HERBICIDE TREATMENTS FOR CONTROLLING INVASIVE BUSH HONEYSUCKLE IN A MATURE HARDWOOD FOREST IN WEST-CENTRAL INDIANA

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Abstract—Asian bush honeysuckles (*Lonicera maackii* [Rupr.] Maxim*, L. morrowii* Gray, and *L. tartarica* L.) have proved extremely invasive in eastern hardwood forests. In addition to displacing native forest ground flora and associated fauna, these understory shrubs pose a threat to forest regeneration. Effective control strategies need to be developed to incorporate into routine silvicultural prescriptions for affected stands. This study tested ten control treatments in a fully stocked, mature central hardwood forest in central Indiana for efficacy and cost. Treatments included: low volume foliar applications of 4 percent triclopyr (Garlon 3A), 3 percent triclopyr (Garlon 3A) + 1/8 percent imazapyr (Arsenal), and 5 percent glyphosate (Glypro Plus), each applied in both early spring and late fall; full basal bark application of 20 percent triclopyr (Garlon 4) in AX-IT basal oil; streamline basal bark application of 20 percent triclopyr (Garlon 4) in AX-IT basal oil; and cut stump treatments with either picloram + 2,4-D (Pathway) or 20 percent triclopyr (Garlon 4) in AX-IT. Treatment timings were chosen to test effectiveness of herbicide control at a time of year when native vegetation would be least vulnerable to off target damage. Efficacy was tested across four shrub size classes. All but one of the low volume foliar applications were equally effective, controlling 70 to 94 percent of bush honeysuckle shrubs between 2 and 8 feet tall. Triclopyr applied in the fall (Nov. 2) provided only 2 percent control. Both basal bark applications provided inconsistent and poor control. Both cut stump treatments were equally effective on the larger two size classes of shrubs, but efficacy declined on smaller shrubs due to operational difficulties of locating all shrubs in a treatment unit. Depending on bush honeysuckle stand stocking and size distribution, treatment costs ranged from $83 per acre to $383 per acre.

INTRODUCTION

The introduction, promotion, invasion, and ultimate vilification of Asian bush honeysuckles (*Lonicera maackii* [Rupr.] Maxim*, L. morrowii* Gray, and *L. tartarica* L., all herein collectively referred to as BHS names) in North America are well documented (Luken and Thieret 1996). Their ecology and impacts on native forest vegetation in the Central Hardwood Region have been extensively studied (Deering and Vankat 1999, Gorchov and Trisel 2003, Hutchinson and Vankat 1997, and Luken and Mattimiro 1991). These honeysuckles have demonstrated a very plastic physiological and morphological response to varying light levels (Luken and others 1995). They attain their fastest growth rates in full sunlight. BHS growth rates increase in direct proportion to increasing amounts of light following forest canopy disturbances. Timber harvesting in forest stands with significant BHS populations in either the understory or on the edges of the forest will only increase the dominance of BHS in the stand. This may adversely affect forest regeneration and most assuredly will harm the native forest herbaceous and shrub components and the wildlife dependent on them (Gould and Gorchov 2000).

The literature, including websites, is replete with general recommendations for controlling BHS. However, little experimental research specific to BHS control has been published. Silvicultural prescriptions for controlling BHS in forest environments are needed.

The objective of this study was to test the effectiveness of various herbicide delivery methods and specific herbicide combinations commonly used in forestry vegetation management to control different sizes of BHS shrubs in a heavily infested, mature, well-stocked Central Hardwood Forest. Herbicides were applied during the dormant season to minimize damage to native vegetation. Preliminary cost data is also presented.

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METHODS

The 14 acre study site was on rolling topography with 5 to 10 percent slopes and primarily east to southeast aspects. Soils consisted of deep silt loam, between 6.5 and 7.5 feet deep. White oak site index (base age 50 years) was 90 feet (NRCS 2005).

The study was located in a mature, well-stocked hardwood forest, in a Vigo County Park, located east of Terre Haute, in west-central Indiana. Tree stocking ranged from 70 square feet to 190 square feet, averaging 114 square feet per acre of basal area. Dominant tree species included sassafras (*Sassafras albidum* [Nutt.] Nees), black cherry (*Prunus serotina* Ehrh.), and red maple (*Acer rubrum* L.) comprising 22 percent, 19 percent and 17 percent, respectively, of the basal area. Miscellaneous oaks (*Quercus*), ash (*Fraxinus*), elm (*Ulmus*), and yellow-poplar (*Liriodendron tulipifera* L.) comprised the remaining stand stocking.

The experimental design was a completely randomized design with 11 different treatments, each replicated three times, applied to 33 ¼-acre square treatment plots. The application methods were low volume foliar, basal bark, and cut stump herbicide applications. Only hand applications (as opposed to mechanized) were chosen for this study because of the need to test applications appropriate for typical native forest conditions; i.e., heavy tree stocking, relatively rough terrain, poor accessibility by motorized equipment, desire to protect native vegetation, and the limited array of equipment typically available to foresters in the region.

The individual treatments were as follows:

1. Control

Low Volume Foliar:
2. SprTriclo = 4 percent triclopyr (12 lb ae/100 gal), 31.8 percent (3 lb/gal) acid equivalent (Garlon 3A[2])
3. SprTriclo+Imaz = 3 percent triclopyr (9 lb ae/100 gal), 31.8 percent (3 lb/gal) acid equivalent (Garlon 3A) + 1/8 percent imazapyr (0.25 lb ae/100 gal), 22.6 percent (2 lb/gal) acid equivalent (Arsenal[3])
4. SprGlyph = 5 percent glyphosate (15 lb ae/100 gal), 30.8 percent (3 lb/gal) acid equivalent (Glypro Plus [see footnote 2])
5. FalTriclo = 4 percent triclopyr (12 lb ae/100 gal), 31.8 percent (3 lb/gal) acid equivalent (Garlon 3A)
6. FalTriclo+Imaz = 3 percent triclopyr (9 lb ae/100 gal), 31.8 percent (3 lb/gal) acid equivalent (Garlon 3A) + 1/8 percent imazapyr (0.25 lb ae/100 gal), 22.6 percent (2 lb/gal) acid equivalent (Arsenal)
7. FalGlyph = 4 percent glyphosate (12 lb ae/100 gal), 30.8 percent (3 lb/gal) acid equivalent (Glypro Plus)

Basal Bark:
8. FullBas = Full Basal 20 percent triclopyr (0.8 lb ae/gal), 44.3 percent (4 lb/gal) acid equivalent [Garlon 4 (see footnote 2)] in AX-IT[4] oil-surfactant low volume basal oil
9. Stream = Streamline 20 percent triclopyr (0.8 lb ae/gal), 44.3 percent (4 lb/gallon) acid equivalent (Garlon 4) in AX-IT oil-surfactant low volume basal oil
10. Cut Stump:Pathway = Undiluted picloram, 3 percent acid equivalent + 2,4-D, 20.9 percent acid equivalent, (Pathway [see footnote 2])
11. Triclo+AX-IT = 20 percent triclopyr (0.8 lb ae/gal), 44.3 percent (4 lb/gal) acid equivalent (Garlon 4) in AX-IT oil-surfactant low volume basal oil

[2] Garlon 3A, Garlon 4, Glypro Plus, and Pathway are registered trade names of Dow AgroSciences.
[3] Arsenal is a registered trade name of BASF Corporation.
[4] AX-IT is a registered trade name of Townsend Chemical.

Foliar herbicides were applied using a hand pump, piston backpack sprayer with an adjustable cone nozzle. Blue dye was added to the herbicide to aide in identifying already-treated areas. Each foliar herbicide treatment was applied in late fall (Nov. 4, 2002) or early spring (Apr. 4 and 10, 2003) to test the feasibility of conducting BHS control operations during periods when native vegetation is dormant but BHS is still photosynthesizing and is possibly capable of absorbing and translocating systemic herbicides through its foliage.

Basal bark herbicide treatments were applied Jan. 7, 2003. Temperatures were below freezing and one-inch of snow was on the ground. The full basal spray was applied with a hand pump diaphragm backpack sprayer, using a cone-jet nozzle. Herbicide was applied from the root collar up the stem to approximately 12 to 15 inches on all sides. The streamline method of basal bark application was applied using a hand-pump, diaphragm backpack sprayer with a 0.0001 inch orifice spray tip that delivers a pencil-lead thick straight stream. Herbicide was sprayed in a 3 inch to 6 inch band, approximately 6 inches from the ground to two sides of the stem. On stems smaller than 1 inch in diameter, herbicide was applied to only one side of the stem.

Cut stump treatments were applied with a two-person crew where one person operated the chainsaw while the second applied herbicide to the stump. The cut stump Pathway treatment was applied on Feb. 13, 2003 using a hand pump piston backpack sprayer, applying herbicide to the cut surface. The cut stump triclo+AX-IT treatment was applied on Jan. 21, 2003 using a diaphragm backpack pump, applying herbicide to the cut surface and to the stump bark. Temperatures were at freezing or below with approximately one inch of snow cover. Treatment application labor time and herbicide volumes were recorded for each treatment plot.

Prior to treatment application, ten 1/385 acre circular subplots were established in each treatment plot. BHS population was determined for each ¼-acre treatment plot by tallying shrubs in the 10-subplot sample by one of the following four size classes:

Class 1 – 0 to 2 feet tall

Class 2 – 2 to 4.5 feet tall

Class 3 – 4.5 to 8 feet tall

Class 4 – over 8 feet tall

Shrub size classes were at first assigned with the aid of a telescoping height pole until field technicians became proficient at assigning classes by ocular estimation.

BHS populations were inventoried in the fall of 2003 and 2004. In the fall of 2003 shrubs were tallied according to 0 percent, 20 percent, 40 percent, 60 percent, 80 percent, 99 percent, and 100 percent damage classes. All damage classes, except 0 percent and 100 percent were subjective estimates of crown percentages showing some form of herbicide damage, i.e., twig, branch death or die back, or leaf necrosis and deformity. The 0 percent class showed no damage while the 100 percent class appeared to be completely dead. Pretreatment, 1st year, and 2nd year BHS populations and efficacy data were determined from sample shrub counts.

Efficacy data was analyzed as the proportion of shrubs dead (100 percent damage class) after the first growing season following treatment. Because proportion data do not usually fit a normal distribution, the proportions were transformed using the following arcsine transformation equation (Zar 1984) prior to statistical analysis:

$$p' = \frac{1}{2}\left[\arcsin\sqrt{\frac{X}{n+1}} + \arcsin\sqrt{\frac{X+1}{n+1}}\right]$$

where

p' = the transformed proportion
X = number of BHS shrubs observed to be dead or assigned to a damage class within a treatment plot
n = total number of BHS shrubs inventoried within a treatment plot.

The transformed efficacy proportion data was then analyzed using a general linear models (GLM) procedure and Duncan's Multiple Range Test (SAS Institute 2001). The control treatment was not included in this analysis since we were most interested in finding the most efficacious treatments and not simply those that were significantly different from doing nothing. Individual treatment data was pooled by herbicide delivery method to compare overall differences between these methods. Treatment data was also pooled by size class to test overall responsiveness of different size BHS to control treatments. The pooled method and size class data were analyzed as factorial combinations of each other in order to test for significant interactions. First year BHS populations were compared to 2nd year populations for each treatment using paired t-tests to show longer-term treatment effects.

RESULTS

The forest understory was dominated by BHS ranging from seedling size to large mature shrubs up to 15 feet tall (table 1). Across all treatment plots, BHS stocking across the full range of sizes averaged 1,596 shrubs per acre. Stocking for shrubs 4.5 feet and taller averaged 519 shrubs per acre. Amur honeysuckle was the most dominant BHS. A small number of patches of Morrow's honeysuckle were interspersed throughout the total BHS population.

Low volume foliar application as an herbicide delivery method on BHS appears to provide better control over a broader range of shrub sizes than basal bark and cut stump methods (fig. 1), with 69 percent, 26 percent, and 26 percent control respectively.

The smallest size class, class 1, sustained significantly lower levels of control (33 percent) than the three larger size classes (fig. 2). This was likely attributable to the difficulty applicators experienced locating and treating shrubs less than two feet in height, especially when they grow amid the dense foliage of the larger shrubs. Many in this size class were simply overlooked.

Significant interactions between herbicide delivery method and height class indicated that individual herbicide delivery methods were best suited to controlling specific BHS shrub sizes (fig. 3). This may be intuitive for anyone with any familiarity with vegetation control methods. Smaller shrubs were most easily treated with foliar applications. Foliar treatments were most effective for size classes 2 and 3. It was impractical to treat the largest shrubs with backpack foliar applications. Basal treatments had overall lower levels of effectiveness across all sizes with marginally better results with size classes 2 and 3 than 1 and 4. Cut stump treatments were effective on shrubs larger than 4.5 feet and ineffectual for smaller shrubs due to the impracticality of trying to find and cut them with a chainsaw.

Low Volume Foliar Treatment Comparisons

Only size class 2 and 3 shrubs were used to determine efficacy of the individual low volume foliar treatments. Because these two size classes responded similarly, their data were combined for analysis and presentation. In year one, for low volume foliar treatments showing acceptable efficacy levels, mean control levels ranged from 70 percent for SprTriclo to 95 percent for SprGlyph (fig. 4). Among the low volume foliar treatments only the FalTriclo treatment was significantly different. All other treatments were equally effective on size class 2 and 3 shrubs. Crown damage greater than 50 percent further reduced BHS overall health and competitiveness in the SprTriclo, SprTriclo+Imaz, FalTriclo+Imaz, and FalGlyph treatments.

Table 1—Asian bush honeysuckle pretreatment shrub inventory by height class for an herbicide trial in an hardwood forest in west-central Indiana

	Size class									
	1 (0 – 2 feet)		2 (2 – 4.5 feet)		3 (4.5 – 8 feet)		4 (8+ feet)		Total (0 – 8+ feet)	
Treatment [a]	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
	shrubs/acre									
SprTriclo	820	167	974	293	692	558	154	117	2,641	1,087
SprTriclo+Imaz	385	308	731	402	449	126	205	34	1,769	859
SprGlyph	551	257	308	102	205	112	51	34	1,115	500
FalTriclo	423	89	308	22	397	151	179	56	1,308	204
FalTriclo+Imaz	295	239	526	148	385	97	0	—	1,205	260
FalGlyph	282	225	333	191	269	102	90	13	974	423
FullBasal	923	332	474	167	410	237	244	114	2,051	681
Streamline	628	128	500	44	397	144	77	77	1,603	237
CSPathway	936	714	269	212	256	26	282	141	1,744	999
CSTriclo+AX-IT	679	400	423	182	397	172	51	34	1,551	749
Total	592	97	485	67	386	63	133	26	1,596	197

SE = standar error; — = not applicable.
[a] See text for individual treatment definitions.

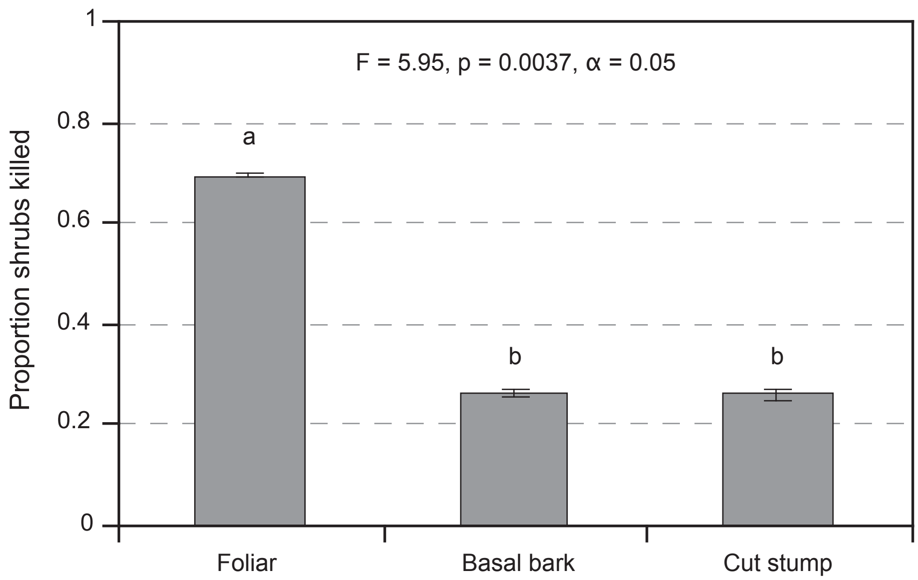

Figure 1—First-year Asian bush honeysuckle control efficacy by method of herbicide delivery in a hardwood forest in west-central Indiana. Efficacy is measured as the proportion of shrubs across all size classes that are killed by the treatment.

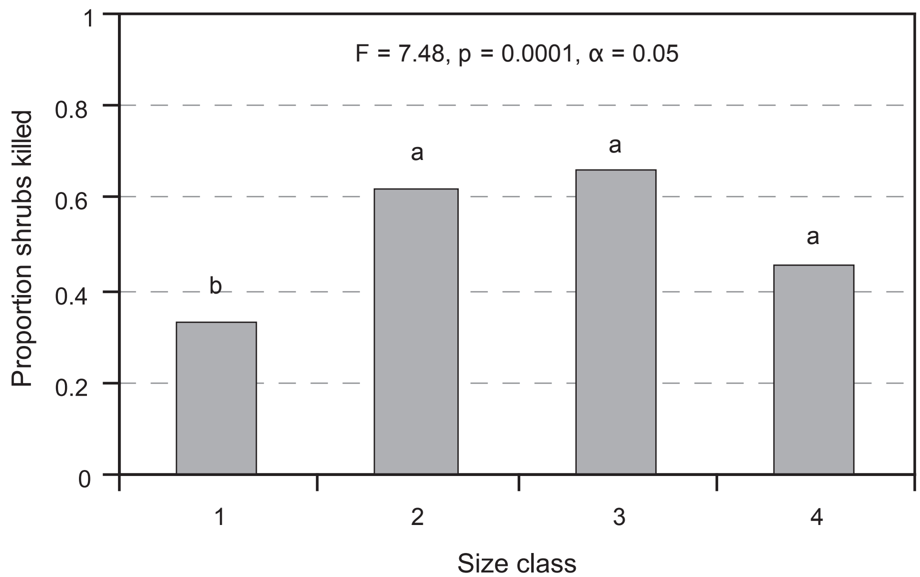

Figure 2—First-year Asian bush honeysuckle control efficacy by size class in a hardwood forest in west-central Indiana. Efficacy is measured as the proportion of shrubs across all treatments that are killed by the treatment. Size classes are: 1 = 0–2 feet tall, 2 = 2–4.5 feet tall, 3 = 4.5–8 feet tall, 4 = over 8 feet tall.

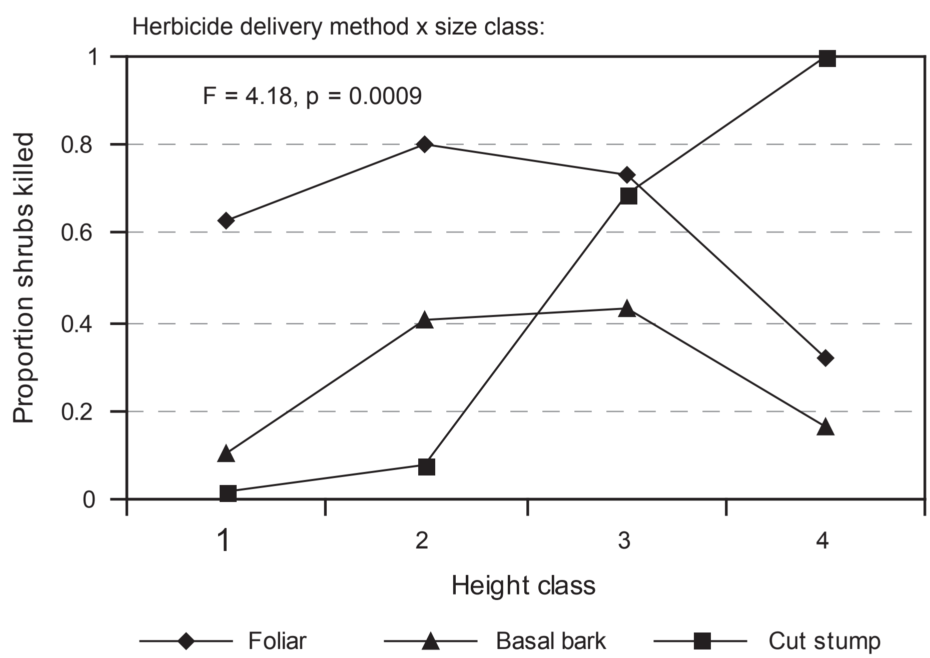

Figure 3—First-year Asian bush honeysuckle control efficacy for herbicide delivery method x height class interaction in a hardwood forest in west-central Indiana. Efficacy is measured as the proportion of shrubs killed by the treatment. Size classes are: 1 = 0–2 feet tall, 2 = 2–4.5 feet tall, 3 = 4.5–8 feet tall, 4 = over 8 feet tall.

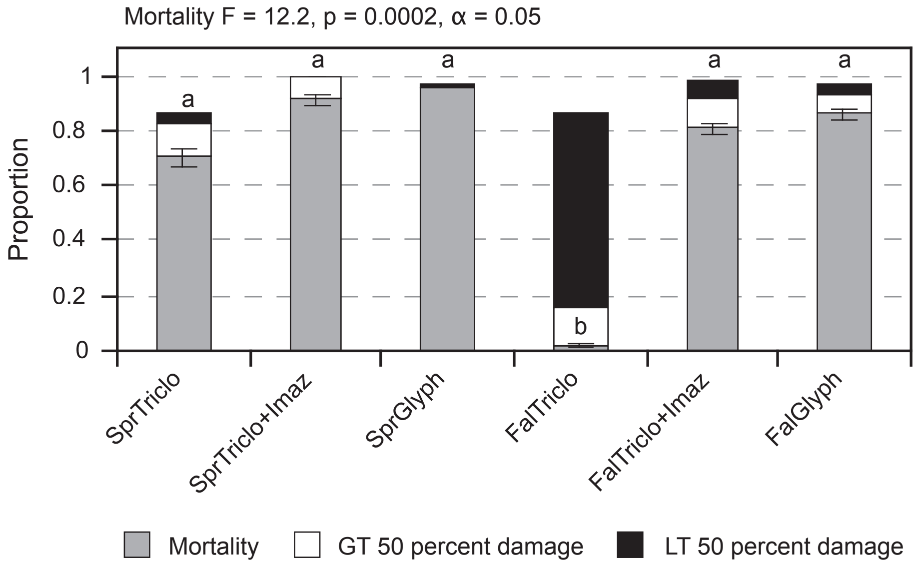

Figure 4—First-year Asian bush honeysuckle control mortality and damage for three low-volume foliar herbicide treatments, each applied in both early spring and early fall, for size classes 2 and 3 (2–8 feet tall) combined in a hardwood forest in west-central Indiana. Mortality and damage are measured as the proportion of shrubs killed or damaged. Damage classes are: GT 50 percent = more than 50 percent of the crown with herbicide-inflicted damage; LT 50 percent = less than 50 percent of the crown with herbicide-inflicted damage, not including shrubs exhibiting no herbicide-related injury.

The FalTriclo treatment was significantly lower than all other treatments with only 2 percent mortality. FalTriclo had no long term effect on any size class of BHS. It, unlike the other herbicides, was apparently not adequately absorbed, translocated, or metabolized by BHS at the lower air temperatures encountered in the early November application to be effective. Air temperatures gradually declined through the last half of October 2002. Nighttime temperatures dropped to 30 °F, 23 °F, and 31 °F for the three successive nights preceding the November 2, 2002 application date, while the daytime highs ranged from 41 to 50 °F. Following treatment application, temperatures remained relatively cool with daytime highs in the mid-40 °F range and nighttime lows ranging from 29 to 42 °F for three successive days. Warmer temperatures followed this through the middle of November. Although leaf abscission did not begin until mid-to-late November, BHS leaf color was just beginning to yellow in early November at this latitude. Most native vegetation was dormant by the treatment application date.

The spring foliar treatment application dates were immediately preceded and followed by daytime highs ranging from 44 to 75 °F and nighttime low temperatures ranging from 61 to 25 °F. BHS shrubs were fully leafed out at this time, while most native woody species were still dormant or were only initiating bud break. A few native herbaceous plants were emerging.

Year 2 BHS inventory data for size classes 2 and 3 combined showed no significant changes from year 1 data for any of the low volume foliar treatments (fig. 5). Resprouting of top-killed BHS was rare to nonexistent in year 2.

Basal Treatment Comparisons

Full basal herbicide applications were most practically used to treat the two larger size classes (classes 3 and 4) considered in this study. This treatment resulted in 15 percent 1st year mortality in size class 4 shrubs and 40 percent 1st year mortality in size class 3 shrubs (fig. 6). In addition to 1st year mortality,

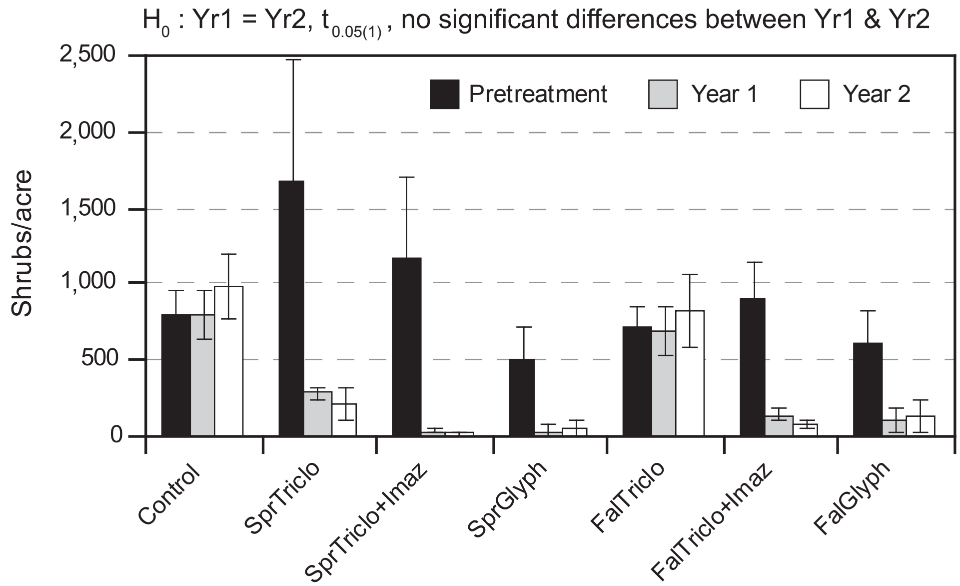

Figure 5—Mean pretreatment, year 1, and year 2 Asian bush honeysuckle populations of size classes 2 and 3 (2–8 feet tall) combined by low-volume foliar herbicide treatments in a west-central Indiana hardwood forest.

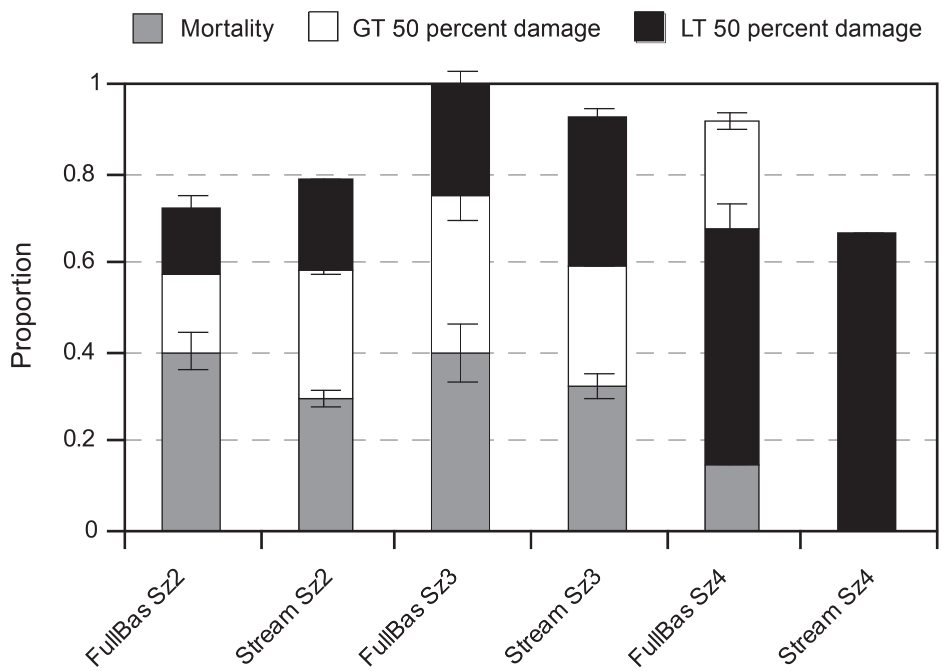

Figure 6—First-year Asian bush honeysuckle control mortality and damage for two basal bark herbicide treatments for size classes 2, 3, and 4 in a west-central Indiana hardwood forest. Mortality and damage are measured as the proportion of shrubs killed or damaged. Damage classes are: GT 50 percent = more than 50 percent of the crown with herbicide-inflicted damage; LT 50 percent = less than 50 percent of the crown with herbicide-inflicted damage, not including shrubs exhibiting no herbicide-related injury. Size classes are: 2 = 2–4.5 feet tall, 3 = 4.5–8 feet tall, 4 = over 8 feet tall.

full basal treatment inflicted greater than 50 percent crown damage to 35 percent and 52 percent of the shrubs in size classes 3 and 4, respectively.

Streamline basal applications were most efficiently used to treat small size classes. Streamline herbicide applications would not be expected to deliver enough herbicide to kill large BHS shrubs. Over 60 percent of class 4 size shrubs experienced light damage (<50 percent crown damage) from this treatment while none experienced heavy damage (>50 percent crown damage) or mortality. However, the streamline treatment did kill 30 percent and 32 percent of shrubs in size classes 2 and 3, respectively. This was not significantly lower than the levels of mortality inflicted by the full basal treatment. In addition, the streamline treatment produced >50 percent crown damage in 28 percent and 27 percent of the shrubs in size classes 2 and 3 respectively. Size class 1 shrubs had much lower efficacy rates for both basal treatments due to the operational difficulty of locating and individually treating such small shrubs.

There were no significant differences between year 1 and year 2 populations for any of the treatment by size class combinations.

Cut Stump Treatment Comparisons

Since cut stump treatments were only practical to apply to larger shrubs, only size classes 3 and 4 were analyzed for efficacy. Furthermore, size classes 3 and 4 were sufficiently similar in their responses to combine them into one class (4.5 - 8+ feet) for analysis.

There were no significant differences in the efficacy between the two cut stump treatments (fig. 7). Both achieved 100 percent control in class 4 size shrubs. Less than 100 percent control was achieved in class 3 shrubs only because of applicator error (both in cutting and applying herbicide). In extremely dense populations of bush honeysuckle, operational scale treatment usually results in less than 100 percent control in the first application.

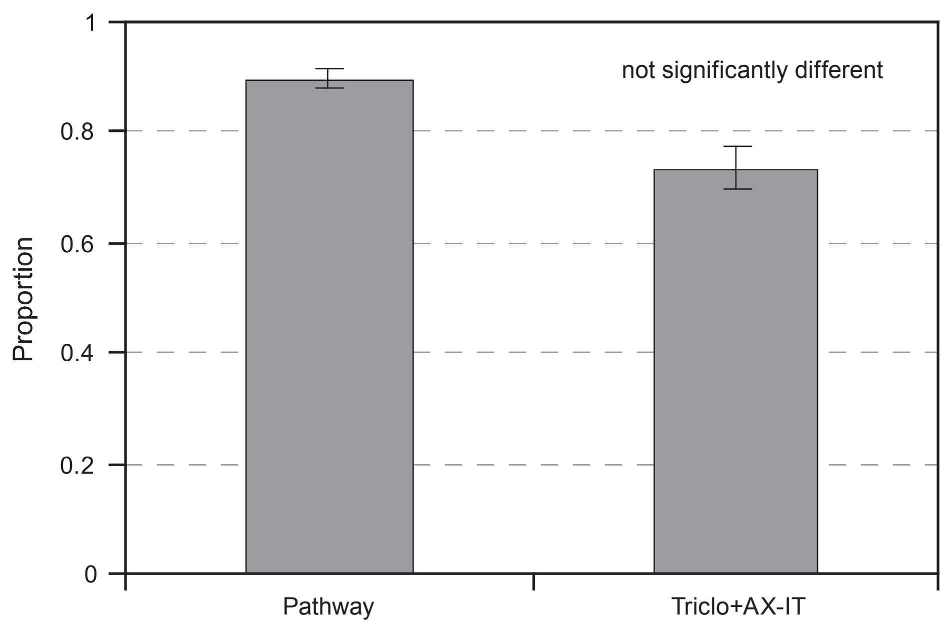

Figure 7—First-year Asian bush honeysuckle control mortality for two cut-stump herbicide treatments for size classes 3 and 4 (4.5–8+ feet tall) combined in a west-central Indiana hardwood forest. Mortality is measured as the proportion of shrubs killed.

Treatment Costs

Table 2 contains treatment labor time, herbicide application rates, and herbicide costs based on product retail prices. Labor costs were not provided as this can vary greatly between applicators. This data should be viewed as preliminary and is presented to provide a range of costs using these methods with the stocking and size distribution of BHS treated in this study. Assuming labor costs of a conservative $25 per hour, total costs ranged from $83 per acre on a low volume foliar glyphosate plot with comparatively lighter BHS stocking (884 BHS per acre less than 4.5 feet tall and 269 BHS per acre greater than 4.5 feet tall) to $383 per acre on a low volume foliar triclopyr plot with very heavy BHS stocking (2,500 BHS per acre less than 4.5 feet tall and 2,192 BHS per acre greater than 4.5 feet tall).

Table 2—Asian bush honeysuckle (BHS) control labor, herbicide application, and herbicide cost rates for an herbicide trial in an hardwood forest in west-central Indiana

Treatment[a]	Plot	BHS < 4.5 feet tall	BHS > 4.5 feet tall	Labor time	Herb. 1 concentr. applied	Herb. 2 concentr. applied	Herb. cost[a]
		- - - - *numbers/acre* - - - -		*hours/acre*	- - - *gallons/acre* - - -		*$/acre*
SprTriclo	1	962	115	1.5	0.64		47.45
SprTriclo	2	1,885	231	1.3	0.45		33.33
SprTriclo	3	2,538	2,192	10.0	1.80		133.21
SprTriclo+Imaz	1	2,461	962	8.2	1.19	0.050	103.71
SprTriclo+Imaz	2	769	577	5.7	0.78	0.033	68.09
SprTriclo+Imaz	3	115	423	3.4	0.53	0.022	45.99
SprGlyph	1	885	269	2.7	0.53		14.60
SprGlyph	2	1,461	500	3.5	0.62		17.08
SprGlyph	3	231	0	2.4	0.44		12.18
FalTriclo	1	846	385	1.3	0.27		20.17
FalTriclo	2	731	962	5.1	0.96		71.17
FalTriclo	3	615	385	6.5	1.24		92.17
FalTriclo+Imaz	1	1,231	308	2.3	0.27	0.011	23.15
FalTriclo+Imaz	2	808	577	1.3	0.24	0.010	20.95
FalTriclo+Imaz	3	423	269	1.7	0.20	0.008	17.18
FalGlyph	1	1,423	308	7.0	0.88		24.11
FalGlyph	2	77	192	2.7	0.34		9.39
FalGlyph	3	346	577	2.0	0.32		8.82
FullBasal	1	462	269	1.4	0.60		23.25
FullBasal	2	1,923	1,077	3.0	1.20		46.50
FullBasal	3	1,808	615	2.1	0.80		31.00
Streamline	1	1,077	615	2.3	0.42		16.43
Streamline	2	1,000	154	1.2	0.13		4.96
Streamline	3	1,308	654	2.1	0.38		14.57
CSPathway	1	3,038	654	6.5	2.68		21.16
CSPathway	2	500	654	6.3	2.60		20.53
CSPathway	3	77	308	3.5	1.00		7.90
CSTriclo+AX-IT	1	2,154	846	6.1	0.62		23.87
CSTriclo+AX-IT	2	1,000	154	1.7	0.15		5.89
CSTriclo+AX-IT	3	154	346	2.3	0.25		9.61

[a] See text for individual treatment definitions.

CONCLUSIONS

The development of BHS control prescriptions should be based on BHS stocking and size distributions, as well as overall forest stand conditions and management priorities, such as the importance of protecting native vegetation. Low volume foliar treatments were effective across a broad range of BHS shrub sizes up to 8 feet tall. Cut stump treatments were most effective and practical for BHS exceeding 4.5 feet tall.

All low volume foliar herbicide combinations, triclopyr, triclopyr + imazapyr, and glyphosate, were equally effective at controlling two to eight feet tall BHS in both early spring and late fall applications, except triclopyr applied in the late fall, which was completely ineffective. Both basal bark applications of 20 percent triclopyr in AX-IT basal oil provided inconsistent and poor control. The streamline method of basal bark application was nearly as effective as the full basal bark application, however, for BHS up to 8 feet tall. More research is needed to develop effective prescriptions for this potentially valuable method of controlling large BHS. Both cut stump treatments, Pathway and 20 percent triclopyr in AX-IT, were equally effective in controlling BHS taller than 4.5 feet.

Once appropriate herbicide delivery methods are chosen the choice of specific herbicide combinations is largely one of comparative costs and potential risks to native vegetation. For instance, the two cut stump treatment herbicides were comparable to one another in cost and effectiveness, but the triclopyr + AX-IT poses less risk to sensitive native species than does Pathway.

BHS control costs were proportionate to BHS stocking and size distribution. In more lightly stocked BHS stands, control costs were in the range of those associated with timber stand improvement (TSI) in the region and could potentially be done in conjunction with scheduled TSI operations. In heavily stocked BHS stands, costs far exceeded those expected for intensive TSI operations. Mechanization of control applications where they are feasible should reduce costs.

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LITERATURE CITED

Deering, R.H.; Vankat, J.L. 1999. Forest colonization and developmental growth of the invasive shrub *Lonicera maackii*. American Midland Naturalist. 141:43-50.

Gorchov, D.L.; Trisel, D.E. 2003. Competitive effects of the invasive shrub, *Lonicera maackii* (Rupr.) Herder (Caprifoliaceae), on the growth and survival of native tree seedlings. Plant Ecology. 166:13-24.

Gould, M.A.; Gorchov, D.L. 2000. Effects of the exotic invasive shrub *Lonicera maackii* on the survival and fecundity of three species of native annuals. American Midland Naturalist. 144:36-50.

Hutchinson, T.F.; Vankat, J.L. 1997. Invasibility and effects of amur honeysuckle in southwestern Ohio forests. Conservation Biology. 11(5):1117-1124.

Luken, J.O.; Goessling, N. 1995. Seedling distribution and potential persistence of the exotic shrub *Lonicera maackii* in fragmented forests. American Midland Naturalist. 133:124-130.

Luken, J.O.; Mattimiro, D.T. 1991. Habitat-specific resilience of the invasive shrub amur honeysuckle (*Lonicera maackii*) during repeated clipping. Ecological Applications. 1(1):104-109.

Luken, J.O.; Thieret, J.W. 1996. Amur honeysuckle, its fall from grace: lessons learned from the introduction and spread of a shrub species may guide future plant introductions. BioScience. 46(1):18-24.

Luken, J.O.; Tholemeier, T.C.; Kunkel, B.A.; Kuddes, L.M. 1995. Branch architecture plasticity of amur honeysuckle (*Lonicera maackii* (Rupr.) Herder): initial response in extreme light environments. Bulletin of the Torrey Botanical Club. 122(3):190-195.

NRCS. 2005. Vigo County soil survey.

SAS. 2001. SAS V. 8.02 for Windows. SAS Institute, Cary, NC.

Zar, J.H. 1984. Biostatistical analysis. Englewood Cliffs, NJ: Prentice-Hall, Inc. 718 p.