

# Amur Honeysuckle (*Lonicera maackii*) Management Method Impacts Restoration of Understory Plants in the Presence of White-Tailed Deer (*Odocoileus virginiana*)

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Management methods for invasive species vary in their restoration success in the presence or absence of herbivores. We investigated the performance of understory plants after management of the invasive shrub Amur honeysuckle using two herbicide-based methods (cut/paint and basal application) in fenced and unfenced plots. The cut/paint method resulted in the removal of above-ground stems, while the basal application method resulted in the dead stems remaining in place. Light level in the cut/paint treatment was higher than in the basal application treatment, which was higher than in the control (no management) treatment. Across fencing treatments, fruit production, height, and subsequent recruitment of transplanted jewelweed were greater in the cut/paint treatment. Across management treatments, jewelweed plants were taller in the fenced treatment. Native species richness was generally higher in the cut/paint and basal application treatments than in the control treatment. There were more jewelweed recruits, more jewelweed fruits, and greater native species richness in the cut/paint treatment than in the basal application treatment in fenced plots, but these measures were similar in both management treatments in unfenced plots. Thus standing dead stems of Amur honeysuckle offered protection from damage in the presence of herbivores, offsetting the advantage of the cut/paint method seen in the fenced plots. There was a trend for more leaves of transplanted wild ginger in the basal application treatment. There were more invasive garlic mustard and more Amur honeysuckle seedlings in the cut/paint treatment than in the control treatment. Our results illustrate the complexities involved in selecting appropriate restoration management techniques given herbivore pressure, differential species response, and presence of multiple invasive species. In our study, we demonstrated that the basal application honeysuckle management method (and therefore perhaps similar methods that leave the dead stems standing) led to increased understory plant restoration success when compared to the cut/paint method.

**Nomenclature:** triclopyr; garlic mustard, *Alliaria petiolata* (Bieb.) Cavara & Grande; honeysuckle, *Lonicera maackii* (Rupr.) Maxim.; jewelweed, *Impatiens capensis* Meerb.; wild ginger, *Asarum canadense* L.; white-tailed deer, *Odocoileus virginiana* Zimmermann.

**Key words:** Forest restoration, herbivore, herbivory, touch-me-not.

Invasive plants can have major impacts on native plant populations, communities, and ecosystems around the world (Pimentel et al. 2005; Sakai et al. 2001). Once an invasive plant has become established in an ecosystem, restoration practitioners frequently seek to reduce popula-

tions of the invasive species through a variety of methods, from mechanical to chemical (e.g., Carlson and Gorchoff 2004; Hartman and McCarthy 2004; Krueger-Mangold et al. 2006; Milligan et al. 2004). Another threat to native ecosystems and their successful restoration is browsing or other forms of damage by herbivores. Sweeney and Czapka (2004) suggest that protecting seedlings from herbivory should be given higher priority than protection from competition during restoration. In Midwestern and eastern forests in the United States, a primary herbivore threatening understory plants is the white-tailed deer, *Odocoileus virginiana* Zimmermann, which is considered a keystone herbivore due to its direct and indirect effects on

DOI: 10.1614/ IPSM-08-108.1

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## Interpretive Summary

Management methods for invasive species may vary in their restoration success in the presence or absence of herbivores. We managed Amur honeysuckle using two herbicide-based methods, the cut/paint method, and the basal application method. For the cut/paint method, we cut and removed the stems, then painted the cut stump with herbicide. For the basal application method, we applied herbicide to the stems and the stems were left in place after death. We compared the success of these two methods in the presence of deer by using fencing to exclude deer from half of the plots. Light level in the cut/paint method was 8 times higher than in the basal application treatment and 24 times higher than in the control (no management). We transplanted two native species, jewelweed and wild ginger into each plot. Fruit production, height, and subsequent jewelweed recruitment was greatest using the cut/paint method. Jewelweed plants were taller when fenced. We also measured native species richness for each treatment combination. Native species richness was generally higher compared to the control when Amur honeysuckle was managed. There were more jewelweed recruits, more jewelweed fruits, and greater species richness in the cut/paint treatment than in the basal application treatment in fenced plots, but measures were more similar for both management methods in unfenced plots. Thus standing dead stems of Amur honeysuckle offered some protection from damage from herbivores, offsetting the advantage of the cut/paint method seen in the fenced plots. The cut/paint method also enhanced success of Amur honeysuckle seedlings and of garlic mustard. Therefore, the basal application treatment or similar method that leaves the dead stems standing is recommended as the most effective treatment for understory plant restoration success due to its protection from deer and the lowered success of invasive species.

both plants and animals (Cote et al. 2004; Rooney 2001; Rooney and Waller 2003). Forest areas where deer had been excluded had lower numbers of invasive species (Webster et al. 2005), thus implicating deer in the success of invasive plants.

Amur honeysuckle [*Lonicera maackii* (Rupr.) Maxim.] is an Asian shrub that is invasive in Midwestern and northeastern U. S. forests (Luken and Thieret 1995; USDA/NRCS 2007). Amur honeysuckle has extended leaf phenology (Trisel 1997) and bird-dispersed fruit (Bartuszevige and Gorchoff 2006), factors that can contribute to its invasive success. Deer may also disperse seeds of Amur honeysuckle, similar to three other bush honeysuckle species (Vellend 2002). Amur honeysuckle is associated with decreased native plant species richness (Collier et al. 2002), and negatively affects the performance of a wide range of both understory and overstory plants (Gorchoff and Trisel 2003; Gould and Gorchoff 2000; Hartman and McCarthy 2007; Miller and Gorchoff 2004). Effects of Amur honeysuckle on other plants can be mediated directly through such factors as shading and allelopathy (e.g., Cipollini et al. 2008a; Gorchoff and Trisel 2003) but it may also have indirect effects (Meiners 2007). The impact of Amur honeysuckle is not limited to plant communities;

its presence also affects birds and herptiles (McEvoy and Durtsche 2004; Schmidt and Whelan 1999).

Control of Amur honeysuckle is a major focus of natural resource agencies and conservation organizations within its invaded range. Because of these efforts, much information has been gained on how to effectively eradicate Amur honeysuckle in natural environments (Conover and Geiger 1993; Gorchoff 2005; Hartman and McCarthy 2004; Nyboer 1992). Management techniques include the cut-and-paint or cut/paint method, where Amur honeysuckle is cut at the base and removed; herbicide is subsequently applied to the cut stump (McDonnell et al. 2005). Three other herbicide-based methods, the basal application method, the foliar spray method, and the injection method (Rathfon and Ruble 2007; Conover and Geiger 1993; Hartman and McCarthy 2004, respectively), result in the killing of Amur honeysuckle with the dead stems left standing in place.

Standing dead stems of Amur honeysuckle could affect restoration success in a number of ways. Standing stems may continue to shade the understory, which may delay the development of plant communities for as long as stems remain standing. Amur honeysuckle produces allelopathic compounds in its tissues (Cipollini et al. 2008a, 2008c; Dorning and Cipollini 2006; Trisel 1997) and thus standing dead stems could continue to contribute allelochemicals to the understory until they decompose completely. In contrast, the presence of standing dead stems may have some positive effects, analogous to the protection from herbivory offered by so-called "nurse plants" (Bakker et al. 2004; Garcia and Obeso 2003). There is some evidence that standing dead stems of Amur honeysuckle may provide protection of transplanted plants from herbivore browsing (Gorchoff and Trisel 2003), but this effect has not been quantified adequately. Hartman and McCarthy (2004) followed survival of transplanted tree seedlings after different methods of Amur honeysuckle management, but deer impact was insufficient to examine for protective effects. The response of the understory plant community to the presence of standing dead stems has not been examined.

Another challenge to forest restoration is the response of invasive plants to restoration efforts (Loh and Daehler 2007). Although poorly replicated, McConnell et al. (2005) found an increase in species richness after management of Amur honeysuckle using the cut/paint method, but Amur honeysuckle seedlings and other invasive species also increased in abundance in the cut/paint treatment. Runkle et al. (2007) also found an increase in species richness 8 yr after removal of Amur honeysuckle; however, this increase was primarily the result in the increase of species with high dispersal ability, such as vines and other weedy species. Luken et al. (1997) found the vine *Vitis vulpina* L. responded positively to Amur honeysuckle

management. No comparisons of the effects of honeysuckle management method on invasive plant responses have been published, but the presence of standing dead stems may slow the response of invasive plants.

The objectives of this study were to determine the effect of the presence or absence of standing dead Amur honeysuckle, the presence or absence of deer, and their interaction on understory plants. We followed the success of transplanted jewelweed (*Impatiens capensis* Meerb.), and transplanted wild ginger (*Asarum canadense* L.) in basal application and cut/paint management treatments. We also followed the plant community (both native and invasive species) in basal application, cut/paint, and control treatments. We predicted that in the absence of deer, the cut/paint management method would best benefit native plant performance, owing to the increase in light and the removal of potentially allelopathic plant material. We predicted that in the presence of deer, the basal application method, which leaves the dead stems standing, would best benefit native plant performance because of the protection conferred by the stems against deer damage.

### Materials and Methods

**Experimental Design.** We established experimental plots during the first week of April in 2005 in Hamilton County Park District's Sharon Woods, located in Sharonville, OH, United States (39°16'40"N, 84°23'56"W). We chose two sites impacted by Amur honeysuckle approximately 0.75 km (0.47 mi) apart from each other. Each site is located in mixed oak-maple-ash forest community with a relatively large amount of Amur honeysuckle, yet still contained some degree of native understory vegetation. Deer density at Sharon Woods was approximately eight deer/km<sup>2</sup> (20 deer/sq mi), which is the management goal at this site (J. Klein, personal communication). Within each site, we selected 3 subsites, with paired 8- by 6-m (26.3- by 19.7-ft) experimental plots at each subsite, for a total of 12 paired plots. Within each subsite, we used a split-split plot experimental design, with the split plot factor of deer exclusion and the split-split plot factor of Amur honeysuckle management method (see Figure 1). We fenced one plot of each pair at each subsite, placing metal fence posts into the ground and attaching plastic deer fencing (1.8 m tall with 5-cm mesh) to the posts. Within each paired plot (fenced and unfenced), we created eight 2- by 3-m subplots. For three of the adjacent subplots, we managed Amur honeysuckle using the cut/paint method, i.e., cutting off the Amur honeysuckle with a handsaw approximately 10 cm from the soil surface, removing the Amur honeysuckle, and painting the stump with the herbicide triclopyr<sup>1</sup> to prevent resprouting. For three of the adjacent subplots, we managed Amur honeysuckle using the basal application method, i.e., applying triclopyr in a

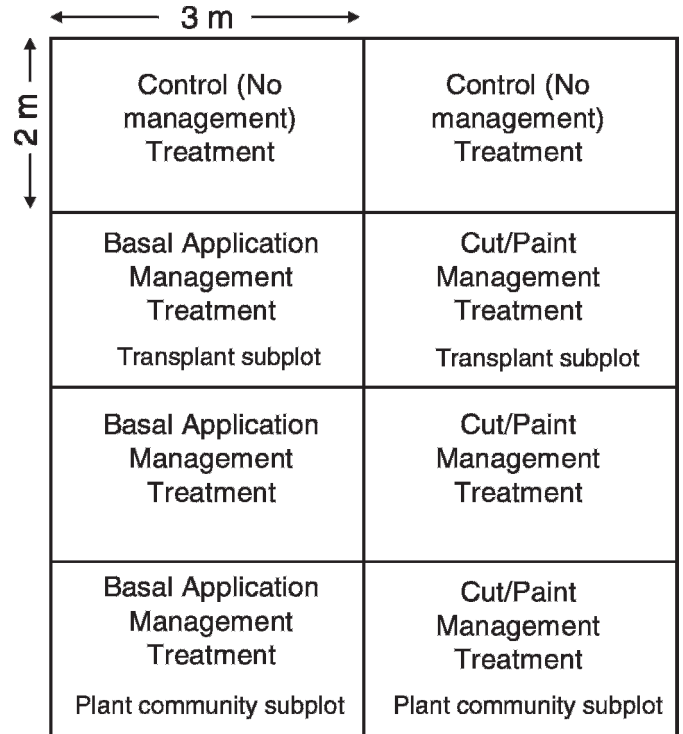


Figure 1. Diagram of experimental set-up of one paired plot. Fenced plots were fenced along the entire 8- by 6-m perimeter of the plot.

band around the entire circumference of the base of each stem. On subsequent visits, we treated the minimal amount of living or sprouting Amur honeysuckle with the same management method as the rest of the subplot. We did not remove any Amur honeysuckle in the remaining two adjacent subplots and these served as our controls. For two of the three management method subplots (i.e., basal application and cut/paint), one subplot was designated as the "transplant subplot" and one was designated as the "plant community subplot" for further treatment and measurements. No further measurements were made on the third management method subplot.

**Study Species and Measurements.** On May 5, 2005, we transplanted four two-leaved rhizomes of wild ginger and six seedlings of jewelweed into our "transplant subplots." Transplants were collected locally. Wild ginger is a shade-tolerant rhizomatous perennial that typically expands into a large clump through asexual reproduction. Wild ginger has been shown to be impacted by Amur honeysuckle (Dorning 2004), and appears to be largely resistant to deer browsing (D. Cipollini, unpublished data). Plants were collected by first excavating rhizomes, which were often several internodes in length with a pair of leaves at each node. Single transplants, each containing one leaf pair, were then created by clipping the rhizome several

centimeters on each side of a node. Jewelweed is an annual herb that is found in a range of light conditions, from forest clearings to closed woodlands (von Wettberg and Schmidt 2005) and reproduces exclusively by seed. Jewelweed is sensitive to deer browsing (Asnani et al. 2006; Williams et al. 2000). Seedlings were transplanted from local populations when they were approximately 5 to 10 cm tall. Transplants were not placed in the control treatment, since we expected survival to be low (see Cipollini et al. 2008b). In 2005, we measured survival and fruit number of transplanted jewelweed on June 2 and June 30, and both height and fruit number on July 21. We measured survival and leaf number of each clump of wild ginger on April 25, 2006 and May 4, 2007. On May 4, 2007, we measured the width of the largest leaf in each clump of wild ginger.

In a 1-m<sup>2</sup> area of each of the transplant subplots (where jewelweed and wild ginger had been transplanted in 2005), we counted the number of seedlings of jewelweed on April 26, 2006 and on April 24, 2007. We were confident that most, if not all, of the seedlings of jewelweed were from fruits of plants that we had transplanted the previous year as there were no other jewelweed plants in the plots except for the ones we transplanted. On April 26, 2006 and April 24, 2007, in one haphazardly chosen control subplot and in both plant community subplots, we counted the number of plants of each vascular plant species in a 1-m<sup>2</sup> area of the subplot; native species richness and number of invasive species were then determined. In all the subplots, we measured light levels<sup>2</sup> at 1 m height on July 6, 2006, which was a bright and mostly cloudless day. All light measurements were made within 65 min of each other.

**Statistical Analyses.** For all analyses, we used a nested split-split plot Analysis of Variance (ANOVA) or Multivariate ANOVA (MANOVA) with site as a fixed factor, subsite as the main plot factor (nested within site), fencing as the split plot factor, and management method as the split-split plot factor (SAS 1999). For MANOVAs, when significance was found using Wilk's  $\lambda$ , separate univariate ANOVAs were performed on each separate date, followed by Tukey's test to determine significance between treatment levels. We analyzed jewelweed fruit production of each plant in 2005, number of jewelweed seedlings per plot in 2006 to 2007, and number of wild ginger leaves of each plant using separate MANOVAs, with each date as a separate variable in the model (von Ende 1993). We analyzed height of each jewelweed, jewelweed survival per subplot, maximum leaf width of each wild ginger, and wild ginger survival per subplot separately using ANOVA. We analyzed native species richness per subplot and number of invasive garlic mustard (*Alliaria petiolata* (Bieb.) Cavara & Grande) per subplot using separate MANOVAs, using each date as a separate variable in the model. We analyzed

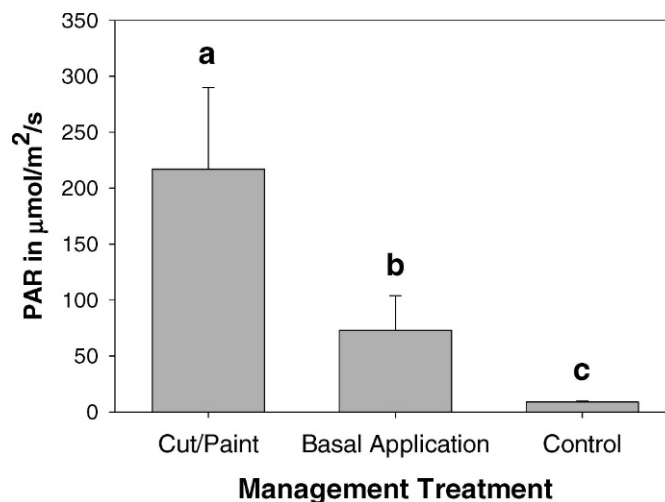


Figure 2. Mean ( $\pm$  standard error [SE]) light levels in treatments where Amur honeysuckle was not removed (control) and where Amur honeysuckle was removed using either the cut/paint method or the basal application method. Management treatments with different letters are significantly different from each other based on Tukey's test at  $P < 0.05$ .

number of Amur honeysuckle seedlings per subplot in spring 2007 using ANOVA. Data were transformed as necessary to meet model assumptions. For light levels, data could not be transformed to meet model assumptions of normality, and a Kruskal-Wallis Rank Sum test was used. The  $\alpha$ -level used for all tests was 0.05.

## Results and Discussion

Management of Amur honeysuckle increased the light reaching the forest floor. Light levels in the cut/paint treatment were significantly higher than the light levels in the basal application treatment, which were in turn significantly higher than the light levels in the control treatment ( $F_{2,76} = 47.10$ ,  $P < 0.001$ ; Figure 2). Management of Amur honeysuckle and leaving the dead stems in place increased light levels over eight times of the light levels in the control. In comparison, the cut/paint treatment increased light levels over 24 times of the light levels in the control. A smaller ( $\sim 10$  times) increase in light after Amur honeysuckle removal was reported in previous work (Luken et al. 1997).

Jewelweed plants were taller in the cut/paint treatment than in the basal application treatment on July 21 ( $F_{1,55} = 21.53$ ,  $P < 0.0001$ ; Figure 3). In the field, height and reproduction of jewelweed were related (Cipollini et al. 2008b). In the MANOVA for transplanted jewelweed fruit production across three dates, there was a significant effect of management treatment ( $F_{3,42} = 4.19$ ,  $P = 0.0111$ ). On June 30, there were significantly more fruits on plants in the cut/paint treatment than on plants in the basal

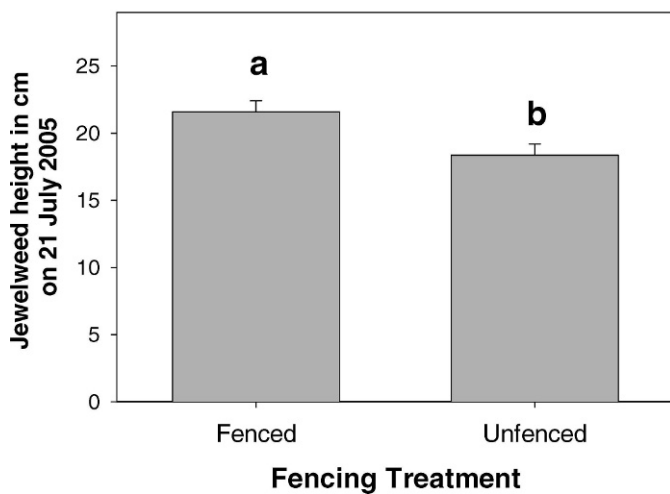
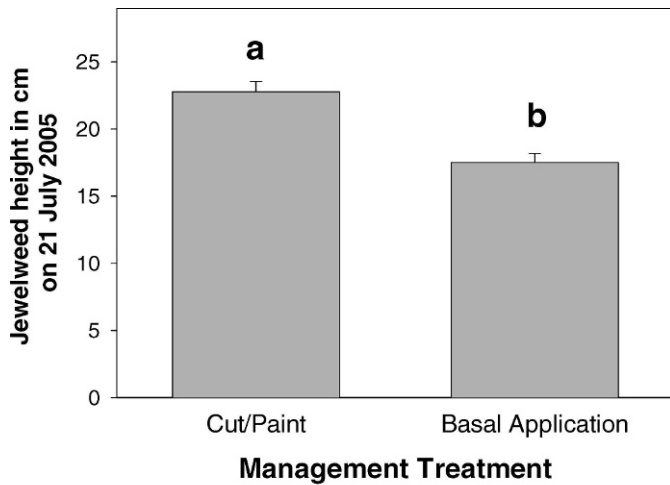


Figure 3. Mean ( $\pm$  standard error [SE]) height of transplanted jewelweed on July 21, 2005 in treatments with Amur honeysuckle removed using either the cut/paint method or the basal application method (top) and in fenced and unfenced treatments (bottom). Letters indicate significant differences between treatments using Tukey's test at  $P < 0.05$ .

application treatment ( $F_{1,44} = 11.77$ ,  $P = 0.0013$ ; Figure 4). In the MANOVA for the number of jewelweed seedlings across 2 yr, there was a significant effect of management method ( $F_{2,9} = 4.86$ ,  $P = 0.0370$ ; Figure 5). In both years, there were more jewelweed seedlings in the cut/paint treatment than in the basal application treatment across fencing treatments ( $F_{1,10} = 4.97$ ,  $P = 0.0499$  and  $F_{1,10} = 10.58$ ,  $P = 0.0087$ , respectively). In the MANOVA across 2 yr, native species richness was significantly affected by management method ( $F_{4,38} = 3.70$ ,  $P = 0.0122$ ; Figure 6). The effect of management method on native species richness approached significance in 2006 ( $F_{2,20} = 3.11$ ,  $P = 0.0667$ ) and was significant in 2007 ( $F_{2,20} = 7.62$ ,  $P = 0.0035$ ), with greater richness in

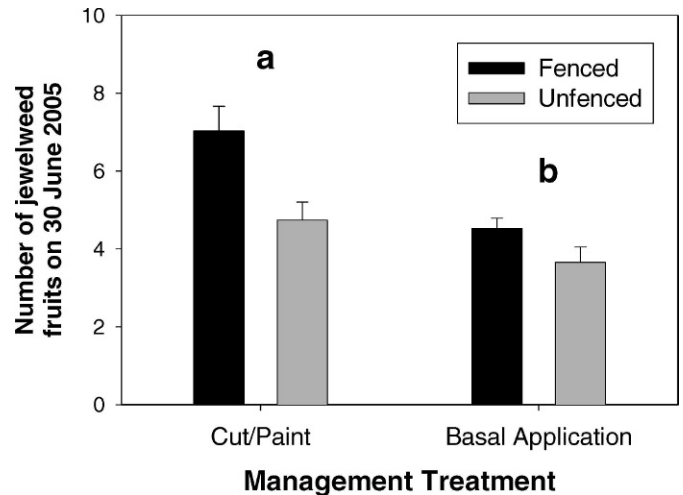


Figure 4. Mean ( $\pm$  standard error [SE]) number of fruits on transplanted jewelweed fruits on June 30, 2005 in fenced and unfenced treatments, with Amur honeysuckle removed using either the cut/paint method or the basal application method. Letters indicate significant differences between management treatments using Tukey's test at  $P < 0.05$ . The effect of the interaction between fencing and management treatments on fruit number was significant ( $P = 0.0034$ ).

the cut/paint and basal application treatment compared to the control treatment. There were no significant treatment effects on survival of jewelweed in the ANOVA.

Previous studies have found that Amur honeysuckle exerts strong aboveground effects on native species (Cipollini et al. 2008b; Gorchov and Trisel 2003; Miller and Gorchov 2004). The positive effects of the cut/paint method on native species richness, jewelweed fruit production, jewelweed height, and jewelweed recruitment is likely due to the increased light intensity. However, alleviation of allelopathy by removal of Amur honeysuckle stems may have contributed to the beneficial effects of this treatment (Cipollini et al. 2008c; Dorning and Cipollini 2006; Trisel 1997). Regardless of mechanism, native plants benefited from management of Amur honeysuckle, with a trend for greater success using the cut/paint method.

Amur honeysuckle management also affected invasive species. There was a significant effect of management method on number of garlic mustard in the MANOVA ( $F_{4,38} = 3.34$ ,  $P = 0.0194$ ). In both years, there were significantly more garlic mustard in the cut/paint treatment than in the control treatment, with the number of garlic mustard in the basal application treatment intermediate between the two ( $F_{2,20} = 4.29$ ,  $P = 0.0282$ ;  $F_{2,20} = 4.99$ ,  $P = 0.0174$ , respectively; Figure 7). The effects of management method on Amur honeysuckle seedlings in 2007 were significant ( $F_{2,20} = 4.11$ ,  $P = 0.0319$ ) and similar to the effects seen for garlic mustard (Figure 8). Luken et al. (1997) found that garlic mustard was one of

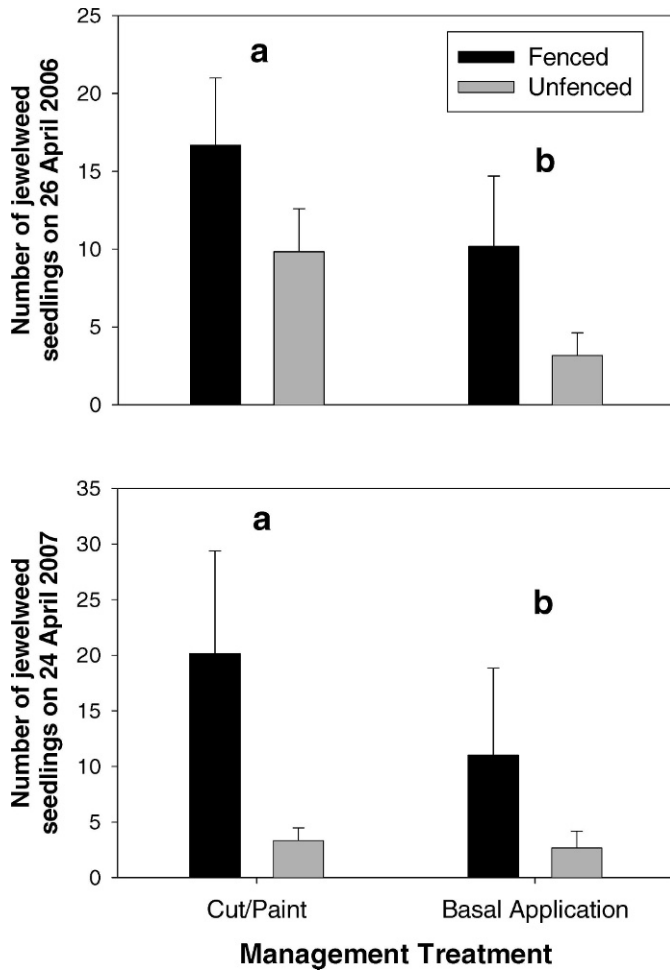


Figure 5. Mean ( $\pm$  standard error [SE]) number of seedlings of jewelweed in 2006 and 2007 in fenced and unfenced treatments, with Amur honeysuckle removed using either the cut/paint method or the basal application method. Letters indicate significant differences between management treatments using Tukey's test at  $P < 0.05$ . The effect of the interaction between fencing and management treatments on fruit number was significant in 2007 ( $P = 0.0184$ ).

the most important species in Amur honeysuckle thickets, yet it did not respond positively to gap formation. Runkle et al. (2007) found a slight but significant increase in garlic mustard on one sampling date after Amur honeysuckle management. In comparison, we found strong responses of garlic mustard to Amur honeysuckle management, as there were seven times more garlic mustard plants in cut/paint treatments than in control treatments in the second year after Amur honeysuckle management. We also found increases in Amur honeysuckle seedlings with management of Amur honeysuckle, similar to the results of McConnell et al. (2005). Therefore, the benefits of using the cut/paint method are diminished when considering its effects on invasive species.

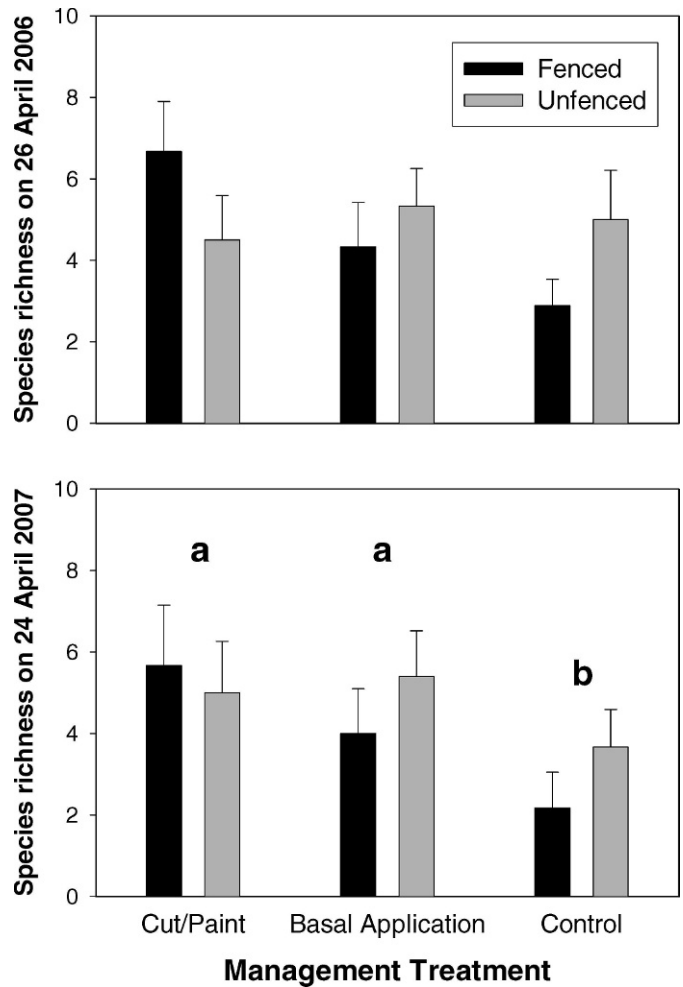


Figure 6. Mean ( $\pm$  standard error [SE]) native species richness in 2006 and 2007 in fenced and unfenced treatments, with Amur honeysuckle not removed (control) and with Amur honeysuckle removed using either the cut/paint method or the basal application method. The effect of management treatment on species richness was approaching significance in 2006 ( $P = 0.0667$ ). Letters indicate significant differences between management treatments using Tukey's test at  $P < 0.05$ . The effect of the interaction between fencing and management treatments on richness was significant in 2007 ( $P = 0.0116$ ).

Light conditions, invasive species, and allelopathy are not the only considerations during restoration, as deer can greatly impact restoration success (e.g., Ruhren and Handel 2003; Sweeney and Czapka 2004). Deer damage observed in this study included not only herbivory, but also physical damage by trampling. Although our fences excluded other herbivores aside from deer, we observed that deer were responsible for the majority of damage in unfenced plots. The density of deer at this site was high enough to have statistically significant main effects on jewelweed height only. On July 21, 2007 transplanted jewelweed were significantly taller when they were fenced ( $F_{1,3} = 10.25$ ,  $P$

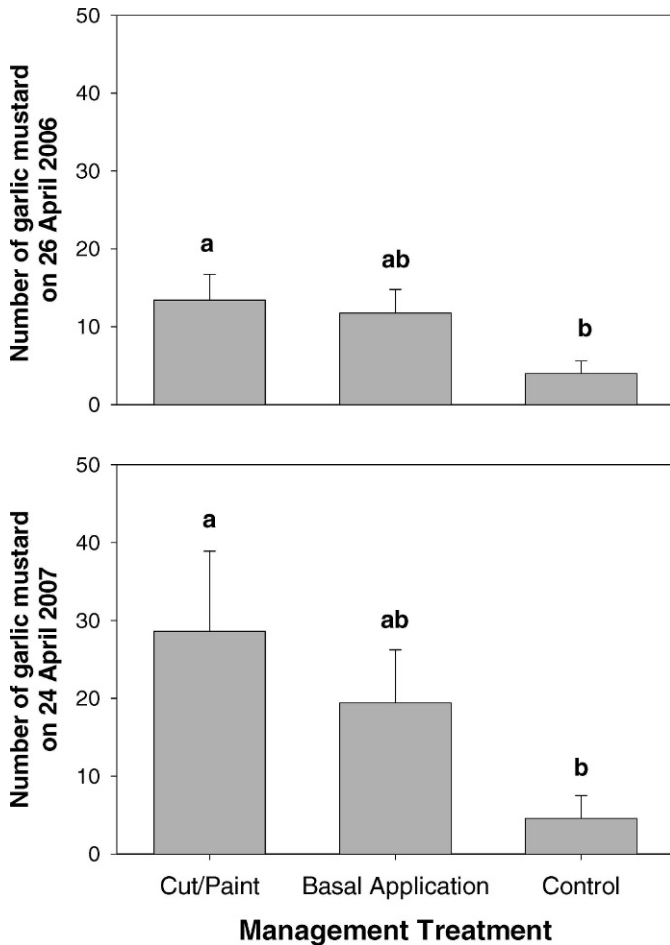


Figure 7. Mean ( $\pm$  standard error [SE]) number of invasive garlic mustard in treatments where Amur honeysuckle was not removed and where Amur honeysuckle was removed using either the cut/paint method or the basal application method. Management treatments with different letters are significantly different from each other based on Tukey's test at  $P < 0.05$ .

= 0.0493; Figure 3). Owing to the nature of our statistical split-split plot design, small differences in the split-plot factor of fencing can not be easily detected (Neter et al. 1996). The experimental design does allow better detection of differences between the split-split plot factor of management method and its interaction with fencing, which was of primary interest in this study.

In the MANOVA for transplanted jewelweed fruit production across three dates, the interaction of fencing and management treatment was significant ( $F_{3,42} = 3.34$ ,  $P = 0.0280$ ). On June 30, there was a significant interaction between management method and fencing on fruit production ( $F_{1,44} = 9.58$ ,  $P = 0.0034$ ; Figure 4). In the MANOVA for the number of jewelweed seedlings across 2 yr, the interaction of fencing and management method was significant on number of seedlings ( $F_{2,9} = 9.09$ ,  $P = 0.0069$ ). In 2007, there was a significant

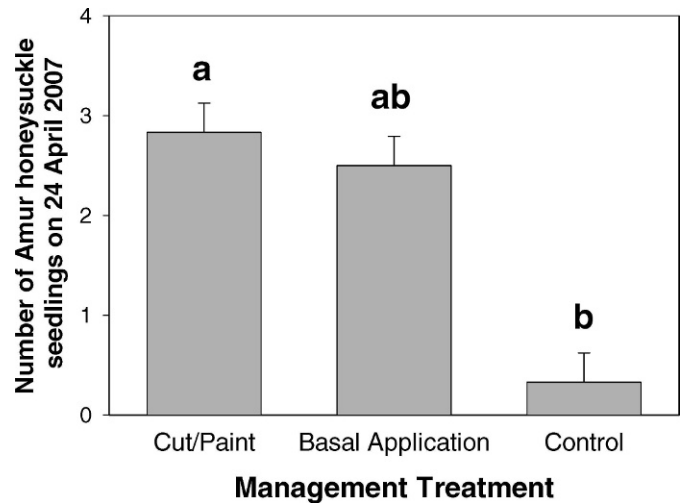


Figure 8. Mean ( $\pm$  standard error [SE]) number of Amur honeysuckle seedlings in treatments where Amur honeysuckle was not removed and where Amur honeysuckle was removed using either the cut/paint method or the basal application method. Management treatments with different letters are significantly different from each other based on Tukey's test at  $P < 0.05$ .

interaction between fencing and management ( $F_{1,10} = 7.91$ ,  $P = 0.0184$ ; Figure 5). The interaction between fencing and management method on native species richness was significant in the MANOVA ( $F_{4,38} = 2.87$ ,  $P = 0.0358$ ). The interaction of fencing and management on native species richness was significant in 2007 ( $F_{2,20} = 5.61$ ,  $P = 0.0116$ ; Figure 6). For jewelweed fruit production, jewelweed recruitment, and native species richness, there was a more strongly positive effect of fencing in the cut/paint treatment than in the basal application treatment. In basal application plots, measurements were more similar whether they were fenced or not.

We therefore found that leaving the dead stems standing provided some protection from deer damage. This is inferred from the less positive effect of fencing on jewelweed fruit production and recruitment and native species richness in the basal application treatment than in the cut/paint treatment. For example, in plots protected from herbivores, jewelweed recruitment in 2007 was twice as high in cut/paint treatments compared to the basal application treatment. In plots exposed to herbivores, jewelweed recruitment was nearly identical in the two management treatments (Figure 5). Thus, the general advantage of using the cut/paint treatment was not seen in the presence of deer. Interestingly, we found that native species richness was higher in our unmanaged control plots when they were not fenced. However, the overall interaction of fencing and management method on species richness was significant even if the control treatment was removed from the statistical analysis. It is important to note

that although differences in species richness were statistically significant, differences were small.

Despite a protective effect from deer, the benefit of using the basal application method in the presence of deer was not great enough to fully recommend its use over the cut/paint method; in our study, even in unfenced plots, native plants generally performed better or the same with the cut/paint method. Due to deer management efforts, the deer density at our study site is only slightly above the carrying capacity of four to six deer/km<sup>2</sup> recommended from studies in Wisconsin and Illinois (Alverson et al. 1988; Anderson 1994; Balgooyen and Waller 1995). In areas where deer density is high, a method that leaves the dead stems standing may be more beneficial than the cut/paint method. Since dead stems start to fall after approximately 2 to 3 yr (K. Cipollini, unpublished data), it is unclear how long the protective effect will persist. At the very least, the short-term protection from deer damage allows time for a deer management program to be implemented before deer can impact restoration efforts after Amur honeysuckle management. Additionally, the costs of each management method in terms of labor and materials must be weighed during consideration of restoration strategy. Clearly, relying on dead stems for protection from herbivores is more cost effective than the installation of deer fencing, though admittedly the restoration benefits may be not as great. The injection method, which, like the basal application method, leaves the dead stems in place, is faster and therefore cheaper than the cut/paint method for larger stems (Hartman and McCarthy 2004). Similarly, the foliar spray method, which also leaves the dead stems standing, is cost effective (T. Borgman, personal communication). We would predict that either the injection or foliar spray method would also have restoration results similar to the basal application method, though further investigation is needed.

We found few treatment effects on wild ginger, which would be expected on the basis of its relative resistance to deer damage and its shade tolerance. On the other hand, the study may have been too short to detect responses in this perennial species. In the MANOVA for wild ginger leaf number, there were no significant treatment effects, yet the effect of management method approached significance ( $F_{2,44} = 2.83$ ,  $P = 0.070$ ). We performed ANOVAs for each separate date to determine the nature of this nonsignificant trend. On April 25, 2006, there were more leaves on plants in the basal application treatment ( $3.28 \pm 0.27$ , mean  $\pm$  standard error [SE]) than in the cut/paint treatment ( $2.53 \pm 0.15$ , mean  $\pm$  SE;  $F_{1,45} = 5.68$ ,  $P = 0.0214$ ). In the ANOVAs for wild ginger leaf width and survival, there were no significant effects. The trend for greater leaf number in the basal application treatment could be due to the propensity of this species to perform better in later successional habitats that have lower light

levels (Damman and Cain 1998). We found that wild ginger is a good candidate for restoration, as rhizome fragments are easy to collect and transplant. They survived (75% survival on average) and grew well (five leaves on average after two years) during our study, consistent with the transplant success found by Mottl et al. (2006). Ruhren and Handel (2003) found that wild ginger had poor transplant success; since their transplants were grown from seed, they may have been much smaller than the rhizome fragments that we transplanted.

Our results indicated that in determining the best method for restoration success, restoration practitioners need to take into account deer populations and invasive species success. The cut/paint method increases light and facilitates greater native plant performance but it can contribute to the success of Amur honeysuckle seedlings and of other invasive species. The cut/paint method is not as successful when deer are present. Methods that leave the dead stems standing may provide temporary protection from browsing and may reduce the success of invasive species, allowing native species to have higher growth, survival, and reproduction. The restoration species of interest must also be considered, as jewelweed and wild ginger responded differently to management methods. Our results indicate that there are differences between restoration management methods in successful understory restoration and that the management method, the effect of deer, the species of interest, and the presence of invasive species must be weighed together in devising restoration strategies. In our study, considering all of the above factors, the basal application treatment or similar method that leaves the dead stems standing is recommended as the most effective treatment for understory plant restoration success.

### Sources of Materials

<sup>1</sup> Pathfinder II®, 13.6% triclopyr, Dow Agrosiences, Indianapolis, IN.

<sup>2</sup> Li-Cor Quantum Sensor, Lincoln, NB.

### Acknowledgments

We thank the Hamilton County Park District for providing funding for this project and permission to perform the research at Sharon Woods. We thank Tom Borgman of the Hamilton County Park District in particular for all his assistance. We thank Jim Rosenberger for statistical advice. We thank Elizabeth Cipollini, Emmett Cipollini, Caitlin Combs, Georgette McClain, Rob Murphy, Jana Reser, Adam Roe, and Yvonne Vadeboncoeur for assisting with field research. Doug Burks, Don Troike, Doug Woodmansee, and the Wilmington College students of BIO 440/441 provided valuable comments throughout this experiment. J. Cardina and two anonymous reviewers provided comments that improved the manuscript.

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*Received August 11, 2008, and approved November 11, 2008.*