ABSTRACT

EVALUATING THE EFFECTIVENESS OF A NOVEL METHOD (TREATING A MAJOR LIMB) TO CONTROL *LONICERA MAACKII*

by Maricruz Rivera-Hernandez

A common invasive shrub in eastern North America is *Lonicera maackii*; it is often controlled with mechanical and chemical methods. In this study, I evaluated the effectiveness of a new method (cut-a-major limb) to kill shrubs 2.4-4.5 m tall. I compared four treatments for efficacy and costs: all combinations of two mechanical methods—cut-a-major limb and space-cuts, with two different herbicides - Garlon 3A and Tordon RTU, in mid-November 2008 at the Ecology Research Center, Oxford, Ohio. Garlon was not effective, but Tordon killed some shrubs, and was more effective in space-cuts than when applied to a major limb. Treating one stem was not effective in killing multi-stemmed shrubs. Cut-a-major limb was not effective on the large shrubs used in this study. Space-cuts with Tordon was more expensive than some previously reported methods, but may be a good alternative to control single-stemmed medium-size shrubs and when spot treatment is needed.
EVALUATING THE EFFECTIVENESS OF A NOVEL METHOD (TREATING A MAJOR LIMB) TO CONTROL *LONICERA MAACKII*

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Advisor____________________________
Dr. David L. Gorchov

Reader____________________________
Dr. Carolyn Keiffer

Reader____________________________
Dr. Sandra Woy-Hazleton
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Introduction

Invasive Plants

Many animals and plants were introduced to the Americas after European explorations, either unintentionally or deliberately (Cox 1999). Exotic species were able to not only prevail in these new ecosystems, but also grow widely. They have spread and colonized North American ecosystems ever since, threatening biological diversity (Vitousek et al. 1997).

President Bill Clinton’s Executive order 13112 (1999: 6183) defines an alien species as "... any species...that is not native to that ecosystem," and invasive species as “an alien species whose introduction does, or is likely to, cause economic or environmental harm or harm to human health.” These definitions indicate that all invasive species could be categorized as alien, but not the other way around; all alien species can not be categorized as invasive.

Pimentel et al (2005) estimated the economic impacts in the U.S. of biological invasions totaled $120 billion per year; of which invasive plants accounted for about $35 billion. Nonnative weeds accounted for $3 billion a year in total herbicide costs (Pimentel et al. 2000). It is very expensive to deal with a particular invasive plant species; for example, Zavaleta (2000 a) compared the benefits of a restoration program with the impacts (e.g. agricultural and hydrological) of tamarisk; the total losses were estimated to be $280-$450 ha$^{-1}$ and the restoration program (planning, removal, revegetation, and monitoring activities) would cost $7,400 ha$^{-1}$; using a discount rate of 0% the cost of restoration would be regained in 17 years or longer.

The introduction of nonnative plant species has have supported by United States officials. For example, Multiflora rose was introduced to control soil erosion, but it spread widely and now is considered a noxious weed (Cox 1999, Kaufman & Kaufman 2007). About 50,000 non-native species have been introduced to the United States (Pimentel et al. 2000), and an estimated 5,000 non-native plants have established in U.S. ecosystems (Morse et al. 1995). Plants from Asia and Europe such as Garlic Mustard (Alliaria petiolata), Bush Honeysuckles (Lonicera maackii, L. morrowii, L. tartarica and L. x bella), and Japanese Honeysuckle (L. japonica) have invaded deciduous forests in the midwestern and eastern United States (Randall & Marinelly 1996; EFETAC no date a). Some of these species were introduced to North America and promoted by different wildlife and conservation organizations (Cox 1999; ODNR 2005), and some of them were promoted by horticultural groups (Hayden-Reichard & White 2001; Bell et al. 2003). More than 700 non-native plant species occur in the state of Ohio (Windus & Kromer 2001). The Ohio Department of Natural Resources identified 60 invasive species that have negatively impacted Ohio natural areas (ODNR no date).

Over the past decades ecologists have researched ecological impacts of nonnative plants on community structure (Vitousek et al. 1996; Vitousek et al. 1997) and ecosystem functioning (Vitousek 1990). Several studies have investigated what habitats are invaded,
and what the effects are, in forests of the eastern U.S. (e.g. Woods 1993; Patrick 1999; Gould & Gorchov 2000; Gorchov & Trisel 2003; Fagan & Peart 2004). Invasive plants have been found to have several impacts in ecosystem functioning such nutrient cycling (Vitousek 1986; Ehrenfeld et al. 2001), change fire regimes (D’Antonio & Vitousek 1992; Brooks et al. 2004) and reduce soil and water availability (D’Antonio & Mahall 1991; Zavaleta 2000 b), potentially impacting native species growth and reproduction (D’Antonio & Mahall 1991) and species richness and abundance (D’Antonio & Vitousek 1992; Mack et al. 2000).

In order to protect biodiversity of forest and park lands, different management techniques have been promoted to control non-native invasive species (Heiligmann 1998; D’Antonio & Meyerson 2002). These include mechanical, chemical and biological control methods. Several studies report benefits and consequences of each method (e.g. Cronk & Fuller 1995; DeWalt 2006; Oehler 2006; INPC 2007), including economic benefits (Cullen et al. 2008), impact on the environment, e.g. on non-target species (Simberloff & Stiling 1996; Shepard et al. 2004; White & Boutin 2007), and soil disturbance (Tu et al. 2001).

Control of Woody Invasive Plants

Generally, mechanical removal is recommended to control woody invasive plants if populations are small, consist of young plants, or if herbicides will impact non-target species (TNEPCC 1996; PA DCNR 2005a; SE-EPPC no date a). The entire plant must be removed; digging tools, weed-pullers and other tools can be used to minimize soil damage (PA DCNR 2005b; Tu et al. 2001). The Invasive Plants Association of Wisconsin is concerned with the effectiveness of the mechanical/manual method, and does not recommend it because it opens gaps in the litter layer where other invasive plants may establish. There are two methods proposed to reduce this effect: 1) cutting roots and/or trunk (Kaufman & Kaufman 2007), and 2) frilling or girdling (CT DEP 1999 a) (Fig. 1). These methods may need to be done at specific times of the year for greatest effectiveness. Mechanical methods are labor intensive, and seedlings can germinate from the seed bank after the plants are removed (Larson 2007). When existing plants are removed other invasive weeds could germinate due to the soil disturbance (Larson 2007). These methods may be done with or without herbicide, but if herbicide is not applied after cutting, the trunks will resprout (IPAW no date a).

Different herbicides, and the integration of mechanical with chemical methods, have been proven effective in controlling woody invasive plants (Newton et al. 1991; Franz & Keiffer 2000; Hartman & McCarthy 2004; Heiligmann & Krause 2006; Pergams & Norton 2006; Lowe et al. 2007) (Fig.1). Methods of killing woody plants with herbicide include: 1) Cut-stump (also known as cut-and-swab and cut-and-paint) – the stems of the tree or shrub are cut as close to the ground as possible and herbicide is applied immediately to the cambial area of the stump. The effectiveness of treatment may be reduced if herbicide is not applied within 30 seconds (Cronk & Fuller 1995). 2) Frilling or girdling – two long parallel cuts are made using an ax or hatchet – 1 or 2
inches in length 0.5 inch of depth and 4 inches apart – that encompass the base of the trunk, the bark is removed and herbicide is applied to the entire cut area (INPC 2002). Frilling is similar to girdling, but in this method continuous cuts are made around the trunk at a downward angle, leaving wood attached to the tree in which the herbicide is applied (Heiligmann 1998; Kilroy & Windell 1999; SE-EPPC no date b). 3) Hack and squirt (also called space cuts) – consistent cuts (about 2 inches long and spaced 1 to 3 inches) are made using a knife, saw, ax, or similar device around the base of the tree, and 2 ml of herbicide are applied in each cut (Heiligmann 1998; SE-EPPC no date b). 4) Foliar application – herbicide is applied to the leaves and stems of the shrub. Foliar application devices are available to reduce the impact on non-target plants (Miller 2003; SE-EPPC no date b). 4) Basal application – 12 to 18 inches of the trunk of tree is sprayed. Harm to non-target plants is prevented by controlling herbicide run-off (Heiligmann 1998). 5) Tree injection – a cavity on the trunk of the tree is made (2 feet above the ground) using an EZ-Ject lance or similar tool, and the herbicide is injected into the tree (Franz & Keiffer 2000; PA DCNR 2005b).

There are numerous herbicide products available on the market, some herbicides are categorized as restricted and some states require an applicator license (see herbicide’s manufacture label for detail information). An herbicide can be effective on some species but not others. Each herbicide contains a label with specifications and recommendations that must be followed (Langeland 2003). Researchers have successfully found methods to control invasive shrubs that reduce labor time, effort, harm and costs. Pergams and Norton (2006) proved that treating a single stem with herbicide will kill whole shrubs of European Buckthorn (Rhamnus cathartica). They studied 15 different treatments; cut-stump and girdling (without herbicide), cut-stump, girdling and basal spray with different herbicides [Brushmaster (PBI/Gordon corporation, Kansas City, MO, U.S.A.); Garlon 4 (Dow AgroSciences LLC, Indianapolis, IN, U.S.A.), Roundup (Monsanto, St. Louis, MO, U.S.A.), Stalker (BASF corporation, Durham, NC, U.S.A), and Tordon RTU (Dow AgroSciences LLC, Indianapolis, IN, U.S.A.)]. They treated shrubs with diameter at breast height (dbh) greater than 3cm and determined the most effective methods were cut-stump and girdling, and both methods required the same amount of time and labor. The most effective herbicides were Tordon, Stalker and Roundup (which was the most expensive in the group).

Amur Honeysuckle (Lonicera maackii)

A common invasive shrub in eastern North America is Amur honeysuckle (Lonicera maackii). Lonicera maackii is native to central and northeastern China, Korea, central Japan, and the Russian Far East (Luken & Thieret 1996). It was first collected by plant explorers Robert Fortune in 1843 and Richard Maack in 1855. Lonicera maackii was introduced to North America in an arboretum in Ottawa and then to the US in 1898 through the New York Botanical Garden. Lonicera maackii was introduced for ornamental and practical landscaping to cover areas and for soil stabilization (Luken & Thieret 1996). It can now be found in 27 of the eastern and midwestern United States, and in Ontario, Canada (USDA no date; EFETAC no date b).
Lonicera maackii was introduced to southwest Ohio in the 1950’s and by the 1960’s had invaded natural areas (Luken & Thieret 1995). To date, it has invaded 27 counties in Ohio (TNC no date). Near Oxford, Ohio, Hutchinson and Vankat (1997) surveyed 93 forest stands and found L. maackii cover averaged 25%, with a maximum cover of 96%.

Luken and Thieret (1995) report that L. maackii grows as tall as 6 meters, with a stem base diameter of 15cm. These shrubs expand their leaves before native species and stay green through late fall (Luken & Thieret 1995). Lonicera maackii flowers are white, changing to yellow (Luken & Thieret 1996), and have a strong sweet scent that attracts bees (Luken & Thieret 1995). Its fruits are green, changing to red in the fall and to orange in the winter (Luken & Thieret 1996). In southwest Ohio, at least five different bird species (American robin, cedar waxwing, European starling, hermit thrush, and northern mockingbird) eat and disperse L. maackii seeds; American robin has been found to be an important disperser because it moves around forest edges (Bartuszevige & Gorchov 2006), which are an optimum germination environment for L. maackii. Lonicera maackii seedlings have been found to have greater growth rates in high light environments such as canopy gaps, disturbed forest and forest edges (Luken et al. 1997). However, L. maackii's morphological plasticity enable the shrub to respond well to both shaded and open habitats (Luken et al. 1995).

Several comparative studies have examined the impact of L. maackii on forest plants of invaded sites versus uninvaded areas. Lower tree seedling density and species richness of tree seedlings were shown in invaded sites (Hutchinson & Vankat 1997). Sites that were under L. maackii crowns showed lower species richness and abundance of herb and tree seedlings, as opposed to plots located away from the shrub (Collier et al. 2002). It was found that stands that had longer residence times of this shrub also showed lower species richness of herbs, as well as richness and density of tree seedlings (Collier et al. 2002). Mean tree basal area was 15% lower in forests invaded by L. maackii (Hartman & McCarthy 2007). Hartman and McCarthy (2008) used the chronosequence method in 16 forest sites to determine the long-term impacts of L. maackii. Sites that had been invaded for more than 18 years had lower species richness and density of seedling, sapling, and herb layers compared to uninvaded sites. Experimental studies showed that L. maackii reduced survival and seed production of the annuals Galium aparine and Impatiens pallida (Gould & Gorchov 2000), individual herb growth and reproduction in the perennials Allium burdickii, Thalictrum thalictroides, and Viola pubescens (Miller & Gorchov 2004), and survival of tree seedlings (Gorchov & Trisel 2003). Dorning and Cipollini (2006) found that L. maackii leaves and root systems inhibit the germination and growth of native herb species and determined that allelopathic effects persist in soil after roots and leaves are removed. The results of these studies support the inclusion of L. maackii on the list of the 13 most invasive plants (targeted for eradication) in Ohio (TNC no date), which are classified as a major threat to forest areas and native communities, and are also difficult to control.
Control Options

Due to the economic and ecological effects, control of *L. maackii* was recommended by Hutchinson and Vankat (1997). First it is important to identify the level of invasion (light or heavy) of the stand to determine which method is appropriate. As with many other invasive species, mechanical and chemical methods are often used to control *L. maackii*. Hand pulling of seedlings is recommended for small infestations, but care must be taken because open soil could potentially lead to re-invasion (Nyboer 1990). In forested habitats, repeated clipping can be used as a primary control method (Luken 1990). However, mechanical methods such as repeated cutting are, when used as the sole method, not effective to control this shrub; the effectiveness of this method increases with the use of chemicals (Luken & Mattimiro 1991). Chemical methods like foliar spray are recommended for larger infestations, but they harm non-target species. The cut-stump and frilling methods offer less risk to non-target species. In fact, one of the most effective methods for eradicating honeysuckle is the cut stump and paint method (Stringer et al. 2008; IPAW no date a, Kroehn-Buenzow no date). There is some debate on whether leaving dead standing stems could affect restoration due to allelopathic compounds in tissues (Trisel 1997; Dornig & Cipollini 2006), or protection of transplanted plants from deer browsing (Gorchov & Trisel 2003). Leaving dead standing stems (e.g. via basal application of herbicide) is suggested to be the best method when an understory restoration program is implemented (Cipollini et al. 2009).

Lowe et al (2007) tested effects on *L. maackii* of three methods considered to be effective at low population density: basal application, cut stump with herbicide, and herbicide application to a dormant stem (spray herbicide on stem, branches and limbs). They used different mixtures of herbicides (Stalker and Garlon 4), Ax-IT basal oil (Townsend Chemical Division, Selma, IN, U.S.A.), and a nonionic surfactant (NIS). Basal and cut-stump treatments were applied to stems with diameters from 1 to 16 cm in late winter of 2003 and early spring of 2004. Treated shrubs were evaluated in July 2003 and August 2004. The mixture of 82% Ax-IT basal oil + 15% Garlon 4 + 3% Stalker was found to be the best for both treatments (100% mortality rate). In the dormant stem method, they sprayed shrubs 0.6 to 1.8 m in height in March of 2004 and evaluated the shrubs in August 2004 and July 2005. Different mixtures were effective, but they recommended 0.125% Stalker (+ 1.5% Garlon 4 + 4% Ax-IT basal oil + 0.25 % NIS) because it had the smallest percentage of herbicide.

Rathfon and Ruble (2007) compared three methods (foliar, basal and cut-stump) and five different herbicides [Garlon 3A, Garlon 4, Glypro Plus, Pathway (Dow AgroSciences LLC, Indianapolis, IN, U.S.A.) and Arsenal (BASF corporation, Durham, NC, U.S.A) at different concentrations (mixed with AX-IT)] on Asian bush honeysuckle (*Lonicera maackii, L. morrowii* and *L. tartarica*). They classified the shrubs into four height classes: class 1 – less than 0.6 m; class 2 - 0.6 to 1.37 m; class 3 - 1.37 to 2.43 m; and class 4 – greater than 2.43 m. Some combinations of herbicide and method were more effective for controlling shrubs within specific categories. For foliar application, two combinations applied in the spring (3% Garlon 3A+1/8% Arsenal; 5% Glypro Plus) and two combinations applied in the fall (3% Garlon 3A+1/8% Arsenal; 4% Glypro Plus)
were effective in controlling 80-95% of the shrubs in classes 2 and 3. Two cut-stump methods with (Pathway RTU; 20% Garlon 4 + AX-IT basal oil) were highly effective in controlling class 3 (< 100 % mortality due to applicator error) and 4 (100% mortality); this method can be applied in summer, fall and spring. All basal bark treatments resulted in poor control of the shrubs, with less than 40% mortality.

One alternative that proved to be highly effective in killing *L. maackii* was injection of glyphosate pellets with an EZ-Ject lance (ArborSystems, Omaha, NE, U.S.A). Franz and Keiffer (2000) tested this method during summer of 1998 and spring and fall of 1999. For the 1998 sample, 78% of the shrubs (stem diameters ranged from 2.5 cm to 11.4 cm) were killed. When the 1999 shrubs (most stems 3.6 cm to 8.9 cm diameter, a few large shrubs between 11.4 cm and 19.8 cm) were assessed, it was found that 56 and 88% of the shrubs were dead for spring and fall groups respectively. Hartman and McCarthy (2004) compared herbicide injection with the cut-stump method and determined both methods were effective. Hartman and McCarthy (2004) recommend cutting and painting with 20% glyphosate for shaded environments and 50% glyphosate for high light environments. Although, the injection method was more expensive (start up costs $599) than cut-stump ($253), they concluded its benefits outweighed its cost. They found injection was effective with large shrubs (they used individuals>1.5 cm diameter), was less strenuous for operators (it requires less operator-hours), and speculated that it had less ecological impact on non-target plants and worker exposure to herbicides.

Although glyphosate has proven effective in killing honeysuckle (Conover & Geiger 1993; Franz & Keiffer 2000; Hartman & McCarthy 2004), a recent study by Heiligmann and Krause (2006) compared the relative effectiveness of glyphosate, triclopyr, picloram, imazapyr and 2,4-D + 2,4-DP in controlling honeysuckle. Glyphosate and 2,4-D + 2,4-DP were categorized as somewhat effective in controlling honeysuckle, while triclopyr, picloram, and imazapyr were categorized as very effective. Picloram, triclopyr and imazapyr can control the target species while having little or no effect on non-target species (Heiligmann & Krause 2006; Jackson & Finley 2007).

Large-scale applications of herbicides are of particular concern for the environment. The misuse of herbicides can cause environmental and human health risks, such as harm to non-target species or water/groundwater, as well as soil pollution. High doses of triclopyr have been found to have some effect on human health, but not carcinogenic effects or birth defects; it is slightly or practically non-toxic to birds and toxic to non-toxic on fish (depending on species); and its effects last for about 30 days (USEPA 1998). The EPA classified undiluted triclopyr in toxic category I (most toxic) due to eye injury. Picloram does not cause birth defects, nerve damage, DNA damage or cancer; it is not toxic to birds but moderately toxic to fish; its half-life in soil is about 90 days. The EPA classified undiluted picloram in category II (USEPA 1995). 2,4-D has some effects on human health and is classified in category I due to eye injury; it has moderate to slightly toxic effects on birds, and is practically non-toxic to small mammals and fresh water fish (USEPA 2005).
Government organizations and NGOs are aware of invasive species threatening natural habitats and native species. But they also recognize that managers must often face the problem of trying to control invasive species with small budgets (e.g. USFWS 2008 a, IPAW no date b; also see Maxwell et al. 2009 for more information). Land managers must often deal with shrub control problems on limited budgets, and would be interested in a new method that would increase the efficiency of killing L. maackii while reducing the effect on non-target species. Treating a major limb was proposed (Hunter 2008, personal communication) as a method that would kill L. maackii shrubs with less labor and herbicide than the alternatives reviewed above.

Hunter (2008, personal communication) devised the cut-a-major-limb treatment and tried it on shrubs that had basal diameters of 3-6 cm in Wilmington, OH. The largest limb was cut on each shrub (diameters ranged from 2-4 cm), and the cut surface was painted with (Cornerstone; Agrilience Company, St. Paul, MN, U.S.A) [41% glyphosate N-(phosphonomethyl) glycine in the form of its isoproplyamine salt and 59% ethoxylated tallowamines]. He performed the method in late spring (May and June 2008), summer (July 2007 and 2008) and early fall (October 2007). His results showed that cutting the largest limb in late spring was more effective in killing L. maackii (88% dead) than cutting in summer (Table 1). While the fall treatment killed both plants, the small sample size used was not sufficient to determine the effectiveness of cut-a-major limb with glyphosate at this time of the year.

Research Goal and Objectives

The goal of this study was to determine whether the cut-a-major-limb treatment was a more efficient, and economically feasible, alternative to current eradication and control strategies for L. maackii. If so, it would be a compelling control method for land managers and private non-profit organizations. This study compared two different methods: space cuts vs. cutting a major limb, each with two different herbicides. In an attempt to systematically assess effectiveness and costs, the following objectives were pursued:

1) Determine effectiveness, as the mortality rate of honeysuckle, with each combination of herbicide and application method
2) Determine costs of each method by estimating the following factors:
   i) total costs (i.e. labor, herbicide and tools)
   ii) physical labor and level of fatigue
   iii) environmental impact on native plants

I hypothesized that the cut-a-major-limb method would be as effective as the space cuts method in killing honeysuckle, but would require less labor.
Methods

Four different treatments were applied to Lonicera maackii shrubs in the northern portion of the woodlot of the Miami University Ecology Research Center (ERC) (39°30’N, 84°44’W), located north-northeast of Oxford, Butler County, Ohio. At ERC the daily average of the lowest and highest temperature from December to February was -3.7 and 5.4 °C, and from June to August was 17.9 and 28.8°C (OARDC weather system). The woodlot is an early successional stand bordered by old fields and dominated by Acer saccharum and Ulmus rubra; common species in the ground layer include Parthenocissus quinquefolia, Stellaria media, Sanicula canadense, Pilea pumila, Hackelia virginiana, Polygonum cespitosum, Impatiens spp. and Viola spp. (Hochstedler & Gorchov 2007). This site was chosen because of high L. maackii density and protection from uncontrolled anthropogenic disturbance.

I selected and numbered 120 L. maackii shrubs that were 2.4 – 4.5 m tall and at least 15 m from the edge. These shrubs were randomly assigned to four treatments. The experiment used a 2 x 2 factorial design comprised of two different herbicides (Tordon RTU and Garlon 3A) and two physical methods (space-cuts and cut-a-major-limb). In Tordon the active ingredients are 5.4% picloram (4-amino-3,5,6, trichloropicolinic acid triisopropanolamine salt) and 20.9% 2,4-D (2,4-dichlorophenoxyacetic acid), with 73.7% inert ingredients. In Garlon the active ingredient is 44.4% triclopyr [(3,5,6-trichloro-2-pyridinyl) oxy] acetic acid, with 55.6% inert ingredients (Dow Agrow Science LLC 1998 a). Tordon RTU was applied undiluted, while Garlon was diluted 1:1 with water, following manufacturer's recommendations (Dow Agrow Science LLC 1998 b).

Herbicides were applied using water bottles with pull-up nozzles. The space-cuts method was performed by making cuts (with a compact axe) c. 2.5 to 4.0 cm long with edges spaced 2 to 6 cm apart. The cuts were made on the largest trunk within 50 cm of the ground; approximately 12 ml of herbicide was applied in each cut. Due to operator error (aiming) some cuts were inconsistent. The cut-a-major-limb method was completed by cutting the largest limb of 2–4 cm diameter of the largest trunk (Fig. 2). If the largest trunk did not have a limb 2–4 cm in diameter below 1.70 m, I cut a limb of this size from another trunk. If no limb of this diameter was accessible, the largest trunk was cut instead. The limb or trunk was cut with Trailblazer telescopic ratcheting anvil loppers. After cutting the limb or trunk, 1–2 ml of herbicide was applied on the cut surface.

Lonicera maackii density was estimated using two parallel belt transects, 10 m apart, of 33.5 x 2 m. Shrubs were classified into three different height categories: small (1.5–2.5m), medium (2.5–4.5m; the size used in the experiment), and large (>4.5 m).

The cut-a-major-limb treatments were performed 16 Nov. 2008 and the space-cut treatments were done 19 Nov. 2008. The temperature those days ranged from cool to cold, with the lowest and highest temperatures of 0.88 and 3.67 °C on 16 Nov., and
-6.72 and 5.22 °C on 19 Nov (Table 2); applications were done during the warmest part of the day. One person performed the physical method and the author applied the herbicide. Initial and ending times were recorded.

The total cost was estimated using herbicide application rates, herbicide cost based on retail prices, and labor costs using Ohio minimum wage of $7.00 per hour.

Evaluation of Methods

In late April 2009, impact of treatment was evaluated by qualitatively assigning each shrub into one of three categories: dead (no new leaves and no stem or basal sprouts on the entire shrub), alive (leaves on most of the branches), and partially dead (those plants that were not dead or alive, such as when the shrub had leaves on some of the branches, or sprouts on either the base and/or any of the trunks). Efficacy of the treatment was recorded for the single-stemmed and multiple-stemmed shrubs (evaluating each trunk of the shrub), with the purpose of determining whether a treatment of a single trunk could kill single-stemmed and multi-stemmed shrubs.

Statistical Analysis

Preliminary analysis showed that none of the 60 shrubs treated with Garlon were killed (Fig. 3). Hence, a binary logistic regression model was performed to estimate L. maackii mortality just using Tordon. The response variable was whether a shrub was dead or not dead (live and partially dead were pooled) (STEMFATE2009). Application method (APPLICATION) was used as a factor, and diameter of the treated stem, number of stems, and height of the shrub (DIAMETER, STEMS, and HEIGHT) were covariates. Logistic regression model was fitted by maximum log-likelihood estimation using JMP 7 (SAS Institute Inc., Cary, NC, USA).

Results

The transect data indicated that the forest understory was dominated by medium shrubs (with a total of 17 shrubs), with only seven small shrubs and six large shrubs. The total of 30 shrubs in the two transects (total area 134 m²) corresponds to a density of 0.22 shrubs/m².

For the group of shrubs that were treated, there were 68 single-stemmed and 52 multi-stemmed shrubs. The mean diameter of the treated stems was 5.63 cm (range 2.4–9.3), and the mean number of stems per shrub was 1.81 (range 1-6).
Eradication Treatment Effectiveness

The logistic regression performed for STEMFATE2009 was significant (p<0.0003, r²= 0.39) (Table 3). The APPLICATION factor was significant; the space-cuts method was more effective than the cut-a-major limb method (Fig. 3A, B). STEMS was also significant: shrubs with one stem were more likely to be dead (11% for cut-a-major limb and 50% for space-cuts) than multiple-stemmed shrubs (0% mortality for each method) (Fig. 3A, B; Table 4). The height of the shrub and diameter of the treated trunk were not significant (Table 3).

Comparison of Costs

For both methods two people were needed. One person operated the axe (for the space-cut) or loppers (for the cut-a-major limb), and the other person applied the herbicide to the shrub and cleaned the area if needed. Overall, space-cuts (with Tordon) was cheaper than the cut-a-major limb method. Total costs ranged from $70 per 30 shrubs (or 134 m²) using space-cuts with Tordon to $130 per 30 shrubs using space-cuts with Garlon (Table 5). In terms of labor, the space-cuts method required less time to apply than the cut-a-major limb method (Table 5).

Discussion

The results of this study indicate that L. maackii cannot be effectively killed by a combination of cutting-a-major limb method and applying certain herbicides. The space-cuts treatment was more effective than cut-a-major limb, but less successful than reported control efforts of L. maackii in previous studies. Franz and Keiffer (2000) used the EZ-Ject injection with glyphosate and found 88% mortality in the fall. Hartman and McCarthy (2004) used injection with glyphosate in the winter and found 98% of the shrubs were killed.

The low percentage of shrubs killed is not due to using ineffective herbicides. The effectiveness of Tordon and Garlon in the treatment of woody species is well-documented. Geyer and Chandler (1979) found that Garlon 3A basal tree injection effectively controlled boxelder (85% and 95%), mulberry (83% and 100%) and silver maple (29% and 100%) in winter and spring respectively; spring gave better results than winter. According to Kline and Hern (1985), Garlon 3A offered a good control over red maple (80%), blackgum (100%), and sourwood (100%), when treatments were applied in June. Pergams and Norton (2006) determined that girdling and cut-stump with Tordon gave no regrowth (i.e. rate of 0 in their qualitative scale of 0–4; where 0 indicated no foliage or basal shoots, and 4 indicated all trunks showed growth).

However, some publications have mentioned that Garlon is not effective in controlling honeysuckle (Nyboer 1990). INPC (2007) found that [foliar] spray with Garlon 3A (at 4%) killed only 2% of bush honeysuckle when applied in fall
(October/November), suggesting that this herbicide may not be absorbed properly by honeysuckle at this time of the year. Hence, more research is needed to see if Tordon RTU and Garlon 3A are more effective in a certain season.

The effectiveness of a method depends not only in the herbicide used, but also time of the year when this is applied. Different application methods, in combination with glyphosate, have effectively killed *L. maackii* when applied at specific times of the year. For cut-stump and injection methods, March (Hartman & McCarthy 2004) and late April (Trisel 1997) were the best months of application, while late autumn worked better for foliar spray (Conover & Geiger 1993). In general, cut-surface methods with glyphosate have been found to be more effective in early fall, followed by spring applications (Franz & Keiffer 2000), because the herbicide movement through root suckers decreases in late fall and may be poor during winter and early spring (CT DEP 1999 b). Thus, future studies should determine whether the efficacy of the cut-a-major limb method with glyphosate application is greater in the fall and late spring than in summer (as Hunter’s results indicate).

Other factors affecting treatment include temperature, soil moisture, and precipitation during and after application method (Boateng 2002). Cold temperatures might have been the cause of low mortality (especially when using Garlon 3A). In this study, the four treatments were implemented in the scope of two days (November 16th and 19th) with temperatures near freezing. While some documents suggest that unwanted trees and shrubs can be treated using tree injection methods (including hack-and-squirt) in summer through winter, these methods should not be practiced when stems are frozen, as it limits uptake of the herbicide to the root system (TDF 2003). Cold temperatures (below 10°C) may cause the herbicide not to perform as well as it should (NS Canada, 2004). Some authors suggest measures that should be taken when herbicides are applied in cooler temperatures. If the application method is applied in cold temperatures, using oil carrier herbicides such as Garlon 4 can kill 100% of bush honeysuckle in winter, and 70–90% in spring (as cited in USFWS, 2008). Lowe et al (2007) applied different mixes of Garlon 4 (an ester--oil-carrier herbicide, as opposed to Garlon 3A, which is an amine--water-based herbicide) and basal oil in cut-surface method in late winter and early spring, and effectively killed 100% of the shrubs. Another option is to add antifreeze (ethylene glycol) according to the label, to prevent freezing of the applied solution in the space-cuts method (TDF 2003). The use of antifreeze is suggested by some herbicide manufacturers (Vegetation Management, LLC; BASF Corporation; E. I. du Pont de Nemours and Company). However, these labels do not clearly specify the appropriate dilution rate (this must be checked directly with the manufacturer). Research should be performed to determine if the presence of antifreeze increases the percent mortality of *L. maackii* treated by cut-a-major limb in fall or winter. The findings from this research will not only be beneficial for control of *L. maackii*, but also of other invasive species.

I found that Tordon was more effective against single-stemmed shrubs than shrubs with multiple stems, which were not killed. This result contrasts with that of Pergams and Norton (2006), who found that girdling or cutting a single stem of multiple-stemmed buckthorn and treating it with herbicide (Roundup, Stalker, or Tordon) usually
resulted in the death of entire shrub. This study did not look at herbicide translocation, but the number of multiple-stemmed shrubs that were alive indicated that neither method with Tordon resulted in the death of the entire shrub (50% of the multiple-stemmed shrubs were partly dead). This result may be an indication of poor transference of the herbicide through a multiple stem system. Herbicide movement across trunks in multiple-stemmed shrubs should be investigated in future studies. However, these findings suggest that each stem of a L. maackii shrub may need to be treated (at least for larger shrubs), rather than a single stem. Franz and Keiffer (2000) found that injecting herbicide in all stems in multiple-stemmed shrubs was more effective (88% killed for shrubs) than injecting the main stem (71%). Perhaps better results can be obtained for the cut-a-major limb method if a major limb on each stem is treated, as opposed to only treating one major-limb.

The lower effectiveness of the cut-a-major limb method in larger shrubs suggests that larger shrubs need more herbicide (>2ml) or cannot be effectively killed with the method. The results of this study, in combination with those of Hunter (2008, personal communication), indicated that a single application of herbicide in the cut-a-major limb may work for small size shrubs (≤2.5m) with diameters ranging 3 to 6 cm, as opposed to larger shrubs (≥ 2.5m), even if small and larger shrubs have the same number of stems. Significant effects have been found between herbicide delivery methods and the size of the shrub (Rathfon and Ruble 2007). For example, foliar spray was more effective with small shrubs (0.6 to 2.4 m) (Rathfon and Ruble 2007).

Tordon was not only more effective than Garlon in this study, but it was also cheaper, and easier to find in local retail outlets. Cubline (2009) suggests that if the project is small and does not require a gallon of herbicide (Garlon 3a is sold by gallon); Tordon RTU will save costs while providing better results.

The cost of removing L. maackii is an important criterion and should be considered; however, few studies have reported it. Costs have been variable across studies (Table 6). Space-cuts with Tordon is cheaper than injection with glyphosate by EZ-Ject, which requires purchase of an expensive lance, but more expensive than basal and foliar spray (which use less herbicide than injection treatments). In many of the projects, the cost of herbicides, tools and equipment is more expensive than labor costs, which could be reduced if volunteers are recruited. In terms of labor costs, cut-a-major limb required more time to measure and identify the appropriate limb than the space-cuts method, where it was easy to identify the largest trunk. Basal spray required the least labor, followed by foliar spray (Table 6). However, basal spray killed less than 40% of target Lonicera shrubs (Rathfon & Ruble 2007), while foliar spray may have higher risk of herbicide drift (Motooka 1999) which may damage non-target species. For example, Trisel (1997) found 100% mortality in the herbaceous layer underneath the shrubs that were sprayed with glyphosate.

The time reported in this study and previous studies (Table 6) are usually overestimates, due to the fact that people performing the treatments are not professionals in honeysuckle removal. Since people performing frequent restoration projects would
likely use less man-hours and the total cost could be less, I compared the costs of treating honeysuckle by different companies/organizations (Table 7). The cost of removing this invasive shrub can vary greatly (Table 7). Again, one of the cheapest methods is foliar spray (Borgman, personal communication 2009), since little equipment and labor is needed. This is followed by a combination of foliar spray (for small shrubs) and cut-stump (for larger shrubs) (Wakeland, personal communication 2009; see Stringer et al 2008 for more information about shrub size and treatments). However, the cost estimate of space-cuts with Tordon in this study is less than that incurred or charged for cut-stump control by professionals (Table 7). In the case of space-cuts, labor costs were more expensive than the costs of herbicide and equipment required to apply the treatments (Table 7). The preferred methods among professional applicators are fall foliar spray (but there is concern of harm to native species, as stated before) and cut-stump, but the latter needs to be followed by foliar spray of stump sprouts (Borgman, personal communication 2009).

I expected space-cuts and cut-a-major-limb would have small impacts on non-target species compared to other methods, but this research showed that space-cuts used more herbicide (20 ml/plant) than cut-a-major limb (2 ml/plant) and other methods. The amount of herbicide applied for the cut-a-major limb method was more uniform, since differences in the amount of herbicide applied in the space-cuts method was due to operator error. The average volume needed for the cut-stump and paint method is 5.23 ml/plant (of concentrated glyphosate), for foliar is 0.887 ml/plant, and for stem injection (EZ-Ject) 5.5 glyphosate capsules/plant (Stringer et al. 2008). This is an important factor to consider when treating larger areas, or areas that contain native plants. However, in the cut-a-major limb and space-cut methods the applicator is able to have more control over herbicide movement than in spraying, because the herbicide is applied directly to the cut, thus minimizing the hazard to off-target plants (Motooka 1999). Future studies must consider using herbicides that are less mobile than Tordon, which has high potential for soil mobility (Dow AgroSciences LLC 1998b); and also monitor non-target species before and after application is performed.

Based on the evidence collected, my hypothesis is rejected. I conclude that cut-a-major limb with Tordon and Garlon in late fall is not as effective as space-cuts or other methods. This research should be viewed as preliminary and is presented to provide more information regarding reduction of herbicide use in restoration projects. The results of this research complement work done by Hunter and other authors on *L. maackii* control. Based on this study, space-cuts with Tordon have been proven to be more effective than cut-a-major limb method in killing *L. maackii*. Space-cuts method could be used in small restoration projects as an alternative to control single-stemmed medium-size shrubs, as it will be economically viable for small areas (because little equipment is required) and will have less impact on non-target species. Perhaps it may also be a valid alternative to consider for larger areas, though it requires more time to apply and more herbicide than other methods. Depending on the budget that land managers have, the space-cuts method may also be feasible for larger restoration projects and when spot treatment is needed.
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Table 1: Effect of cut-a-major limb treatment on *L. maackii* shrubs in Wilmington, OH. Limbs were cut and painted with glyphosate by Paul Hunter. Data provided by P. Hunter (2008, personal communication)

<table>
<thead>
<tr>
<th>Date of Application</th>
<th>No. Shrubs Treated</th>
<th>Shrubs Killed</th>
<th>Shrubs Partially Killed</th>
<th>Shrubs Alive</th>
</tr>
</thead>
<tbody>
<tr>
<td>July, 2007</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>October, 2007</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>May, 2008</td>
<td>6</td>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>June, 2008</td>
<td>11</td>
<td>9</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>July, 2008</td>
<td>31</td>
<td>17</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>51</td>
<td>35</td>
<td>14</td>
<td>2</td>
</tr>
</tbody>
</table>
Table 2: Daily minimum and maximum temperature (° C) of the week when herbicide was applied (Miami University Weather Station)

<table>
<thead>
<tr>
<th>Date</th>
<th>Lowest Temperature</th>
<th>Highest Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/16/2008</td>
<td>0.88</td>
<td>3.67</td>
</tr>
<tr>
<td>10/17/2008</td>
<td>-1.83</td>
<td>2.67</td>
</tr>
<tr>
<td>10/18/2008</td>
<td>-5.16</td>
<td>1.05</td>
</tr>
<tr>
<td>10/19/2008</td>
<td>-6.72</td>
<td>5.22</td>
</tr>
<tr>
<td>10/20/2008</td>
<td>-1.78</td>
<td>3.11</td>
</tr>
<tr>
<td>10/21/2008</td>
<td>-5.11</td>
<td>-0.11</td>
</tr>
<tr>
<td>10/22/2008</td>
<td>-8.94</td>
<td>0.17</td>
</tr>
</tbody>
</table>
Table 3: Results of logistic regression of STEMFATE2009 (alive or dead) on APPLICATION method, with STEMS, DIAMETER and HEIGHT as covariates, for 60 *L. maackii* shrubs treated with Tordon in Nov. 2008 at the ERC in Oxford, OH. Mortality was assessed April 2009. * indicates effects significant at P<0.01

<table>
<thead>
<tr>
<th>Source</th>
<th>Likelihood Ratio</th>
<th>Prob&gt;Chisq</th>
</tr>
</thead>
<tbody>
<tr>
<td>APPLICATION</td>
<td>7.17</td>
<td>0.0074*</td>
</tr>
<tr>
<td>STEMS</td>
<td>14.74</td>
<td>0.0001*</td>
</tr>
<tr>
<td>DIAMETER (meters)</td>
<td>0.23</td>
<td>0.6334</td>
</tr>
<tr>
<td>HEIGHT (meters)</td>
<td>2.04</td>
<td>0.1528</td>
</tr>
</tbody>
</table>
Table 4: Number of treated stems and means of base diameter, height, and stem number for live and dead shrubs that were treated (using space-cuts and cut-a-major limb method with Tordon and Garlon herbicides) at the ERC in Oxford, Ohio

<table>
<thead>
<tr>
<th>Mean</th>
<th>Dead, N=10</th>
<th>Not Dead, N=110</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base diameter of the Treated Stem (cm)</td>
<td>5.47</td>
<td>5.80</td>
</tr>
<tr>
<td>Height (m)</td>
<td>3.48</td>
<td>3.68</td>
</tr>
<tr>
<td>Number of stems</td>
<td>1.0</td>
<td>1.89</td>
</tr>
</tbody>
</table>
Table 5: Cost comparison of treating 30 *L. maackii* shrubs with each method

<table>
<thead>
<tr>
<th>Method</th>
<th>Amount of Herbicide Used (ml)</th>
<th>Cost of tools ($)</th>
<th>Herbicide Cost ($)</th>
<th>Amount of Labor (hrs)</th>
<th>Total Material Costs ($)</th>
<th>Total Costs ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut-a-major limb</td>
<td>60.00</td>
<td>66.00</td>
<td>5.40</td>
<td>1.95</td>
<td>71.40</td>
<td>98.70</td>
</tr>
<tr>
<td>Garlon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cut-a-major limb</td>
<td>60.00</td>
<td>66.00</td>
<td>0.95</td>
<td>1.60</td>
<td>66.95</td>
<td>89.35</td>
</tr>
<tr>
<td>Tordon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Space-cuts</td>
<td>800.00</td>
<td>40.00</td>
<td>72.00</td>
<td>1.28</td>
<td>112.00</td>
<td>129.92</td>
</tr>
<tr>
<td>Garlon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Space-cuts</td>
<td>600.00</td>
<td>40.00</td>
<td>9.48</td>
<td>1.45</td>
<td>49.48</td>
<td>69.78</td>
</tr>
<tr>
<td>Tordon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: The costs of the herbicide were calculated using the number of milliliters of diluted (or undiluted) herbicide that was used. The retail cost of Tordon RTU was $14.95 for a 946 ml bottle and of Garlon 3A was $90.00 for 1000 ml. Total labor time includes finding the corresponding labeled shrub, measurements (i.e. limb diameter) and treatment application (mechanical/ herbicide method). The total labor costs were calculated by multiplying the total amount of man-hours spent by the labor rate per man-hour, using the Ohio minimum wage of ($7/hr). For example, two people spent 1.28 hr in the space-cuts/Garlon application treatment, so the labors costs were calculated as 2(persons) x 1.28(hours/person) x 7($/hour) = $17.92.
Table 6: Cost comparison among different studies of chemical control of *Lonicera* shrubs; contains treatment labor time, material costs (tools, herbicide, etc.)

<table>
<thead>
<tr>
<th>Method/Herbicide used</th>
<th>Materials ($)</th>
<th>Labor Time (person-hr/1000 m²)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection EZ-Ject with glyphosate</td>
<td>599.00</td>
<td>45.45</td>
<td>Hartman and McCarthy (2004)</td>
</tr>
<tr>
<td>Cut and Paint with glyphosate</td>
<td>253.00</td>
<td>106.06</td>
<td>Hartman and McCarthy (2004)</td>
</tr>
<tr>
<td>Foliar Spray with glyphosate</td>
<td>220.50</td>
<td>3.12</td>
<td>Trisel (1997)</td>
</tr>
<tr>
<td>Cut and Paint with glyphosate</td>
<td>226.50</td>
<td>14.37</td>
<td>Trisel (1997)</td>
</tr>
<tr>
<td>Cut and paint with Garlon 3A+AX-IT</td>
<td>5.90</td>
<td>3.01</td>
<td>Rathfon and Ruble (2007)</td>
</tr>
<tr>
<td>Basal Bark with Garlon 4+AX-IT</td>
<td>11.49</td>
<td>0.74</td>
<td>Rathfon and Ruble (2007)</td>
</tr>
<tr>
<td>Foliar with Triclopyr</td>
<td>22.77</td>
<td>1.61</td>
<td>Rathfon and Ruble (2007)</td>
</tr>
<tr>
<td>Foliar spray with glyphosate</td>
<td>2.02</td>
<td>1.14</td>
<td>Stringer et al (2008)</td>
</tr>
<tr>
<td>EZ-Ject with glyphosate</td>
<td>249.00</td>
<td>4.45</td>
<td>Stringer et al (2008)</td>
</tr>
<tr>
<td>Space-cuts with Tordon</td>
<td>110.76</td>
<td>21.64</td>
<td>This study</td>
</tr>
</tbody>
</table>

Notes: Labor time was calculated using the time reported in each study and transformed to person-hours to treat 1000 m². This study used 1 hr and 27min to treat 30 shrubs (2.9 person-hours to eradicate 134 m²). Some of these times are expected to be an overestimation (since volunteers were used) of actual time for people working in eradication programs (trained employees would treat more shrubs per hour). The cost of the herbicide was calculated using the area and cost reported by each study, and converting to the cost to treat 1000m². Hartman and McCarthy (2007) only provided the start up cost, which was the cost of the gallon of herbicide without specifying the amount of herbicide used/left over after the experiment.  
1 The author only provided the costs of the herbicide
Table 7: Cost comparison of removing *Lonicera maackii* among different organizations; contains total costs provided by different organizations in Ohio and Indiana

<table>
<thead>
<tr>
<th>Method and Herbicide used</th>
<th>Total costs ($/1000 m²)</th>
<th>Total Costs ($/ Acre)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contracted foliar spray with 1 ¼% glyphosate</td>
<td>61.78</td>
<td>250</td>
<td>Borgman (2009)</td>
</tr>
<tr>
<td>Contracted cut-stump with 33% glyphosate</td>
<td>790.74</td>
<td>3,200</td>
<td>Borgman (2009)</td>
</tr>
<tr>
<td>Contracted Brush mowing</td>
<td>195.40</td>
<td>900</td>
<td>Borgman (2009)</td>
</tr>
<tr>
<td>In house foliar spray with 1 ¼% glyphosate</td>
<td>37.10¹</td>
<td>150</td>
<td>Borgman (2009)</td>
</tr>
<tr>
<td>In house Cut-stump with 33% glyphosate</td>
<td>296.53</td>
<td>1,200</td>
<td>Borgman (2009)</td>
</tr>
<tr>
<td>Foliage Spray with 4% glyphosate and blue die (in shrubs &lt; 6 foot high and smaller) combined with Cut-stump with 50% dicamba and water (Banvel) (in bushes &gt; 6 foot high)</td>
<td>82.29²</td>
<td>333</td>
<td>Wakeland (2009)</td>
</tr>
<tr>
<td>Cut-stump with glyphosate</td>
<td>362.70³</td>
<td>1,468</td>
<td>Devore (2009)</td>
</tr>
<tr>
<td>Space-Cuts with Tordon</td>
<td>262.24</td>
<td>939</td>
<td>This study</td>
</tr>
</tbody>
</table>

Notes: The total costs were calculated using the costs reported by each person and transformed to treat 1000 m². For example, this study used 600 ml of herbicide to treat 134 m² ($9.48) and 2.9 person-hours; therefore, treating an acre will cost [ $286.36 (herbicide costs)+ 87.58 person-hours ($7.00)+ $40 (axe)].

¹ This reported cost does not include equipment expenses

² This reported cost is for larger infestations and does not include removing the brush from site

³ This reported cost includes removing all of the stems, chipping them up and hauling them away
Methods:
- Mechanical (1, 2, 5)
- Chemical (1, 2, 3, 4, 5)

1. Girdling (fig. 1, 2, 4)
2. Frilling (fig. 3)
3. Space-cuts (fig. 5)
4. Basal Bark (fig. 6)
5. Cut-Sump (fig. 7, 8)

Figure 1: Methods commonly used to treat undesirable trees and shrubs (including *Lonicera maackii*) (figures reproduced with permission from Heiligmann 1998)
Figure 2: Cut-a-major limb method. The largest limb of this *L. maackii* in the ERC, Oxford, OH was cut with loppers and painted with Tordon.
Figure 3: Effects of Nov. 2008 herbicide and application on April 2009 fate of (A) single-stemmed and (B) multiple-stemmed shrubs. The two application methods were cut-a-major limb (CML) and space-cuts (SC).