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A comparison of three foliar-applied herbicides for controlling mountain laurel thickets in the mixed-oak forests of the central Appalachian Mountains, USA☆

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A B S T R A C T

In the Appalachian Mountains of eastern North America, mountain laurel (*Kalmia latifolia*) thickets in mixed-oak (*Quercus* spp.) stands can lead to hazardous fuel conditions, forest regeneration problems, and possible forest health concerns. Generally, land managers use mechanical means or prescribed fire to control mountain laurel thickets, but these treatments are expensive, dangerous to implement, or have short-term effectiveness. From 2012 to 2016, we compared the effectiveness of three herbicides applied as broadcast foliar treatments at varying rates and in different months for reducing mountain laurel thickets. Triclopyr (ester formulation) top-killed mountain laurel within a few weeks at most month/rate combinations, but subsequent sprouting reduced overall effectiveness by year 3. Conversely, imazapyr provided little initial control of mountain laurel, but by year 3, the herbicide had killed nearly all the treated shrubs with no subsequent sprouting regardless of the month of application or rate. Glyphosate had limited effectiveness; spraying in August at 8 and 12 L/ha killed the mountain laurel over 3 years with little sprouting while all others treatments had little or no impact. From these results, it appears that several month/rate combinations of all three herbicides have potential for controlling mountain laurel thickets and merit further testing to refine application procedures.

1. Introduction

Throughout forests of the northern hemisphere, some species of heath shrubs (Family: Ericaceae) can form persistent understories (Royo and Carson, 2006). In the Appalachian Mountains of eastern North America, mountain laurel (*Kalmia latifolia*) is one such species (Brose, 2016; Chastain and Townsend, 2008; Monk et al., 1985). The shrub grows to 4 m tall and broad, is evergreen and shade tolerant, and occurs primarily on dry and intermediate moisture sites (Chapman, 1950; Kurmes, 1961). Mountain laurel spreads via layering of the lowermost branches as well as through dissemination of thousands of minute seeds (Chapman, 1950; Kurmes, 1961). In the absence of recurring fire, these silvical characteristics lead to dense thickets that can consist of thousands of stems/hectare and cover several hectares (Brose, 2016; Chapman, 1950; Monk et al., 1985).

Mountain laurel thickets can lead to several forest management problems. Because they occur on dry and intermediate sites, mountain laurel thickets often dominate the understories of the ecologically and economically important mixed-oak (*Quercus* spp.) forests. Their evergreen leaves cast perpetual dense shade. The resulting light level on the forest floor is usually less than 5 percent of full sunlight (Beckage et al., 2000; Clinton et al., 1994; Monk et al., 1985), a level too low for the long-term survival and development of oak seedlings (Brose, 2011; Frey and Ashton, 2018; Miller et al., 2014). Consequently, oak seedlings are usually scarce, small, and suppressed in mountain laurel thickets, making regeneration of this valuable forest type an arduous protracted process. Also, mountain laurel thickets are highly flammable; their leaves have a waxy cuticle and they contain volatile phenolic compounds. Mountain laurel thickets burn with high intensity posing a threat to human life and property as demonstrated by the fall 2016 fires in eastern Tennessee (Gabbert, 2016; Wilent, 2017). Finally, mountain laurel is susceptible to *Phytophthora ramorum*, the fungus that causes sudden oak death in California and Oregon, making the shrub a likely host if the disease becomes established in the eastern United States (Tooley et al., 2004; Tooley and Kyde, 2007).

Presently, forest managers rely on crushing, mowing, and prescribed fire to reduce the size and density of mountain laurel thickets, but these methods have serious limitations. Crushing is a low cost method done by skidders during a timber harvest, but not all mountain laurel thickets occur in stands suitable for a commercial harvest. Mowing costs range from $500 to $1000 per hectare (pers. comm. Andrea Hille, Silviculturist, Allegheny National Forest; Rob Beleski,

☆ Mention of a specific herbicide or surfactant in this manuscript does not constitute an endorsement of that product by the USDA Forest Service.

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Silviculture Section Chief, Pennsylvania Bureau of Forestry). Prescribed fires in mountain laurel thickets can produce flame lengths exceeding 7 m resulting in the damage and/or death of the overstory trees (Waldrop and Brose, 1999; Waldrop et al., 2008). Finally, both of these methods control mountain laurel for just a few years; post-treatment sprouting by the shrub re-establishes the thicket in 5–10 years (Brose 2017). Foliar herbicide applications may provide a more effective means of treating mountain laurel thickets than mowing and prescribed fire.

Foliar herbicides applied by mechanized spray equipment or by backpack sprayers have a long history of research and use in Pennsylvania. Horsley (1981) and Horsley and Bjorkbom (1983) pioneered the use of glyphosate as a site preparation technique to control hay-scented fern (*Dennstaedtia punctilobula*), root suckers of American beech (*Fagus grandifolia*), and striped maple (*Acer pensylvanicum*) in northern hardwood forests prior to regeneration harvests. Subsequent research identified sulfometuron methyl as an appropriate herbicide to reduce undesirable grasses and sedges that germinate en masse from stored seed after a timber harvest and prevent fern rhizome fragment development (Horsley 1988, 1990, 1991). More recently, researchers studied the effects of herbicides on non-target vegetation (Ristau 2010, 2017; Ristau et al., 2011). Conversely, foliar herbicide applications for controlling mountain laurel have not been extensively studied and the research used outdated chemicals. For example, Romancier (1971) found that spraying mountain laurel sprouts with 2,4,5-Trichlorophenoxyacetic acid solution (2,4,5-T) controlled them with no resprouting. However, 2,4,5-T was discontinued in the early 1980s.

Between 2012 and 2016, we tested three foliar herbicides commonly used in forestry operations to kill interfering understory vegetation as potential controls for mountain laurel thickets. We evaluated the application of three herbicides in four months and at three spray rates because month of application and spray rate strongly affect herbicide efficacy (Horsley and Bjorkbom, 1983; Horsley, 1988, 1994; Jackson and Finley, 2005). Our hypothesis was that least one herbicide/month/rate combination that would reduce dense mountain laurel cover to less than 20 percent, the threshold at which mountain laurel ceases to interfere with hardwood seedlings (Brose 2016). Knowing which chemical, dosage rate, and month of application provides the most control of mountain laurel will inform foresters challenged by mountain laurel thickets and, possibly, by other ericaceous shrubs.

2. Methods

2.1. Study sites

This study was conducted from 2012 to 2016 in four mixed-oak stands located in northwestern and central Pennsylvania (Fig. 1). The northwestern stands were Edeburn Hill (EBH) on Clear Creek State Forest (41.318 N, 79.039 W) and Hoover-Nelson Road (HNR) on Moshannon State Forest (41.061 N, 78.510 W) while the central stands were Pine Creek Hollow (PCH) on Bald Eagle State Forest (40.971 N, 77.203 W) and Shade Mountain (SHM) on Game Lands 107 (40.672 N, 77.343 W). Despite being 50 to 200 km from each other, the four study stands shared a number of characteristics. Each stand was 15- to 20-ha, had an elevation of approximately 550 m, a southerly aspect, and an oak site index$_{50}$ of 15–18 m (Braker, 1981; Hallowich, 1988; Lipscomb and Farley, 1981; Zarichansky, 1964). The upper canopy trees were 20–25 m tall and consisted primarily of chestnut oak (*Quercus montana*) and northern red oak (*Q. rubra*). Black oak (*Q. velutina*), scarlet oak (*Q. coccinea*), white oak (*Q. alba*), pitch pine (*Pinus rigida*), and eastern white pine (*P. strobus*) were also present. Associated midstory tree species included black birch (*Betula lenta*), blackgum (*Nyssa sylvatica*), red maple (*Acer rubrum*), sassafras (*Sassafras albidium*), and serviceberry (*Amelanchier arborea*). Canopy cover was not ubiquitous due to past disturbances. We visually estimated overstory stocking to be more than 70 percent. Mountain laurel dominated the understory plant community; visual estimates indicated thickets occupied at least 70 percent of each stand and ranged in height from 1 to 2 m. Also present were other shrub species such as bear oak (*Q. ilicifolia*), blueberry (*Vaccinium* spp.), huckleberry (*Gaylussacia* spp.), and sweet fern (*Comptonia peregrina*). Herbaceous plant diversity was quite limited; it consisted of scattered specimens of beetleweed (*Galax aphylla*), Virginia tephrosia (*Tephrosia virginiana*), trailing arbutus (*Epigaea repens*), and wintergreen (*Gautheria procumbens*). Similarly, hardwood reproduction was infrequent and consisted of small seedlings of the same species as the overstory and midstory trees.

Because these sites were 50–200 km apart, they differed in a number of characteristics. EBH and HNR were in the Allegheny Plateau region while PCH and SHM were in the Ridge/Valley region (Schultz, 1999). EBH and PCH were situated on midslope benches while HNR and SHM were located at/near hilltops. Local climate varied with EBH and HNR being the coolest and wettest (−10.8 to 25.1 C, 1100 mm precipitation) while PCH and SHM were the warmest and driest (−6.4 to 30.1 C, 950 mm precipitation) (Braker, 1981; Hallowich, 1988; Lipscomb and Farley, 1981; Zarichansky, 1964).

2.2. Study design, installation, and measurements

We designed the study as a 3 × 3 × 4 factorial with the four sites serving as replicates. The factors were three foliar herbicides, three spray rates, and four application times. The herbicides were glyphosate (Rodeo*), imazapyr (Chopper Gen II*), and triclopyr ester (Garlon 4 Ultra*). We chose these herbicides because they are commonly used in forest management to control undesirable understory vegetation (Jackson and Finley, 2005; Kochenderfer et al., 2011). Herbicide product labels approved by the U.S. Environmental Protection Agency (EPA) specify a maximum of 20 L per hectare (l/ha) for glyphosate and triclopyr and 8 l/ha for imazapyr (Senseman, 2007). For glyphosate and triclopyr, we chose spray rates of 4, 8, and 12 l/ha and 2, 4, and 6 l/ha for imazapyr. We chose these rates based on consultation with knowledgeable local foresters. The application times were between the 10th and 20th of April, June, August, and October 2013. We chose these months because mountain laurel is evergreen so April and October spraying may be possible, June is when the shrub is producing new growth that does not yet have a waxy cuticle, and August is the traditional spraying month in Pennsylvania (Horsley and Blorkbom, 1983; Horsley, 1994). For the remainder of this paper, the herbicides are referred to by their chemical names, the application times by their month, and rates by their l/ha amounts.

In 2012, we installed the study in each stand by locating and inventorying two hundred 40-m^2 (3.6 m radius) circular plots arranged in 40 rows of 5 plots each. The rows were at least 15 m apart and the plots within a row were 10–15 m apart based on each plot having at least 50 percent cover of mountain laurel. The center of each plot was marked with a 1-m fiberglass rod and the plot boundary was delineated with flagging. Each plot was inventoried for the percent cover of mountain laurel using established guidelines (Brose et al., 2008) and the height of the tallest mountain laurel was measured to the nearest 15 cm. After the pre-treatment inventory was completed in each stand, we randomly assigned each row of plots to one of the 36 herbicide/rate/month combinations with four rows serving as untreated controls.

In 2013, we prepared the herbicide solutions shortly before each spraying under controlled conditions at the Forestry Sciences Laboratory in Irvine, Pennsylvania. A non-ionic surfactant (Cide-Kick*) was used in all solutions at a rate of 2 l/ha to improve herbicide penetration through the waxy cuticle. Pennsylvania Bureau of Forestry foresters used backpack sprayers to apply the foliar herbicides during April, June, August, and October on the randomly assigned rows of plots. Each backpack sprayer was assigned to and only used with one herbicide to avoid cross contamination. Additionally, each backpack sprayer was thoroughly rinsed when switching from one spray rate to another to ensure the rates remained consistent.