# Improving Coastal Plain Hardwoods for White-tailed Deer and Wild Turkeys with Forest Stand Improvement and Prescribed Fire

by

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Abstract

Hardwood forests in the Coastal Plain often are not actively managed, as many landowners and managers fear that forest management will damage mast-producing hardwood species. Accordingly, forage and cover for game species, including white-tailed deer (*Odocoileus virginianus*) and wild turkeys (*Meleagris gallopavo*), often are lacking as a result of limited sunlight in the understory. Nonetheless, some managers are unwilling to reduce canopy coverage and apply prescribed fire because of a lack of knowledge on effects of these practices within the system. Therefore, we applied noncommercial forest stand improvement (FSI) and prescribed fire in four hardwood stands in the Coastal Plain of Alabama. Forest stand improvement was implemented by cutting and killing undesirable tree species to allow approximately 30% sunlight into stands. FSI was conducted with triclopyr in half the treatment units, and a mixture of triclopyr and imazapyr in the other half to evaluate herbicide efficacy and nontarget mortality. Prescribed fire was subsequently applied to half of each herbicide treatment unit in each stand. We evaluated the effects of canopy reduction and prescribed fire on deer forage and turkey brooding cover, as well as the impact of treatments on residual trees.

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# Introduction

Forest management practices often are implemented in the southeastern US to improve habitat conditions for a variety of wildlife species. White-tailed deer (*Odocoileus virginianus*; hereafter, deer) and wild turkeys (*Meleagris gallopavo*; hereafter, turkeys) are two species for which management is commonly implemented to benefit their populations. These species provide recreational opportunity to millions of hunters annually, and both depend on understory vegetation for forage and cover. For example, deer nutrition provided by understory vegetation influences antler growth and female productivity, and vegetation structure is critical for turkey poult survival (French et al. 1956, Verme 1965, Speake et al. 1985).

Given the interest in improving habitat quality for these species, efforts have been made to determine how various forest management practices influence food and cover resources. Abundant research has documented how canopy reduction and prescribed fire can improve conditions for deer and turkeys in pine (*Pinus* spp.) systems of the Coastal Plain. However, upland hardwood stands compose a significant proportion of forests in the Coastal Plain, and little is known about their response to canopy reduction and prescribed fire. Although species composition in Coastal Plain hardwoods differs, research conducted in the Ridge-and-Valley physiographic province indicated canopy reduction and fire can be applied in upland hardwoods to increase deer forage and turkey brooding cover (Lashley et al. 2011, McCord et al. 2014).

To further understand the potential to increase habitat quality for important game species in Coastal Plain hardwoods, Auburn University initiated a study in cooperation with Alabama Department of Conservation and Natural Resources to investigate the influence of forest management on various habitat components in upland hardwoods. The goal of the project was to understand how deer forage and turkey brooding cover were influenced by canopy reduction and prescribed fire, as well as the effects of these treatments on residual mast-producing trees. Noncommercial canopy reduction was implemented on four upland hardwood stands on Barbour County WMA during January/February 2018, and portions of the stands were burned during March 2019. Vegetation measurements were collected in these stands from May–August 2018/19 to determine how treatments influenced understory vegetation and residual overstory trees. The specific objectives were to:

1. evaluate effects of FSI and prescribed fire on deer forage and turkey brooding cover in Coastal Plain upland hardwoods,
2. monitor effects of low-intensity prescribed fire (scorch) on mast-producing hardwoods , and
3. compare efficacy and nontarget mortality associated with the application of triclopyr and a mixture of triclopyr and imazapyr via girdle-and-spray in upland hardwoods.

This thesis is divided into two chapters. Chapter 1 is formatted for publication in the Wildlife Society Bulletin, and discusses the effects of FSI and prescribed fire on deer forage and turkey brooding cover in upland hardwoods. Chapter 2 is formatted for publication in Forest Science, and compares triclopyr versus a mixture of triclopyr and imazapyr applied via girdle-and-spray as part of an FSI operation.

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CHAPTER 1

# IMPROVING COASTAL PLAIN HARDWOODS FOR DEER AND TURKEYS WITH CANOPY REDUCTION AND FIRE

**ABSTRACT** Prescribed fire and canopy reduction are accepted forest management practices to increase forage and cover for white-tailed deer (*Odocoileus virginianus*) and wild turkeys (*Meleagris gallopavo*) in forested uplands throughout the southeastern U.S. However, the use of prescribed fire to improve conditions for these species has not been evaluated in upland hardwood forests of the Coastal Plain, and some managers remain skeptical of the utility of fire in this ecoregion. We designed a manipulative experiment to measure deer and turkey habitat components following canopy reduction and prescribed fire in four upland hardwood stands in the Coastal Plain of Alabama. Specifically, we used herbicide to kill trees with low value to deer and turkeys and retained oaks (*Quercus* spp.) and other species considered important as part of a forest stand improvement (FSI) operation to reduce canopy coverage. We then applied low-intensity prescribed fire to half of each treatment unit. One unit in each replicate served as a control. We measured total understory plant coverage, biomass of deer forage, and turkey brooding cover two years following canopy reduction and one year after fire. Coverage of herbaceous plants increased by 134% in FSI/Burn, and coverage of woody and semi-woody plants increased by 33% and 97%, respectively, following FSI only. Deer forage biomass was greater in both FSI and FSI/Burn compared to control, but there was no difference in deer forage biomass between FSI and FSI/Burn. FSI/Burn provided better turkey brooding cover than FSI or control. No overstory trees were killed by fire. We detected minor cambium damage to only 13% of water oaks (*Quercus nigra*) in the FSI/Burn units; other species only showed light bark

charring or no sign of burning. We recommend FSI and low-intensity prescribed fire in Coastal Plain hardwoods to improve brooding cover for turkeys and understory forage for deer while retaining acorn production.

## INTRODUCTION

White-tailed deer (*Odocoileus virginianus*) and wild turkeys (*Meleagris gallopavo*) are the two most hunted game species in the southeastern U.S. (U.S. Department of Interior 2017). Millions of hectares of public land are managed to provide habitat for these species, and approximately 85 MM-ha are owned or leased for hunting in the Southeast (Macaulay 2016). Therefore, understanding how forest management influences habitat quality for these species is important for landowners and managers across the region. Providing adequate nutrition for deer can have major impacts on both body condition and productivity. For example, body growth and productivity of females is greater when adequate nutrition is available (Verme 1965). Additionally, antler growth is decreased when nutrition is suboptimal (French et al. 1956, Harmel et al. 1989). Although hard mast (i.e., acorns) can be an important food source for deer (Feldhammer et al. 1989, Wentworth et al. 1992), approximately 70% of their annual diet consists of forbs and browse (Hewitt 2011), both of which occur in the understory of woodland plant communities.

In addition to providing deer forage, composition and structure of understory plant communities are important for turkey brood-rearing. High-quality brooding cover is typically found in areas with an open canopy and herbaceous understory (Metzler and Speake 1985, Healy 1985, Campo et al. 1989, Wood et al. 2018). Without adequate groundcover, broods suffer high mortality rates from predation (Speake et al. 1985, Spears et al. 2010). Since the structure of brooding cover may influence poult survival (Metzler and Speake 1985), managing for cover to reduce poult mortality during their most vulnerable flightless stage is beneficial where turkeys are a focal species (Speake et al. 1985, Vander Haegen et al. 1988, Peoples et al. 1995).

Forest management practices that decrease canopy coverage typically increase forage for deer and enhance cover for turkeys. Reductions in canopy coverage often are achieved using various commercial timber harvest methods, and previous work has indicated availability of deer forage improves following implementation of a clearcut, shelterwood harvest, or thinning (Blair and Enghardt 1976, Ford et al. 1994, Peitz et al. 1999, Lashley et al. 2011, Nanney et al. 2018). For landowners without merchantable timber, noncommercial techniques, such as forest stand improvement (FSI), are an option to reduce canopy closure. FSI entails using herbicide to kill undesirable trees within a forest stand, and has been shown to increase deer forage biomass and turkey brooding cover in hardwood forests of the Ridge-and-Valley physiographic province (Lashley et al. 2011, McCord et al. 2014). Additionally, FSI treatments that release oak crowns can increase acorn production among remaining tress (Bellocq et al. 2005, Brooke et al. 2019).

Prescribed fire often is applied following canopy reduction to improve understory conditions for deer and turkeys, yet the use of prescribed fire within upland hardwood forests of the southeastern Coastal Plain has not been investigated. Many upland hardwood forests in the region are composed of tree species that facilitate fire (Kane et al. 2008), and prescribed fire has been applied to hardwood forests managed for deer and turkeys in other regions (Lashley et al. 2011, McCord et al. 2014). Although some managers are hesitant to apply fire that may damage overstory oaks, low-intensity prescribed fire can be applied with little or no damage to residual trees (Brose and Van Lear 1999, Marschall et al. 2014, McCord et al. 2014). Thus, increasing our understanding of the effects of prescribed fire within Coastal Plain hardwoods could provide opportunities to improve understory structure and species composition for deer and turkeys while retaining acorn production in upland hardwoods.

Based on the potential of canopy reduction and prescribed fire to increase habitat quality for deer and turkeys in Coastal Plain hardwoods, combined with the limited information on these practices in this region, we designed an experiment to evaluate the effects of prescribed fire and noncommercial canopy reduction on deer forage and turkey brooding cover, as well as response of retained overstory trees, in Coastal Plain hardwoods. We hypothesized a combination of prescribed fire and noncommercial canopy reduction would increase forage biomass, increase herbaceous plant coverage, and improve understory vegetation structure for turkey broods. We predicted low to moderate damage to retained overstory trees.

**STUDY AREA**

We conducted our study in 4, 5-ha hardwood-dominated stands on Barbour County Wildlife Management Area (WMA) in Barbour County, AL. The WMA was 11,418-ha in area, located in the Coastal Plain physiographic region, and managed by the Alabama Department of Conservation and Natural Resources. Composition of overstory species in the study stands included southern red oak (*Quercus falcata*), white oak (*Q. alba*), water oak (*Q. nigra*), yellow-poplar (*Liriodendron tulipifera*), sweetgum (*Liquidambar styraciflua*), and red maple (*Acer rubrum*). All stands had northern aspects, and were located within different watersheds across the WMA. The climate in Barbour County, AL was subtropical, with a mean annual temperature of 18 °C and mean annual precipitation of 133 cm (NOAA 2019).

Soils in the northern replicate stand were well-drained, and consisted primarily of Luverne-Springhill complex and Luverne sandy loam. Soils in the two central replicate stands were well drained, and consisted primarily of Luverne-Springhill complex and Blanton-Bonneau complex. Soils in the southern replicate stand were well-drained, and consisted primarily of Springhill-Lucy complex, Cowarts loamy sand, and Springhill-Troup complex (NRCS 2017).

## METHODS

### *Treatments*

We divided each of the four replicates into 2, 2-ha treatment units and 1, 1-ha untreated control. We randomly assigned treatments to each treatment unit. Treatments included a forest stand improvement (FSI) cut with and without prescribed fire. Our goal was to reduce canopy coverage and allow at least 30% sunlight into each stand by removing trees with relatively limited value to deer and turkeys (e.g., sweetgum, red maple, and yellow-poplar). Conversely, we typically retained trees that produce hard or soft mast used by deer and turkeys (e.g., oak, blackgum [*Nyssa sylvatica*], flowering dogwood [*Cornus florida*], black cherry [*Prunus serotina*], and common persimmon [*Diospyros virginiana*]), though we did kill trees of those species with poor growth form, or when necessary to reach canopy reduction goals.

We treated trees selected for removal that were ≥13-cm diameter at breast height (DBH) during January–February 2018 by girdling the stem with a chainsaw and spraying herbicide into the cut. We felled trees selected for removal that were <13-cm DBH, and applied herbicide to the stump. We used a 1:1 mixture of Garlon® 3A (Dow AgroSciences, Indianapolis, IN) and water or a solution of 50% Garlon® 3A, 40% water, and 10% Arsenal® AC (BASF Corporation, Research Triangle Park, NC), mixed in that order, to treat each stem. As part of an herbicide efficacy trial, we split each treatment unit in half and assigned an herbicide treatment to each. However, canopy closure did not differ between herbicide applications, so we pooled data across these treatments for analysis (Table A1).

We applied low-intensity prescribed fire to half of each treatment unit during March 2019. We conducted burns with a mixing height >500 m, 20–35% relative humidity, 0–17℃ temperature, and wind speeds of 8–13 km/hr. We used low-intensity backing and strip-heading fires, and limited flame heights to 15–45 cm to minimize damage to overstory trees. Additionally, we removed large woody debris from the base of residual trees prior to burning, as presence of slash at the base of trees is associated with damage from prescribed burning (Brose and Van Lear 1999). Average rate of spread for backing fires was 20 m/h.

*Data Collection*

We used line-intercept transects during May–June of 2018 and 2019 to determine percent coverage of plants, by species, in each treatment unit and control. We created three random points within each treatment unit, and located transects along 3, 11.3-m lines radiating at 0°, 120°, and 240° from each point. We recorded horizontal coverage of each plant along transects, and later grouped species based on the following growth habits: herbaceous (forbs and grasses), semi-woody (vines and brambles), and woody (trees and shrubs). We also recorded whether each plant had been browsed by deer.

From each of the three random points, we measured visual obstruction using a 2-m vegetation profile board (Nudds 1977) with alternating black and white 50-cm intervals. We defined the visual obstruction within each segment on a scale of 1-5, where 1=0–19%, 2=20–39%, 3=40–59%, 4=60–79%, and 5=80–100%. We placed the profile board 15 m downslope and 15 m upslope of plot center, and measured visual obstruction facing the board from plot center at a height of 1 m.

During July 2019, we collected deer forage biomass samples from 10, 1.5-$m^2$ frames randomly placed throughout each treatment unit. We identified deer forage plants as any plant species that had been browsed on our line-intercept transects, or those noted as moderately to highly selected deer forages in the literature (Miller and Miller 1999, Harper 2019). We collected the growing tips and leaves of these plants following the technique outlined in Lashley et al. (2014) to mimic deer herbivory. We dried forage samples to constant mass at 50℃ and weighed them to determine the biomass (kg) of deer forage within each frame. Samples then were extrapolated to estimate the biomass of deer forage per hectare within each stand.

We also measured infiltration of photosynthetically active radiation (PAR) using an AccuPAR® LP-80 PAR/LAI ceptometer (Decagon Devices, Inc., Pullman, WA) along a diagonal transect across each treatment unit. We recorded PAR readings every 1 m at a height of 1.4 m above ground. We did not include measurements ≤20 m from each end of the transect to avoid sampling the edge of a unit. We paired these measurements with measurements taken simultaneously by a ceptometer in full sunlight to determine the percent PAR reaching the understory in each stand.

Finally, we established five 0.04-ha timber cruise plots in each FSI/Burn unit during the 2019 growing season to document effects of prescribed fire on overstory oaks, as well as other species that produce mast consumed by deer and turkeys, including flowering dogwood, black cherry, black gum, and common persimmon. First, we documented mortality of any trees not treated with herbicide. We also categorized basal char within four quadrants around each tree according to Thies et al. (2006). The categories were: 0 (no char), 1 (superficial, light scorching), 2 (moderate scorch with uniformly black bark), 3 (deep charring to the point that some surface characteristics of the bark are lost), and 4 (bare wood visible). Trees that had at least one quadrant with category 3 or 4 scorch were considered to have cambium damage (Thies et al.

2006). In addition to the categorical char classification, we measured bole char height on each tree, which has been used previously to predict mortality following fire (Keyser et al. 2018).

*Analysis*

We used a mixed-effect analysis of variance (ANOVA) in package "nlme" (Pinheiro et al. 2018) in Program R (R Core Team 2018) to examine the relationships among canopy reduction, fire, and the change in percent coverage of deer forage, herbaceous, woody, and semiwoody plants from 2018–2019. We analyzed the change in percent coverage to standardize each unit according to vegetation conditions present prior to treatment application, and nested treatment unit within stand as random effects to account for variation within and among stands.

We also used a mixed effects ANOVA to evaluate the effects of FSI and prescribed fire on visual obstruction in 2019. We analyzed visual obstruction of the stratum <0.5 m, the 0.5–1 m stratum, and the sum of the two strata >1 m. We summed the two strata above 1 m because vegetation below this height offers concealment for poults, whereas vegetation above this height may block the vision of hens, inhibiting their ability to detect predators (Healy 1985, Peoples et al. 1996, McCord et al. 2014). Additionally, we used a mixed-effects ANOVA to evaluate the effects of FSI and prescribed fire on deer forage biomass within each stand, with treatment unit nested within stand as a random effect. To determine the effects of fire on overstory species, we calculated the average maximum bole char height on trees within FSI/Burn. We also calculated the proportion of trees that had a bole char rating of 3 or 4 (visible cambium damage) within at least one quadrant. Finally, we used a mixed-effects ANOVA to evaluate the effects of FSI and prescribed fire on PAR, with stand as a random effect. We set $\alpha = 0.05$ for all statistical tests.

**RESULTS**

During January–February 2018, we reduced average overstory basal area from 28 to 13 $m^2$/ha in the FSI and FSI/Burn treatment units, which allowed 35.9% (±1.3) sunlight into the stands. Percent PAR infiltration was greater in FSI and FSI/Burn compared to control (Figure 1.1). We sampled vegetation along 180 transects/yr during 2018 and 2019. Commonly observed understory plants present in each treatment unit included Virginia creeper (*Parthenocissus quinquefolia*), spike uniola (*Chasmanthium laxum*), low panicgrass (*Dichanthelium* spp.), muscadine (*Vitis rotundifolia*), greenbriar (*Smilax* spp.), burnweed (*Erechtites hieraciifolius*), and blackberry (*Rubus* spp.).

The increase in total understory vegetation coverage between 2018–2019 was greater in both FSI and FSI/Burn treatments compared to control (Table 1.1). However, analyzing plant coverage by growth form revealed the increase in herbaceous plants was greater in FSI/Burn compared to control, whereas the increase in woody and semiwoody plants was greater in FSI compared to control or FSI/Burn (Figure 1.2). Specifically, coverage of herbaceous plants increased by 134% and 53% in FSI/Burn and FSI, respectively, but decreased by 27% in control (Table 1.2). Coverage of semiwoody plants increased by 97% in FSI, whereas coverage of semiwoody plants declined by 33% in control and 10% in FSI/burn (Table 1.2). Woody plant coverage increased by 33% in FSI, but declined by 9% in control and 26% in FSI/Burn (Table 1.2).

Deer forage biomass was similar in FSI and FSI/Burn, but both produced more than control (Table 1.3 and Figure 1.3). In 2019, visual obstruction was greater <0.5 m, 0.5–1 m, and 1–2 m in FSI than control (Table 1.4). Visual obstruction was less in the 1–2-m stratum but greater in the <0.5-m stratum in FSI/Burn compared to control. (Figure 1.4).

We did not observe any mortality among untreated trees in FSI/Burn. Average bole char height in these treatment units was 0.4 m (±0.08), and 96% of mast producers were in scorch categories 0–2 (i.e., no cambium damage). No mast producers had category 4 (bare wood visible) scorch. We recorded 5 water oaks (13% of species sample) with category 3 (some surface characteristics of bark lost) scorch (Table 1.5). No other mast-producing species had greater than category 2 damage.

**DISCUSSION**

The application of FSI and prescribed fire increased deer forage availability and improved turkey brooding cover within our study areas. Canopy reduction of approximately 30% allowed sufficient sunlight to increase biomass of deer forage compared to control. Pairing FSI treatments with a single prescribed fire did not change forage biomass estimates compared to FSI alone, but it changed plant composition with increased coverage of herbaceous plants. Cover provided for a female turkey and brood was improved in stands that received additional sunlight. Vegetation that would obscure vision of a female attempting to detect predators, which hens select against (Campo et al. 1989, Wood et al. 2018), was least (offering better visibility) in FSI/Burn. Herbaceous vegetation, especially forbs, also is important for insect production for broods (Healy 1985, Harper et al. 2001), and we measured the greatest increase in herbaceous plant cover following the FSI/Burn.

Our results are similar to those of Lashley et al. (2011) and McCord et al. (2014) in the Ridge and Valley. However, they evaluated vegetation response beginning 5 years after initial canopy reduction, and after multiple prescribed fires. Our results two years after canopy reduction and immediately following a single fire indicate that implementing these practices in Coastal Plain hardwoods can quickly result in improved understory vegetation composition and structure for deer and turkeys. Specifically, understory vegetation in our study responded similarly to what has been documented in other systems as canopy reduction resulted in an increase in woody and semiwoody plants, and the application of prescribed fire increased coverage of herbaceous plants (Masters et al. 1993, Peitz et al. 1999, Iglay et al. 2010, Nanney et al. 2018). Although we did not document a difference in deer forage biomass between FSI and FSI/Burn, we did not conduct nutrient analysis on the collected forage. Forbs typically are greater quality forage plants than semiwoody or woody plants (Lashley et al. 2011, Nanney et al. 2018), and it is likely that nutritional carrying capacity in FSI/Burn was greater than FSI because of increased coverage of herbaceous plants.

Despite the concern associated with application of prescribed fire in upland hardwoods in the Coastal Plain, continued disturbance is necessary to maintain desirable conditions for deer and turkeys. We expected low to moderate damage to overstory mast producers following the application of fire to our stands, as species such as water oak are not considered to be fire tolerant (Heyward 1939, Dey and Schweitzer 2015). Despite the lower tolerance of many Coastal Plain hardwood species compared to Southern yellow pine species, the low-intensity, dormant-season fires we applied resulted in cambium damage to <5% of retained mast-producing trees, and we documented no fire-associated mortality. Furthermore, based on our bole char height results, subsequent mortality associated with the low-intensity fires we prescribed is unlikely (Keyser et al. 2018). Water oak was the only species with visible cambium damage on a portion of the stem, but this only occurred on 13% of the water oaks we evaluated. Thus, we saw limited damage to oaks within the stand, even in the species most susceptible to fire damage. Cambium severance on a portion of the stem does not necessarily lead to mortality, as trees with cambium damage often survive (Marschall et al. 2014). Nonetheless, reduced fire tolerance of water oak should be considered before prescribing fire in stands dominated by the species. However, most upland forests of the Coastal Plain contain a variety of oak and other mast-producing species, and our findings of minimal fire damage to mast producers is consistent with research conducted in other regions (Brose and Van Lear 1999, Marschall et al. 2014, McCord et al. 2014, Keyser et al. 2018). Moreover, the objectives of many landowners would be better met, even if substantial proportions of water oaks were killed, by the increased warm-season forage for deer and enhanced brooding structure for wild turkeys.

For managers interested in deer and turkeys, understanding the effect of our treatments on both the understory and acorn production is important. Previous measures of acorn production following canopy reduction and prescribed fire indicate acorn production is increased by cutting/killing undesirable species and releasing the crowns of desirable trees (Lombardo and McCarthy 2008, Brooke et al. 2019). Therefore, management of hardwood stands using these techniques will allow managers to improve forage and cover for deer and turkeys during the growing season without sacrificing acorn availability during fall and winter. Hardwood forests managed in this manner will have much greater value for deer and turkeys, as acorns are only available for a few months each year, and oak species do not produce mast crops annually (Johnson et al. 2009, Brooke et al. 2019). Future efforts should focus on understanding long-term effects of using frequent, low-intensity fire in Coastal Plain hardwoods on understory structure, forage quantity and quality, and acorn production.

## MANAGEMENT IMPLICATIONS

Our study and others indicate allowing at least 30% sunlight into the stand is sufficient to stimulate the understory and increase deer forage and improve turkey brooding cover. We recommend this level of FSI along with low-intensity prescribed fire to improve Coastal Plain hardwoods for these species. Trees that produce mast for deer and turkeys should be retained after reaching the desired canopy reduction during FSI operations. Low-intensity prescribed fire may be implemented to increase the herbaceous understory component, provide increased visibility, and prevent a woody midstory from developing that will shade out the herbaceous understory and reduce brood cover. Large woody debris should be removed from the base of residual trees before applying fire, as large woody debris following FSI may damage residual trees while burning. Continued disturbance using fire or additional FSI will be necessary to maintain woodland conditions over time in these stands.

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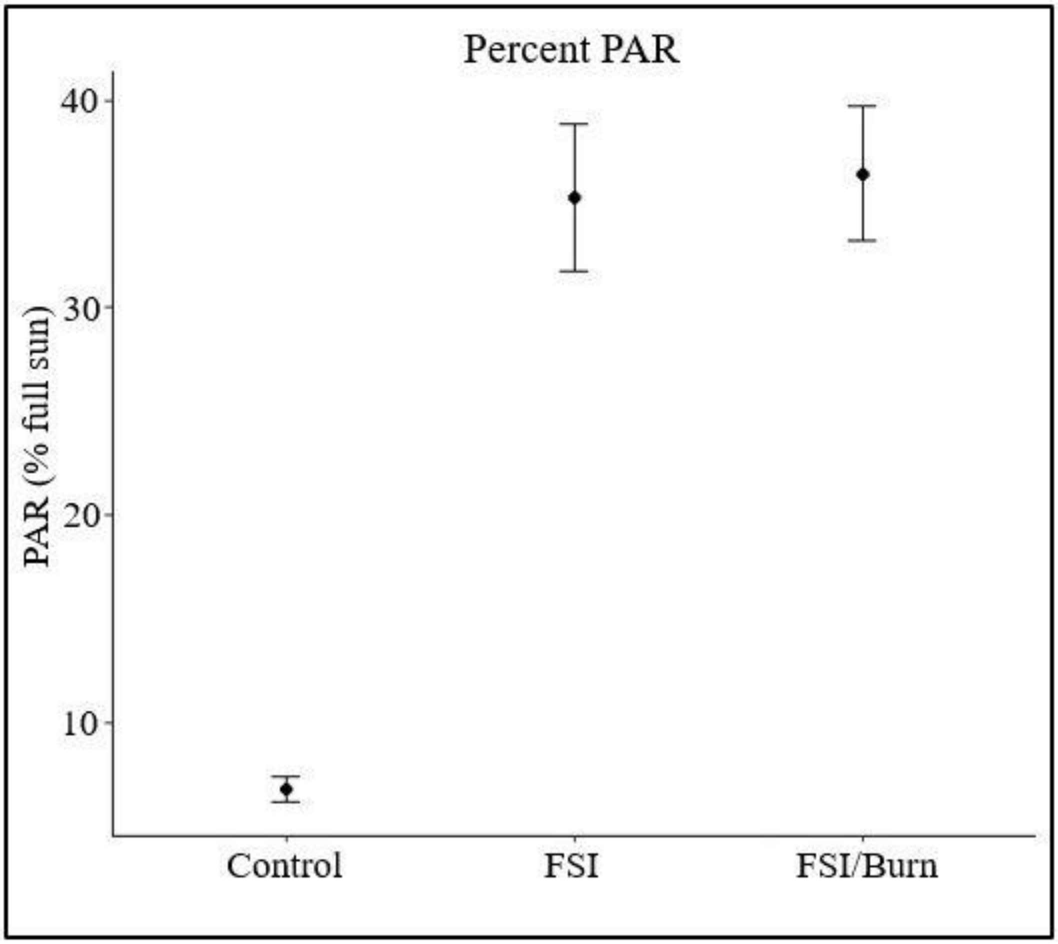


Figure 1.1. Photosynthetically active radiation (PAR) infiltration in hardwood stands in Alabama in August 2019. Calculated based on the percent (%) infiltration in-stand compared to measurements taken simultaneously in full sunlight. Error bars represent 95% confidence limits.

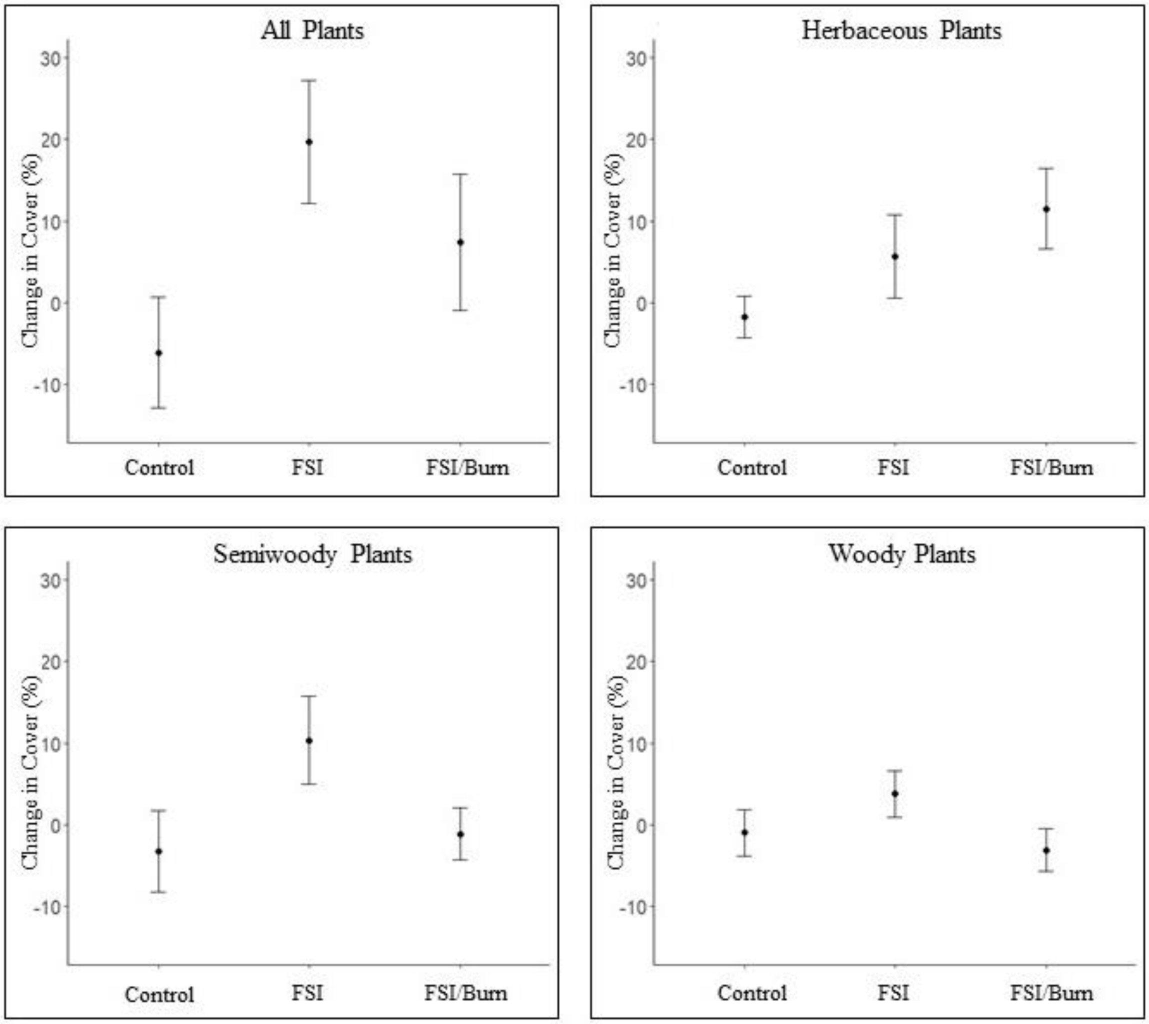


Figure 1.2. Change in percent (%) coverage of understory vegetation, including all plants, herbaceous plants, semiwoody plants, and woody plants from 2018–2019 following forest stand improvement, with and without prescribed fire, in upland hardwood stands in the Coastal Plain of Alabama. Error bars represent 95% confidence limits.

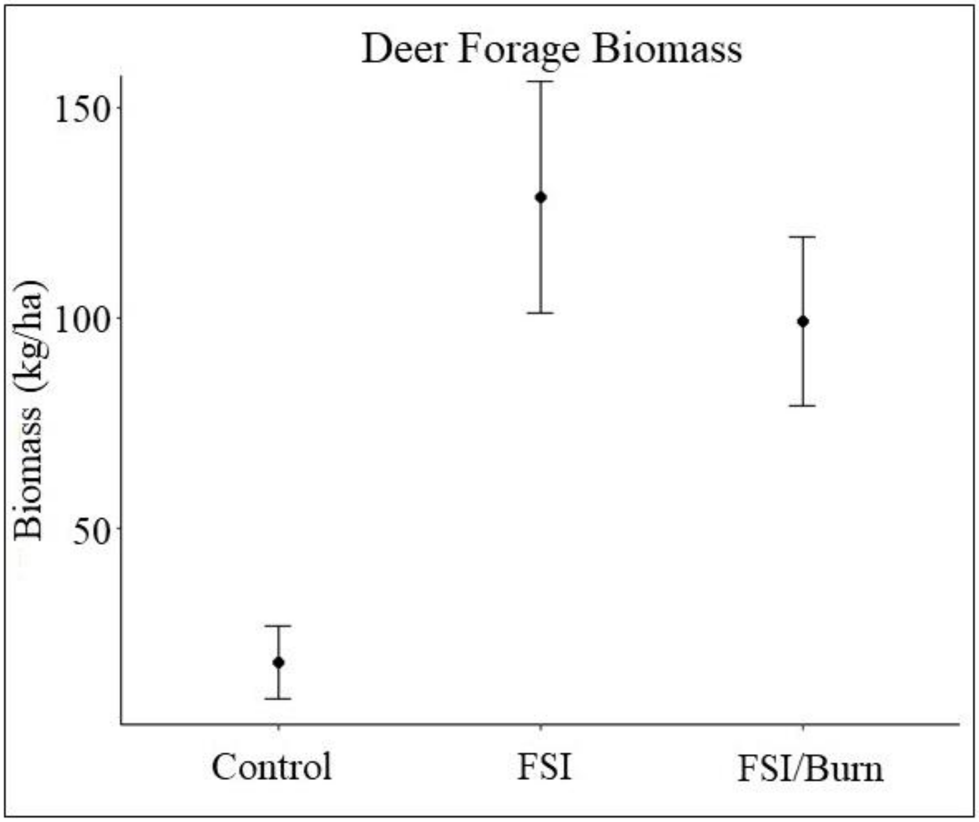


Figure 1.3. Biomass of deer forage (kg/ha) in July 2019 following forest stand improvement, with and without prescribed fire, in upland hardwood stands in the Coastal Plain of Alabama. Error bars represent 95% confidence limits.

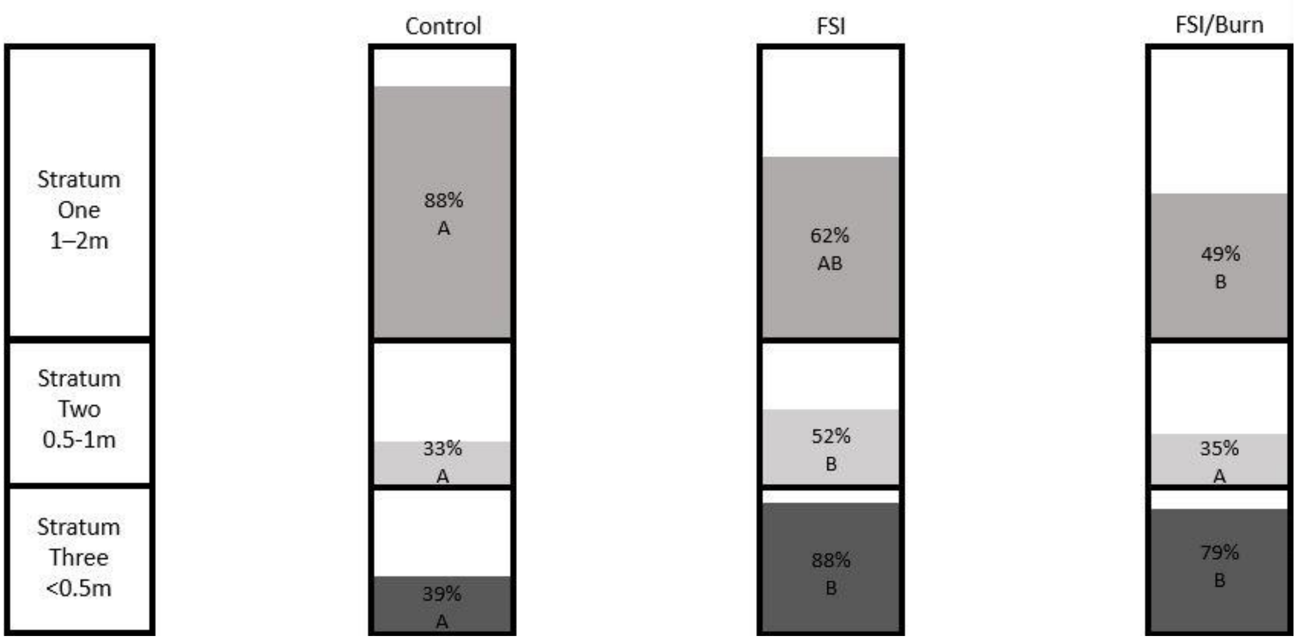


Figure 1.4. Visual obstruction scores in May/June 2019 in upland hardwood stands treated with forest stand improvement and prescribed fire. Scores were assigned on a scale of 1-5, where 1=0–19%, 2=20–39%, 3=40–59%, 4=60–79%, and 5=80–100%. Average scores within each stratum were divided by 5 to calculate the percent visual obstruction within this figure. Within each stratum, different letters signify treatments with different visual obstruction scores.

Table 1.1. Parameter estimates (β), standard errors (SE), 95% confidence limits (LCL and UCL), and *P*-values predicting the effect of forest stand improvement and prescribed fire on the change in percent (%) coverage of understory vegetation between 2018–2019 in upland hardwood stands in the Coastal Plain of Alabama.

| | **β** | **SE** | **LCL** | **UCL** | ***P*-value** |
|---|---|---|---|---|---|
| All Plants | | | | | |
| Control | -6.2 | 6.1 | -18.4 | 5.7 | 0.31 |
| FSI | 19.7 | 5.1 | 9.8 | 29.6 | <0.001 |
| FSI/Burn | 7.4 | 5.1 | -2.6 | 17.3 | 0.03 |
| Herbaceous | | | | | |
| Control | -1.8 | 3.6 | -8.8 | 5.2 | 0.56 |
| FSI | 5.7 | 2.8 | 0.2 | 11.2 | 0.07 |
| FSI/Burn | 11.5 | 2.8 | 2.8 | 6 | 0.003 |
| Semiwoody | | | | | |
| Control | -3.3 | 3.2 | -9.5 | 2.9 | 0.30 |
| FSI | 10.3 | 2.4 | 5.6 | 15.1 | 0.001 |
| FSI/Burn | -1.2 | 2.4 | -6 | 3.6 | 0.55 |
| Woody | | | | | |
| Control | -1 | 1.9 | -4.7 | 2.6 | 0.58 |
| FSI | 3.8 | 1.4 | 1 | 6.5 | 0.04 |
| FSI/Burn | -3.2 | 1.4 | -5.9 | -0.4 | 0.33 |

Table 1.2: Percent (%) coverage of understory vegetation in upland hardwood stands in the Coastal Plain of Alabama during May–June, and the average percent (%) increase in coverage between 2018–2019. Stands in FSI and FSI/Burn were treated with FSI during January–February 2018, and prescribed fire was applied to FSI/Burn in March 2019.

| | **2018 Coverage** | **SE** | **2019 Coverage** | **SE** | **Percent Increase** |
|---|---|---|---|---|---|
| All Plants | | | | | |
| Control | 27.8 | 2.5 | 21.6 | 2.6 | -22.2% |
| FSI | 32.9 | 2.2 | 52.6 | 4.5 | 59.9% |
| FSI/Burn | 32.4 | 1.2 | 39.8 | 1 | 22.8% |
| Herbaceous | | | | | |
| Control | 6.7 | 1.2 | 4.9 | 0.8 | -26.6% |
| FSI | 10.7 | 1.7 | 16.4 | 2.8 | 52.8% |
| FSI/Burn | 8.6 | 0.4 | 20.1 | 0.4 | 134% |
| Semiwoody | | | | | |
| Control | 10.2 | 1.3 | 6.8 | 0.7 | -32.7% |
| FSI | 10.6 | 1.5 | 21 | 3.6 | 97.3% |
| FSI/Burn | 11.3 | 1 | 10.1 | 1.2 | -10.5% |
| Woody | | | | | |
| Control | 10.9 | 2.6 | 9.9 | 1.3 | -9.4% |
| FSI | 11.4 | 0.7 | 15.2 | 1.7 | 32.9% |
| FSI/Burn | 12.2 | 1.4 | 9.1 | 0.3 | -25.9% |

Table 1.3. Parameter estimates (β), standard errors (SE), 95% confidence limits (LCL and UCL), and *P*-values predicting the effect of forest stand improvement and prescribed fire on white-tailed deer (*Odocoileus virginianus*) forage biomass (kg/ha) in upland hardwood stands in the Coastal Plain of Alabama.

| | **β** | **SE** | **LCL** | **UCL** | ***P*-value** |
|---|---|---|---|---|---|
| Control | 18.01 | 20.63 | -22.43 | 58.45 | 0.38 |
| FSI | 128.40 | 17.84 | 93.45 | 163.36 | 0.003 |
| FSI/Burn | 99.12 | 17.84 | 64.15 | 134.06 | 0.01 |

Table 1.4. Means and standard errors for visual obstruction scores in Coastal Plain hardwood stands treated with forest stand improvement and prescribed fire, 2019. Scores were assigned on a scale of 1-5, where 1=0–19%, 2=20–39%, 3=40–59%, 4=60–79%, and 5=80–100%.

| | **β** | **SE** | **LCL** | **UCL** | ***P*-value** |
|---|---|---|---|---|---|
| <u><0.5-m</u> | | | | | |
| Control | 1.97 | 0.33 | 1.33 | 2.61 | <0.001 |
| FSI | 4.39 | 0.22 | 3.80 | 4.98 | <0.001 |
| FSI/Burn | 3.97 | 0.22 | 3.38 | 4.56 | <0.001 |
| <u>0.5–1-m</u> | | | | | |
| Control | 1.63 | 0.30 | 1.04 | 2.21 | <0.001 |
| FSI | 2.56 | 0.28 | 2.06 | 3.07 | 0.02 |
| FSI/Burn | 1.75 | 0.28 | 1.24 | 2.26 | 0.67 |
| <u>1–2-m</u> | | | | | |
| Control | 4.38 | 0.50 | 3.40 | 5.35 | <0.001 |
| FSI | 3.11 | 0.60 | 2.22 | 4.00 | 0.08 |
| FSI/Burn | 2.45 | 0.60 | 1.56 | 3.35 | 0.02 |

Table 1.5. Scorch on oaks and other tree species that produce mast for deer and turkeys in Coastal Plain hardwood stands following a single low-intensity prescribed fire. Scorch categories are as follows: 1=superficial, light scorching; 2=moderate scorch with uniformly black bark; 3=deep charring to the point that some surface characteristics of the bark are lost; and 4=bare wood visible.

| **Oak Species** | | **Other Mast Producers** | |
|---|---|---|---|
| Scorch Category | Number of Trees | Scorch Category | Number of Trees |
| No Scorch | | No Scorch | |
| Post oak | 1 | Dogwood | 1 |
| Scarlet oak | 1 | | |
| Southern red oak | 1 | | |
| Water oak | 5 | | |
| White oak | 9 | | |
| One | | One | |
| Post oak | 4 | Black cherry | 5 |
| Southern red oak | 24 | Persimmon | 2 |
| Water oak | 13 | Black gum | 3 |
| White oak | 21 | | |
| Two | | Two | |
| Southern red oak | 6 | Black cherry | 2 |
| Water oak | 16 | | |
| White oak | 1 | | |
| Three | | Three | |
| Water oak | 5 | None | |
| Four | | Four | |
| None | | None | |

CHAPTER 2

# MIXTURE OF TRICLOPYR AND IMAZAPYR MORE EFFECTIVE AND SAFE AS TRICLOPYR ALONE FOR HARDWOOD FOREST STAND IMPROVEMENT


**ABSTRACT**

Treatment of individual trees in hardwood stands typically is conducted with herbicides that have no soil activity, such as triclopyr. However, triclopyr is not effective on some tree species. Applying a mixture of triclopyr and imazapyr would broaden the spectrum of tree species controlled, but nontarget mortality may be problematic as imazapyr may affect other trees through soil activity. We applied herbicide via girdle-and-spray as part of a Forest Stand Improvement (FSI) treatment in four upland hardwood stands in the Upper Coastal Plain of Alabama. We compared effects of using triclopyr alone to a mixture of triclopyr and imazapyr 18-months post-treatment. Only one untreated sweetgum (*Liquidambar styraciflua*) out of 440 trees was killed in the stands treated with the herbicide mixture (0.5% nontarget mortality rate). Nontarget mortality did not differ between treatments. However, the herbicide mixture controlled hickory (*Carya* spp.) and sourwood (*Oxydendrum arboreum*) better than triclopyr alone, with 56% of hickory treated with triclopyr still alive 18-months later, compared to 0% of hickory treated with the mixture. Our results indicate a mixture of triclopyr and imazapyr provides better control than triclopyr alone, and there is no risk to nontarget tree species in hardwood stands when used according to label recommendations.


**INTRODUCTION**

Selective removal of individual trees in hardwood forests accomplishes a variety of silvicultural and wildlife habitat-related objectives. For example, oak (*Quercus* spp.) regeneration depends on sunlight provided by canopy gaps (Hannah 1987, Brose et al. 1999), and growth rates of crop trees are greater following release from competition (Wendel and Lamson 1987, Lamson et al. 1990, Kochenderfer et al. 2001). Additionally, sunlight availability influences forest understory development, and silvicultural techniques that reduce canopy coverage can improve conditions for various wildlife species (Masters et al. 1993, Mixon et al. 2009, Lashley et al. 2011, McCord et al. 2014).

Overstory reduction often is accomplished with a commercial timber harvest. However, the ability to conduct a commercial harvest depends upon the availability of markets for harvested timber. If trees are not merchantable because of species composition, size class, or volume, noncommercial techniques may be used to reduce canopy coverage (Nyland 2002). These techniques collectively are referred to as forest stand improvement (FSI) techniques and can be applied to manipulate both economic and ecological conditions in a forest (Wendel and Lamson 1987, Nyland 2002, Lashley et al. 2011, McCord et al. 2014). Commonly, FSI is conducted by killing trees using herbicide introduced into the cambium (Pariona et al. 2003, DiTomaso et al. 2004, Ohlson-Kiehn et al. 2006, Lewis and McCarthy 2008).

One important consideration when conducting FSI is herbicide selection, as various chemicals may have differential efficacy on certain species (Kochenderfer et al. 2001, DiTomaso et al. 2004, DiTomaso and Kyser 2007). Triclopyr and imazapyr are two of the most commonly used forestry herbicides, and they often are introduced into the tree following mechanical treatment to the cambium (Ezell et al. 1999, DiTomaso and Kyser 2007, Alkire et al. 2012). However, Arsenal® Applicators Concentrate (BASF Corporation 2017; hereafter, Arsenal® AC), which contains imazapyr, is not effective for control of elm (*Ulmus* spp.), hornbeam (*Carpinus caroliniana*), or leguminous species. Garlon® 3A (Dow AgroSciences 2016), which contains triclopyr, is not effective for control of hickory (*Carya* spp.) or sourwood (*Oxydendrum* *arboreum*). Use of an herbicide that will not control various undesirable species that may be present in a forest stand is not efficient, and it is not practical to apply different herbicides based on individual tree species. Therefore, using an herbicide mixture may be most efficient and effective in forest stands with a diverse species composition.

FSI often is applied in order to increase crop tree growth or mast production within the stand (Wendel and Lamson 1987, Brooke et al. 2019), so it is critical to minimize nontarget mortality among untreated trees. Multiple factors influence the likelihood of nontarget mortality, including tree diameter, distance to treated trees, species of tree, soils, and the herbicide used (Kochenderfer et al. 2001, DiTomaso and Kyser 2007, Lewis and McCarthy 2008). Triclopyr is often used for FSI because it has a shorter half-life, is more selective than imazapyr, and results in little nontarget mortality (Kochenderfer et al. 2001, DiTomaso and Keyser 2007). In contrast, nontarget mortality rates associated with use of imazapyr in FSI operations vary widely. For example, Alikre et al. (2012) reported only 0.7% crown reduction to untreated overstory sweetgum (*Liquidambar styraciflua*) 12 months after treatment of midstory trees with imazapyr in Mississippi. They applied a solution of 20% Arsenal® AC via hack-and-squirt to all non-oaks in the midstory, and used 0.03 oz (1 ml) per 1 in (2.5 cm) DBH.  However, Lewis and McCarthy (2008) observed 57% mortality in black cherry (*Prunus serotina*) and 0% mortality in pawpaw (*Adimina triloba*) trees adjacent to 3–4.9 in (7.5 to 12.5 cm) DBH tree-of-heaven (*Ailanthus altissima*) that had been injected with four 0.03 oz (1 g) capsules containing 83.5% imazapyr. Site specific variables also may influence nontarget damage. Kochenderfer et al. (2001) reported 0–66% of nontarget black cherry and yellow-poplar (*Liriodendron tulipifera*) trees were damaged following treatment of various hardwood competitors with imazapyr. Their study was focused on crop tree release via hack-and-squirt, and they had a target application of 0.05 oz (1.5

ml) of 7.5% concentration Arsenal® AC per 1 in (2.5 cm) DBH. However, there has been no previous evaluation of the tradeoff between nontarget mortality and herbicide efficacy when these herbicides are applied in a mixture via girdle-and-spray to control a variety of species.

Despite the potential benefits of using a mixture of triclopyr and imazapyr in a FSI operation, the nontarget mortality concerns associated with using imazapyr should be evaluated. We designed an experimental study to measure the efficacy and nontarget mortality rates associated with triclopyr alone compared to a mixture of triclopyr and imazapyr when implementing FSI. We hypothesized that we would see greater control of target trees with a mixture of triclopyr and imazapyr compared to triclopyr alone, and that we would not see widespread nontarget mortality rates following application of either herbicide.

## MATERIALS AND METHODS

### Study Area

We conducted our study within 4 upland hardwood-dominated stands on Barbour Wildlife Management Area (WMA). Barbour WMA was located in Barbour County within the Upper Coastal Plain physiographic region of Alabama, and was managed by the Alabama Department of Conservation and Natural Resources. Overstory species composition included southern red oak (*Quercus falcata*), white oak (*Quercus alba*), yellow-poplar, sweetgum, water oak (*Quercus nigra*), and red maple (*Acer rubrum*), and mean pretreatment overstory basal area was approximately 120 $ft^2$/ac (27.5 $m^2$/ha). Midstory species composition included sparkleberry (*Vaccinium arboretum*), wax myrtle (*Morella cerifera*), and sweetgum. Prior to treatment, understory species composition was limited to primarily Virginia creeper (*Parthenocissus quinquefolia*), spike uniola (*Chasmanthium laxum*), low panicgrass (*Dichanthelium* spp.), and greenbriar (*Smilax* spp.).

Study stands all had northern aspects, and all were located within different drainages. The climate in Barbour County was subtropical, with a mean annual temperature of 65 °F (18 °C) and mean annual precipitation of 52 in (133 cm) (NOAA 2019). Soils in the northern replicate were well-drained, and consisted primarily of Luverne-Springhill complex and Luverne sandy loam. Soils in the two central replicates were well-drained, and consisted primarily of Luverne-Springhill complex and Blanton-Bonneau complex. Soils in the southern replicate were well-drained, and consisted primarily of Springhill-Lucy complex, Cowarts loamy sand, and Springhill-Troup complex (NRCS 2017).

**Experimental Design and Treatments**

We randomly assigned a treatment to 2, 4 ac (1.6 ha) plots within each stand. Treatments consisted of FSI reducing canopy closure from approximately 5% to 35% by girdle-and-spray or felling. We marked trees in each stand prior to treatment. In the triclopyr treatment, we applied a 1:1 Garlon® 3A (triclopyr)-water mixture to the treated trees. In the herbicide mixture treatment, we applied a mixture of 50% Garlon® 3A, 40% water, and 10% Arsenal® AC (imazapyr), mixed in that order to prevent gelling. We retained trees within the stand based on species, crown class, and form. We favored species that produced mast valuable for white-tailed deer (*Odocoileus virginianus*) and wild turkeys (*Meleagris gallopavo*), such as oaks, persimmon (*Diospyros virginiana*), and black cherry, for retention. Common species we treated included sweetgum, red maple, yellow-poplar, hickory, and water oak.

We cut down trees with a diameter at breast height (DBH) of <4 in (10 cm) and applied herbicide with a spray bottle to the cambium of the stump. We girdled trees with DBH of >4 in (10 cm) with a chainsaw just deep enough to sever the cambium layer, and applied herbicide with a spray bottle all the way around the cut. For both girdled and felled trees, we applied approximately 0.017 oz (0.5 ml) of solution per in DBH. At this rate of solution, we applied 0.0085 oz (0.25 ml) of Garlon® 3A per in DBH to treated trees in the triclopyr treatment units, and 0.0085 oz (0.25 ml) of Garlon® 3A and 0.0017 oz (0.05 ml) of Arsenal® AC per in DBH to treated trees in the mixture treatment units. We implemented FSI activities during January and February 2018, and evaluated them during July and August 2019.

**Data Collection**

Two growing seasons after herbicide application, we documented tree response to treatments using 10 randomly placed 0.1 ac (0.04 ha) fixed-radius plots in each treatment unit during July/August. We measured and identified trees >4 in (10 cm) DBH within each fixed-radius plot, and recorded whether they had been girdled and treated with herbicide. Additionally, we classified each tree based on ocular evaluation of the crown in a manner similar to Alkire et al. (2012). We classified trees as alive if they had <25% crown reduction and no visible herbicide damage to the leaves. We classified trees as dying if they had 25–75% crown reduction and visible herbicide damage to the leaves. We classified trees as dead if they had >75% crown reduction. If mortality or damage was present in untreated trees, we measured the distance to the nearest treated tree and recorded the species of both trees.

**Statistical Analysis**

We used a chi-square test to compare the proportion of treated trees that were alive, dying, and dead between herbicide treatments, across species. We also examined those data to determine whether there were any notable differences in herbicide susceptibility for a given genera or species. If so, we used a chi-square test to determine whether the proportion of those trees alive, dying, or dead differed between herbicide treatments. Finally, we used a mixed-effects ANOVA in package “nlme” (Pinheiro et al. 2018) in Program R (R Core Team 2018) with herbicide treatment as the fixed effect, percent nontarget mortality in each treatment unit as the response variable, and stand as a random effect to examine the effects of each herbicide treatment on nontarget mortality.

## RESULTS

We treated approximately 2,000 trees with herbicide via girdle-and-spray across the four stands. We evaluated herbicide efficacy on 546 treated trees (Table 1) and nontarget mortality among 440 untreated trees. Efficacy differed between herbicide treatments ($\chi^2 = 34.15$, DF=2, $p < 0.001$). Specifically, 9% of trees treated with triclopyr were still alive following treatment, compared to 0% of trees treated with the mixture (Figure 1). Of the trees still alive, 88% were hickory species (Table 2). More than half of the hickory trees treated with triclopyr were still alive (Figure 1), and the mixture achieved greater control of hickory than triclopyr alone ($\chi^2 = 18.3$, DF=2, $p < 0.001$). Although our sample size was insufficient to observe statistically significant differences for other species, it is likely that sourwood also had lower vulnerability to triclopyr alone, with 67% of treated stems still alive ($\chi^2 = 5.9$, DF=2, $p$=0.052). We observed one nontarget mortality: an untreated 19.5 in (49.5 cm) DBH sweetgum in a stand treated with the herbicide mixture that was 5 ft (1.5 m) from a 9.6 in (24.4 cm) sweetgum that had been treated via girdle-and-spray. Thus, we recorded an overall nontarget mortality rate of 0.5% (1 of 217) for the herbicide mixture, which did not differ from the nontarget mortality rate of 0% for the triclopyr treatment (Table 3).

## DISCUSSION

Susceptibility to various herbicides differs among tree species, which we documented when comparing triclopyr to a mixture of triclopyr and imazapyr. However, triclopyr alone resulted in sufficient control of nearly all trees except for hickory and sourwood. Nearly half of the treated hickory and a third of treated sourwood were still alive 18-months post-treatment, which is not surprising given that triclopyr is not labeled for control of hickory or sourwood. Nonetheless, triclopyr is still widely recommended for FSI operations in mixed hardwood stands. Hickory and sourwood comprised approximately 15% of the stems we targeted for removal in the Coastal Plain of Alabama. Elsewhere, Goode et al. (2018) reported 11% relative dominance of hickory and sourwood in the Cumberland Plateau of Alabama, and Rose and Rosson (2007) reported basal area of hickory was 10.5 $ft^2$/ac (2.4 $m^2$/ha) in Forest Inventory and Analysis plots in Virginia where hickory was present. Thus, hickory and/or sourwood are well-represented in many eastern hardwood stands, and failure to control these species may diminish success of FSI efforts. If managers plan to remove a portion of the hickory and sourwood trees within a forest stand, using a herbicide or herbicide mixture with greater efficacy than we documented for triclopyr alone should be considered.

Although including imazapyr in the mixture increased our control of hickory and sourwood, imazapyr is not labeled to control legumes, such as black locust (*Robinia pseudoacacia*), honeylocust (*Gleditsia triacanthos*), or eastern redbud (*Cercis canadensis*). Imazapyr also fails to control other species relatively common in some areas, including elm and hornbeam. Thus, applying a mixture of the two herbicides may be necessary to ensure management objectives are met in stands with a diverse mixture of tree species.

We documented only one nontarget tree killed following in-stand application of the triclopyr and imazapyr mixture using the girdle-and-spray technique. Nontarget tree mortality from herbicide use is most likely to occur when residual trees are in close proximity to trees of the same species (DiTomaso et al. 2004), especially when the tree species is clonal (DiTomaso and Keyser 2007). The nontarget mortality we recorded was in close proximity to a treated sweetgum, and sweetgum root sprouting is extremely common (Burns and Honkala 1990). Therefore, it is possible that herbicide transfer occurred through root connections and not through the soil. However, a single sweetgum mortality among hundreds of untreated trees suggests that the probability of root or soil transfer of our herbicide mixture to nontarget trees following gridle-and-spray is extremely low.

Soil composition is commonly considered an important factor associated with nontarget herbicide mortality when soil active herbicides are used. Soils with lower clay and organic matter content, as found in our stands, allow greater herbicide movement than those with greater clay and organic matter contents (Anderson 1996). Kochenderfer et al. (2001) reported limited damage associated with imazapyr applied during crop tree release treatments on two sites, but observed 66% nontarget mortality on a third site with lower clay and organic matter content. This led the authors to recommend against the use of imazapyr for single-tree treatments, regardless of soil type. However, we did not observe widespread nontarget herbicide mortality on four sites with soils that were low in clay and organic matter, despite examining a wider suite of tree species and giving more time for nontarget herbicide mortality to manifest than Kochenderfer et al. (2001).

The disparity in application rates likely is the primary difference between our results and previous studies. For example, Kochenderfer et al. (2001) applied 0.03 oz (0.11 ml) of Arsenal® AC per inch DBH and Lewis and McCarthy (2008) applied 0.03 oz (0.8 g) of imazapyr per inch DBH. In contrast, we only applied 0.0017 oz (0.05 ml) of Arsenal® AC, or 0.008 oz (0.2 g) of imazapyr per in DBH. Given the high efficacy rates we observed (except on hickory treated with triclopyr alone), it is clear that using higher rates of imazapyr is unnecessary. Our study provides evidence that wide-scale nontarget mortality concerns associated with the use of imazapyr in mixed hardwood stands are likely unwarranted if similar herbicide rates and application techniques are used.

## MANAGEMENT AND POLICY IMPLICATIONS

Forest stand improvement (FSI) is a noncommercial practice typically conducted by cutting and using herbicide to kill undesirable trees. Consideration must be given to herbicide selection, which is based on efficacy on target species while minimizing nontarget mortality of residual trees. We found that a mixture of triclopyr and imazapyr applied via girdle-and-spray had higher efficacy than triclopyr alone, which failed to control a significant proportion of treated hickory and sourwood. Despite hesitance of some managers to use imazapyr for FSI in mixed hardwood stands, we found no evidence of nontarget mortality that warrants concern 18-months after application to cut stumps or girdled trees as part of a mixture.

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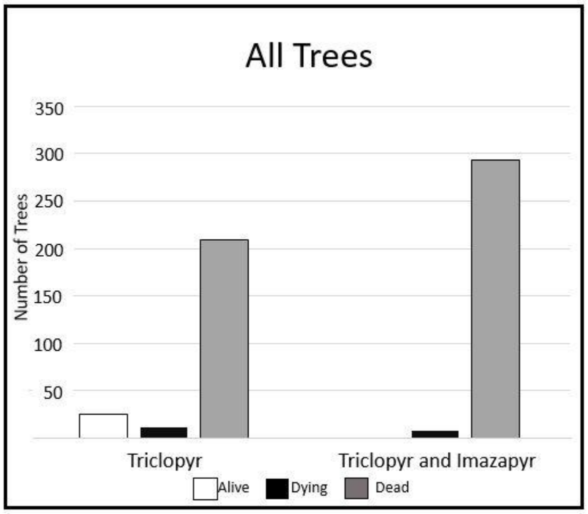
Figure 2.1. Status of trees treated with triclopyr and a mixture of triclopyr and imazapyr in upland hardwood stands in the Upper Coastal Plain of Alabama. We applied herbicide in January–February 2018 via girdle-and-spray, and evaluated the status of the treated trees 18-months later.



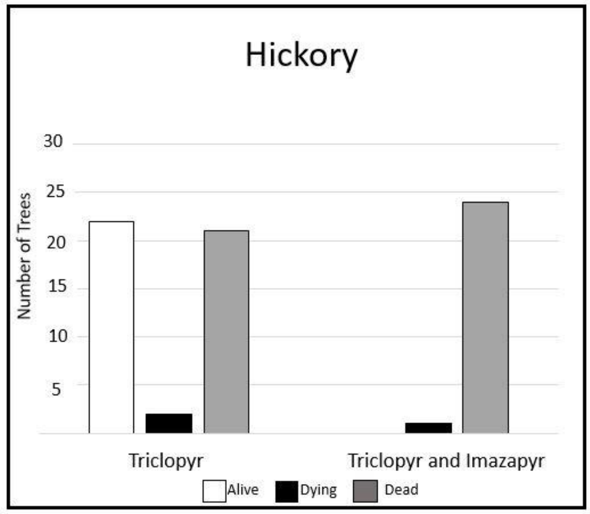



Table 2.1. Number of alive, dying, and dead trees in Upper Coastal Plain hardwood stands treated with triclopyr and a mixture of triclopyr and imazapyr that was applied via girdle-and-spray. Trees were treated in January–February 2018, and were evaluated 18-months later.

| | **Triclopyr** | | | **Mixture** | | |
|---|---|---|---|---|---|---|
| | **Alive** | **Dying** | **Dead** | **Alive** | **Dying** | **Dead** |
| *Acer rubrum* | 0 | 0 | 9 | 0 | 0 | 34 |
| *Carpinus* spp. | 0 | 0 | 2 | 0 | 1 | 5 |
| *Carya* spp. | 22 | 2 | 21 | 0 | 1 | 24 |
| *Celtis laevigata* | 0 | 0 | 0 | 0 | 0 | 1 |
| *Fraxinus* spp. | 1 | 1 | 7 | 0 | 0 | 2 |
| *Liquidambar styraciflua* | 0 | 0 | 63 | 0 | 0 | 77 |
| *Liriodendron tulipifera* | 0 | 5 | 20 | 0 | 3 | 43 |
| *Magnolia virginiana* | 0 | 0 | 0 | 0 | 0 | 1 |
| *Nyssa sylvatica* | 0 | 3 | 5 | 0 | 0 | 7 |
| *Ostrya virginiana* | 0 | 0 | 0 | 0 | 0 | 2 |
| *Oxydendrum arboreum* | 2 | 0 | 1 | 0 | 1 | 6 |
| *Pinus glabra* | 0 | 0 | 2 | 0 | 0 | 0 |
| *Pinus taeda* | 0 | 0 | 20 | 0 | 0 | 40 |
| *Prunus serotina* | 0 | 0 | 0 | 0 | 0 | 1 |
| *Quercus alba* | 0 | 0 | 16 | 0 | 1 | 19 |
| *Quercus coccinea* | 0 | 0 | 0 | 0 | 1 | 0 |
| *Quercus falcata* | 0 | 0 | 5 | 0 | 0 | 8 |
| *Quercus nigra* | 0 | 0 | 28 | 0 | 0 | 16 |
| *Quercus stellata* | 0 | 0 | 4 | 0 | 0 | 0 |
| *Ulmus alata* | 0 | 0 | 6 | 0 | 0 | 7 |

Table 2.2. Percent of treated trees in upland hardwood stands in the Upper Coastal Plain of Alabama still alive following application of triclopyr herbicide via girdle-and-spray. We applied herbicide during January–February 2018, and evaluated the treated stems during July–August 2019.

| | **Percent Alive** | **Number Alive** | **Total Treated** |
|---|---|---|---|
| Hickory (*Carya* spp.) | 55.5% | 25 | 45 |
| Sourwood (*Oxydendrum arboreum*) | 66.6% | 2 | 3 |
| Green ash (*Fraxinus pennsylvanica*) | 11.1% | 1 | 9 |

Table 2.3. Parameter estimates (β), standard errors (SE), 95% confidence limits (LCL and UCL), and *P*-values predicting herbicide-associated nontarget mortality rates for residual trees in upland hardwoods stands in Alabama treated with forest stand improvement. We applied the different herbicide mixtures via girdle-and-spray during January–February 2018, and evaluated nontarget mortality 18-months later.

| | **β** | **SE** | **LCL** | **UCL** | ***P*-value** |
|---|---|---|---|---|---|
| Triclopyr | 0 | 0.004 | -0.01 | 0.01 | 1 |
| Triclopyr and Imazapyr | 0.005 | 0.005 | -0.01 | 0.02 | 0.39 |

Appendix

Table A1. Parameter estimates (β), standard errors (SE), 95% confidence limits (LCL and UCL), and *P*-values predicting the percent (%) PAR in the understory of Coastal Plain hardwood stands treated with FSI with triclopyr and a mixture of triclopyr and imazapyr, with and without prescribed fire.

| | **B** | **SE** | **LCL** | **UCL** | ***P*-value** |
|---|---|---|---|---|---|
| Control | 6.8 | 2.2 | 2.5 | 11.1 | 0.002 |
| Triclopyr | 33.5 | 3.1 | 29.2 | 37.7 | <0.001 |
| Triclopyr/Burn | 35.1 | 3.1 | 30.8 | 39.4 | <0.001 |
| Mixture | 37.1 | 3.1 | 32.9 | 41.4 | <0.001 |
| Mixture/Burn | 37.7 | 3.1 | 33.5 | 42 | <0.001 |