Invasive Plant Science and Management (2010) 3:60-69

Effectiveness of two-stage control strategies for Japanese barberry (*Berberis thunbergii*) varies by initial clump size

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Japanese barberry is listed as an invasive shrub in 20 states and 4 Canadian provinces. Control of Japanese barberry was evaluated using several two-step processes over 16 months using a total of 1100 clumps at six study areas. Initial treatments in spring (prescribed burning, mechanical mowing with a brush saw or rotary wood shredder) reduced the size of established barberry clumps. Follow-up treatments in mid-summer to kill new ramets that developed from surviving root crowns were foliar applications of triclopyr or glyphosate, directed heating with a propane torch, and untreated controls. Mortality was defined as the absence of ramets from a root crown and not the mortality of individual ramets of a given clump. Clump mortality and size of new ramets did not differ among initial treatments. However, larger clumps had higher survival and larger sprouts than smaller clumps sixteen months after initial treatment. Effectiveness of follow-up treatments varied by clump size. Two follow-up treatments of directed heating using propane torches were as effective as herbicides for clumps that were initially smaller than 120 cm. For clumps with pretreatment sizes of 120 cm and larger, clump mortality following herbicide treatments (90%) and directed heating (65%) was greater than for clumps that had no follow-up treatments (35%). While clump sizes did not differ between follow-up methods one-year after treatment, both follow-up treatments resulted in smaller clumps than untreated controls. Effective control of Japanese barberry can be achieved in a single growing season by integrating an early-season initial treatment (prescribed fire or mechanical) that kills the aboveground tissues with a mid-season follow-up treatment such as directed heating or targeted herbicide application.

Nomenclature: Glyphosate; triclopyr; Japanese barberry, *Berberis thunbergii* DC. BEBTH.

Keywords: propane torch; mechanical control; herbicide; mortality; invasive shrub

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Invasive woody shrubs are a problem for natural resource managers throughout the United States (Marler 2000, Barton et al. 2004, Webster et al. 2006), and elsewhere (Radford et al. 2001, Buckley et al. 2003). In the northeastern United States, Japanese barberry (*Berberis thunbergii*) is an emerging species of concern that is classified as invasive in 20 states and 4 Canadian provinces. It is also established in another 11 states (USDA, NRCS 2008). Japanese barberry is primarily an invader of abandoned agricultural fields (DeGasperis and Motzkin 2007, Mosher et al. 2009) that is able to persist in low light levels (Harrington et al. 2004) and can spread by layering (Ehrenfeld 1999, DeGasperis and Motzkin 2007). Recruitment of Japanese barberry under established trees is low because of the lack of a seed bank (DôAppollonio 1997).

Barberry and other non-native shrubs can form dense thickets that inhibit forest regeneration and native herbaceous plant populations (Kourtev et al. 1998, Collier and Vankat 2002, Gorchov and Trisel 2003, Miller and Gorchov 2004), and alter soil biota and chemistry (Ehrenfeld et al. 2001), as well as soil structure and function (Kourtev et al. 2003). Japanese barberry is associated with greatly enhanced levels of blacklegged ticks (*Ixodes scapularis*; Elias et al. 2006) that can transmit the causal agents of several diseases including Lyme disease (*Borrelia burgdorferi*), human granulocytic anaplasmosis (*Anaplasma phagocytophilum*), and human babesiosis (*Babesia microti*; Magnarelli et al. 2006). By maintaining high populations of infected ticks, barberry infestations can function as disease foci that have an indirect, adverse effect on human health. Thus, controlling barberry may directly benefit human health in the Northeast and upper Midwest where both Lyme disease and barberry are problematic (Williams et al. 2009).

Current recommendations to control barberry include root wrenching, herbicide applications to cut stems, and foliar applications of herbicide to intact plants. The first two measures, while effective, are limited to smaller infestations because they require substantial physical labor. Root wrenching also exposes mineral soil that can be colonized by other invasive species. Unfortunately, there is little information in the literature on using herbicides to control Japanese barberry; most available information is anecdotal. Although fact sheets indicate that both glyphosate and triclopyr can be effective for controlling Japanese barberry (Rhoads and Block 2002, Plant Conservation Alliance 2006), we could find only one refereed paper that included herbicide treatment (Silander and Klepeis 1999). They reported that foliar application of glyphosate resulted in complete control on seven 3.0 x 2.5 m plots.

Alternatives to herbicides are needed where their use is restricted by regulations (e.g., parks, drinking water supply watersheds) or deeds (e.g., natural areas). One possibility for smaller infestations (< 10 ha) is directed heating using portable torches. Our initial work found that propane torches can provide control of Japanese barberry for at least one year (Ward et al. 2009). Propane torches were reported as effective for controlling eastern redcedar (*Juniperus virginiana*) in Oklahoma (Engle and Stritzke 1992), American beech (*Fagus grandifolia*) in Maine (Ostrofsky 2005), and bellyache bush (*Jatropha gossypiifolia*) in Australia (Vitelli and Madigan 2004). Directed heating with butane torches resulted in 60% mortality of Cornish heath (*Erica vagans*) in Spain (Obeso and Vera 1996). Cavanagh and Weyrick (1978) described kerosene torches as effective for control of a variety of hardwood species in New Hampshire.

This report expands on the earlier study (Ward et al. 2009) by including an additional follow-up treatment (described in Methods) and examining the growth and survival through the middle of the second growing season (sixteen months). The earlier report compared the effectiveness of various treatment combinations for controlling Japanese barberry after one growing season (seven months). The specific objectives were: 1) compare a two-step control process using two mechanical removal methods and prescribed burning in the first stage and two herbicides and directed heating in the second stage and 2) compare the efficacy of these methods over a range of clump sizes.

Materials and Methods

Study Areas.

Between January-March 2007, six study areas were established to examine Japanese barberry control alternatives. Two study areas were established on the Centennial Watershed State Forest in Redding, CT on a forest jointly managed by the Connecticut Department of Environmental Protection, the Aquarion Water Company, and The Nature Conservancy. Two study areas were established on a South Central Connecticut Regional Water Authority (RWA) property in North Branford, CT. A fifth study area was established in Salisbury, CT on lands managed by The Nature Conservancy. The sixth study area was established in Storrs, CT on University of Connecticut Forest land.

All study areas were agricultural fields or pastures abandoned before 1940. Upper canopies were primarily mixed hardwoods on all plots, except the Salisbury plot which was replanted with white pine (*Pinus strobus*) in the early 1900s. Management was limited to fuelwood harvests of declining and subcanopy trees, except on one plot where a salvage harvest of eastern hemlock (*Tsuga canadensis*) in the early 1990s removed ~70% of stand basal area. Stands had similar soils and climates. Details on stand histories, forest composition, soil types, and local climate can be found in Ward et al. (2009).

Each study area had two blocks of four contiguous 30m x 30m square subplots, except the Salisbury study area that had only one block of four subplots. Each block was randomly assigned one of three initial treatments prior to leaf out. Subplots within each block were randomly assigned distinct follow-up treatments in mid-summer. Treatment details are given below.

Twenty-five barberry clumps (an individual plant comprising numerous ramets) over a range of clump sizes were selected within each subplot for a total of 1100 clumps (Table 1). Each clump location was mapped and a numbered aluminum tag on a wire stake was placed adjacent to each clump for positive identification. Crown width (cm), crown height (cm), basal width (cm), number of live ramets (individual stems of a clump), and diameter (mm) of the largest ramet of each clump were recorded prior to treatment in spring 2007. Clump width and height measurements were repeated in September 2007 and again in July 2008.

For analysis, clump size was arbitrarily defined as the average of crown height and crown diameter (Table 1). Each clump was assigned to one of five size classes for analysis: < 90 cm, 90-119 cm, 120-149 cm, 150-179 cm, and ≥ 180 cm (approximately < 3ft, 3-4 ft, 4-5 ft, 5-6 ft, and > 6 ft).

First stage – initial treatments.

Three initial treatments were used to reduce the size of established barberry clumps: mechanical mowing with a rotary wood shredder, mechanical mowing with a brush saw, and prescribed burning. The mechanical mowing using a hydraulically driven, rotary wood shredder[1] mounted to a compact track loader[2] was completed in March 2007. Barberry clumps missed by the rotary wood shredder (e.g., adjacent to trees, stone walls, or large rocks) were cut using a brush saw[3]. Brush saw treatments were completed in April 2007.

Prescribed burning treatments were completed in April 2007. Initial ignition pattern for the prescribed fires was a ring fire ignited by a drip torch. Low flame heights (< 50 cm) and low rate of spread following initial ignitions required strip ignitions at 10-100 meter intervals to burn all sections of treated plots. Fall burning was not considered because conditions are seldom suitable for prescribed fires between leaf-drop and snowfall in the Northeast.

Statistical Analyses. Mortality in the following sections is defined as clumps that had no live aboveground ramets (i.e., sprouts or stems) at the time of measurement; it does not refer to mortality of individual ramets of a given clump. For all three measurement periods, both skewness and kurtosis of clump sizes were less than two indicating that the distributions did not differ significantly from a normal distribution and did not require transformations.

Repeated measures analysis of variance for clump size using SYSTAT 10[4] was used with date (sample period) as the within subjects factor, and study area, initial treatment, follow-up treatments, and interaction of initial and follow-up treatments as the between subjects factors. Differences were judged significant at $p \leq 0.05$. Chi-square statistics were used to determine whether mortality differed among treatments and size classes. Only clumps on subplots without follow-up treatments were included in the analysis. Procedures defined by Neter et al. (1982, p 325-329) were used to determine differences among size classes. Differences for all comparisons were considered significant at $p \leq 0.05$.

We used Bonferroni-adjusted probabilities to maintain $p \leq 0.05$ for all comparisons, i.e., there is less than a 5% chance that even one of the comparisons could have been declared significant if drawn from a random population. This is a very conservative standard and may have excluded some actual differences.

Second stage – follow-up treatments.

The follow-up steps used to treat the new ramets in July 2007 (mid-summer) were: directed flame with a 100,000 BTU propane torch[5], foliar application[6] of glyphosate[7], foliar application of triclopyr[8], and no follow-up treatment (control). Directed heating treatments were repeated in October 2007 after remeasurement and leaf-drop. Herbicides were not examined on RWA study areas per company policy. Therefore, the herbicide treatments were replaced with directed flame following initial spring flush in early June and directed flame following initial spring flush and again in early August.

Directed flame was applied until individual ramets became carbonized and began to glow. Treatment times varied from 10-40 seconds depending on initial clump size. All directed flame treatments were completed when the leaves on the forest floor were damp or wet, including periods of light to moderate precipitation.

Herbicide sprays were diluted per label instructions and were applied to target foliage until wet using hand-pressurized backpack sprayers. Only barberry foliage was targeted to minimize impact to native species. The following herbicides were sprayed: glyphosate (2.0% solution) and triclopyr (4.6 % solution). A dye was added to the tank mixes to prevent spraying clumps more than once and to identify clumps that had not been treated.

Statistical Analyses. Because initial treatments and interaction of initial and follow-up treatments had no significant effect on clump mortality or final clump sizes, initial treatment was not included as a factor in the analysis of the effects of follow-up treatments. Since company policies did not permit herbicide applications at the RWA study areas, the four study areas where herbicides were used were analyzed separately from the two study areas where herbicides were not used.

For study areas where herbicides were used, repeated measures analysis of variance for clump size using SYSTAT 10 was used with date (sample period) as the within subjects factor, and study area and follow-up treatments as the between subjects factors. Where an interaction between treatment and date existed, t-tests were used to test for differences in clump size among treatments. Differences were judged significant at $p \leq 0.05$ after Bonferroni adjustments. Chi-square statistics were used to determine whether mortality differed among treatments and size classes. Procedures defined by Neter et al. (1982, p 325-329) were used to determine differences among treatments The two study areas where herbicides were not used were included in the comparison of timing of directed flame treatments using propane torches. Analyses were completed as described for the study areas where herbicide was used.

To compare effect of follow-up treatments by clump size, a three-factor (study area, follow-up treatment, size class) analysis of variance was used to examine the effect of follow-up treatment on clump size in September 2007 and July 2008. Tukeyǒs HSD test was used to test for significant differences among treatments and size classes. Differences were judged significant at $p \leq 0.05$.

Results and Discussion

Initial clump size did not differ among initial treatments ($F_{2,1095}$=0.563, P=0.569) or follow-up treatments ($F_{2,1095}$=2.157, P=0.116). Basal width, the number of ramets, and size of the largest ramet in each clump increased with increasing clump size (Table 2). The largest size class averaged 3 times more ramets than the smallest size class and also had ramets with larger diameters.

First stage – initial treatments.

Repeated measures ANOVA indicated no effect of initial treatment ($F_{3,161}$=0.682, P=0.507), interaction of initial and follow-up treatment ($F_{4,161}$=1.785, P=0.134), or interaction of sample date and initial treatment ($F_{4,322}$=1.553, P=0.187) on resultant clump size. Similarly, mortality for a given clump size class did not differ among initial treatments when there was no follow-up treatment (Figure 1). Therefore, initial treatments were pooled in the following analyses.

At the end of the first growing season, clump mortality was higher for clumps with initial sizes < 90 cm than for clumps > 180 cm (Figure 2). Similar results were noted in Massachusetts where barberry was not killed by a single treatment of mechanical control or prescribed burning (Richburg 2005). Unexpectedly, although there were no additional treatments, mortality increased for all size classes through July 2008. Through July 2008, fifteen months after the initial treatments, mortality of clumps < 150 cm was 39% or higher, and was greater than for clumps with initial sizes ≥ 180 cm.

While no clumps with three or more stems (n=71) died over a two-year period in New Jersey (Ehrenfeld 1999), 14% of clumps with at least five stems (n=271) died in our study. This delayed increase in mortality was unexpected because Japanese barberry is able to replace carbohydrate reserves within one month of leafout (Richburg 2005). Following initial treatments in our study, new ramets quickly developed from dormant basal buds and were fully expanded by early July. This provided three months to replenish the carbohydrate reserves needed for respiration during the dormant season and the spring flush.

Fifteen months after a single treatment, clump mortality and size did not differ among clumps that were initially smaller than 180 cm. Recall that initial treatments removed all aboveground ramets by cutting or lethal heating by prescribed fire, so with the exception of an occasional missed ramet, the clumps consisted entirely of new ramets. Clump sizes in September 2007 ($F_{4,241}$=7.367, P<0.001) and in July 2008 ($F_{4,184}$=3.141, P=0.016) differed among pre-treatment clump size, i.e., clumps that were small before initial treatment were small after new ramets had developed. Without a follow-up treatment, clump sizes recovered to approximately half of their original size by the end of the first growing season after treatment and continued to grow in 2008 (Table 3). Surprisingly, by July 2008, there was no size difference between clumps that had been smaller than 90 cm before initial treatment and those less than 180 cm (Table 3). However, clumps that had been at least 180 cm before treatment were larger than clumps that had been smaller than 150 cm before treatment.

Second stage – follow-up treatments.

This section on follow-up treatments first compares the effectiveness of the two schedules of directed heating using propane torches and then compares the effectiveness of different herbicides. For the final analysis, the two heat treatment schedules were pooled because they were equally effective. Similarly, the two herbicides treatments were pooled.

Directed heating timing schedules. Clump sizes in July 2008 ($F_{1,51}$=2.588, P=0.114) and mortality (Figure 3) did not differ between the June/August and July/October follow-up treatment schedules. An earlier report found that both pre- and post-leafout treatments using directed heating with propane torches were equally effective (Ward et al. 2009). This suggests that there is a wide window of treatment opportunities when using propane torches with the initial treatment period extending from March through June and the follow-up treatment period extending from July through October.

Follow-up treatment schedules were combined in the following analyses because there was no difference between schedules. Except for clumps in the 120-149 cm size class prior to initial treatment, a single follow-up treatment using a propane torch did not increase clump mortality (Figure 3). Two follow-up treatments of directed heating with a propane torch did result in significantly higher mortality. Nearly 80% of clumps that had been smaller than 180 cm had no live ramets in July 2008 after two follow-up treatments with a propane torch.

Both initial size class ($F_{4,160}$=7.738, P<0.001) and the number of follow-up treatments using propane torches ($F_{2,160}$=52.236, P<0.001) had significant effects on clump size in July 2008. Clumps treated twice were at least 55% smaller than clumps without a follow-up treatment for all size classes (Table 4). By comparison, clumps treated only once were not smaller than clumps without follow-up treatment. With a single follow-up treatment using propane torches, more than 60% of barberry clumps that were initially larger than 150 cm had new sprouts in 2008. While this treatment did not kill larger barberry clumps, the treatments were successful in reducing the size of the larger clumps by nearly 50% (Table 4).

Propane torches were effective for controlling American beech without root suckering in Maine (Ostrofsky 2005). Larger diameter stems required longer treatment periods for effective control using a kerosene torch in New Hampshire (Cavanagh and Weyrick 1978). The prescription for the number of follow-up treatments using a propane torch can vary by initial clump sizes. For plots where most barberry clumps were smaller than 150 cm, a single follow-up treatment would result in similar mortality levels to two follow-up treatments and would be less expensive. Two follow-up treatments should be planned in stands where the initial (pretreatment) clump size is larger than 150 cm.

Comparison of Herbicides. Measurements made in July 2008, one year after follow-up treatments, indicated that glyphosate and triclopyr foliar applications were equally effective for all clump sizes (Figure 4). Mortality did not differ among herbicides (χ^2=0.885, d.f.=1, p<0.347) and averaged 91%. Glyphosate did not appear to be as effective as triclopyr at the end of the first growing season, 10% vs. 4% survival, respectively (χ^2=4.473, d.f.=1, p=0.034). However, by mid-July of the second growing season, there was no difference between glyphosate and triclopyr, 7% and 10% survival, respectively (p<0.16). For the clumps treated with triclopyr, 7% (11/168) without a live ramet in September 2007 had at least one new ramet in July 2008. In contrast, for the clumps treated with glyphosate, 41% (7/17) of the clumps with a live ramet in September did not have a live ramet in 2008. Because clump mortality did not differ between herbicides, they were combined in the comparison of directed heating using propane torches and herbicides.

While an earlier study found foliar application of glyphosate provided complete control on 3.0x2.5 m plots (Silander and Klepeis 1999), we found some clumps did survive this treatment (Figure 4). Where complete eradication, and not control, is the desired management goal, the combination of delayed mortality (glyphosate) and new ramets from apparently dead clumps, i.e. ófalse mortalityô (triclopyr) suggests that a second follow-up treatment should be delayed until after leafout the second year. This will ensure that all surviving clumps are treated (triclopyr) and material will not be wasted on clumps that will die during the dormant season (glyphosate). In other words, delaying treatment will decrease application costs when glyphosate is used because those clumps dying during the dormant season will not have to be treated and will increase effectiveness when triclopyr is used because clumps expressing ófalse mortalityô will be treated when they form new ramets the following spring.

Because the herbicides used in this study have been found effective for other co-occuring invasive species, proper herbicide selection will allow control of more than one species while treating an infestation. Glyphosate and triclopyr, but not 2,4-D, cut surface treatment were effective for control of *Rhamnus carthartica* in IL (Pergams and Norton 2006). Triclopyr was effective for *Lonicera maackii* in OH (Cipollini et al. 2009). Glyphosate controlled *Microstegium vimineum* in NC (Judge et al. 2008), *Lonicera morrowii* in PA (Love and Anderson 2008), and *Rosa multiflora* in OH (Loux et al. 2005).

Comparison of follow-up methods.

Repeated measures ANOVA indicated follow-up treatments ($F_{2,167}$=5.575, P=0.004) and the interaction of sample date and follow-up treatment ($F_{4,334}$=41.695, P<0.001) affected resultant clump size. As noted above, there was no interaction between initial and follow-up treatments on clump size or mortality. This was not unexpected because the initial treatment, while removing the live aboveground stems, did not directly kill the latent buds and meristematic tissues in the root crown.

Relative to clumps that did not have a follow-up treatment, both directed heating with propane torches and foliar application of herbicides increased clump mortality (Figure 5) and reduced clump size (Figure 6). Both initial size class ($F_{4,181}$=5.163, P=0.001) and follow-up treatment type ($F_{2,181}$=41.276, P<0.001) had significant effects on clump size in July 2008. The relative effectiveness of directed heating versus herbicide treatments varied by pretreatment clump size. Two follow-up treatments of directed heating using propane torches were as effective as herbicides for clumps that were initially smaller than 120 cm (Table 5).

For clumps with pretreatment sizes of 120 cm and larger , clump mortality following directed heating was greater than for clumps that had no follow-up treatments, and herbicide treatments resulted in higher mortality rates than directed heating (Figure 5). Although mortality of these larger clumps differed between follow-up treatments, clump sizes in July 2008 did not differ between the treatments and both follow-up treatments yielded smaller clumps in July 2008 than for untreated controls (Table 5).

An integrated approach, such as burning followed by herbicide application, can improve herbicide effectiveness (DiTomaso et al. 2006). The technique of an initial treatment to reduce plant size, as in this study, has the additional benefits of reducing both the amount of material applied on a per area basis and damage to non-target species by the inevitable over-spray.

Treatment prescriptions.

In areas where invasive species have become dominant, the first step to re-establishing native vegetation is the reduction or elimination of the invasive species in as minimally intrusive method as possible. Ideally, the treatment would minimize soil exposure and minimize impact to any native plants already on the site. Our study found that effective control of Japanese barberry can be achieved in a single growing season by integrating an early-season initial treatment (prescribed fire or mechanical) that kills the aboveground tissues with a mid-season follow-up treatment such as directed heating or directed spray herbicide application.

The prescription for which combination of initial and follow-up treatment to use will vary by the size of barberry clumps, the goal of the treatment, site and personnel factors, and local regulations. The choice of the initial treatment to reduce clump size by killing aboveground ramets will depend on such factors as the size and extent of the treatment area, the relative height and density of the infestation, and availability of local assets (e.g., personnel qualified for prescribed burning). Where feasible, prescribed burning can quickly treat large areas as the required resources (e.g., personnel, equipment) differ little between burns of 1 ha and 20 ha. For most managers, however, mechanical control will be used for initial treatments.

Both forms of mechanical treatment examined in this study resulted in minimal soil exposure (pers. obs.) and provided similar control (Figure 1). More soil may have been exposed using the rotary wood shredder if the operation had not been conducted when the soil was frozen. Workers become quickly discouraged when using a brushsaw as the initial treatment in barberry infestations taller than waist high because of multiple spine strikes to the face and neck. Productivity of hourly employees or volunteers cutting tall barberry clumps would probably decrease quickly if more than a small patch was being treated. Therefore, we suggest using mechanized equipment to flatten or cut working corridors in taller infestations to provide access and increase worker productivity.

A pretreatment survey of the initial size classes will allow the natural resource manager to determine whether or not a follow-up treatment of directed heating with propane torches will be effective. An infestation with most clumps smaller than 120 cm can be effectively treated with a propane torch with the knowledge that some of the larger clumps will survive and require further treatment (Fig 5). However, effective control of infestations with clumps larger than 150 cm will require several years using propane torches or a single application of herbicide.

Without a follow-up treatment, Japanese barberry quickly recovers from removal of aboveground ramets (Table 3). Therefore, the scale of effective control is limited to the scale of the follow-up treatment that can be implemented. For follow-up treatments in parks, nature preserves, and forests where herbicide use is restricted and where barberry infestations are still light, directed heating with propane torches provides an alternative control technique that mimics the effects of a controlled burn without the logistical constraints.

Directed heating with propane torches and foliar application of herbicides provided similar levels of control for clumps smaller than 120 cm pre-treatment (Figure 4, Table 5). While both glyphosate and triclopyr provided better control of larger clumps than directed heating, the herbicides did not result in complete eradication. Treating the few small clumps that survive the follow-up treatment will remove a source of propagules and spread via layering. Because personnel availability for herbicide application may be limited in jurisdictions that require applicator certification, herbicide application may limit the use of volunteers. We found that the use of a marker dye in herbicide mixture allowed missed clumps to be easily identified, reduced the number of clumps sprayed more than once, and minimized application to non-target vegetation.

When a non-chemical follow-up treatment such as directed heating with a propane torch is selected or required, multiple follow-up treatments will be needed, especially for clumps larger than 150 cm pre-treatment (Figure 3). For plots where most barberry clumps are smaller than 150 cm, a single follow-up treatment will result in mortality levels similar to two treatments and will be less expensive. Therefore, two follow-up treatments should be planned in stands where the average clump size is larger than 150 cm.

Quality control is essential when using a propane torch as per our experience with multiple personnel. Top-killing live stems without simultaneously killing latent basal buds is a waste of time and resources that results in poor control. Directed heat treatments accomplished when leaf litter was damp, or in moderate rains, were both effective and eliminated the risk of a wildfire.

Although not documented, we observed very few new Japanese barberry seedlings in the study areas. Susceptibility of particular tracts to invasion (colonization) by non-native species is dependent on propagules, environmental conditions, and disturbance histories. For many invasive species, there is a ówindow of opportunityô for establishment (DeGasperis and Motzkin 2007). Most Japanese barberry infestations became established in abandoned agricultural fields

(Mosher et al. 2009) and the paucity of barberry in the seedbank under established stands (DôAppollonio 1997) suggests eradication may provide long-term control requiring only periodic spot treatment. The greatly reduced size of barberry clumps following treatment (Table 5) should increase available growing space and reduce competition for the establishment of desirable forest regeneration and native herbaceous vegetation.

Sources of Materials

[1]Rotary wood shredder (Model# BH74FM, Bull Hog®, Fecon Inc., Lebanon, OH)

[2]Track loader (Model# T300, Bobcat®, West Fargo, ND)

[3]Brush saw (Model FS 550, Stihl®, Inc., Virginia Beach, VA)

[4]SYSTAT 10 (SPSS, Inc., Chicago, IL)

[5]Propane torch (BP 223 SVC Weed Dragon, Flame Engineering Inc., LaCrosse, KS)

[6]Backpack sprayer (Solo® Model LCS-2, Newport News, VA)

[7]Glyphosate (Glyphomax Plus, Dow AgroSciences, Indianapolis, IN)

[8]Triclopy (Garlon 3A, Dow AgroSciences, Indianapolis, IN)

Acknowledgments

We would like to thank Aquarion Water Company, Connecticut Chapter ï The Nature Conservancy, South Central Connecticut Regional Water Authority, and Weed-It-Now Program ï The Nature Conservancy for financial and technical assistance as well as study sites. Connecticut Department of Environmental Protection-Division of Forestry and Lord Creek Farm provided additional study sites and personnel assistance. J.P. Barsky, M.R. Short, R.M. Cecarelli, R.J. Hannan, Jr., C. Ariori, K. Drennan, E. Kiesewetter, F. Pacyna, G. Picard, D. Tompkins, and R. Wilcox assisted with plot establishment, treatments, and data collection.

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Interpretive Summary

Japanese barberry is an invasive shrub in the Midwest and Northeast United States and in southeastern Canada that forms dense thickets which can inhibit forest regeneration and native herbaceous plant populations, and is associated with enhanced populations of blacklegged ticks that can transmit the causal agent of Lyme disease. We evaluated a two-stage process that can largely eliminate Japanese barberry in a single growing season. The initial treatment (prescribed fire or mechanical mowing) kills the aboveground stems before or immediately after leaf-out. A follow-up treatment (directed heating with a propane torch or targeted herbicide application) in mid-summer kills the small sprouts that develop from the root crown. Because the treated clumps are half the size of the original clumps, or less, impact to the existing native vegetation is minimized. Japanese barberry quickly recovers from the initial treatment in the absence of a follow-up treatment; therefore, the scale of effective control is limited to the scale of the follow-up treatment that can be implemented in a given year. For follow-up treatments in parks, nature preserves, and area where herbicide use is restricted, directed heating with propane torches provides an alternative control technique. However, directed heating with propane torches is only as effective as foliar application of herbicides for clumps smaller than 120 cm. For both follow-up treatment options, some clumps will survive and eradication will require additional treatments the following summer.

Table 1. Distribution of Japanese barberry clumps among initial and follow-up treatments by size class (cm) prior to treatments.

Follow-up treatment	Size class (cm)	Initial treatment Brushsaw	Shredder	Fire	Combined
None	<90	21	15	4	40
	90-119	21	21	9	51
	120-149	25	43	26	94
	150-179	18	30	22	70
	>180	15	16	14	45
	None subtotal	100	125	75	300
Directed heating	<90	12	22	5	39
	90-119	24	27	17	68
	120-149	38	60	38	136
	150-179	38	49	43	130
	>180	13	42	22	77
	Torch subtotal	125	200	125	450
Herbicide	<90	7	11	4	22
	90-119	27	30	17	74
	120-149	47	65	21	133
	150-179	33	32	8	73
	>180	36	12	-	48
	Herb subtotal	150	150	50	350
Combined		375	475	250	1100

Table 2. Mean (standard error) initial sizes of Japanese barberry clumps by pretreatment size class. Count-number of live ramets per clump, Diam-diameter (mm) of largest ramet, N-number of clumps.

Size class (cm)	-----Crown size (cm)----- Height	Width	Basal width (cm)	----------Ramets---------- Count	Diam	N
<90	80.3 (2.5)a	68.7 (2.4)a	8.7 (0.5)a	8.7 (0.7)a	6.1 (0.2)a	101
90-119	106.8 (1.4)b	106.7 (1.5)b	11.4 (0.4)b	13.2 (0.6)b	7.9 (0.1)b	193
120-149	126.8 (0.9)c	143.1 (1.0)c	15.5 (0.4)c	19.3 (0.5)c	9.6 (0.2)c	363
150-179	152.3 (1.0)d	174.2 (1.1)d	18.3 (0.5)d	22.8 (0.7)d	11.7 (0.2)d	273
≥ 180	187.6 (1.9)e	216.2 (2.4)e	23.9 (0.8)e	29.3 (1.0)e	15.2 (0.4)e	170

[a]Column values followed by the same letter were not significantly different at $P \leq 0.05$.

Table. 3. Mean (standard error) clump size in 2007 and 2008 by pretreatment clump size for clumps that had no follow-up treatment.

Pretreatment	September 2007[a]			July 2008		
clump size (cm)	Mean (SEM)		N	Mean (SEM)		N
< 90	53.9 (5.9)	a	27	76.7 (8.0)	a	20
90-119	61.4 (4.6)	ab	43	81.6 (6.4)	a	31
120-149	68.8 (3.3)	ab	78	84.8 (4.5)	a	57
150-179	73.6 (3.8)	b	60	89.4 (4.9)	ab	47
≥ 180	92.1 (4.6)	c	43	106.6 (5.7)	b	39

[a]Column values followed by the same letter were not significantly different at P ≤ 0.05.

Table 4. Mean (standard error) clump size July 2008 by pretreatment clump size and number of direct heating treatments with propane torches.

Pretreatment	No follow-up[a]			One follow-up			Two follow-up		
clump size (cm)	Mean (SEM)		N	Mean (SEM)		N	Mean (SEM)		N
<90	75.0 (11.6)	a	8	-		1	32.4 (18.8)	a	3
90-119	80.5 (10.2)	a	11	84.0 (29.6)	a	2	19.9 (15.7)	b	6
120-149	90.7 (6.5)	a	24	64.9 (14.1)	ab	5	40.0 (7.9)	b	16
150-179	94.3 (6.6)	a	20	53.2 (9.8)	b	10	46.1 (7.9)	b	14
>=180	122.5 (6.4)	a	23	103.8 (9.8)	a	10	47.3 (8.2)	b	14

[a]Row values followed by the same letter were not significantly different at P ≤ 0.05.

Table. 5. Mean (standard error) clump size (cm) July 2008 among follow-up treatments for initial clump size classes.

Pretreatment	No follow-up[a]			Directed heating			Herbicide		
clump size (cm)	Mean (SEM)		N	Mean (SEM)		N	Mean (SEM)		N
<90	63.6 (8.2)	a	12			1	27.8 (11.8)	a	2
90-119	71.7 (6.8)	a	20	19.2 (6.2)	b	5	58.6 (16.2)	ab	4
120-149	80.2 (5.0)	a	33	34.6 (5.2)	b	11	52.4 (7.6)	b	9
150-179	91.0 (7.1)	a	27	46.5 (3.8)	b	19	51.4 (5.3)	b	7
≥ 180	101.9 (8.3)	a	16	61.6 (6.3)	b	16	55.5 (7.1)	b	9

[a]Row values followed by the same letter were not significantly different at P ≤ 0.05.

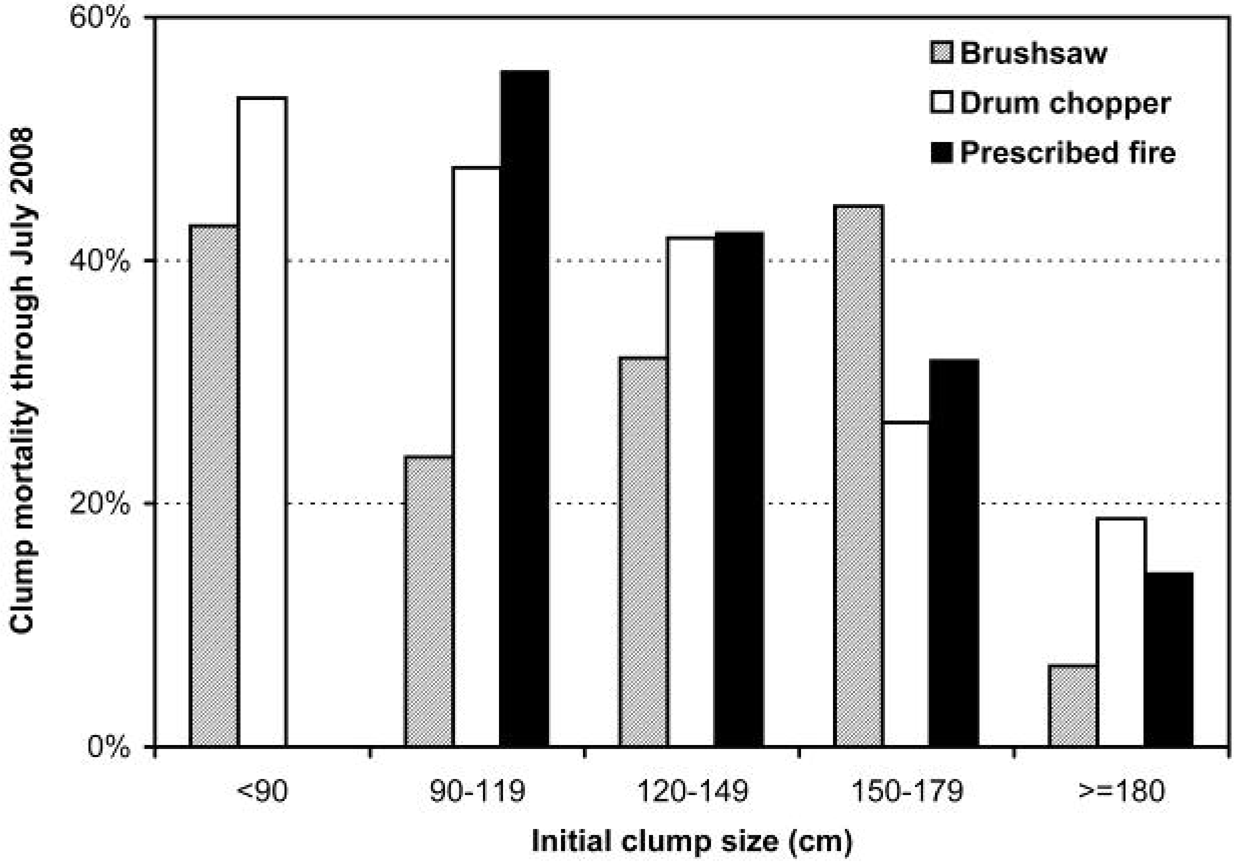

Figure 1. Mortality of clumps that had no follow-up treatment by pre-treatment clump size class and initial treatment.

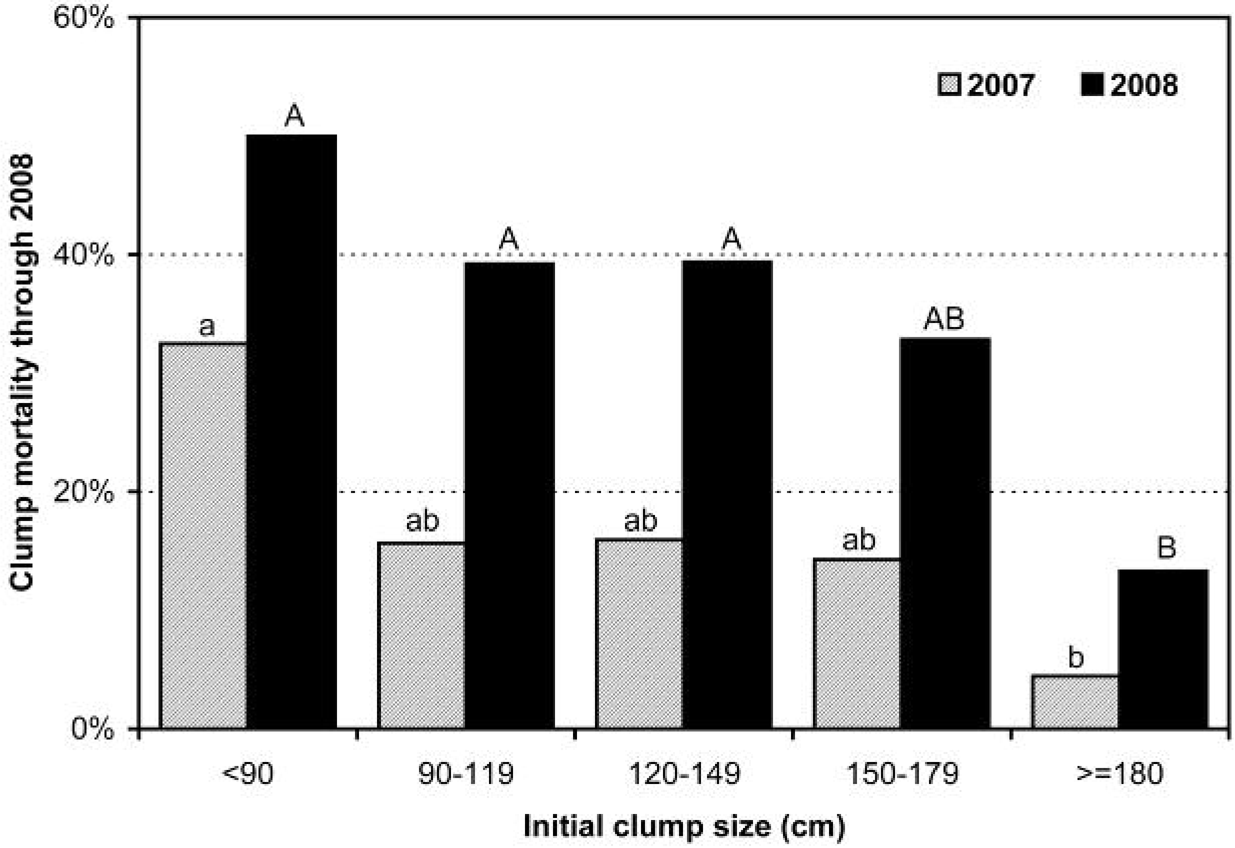

Figure 2. Mortality of clumps that had no follow-up treatment by initial clump size at end of the first growing season (2007) and second growing season (2008). For a given year, clump sizes with the same letter were not significantly different at $P \leq 0.05$.

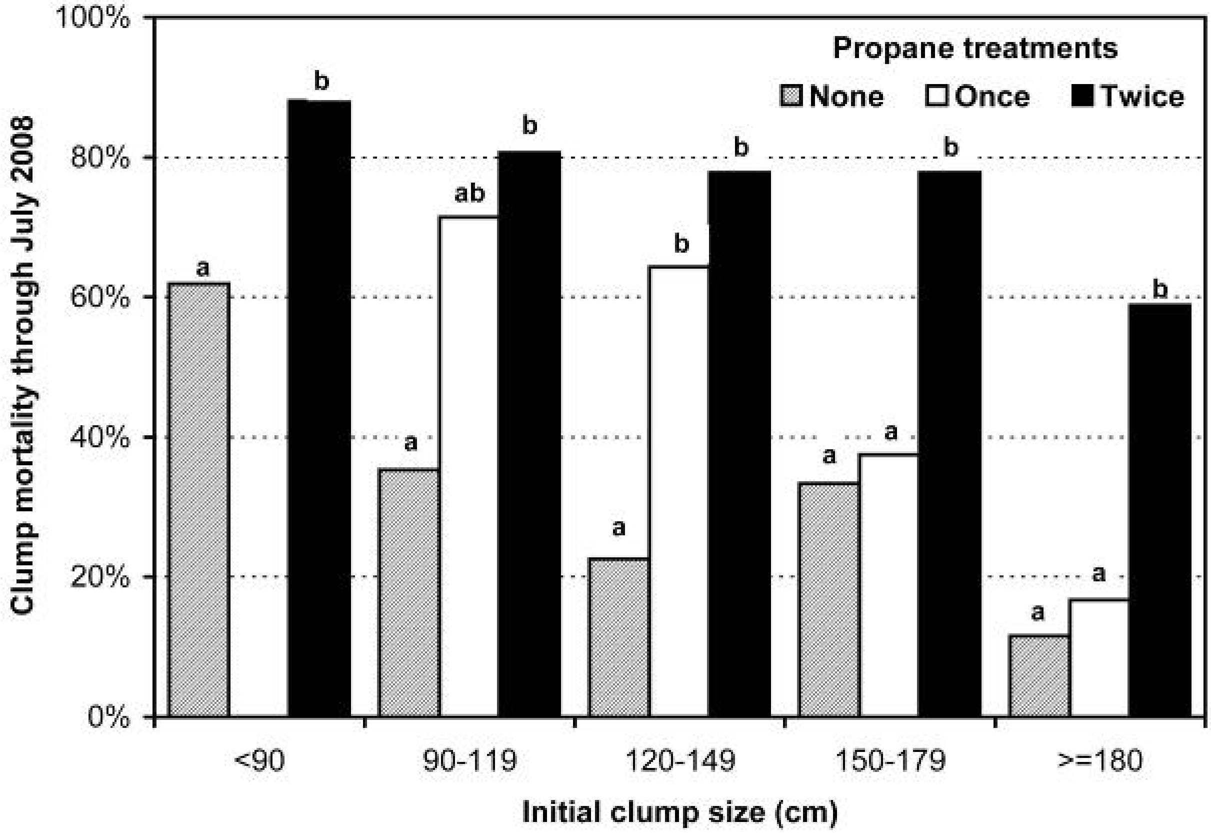

Figure 3. Clump mortality through July 2008 by initial clump size and number of follow-up direct heating treatments with propane torches. For a given size class, the number of treatments with the same letter were not significantly different at $P \leq 0.05$. Only treatment/size class combinations with at least five clumps are shown.

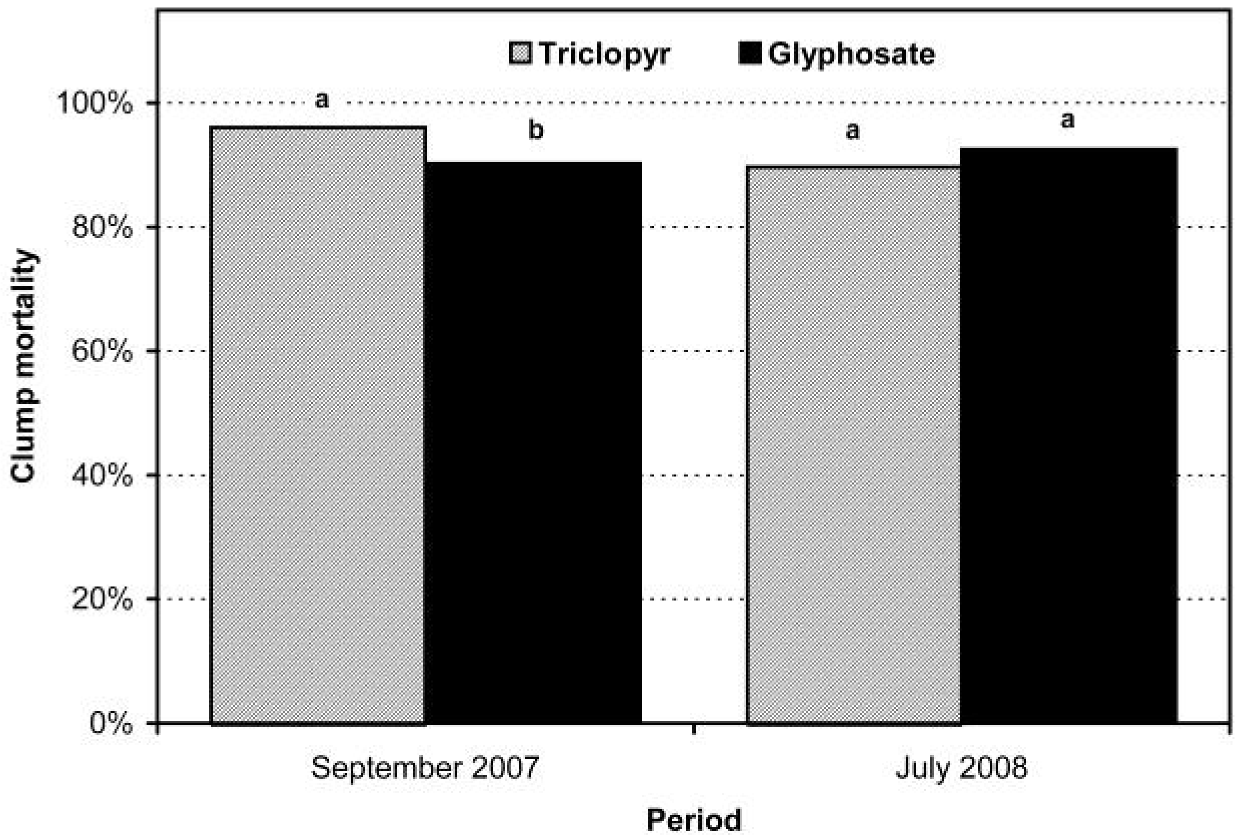

Figure 4. Mortality of clumps at end of the first growing season (2007) and second growing season (2008) by herbicide treatment. Treatments with the same letter for a given year were not significantly different at $P \leq 0.05$.

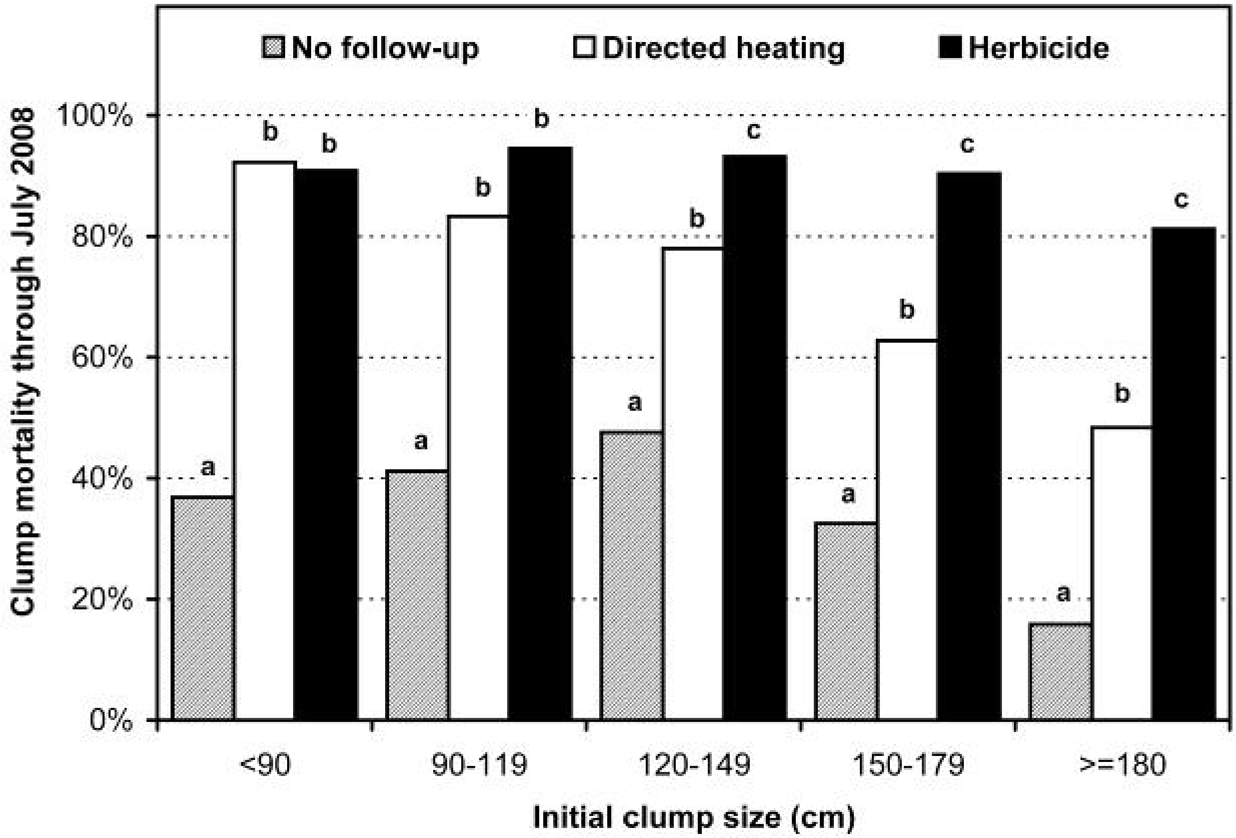

Figure 5. Clump mortality through July 2008 by initial clump size and follow-up treatment type. Treatments with the same letter for a given clump size were not significantly different at $P \leq 0.05$.

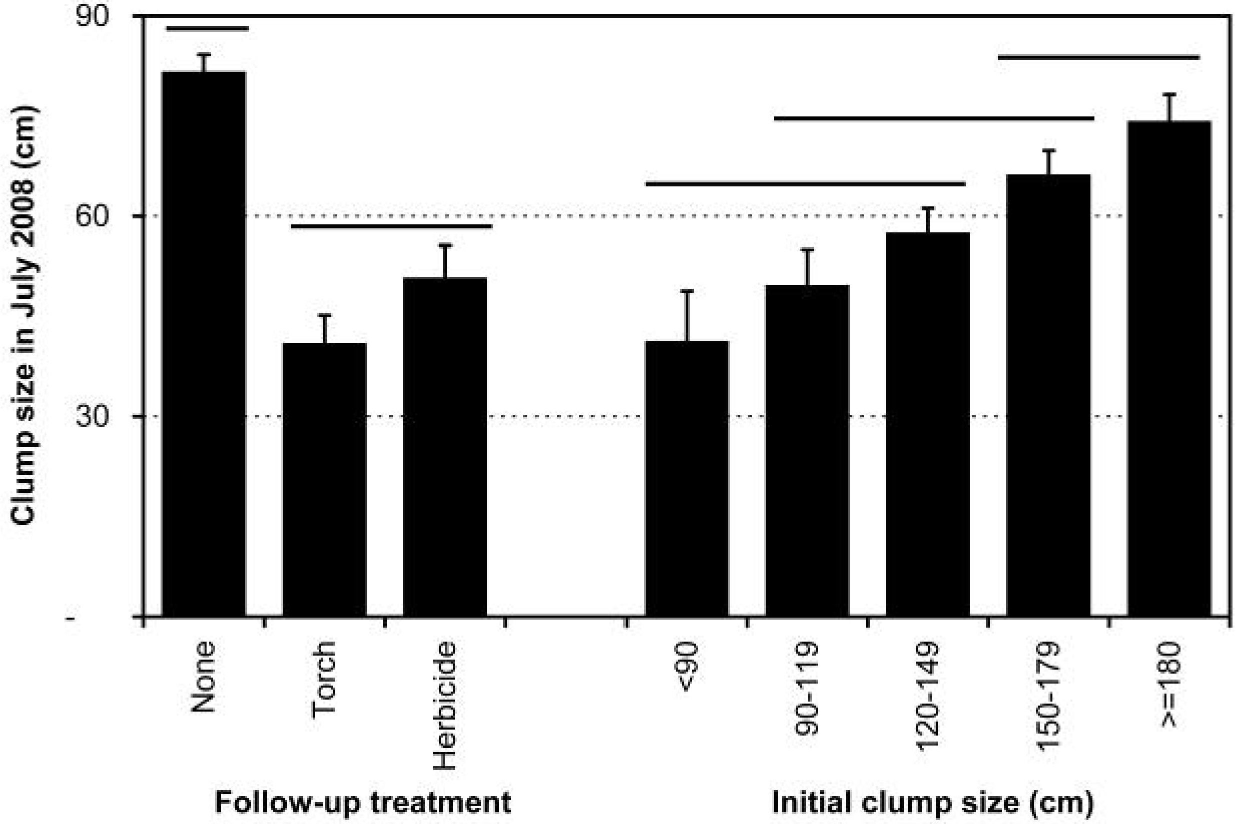

Figure 6. Clump size through July 2008 by follow-up treatment and initial clump size. Treatments/initial size classes linked by horizontal lines above bars were not found significantly different using Tukeyős HSD test at $P \leq 0.05$.