# FIELD TEST OF FOLIAR-SPRAY HERBICIDES TO CONTROL MOUNTAIN LAUREL IN MATURE MIXED-OAK FORESTS IN WESTERN MARYLAND

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**Abstract**—Successful oak (*Quercus* spp.) regeneration requires the presence of competitive sources of oak reproduction before parent oaks are harvested. Mountain laurel (*Kalmia latifolia*) in the understory of many Appalachian forests prevents new oak seedlings from receiving adequate sunlight to survive and grow into competitive size classes. This study examined the efficacy of three herbicides (triclopyr, glyphosate, or imazapyr) applied as a foliar spray on mountain laurel in a mature mixed-oak forest. Each herbicide was applied at three rates, expressed as quarts per acre. The herbicides were mixed in water with a surfactant added to achieve application rates within U.S. Environmental Protection Agency label limits. The nine herbicide/rate combinations were applied once each in four different months (April, June, August, or October). Efficacy was quantified by the percentage of mountain laurel foliage controlled 12 months after treatment on 200 randomly assigned 0.005-acre plots. Triclopyr applied at 4.8 quarts per acre provided > 85 percent foliage control in all four months. Glyphosate applied at 4.8 quarts per acre also provided > 85 percent foliage control in April, June, and August. Imazapyr provided significantly less foliage control, and some hardwood trees were damaged adjacent to plots treated with imazapyr. Study results for all 36 herbicide/rate/month combinations are provided.

## INTRODUCTION

Numerous research studies have indicated that successful oak (*Quercus* spp.) regeneration depends on the presence of competitive sources of oak reproduction when overstory harvests or other stand-replacing disturbances occur (Dey 2014, Loftis 2004). One reason why large, competitive advanced reproduction does not develop in mature mixed-oak forests is that interfering plants in the understory limit the availability of sunlight (Brose and others 2008, Rebbeck and others 2011). Examples of interfering plants include ferns, grasses, suppressed shade-tolerant trees, and various evergreen or deciduous shrubs. Fire suppression, heavy deer browsing, and repeated partial harvest practices have contributed to the development of interfering plants (Nowacki and Abrams 2008, Rooney 2009, Schuler 2004). Such interference often develops and persists over many decades. Without a natural or prescribed intervention to reduce the interference, successive acorn crops rarely become competitive advanced seedlings to sustain the oak component in the next stand (Loftis 1985, 1990).

Remedial measures for controlling interfering plants include mechanical methods, herbicides that involve either broadcast or stem-applied methods, and prescribed fire. Mechanical methods include the use of brush saws, chainsaws, girdling, disking, or simply crushing with large machinery to reduce low shade that may be suppressing desirable reproduction (Lof and others 2012, Nyland and others 2006). Hand methods can effectively target individual plants but can be relatively labor intensive and costly. None of the mechanical methods mentioned, however, eliminates sprouting from cut stumps or damaged roots. If the controlled plants sprout and become reestablished in just a few years, small advanced oak reproduction may not have enough time to grow into competitive size classes (Brose 2011, Miller and others 2014).

Herbicide treatments can also be applied to control interfering plants. Hack-and-squirt methods are effective at controlling small trees (Miller and others 2004, Schweitzer and Dey 2015). Basal bark methods are effective at controlling small woody stems, although

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the cost becomes prohibitive where prescriptions involve numerous stems over large acreages (Miller 1990, Zedaker 1986). Broadcast foliar-spray methods are often more efficient than target-specific methods for dense coverage of interference whose height does not exceed 15 to 20 feet (Horsley and Bjorkbom 1983, Nyland and others 2006). It is often necessary to apply stem injection treatments as a follow-up to foliar-spray treatments to control taller interference. For root-sprouting species, the cut-stump method can control thousands of stems with a relatively small volume of herbicide per acre (Kochenderfer and others 2013). Dense interference from grasses and ferns can be controlled with broadcast treatments of glyphosate and sulfometuron methyl (Engelman and Nyland 2006, Horsley 1991).

Prescribed fires are often recommended for reducing woody interference and preparing the seedbed for a future acorn crop in mature oak stands (Brose and others 2014). Such treatments are effective at reducing low woody interference, while taking care to avoid damage to the overstory trees. Historically, mountain laurel (*Kalmia latifolia*) was likely controlled under mature mixed-oak forests by repeated wildfires (Monk and others 1985). More recently, however, effective landscape-scale fire exclusion has promoted the development of low woody interference in the majority of mature oak stands, including vast areas of mountain laurel and other ericaceous shrubs (Brose and others 2014, Nowacki and Abrams 2008). Although prescribed fires can be applied to control mountain laurel interference in oak stands, forest managers have experienced three major drawbacks with this approach. First, fires applied in mature stands with dense mountain laurel interference tend to be relatively severe with much higher flame lengths and faster rates of spread that cause real or perceived damage to the value of merchantable overstory timber. Second, in stands where advanced oak reproduction is sparse or too small to be resistant, fire can eliminate any advanced oak reproduction that is present until the next acorn crop. Third, mountain laurel can sprout quickly after the fire treatment and regain its interference status before adequate competitive oak reproduction develops (Elliott and others 1999, Moser and others 1996).

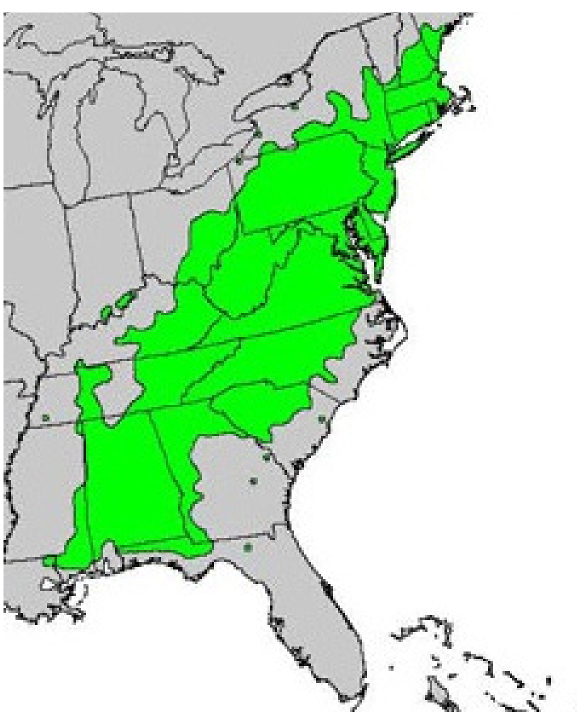

Figure 1—Native range of mountain laurel found mostly on dry, acid soils often associated with mixed-oak forests.

A broadcast foliar-spray herbicide treatment may be a better method for reducing mountain laurel interference if preservation of timber value and control of sprouting are needed throughout the oak regeneration process. The objective of this study was to quantify the effects of three foliar-spray herbicides applied at three rates per acre and at four different times of the year on the percentage of mountain laurel foliage controlled 12 months after treatment. The results would allow forest managers to formulate a mechanized broadcast prescription to successfully control mountain laurel, with some flexibility in the prescription to be consistent with other management objectives.

## Background on Mountain Laurel

Mountain laurel is an evergreen shrub that develops dense thickets over many decades beneath mature forests in the Appalachian Mountains (fig. 1). If allowed to spread without the controlling influence of wildfires or other disturbances, individual plants can live as long as 40 to 60 years (McNab and Clinton 2004). It is generally associated with dry, acid soils where it can cover large areas and interfere with tree regeneration mainly by shading the forest floor and competing for moisture (Chastain and Townshend 2008, Kaeser and others 2008). This species of *Kalmia* is not considered to be allelopathic (Eppard and others 2005). It reproduces mostly by sprouting and layering, although it is capable of reproducing by seed (Malek and others 1989, Rathcke 2003).

Leaf longevity of mountain laurel can affect its sensitivity to foliar-spray herbicide treatments. Twig and foliar growth occurs in early April through June, and flowering usually occurs in May (Richardson and O'Keefe 2009). Mature leaves develop a thick, waxy cuticle that may inhibit absorption of water-soluble herbicides unless a surfactant is added to improve spread and penetration. New leaves remain on the plant for 2 to 3 years, with most dropping between spring and autumn of the second year. As a result, about half of the leaves present from spring to autumn are new leaves, while the other half are 1 to 2 years old (Monk and others 1985).

### Background on Herbicides and Surfactant

Triclopyr is a selective systemic herbicide that mimics auxin, a plant hormone involved in cell growth (Tu and others 2001). Once absorbed, triclopyr causes disorganized cell growth and vascular tissue destruction. It is effective at controlling sprouting because it stays active in target plants until they die. The ester formulation used in this study is relatively non-toxic to terrestrial animals, but can be toxic to fish and aquatic invertebrates if it reaches water systems. However, it is generally not mobile in soil, so applications should be planned to avoid movement through surface runoff or melting snow.

Glyphosate is a non-selective systemic herbicide that interferes with the formation of amino acids used to synthesize proteins, and thereby kills the plant by disrupting metabolism (Carlisle and Trevors 1988). Glyphosate has relatively low toxicity to birds and mammals (Evans and Batty 1986). The Rodeo® form of glyphosate used in this study is rated for aquatic use. It rapidly binds to soil particles, thus making it relatively immobile and incapable of absorption by non-target plant root systems (Feng and Thompson 1990). Degradation occurs mainly by microbial metabolism in the soil (Carlisle and Trevors 1988).

Imazapyr is a selective systemic herbicide that inhibits the enzyme acetolactate synthase, which catalyzes the production of amino acids essential for cell growth (Tu and others 2001). Unlike the other herbicides used in this study, imazapyr does not bind well to soil particles (McDowell and others 1997). It can leach from the roots of treated plants and damage nearby non-target plants by absorption through their root systems (DiTomaso and Kyser 2007, Kochenderfer and others 2001, Lewis and McCarthy 2008). It exhibits relatively low toxicity to birds, mammals, and fish (Patten 2003, Tatum 2004). Imazapyr is not readily metabolized in plants and provides relatively slow control of target vegetation (Tu and others 2001).

Haller and Stocker (2003) reported the relative toxicity of several adjuvants, including the limonene non-ionic surfactant Cide-Kick® that was added to the herbicides used in this study. They concluded that acutely toxic concentrations would be avoided where label recommendations were followed under normal use conditions, as was done in this study.

## STUDY SITE

The study site is a 49-acre mature, mixed-oak forest located within the Potomac-Garrett State Forest in western Maryland. Basal area averaged 128 square feet per acre, relative density was 106 percent, and the quadratic mean diameter at breast height (d.b.h.) was 10 inches. The overstory trees date to the early 1920s and are composed of 35 percent chestnut oak (*Q. montana*), 20 percent northern red oak (*Q. rubra*), 16 percent red maple (*Acer rubrum*), 16 percent blackgum (*Nyssa sylvatica*), 5 percent sweet birch (*Betula lenta*), 4 percent white oak (*Q. alba*), 2 percent scarlet oak (*Q. coccinea*), and 2 percent sassafras (*Sassafras albidum*). Fire was excluded from the study site since the 1920s. The species composition was typical of the mixed mesophytic forest described by Braun (1950), with a site index of 65 for northern red oak, base age 50 years. Elevation on the study site ranges from 2,780 to 2,860 feet, with 0 to 15 percent slopes on a ridgetop or slightly west aspect. Annual precipitation averages 45 inches and is evenly distributed throughout the year. Few advanced oak seedlings were present, and oak regeneration stocking was zero as defined by Brose and others (2008). Stocking of tall woody interference and low woody interference was 70 percent and 65 percent, respectively. The low woody interference was composed mainly of mountain laurel ranging in height from 3 to 11 feet. Soils are described as Dekalb very stony sandy loam and Leetonia very stony sandy loam (Stone and Matthews 1974).

## METHODS AND DESIGN

The treatments consisted of three herbicides, applied at three rates per acre, and applied once each in four different months. The herbicides tested in this study were triclopyr as Garlon® 4 Ultra, glyphosate as Rodeo®, and imazapyr as Chopper® Gen2™. Cide-Kick® surfactant was added to each herbicide to improve spread and penetration. The herbicide solutions, including appropriate volumes of undiluted herbicide, water, and surfactant, were mixed under controlled conditions off-site (table 1). The application rates were 1.6, 3.2, and 4.8 quarts per acre for triclopyr and glyphosate, and 0.8, 1.6, and 2.4 quarts per acre for imazapyr. Product labels approved by the U.S. Environmental Protection Agency specify a maximum of 8 quarts per acre for triclopyr and glyphosate and 3 quarts per acre for imazapyr. Previous guidelines for controlling mountain laurel with foliar-spray treatments were considered when setting the application rates in this study (Jackson and Finley 2005, Kochenderfer and others 2012). Finally, the treatments were applied in April, June, August, or October 2013 to determine if efficacy varied by month of application.

The study was based on a completely randomized design. Two hundred permanent circular plots were established where a somewhat ubiquitous understory cover of mountain laurel was present.

**Table 1—Herbicide solution components and total solution volume applied to each 0.005-acre plot and the equivalent herbicide application rate per acre for each treatment**

| Herbicide name & concentration | Herbicide volume | Water volume | Surfactant volume[1] | Total solution volume | Application rate |
|---|---|---|---|---|---|
| | ------------------------ milliliters per plot ------------------------ | | | | quarts per acre |
| 1% triclopyr[2] | 7.6 | 745.6 | 3.8 | 757 | 1.6 |
| 2% triclopyr | 15.2 | 738.0 | 3.8 | 757 | 3.2 |
| 3% triclopyr | 22.8 | 730.4 | 3.8 | 757 | 4.8 |
| 1% glyphosate[3] | 7.6 | 745.6 | 3.8 | 757 | 1.6 |
| 2% glyphosate | 15.2 | 738.0 | 3.8 | 757 | 3.2 |
| 3% glyphosate | 22.8 | 730.4 | 3.8 | 757 | 4.8 |
| 0.5% imazapyr[4] | 3.8 | 749.4 | 3.8 | 757 | 0.8 |
| 1.0% imazapyr | 7.6 | 745.6 | 3.8 | 757 | 1.6 |
| 1.5% imazapyr | 11.4 | 741.8 | 3.8 | 757 | 2.4 |
| Control | 0 | 0 | 0 | 0 | 0 |

[1]Non-ionic surfactant as Cide-Kick® (100% active ingredient [a.i.]); [2]triclopyr as Garlon® 4 Ultra (60.5% a.i.); [3]glyphosate as Rodeo® (53.8% a.i.); [4]imazapyr as Chopper® Gen2™ (26.7% a.i.).

Each plot was 8.3 feet in radius, thus covering 0.005 acre. Plots were separated by untreated buffer zones of at least 25 feet to isolate the effect of the herbicide treatments between plots. The center of each plot was marked with a permanent rod, and a nearby witness tree was painted with a colored ring to facilitate locating the plots. Five plots were randomly assigned to each of the 36 treatments (180 plots) and untreated controls (20 plots).

Before treatment, the perimeter of each plot was marked with colored flagging at several points on the ground to indicate the correct radius from the center point. The initial percent cover of mountain laurel foliage within each plot was determined to the nearest 5 percent and recorded. The volume of herbicide solution for each treatment was pre-measured and put in separate bottles such that each plot received an equal amount of herbicide solution. The herbicide treatments were applied with a hand-held garden sprayer, the entire content of each pre-measured bottle was applied to a plot, and the foliage within a plot was completely wetted. Care was taken to clean and rinse each garden sprayer before and after each treatment. Treatments were applied on days when the weather was dry, and no rain was expected for at least 48 hours after treatment. The difference between the initial cover of foliage and the cover of foliage 12 months later was used to quantify the efficacy of the treatments.

## ANALYSES

Two analyses were conducted. The first analysis was a completely randomized design to compare the percentage of foliage controlled on the treated plots to that observed on the control plots.
The second analysis focused on a completely randomized factorial (3×3×4) design to examine the effect of the herbicide (factor 1), the application rate per acre (factor 2), and the month of application (factor 3) on the percentage of foliage controlled on the treated plots, excluding the control plots. The resulting fixed effect model has the form:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + \theta_k + (\alpha\beta)_{ij} + (\alpha\theta)_{ik} + (\beta\theta)_{jk} + (\alpha\beta\theta)_{ijk} + \varepsilon_{ijk}$$

where,

$Y$ = the percentage of mountain laurel foliage controlled,

$\mu$ = the overall mean,

$\alpha$ = the effect of the herbicide,

$\beta$ = the effect of the application rate per acre,

$\theta$ = the effect of month of application,

$\varepsilon$ = the random error.

Herbicide, application rate per acre, and month of application were fixed effects; the remaining terms represent the interaction of factors in the full model. The generalized linear mixed model routine in SAS was used for all statistical analyses (SAS Institute Inc. 2011). Initially, percent cover of mountain laurel in the pre-treatment inventory of plots was evaluated as a possible covariate in the model, but was not statistically significant. A pseudo-likelihood estimation technique via PROC GLIMMIX was used to model the efficacy of the treatments. A beta distribution and a logit link function were used because the response variable was a percentage with many small and large values. The Tukey-Kramer least squares mean separation test was used for all multiple comparisons. The differences between treatment means were considered to be statistically significant when $p < 0.05$. For each analysis, the residuals were tested for normality by the Shapiro-Wilk test and for homogeneity of variance by the Levene test.

## RESULTS

In the first analysis, all treatments significantly reduced the cover of mountain laurel foliage compared to untreated controls ($p < 0.01$) (fig. 2). In the second analysis, foliage control differed among herbicides ($p < 0.01$), application rates ($p < 0.01$), and month of application ($p < 0.01$). The interactions of factors in the full model were statistically significant as well ($p < 0.01$), thus indicating a dose response for each herbicide that varied by month (table 2). In general, efficacy increased at higher application rates of each herbicide tested.

Mountain laurel was most sensitive to herbicide treatments in the June applications. New leaves emerge in May and June and have less waxy coating than mature leaves present at other times of the year. Foliage control was > 90 percent for both triclopyr and glyphosate applied at 1.6, 3.2, and 4.8 quarts per acre in June (table 2). With imazapyr, foliage control was > 55 percent at 1.6 and 2.4 quarts per acre in June, but was < 42 percent for all other treatments (table 2).

The October treatments of all herbicides and application rates exhibited the lowest foliage control compared to other months, but a dose response was still evident. For example, foliage control increased from 25 to 86 percent as the triclopyr application rate increased from 1.6 to 4.8 quarts per acre in October (table 2). Similarly, foliage control increased from 13 to 29 percent for glyphosate and from 10 to 22 percent for imazapyr as the application rates increased from low to high.

Among the three herbicides tested, triclopyr exhibited the most consistent control of mountain laurel foliage, with > 75 percent control at 3.2 quarts per acre and > 85 percent control at 4.8 quarts per acre in each of the months tested (table 2). Glyphosate provided similar foliage control compared to triclopyr in June and August, but significantly less control in April and October. Imazapyr provided > 55 percent control at 1.6

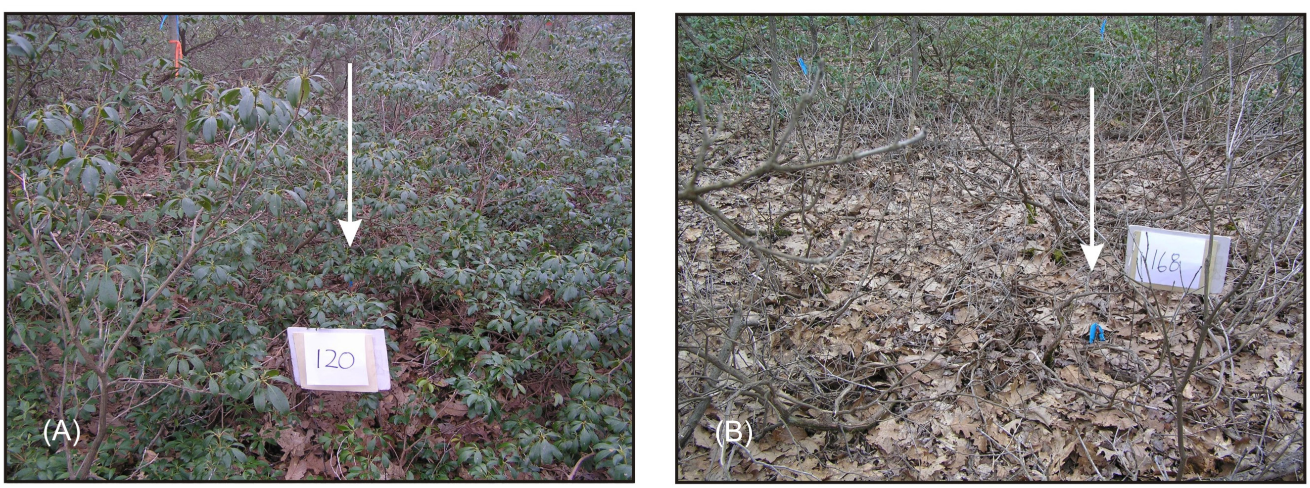


Figure 2—Mountain laurel foliage cover 12 months after (A) no treatment and (B) treatment with 4.8 quarts per acre Garlon® 4 Ultra. White arrows indicate plot centers. (photos by Gary W. Miller)

**Table 2—Mean percentage of mountain laurel foliage controlled 12 months after foliar-spray treatments, n=5 observations for each entry, one standard error in parentheses, followed by results of multiple comparisons[1]**

| Herbicide | Application rate | Month of application 2013 | | | |
|---|---|---|---|---|---|
| | | April | June | August | October |
| | quarts per acre | ----------- percentage of foliage controlled ------------ | | | |
| triclopyr[2] | 1.6 | 61.5 (9.8)e | 94.8 (0.1)b | 81.1 (5.0)d | 24.6 (5.8)i |
| | 3.2 | 87.0 (6.8)cd | 94.7 (0.1)b | 76.7 (4.5)d | 75.8 (1.9)d |
| | 4.8 | 99.0 (1.0)a | 91.8 (1.9)c | 92.1 (1.3)c | 86.3 (6.0)cd |
| glyphosate[3] | 1.6 | 18.0 (3.4)gh | 92.6 (2.1)bc | 56.1 (6.2)e | 12.6 (1.2)h |
| | 3.2 | 73.3 (9.5)d | 97.9 (1.3)a | 92.0 (1.3)c | 27.6 (6.8)fg |
| | 4.8 | 89.8 (4.9)cd | 97.8 (1.4)a | 91.8 (1.6)c | 29.2 (5.9)fg |
| imazapyr[4] | 0.8 | 40.0 (9.9)ef | 17.2 (2.6)gh | 17.7 (5.1)gh | 10.4 (0.3)j |
| | 1.6 | 41.5 (7.8)ef | 57.1 (13.4)e | 36.1 (8.0)fg | 14.7 (2.2)hi |
| | 2.4 | 41.1 (6.8)ef | 62.7 (14.9)de | 36.5 (3.9)f | 21.6 (1.7)g |
| Control | | 0 | 0 | 0 | 0 |

[1]Entries followed by the same letter are not significantly different at $\alpha = 0.05$; [2]triclopyr as Garlon® 4 Ultra (60.5% a.i.); [3]glyphosate as Rodeo® (53.8% a.i.); [4]imazapyr as Chopper® Gen2™ (26.7% a.i.).

quarts per acre and > 60 percent control at 2.4 quarts per acre in June, but significantly less control in August and October.

## DISCUSSION

Each of the treatments tested in this study offers at least one superior attribute, depending on management objectives. For example, imazapyr provided less foliage control than triclopyr and glyphosate, but small conifer seedlings are not sensitive to imazapyr at the application rates tested. The forest manager might choose to accept less control of mountain laurel foliage in cases where less damage to conifer seedlings is an acceptable tradeoff. Similarly, glyphosate is the least expensive herbicide of the three tested in this study, and it is also effective in other foliar-spray, injection, and cut-stump treatments. The forest manager might choose to apply glyphosate to control mountain laurel because it is versatile, and any remaining herbicide can be used for many other herbicide application prescriptions. Triclopyr provided superior foliage control in each month tested, and it is the least mobile of the three herbicides tested, both within the vascular system of the target plant and within the soil and environment. However, Garlon® 4 Ultra is relatively volatile at temperatures > 80 degrees Fahrenheit, thus increasing the risk of damage to non-target plants on hot days. Triclopyr and imazapyr also provide greater control of post-treatment sprouting of the target plant compared to glyphosate (Kochenderfer and others 2012).

Regarding timing, April treatments are superior because most other desirable vegetation is still dormant in early spring. Only the mountain laurel foliage and other evergreen plants are likely to be damaged by foliar-spray treatments applied in April. October is another time when many desirable plants are dormant, but efficacy declined significantly in autumn when mountain laurel growth is waning (table 2). Although mountain laurel was most sensitive to the herbicide treatments applied in June, some management objectives may be inconsistent with late spring-early summer operations. Many species of songbirds are actively nesting and fledging young in mountain laurel at that time of year. Forest managers might avoid June treatments to minimize disturbance to songbird breeding activity. Desirable tree seedlings and most herbaceous species are actively growing by mid-June, so herbicide treatments at that time may result in unacceptable collateral damage to non-target species

The percentage of foliage control is expected to increase beyond 12 months for each of the herbicides tested. Efficacy exceeded 85 percent for most of the medium and high application rates for triclopyr and glyphosate after 12 months. Foliage control and plant mortality will likely approach 100 percent in the second growing season after treatment. Imazapyr in particular is documented to take longer than the other herbicides to control target vegetation, due in part to its slower metabolism.

For each treatment, foliage control did not extend beyond the perimeter of the plots. Foliage outside the plots was not affected, even where control reached 100 percent. The study site had an obvious “spotted” appearance where mountain laurel foliage was missing in somewhat perfect circles 12 months after treatment. Although mountain laurel reproduces in part by layering, this observation indicates that the herbicide treatments had limited mobility through root networks, and that herbicide contact with foliage was the primary mechanism of absorption. When planning mechanized broadcast treatments, it is important to obtain adequate herbicide contact with foliage and sufficient absorption of active ingredient to achieve the desired degree of control.

A damage assessment was conducted in mid-September 2014, about 11 to 17 months after the treatments, to determine if non-target trees on or adjacent to the treated plots had suffered any herbicide damage. No damage was associated with plots treated with triclopyr or glyphosate. All plots treated with imazapyr in April, June, or August had damaged trees on or within 13 feet of the plot. Only two plots treated with imazapyr in October had nearby damaged trees 11 months after treatment, but additional damage may become apparent in later assessments. Damaged trees were either completely defoliated or exhibited deformed or chlorotic leaves. Species damaged around plots treated with imazapyr included red maple, blackgum, sassafras, and sweet birch. One 15-inch d.b.h. chestnut oak had deformed leaves in its upper crown. Damaged trees ranged in size from 3 to 16 inches d.b.h., and it was assumed that imazapyr was absorbed through root uptake within the treated plots. Assessments will be continued for several years to determine the full extent of damage to non-target plants.

The results of this study indicate the need for further research on foliar-spray herbicide control of mountain laurel. In this study the herbicide treatments were applied by hand, assuring that foliage was thoroughly wetted and the volume of herbicide delivered per unit area was consistent. Further testing is needed at operational scales using mechanized broadcast spray equipment to define how the results may vary under real-world conditions. In addition, the treated plots will be monitored for several years to quantify any increases in efficacy that may occur in subsequent growing seasons, the degree to which mountain laurel plants become reestablished after the herbicide treatments, and whether collateral damage or additional mountain laurel mortality occurs outside the treated plots. Finally, additional testing is needed on other sites, where soil and other ecological conditions may differ, to see if the results reported here can be expected over a larger geographic region.

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