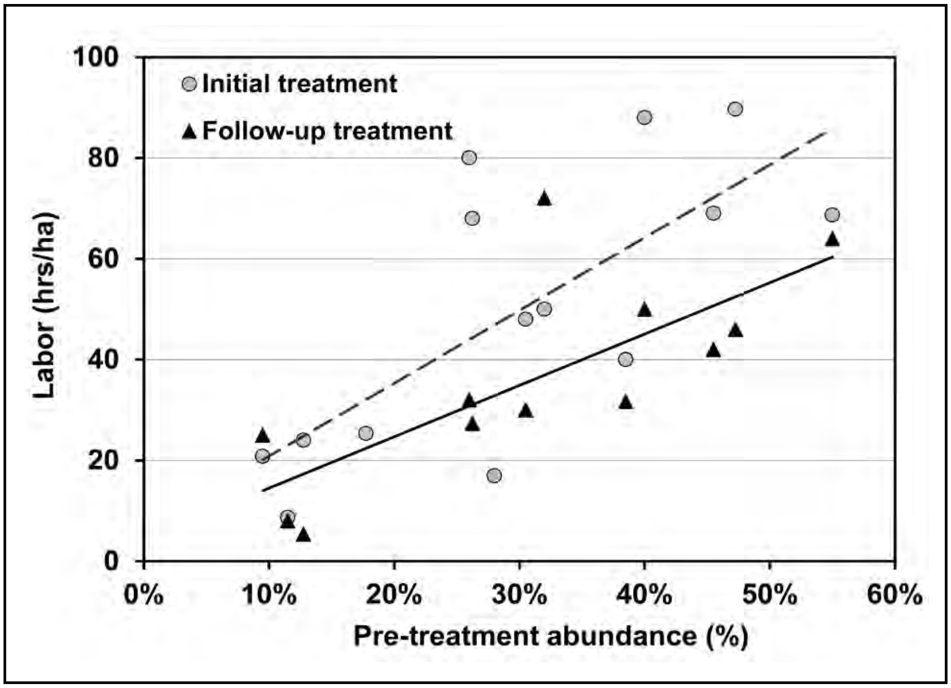

Figure 6 - Labor (hour/ha) by estimated pre-treatment abundance (%) needed for initial and follow-up Japanese barberry control treatments.

lower mortality of barberry clumps using brush-saws than when propane torches are used (Ward et al. 2010). Another problem is that propane pressure decreased after less than one hour of continual usage. This both reduced the flame intensity–increasing labor costs without increasing propane use–and required periodic switching between tanks. However, this provided for periodic breaks that reduced mental and physical fatigue.

The benefits of controlling barberry go beyond restoration of native plants. Relative to forests with a native shrub layer, enhanced levels of blacklegged or 'deer' ticks were found in areas dominated by invasive shrubs, including barberry, in Maine (Lubelczyk et al. 2004; Elias et al. 2006) and Connecticut (Williams et al. 2009). Blacklegged ticks can transmit the causal agents of several diseases including Lyme disease (*Borrelia burgdorferi*), human granulocytic anaplasmosis (*Anaplasma phagocytophilum* Theiler), and human babesiosis (*Babesia microti* Franca.; Magnarelli et al. 2006). Thus, controlling barberry can have a positive impact on human health by lowering the risk of exposure to tick-borne diseases.

Directed heating will not permanently eliminate invasives from a site unless the underlying factors such as high deer densities (Knight et al. 2009), site disturbance, and high seed input of invasives (Henderson and Chapman 2006) are also eliminated. However, the use of directed heating with propane torches provides an additional tool that provides available growing space for the establishment and development of native herbaceous and woody species for habitat restoration projects on properties where herbicide use is restricted.

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Jeff Ward is the Chief Scientist of the Department of Forestry and Horticulture. His research has focused on long-term population dynamics of woody plants in natural areas, alternative methods of controlling invasive species, and growth response of individual trees following stand disturbance.

Scott Williams is an Assistant Scientist in Department of Forestry and Horticulture studying the impacts overabundant white-tailed deer have on natural and managed ecosystems, and interaction of invasive shrubs, rodent, and ticks on Lyme disease risk.

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