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Effects of selective herbicide application on vegetation and invertebrates for northern bobwhite, and small mammal communities within managed pine forests

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EFFECTS OF SELECTIVE HERBICIDE APPLICATION ON VEGETATION AND INVERTEBRATES FOR NORTHERN BOBWHITE, AND SMALL MAMMAL COMMUNITIES WITHIN MANAGED PINE FORESTS

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DEDICATION

This thesis is dedicated to my loving husband, Allan and to my parents, Glendon and Helen James. Allan has given me his love, friendship, and support throughout our marriage. I could not have accomplished so much without him. My parents have always encouraged me and have been a major influence in making me the person that I am today.

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ABSTRACT

Decline of northern bobwhite (*Colinus virginianus*) populations during the past 30 years in southern portions of their range has increased efforts to improve habitat quality by integration of wildlife and forest management. Prescribed burns and herbicides have potential to benefit bobwhites, vegetation, invertebrates, and small mammal communities in pine-dominated systems. This study was conducted at 700-hectare Louisiana State University Idlewild Research Station of LSU's Agricultural Center in East Feliciana Parish. The experiment was conducted on 3, 10.12-hectare, 75 to 85 year–old, over–mature, uneven–aged pine stands on hilltops and sloping terrain. Experimental design included vegetation, invertebrate, and small mammal response to 3 treatments of 2 types of selective herbicide (imazapyr, imazapyr + glyphosate) and a control applied after an initial prescribed burn. Each stand served as whole plots and treatments as subplots within a split–plot arrangement. Treatments were randomly assigned and replicated across 3 stands. Herbicide treatments were more effective at improving vegetational structure for brood–rearing and nesting bobwhites. Plant and invertebrate species diversity declined on herbicide treatments during the first year, but increased on imazapyr plots during the second year. Bobwhite food plants increased on imazapyr plots for the first year and were greater on both herbicide treatments the second year. Herbicides reduced sweetgum but neither negatively affected hard mast producing species > 10 cm dbh. High overstory canopy closure and drought conditions may have negatively affected vegetation response. Herbicides did not produce bare ground percentages preferred by bobwhites. Prescribed burn alone created and maintained escape cover more suitable for bobwhites. Overall, imazapyr provided greater benefits to bobwhite, retained floristic species diversity, and greatly improved invertebrate diversity. Small mammal abundance increased on herbicide treatments presumably because of changes in vegetational characteristics and communities, and increased plant and invertebrate

diversity on imazapyr treatments. Additionally, *Peromyscus* species was most common mammal trapped on all plots. Future research should evaluate vegetative response to herbicides under variable canopy conditions and different imazapyr application rates. We recommend managers target areas where prescribed burns are not possible and apply imazapyr strategically to create diverse, patchy habitat.

CHAPTER 1 INTRODUCTION

The decline of Northern Bobwhite (*Colinus virginianus*, L.; hereafter bobwhite) populations during the past 30 years in southern portions of their range (Droege and Sauer 1990, Brennan 1991, Sauer et al. 1997) has increased efforts to improve habitat quality by integrating wildlife habitat management with forest management. Decreased use of fire as a management tool has increased use of herbicides in pine forests (Brennan 1991, Burger and Chamberlain 2001), but little research has examined habitat quality for bobwhites within mature southeastern pine forests following application of selective herbicides. Additionally, little research has examined small mammal response within mature southeastern pine forests following application of herbicides designed to reduce hardwood midstory and understory, and promote herbaceous vegetation and legumes. Therefore, objectives of this study were to determine effects of herbicide application in combination with prescribed burn on vegetation, availability and diversity of food plants and invertebrates for bobwhite, and small mammal communities within managed pine forests. This study was conducted at the 700-hectare Louisiana State University (LSU) Idlewild Research Station which is part of the LSU Agricultural Center in East Feliciana Parish. The experiment was conducted on 3, 10.12 hectare, 75 to 85 year-old, over-mature, uneven-aged pine stands on hilltops and sloping terrain (Langston 1981). The experimental design included vegetation, invertebrate, and small mammal response to 3 treatments of 2 types of selective herbicide and a control applied after an initial prescribed burn. Each stand served as whole plots and treatments as subplots within a split-plot arrangement. Treatments were randomly assigned and replicated across 3 stands.

CHAPTER 2 STUDY AREA

This study was conducted at the 700-hectare LSU Idlewild Research Station (hereafter Idlewild) which is part of the LSU Agricultural Center in East Feliciana Parish. Idlewild is located south of Clinton, Louisiana, east of state highway 67, and 72 km north of Baton Rouge.

The experiment was conducted on 3, 10.12 hectare, 75 to 85 year-old, over-mature, uneven-aged pine stands on hilltops and sloping terrain (Langston 1981). Experimental sites were previously burned on a 3 to 5 year rotation. Sites were logged August to December 1977 to reduce basal area, and create shelterwood and select cut plots (Langston 1981).

Experimental sites consist mainly of loblolly pine (*Pinus taeda,* L.), shortleaf pine (*P. echinata,* Miller), and dense hardwood growth consisting mainly of southern red oak (*Quercus falcata,* Michx.), sweetgum (*Liquidambar styraciflua,* L.), flowering dogwood (*Cornus florida,* L.), water oak (*Q. nigra*, L.), yaupon (*Ilex vomitoria*, Aiton), winged elm (*Ulmus alata*, Michx), and blackgum (*Nyssa sylvatica*, Marshall). Understory species consists mainly of sweetleaf (*Symplocos tinctoria*, (L.) L'Her), blackberry (*Rubus* spp.), waxmyrtle (*Myrica cerifera*, L.), sparkleberry (*Vaccinium arboreum*, Marsh.), greenbriars (*Smilax* spp.), wild azalea (*Rhododendron* spp.), and Japanese climbing fern (*Lycopodium japonicum*, Thunb.). Each stand was separated by even-aged pine stands at approximately 0.32 km. Soil characteristics are mainly Providence silt loam (Type Fragiudalf) with 0 - 8 % slopes on ridge tops. Some Lexington silt loam (Type Paleudult) were present with 1 - 20 % on slopes. Small areas of Ruston fine sandy loam (Type Paleudult) were present with 8 - 20 % on slopes (Langston 1981).

CHAPTER 3 BOBWHITE HABITAT

INTRODUCTION AND LITERATURE REVIEW

Bobwhite populations have declined over the past 30 years in the southern region of their geographic range (Droege and Sauer 1990, Brennan 1991, Sauer et al. 1997). Historically, bobwhite have been a socially, politically, and economically important species in the southeastern United States. Bobwhite require a diverse, patchy habitat that includes: open areas of herbaceous vegetation, especially legumes, a rich source of associated invertebrates, grassy areas for nesting, heavy brush or woody cover, bare ground with little litter coverage, and cropland (Stoddard 1931, Scott and Klimstra 1954, Stoddard 1962, Roseberry and Sudkamp 1998). Possible reasons for bobwhite decline are loss of early successional habitat (Thompson and DeGraaf 2001) from reduction in timber harvesting (increased forest maturation) (Trani et al. 2001), changes in habitat from small farms with brushy fence lines and hedgerows to clean–farming, silvicultural practices creating large monocultural crops, and more recently, reduction of fire as a silvicultural tool (Klimstra 1982, Brennan 1991).

Bobwhites have been historically associated with vast prairie pine forests in the hills of the Southeastern United States (Stewart 2003). Fire occurred every 3 – 5 years that were set by lightening or by Native Americans in the 1700 and 1800s. Understory vegetation was prairie–like and hardwood underbrush was controlled, which created habitat that bobwhites depend upon for food, insects, nesting, and brood–rearing (Stewart 2003). Today, prescribed burns are used to maintain early successional habitats. Traditional silvicultural practice is to burn at 3 – 5 year intervals in southern pine forests to control competing hardwoods and brush, consume dead organic material, and produce an open understory (Wenger 1984). Prescribed burns also produce good habitat for bobwhite and other ground–nesting birds because it reduces

litter, increases herbaceous growth and bare ground, increases associated invertebrates required for reproduction and brood–rearing (Stoddard 1931; 1962), and reduces woody encroachment and midstory competition with desired vegetation (Wright 1974, Bragg and Hulbert 1976, Lewis et al.1981). However, burned stands at southern latitudes often revert to dense hardwood understory with little herbaceous growth in ≤ 3 years. Unfortunately, more frequent burns are not possible because restrictive legislation has reduced prescribed burns as a management tool in the past decade (Burger and Chamberlain 2001, Haines et al. 2001). Funding limitations, lack of qualified professionals and technicians, narrow windows for conducting burns, and risk averse policies of an agency or a company are other reasons for decreased burn frequency (Haines et al. 2001). Because of these restrictions, states need to burn twice as often as presently set goals, but publicly–owned lands are near required goals in the South (Haines et al. 2001). Consequently, bobwhite are likely to leave these areas 2 years after initial burn. Therefore, alternative chemical methods like selective herbicide application has become the mainstay of post–emergence weed control in forestry (Walstad and Kuch 1987). However, little research has examined habitat quality for bobwhites within mature southeastern pine forests following application of selective herbicides.

Vegetation Response

Recent research using selective herbicides to alter structural composition of understory vegetation and increase conifer growth demonstrate short–term results. Therefore, continued vegetation control is necessary. Freedman et al. (1993) used glyphosate to release small conifers in a 6–year study in Nova Scotia. Results included: (1) 64 to 95% vegetation reduction with non–uniform damage on spray blocks where glyphosate did not contact vegetation, (2) some conifer needle–tip burn, (3) substantial recovery of raspberry (*Rubus* spp.) and various

herbaceous angiosperms remained abundant several years after application, (4) hardwoods with small deformed foilage at the end of the first year post–treatment but larger foilage cover from clones, (5) greater numbers and sustained growth of conifers during summer on treatment plots versus control, (6) no extinction of plant taxa, and (7) 66 % recovery of some shrubs after 99% initial apparent mortality. Results from other long–term studies on southern loblolly pine stands were had similar results (Lauer et al. 1993, Glover and Zutter 1993, Clason 1993).

Busby et al. (1998) indicated that quality of Land Expectation Value (LEV) was directly related to initial site quality, and plots with imazapyr had the most improvement in herbaceous release in loblolly pine stands. Shaw et al. (2001) reported that spring application of imazapyr, imazapic, and hexazinone improved populations, heights, and dry weights of Austrian winterpea, annual ryegrass, hairy vetch, crimson clover, and white clover compared to the control in Mississippi. Imazapyr and control late–season yields were similar for all species for spring and summer applications. Ross et al. (1986) used glyphosate combined with disking to produce greater Ponderosa pine (*Pinus ponderosa*, Douglas ex Lawson & C. Lawson) growth, reduce hardwood canopy growth, and increase herbaceous cover in an 8–year study in south–central Oregon. In contrast, a 10–year study by Harrington et al. (1995) on Douglas fir (*Pseudotsuga*) forests of Washington and Oregon Coast Ranges resulted in 8–12% less shrub cover on triclopyr or glyphosate treated plots. Only repeated application using hexazinone and triclopyr in April or May resulted in large and sustained reductions of hardwoods. Boyd et al. (1995) reported that imazapyr significantly increased *Rubus argustus* Lind and legumes, and decreased *Diospyros virginiana* L., whereas glyphosate reduced *Vaccinium* spp. 7 years post–herbicide treatment in central Georgia.

Invertebrate Response

Early successional habitats of annual grasses and forbs have been associated with abundant and diverse insect communities by providing more palatable, nutritious food sources (Menhinick 1967, Hurst 1972, Southwood et al. 1979, Schowalter 1985, Lawton 1983). Phytophagous arthropods (plant–eating invertebrates) are important during reproductive periods and chick development in bobwhite (Rosene 1969, Eubanks and Dimmick 1974). Female bobwhite especially depend on arthropods and snails while brooding (Brennan and Hurst 1995). Recent findings have suggested that strip disking with or without seeding with legumes on old fields in Mississippi produces greater abundance of phytophagous invertebrates (Orthoptera – grasshoppers, crickets, and katydids; Homoptera – scale insects, cicadas, leafhoppers, aphids, and allies; Coleoptera – beetles and weevils; Hemiptera – true bugs; Lepidoptera – larvae of butterflies, skippers, and moths; Jackson et al. 1987, Manley et al. 1994). Greater abundance of invertebrates were associated with old fields containing an abundance of partridge peas (*Chamaecrista fasciculata*, Michx), and their canopy concentrated invertebrates near the ground making them more accessible to bobwhite chicks (Jackson et al 1987). Fuller (1994) reported greater abundances of invertebrates and bobwhite associated with forest stands managed for red–cockaded woodpecker (*Picoides borealis*, Vieillot) using mechanical hardwood midstory removal and short rotation prescribed burn (U.S. Forest Service 1995). Madison et al. (1995) reported that fall disking provided greater invertebrate abundance than control in the first post–treatment year, and greater invertebrate abundance on glyphosate treatments in the second post–treatment year on tall fescue dominated fields in Kentucky being improved for bobwhite. Differences in relative abundance, ordinal richness, and biomass of invertebrates were not

observed between glyphosate and control plots in tall fescue Conservation Reserve Program fields in Mississippi (Greenfield et al. 2001).

Bobwhite Response

Research to improve habitats for bobwhite has been conducted in various regions of their geographical range. A 6–year study in 6 midwestern states to compare Conservation Reserve Program (CRP) fields and croplands using various methods of disturbances including mowing, herbicides, and burning reported 3–fold increases in nesting species, and nearly 14–fold increases in total nests on CRP fields compared to row crop fields (Best et al. 1997). Burger and Chamberlain (2001) reported a 4–fold increase in abundance of bobwhite on red–cockaded woodpecker habitat and adjacent areas in Homochitto National Forest in Mississippi using prescribed burn following mechanical midstory removal operation. Decreased canopy cover stimulated herbaceous and grass ground cover, with greater herbaceous height and cover among grasses preferred by bobwhite for nesting and brood rearing. Cooper (1996) reported similar results with greater abundance of seed producing plants. Forrester et al. (1998) associated cooler temperatures in landscapes with herbaceous ground cover during the hottest seasons in the gulf coast prairies and plains of south Texas. Bobwhite remained in areas with greater herbaceous cover and avoided open areas when possibility of long periods of sun exposure could raise operative temperatures above critical points (> 30° C during covey season and 39° C during pair–nesting and brood–rearing season (Forester et al. 1998). Finally, Greenfield et al. (2001) reported that using burn or burn–glyphosate produced the percentage of bare ground similar to structural characteristics of plant communities required for brood–rearing bobwhites in Mississippi. Similar studies in Mississippi and Missouri reported that herbicide or

burn–herbicide produced desirable percentage of forb canopies (Burger et al. 1994, Taylor and Burger 2000).

METHODS

We measured vegetation and invertebrate response after an initial prescribed burn before treatment in year 2000, and 2 consecutive years (2001–2002) after treatments of 2 types of selective herbicide were applied. Control plots were those burned in 2000 and subsequently maintained on a 2–year burn rotation. Each stand served as a whole plot and treatments as subplots within a split–plot arrangement. Treatments were randomly assigned and replicated across 3 stands.

Site Preparation

We applied an initial dormant season burn in January and February to provide uniformity within stands before treatment application (Walstad and Kuch 1987). Louisiana Department of Agriculture and Forestry – Office of Forestry 1993 recommendations were followed during prescribed burning. We burned stand 1 on 27 January 2000 and burn conditions were as follows: air temperature 8.33° C (47° F), surface winds E 29km/h (18 mph), and relative humidity was 54% (www.boi.noaa.gov). We burned stand 2 and 3 on 17 February 2000 and burn conditions were: air temperature 26.1° C (79° F), surface winds SE 16km/h (10 mph), and relative humidity was 54% (www.boi.noaa.gov).

We subdivided each 10.12–hectare stand into 3, 3.37–hectare plots and marked each plot with flagging at corners and midpoints. A bulldozer was used to establish plot perimeters.

Herbicide Application

We applied imazapyr and imazapyr with glyphosate to plots of each stand at rates of 453.6 g of imazapyr / 0.405–ha (16–oz / acre) and 1077.30–g of glyphosate + imazapyr /

0.405–ha (38 oz /acre) in September 2000 for optimum timing of herbicide application (Miller 1989). Herbicides were broadcast sprayed with a t–boom system mounted on a skidder. Imazapyr was mixed at rates to control hardwood growth and release herbaceous vegetation, and imazapyr was mixed with glyphosate to contribute to the control of imazapyr–tolerant species. Imazapyr is used as an amino acid synthesis inhibitor for residual control that is absorbed through the leaves, stems, and roots (Superior Forestry Service 1991). Glyphosate is absorbed through plant foliage and is used to inhibit production of 5–enolpyruvyl–3–phosphoshikimate (EPSP) synthase, an enzyme required for plant growth and life by inhibiting conversion of phosphoenolpyruvate and 3–phosphoshikimic acid to 5–enolpyruvyl–3–phosphoshikimic acid by inhibiting the enzyme 5–enolpyruvyl–3–phosphoshikimate synthase (Monsanto 2002). We applied imazapyr to treatment plots first and glyphosate was then added to the remaining imazapyr mixture and applied to respective treatment plots. We prepared herbicide mixtures immediately prior to application to minimize hydrolysis and degradation of the herbicide in the spray tank (Miller and Glover 1991).

Second Year Post–Treatment Burn

We conducted a second year post–treatment burn in February 2002 to remove excess debris from experimental plots, and to serve as a standard fire on a 2–year interval for control plots. Louisiana Department of Agriculture and Forestry – Office of Forestry 1993 recommendations were followed during prescribed burn. We burned one stand on 14 February 2002 and burn conditions were as follows: air temperature 18.3° C (65° F), surface winds NE 11km/h (7 mph), and relative humidity was 25% (www.boi.noaa.gov). We burned 2 stands on 21 February 2002 and burn conditions were as follows: air temperature 7.2° C (45° F), surface winds N 14km/h (9 mph), and relative humidity was 75% (www.boi.noaa.gov). Burning was

difficult in some areas because 2.79 cm (1.1 in) of rain fell on 20 February 2002.

Weather Conditions

Drought conditions for Louisiana began in spring 1998 and continued through initiation of our study prior to herbicide application and second year post–treatment (National Climatic Data Center 2002). May through October 2000 was the driest period for Louisiana in the last 106 years. Average 2000 summer temperature and precipitation were 28° C (82.4° F) and 25.55 cm, respectively. Cumulative effects for this period match the worst drought occurrences of the 20th Century. Precipitation was near to above normal for summer 2001 (58.50 cm) (22.83in) and near normal for summer 2002 (39.24 cm) (15.35in). Summer temperature was near normal for 2001 (27.1° C; 80.9° F) and near normal for 2002 (27.3° C; 81.2° F). However, September 2000 to August 2001 was the third consecutive respective period with below average precipitation, and September 2001 to August 2002 was the fourth respective period with below normal precipitation.

Vegetation Response

We measured vegetation structure in each subplot from June through August annually after the initial burn and 2 years post treatment. We systematically located 5 circular 0.04–ha (1/10–acre) subplots within each plot and divided each subplot into center, north, east, south, and west quadrants. We measured vegetation composition, overstory canopy closure, vertical obstruction (VOR), average vegetation height (VegAve), maximum vegetation height (VegMax), and litter depth at subplot center and 10–m in each cardinal direction. We measured vegetation composition with a 0.5–m^2 Daubenmire frame to determine percentage coverage of grass, forb, woody, vine, debris, bare ground, and fern (Daubenmire 1959). We measured canopy closure with a forest densiometer (Lemmon 1949, Avery 1975, Wenger 1984). We measured vegetation

height with a 1.4−m Robel pole to determine vertical obstruction, and average and maximum vegetation heights (Greenfield et al. 2001). We measured pine and hardwood species > 10−cm dbh using a diameter tape and an ultrasonic digital instrument at 1.4−m above ground to determine pine and hardwood composition within each 0.04−ha circular subplot (Avery 1975, Wenger 1984). An absolute count of number of stems less than 10−cm diameter was determined within each 0.04−ha circular subplot to determine midstory canopy coverage. We used the line intercept method (Canfield 1941) on a 20−m diagonal through subplot center to determine plant species diversity 0.5−m above ground. We identified hardwoods and herbaceous vegetation to species for important bobwhite food plants and other vegetation were identified to genus (Martin et al. 1951, Radford et al. 1968, Miller and Miller 1999, Duncan and Duncan 1999).

Invertebrate Response

We measured invertebrate species diversity and abundance using sweep nets and pit fall traps before treatment and annually for 2 years post−treatment (Koricheva et al. 2000). We sampled invertebrates with sweep nets during mid−day (1400) in late June to coincide with the peak brood−rearing period for bobwhite (Rosene 1969). We sampled at the same circular plots used for vegetation sampling on 20−m diagonal transects once using a 38−cm diameter sweep net. Samples were transferred to plastic bags for processing in the laboratory (15 sub−samples per stand, 45 sub−samples total), and finally transferred to 70% ethanol (Koricheva et al. 2000, L. M. Hooper−Bui, personal communication). We installed pit fall traps within 1−m of plot center and sampled invertebrates in late June over a 3−day period (15 sub−samples / stand for 3 days totaling 135 sub−samples). Pit fall traps were made of a 400−ml, 3−corner plastic beaker used to hold a 250−ml 3−corner collection beaker trimmed to fit inside the larger beaker, (3) 91.4

× 10.16–cm (36 × 4 in) aluminum sheet metal strips used as diverters to the trap, and a 36 × 36 × 30–cm piece of aluminum sheet metal folded at the corners to serve as a rain shield over the trap (Hooper-Bui and Pranschke 2003). We used ethylene glycol in each pitfall trap to trap invertebrates. We transferred daily collections to heavy–duty freezer bags and processed them in the laboratory by washing samples twice before storing them in 70% ethanol (Hooper-Bui and Pranschke 2003). We identified invertebrates to class and order (Arnett and Jacques 1981, O'Toole 2000).

Statistical Analysis

We used a split–plot, completely randomized design to test 2 distinct responses to herbicide application (Cochran and Cox 1957, Petersen 1985, Milliken and Johnson 1992). We treated stands as whole–plot effects and treatments as split–plot effects (Cochran and Cox 1957, Petersen 1985, Milliken and Johnson 1992). We tested the null hypothesis of no difference among treatments for all vegetation variables, and invertebrate richness and diversity. We ran annual models using SAS system for windows (SAS Institute Inc. 1992) because the burn in 2002 was expected to create yearly differences in treatment by year because of renovating effects of fire. We discuss only those treatment effects that did not exhibit an interaction between block and treatment. The first model tested response of understory vegetational structural characteristics and canopy coverage of preferred bobwhite food to herbicide application using a split–plot analysis of variance (ANOVA). We created a new variable for the first analysis called food that included plant genera and species important to bobwhite during summer months (*Acalypha* spp., *Ambrosia* spp., *Andropogon* spp., *Centrosema virginianum*, *Chamaecrista fasciculata*, *Chasmanthium* spp., *Clitoria mariana*, *Dicanthelium* spp. *Diodia teres*, *Lespedeza* spp., *Lonicera* spp., *Muhlenbergia schreberi*, *Oxalis* spp., Poaceae, *Rubus* spp., *Solanum*

carolinense, *Solidago canadensis*, *Solidago rugosa*, *Sorghum* spp., *Tridens flavus*, *Vaccinium arboreum*, *Vaccinium elliottii*, *Vaccinium* spp., and *Vicia* spp.) to determine the total proportion of bobwhite food per treatment (Table 1). Most studies reported crop contents of bobwhites during the hunting season and rated the importance of those species. However, we used only those results from research that identified plant species important to bobwhites during summer months for our analysis. The second model tested invertebrate response to herbicide application using a split–plot ANOVA. We grouped invertebrate orders that had few occurrences into 1 variable called, Other, and it included orders: Thysanoptera, Neuroptera, Isoptera, Dictyoptera, Zoraptera, Dermaptera, Plecoptera, Protura, Phasmida, Diplura, Psocoptera, Anoplura, Trichoptera, and Odonata. A significant *F*–test was used to determine treatment main effects and Tukey's Multiple Comparison to compare among treatments (Milliken and Johnson 1992).

We used Shannon's Diversity Index (H) to evaluate pre and post–treatment species diversity floristics and invertebrate Orders. H ($H = -\sum pi \ln pi$) was based on information theory and was the degree of difficulty in correctly predicting the species of the next individual sampled (Shannon–Weaver 1949). H depicted plant or invertebrate species diversity proportional to number of species per year and treatment. Furthermore, H was roughly proportional to the logarithm of the number of species and was sensitive to changes in rare species in a community sample. Values of H increase with the number of species in a community and could be greater than or equal to zero. We used e^H to show evenness of species detected per treatment and year.

Table 1. Floristics on all plots on 75 to 85 year–old uneven–aged pine stands in east central Louisiana. Floristics are rated by author as none, low, moderate, and high for bobwhite food plants. Floristics in bold represent important bobwhite food plants during summer months. Other floristics rated moderate or high that are not in bold are fall and winter bobwhite foods.

Scientific Name	**Common Name**	**James and Karl Miller 1999**	**Brazil 1993**	**Landers & Johnson 1976**	**Harshlarger & Buckner 1971**	**McRae et al. 1979**	**Curtis et al. 1990**
***Acalypha* spp.**	Three-seeded Mercury	Mod	Low	Low	Low		
***Ambrosia* spp.**	Ragweed	High	Low	High	Low		
***Andropogon* spp.**	Broomsedge	Low–seed High–nesting	Low				
Aralia spinosa	Hercules Club	None					
Arthraxon hispidus	Joint-head Arthraxon						
Aster spp.	Aster	Low		Low			
Athyrium filix-femina	Southern Lady Fern	None					
Berchemia scandens	Rattanvine	High					
Bignonia capreolata	Crossvine	None					
Broussonetia papyrifera	Paper Mulberry						
Callicarpa americana	American Beautyberry	Low	Low	Mod		High	
Campsis radicans	Trumpetcreeper	None					
Carya spp.	Hickory			Low			
Centrosema virginianum	Spurred Butterfly Pea	Mod	Low	High		High	
Chamaecrista fasciculata	Partridge Pea	Mod	High	High	High		
***Chasmanthium* spp.**	spikegrass	Low					
Cirsium spp.	Thistle	None					
Clitoria mariana	Butterfly Pea	Low		Low			
Conyza spp.	Horseweed	None					
Cornus florida	Flowering Dogwood		Low	High			
Croptilon spp.	Goldenweed	None					
***Dicanthelium* spp.**	Low Panicgrass	High		High		High	Low
Diodia teres	Poorjoe	Low to Mod	Low	High			
Diospyros virginiana	Common Persimmon						

Table 1. Continued

Table 1. Continued

Scientific Name	Common Name	James and Karl Miller 1999	Brazil 1993	Landers & Johnson 1976	Harshlarger & Buckner 1971	McRae et al. 1979	Curtis et al. 1990
Elephantopus tomentosus	Elephant's-Foot	None		Low			
Erechtites hieracifolia	American Burnweed	None					
Erythrina herbacea	Cherokee Bean						
Eupatorium spp.	Boneset	Cover		Low			
Euphorbia spp.	Spurge	Low	Low	Low	Low		
Euthamia spp.	Flat-topped Goldenrod	None					
Forb							
Fungus							
Galium spp.	Bedstraw	None		Low			
Gelsemium spp.	Jessamine vine	None					
Halesia dipteria	Silverbell			Low			
Hamamelis virginia	Witch-hazel	Low					
Helianthus spp.	Sunflower	Low	Low	Low			
Hypericum hypericoides	St. Andrew's-cross	Low		Low			
Hypericum mutilum	Dwarf St. Johnswort	Low		Low			
Ilex glabra	Gallberry	Low	Low		Low		
Ilex opaca	American Holly	Low	Low	Low			
Ilex_vomitoria	Yaupon	Low	Low	Low			
Lamiaceae spp.	Mountain Mint or Wild-Basil	None		Low			
Lepedium virginicum	Virginia Pepperweed	Low		Low			
***Lespedeza* spp.**	Lespedeza	High	High	High	High		Low
Liquidambar styraciflua	Sweetgum		Low	High		High	
Liriodendron tulipifera	Tulip Tree			Low			
***Lonicera* spp.**	Honeysuckle	High	High	High			
Ludwigia alternifolia	Seedbox	None					
Ludwigia spp.		None					
Lygodium japonicum	Japanese Climbing fern						
Mikania scadens	Climbing Hempweed	None					

Table 1. Continued

Table 1. Continued

Scientific Name	**Common Name**	**James and Karl Miller 1999**	**Brazil 1993**	**Landers & Johnson 1976**	**Harshlarger & Buckner 1971**	**McRae et al. 1979**	**Curtis et al. 1990**
Mitchella repens	Partridge-berry	Low		Low			
Monarda fistulosa	Wild Bergomot	None					
Morus rubra	Red Mulberry			Low			
Muhlenbergia schreberi	Nimblewill	None		Low			
Myrica cerifera	Waxmyrtle	Low	Low	Low	Mod		
Nyssa sylvatica	Blackgum			Low		High	
Ostrya virginiana	American Hop Hornbeam		Low				
Osmunda regalis	Royal Fern						
***Oxalis* spp.**	Woodsorrel	Low	Low	High	Low		
Oxydendrum arboreum	Sourwood						
Parthenocissus quinquefolia	Virginia Creeper	None	Low				
Passiflora lutea	Broadleaf Maypop	Low	Low	Low			
Persea borbonia	Redbay		Low	Low	Low		High
Phlox spp.	Phlox						
Pinus echinata	Shortleaf Pine		High	High	High	High	
Pinus taeda	Loblolly Pine		High	High		High	
Pinus seedlings							
***Poaceae* spp.**	Grass Family				High		
Polystichum acrostichoides	Christmas Fern	None					
Polypremum procumbens	Rustweed	None					
Prunus serotina	Wild Black Cherry		Low	Low		High	
Pteridium aquilinum	Brackenfern	Minor Cover					
Pycnanthemum incanum	Mountain Mint	None		Low			
Quercus alba	White Oak		High	High		High	Mod
Quercus falcata	Southern Red Oak		High	High		High	Mod
Quercus laurifolia	Laurel Oak		High	High		High	Mod
Quercus muehlenbergii	Chinkapin Oak		High	High		High	Mod
Quercus nigra	Water Oak		High	High		High	Mod

Table 1. Continued

Table 1. Continued

Scientific Name	Common Name	James and Karl Miller 1999	Brazil 1993	Landers & Johnson 1976	Harshlarger & Buckner 1971	McRae et al. 1979	Curtis et al. 1990
Quercus pagoda	Cherrybark Oak		High	High		High	Mod
Quercus phellos	Willow Oak		High	High		High	Mod
Quercus stellata	Post Oak		High	High		High	Mod
Quercus spp.	Oak		High	High		High	Mod
Rhododendron spp.	Azalea						
Rhus copallinum	Winged Sumac	Low	High	High	Low		
Rhus glabra	Smooth Sumac	Low	Mod	High	Low		
Rhynchospora spp.	Beakrush	None		Low			
***Rubus* spp.**	Blackberry	Low	Low	High	Low	High	
Rudbeckia spp.	Coneflower	None					
Ruellia spp.	Petunia						
Salvia spp.	Sage		Low	Low			
Sanicula canadensis	Canadian Black Smakeroot			Low			
Sassafras albidum	Sassafras			High			
Smilax spp.	Greenbrier						
Smilax bona-nox	Catbrier						
Smilax glabra	Sarsaparilla						
Smilax glauca	Cat Sawbrier		Low				
Smilax lanceolata	Lanceleaf Greenbrier		Low				
Smilax laurifolia	Laurel-Leafed Greenbrier						
Smilax pumila	Hairy Greenbrier						
Smilax rotundifolia	Roundleaf Greenbrier						
Solanum carolinense	Horsenettle, Nightshade	Low	Low	High			
Solidago canadensis	Canada Goldenrod	Low	Low	High			
Solidago rugosa	Fireworks Goldenrod	None		Low			
Sonchus spp.	Sow Thistle	None					
***Sorghum* spp.**	Johnson Grass	Mod	Low	High			Low
Styrax americana	American Snowbell						

Table 1. Continued

Table 1. Continued

Scientific Name	**Common Name**	**James and Karl Miller 1999**	**Brazil 1993**	**Landers & Johnson 1976**	**Harshlarger & Buckner 1971**	**McRae et al. 1979**	**Curtis et al. 1990**
Stylosanthus biflora	Pencilflower	Low		Low			
Symplocos tinctoria	Sweetleaf	None					
Tephrosia spp.	Goat's Rue	Low	Low	Low			
Toxicodendron radicans	Poison-ivy	Low		Low			
Tridens flavus	Purpletop	Low		Low			
Ulmus alata	Winged Elm	None		Low			
Vaccinium arboreum	Sparkleberry	Low - Mod	Low	Low	High		Low
Vaccinium elliottii	Elliott's Blueberry	High	Mod	Low	High		Low
Vaccinium spp.	Blueberry	Low to Mod	Low	Low	High		Low
Veronica spp.	Ironweed			Low			
***Vicia* spp.**	Vetch	Low	Low	High			
Viola spp.	Violet or Pansy	Low to Mod		Low			
Vitis spp.	Grape			High			

RESULTS

Vegetation

Prior to Herbicide Treatment (2000)

Structural

We detected differences in number of hardwoods ($F_{2,}44$, 1.59, $P = 0.051$) and litter depth ($F_{2,}44$, 7.11, $P = 0.027$) between stands and plots before herbicide application in September 2001 (Table 2, 3). The number of hardwoods were greater on pre-treatment plots (imazapyr Mean 5.65 ± SE 0.64, imazapyr + glyphosate Mean 4.75 ± SE 0.39; $P \leq 0.05$, Figure 1) and litter depth was greater on control (Mean 0.08 ± SE 0.02) and imazapyr + glyphosate plots (Mean 0.08 ± SE 0.02, $P \leq 0.05$, Figure 2).

Overstory

We detected differences in number of *Liquidambar styraciflua* ($F_{2,44} = 6.17$, $P = 0.005$) between stands and plots before herbicide application in September 2001 (Table 3, 4). The number of *Liquidambar styraciflua* was greater on imazapyr + glyphosate plots (20, $P \leq 0.5$). Twenty−one species were identified that included 2 pine species and 19 hardwood species.

Floristics

We detected differences in proportion of *Elephantopus tomentosus* ($F_{2,44} = 3.56$, $P = 0.039$), *Myrica cerifera* ($F_{2,44} = 3.62$, $P = 0.037$), *Passiflora lutea* ($F_{2,44} = 3.60$, $P = 0.038$), and *Rhus* spp. ($F_{2,44} = 3.07$, $P = 0.023$) between stands and plots before herbicide application in September 2001 (Table 3, 5). *Elephantopus tomentosus* was greatest on imazapyr + glyphosate plots (Mean 2.48 ± SE 0.61, $P \leq 0.5$). *Myrica cerifera* (Mean 2.48 ± SE 0.53, $P \leq 0.5$) and *Rhus* spp. were greatest on imazapyr plots (Mean 5.55 ± SE 1.31, $P \leq 0.5$). *Passiflora lutea* was greatest on imazapyr + glyphosate plots (Mean 0.5 ± SE 0.03, $P \leq 0.5$).

Table 2. Mean vegetation structural characteristics (2000) prior to herbicide application on 75 to 85 year–old uneven–aged pine stands in east central Louisiana. Identical letters within rows are not statistically different per Tukey's HSD (P<0.05). * Indicates stand by treatment interaction. Significant variables are in BOLD.

Treatment Variable		**Control**		**Imazapyr**		**Imazapyr + Glyphosate**		**Pr > F**	
		Mean ± SE		**Mean ± SE**		**Mean ± SE**			
Grass	(%)	9.69 ± 2.48		7.28 ± 2.30		3.79 ± 0.72		0.0942	
Forb	(%)	5.80 ± 1.25		10.96 ± 2.25		5.12 ± 1.03		0.1976	
Woody	(%)	43.95 ± 5.11		45.44 ± 4.91		40.91 ± 5.40		0.4441	*
Vine	(%)	23.35 ± 3.56		20.91 ± 3.00		23.79 ± 2.94		0.7841	
Debris	(%)	10.48 ± 2.20		13.65 ± 4.93		23.33 ± 4.38		0.0631	
Bground	(%)	0.48 ± 0.38		0.13 ± 0.13		0.51 ± 0.29		0.5911	
Fern	**(%)**	4.85 ± 2.46	A	0	B	1.78 ± 1.52	AB	0.0451	*
Canopy	(%)	93.72 ± 0.55		93.25 ± 1.11		93.32 ± 1.58		0.9208	*
VOR	(m)	0.43 ± 0.05		0.31 ± 0.05		0.34 ± 0.06		0.2105	*
Vegmax	(m)	1.39 ± 0.03		1.21 ± 0.08		1.25 ± 0.04		0.0859	
Vegave	(m)	0.87 ± 0.06		0.74 ± 0.09		0.79 ± 0.07		0.2759	
Litdepth	**(cm)**	0.08 ± 0.02	A	0.05 ± 0.01	B	0.08 ± 0.02	AB	0.0269	
Pnumber	(n)	3.01 ± 0.23		2.98 ± 0.20		3.51 ± 0.22		0.1876	
Pinedist	(m)	6.55 ± 0.32		6.65 ± 0.27		6.70 ± 0.28		0.9407	
Pinedbh	(cm)	39.80 ± 1.66		36.89 ± 2.41		35.63 ± 1.86		0.3852	
Pmidst	(n)	0.93 ± 0.56		0.87 ± 0.35		1.67 ± 0.76		0.5413	
Hwnumber	**(n)**	2.66 ± 0.27	B	5.65 ± 0.64	A	4.75 ± 0.39	A	<.0001	
Hwdist	(m)	6.31 ± 0.34		6.92 ± 0.30		6.53 ± 0.28		0.6930	
HWdbh	(cm)	21.89 ± 1.54		19.03 ± 1.58		18.70 ± 0.97		0.1399	
Hwmidst	(n)	13.33 ± 3.74		10.00 ± 4.11		15.13 ± 3.31		0.6090	

Table 3. Variables found significant in one or more years prior to herbicide application (2000) and post–herbicide years (2001–2002) in 75 to 85 year–old uneven–aged pine stands in east central Louisiana. Variables listed below *Liquidambar styraciflua* trees represent mean proportion of floristics and mean abundance of invertebrates. * indicates variables important to bobwhite.

Treatment		**Control**			**Imazapyr**			**Imazapyr + Glyphosate**		
Year		**2000**	**2001**	**2002**	**2000**	**2001**	**2002**	**2000**	**2001**	**2002**
* Bare Ground	(%)	0.48	0.61	0.50	0.13	1.63	3.49	0.51	1.23	8.13
* Debris	(%)	10.48	6.24	10.74	13.65	41.72	20.12	23.33	61.95	45.49
Fern	(%)	4.85	5.23	15.65	0	1.12	3.84	1.78	0.05	0.61
HW Midstory	(n)	13.33	8.27	5.13	10	3	3.13	15.13	2.93	3.07
HW Number	(n)	2.66	2.88	2.83	5.65	4.43	5.98	4.75	3.82	4.33
* Litter Depth	(cm)	0.08	0.08	0.01	0.05	0.10	0.008	0.08	0.10	0.01
* VegMax	(m)	1.39	1.43	1.39	1.21	0.84	1.11	1.25	0.77	0.87
* Vines	(%)	23.35	19.25	17.73	20.91	19.99	36.15	23.79	11.76	15.67
VOR	(m)	0.43	0.62	0.95	0.31	0.12	0.25	0.34	0.07	0.08
* Woody	(%)	43.95	60.19	43.06	45.44	30	21.32	40.91	16.8	9.91
Liquidambar styraciflua Trees > 10 cm dbh	(n)	4	4	4	4	2	3	20	13	15
Acer rubrum		1	1.15	0.93	1.2	0.22	0.67	0.17	0.05	0.02
* Bobwhite Food Plants		20.87	15.8	17.4	23.13	24	40.85	16.4	9.43	30.72
Callicarpa americana		6.8	8.87	9.27	4.6	1.60	7.22	7.43	0.88	2.52
Debris		13.48	2.63	2.79	15.23	8.99	4.10	22.5	13.38	8.30
Dicanthelium spp.		0	0.67	0.62	0	0.33	2.12	0.32	1.27	6.35
Elephantopus tomentosus		0.98	0.37	0.93	0.98	0.43	0.50	2.48	0.65	2.08
Erechtites hieracifolia		0.07	0	0.02	0.05	0	0.82	0	0.07	2.17
Ground		0.02	0.03	0.67	0.25	0	2.27	0.28	0.02	4.40
Hypericum hypericoides		0.03	0.03	0	0.12	0.03	0.07	0	0.08	0.27
* *Lespedeza* spp.		0	0	0	0.03	0.35	0.42	0	0.03	0.07

Table 3. Continued

Table 3. Continued

Treatment		**Control**			**Imazapyr**			**Imazapyr + Glyphosate**	
Year	**2000**	**2001**	**2002**	**2000**	**2001**	**2002**	**2000**	**2001**	**2002**
Liquidambar styraciflua	4.15	6.73	5.37	7.43	0.38	0.58	6.08	0	0.27
Lygodium japonicum	3.69	3.12	3.40	1.62	0	0.62	0.98	0.07	0.83
Mitchella repens	0.07	0.17	0.13	0.18	0.05	0.17	1.15	0.58	0.30
Myrica cerifera	1.27	1.97	1.90	2.48	4.2	1.18	1.10	0.68	0.12
Passiflora lutea	0	0	0.13	0	0.12	0	0.05	0	0
Pinus seedlings	0.07	0.32	0.05	0	2.68	1.03	0	4.35	0.45
Prunus serotina	1.11	0.98	0.73	0.78	0	0.12	0.83	0.02	0.17
Pteridium aquilinum	7.55	7.65	7.53	1.60	0.63	1.73	0.82	0.35	0.77
Pycnanthemum incanum	0	-	0.42	0.47	-	0.65	0.07	-	1.03
Quercus spp.	4.05	4.35	4.63	6.92	0.97	1.67	4.63	0.42	0.28
Rhus spp.	2.50	1.67	3.03	5.55	0.02	0.75	3.58	0	0.07
* *Rubus* spp.	8.08	7.45	9.59	8.62	19.10	28.87	9.10	6.15	15.02
Sassafras albidum	0.12	0.28	0.78	0.03	0	0	0	0	0
Vitis spp.	8.05	6.88	7.03	6.45	0.27	1.05	0.80	0.52	0.97
Order Acari	0.27	1.47	1.00	0.47	1.07	0.33	0	0.33	1.60
* Order Diptera	0.93	10.33	2.53	0.60	2.80	1.27	1.00	2.67	1.27
* Order Hemiptera	1.20	0.80	0.40	0.47	0.60	0.27	0.27	0.13	0.27
* Order Homoptera	1.93	6.33	0.07	1.60	2.33	0.20	3.13	0.93	0.13
Order Thysanura	1.20	0	0.13	0.47	0.33	0	0.40	0	0

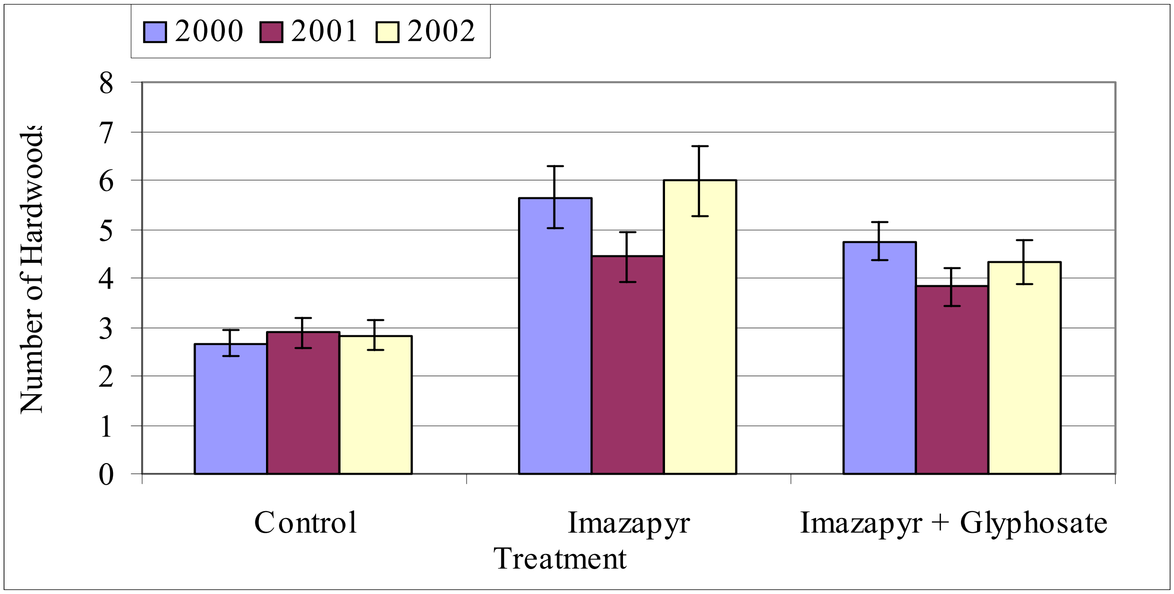

Figure 1. Number of hardwoods > 10cm dbh prior to herbicide application (2000) and post herbicide application (2001–2002) on 75–85 year–old uneven aged pine stands in east central Louisiana.

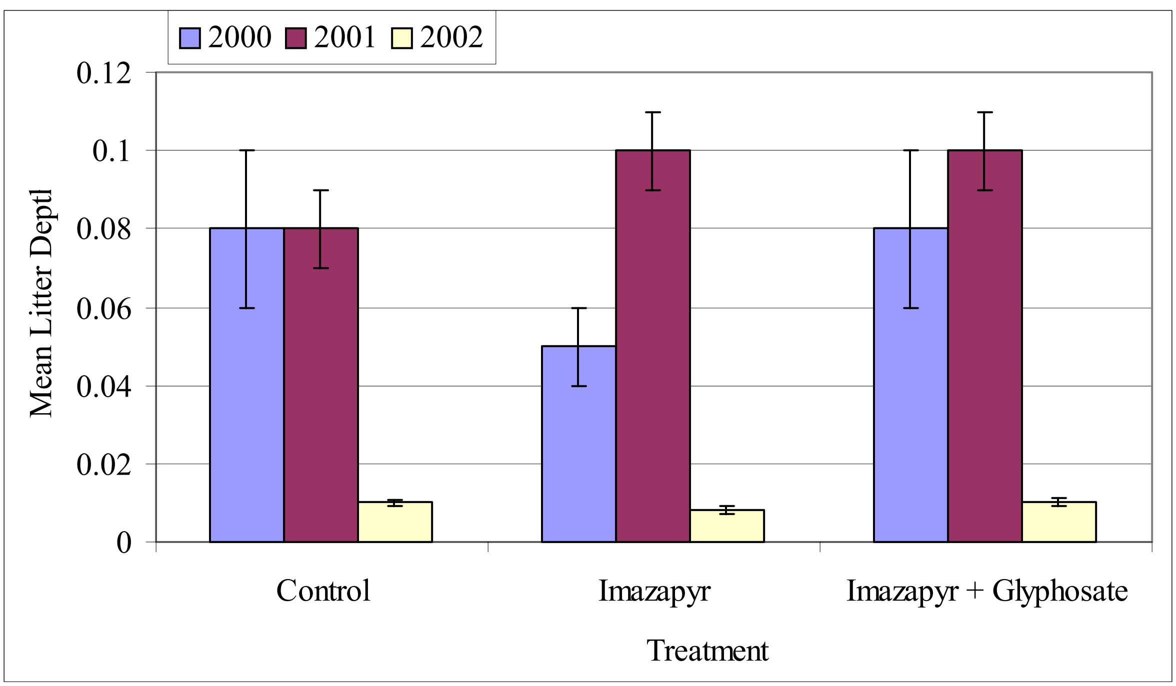

Figure 2. Mean litter depth prior to herbicide application (2000) and post herbicide application (2001–2002) on 75–85 year–old uneven aged pine stands in east central Louisiana.

Table 4. Number of hardwood and pine species that occurred on all 0.04–ha (1/10–acre) subplots (2000) prior to herbicide application on 75 to 85 year–old uneven–aged pine stands in east central Louisiana. Identical letters within rows are not statistically different per Tukey's HSD ($\underline{P}$<0.05). * Indicates stand by treatment interaction. Significant variables are in BOLD.

Treatment Variable	2000 Control (n)	2000 Imazapyr (n)	2000 Imazapyr + Glyphosate (n)	Pr>F
Acer rubrum	0	2	0	0.1501
Aralia spinosa	0	2	0	0.3779
Carya spp.	2	3	0	0.5161
Cornus florida	4	2	7	0.6692 *
Diospyros virginiana	0	0	2	0.3779
Liquidambar styraciflua	4 B	4 B	20 A	0.0050
Liriodendron tulipifera	2	2	0	0.2763
Nyssa sylvatica	3	0	1	0.5212
Ostrya virginiana	1	0	0	0.3779
Oxydendrum arboreum	0	0	2	0.0832 *
Prunus serotina	1	0	0	0.3779
Quercus alba	8	10	11	0.7608 *
Quercus falcata	7	3	7	0.5196
Quercus laurifolia	1	1	0	0.6107
Quercus nigra	4	18	7	0.2657
Quercus pagoda	2	4	1	0.4670
Quercus stellata	1	0	4	0.3183
Symplocos tinctoria	0	0	2	0.0832
Ulmus alata	1	0	5	0.1501
Unknown	0	1	0	0.3779
Pinus echinata	23	16	18	0.9464
Pinus taeda	41	44	61	0.2477
TOTAL	105	112	148	

Table 5. Mean proportion of floristics prior to herbicide applications (2000) on 75–85 year–old pine stands in east central Louisiana. Identical letters within rows are not statistically different per Tukey's HSD ($P<0.05$). * indicates treatment by stand interaction. Significant variables are in BOLD.

Treatment		**Control**	**Imazapyr**	**Imazapyr + Glyphosate**	**Pr>F**
Scientific Name	**Common Name**	**Mean ± SE**	**Mean ± SE**	**Mean ± SE**	
Acalypha spp.	Three–seeded Mercury, Copperleaf	0	0.01 ± 0.01	0	0.3779
Acer rubrum	Red Maple	1.00 ± 0.48	1.20 ± 0.62	0.17 ± 0.12	0.2309
Ambrosia spp.	Ragweed	0.02 ± 0.02	0	0	0.3779
Andropogon spp.	Broomsedge	0.13 ± 0.13	0.37 ± 0.37	0	0.5136
Aster spp.	Aster	0	0	0.02 ± 0.02	0.3779
Broussonetia papyrifera	Paper Mulberry	0.05 ± 0.05	0	0.10 ± 0.10	0.5542
Callicarpa americana	American Beautyberry	6.80 ± 2.27	4.60 ± 1.28	7.43 ± 1.68	0.5077
Campsis radicans	Trumpetcreeper	0	0	0.03 ± 0.03	0.3779
Carya spp.	Hickory	0.27 ± 0.15	0.47 ± 0.27	0.42 ± 0.31	0.8365
Chamaecrista fasciculata	Partridge Pea	0.15 ± 0.06	0.28 ± 0.17	0.17 ± 0.09	0.6183 *
Clitoria mariana	Butterfly Pea	0.05 ± 0.35	0.85 ± 0.35	0.42 ± 0.15	0.5337
Cornus florida	Flowering Dogwood	2.85 ± 1.03	2.48 ± 0.79	1.67 ± 0.67	0.5405
Debris		13.48 ± 2.89	15.23 ± 5.17	22.5 ± 4.36	0.2459
Dicanthelium spp.	Low Panicgrass	0	0	0.32 ± 0.22	0.0841 *
Diospyros virginiana	Common Persimmon	0.89 ± 0.45	0.58 ± 0.28	0.12 ± 0.08	0.2615
Elephantopus tomentosus	Elephant's–Foot	0.98 ± 0.33 A	0.98 ± 0.33 A	2.48 ± 0.61 A	0.0389
Erechtites hieracifolia	American Burnweed	0.07 ± 0.07	0.05 ± 0.04	0	0.5441
Erythrina herbacea	Cherokee Bean	0	0.02 ± 0.02	0	0.3779
Eupatorium spp	Boneset	0.42 ± 0.27	0.47 ± 0.17	0.08 ± 0.37	0.6081
Euphorbia spp.	Spurge	0.03 ± 0.03	0.12 ± 0.07	0.08 ± 0.06	0.5196
Euthamia spp.	Flat–topped Goldenrod	0.10 ± 0.05	0.13 ± 0.08	0.22 ± 0.22	0.8175
Forb		0.68 ± 0.25	0.25 ± 0.14	0.73 ± 0.37	0.3288
Fungus		0	0.02 ± 0.02	0	0.3779

Table 5. Continued

Table 5. Continued

Treatment		Control	Imazapyr	Imazapyr + Glyphosate	Pr>F
Scientific Name	Common Name	Mean ± SE	Mean ± SE	Mean ± SE	
Ground	Bare Ground	0.02 ± 0.02	0.25 ± .20	0.28 ± 0.17	0.4050
Hamamelis virginiana	Witch–hazel	0.22 ± 0.22	0	0	0.3779
Helianthus spp.	Sunflower	0.08 ± 0.08	0	0	0.3779
Hypericum hypericoides	St. Andrew's–cross	0.03 ± 0.03	0.12 ± 0.12	0	0.4862
Hypericum mutilum	Dwarf St. Johnswort	0	0	0.02 ± 0.02	0.3779
Ilex glabra	Gallberry	0.68 ± 0.63	0.17 ± 0.17	0.07 ± 0.07	0.4778
Ilex opaca	American Holly	0.17 ± 0.12	0	0.18 ± 0.14	0.3441
Ilex vomitoria	Yaupon	6.12 ± 2.00	6.79 ± 1.29	6.65 ± 1.09	0.2277
Lamiaceae	Mountain Mint or Wild–Basil	0	0.03 ± 0.03	0.07 ± 0.07	0.5542
Lespedeza spp.	Lespedeza	0	0.03 ± 0.03	0	0.3779
Liquidambar styraciflua	Sweetgum	4.15 ± 1.15	7.43 ± 1.51	6.08 ± 1.22	0.1955
Lonicera spp.	Honeysuckle	0.33 ± 0.10	0.32 ± 0.14	0.23 ± 0.13	0.8405
Ludwigia spp.		0.10 ± 0.07	0	0	0.1799
Lygodium japonicum	Japanese Climbing fern	3.69 ± 1.44	1.62 ± 0.65	0.98 ± 0.45	0.1452
Mikania scadens	Climbing Hempweed	0.10 ± 0.06	0	0.02 ± 0.02	0.0895
Mitchella repens	Partridge–berry	0.07 ± 0.05	0.18 ± 0.11	1.15 ± 0.73	0.1387
Monarda fistulosa	Wild Bergomot	2.08 ± 0.87	1.13 ± 0.34	0.63 ± 0.25	0.1790
Muhlenbergia schreberi	Nimblewill	0	0	0.10 ± 0.07	0.0832 *
Myrica cerifera	Waxmyrtle	1.27 ± 0.26 AB	2.48 ± 0.53 A	1.10 ± 0.41 B	0.0370
Nyssa sylvatica	Blackgum	0.33 ± 0.21	0.32 ± 0.24	0.67 ± 0.34	0.5313
Osmunda regalis	Royal Fern	0.07 ± 0.07	0	0	0.3779
Oxalis spp.	Woodsorrel	0.08 ± 0.05	0.48 ± 0.31	0.15 ± 0.10	0.6894 *
Parthenocissus quinquefolia	Virginia Creeper	0.70 ± 0.5	0.27 ± 0.13	0.10 ± 0.10	0.3845
Passiflora lutea	Broadleaf Maypop	0 A	0 A	0.05 ± 0.03 A	0.0376
Persea borbonia	Redbay	0	0.08 ± 0.07	0.03 ± 0.03	0.3779
Pinus seedlings		0.07 ± 0.07	0	0	0.3779

Table 5. Continued

Table 5. Continued

Treatment		Control	Imazapyr	Imazapyr + Glyphosate	Pr>F
Scientific Name	**Common Name**	**Mean ± SE**	**Mean ± SE**	**Mean ± SE**	
Poaceae spp.	Grass Family	8.77 ± 2.07	9.32 ± 2.63	4.03 ± 0.89	0.1199
Polystichum acrostichoides	Christmas Fern	0	0	0.10 ± 0.10	0.3779
Prunus serotina	Wild Black Cherry	1.11 ± 0.63	0.78 ± 0.51	0.83 ± 0.46	0.8771
Pteridium aquilinum	Brackenfern	7.55 ± 4.01 A	1.60 ± 1.34 A	0.82 ± 0.54 A	0.0485 *
Pycnanthemum incanum	Mountain Mint	0 B	0.47 ± 0.22 A	0.07 ± 0.07 B	0.0026 *
Quercus spp.	Oak	4.05 ± 1.21	6.92 ± 2.34	4.63 ± 1.87	0.4838
Rhododendron spp.	Azalia	0.26 ± 0.19	0.03 ± 0.03	0.38 ± 0.27	0.4355
Rhus spp.	Sumac	2.50 ± 0.61 AB	5.55 ± 1.31 A	3.58 ± 1.41 B	0.0233
Rubus spp.	Blackberry	8.08 ± 1.42	8.62 ± 1.59	9.10 ± 0.95	0.8572
Sanicula canadensis	Canadian Black Smakeroot	0	0	0.12 ± 0.12	0.3779
Sassafras albidum	Sassafras	0.10 ± 0.07	0.03 ± 0.03	0	0.3229
Smilax spp.	Greenbrier	0	0.07 ± 0.04	0.02 ± 0.02	0.1708
Solidago spp.	Goldenrod	0.98 ± 0.43	1.23 ± 0.47	0.45 ± 0.27	0.3770
Sonchus spp.	Sow Thistle	0.07 ± 0.07	0	0	0.3779
Stylosanthus biflora	Pencilflower	0	0.03 ± 0.03	0	0.3779
Symplocos tinctoria	Sweetleaf	5.67 ± 2.48	5.13 ± 2.03	6.62 ± 2.52	0.6572
Tephrosia spp.	Goat's Rue	0	0.27 ± 0.25	0.15 ± 0.15	0.5391
Toxicodendron radicans	Poison–ivy	0.35 ± 0.31	0.17 ± 0.07	0.62 ± 0.62	0.7293
Ulmus alata	Winged Elm	0.33 ± 0.16	0.33 ± 0.15	0.05 ± 0.04	0.2399
Vaccinium spp.	Blueberry	1.82 ± 0.69	1.62 ± 0.66	1.18 ± 0.36	0.7361
Vicia spp.	Vetch	0	0	0.25 ± 0.22	0.2849
Viola spp.	Violet or Pansy	0.08 ± 0.05	0.32 ± 0.18	0	0.0964
Vitis spp.	Grape	8.05 ± 2.13	6.45 ± 1.41	0.80 ± 2.51	0.9082
Food	Bobwhite Food Plants	20.87 ± 2.94	23.13 ± 3.50	16.40 ± 1.57	0.2525

Plant Species Diversity (2000 –2002)

Plant species diversity prior to herbicide application was similar on imazapyr (H = 0.94, Table 6) and control plots (H = 0.94), but was slightly less on imazapyr + glyphosate plots (H = 0.92). During the first year post–herbicide application, there was greater plant species diversityon control plots (H = 0.95), followed by imazapyr (H = 0.72), and imazapyr + glyphosate treatments (H = 0.58). Second year post–herbicide application exhibited greater plant species diversity on imazapyr plots (H = 0.86), followed by control (H = 0.91), and imazapyr + glyphosate treatments (H = 0.58). Evenness of plant species was slightly > 1 on all plots prior to and post-herbicide application, indicating an even distribution of plant species across stands.

We identified percent changes from 2000 to 2001 per treatment (Table 6). The greatest negative percent change was on imazapyr + glyphosate plots (-37 %) in the first year post–herbicide application and on control plots (-36 %) in 2002 following February prescribed burn. The greatest positive percent change occurred on imazapyr plots (+19 %) in the second–year post– herbicide application.

First Year Post Treatment (2001)

Structure

We identified stand by treatment interactions for vine ($F_{2,44} = 4.72$, $P = 0.00$), canopy closure ($F_{2,44} = 6.63$, $P = 0.001$), vegmax ($F_{2,44} = 19.12$, $P = <0.001$), and vegave ($F_{2,44} = 14.70$, $P = < 0.001$, Table 7). We detected treatment effects for woody ($F_{2,44} = 36.59$, $P = < 0.001$), debris ($F_{2,44} = 56.83$, $P = < 0.001$), VOR ($F_{2,44} = 50.29$, $P = < 0.001$), number of hardwoods ($F_{2,44} = 4.27$, $P = 0.016$), and hardwood midstory ($F_{2,44} = 3.30$, $P = 0.048$, Table 3). Number of hardwoods was greatest in imazapyr plots (4.43 ± 0.52, $P \leq 0.05$, Figure 1). Woody was greatest in control plots (Mean $60.19 \pm$ SE 4.89, $P \leq 0.05$, Figure 3). Debris was greatest in

Table 6. Shannon's Diversity Index ($H = -\sum pi \ln pi$) determined using line intercept prior to herbicide application (2000) and 2 years post treatment (2001–2002) on 75–85 year–old pine stands in east central Louisiana. H depicts the relative abundance of species. e^H is Shannon's Diversity Index but transformed to show the relative distribution of the number of species or evenness of species abundances. * Pre–treatment values for 2000 Imazapyr and 2000 Imazapyr + Glyphosate. Percent change of increase (+) or decrease (–) between years.

Trt	**Control**			**Imazapyr**			**Imazapyr + Glyphosate**		
Year	2000	2001	2002	2000 *	2001	2002	2000 *	2001	2002
H	0.94	0.95	0.61	0.94	0.72	0.86	0.92	0.58	0.58
% Change	NA	+ 1	- 36	NA	- 23	+ 19	NA	- 37	0
e^H	2.57	2.56	1.84	2.56	2.05	2.36	2.51	1.78	1.78

Table 7. Mean vegetation structural characteristics (2001) first year post–herbicide application on 75 to 85 year–old uneven–aged pine stands in east central Louisiana. Identical letters within rows are not statistically different per Tukey's HSD (P<0.05). * Indicates variables with stand × treatment interactions. Significant variables are in BOLD.

Treatment Variable		Control		Imazapyr		Imazapyr + Glyphosate		Pr > F
		Mean ± SE		Mean ± SE		Mean ± SE		
Grass	(%)	3.52 ± 1.19		1.71 ± 0.58		2.56 ± 0.68		0.3584
Forb	(%)	3.41 ± 0.73		3.49 ± 1.04		5.28 ± 1.22		0.2458
Woody	**(%)**	60.19 ± 4.89	A	30.00 ± 3.57	B	16.80 ± 1.87	C	<.0001
Vine	**(%)**	19.25 ± 3.25	AB	19.99 ± 2.44	A	11.76 ± 2.28	B	0.0236 *
Debris	**(%)**	6.24 ± 1.95	B	41.72 ± 6.11	A	61.95 ± 3.12	A	<.0001
Bground	(%)	0.61 ± 0.45		1.63 ± 1.04		1.23 ± 1.20		0.7591
Fern	(%)	5.23 ± 3.13		1.12 ± 1.12		0.05 ± 0.05		0.1524
Canopy	(%)	92.52 ± 0.88		91.27 ± 1.05		90.23 ± 0.83		0.1168 *
VOR	**(m)**	0.62 ± 0.06	A	0.12 ± 0.04	B	0.07 ± 0.03	B	<.0001
Vegmax	**(m)**	1.43 ± 0.01	A	0.84 ± 0.11	B	0.77 ± 0.14	B	<.0001 *
Vegave	**(m)**	1.05 ± 0.06	A	0.40 ± 0.07	B	0.54 ± 0.14	B	<.0001 *
Litdepth	(cm)	0.08 ± 0.01		0.10 ± 0.01		0.10 ± 0.01		0.1002
Pnumber	(n)	3.00 ± 0.23		2.93 ± 0.20		3.64 ± 0.23		0.1698
Pinedist	(m)	6.55 ± 0.31		6.69 ± 0.28		6.70 ± 0.28		0.8502
Pinedbh	(cm)	39.85 ± 1.62		37.49 ± 2.43		35.72 ± 1.87		0.4186
Pmidst	(n)	0.53 ± 0.35		0.47 ± 0.27		1.13 ± 0.55		0.4454
Hwnumber	**(n)**	2.88 ± 0.32		4.43 ± 0.52		3.82 ± 0.39		0.0160
Hwdist	(m)	6.41 ± 0.33		6.55 ± 0.34		6.76 ± 0.35		0.2260
HWdbh	(cm)	21.29 ± 1.45		20.08 ± 1.84		19.56 ± 1.19		0.2973
Hwmidst	(n)	8.27 ± 2.47		3.00 ± 1.57		2.93 ± 1.03		0.0482

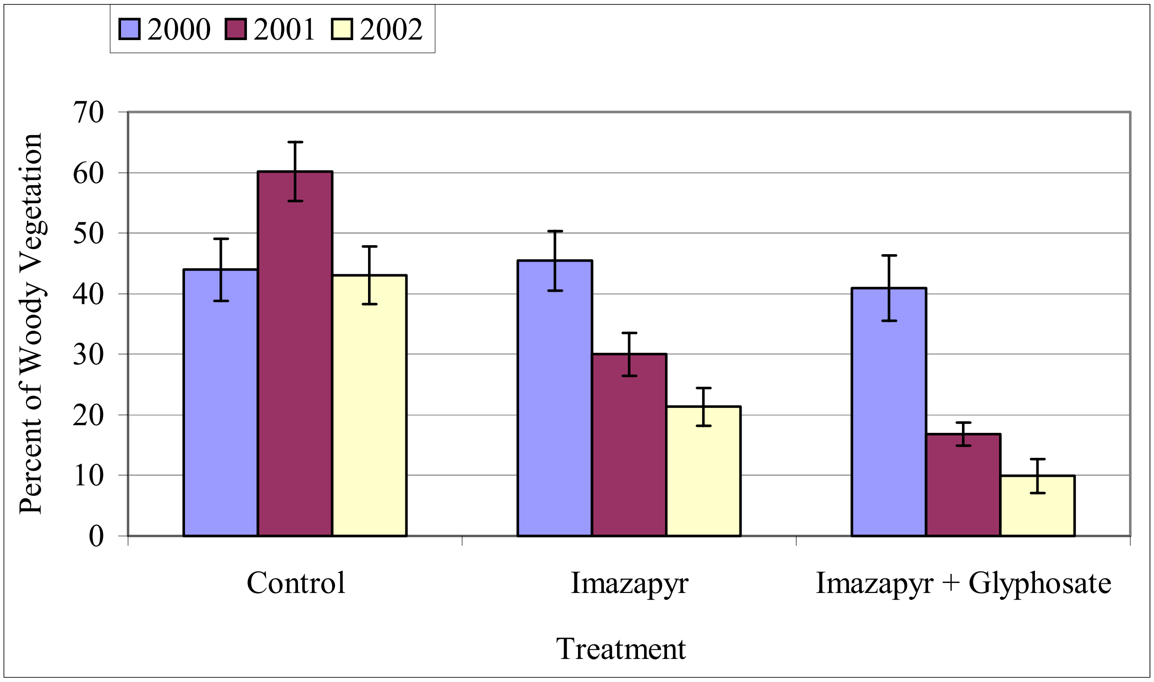

Figure 3. Percentage of woody vegetation prior to herbicide application (2000) and post herbicide application (2001–2002) on 75–85 year–old uneven aged pine stands in east central Louisiana.

both herbicide treatments (imazapyr Mean 41.72 ± SE 6.11, imazapyr + glyphosate Mean 60.95 ± SE 3.12, $P \leq 0.05$, Figure 4). VOR was greatest in control plots (Mean 0.62 ± SE 0.06, $P \leq 0.05$, Figure 5). Hardwood midstory was greatest in control plots (Mean 8.27 ± SE2.47, $P \leq 0.05$, Figures 6).

We identified percent changes from 2000 to 2001 per treatment for significant variables in both years (Table 8). Greatest positive and negative percent changes on imazapyr plots occurred for bare ground (+1154 %), debris (+561 %), litter depth (+100 %), and HW number (-22 %). Greatest positive and negative percent changes on control plots occurred for fern (+8 %), HW number (+8 %), VegMax (+3 %), VOR (+44 %), woody vegetation (+37 %), and debris (-40 %). Greatest negative percent changes on imazapyr + glyphosate plots occurred for fern (-97 %), HW midstory (-81 %), Vegmax (-38 %), vines (-51 %), VOR (-79 %), and woody (-59 %).

Overstory

We detected no treatment by stand interactions of trees greater than 10−cm dbh. We detected treatment effects for *Liquidambar styraciflua* ($F_{2,44} = 3.79$, $P = 0.032$). *Liquidambar styraciflua* was greatest in imazapyr + glyphosate treatments (13, $P \leq 0.05$, Table 9). Twenty species were identified that included 2 pine species and 18 hardwood species. The greatest percent change for *Liquidambar styraciflua* occurred on imazapyr plots (-50, Table 8).

Floristics

We identified stand by treatment interactions for *Cornus florida* ($F_{2,44} = 2.70$, $P = 0.046$), *Euphorbia* spp. ($F_{2,44} = 2.67$, $P = 0.048$), *Lespedeza* spp. ($F_{2,44} = 3.65$, $P = 0.013$), *Parthenocissus quinquefolia* ($F_{2,44} = 2.86$, $P = 0.037$), *Prunus* serotina ($F_{2,44} = 3.07$, $P = 0.028$), *Pteridium aquilinum* ($F_{2,44} = 3.38$, $P = 0.019$), *Rhus* spp. ($F_{2,44} = 5.12$, $P = 0.002$), *Symplocos tinctoria* ($F_{2,44} = 2.59$, $P = 0.053$), and *Ulmus alata* ($F_{2,44} = 2.60$, $P = 0.052$, Table 10). We

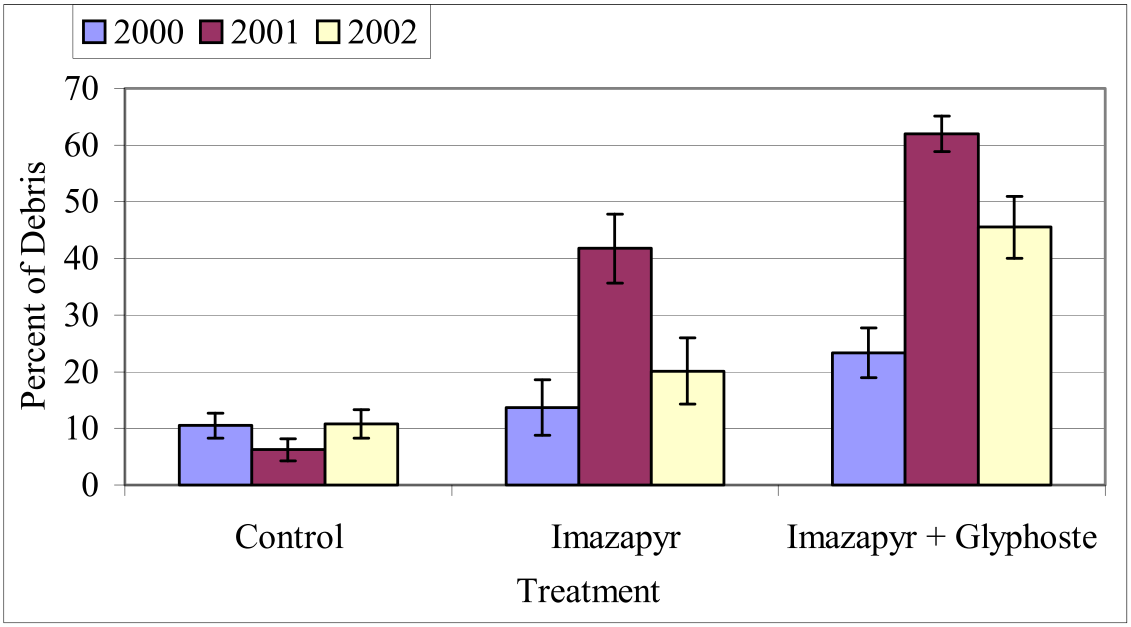

Figure 4. Percentage of debris prior to herbicide application (2000) and post herbicide application (2001–2002) on 75–85 year–old uneven aged pine stands in east central Louisiana.

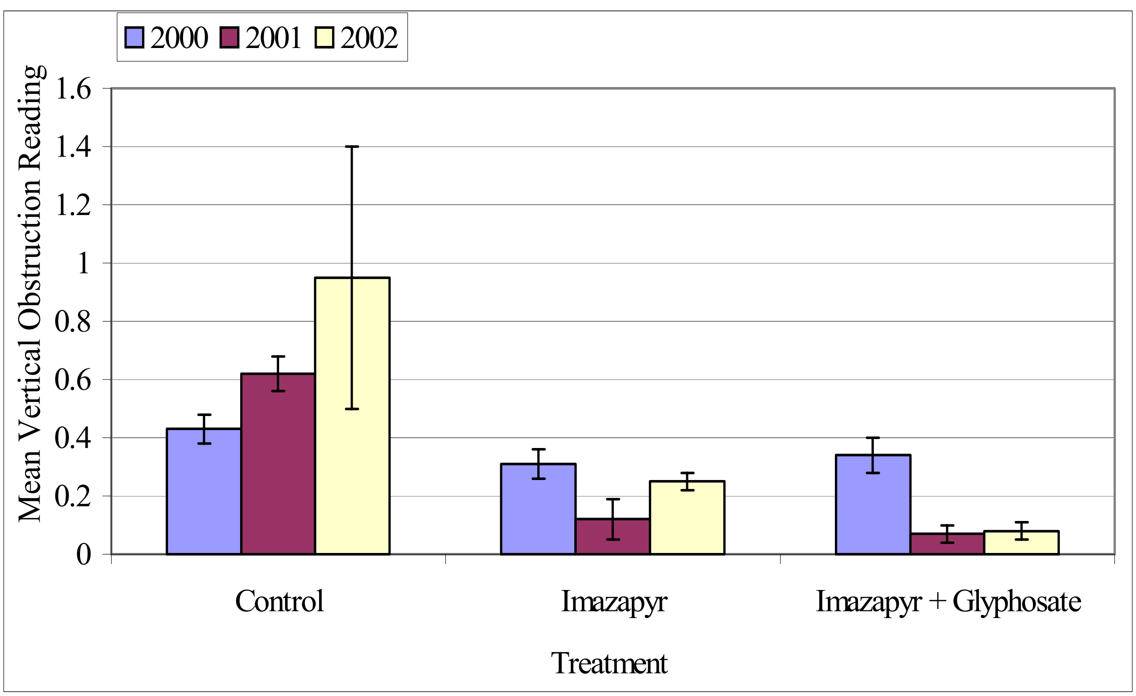

Figure 5. Mean vertical obstruction reading prior to herbicide application (2000) and post herbicide application (2001–2002) on 75–85 year–old uneven aged pine stands in east central Louisiana.

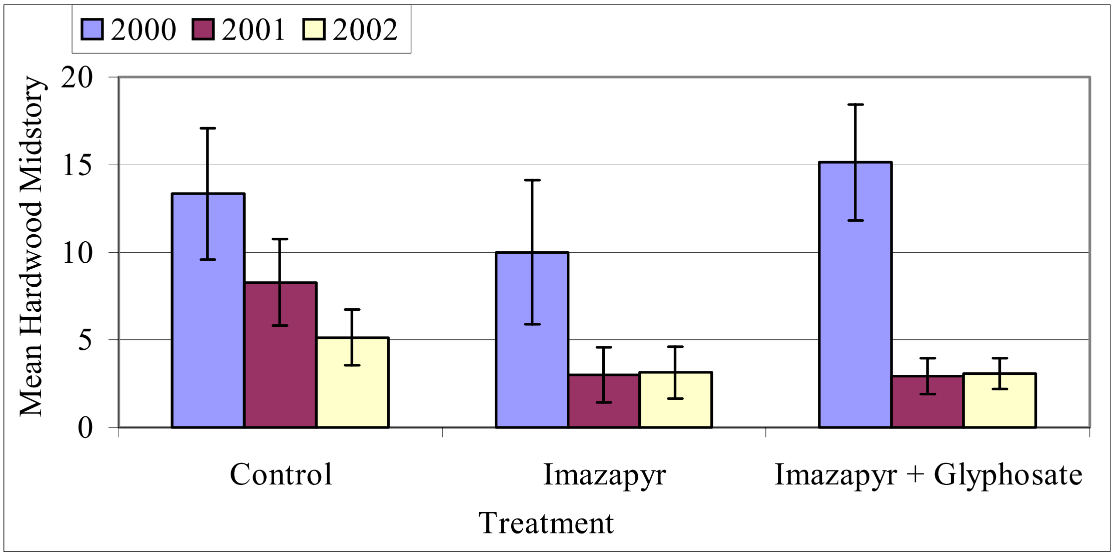

Figure 6. Mean hardwood midstory less than 10 cm dbh prior to herbicide application (2000) and post herbicide application (2001–2002) on 75–85 year–old uneven aged pine stands in east central Louisiana.

Table 8. Percentage change for vegetative variables found significant prior to herbicide application (2000) and post–herbicide application (2001–2002) in 75 to 85 year–old uneven–aged pine stands in east central Louisiana. Columns left blank had no recorded values for that year. * indicates variables important to bobwhite. Variables with value 0 for between year comparison are depicated as a + of – percentage change.

Treatment	**Control**		**Imazapyr**		**Imazapyr + Glyphosate**	
Year	**2001**	**2002**	**2001**	**2002**	**2001**	**2002**
* Bare Ground (Structure)	+ 27	+ 18	+ 1154	+ 114	+ 141	+ 561
* Debris (Structure)	- 40	+ 72	+ 561	- 52	+ 166	- 26.6
Fern (Structure)	+ 8	+ 199	+	+ 243	- 97	+ 1,120
HW Midstory (Structure)	- 38	- 38	- 70	+ 4	- 81	+ 4.8
HW Number (Structure)	+ 8	- 2	- 22	+ 35	- 20	+ 13.4
* Litter Depth (Structure)	0	- 88	+ 100	- 92	+ 25	- 90
* VegMax (Structure)	+ 3	- 3	- 31	+ 32	- 38	+ 13
* Vines (Structure)	- 17	- 8	- 4	+ 81	- 51	+ 33.2
VOR (Structure)	+ 44	+ 53	- 61	+ 108	- 79	+ 14.3
* Woody (Structure)	+ 37	- 29	- 34	- 29	- 59	- 41
Liquidambar styraciflua > 10 cm dbh	0	0	- 50	+ 50	- 35	+ 15.4
Acer rubrum	+ 15	- 19	- 82	+ 205	- 71	- 60
* Bobwhite Food Plants	- 24	+ 10	+ 4	+ 70	- 43	+ 225.8
Callicarpa americana	+ 30	+ 5	- 65	+ 351	- 88	+ 186.4
* Debris	- 81	+ 6	- 41	- 54	- 41	- 38
Dicanthelium spp.	+	- 8	+	+ 524	+ 297	+ 400
Elephantopus tomentosus	- 62	+ 151	- 56	+ 16	- 74	+ 220
Erechtites hieracifolia	-	+	-	+	+	+ 3,000
* Ground	+ 50	+ 2133	-	+	- 93	+ 21,900
Hypericum hypericoides	0	-	- 75	+ 133	+	+ 237.5
* *Lespedeza* spp.			+ 1,067	+ 20	+	+ 133.3

Table 8. Continued

Table 8. Continued

Treatment	**Control**		**Imazapyr**		**Imazapyr + Glyphosate**	
Year	**2001**	**2002**	**2001**	**2002**	**2001**	**2002**
Liquidambar styraciflua	+ 62	- 20	- 95	+ 53	-	+
Lygodium japonicum	- 15	+ 9	-	+	- 93	+ 1,085.7
Mitchella repens	+ 143	- 24	- 72	+ 240	- 50	- 48.3
Myrica cerifera	+ 55	- 4	+ 69	- 72	- 38	- 82.4
Passifloa lutea		+	+	-	-	0
Pinus seedlings	+ 357	- 84	+	- 62	+	- 89.7
Prunus serotina	- 12	- 26	-	+	- 98	+ 750
Pteridium aquilinum	+ 1	- 2	- 61	+ 175	- 57	+ 120
Pycnanthemum incanum		+	-	+	-	+
Quercus spp.	+ 7	+ 6	- 86	+ 72	- 91	- 33.3
Rhus spp.	- 33	+ 81	- 100	+ 3,650	-	+
* *Rubus* spp.	- 8	+ 29	+ 122	+ 51	- 32	+ 144.2
Sassafras albidum	+ 180	+ 179	-	0		
Vitis spp.	- 15	+ 2	- 96	+ 289	- 35	+ 86.5
Order Acari	+ 444	- 32	+ 128	- 69	+	+ 384.8
* Order Diptera	+ 1,011	- 76	+ 367	- 55	+ 167	- 52.4
* Order Hemiptera	- 33	- 50	+ 28	- 55	- 52	+ 107.7
* Order Homoptera	+ 228	- 99	+ 46	- 91	- 70	- 86
Order Thysanura	-	+	- 30	-	-	0

Table 9. Number of hardwood and pine species that occurred on all 0.04–ha (1/10–acre) subplots (2001) first–year post–herbicide application on 75–85 year–old uneven–aged pine stands in east central Louisiana. Identical letters within rows are not statistically different per Tukey's HSD ($\underline{P}$<0.05). * Indicates stand by treatment interaction. Significant variables are in BOLD.

Treatment Variable	**2001**			**Pr>F**
	Control (n)	**Imazapyr (n)**	**Imazapyr + Glyphosate (n)**	
Acer rubrum	0	1	0	0.3779
Aralia spinosa	0	2	0	0.3779
Carya spp.	2	1	0	0.3130
Cornus florida	2	3	3	0.9094
Liquidambar styraciflua	4 AB	2 B	13 A	0.0279
Liriodendron tulipifera	2	2	0	0.2763
Nyssa sylvatica	4	4	0	0.2618
Oxydendrum arboreum	0	0	1	0.3779
Prunus serotina	2	1	3	0.8081
Quercus alba	6	6	7	0.9864
Quercus falcata	4	6	6	0.8442
Quercus laurifolia	1	0	1	0.6107
Quercus nigra	3	13	5	0.2930
Quercus pagoda	7	0	1	0.1995
Quercus prinus	0	0	1	0.3779
Quercus stellata	4	1	4	0.4493
Symplocos tinctoria	0	0	2	0.3779
Ulmus alata	1	0	3	0.1501
Pinus echinata	23	16	20	0.6895
Pinus taeda	41	44	60	0.2270
TOTAL	106	102	130	

Table 10. Mean proportion of floristics (2001) first year post–herbicide application on 75–85 year–old pine stands in east central Louisiana. Identical letters within rows are not statistically different per Tukey's HSD (P<0.05). * Indicates stand by treatment interaction. Significant variables are in BOLD.

Treatment		Control		Imazapyr		Imazapyr + Glyphosate		Pr>F
Scientific Name	Common Name	Mean ± SE		Mean ± SE		Mean ± SE		
Acer rubrum	Red Maple	1.15 ± 0.44	A	0.22 ± 0.15	AB	0.05 ± 0.04	B	0.0220
Andropogon spp.	Broomsedge	1.45 ± 0.78		2.03 ± 0.91		0.78 ± 0.56		0.6210
Berchemia scandens	Rattanvine	0.02 ± 0.02		0		0		0.3779
Bignonia capreolata	Crossvine	0.05 ± 0.05		0		0.02 ± 0.02		0.5032
Callicarpa americana	American Beautyberry	8.87 ± 2.49	A	1.60 ± 0.49	B	0.88 ± 0.40	B	<.0001
Carya spp.	Hickory	0.25 ± 0.17		0		0.23 ± 0.23		0.4853
Centrosema virginianum	Spurred Butterfly Pea	0.02 ± 0.02		0		0		0.3779
Chamaecrista fasciculata	Partridge Pea	0		0		0.02 ± 0.02		0.3779
Chasmanthium spp.	Spikegrass	2.57 ± 1.59		0		0		0.0970
Clitoria mariana	Butterfly Pea	0.05 ± 0.04		0.12 ± 0.10		0.05 ± 0.05		0.7137
Conyza spp.	Horseweed	0.05 ± 0.05		0		0		0.3779
Cornus florida	Flowering Dogwood	2.82 ± 1.28	A	0.18 ± 0.17	B	0.35 ± 0.18	B	0.0156 *
Croptilon spp.	Goldenweed	0		0		0.05 ± 0.05		0.3779
Debris		2.63 ± 0.42	B	8.99 ± 1.02	A	13.38 ± 1.09	A	0.0061
Dicanthelium spp.	Low Panicgrass	0.67 ± 0.22		0.33 ± 0.12		1.27 ± 0.44		0.1053
Diospyros virginiana	Common Persimmon	0.43 ± 0.22	A	0	B	0.05 ± 0.05	AB	0.0386
Elephantopus tomentosus	Elephant's–Foot	0.37 ± 0.16		0.43 ± 0.16		0.65 ± 0.31		0.6199
Erechtites hieracifolia	American Burnweed	0		0		0.07 ± 0.05		0.1669
Eupatorium spp	Boneset	0.45 ± 0.24		0.13 ± 0.08		0.33 ± 0.20		0.4413
Euphorbia spp.	Spurge	0.07 ± 0.04		0		0		0.0832 *
Forb		0.25 ± 0.14		0.33 ± 0.17		0.20 ± 0.13		0.7982
Gelsemium spp.	Jessamine vine	0.18 ± 0.08		0.08 ± 0.05		0.03 ± 0.03		0.2048
Ground	Bare Ground	0.03 ± 0.03		0		0.02 ± 0.02		0.5542

Table10. Continued

Table 10. Continued

Treatment		Control		Imazapyr		Imazapyr + Glyphosate		Pr>F
Scientific Name	Common Name	Mean ± SE		Mean ± SE		Mean ± SE		
Halesia dipteria	Silverbell	0.08 ± 0.06		0		0.03 ± 0.03		0.3381
Hamamelis virginiana	Witch–hazel	0.17 ± 0.17		0		0		0.3779
Hypericum hypericoides	St. Andrew's–cross	0.03 ± 0.03		0.03 ± 0.02		0.08 ± 0.06		0.6265
Hypericum mutilum	Dwarf St. Johnswort	0		0.02 ± 0.02		0		0.3779
Ilex glabra	Gallberry	0.72 ± 1.34		0		0.35 ± 0.35		0.2502
Ilex opaca	American Holly	0.18 ± 0.14		0		0.25 ± 0.18		0.3360
Ilex vomitoria	Yaupon	7.65 ± 1.61		11.88 ± 2.31		8.05 ± 1.57		0.2115
Lespedeza spp.	Lespedeza	0		0.35 ± 0.22		0.03 ± 0.02		0.0544 *
Liquidambar styraciflua	Sweetgum	6.73 ± 1.63	A	0.38 ± 0.19	B	0	B	<.0001
Lonicera spp.	Honeysuckle	0.13 ± 0.13		0		0		0.3779
Lygodium japonicum	Japanese Climbing fern	3.12 ± 1.54	A	0	A	0.07 ± 0.07	A	0.0356
Mikania scadens	Climbing Hempweed	0.03 ± 0.03		0		0		0.3779
Mitchella repens	Partridge–berry	0.17 ± 0.09	B	0.05 ± 0.03	B	0.58 ± 0.19	A	0.0079
Monarda fistulosa	Wild Bergomot	1.13 ± 0.67		0.65 ± 0.48		0.77 ± 0.33		0.7772
Myrica cerifera	Waxmyrtle	1.97 ± 0.49		4.20 ± 1.71		0.68 ± 0.22		0.0776
Nyssa sylvatica	Blackgum	0.47 ± 0.27		0.38 ± 0.38		0		0.4411
Ostrya virginiana	American Hop Hornbeam	0.08 ± 0.08		0		0		0.3779
Osmunda regalis	Royal Fern	0.03 ± 0.03		0		0		0.3779
Oxalis spp.	Woodsorrel	0.08 ± 0.04		0.22 ± 0.17		0.03 ± 0.12		0.3660
Parthenocissus quinquefolia	Virginia Creeper	0.65 ± 0.43		0.48 ± 0.20		0.33 ± 0.17		0.7087 *
Passiflora lutea	Broadleaf Maypop	0		0.12 ± 0.12		0		0.3779
Pinus seedlings		0.32 ± 0.17	B	2.68 ± 0.79	A	4.35 ± 1.88	A	<.0001
Poaceae spp.	Grass Family	0.33 ± 0.16		0.25 ± 0.17		0.47 ± 0.21		0.7010
Polystichum acrostichoides	Christmas Fern	0		0.03 ± 0.03		0.03 ± 0.03		0.6107
Prunus serotina	Wild Black Cherry	0.98 ± 0.64		0		0.02 ± 0.02		0.0629
Pteridium aquilinum	Brackenfern	7.65 ± 4.40	A	0.63 ± 0.63	A	0.35 ± 0.16	A	0.0386

Table 10. Continued

Table 10. Continued

Treatment		Control		Imazapyr		Imazapyr + Glyphosate		Pr>F
Scientific Name	**Common Name**	**Mean ± SE**		**Mean ± SE**		**Mean ± SE**		
Quercus spp.	Oak	4.35 ± 1.39	A	0.97 ± 0.47	B	0.42 ± 0.25	B	0.0144 *
Rhododendron spp.	Azalea	1.00 ± 0.69		0.08 ± 0.05		0.13 ± 0.08		0.2277
Rhus spp.	Sumac	1.67 ± 0.66	A	0.02 ± 0.02	B	0	B	0.0004 *
Rubus spp.	Blackberry	7.45 ± 1.36		19.10 ± 3.37		6.15 ± 1.12		0.2284
Ruellia spp.	Petunia	0		0.02 ± 0.02		0.05 ± 0.05		0.5032
Sassafras albidum	Sassafras	0.28 ± 0.23		0		0		0.2218
Smilax spp.	Greenbrier	1.90 ± 0.94		0.08 ± 0.17		1.25 ± 0.44		0.4440
Solidago spp.	Goldenrod	1.03 ± 0.47		1.25 ± 0.53		0.25 ± 0.12		0.1739
Styrax americana	American Snowbell	0		0		0.03 ± 0.03		0.3779
Stylosanthus biflora	Pencilflower	0		0.03 ± 0.03		0		0.3779
Symplocos tinctoria	Sweetleaf	5.18 ± 1.76		4.12 ± 1.81		0.72 ± 0.62		0.0805 *
Toxicodendron radicans	Poison–ivy	0.17 ± 0.15		0		0.20 ± 0.18		0.5500
Ulmus alata	Winged Elm	0.20 ± 0.13		0		0.07 ± 0.04		0.1597 *
Vaccinium spp.	Blueberry	2.02 ± 1.11		0.35 ± 0.18		0.08 ± 0.05		0.0971
Viola spp.	Violet or Pansy	0.05 ± 0.03		0.08 ± 0.07		0.27 ± 0.13		0.1702
Vitis spp.	Grape	6.88 ± 1.66	A	0.27 ± 0.10	B	0.52 ± 0.38	B	<.0001
Food	Bobwhite Food Plants	15.8 ± 2.90	AB	24.00 ± 4.35	A	9.43 ± 1.66	B	0.0071

detected treatment effects for *Acer rubrum* ($F_{2,44}$ = 4.25, P = 0.022), *Callicarpa americana* ($F_{2,44}$ = 12.54, P = < 0.001), debris ($F_{2,44}$ = 5.90, P = 0.006), *Diospyros virginiana* ($F_{2,44}$ = 3.74, P = 0.034), *Liquidambar styraciflua* ($F_{2,44}$ = 14.58, P = < 0.001), *Lygodium japonicum* ($F_{2,44}$ = 3.67, P = 0.036), *Mitchella repens* ($F_{2,44}$ = 5.55, P = 0.008), *Pinus* seedlings ($F_{2,44}$ = 13.28, P = < 0.001), *Quercus* spp. ($F_{2,44}$ = 4.78, P = 0.014), *Vitis* spp. ($F_{2,44}$ = 15.59, P = < 0.001), and bobwhite food ($F_{2,44}$ = 5.70, P = 0.007, Table 3 and 10). *Acer rubrumn* (Mean 1.15 ± SE 0.44), *Callicarpa americana* (Mean 8.87 ± SE 2.49), *Diospyros virginiana* (Mean 0.43 ± SE 0.22), *Liquidambar styraciflua* (Mean 6.73 ± SE 1.63), *Lygodium japonicum* (Mean 3.12 ± SE 1.54), *Quercus* spp. (Mean 4.35 ± SE 1.39), and *Vitis* spp. (Mean 6.88 ± SE 1.66) were greatest in control plots ($P \leq 0.05$). Debris (imazapyr Mean 8.99 ± SE 1.02, imazapyr + glyphosate Mean 13.38 ± SE 1.09) and pine seedlings (imazapyr Mean 2.68 ± SE 0.79, imazapyr + glyphosate Mean 4.35 ± SE 1.88) were greatest in herbicide plots ($P \leq 0.05$). *Mitchella repens* was greatest in imazapyr + glyphosate plots (Mean 0.58 ± SE 0.19, $P \leq 0.05$). Bobwhite food was greatest in imazapyr plots (Mean 24.00 ± SE 4.35, $P \leq 0.05$, Figure 7).

We identified percent changes from 2000 to 2001 per treatment for variables that were significant in either year (Table 8). The greatest positive and negative percent changes on imazapyr + glyphosate plots occurred for *Dicanthelium* spp. (+297 %), bobwhite food plants (-43 %), *Callicarpa* americana (-88 %), *Elephantopus tomentosus* (-74 %), ground (-93 %), *Lygodium japonicum* (-93 %), *Myrica* cerifera (-38 %), *Prunus serotina* (-98 %), *Quercus* spp. (-91 %), and *Rubus* spp. (-32 %). The greatest positive and negative percent changes on control plots occurred for *Acer rubrum* (+15 %), *Callicarpa americana* (+30 %), ground (+50 %), *Liquidambar styraciflua* (+62 %), *Mitchella repens* (+143 %), *Pinus* seedlings (+357 %), *Pteridium aquilinum* (+1 %), *Quercus* spp. (+7 %), and *Sassafras albidum* (+180 %). The

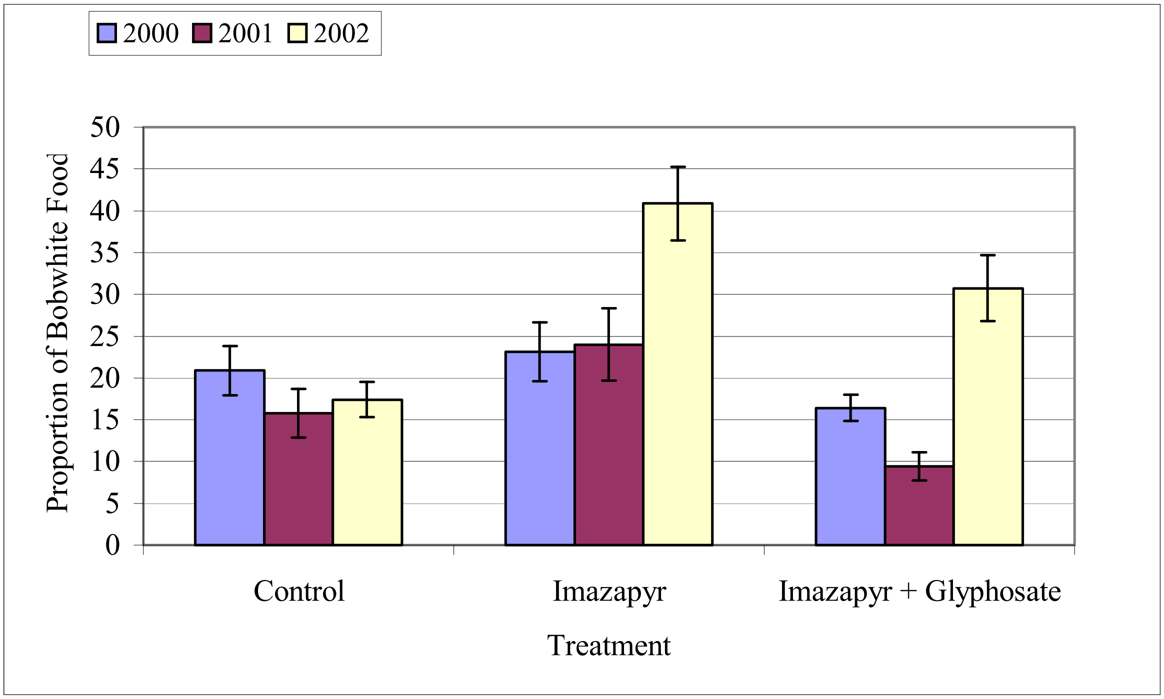

Figure 7. Proportion of bobwhite food plants prior to herbicide application (2000) and post–herbicide application (2001–2002) on 75–85 year–old pine stands in east central Louisiana.

greatest positive and negative percent changes on imazapyr plots occurred for bobwhite food plants (+4 %), *Lespedeza* spp. (+1,067 %), *Myrica cerifera* (+69 %), *Rubus* (+122 %), *Acer rubrun* (-82 %), *Hypericum* hypericoides (-75 %), Liquidambar *styraciflua* (-95 %), *Mitchella repens* (-72 %), *Pteridium aquilinum* (-61 %), *Rhus* spp. (-100 %), and *Vitis* (-96 %).

Second Year Post Treatment (2002)

Structure

We identified stand by treatment interactions for forb ($F_{2,44}$ = 4.98, P = 0.003), vegave ($F_{2,44}$ = 3.11, P = 0.027), and number of pines ($F_{2,44}$ = 2.67, P = 0.033; Table 11). We detected treatment effects for woody ($F_{2,44}$ = 22.68, P = < 0.001), vine ($F_{2,44}$ = 8.10, P = 0.001), debris ($F_{2,44}$ = 9.89, P = 0.001), bare ground ($F_{2,44}$ = 6.57, P = 0.004), fern ($F_{2,44}$ = 7.57, P = 0.002), VOR ($F_{2,44}$ = 2.88, P = 0.069), vegmax ($F_{2,44}$ = 18.56, P = < 0.001), litter depth ($F_{2,44}$ = 3.11, P = 0.056), and number of hardwoods ($F_{2,44}$ = 8.68, P = 0.001, Table 3). Number of hardwoods (Mean 5.98 ± SE 0.71) and vines (Mean 36.15 ± SE 5.30) were greatest in imazapyr treatments ($P \leq 0.05$, Figures 1 and 8). Litter depth was greatest in control (Mean 0.01 ± SE 0.007) and imazapyr + glyphosate plots (Mean 0.01 ± SE 0.001, $P \leq 0.05$, Figure 2). Woody (Mean 43.06 ± SE 4.76), VOR (Mean 0.95 ± SE 0.45), fern (Mean 15.65 ± SE 5.33), and vegmax (Mean 1.39 ± SE 0.02) were greatest in control plots ($P \leq 0.05$, Figures 3, 5, 9, and 10). Debris (Mean 45.49 ± SE 5.41) and bare ground (Mean 8.13 ± SE 2.41) were greatest in imazapyr + glyphosate treatments ($P \leq 0.05$, Figures 4 and 11).

We identified percent changes from 2001 to 2002 per treatment for significant variables in either year (Table 8). Greatest positive and negative percent changes on imazapyr + glyphosate plots occurred for bare ground (+561 %), fern (+1,120 %), and HW midstory (+4.8 %), and woody (-41 %). Greatest positive and negative percent changes on control plots

Table 11. Mean vegetation structural characteristics (2002) second year post–herbicide application on 75 to 85 year–old uneven–aged pine stands in east central Louisiana. Identical letters within rows are not statistically different per Tukey's HSD (P<0.05). * Indicates stand by treatment interaction. Significant variables are in BOLD.

Treatment Variable		**Control** Mean ± SE		**Imazapyr** Mean ± SE		**Imazapyr + Glyphosate** Mean ± SE		**Pr > F**
Grass	(%)	5.75 ± 2.12		8.12 ± 2.11		10.53 ± 3.11		0.3982
Forb	(%)	6.20 ± 1.60		7.47 ± 1.41		9.87 ± 2.31		0.3504 *
Woody	(%)	43.06 ± 4.76	A	21.32 ± 3.14	B	9.91 ± 2.82	B	<.0001
Vine	(%)	17.73 ± 3.96	B	36.15 ± 5.30	A	15.67 ± 2.61	B	0.0012
Debris	(%)	10.74 ± 2.52	B	20.12 ± 5.83	AB	45.49 ± 5.41	A	<.0001
Bground	(%)	0.50 ± 0.18	B	3.49 ± 1.37	AB	8.13 ± 2.41	A	0.0005
Fern	(%)	15.65 ± 5.33	A	3.84 ± 1.88	B	0.61 ± 0.33	B	0.0018
Canopy	(%)	91.70 ± 1.21		90.95 ± 1.34		86.09 ± 6.19		0.5299
VOR	(m)	0.95 ± 0.45		0.25 ± 0.03		0.08 ± 0.03		0.0690
Vegmax	(m)	1.39 ± 0.02	A	1.11 ± 0.05	B	0.87 ± 0.09	C	<.0001
Vegave	(m)	0.71 ± 0.04	A	0.41 ± 0.04	B	0.26 ± 0.04	C	<.0001 *
Litdepth	(cm)	0.01 ± 0.007	A	0.008 ± 0.001	B	0.01 ± 0.001	A	0.0563
Pnumber	(n)	3.12 ± 0.26		2.83 ± 0.19		3.68 ± 0.25		0.1420 *
Pinedist	(m)	6.50 ± 0.31		6.62 ± 0.29		6.69 ± 0.27		0.8407
Pinedbh	(cm)	39.83 ± 1.81		38.21 ± 2.43		35.34 ± 1.89		0.3262
Pmidst	(n)	0.56 ± 0.32		0.40 ± 0.27		0.88 ± 0.46		0.7108
Hwnumber	(n)	2.83 ± 0.31	B	5.98 ± 0.71	A	4.33 ± 0.44	AB	<.0001
Hwdist	(m)	6.32 ± 0.33		6.29 ± 0.33		6.59 ± 0.30		0.3230
HWdbh	(cm)	21.99 ± 1.48		19.56 ± 1.74		18.93 ± 1.10		0.1814
Hwmidst	(n)	5.13 ± 1.60		3.13 ± 1.47		3.07 ± 0.88		0.4783

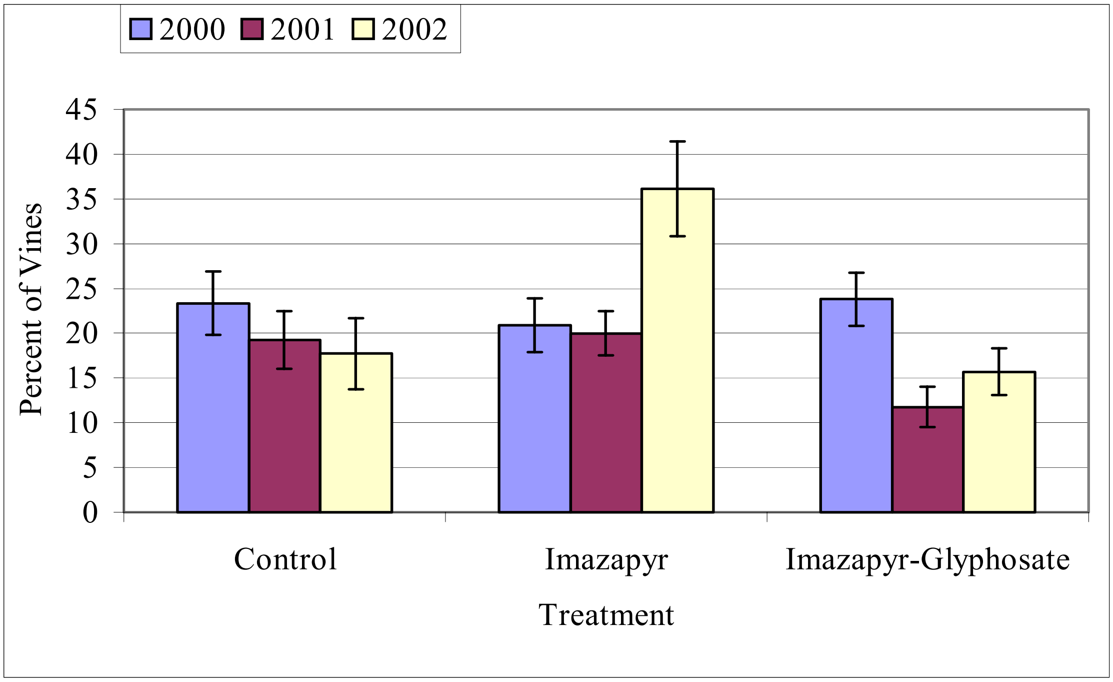

Figure 8. Percentage of vines prior to herbicide application (2000) and post herbicide application (2001–2002) on 75–85 year–old uneven aged pine stands in east central Louisiana.

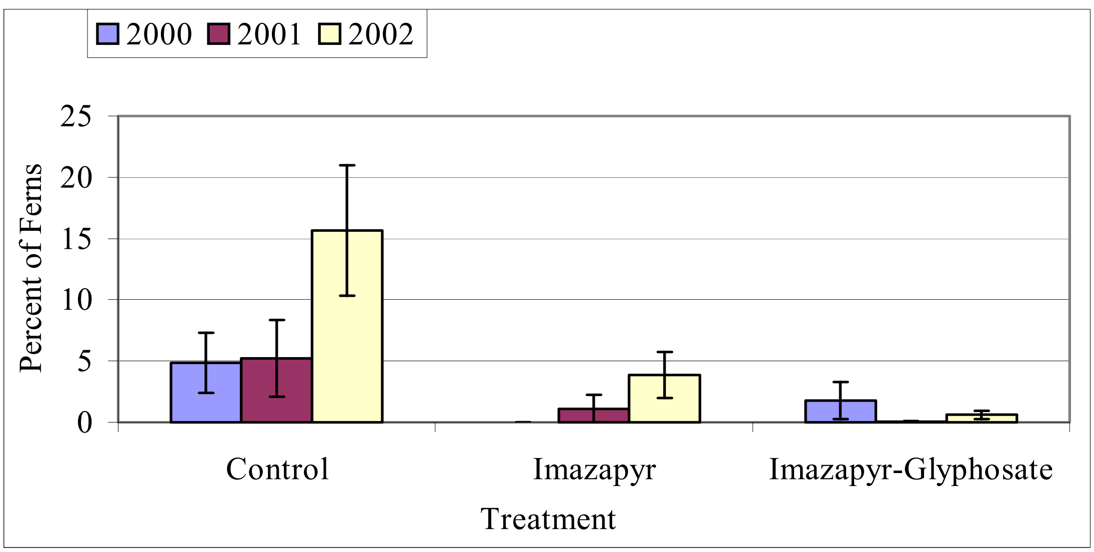

Figure 9. Percentage of ferns prior to herbicide application (2000) and post herbicide application (2001–2002) on 75–85 year–old uneven aged pine stands in east central Louisiana.

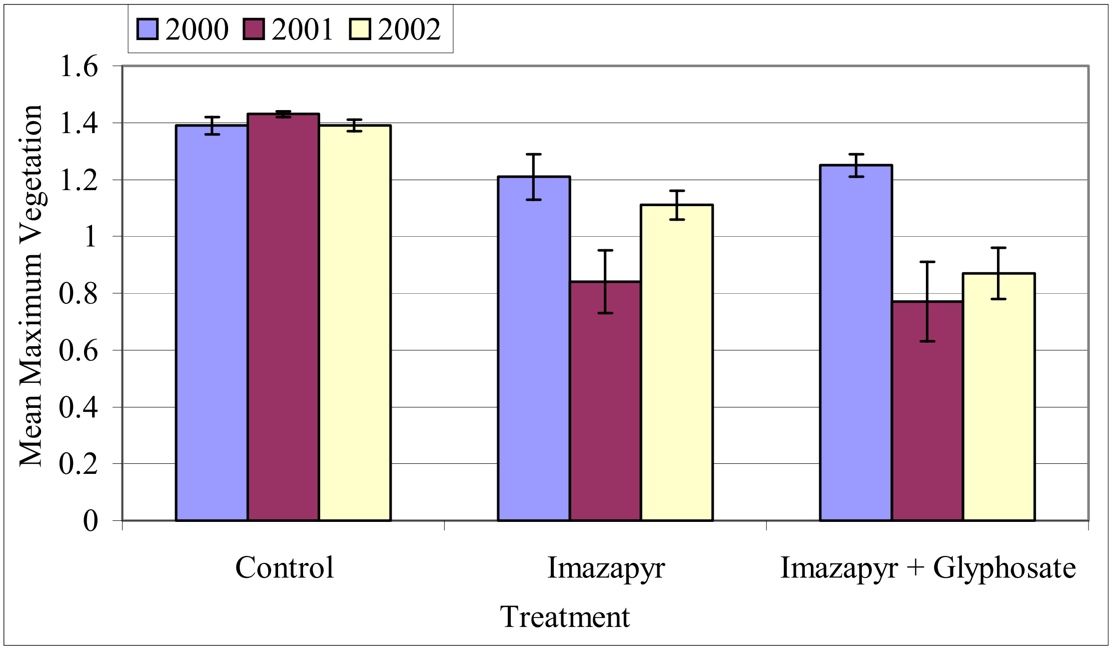

Figure 10. Mean maximum vegetation prior to herbicide application (2000) and post herbicide application (2001–2002) on 75–85 year–old uneven aged pine stands in east central Louisiana.

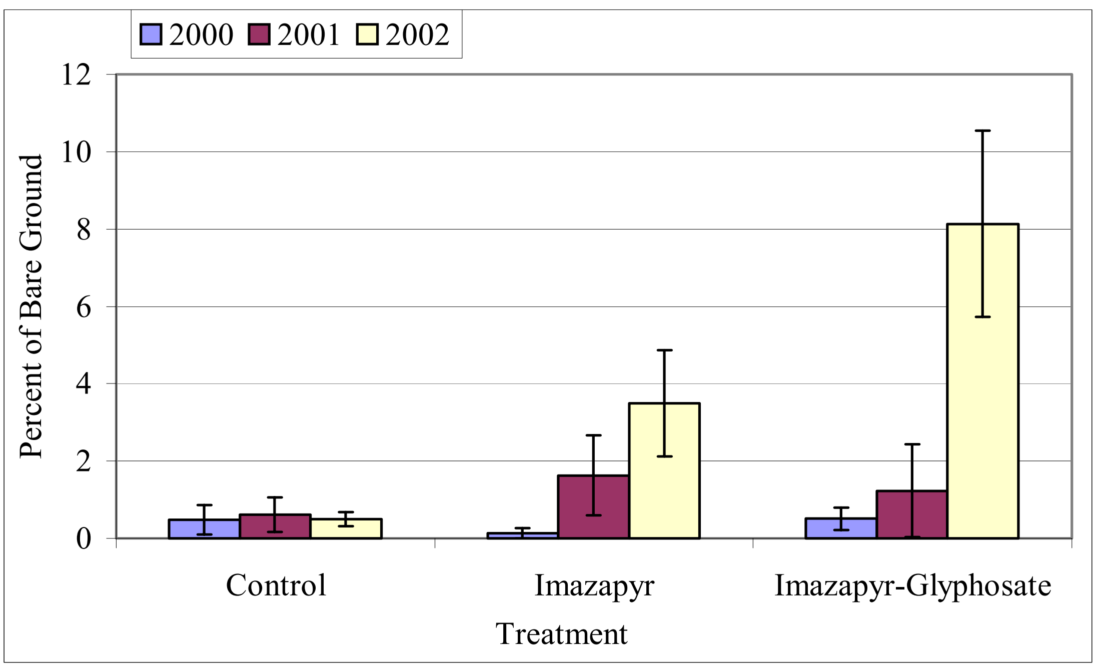

Figure 11. Percentage of bare ground prior to herbicide application (2000) and post herbicide application (2001–2002) on 75–85 year–old uneven aged pine stands in east central Louisiana.

occurred for debris (+72 %), HW midstory (-38 %), HW number (-2 %), VegMax (-3 %), and vines (-8 %). Greatest positive and negative percent changes for imazapyr plots occurred for HW number (+35 %), VegMax (+32 %), vines (+81 %), VOR (+108 %), debris (-52 %) and litter depth (-92 %).

Overstory

We identified stand by treatment interactions of trees greater than 10–cm for *Nyssa sylvatica* ($F_{2,44} = 2.52$, $P = 0.058$) and *Oxydendrum arboreum* ($F_{2,44} = 2.67$, $P = 0.048$; Table 12). We detected treatment effects for *Liquidambar styraciflua* ($F_{2,44} = 4.59$, $P = 0.017$). *Liquidambar styraciflua* was greatest in imazapyr + glyphosate plots ($P \leq 0.05$). Twenty species were identified that included 2 pine species and 18 hardwood species. Twenty–two species were identified prior to herbicide treatment and 20 remained in 2002. The greatest percent change for *Liquidambar styraciflua* occurred on imazapyr plots (+50, Table 8).

Floristics

We identified stand by treatment interactions for debris ($F_{2,44} = 2.62$, $P = 0.051$), *Eupatorium* spp. ($F_{2,44} = 42.56$, $P = 0.055$), *Parthenocissus quinquefolia* ($F_{2,44} = 2.72$, $P = 0.045$), *Pteridium aquilinum* ($F_{2,44} = 2.75$, $P = 0.043$), *Sassafras albidum* spp. ($F_{2,44} = 4.04$, $P = 0.008$), and *Vitis* spp. ($F_{2,44} = 2.95$, $P = 0.033$; Table 13). We detected treatment effects for *Callicarpa americana* ($F_{2,44} = 3.21$, $P = 0.052$), *Dicanthelium* spp. ($F_{2,44} = 9.21$, $P = 0.001$), *Elephantopus tomentosus* ($F_{2,44} = 3.38$, $P = 0.045$), *Erechtites hieracifolia* ($F_{2,44} = 4.57$, $P = 0.017$), Ground ($F_{2,44} = 3.37$, $P = 0.046$), *Hypericum hypericoides* ($F_{2,44} = 2.84$, $P = 0.072$), *Liquidambar styraciflua* ($F_{2,44} = 6.89$, $P = 0.003$), *Myrica cerifera* ($F_{2,44} = 7.26$, $P = 0.002$), *Quercus* spp. ($F_{2,44} = 3.85$, $P = 0.031$), *Rhus* spp. ($F_{2,44} = 4.83$, $P = 0.014$), *Rubus* spp. ($F_{2,44} = 3.31$, $P = 0.048$), and bobwhite food ($F_{2,44} = 11.08$, $P < 0.001$, Table 3). *Liquidambar*

Table 12. Number of hardwood and pine species that occurred on all 0.04–ha (1/10–acre) subplots in (2002) second–year post–herbicide application on 75–85 year–old uneven–aged pine stands in east central Louisiana. Identical letters within rows are not statistically different per Tukey's HSD ($P<0.05$). * Indicates stand by treatment interaction. Significant variables are in BOLD.

Treatment Variable	**2002**			**Pr>F**
	Control (n)	**Imazapyr (n)**	**Imazapyr + Glyphosate (n)**	
Acer rubrum	0	1	0	0.3779
Aralia spinosa	0	2	0	0.3779
Carya spp.	2	1	0	0.5542
Cornus florida	2	1	7	0.4851
Liquidambar styraciflua	4 B	3 B	15 A	0.0168
Liriodendron tulipifera	2	2	0	0.2763
Nyssa sylvatica	4	5	0	0.2708 *
Ostrya virginiana	1	0	0	0.3779
Oxydendrum arboreum	0	0	2	0.0832 *
Prunus serotina	2	1	3	0.8081
Quercus alba	6	7	7	0.9672
Quercus falcata	5	5	6	0.9513
Quercus laurifolia	1	1	1	0.6107
Quercus nigra	3	16	6	0.3701
Quercus pagoda	5	1	1	0.3996
Quercus stellata	4	1	4	0.4493
Symplocos tinctoria	0	0	2	0.1501
Ulmus alata	1	1	3	0.4199
Pinus echinata	19	15	18	0.8744
Pinus taeda	46	45	61	0.2525
TOTAL	107	108	136	

Table 13. Mean proportion of floristics (2002) second year herbicide application on 75–85 year–old pine stands in east central Louisiana. Identical letters within rows are not statistically different per Tukey's HSD (P<0.05). * Indicates stand by treatment interaction. Significant variables are in BOLD.

Treatment		**Control**		**Imazapyr**		**Imazapyr + Glyphosate**		**Pr>F**
Scientific Name	**Common Name**	**Mean ± SE**		**Mean ± SE**		**Mean ± SE**		
Acalypha spp.	Three–seeded Mercury	0		0		0.02 ± 0.02		0.3779
Acer rubrum	Red Maple	0.93 ± 0.48		0.67 ± 0.31		0.02 ± 0.02		0.1298
Ambrosia spp.	Ragweed	0		0		0.02 ± 0.02		0.3779
Andropogon spp.	Broomsedge	0.47 ± 0.26		1.68 ± 0.89		0.85 ± 0.46		0.3076
Arthraxon hispidus	Joint–head Arthraxon	0		0.02 ± 0.02		0		0.3779
Athyrium filix–femina	Southern Lady Fern	0		0		0.02 ± 0.02		0.3779
Callicarpa americana	American Beautyberry	9.27 ± 2.28		7.22 ± 2.02		2.52 ± 0.56		0.0523
Carya spp.	Hickory	0.48 ± 0.48		0.33 ± 0.33		0.22 ± 0.22		0.8566
Centrosema virginianum	Spurred Butterfly Pea	0.03 ± 0.03		0.07 ± 0.07		0.15 ± 0.08		0.3914
Chamaecrista fasciculata	Partridge Pea	0.15 ± 0.09		0.18 ± 0.10		0.07 ± 0.04		0.6289
Chasmanthium spp.	Spikegrass	0.15 ± 0.09		0.58 ± 0.35		0.63 ± 0.28		0.1956
Cirsium spp.	Thistle	1.70 ± 0.73		0		0		0.3779
Clitoria mariana	Butterfly Pea	0.20 ± 0.10		0.38 ± 0.15		0.25 ± 0.09		0.5437
Cornus florida	Flowering Dogwood	1.33 ± 0.57		0.17 ± 0.08		0.18 ± 0.11		0.0967
Croptilon spp.	Goldenweed	0.30 ± 0.22		0.08 ± 0.06		0.08 ± 0.08		0.4776
Debris		2.79 ± 0.35	B	4.10 ± 0.78	B	8.30 ± 0.95	A	<.0001 *
Dicanthelium spp.	Low Panicgrass	0.62 ± 0.29	B	2.12 ± 0.48	AB	6.35 ± 1.20	A	0.0006
Diodia teres	Poorjoe	0		0		0.05 ± 0.05		0.3779
Diospyros virginiana	Common Persimmon	0.67 ± 0.33		0.38 ± 0.38		0		0.2275
Elephantopus tomentosus	Elephant's–Foot	0.93 ± 0.31	AB	0.50 ± 0.20	B	2.08 ± 0.63	A	0.0453
Erechtites hieracifolia	American Burnweed	0.02 ± 0.02	B	0.82 ± 0.44	AB	2.17 ± 0.81	A	0.0170
Eupatorium spp.	Boneset	1.05 ± 0.32		0.48 ± 0.18		1.15 ± 0.52		0.2467 *
Euphorbia spp.	Spurge	0.02 ± 0.02		0		0.03 ± 0.03		0.5542

Table 13. Continued

Table 13. Continued

Treatment		Control		Imazapyr		Imazapyr + Glyphosate		Pr>F
Scientific Name	**Common Name**	**Mean ± SE**		**Mean ± SE**		**Mean ± SE**		
Euthamia spp.	Flat–topped Goldenrod	0.03 ± 0.03		0.03 ± 0.03		0.08 ± 0.08		0.6107
Forb		0.10 ± 0.10		0		0.08 ± 0.08		0.6058
Fungus		0		0		0.08 ± 0.08		0.1609
Galium spp.	Bedstraw	0		0		0.03 ± 0.03		0.3779
Gelsemium spp.	Jessamine Vine	0		0.03 ± .02		0		0.3779
Ground		0.67 ± 0.20	B	2.27 ± 0.64	AB	4.40 ± 1.51	A	0.0457
Halesia diptera	Silverbell	0		0.03 ± 0.03		0		0.3779
Hamamelis virginiana	Witch–hazel	0.22 ± 0.22		0		0.05 ± 0.05		0.4656
Helianthus spp.	Sunflower	0		0.07 ± 0.05		0.03 ± 0.03		0.4329
Hypericum hypericoides	St. Andrew's–cross	0		0.07 ± 0.04		0.27 ± 0.14		0.0716
Ilex glabra	Gallberry	1.68 ± 1.30		1.45 ± 1.26		0.12 ± 0.07		0.5162
Ilex opaca	American Holly	0.10 ± 0.10		0		0		0.3779
Ilex vomitoria	Yaupon	3.83 ± 0.80		5.87 ± 1.35		3.22 ± 0.83		0.1979
Lepedium virginicum	Virginia Pepperweed	0		0.02 ± 0.02		0		0.3779
Lespedeza spp.	Lespedeza	0		0.42 ± 0.27		0.07 ± 0.05		0.1724
Liquidambar styraciflua	Sweetgum	5.37 ± 1.77	A	0.58 ± 0.46	B	0.27 ± 0.19	B	0.0029
Liriodendron tulipifera	Tulip Tree	0		0.03 ± 0.03		0		0.3779
Lonicera spp.	Honeysuckle	3.40 ± 1.97		0.10 ± 0.10		0		0.4409
Lygodium japonicum	Japanese Climbing fern	3.40 ± 1.97		0.62 ± 0.38		0.83 ± 0.42		0.2074
Mikania scadens	Climbing Hempweed	0		0.03 ± 0.03		0.05 ± 0.05		0.5883
Mitchella repens	Partridge–berry	0.13 ± 0.09		0.17 ± 0.10		0.30 ± 0.10		0.3671
Monarda fistulosa	Wild Bergomot	3.08 ± 0.56		1.72 ± 0.41		2.20 ± 0.70		0.2127
Morus rubra	Red Mulberry	0.05 ± 0.05		0		6.07 ± 1.58		0.3779
Muhlenbergia schreberi	Nimblewill	1.78 ± 0.46		3.88 ± 2.02		6.07 ± 1.58		0.1221
Myrica cerifera	Waxmyrtle	1.90 ± 0.46	A	1.18 ± 0.31	AB	0.12 ± 0.09	B	0.0022
Nyssa sylvatica	Blackgum	0.30 ± 0.13		0.18 ± 0.15		0.07 ± 0.04		0.3887

Table 13. Continued

Table 13. Continued

Treatment		Control		Imazapyr		Imazapyr + Glyphosate		Pr>F
Scientific Name	Common Name	Mean ± SE		Mean ± SE		Mean ± SE		
Oxalis spp.	Woodsorrel	0		0.05 ± 0.05		0.12 ± 0.06		0.2142
Parthenocissus quinquefolia	Virginia Creeper	0.43 ± 0.33		0.52 ± 0.25		0.32 ± 0.23		0.8616 *
Passiflora lutea	Broadleaf Maypop	0.13 ± 0.13		0		0		0.3779
Phlox spp.	Phlox	0.13 ± 0.13		0.03 ± 0.03		0		0.4729
Pinus seedlings		0.05 ± 0.03		1.03 ± 0.52		0.45 ± 0.25		0.1215
Poaceae spp.	Grass Family	0		0.07 ± 0.07		0		0.3779
Polystichum acrostichoides	Christmas Fern	0		0.03 ± 0.03		0		0.3779
Polypremum procumbens	Rustweed	0		0.07 ± 0.07		0		0.3779
Prunus serotina	Wild Black Cherry	0.73 ± 0.43		0.12 ± 0.07		0.17 ± 0.10		0.2174
Pteridium aquilinum	Brackenfern	7.53 ± 4.17		1.73 ± 1.18		0.77 ± 0.52		0.4260 *
Pycnanthemum incanum	Mountain Mint	0.42 ± 0.24		0.65 ± 0.29		1.03 ± 0.53		0.5016
Quercus spp.	Oak	4.63 ± 1.84	A	1.67 ± 0.82	AB	0.28 ± 0.18	B	0.0306
Rhododendron spp.	Azalea	1.07 ± 0.70		0.13 ± 0.10		0.03 ± 0.03		0.1750
Rhus spp.	Sumac	3.03 ± 0.94	A	0.75 ± 0.75	AB	0.07 ± 0.07	B	0.0139
Rhynchospora spp.	Beakrush	0.02 ± 0.02		0		0		0.3779
Rubus spp.	Blackberry	9.59 ± 1.45	B	28.87 ± 4.07	A	15.02 ± 2.91	AB	0.0480
Ruellia spp.	Petunia	0.13 ± 0.06		0.03 ± 0.03		0.10 ± 0.07		0.3517
Salvia spp.	Sage	0		0		0.05 ± 0.07		0.3779
Sassafras albidum	Sassafras	0.78 ± 0.47	A	0	B	0	B	0.0261 *
Smilax spp.	Greenbrier	1.02 ± 0.39		0.68 ± 0.26		0.95 ± 0.23		0.7221
Solanum carolinense	Horsenettle, Nightshade	0		0		0.02 ± 0.02		0.3779
Solidago spp.	Goldenrod	1.53 ± 0.56		2.12 ± 0.56		0.90 ± 0.41		0.2506
Sorghum spp.	Johnson Grass	0.03 ± 0.03		0		0		0.3779
Stylosanthus biflora	Pencilflower	0.17 ± 0.17		0		0		0.3779
Symplocos tinctoria	Sweetleaf	4.67 ± 2.09		3.97 ± 2.41		0.48 ± 0.24		0.2319
Tephrosia spp.	Goat's Rue	0.03 ± 0.03		0.05 ± 0.05		0.02 ± 0.02		0.8081

Table 13. Continued

Table 13. Continued

Treatment		**Control**	**Imazapyr**	**Imazapyr + Glyphosate**	**Pr>F**
Scientific Name	**Common Name**	**Mean ± SE**	**Mean ± SE**	**Mean ± SE**	
Toxicodendron radicans	Poison–ivy	0.13 ± 0.06	0.15 ± 0.09	0.37 ± 0.28	0.5440
Tridens flavus	Purpletop	0	0.05 ± 0.05	0	0.3779
Ulmus alata	Winged Elm	0	0.03 ± 0.03	0	0.3779
Vaccinium spp.	Blueberry	1.25 ± 0.58	0.25 ± 0.14	0.15 ± 0.12	0.0829
Veronica spp.	Ironweed	0	0.05 ± 0.05	0	0.3779
Viola spp.	Violet or Pansy	0.02 ± 0.02	0.07 ± 0.51	0.17 ± 0.09	0.2445
Vitis spp.	Grape	7.03 ± 1.91 A	1.05 ± 0.34 B	0.97 ± 0.29 B	0.0085 *
Food	Bobwhite Food Plants	17.4 ± 2.09 B	40.85 ± 4.40 A	30.72 ± 3.94 A	0.0002

styraciflua (Mean 5.37 ± SE 1.77) was greatest in control plots ($P \leq 0.05$). *Dicanthelium* spp. (imazapyr Mean 2.12 ± SE 0.48, imazapyr + glyphosate Mean 6.35 ± SE 1.20), *Erechtites hieracifolia* (imazapyr Mean 0.82 ± SE 0.44, imazapyr + glyphosate Mean 2.17 ± SE 0.81), ground (imazapyr Mean 2.27 ± SE 0.64, imazapyr + glyphosate Mean 4.40 ± SE 1.51), *Rubus* spp. (imazapyr Mean 0.75 ± SE 0.75, imazapyr + glyphosate Mean 0.07 ± SE 0.07), and bobwhite food (imazapyr Mean 40.85 ± SE 4.40, imazapyr + glyphosate Mean 30.72 ± SE 3.94) were greatest in herbicide treatments ($P \leq 0.05$, Figure 7). *Elephantopus tomentosus* (Mean 2.08 ± SE 0.63) and *Hypericum hypericoides* (Mean 0.27 ± SE 0.14) were greatest in imazapyr + glyphosate treatments ($P \leq 0.05$). *Mitchella repens* (control Mean 0.13 ± SE 0.09, imazapyr + glyphosate Mean 0.30 ± SE 0.10), *Quercus* spp. (control Mean 4.63 ± SE 1.84, imazapyr + glyphosate Mean 0.28 ± SE 0.18), and *Rhus* spp. (control Mean 3.03 ± SE 0.94, imazapyr + glyphosate Mean 0.07 ± SE 0.07) were greatest in imazapyr treatments and control plots ($P \leq 0.05$). *Callicarpa americana* (Mean 9.27 ± SE 2.28) and *Myrica cerifera* (Mean 1.90 ± SE 0.46) were greatest in control plots ($P \leq 0.05$).

We identified percent changes from 2001 to 2002 per treatment for significant variables in either year (Table 8). Greatest positive and negative percent changes on imazapyr + glyphosate plots occurred for bobwhite food plants (+226 %), *Elephantopus tomentosus* (+220 %), *Erechtites hieracifolia* (+3,000 %), ground (+21,900 %), *Hypericum hypericoides* (+238 %), *Lespedeza* spp. (+133 %), *Lygodium japonicum* (+1,086 %), *Prunus serotina* (+750 %), *Rubus* spp. (+144 %), *Acer rubrum* (-60 %), *Mitchella repens* (-48 %), *Myrica cerifera* (-82 %), *Pinus* seedlings (-90 %), and *Quercus* spp. (-33 %). Greatest positive and negative percent changes on control plots occurred for debris (+6 %), *Sassafras albidum* (+179 %), *Dicanthelium* spp. (-8 %), *Liquidambar styraciflua* (-20 %), *Prunus serotina* (-26 %), and *Pteridium incanum* (-2 %).

Greatest positive and negative percent changes on imazapyr plots occurred for *Acer rubrum* (+205 %), *Callicarpa americana* (+351 %), *Dicanthelium* spp. (+524 %), *Liquidambar styraciflua* (+53 %), *Mitchella repens* (+240 %), *Pteridium aquilinum* (+175 %), *Quercus* spp. (+72 %), *Rhus* spp. (+3,650 %), *Vitis* spp. (+289 %), and debris (-54 %) on imazapyr plots.

Invertebrates

Prior to Herbicide Treatment (2000)

Abundance

We identified stand by treatment interactions for Homoptera ($F_{2,44}$ = 4.11, P = 0.018) and Collembola ($F_{2,44}$ = 4.18, P = 0.001, Table 14). We detected treatment effects for Hemiptera ($F_{2,44}$ = 1.52, P = 0.042), Thysanura ($F_{2,44}$ = 1.58, P = 0.019), and Araneae ($F_{2,44}$ = 12.84, P = 0.038, Table 14). Hemiptera and Thysanura were greatest in control and imazapyr plots. Araneae was greatest in control and imazapyr + glyphosate plots.

Invertebrate Species Diversity (2000 –2002)

Invertebrate species diversity prior to herbicide application was greatest on control plots (H = 9.05, Table 15) followed by imazapyr + glyphosate plots (H = 5.66) and then imazapyr plots (H = 3.72). During the first year post–herbicide application there was greater invertebrate species diversity on control plots (H = 7.87), followed by imazapyr (H = 6.75) and then imazapyr + glyphosate treatments (H = 2.92). Second year post–herbicide application exhibited greater invertebrate species diversity on imazapyr plots (H = 16.56), followed by imazapyr + glyphosate treatments (H = 7.38), and then control (H = 1.43). The distribution of species within and among treatments was highly variable for all years.

We identified percent changes from 2000 to 2001 per treatment. The greatest negative percent change was on control plots (-82 %) in the first year post– herbicide application and on

Table 14. Mean invertebrate abundance (2000) prior to herbicide application on 75 to 85 year–old uneven–aged pine stands in east central Louisiana. * Indicates stand by treatment interaction. Significant variables are in BOLD.

Treatment Variable	**Control**		**Imazapyr**		**Imazapyr + Glyphosate**		**Pr > F**
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	
Coleoptera	3.80	0.64	3.93	0.73	3.53	0.68	0.9149
Homoptera	1.93	0.44	1.60	0.49	3.13	0.67	0.0498 *
Orthoptera	2.13	0.44	1.53	0.35	1.27	0.30	0.1902
Hemiptera	1.20 A	0.28	0.47 AB	0.34	0.27 B	0.12	0.0419
Hymenoptera	17.20	2.04	16.27	4.89	15.87	1.77	0.9541
Diptera	0.93	0.21	0.60	0.33	1.00	0.47	0.6925
Lepidoptera	0.40	0.16	0.33	0.12	0.27	0.12	0.7951
Thysanura	1.20 A	0.30	0.47 AB	0.19	0.40 B	0.13	0.0187
Collembola	8.40	2.87	4.80	1.08	5.93	1.19	0.2395 *
Chilopoda and Diploda	0.40	0.29	0.40	0.16	0.60	0.19	0.7689
Isopoda	0.13	0.09	0.40	0.27	0	0	0.1693
Araneae	13.67 A	3.27	6.20 B	1.00	9.33 AB	1.28	0.0383
Acari	0.27	0.21	0.47	0.21	0	0	0.1719
Other	0.87	0.38	0.80	0.26	1.00	0.19	0.8710

Table 15. Shannon's Diversity Index ($H = -\sum pi \ln pi$) for invertebrates prior to herbicide application (2000) and 2 years post treatment (2001–2002) on 75–85 year–old pine stands in east central Louisiana. H depicts relative abundance of species. e^H is Shannon's Diversity Index but transformed to show the relative distribution of the number of species or evenness of species abundances. * Pre–treatment values for 2000 Imazapyr and 2000 Imazapyr + Glyphosate.

Trt	**Control**			**Imazapyr**			**Imazapyr + Glyphosate**		
Year	2000	2001	2002	2000*	2001	2002	2000*	2001	2002
H	9.05	7.87	1.43	3.72	6.75	16.56	5.66	2.92	7.38
% Change	NA	– 13	– 82	NA	+ 82	+ 145	NA	– 48	+ 153
e^H	8548.74	2619.07	4.17	41.32	858.66	15,521,706.17	286.68	18.65	1599.92

control plots (-36 %) in 2002 following February prescribed burn. The greatest positive percent change occurred on imazapyr plots (+19 %) in the second−year post− herbicide application.

First Year Post Treatment (2001)

Abundance

We identified stand by treatment interactions for other invertebrates ($F_{2,44}$ = 5.22, P = 0.029, Table 16). We detected treatment effects for Homoptera ($F_{2,44}$ = 5.61, P = 0.001), Diptera ($F_{2,44}$ = 3.08, P = 0.004), Thysanura ($F_{2,44}$ = 1.02, P = 0.040), and Acari ($F_{2,44}$ = 3.21, P = 0.004, Table 16). Homoptera and Diptera were greatest in control plots. Acari was greatest in imazapyr treatment and control plots. Thysanura was greatest on imazapyr plots.

Second Year Post Treatment (2002)

Abundance

We identified stand by treatment interactions for Coleoptera ($F_{2,44}$ = 2.88, P = 0.003), Collembola ($F_{2,44}$ = 2.12, P = 0.052), and Araneae ($F_{2,44}$ = 2.98, P = 0.038, Table 17). We did not detect treatment main effects for the remaining invertebrate variables.

DISCUSSION

Bobwhites require a diverse, patchy habitat that includes: open areas of herbaceous vegetation, especially from legumes, a rich source of associated invertebrates, grassy areas for nesting, heavy brush or woody cover, bare ground with little litter coverage, and cropland (Stoddard 1931, Scott and Klimstra 1954, Stoddard 1962, Roseberry and Sudkamp 1998). Additionally, bobwhites require structurally different nesting and brood−rearing habitat (Burger et al. 1994). Bobwhites nest in 1 to 2 year post−fire pine/grassland areas with predominantly perennial grasses, 25–75 % bare ground, ≤ 50 % herbaceous vegetation, 20–37 % woody growth, > 10 % vines, > 60 % debris, and light litter (Roseberry and Klimstra 1984, Schroeder 1985,

Table 16. Mean invertebrate abundance for 1 year post–herbicide application (2001) on 75 to 85 year–old uneven–aged pine stands in east central Louisiana. Identical letters within rows are not statistically different per Tukey's HSD (P<0.05). * Indicates stand by treatment interaction. Significant variables are in BOLD.

Treatment Variable	Control			Imazapyr			Imazapyr Glyphosate			Pr > F	
	Mean		SE	Mean		SE	Mean		SE		
Coleoptera	3.80		0.55	2.73		0.69	3.53		0.55	0.4075	
Homoptera	6.33	A	1.49	2.33	B	0.59	0.93	B	0.66	0.0002	
Orthoptera	3.60		0.90	2.67		0.56	0.07		0.40	0.4444	
Hemiptera	0.80		0.37	0.60		0.21	0.13		0.13	0.1535	
Hymenoptera	12.67		2.14	10.47		2.01	7.87		1.27	0.3547	
Diptera	10.33	A	2.82	2.80	B	0.65	2.67	B	1.40	0.0043	
Lepidoptera	0.73		0.21	0.73		0.25	0.20		0.11	0.1205	
Thysanura	0		0	0.33		0.16	0		0	0.0402	
Collembola	6.07		1.45	14.00		6.00	10.33		2.44	0.3213	
Chilopoda and Diploda	0.13		0.13	0.07		0.07	0.07		0.07	0.8471	
Isopoda	2.00		0.97	8.80		4.46	2.53		1.32	0.0933	
Araneae	11.27		2.98	8.87		1.13	8.87		1.60	0.6651	
Acari	1.47	A	0.31	1.07	AB	0.23	0.33	B	0.16	0.0035	
Other	1.47	AB	0.43	2.27	A	0.51	0.67	B	0.29	0.0043	*

Table 17. Mean invertebrate abundance for 2 years post–herbicide application (2002) in 75 to 85 year–old uneven–aged pine stands in east central Louisiana. No significant differences were detected. * Indicates stand by treatment interaction. Significant variables are in BOLD.

Treatment Variable	Control		Imazapyr		Imazapyr + Glyphosate		Pr > F
	Mean	SE	Mean	SE	Mean	SE	
Coleoptera	8.27	2.29	9.00	2.17	4.73	1.27	0.1829 *
Homoptera	0.07	0.07	0.20	0.11	0.13	0.09	0.6107
Orthoptera	0.53	0.16	0.80	0.35	0.93	0.25	0.5883
Hemiptera	0.40	0.16	0.27	0.15	0.27	0.12	0.7532
Hymenoptera	11.00	1.71	11.40	2.38	18.53	3.96	0.1354
Diptera	2.53	0.73	1.27	0.40	1.27	0.34	0.1761
Lepidoptera	0.07	0.07	0	0	0	0	0.3779
Thysanura	0.13	0.09	0	0	0	0	0.1501
Collembola	21.80	5.01	28.40	8.57	9.07	2.92	0.0613 *
Chilopoda and Diploda	0.07	0.07	0.33	0.16	0.40	0.19	0.2817
Araneae	2.73	0.46	1.67	0.37	4.87	1.76	0.0642 *
Acari	1.00	0.46	0.33	0.13	1.60	0.57	0.1521
Other	0.67	0.30	0.73	0.27	0.93	0.25	0.5779

Tonkovich and Stauffer 1993, Burger et al. 1994, Taylor 1996, Taylor and Burger 2000). Contrastingly, brood–rearing bobwhites require predominantly broad–leaved herbaceous vegetation, < 50 % perennial grasses, 19 – ≥ 61 % bare ground to locate invertebrates, 20 % woody vegetation, > 61 % debris, an abundance of insects, and scattered shrubs or brush for thermal cover (DeVos and Mueller 1993, Tonkovich and Stauffer 1993, Burger et al. 1994, Taylor and Guthery 1994, Taylor 1996, Taylor and Burger 2000). Bobwhite chicks require a high protein diet during the first 10 weeks after hatching (Nestler et al. 1942), and invertebrates are the primary source of protein (Handley 1931, Hurst 1972, Jackson et al. 1987).

Both herbicide treatments were generally more effective than prescribed fire alone at improving vegetational structure for brood–rearing and nesting bobwhites during the first year post treatment. Both herbicides reduced percentage of woody vegetation close to the 37 % described as habitat used by brood–rearing bobwhites in Mississippi (Taylor and Burger 2000). Moreover, both herbicides reduced woody vegetation similar to 20 % described as good nesting habitat by Roseberry and Klimstra (1984). Additionally, hardwood midstory < 10 cm dbh was approximately 2 times less on herbicide plots. Both herbicide treatments created more debris, but levels were similar to 63–67 % associated with greater numbers of brood–rearing bobwhites and 67 – 71 % preferred by nesting bobwhites in Missouri and Mississippi (Burger et. al. 1994, Taylor and Burger 2000). Although debris and woody vegetation were at desirable levels for bobwhite nesting cover, herbaceous communities and predominantly perennial grasses typically associated with bobwhite brood–rearing and nesting habitat were not at desireable levels (Roseberry and Klimstra 1984, Schroeder 1985, Tonkovich and Stauffer 1993, Burger et al. 1994, Taylor 1996, Taylor and Burger 2000). From the standpoint of escape cover, control plots had greater VOR and came closest to habitat with > 1 m vertical obstruction described by Davis

(1964) as essential for bobwhite escape cover.

Plant species diversity declined on both herbicide treatments during the first year post treatment, but bobwhite food plants increased on imazapyr plots. During the first year post treatment, *Lygodium japonicum*, *Pteridium aquilinum,* and *Vitis* spp. dominated the understory on control plots, whereas pine seedlings were dominant on herbicide plots. Release of pine seedlings from glyphosate is consistent with manufacturer specifications and other research studies (Ross et al. 1986, Freedman et al. 1993, Lauer et al. 1993, Glover and Zutter 1993, Clason 1993). Imazapyr and imazapyr – glyphosate were effective at controlling undesirable species (hardwoods seedlings, *Lygodium japonicum*, *Pteridium aquilinum*), but both herbicides killed or prevented release of some vegetation, thereby resulting in less species diversity than control plots initially. Wendel and Kochenderfer (1982) found that glyphosate killed *Pteridium aquilinum*, *Andropogon* spp., *Quercus* spp., *Acer rubrum*, *Aralia spinosa*, and *Rubus* spp in central Appalachian hardwood forests of West Virginia.

During the second growing season post – treatment both herbicide treatments were more effective than prescribed fire alone at improving vegetational structure for brood–rearing and nesting bobwhites. Both herbicide treatments continued to reduce woody vegetation. Imazapyr was more effective at controlling woody vegetation while reducing litter depth for nesting and brood – rearing bobwhites relative to imazapyr + glyphosate but all treatments were at desirable levels reported by Rosene (1969) for easy movement when searching for food. Imazapyr application increased vines (*Lonicera* spp., *Gelsemium* spp., *Rubus* spp., *Smilax* spp., and *Vitis* spp.). Bobwhites consistently used areas with ≥ 10 % *Lonicera* spp. in Virginia (Tonkovich and Stauffer 1993) and Tennessee (Yoho and Dimmick 1972). *Rubus* spp. and *Vitis* spp. were the dominant vine species encountered in our study, and *Rubus* spp. is an important food source for

bobwhites in summer, fall, and winter (Landers and Johnson 1976, McRae et al. 1979, Curtis et al. 1990, Brazil 1993).

All treatments contained very low percentages of bare ground (<10%) throughout our study. Bare ground is an essential component for quality bobwhite habitat because it improves foraging success for locating seeds and invertebrates. Imazapyr – glyphosate treatment increased bare ground similar to 6% described by Burger et al. (1994) associated with optimal nesting habitat in Missouri. However, most studies reported 25 – 75% bare ground as optimal nesting habitat (Guthery 1986, Rice et al. 1992, Tonkovich and Stauffer 1993, Taylor and Burger 2000). Neither treatment nor control met 19 to ≥ 61 % bare ground preferred by brood – rearing bobwhite (Tonkovich and Stauffer 1993, Burger et al. 1994, Taylor and Burger 2000). Although all treatments exhibited little bare ground, imazapyr – glyphosate produced greater bare ground during our study. Our results suggest that if creating bare ground to produce brood – rearing habitat is desirable in these forests, then additional mechanical manipulations are necessary.

Plant species diversity increased on imazapyr treatments during the second year post–treatment, and bobwhite food plants were greater on herbicide treatments than controls. Busby et al. (1998) reported that imazapyr provided the greatest improvement in land expectation values compared to glyphosate on loblolly stands in central Georgia. Other studies reported that plant species richness and diversity were reduced on control plots versus herbicide treatment (Ross et al. 1986, Harrington et al. 1995, and Sullivan et al. 1996). *Liquidambar styraciflua, Lonicera* spp., *Lygodium japonicum*, *Pteridium aquilinum,* and *Vitis* spp. were dominant on control plots only. Percentage of ferns was greatest on control plots, and Brackenfern (*Pteridium aquilinum)* and *Lygodium japonicum* were observed as the primary fern

species on our study plots. Brackenfern was associated with greatly reduced plant diversity in 1–3 year–old conifer seedlings in California (McDonald and Fiddler 1993).

Although both herbicide treatments greatly reduced sweetgum, neither negatively affected hard mast producing species > 10 cm dbh. Sweetgum are considered undesirable when managing pine forests for bobwhite, primarily because of their propensity to stump sprout following disturbance (Wenger 1953) and ability to outcompete desirable forbs and legumes. Conversely, mast–producing hardwoods are important for bobwhite, particularly during winter (Landers and Johnson 1976, McRae et al. 1979, Curtis et al. 1990, Brazil 1993). Our findings suggest that application of imazapyr and imazapyr in conjunction with glyphosate will not likely affect the availability of mature, mast producing species, although regeneration will be negatively affected through reductions in woody understory species. However, long – term effects of Imazapyr application on mast production is not known.

Vegetative response following herbicide application and fire in our study was likely negatively affected by relatively high overstory canopy coverage and extended drought conditions. Canopy values ≤ 50 % are typically associated with greater numbers of bobwhites (Stoddard 1931, Rosene 1969, Lee and Brennan 1994) and habitats containing > 50 % overstory canopy coverage have been determined to be marginal or unsuitable (Stoddard 1931, Rosene 1969, Lee and Brennan 1994). Crowns of 75 – 85 year old pines combined with scattered hardwood species on our plots produced greater canopy closure than what is desirable for bobwhites. Additionally, drought conditions that began in 1998 and continued through the duration of our study may have negatively affected growth and dispersion of desired bobwhite vegetation (National Climatic Data Center 2002). Effects of imazapyr and glyphosate herbicides may have been amplified during drought conditions (BASF 2002). Specifically, drought

conditions can increase herbicide carryover because plants are not able to take up as much herbicide when they are moisture stressed, hydrolysis (reaction in soil where water breaks down herbicide into an inactive form) can not occur when the soil is too dry, and microbial activity that breaks down herbicides into naturally occurring forms in the soil almost stops (Parker 1993).

Invertebrate species diversity declined on both herbicide treatments during the first year post treatment but was greatest on imazapyr plots during the 2nd year post treatment. Specifically, Homoptera (scale insects, cicadas, leafhoppers, aphids, and allies) and Diptera (flies) were more abundant on control plots, suggesting that foraging quality of areas treated with imazapyr and imazapyr + glyphosate is lower initially. Homoptera are phytophagous invertebrates important during bobwhite reproductive periods and chick development (Rosene 1969, Eubanks and Dimmick 1974). Greater abundance of Homopteran insects during the 1st year post–treatment on control plots was likely attributable to higher plant species diversity (Koricheva et al. 2000). Additionally, glyphosate residues are toxic to some invertebrates (EPA 1997), therefore herbicide application on imazapyr + glyphosate plots may have reduced diversity of invertebrates initially. Conversely, invertebrate diversity was greatest on imazapyr plots during the 2nd year post treatment and increased 4–fold over the course of our study, attributable to simultaneous increases in plant species diversity. Abundant and diverse invertebrate communities have been associated with greater amounts of grasses and forbs because they provide more palatable nutritious food sources (Menhinick 1967, Hurst 1972, Southwood et al. 1979, Schowalter 1985, Lawton 1983, and Koricheva et al. 2000). Grasses and forbs were reduced on herbicide plots initially, but increased during the 2nd year post treatment. Madison et al. (1995) reported that spring burn provided greater invertebrate abundance in the first year after treatment compared to spring glyphosate application on tall fescue (*Festuca*

arundinacea)–dominated fields in Kentucky. However, invertebrate abundance and plant species richness were greater on glyphosate treatment sites during the 2nd year post treatment.

Individual invertebrate species will respond differently to environmental changes that occur because of fire (altered vegetation relationships, removal of litter, increased soil temperature, and moisture loss; McCoy 1987, Anderson et al. 1989, Willig and McGinley 1999). Larsen and Williams (1999) observed that ground beetle fauna (Coleoptera) in tall grass prairies of Iowa were most diverse several years after a fire. The 2–year burn rotation used in our study may have negatively affected Coleoptera and similar orders.

MANAGEMENT IMPLICATIONS

Both herbicides improved brood–rearing and nesting habitat for bobwhites. Overall, Imazapyr provided a greater benefit than imazapyr + glyphosate, retained floristic species diversity, and greatly improved invertebrate diversity. Herbicides are typically used to improve conditions for pine and hardwood production, but they also are used as habitat management for wildlife. Increased use of herbicides in recent years has occurred because of restricted use of prescribed burning (Haines et al. 2001). However, prescribed burning has historically been used to manage and maintain pine and pine–hardwood forest ecosystems (Robbins and Myers 1992) that increase the production of native legumes used by bobwhites (Lewis and Harshbarger 1986). Absence of fire in these forest ecosystems will eventually cause early successional pine–grasslands to revert to thick hardwood midstory that will eventually become a closed pine–hardwood canopy with little herbaceous vegetation (Engstrom et al. 1984, Wilson et al. 1995). Additionally, absence of fire has reduced pine–grassland ecosystems and has contributed to > 70 % decline in bobwhites in the past 30 years. Other species associated with these ecosystems also have declined such as the red – cockaded woodpecker (*Picoides borealis*),

Bachman's sparrow (*Aimophila aestivalis*), gopher tortoise (*Gopherus polyphemus*), and the indigo snake (*Drymarchon corais couperi;* Engstrom et al. 1996).

The application of imazapyr improved the quality of habitat for northern bobwhite more than prescribed burning alone in our study. However, our findings suggest that the greatest net benefit from imazapyr application occurred following the renovating fire prior to and during the second growing season. Managers should recognize the potential beneficial effects of imazapyr application for bobwhite, but also should be cognizant of the continued importance of prescribed fire in managing landscapes for bobwhite.

Vegetative improvements to herbicide application may have been greater (i.e., increased percentages of herbaceous vegetation and associated invertebrates) had canopy closure been reduced. Our stands had > 90 % canopy closure, but ideally < 50 % would be associated with higher quality bobwhite habitat. It is likely that reduced canopy coverage on our research plots would have improved response of many herbaceous species following herbicide application, and prescribed fire during the second growing season. Future research should evaluate vegetative response to herbicide application under variable canopy conditions. Managers may consider reducing basal area if canopy coverage exceeds 90% to create the greatest net benefit to bobwhites when using herbicides.

Imazapyr used at 453.6 g / 0.405 ha (16 oz / acre) was effective at improving habitat quality for bobwhite in our stands. Given the cost associated with imazapyr (approx. $600 US / gallon), private landowners may be limited from using it to improve bobwhite habitat on their lands. Within pine forests, whether imazapyr application at lower rates will improve bobwhite habitat to levels observed in our study is unclear. Therefore, we recommend future research examine relative efficacy of imazapyr at different application rates, offering landowners the

opportunity to reduce costs associated with habitat improvement.

Bobwhites require diverse, patchy habitat to successfully survive and reproduce, therefore wide–spread application of imazapyr in forested stands would not achieve this goal. For instance, bobwhites prefer vegetation > 1 m for escape cover. Vertical obstruction reading on control plots in our study indicated that prescribed fire alone created and maintained cover more suitable for bobwhites. We recommend that managers target areas where prescribed burns are not possible, or areas where relative benefits of prescribed fire are low because of advanced understory succession. The application of imazapyr to these stands would improve bobwhite habitat at the landscape scale, and coupled with the continuation of prescribed fire when possible, would create diverse, patchy habitat typically associated with greater numbers of bobwhites. Furthermore, bare ground is a critical component of quality brood–rearing habitat, and no treatments in our study produced sufficient bare ground for bobwhites to efficiently locate food. It is likely that managers will need to use alternative mechanical methods (i.e., strip disking) following prescribed burning and/or herbicide application to produce 25 – 75 % bare ground for optimal nesting habitat and 19 to ≥ 61 % for brood – rearing habitat.

CHAPTER 4 SMALL MAMMALS

INTRODUCTION

Traditional silvicultural practice is to burn at 3 to 5 year intervals in southern pine forests to control competing hardwoods and brush, consume dead organic material, and produce an open understory (Wenger 1984). Unfortunately, it is not possible to burn more frequently because restrictive legislation has reduced prescribed fire as a management tool in the past decade because of associated hazards (Burger and Chamberlain 2001, Haines et al. 2001), funding limitations, lack of qualified professionals and technicians, narrow windows for conducting burns, and risk averse policies of an agency or company (Haines et al. 2001). Therefore, alternative chemical methods like selective herbicide application have become the mainstay of post-emergence weed control in forestry (Walstad and Kuch 1987). However, little research has examined small mammal response within mature southeastern pine forests following the application of herbicides. The specific objective of our study was to provide cursory evaluation of the responses of small mammals to habitat manipulations using herbicides.

Research examining responses of small mammals to increased herbaceous growth and reduced hardwoods using herbicide application have generally produced similar results. McMurry et al. (1993; 1994; 1995) and Sullivan et al. (1997) reported increased mice and rat densities on herbicide treated sites, whereas O'Connel and Miller (1994) reported greater species diversity on mechanical treated sites where V-blades and root rakes were used to shear residuals and windrow site material. Sullivan et al. (1997) reported that using glyphosate after clear-cutting and slash burning produced no adverse affects on reproduction, survival, or growth of deer mice (*Peromyscus maniculatus* Wagner) and voles. Additionally, Sullivan et al. (1997) reported that deer mice decreased in the first post–treatment winter and summer following

herbicide treatment but increased in subsequent years, whereas Oregon voles (*Microtus oregoni* Bachman) showed little difference in abundance between control and herbicide treatment. Research at Cross Timbers Experimental Station in Stillwater, Oklahoma produced similar results using triclopyr and/or tebuthiuron with prescribed burning to alter upland hardwood forests to tall grass prairie habitat (McMurry et al. 1996). McMurry et al. (1993; 1994; 1996) reported white-footed mice (*P. leucopus*), cotton rat (*Sigmodon hisiudus* Say and Ord), and eastern woodrat (*Neotoma floridana* Ord) densities increased and greater proportions of juveniles were captured as forbs, grasses, and woody vegetation increased and overstory canopy decreased. Additionally, declines in small mammal densities coincided with declines in forbs on treated sites until population densities resembled those on control sites in the third year, and fewer white–footed mice were trapped on burned than unburned sites. In contrast, O'Connel and Miller (1994) reported greater species diversity and densities on mechanical treatments (shearing and windrowing residuals) at 3 years post–treatment, but no difference 2 and 5–year post–treatments for 7 small mammal species.

METHODS

Refer to Chapter 1 for information on site preparation, herbicide application, prescribed burns, and weather conditions. Small mammals were live–trapped to estimate relative abundance and species richness before herbicide treatment in June, and 2 years post–treatment during February and June. We used Sherman live–traps to capture small mammals within each plot on a 5 × 5 grid, with 25 traps located at 10–m intervals. One trap was placed within 1–m of each circular subplot and baited with peanut butter and oatmeal. Trapping consisted of 4 consecutive trapping nights and traps were checked in the morning. Traps were left open during the day with adequate cover placed over the trap to prevent overheating during summer and

freezing during winter. Non–absorbent cotton bedding was placed in traps when overnight temperatures were expected to fall near or below freezing. A granular ant barrier (Talstar 0.6 % bifenhrin; FMC Corporation), was used at 21.2g/0.0929m^2 (21.2 g/ft$^{2)}$ and broadcast over a 1−m radius at each trap to reduce red-imported fire ant (*Solenopsis invicta* Buren) activity and prevent ant attacks on captured mammals. Captured animals were transferred to a plastic bag and weighed with a Pesola spring balance. We examined animals to determine species, sex, age, and reproductive status (Davis 1956, Lowery 1975). Animals were marked using toe clipping and treated with an analgesic / anesthetic before and after clipping to minimize pain and infection (Davis 1956, AD-HOC 1985, AD-HOC 1987). *Glaucomys volans* was recorded when live trapped, but were not marked. We determined abundance, species richness, trapping success, and percentage of successful traps for small mammals per treatment and season (June, February) and made comparisons across treatments to develop generalizations about small mammal response to herbicide and prescribed burn.

RESULTS

We captured 167 small mammals during 20 trap nights during our study prior to and 2 years post–herbicide treatment.

Prior to Herbicide Treatment (June 2000)

Relative abundance was similar on imazapyr and control plots (Table 18 and Figure 12). Animals were not trapped on 2 of 9 plots (control and imazapyr + glyphosate). We captured 30 individuals; 11 on imazapyr, 8 on imazapyr + glyphosate, and 11 on control plots respectively. Species richness was higher on plots prior to imazapyr + glyphosate application (imazapyr 2, imazapyr + glyphosate 3, control 2). Trapping success was approximately 2 −3 times higher on

Table 18. Small mammal abundance and species richness prior to herbicide application (2000) and post treatment (2001–2002) on 75–85 year–old uneven–aged pine stands in east central Louisiana.

Year / Season	Treatment Imazapyr (n)	Imazapyr + Glyphosate (n)	Control (n)
2000 June	11 1 – *Ochrotomys nuttalli* 10 – *Peromyscus* spp.	8 1 – *Ochrotomys nuttalli* 1 – *Microtus pinetorum* 5 – *Peromyscus* spp. 1 – Unknown	11 1 – *Sigmodon hispidus* 10 – *Peromyscus* spp.
2001 February	11 11 - *Peromyscus* spp.	7 7 - *Peromyscus* spp.	5 5 - *Peromyscus* spp.
2001 June	7 7 – *Peromyscus* spp.	12 1 – *Blarina brevicauda* 11 – *Peromyscus* spp.	11 2 – *Ochrotomys nuttalli* 3 – *Sigmodon hispidus* 6 – *Peromyscus* spp.
2002 February	14 1 – *Neotoma floridana* 1 – *Ochrotomys nuttalli* 11 – *Peromyscus* spp. 1 – *Glaucomys volans*	14 1 – *Glaucomys volans* 13 – *Peromyscus* spp.	11 11 - *Peromyscus* spp.
2002 June	17 17 - *Peromyscus* spp.	16 16 - *Peromyscus* spp.	12 1 – *Ochrotomys nuttalli* 11 – *Peromyscus* spp.

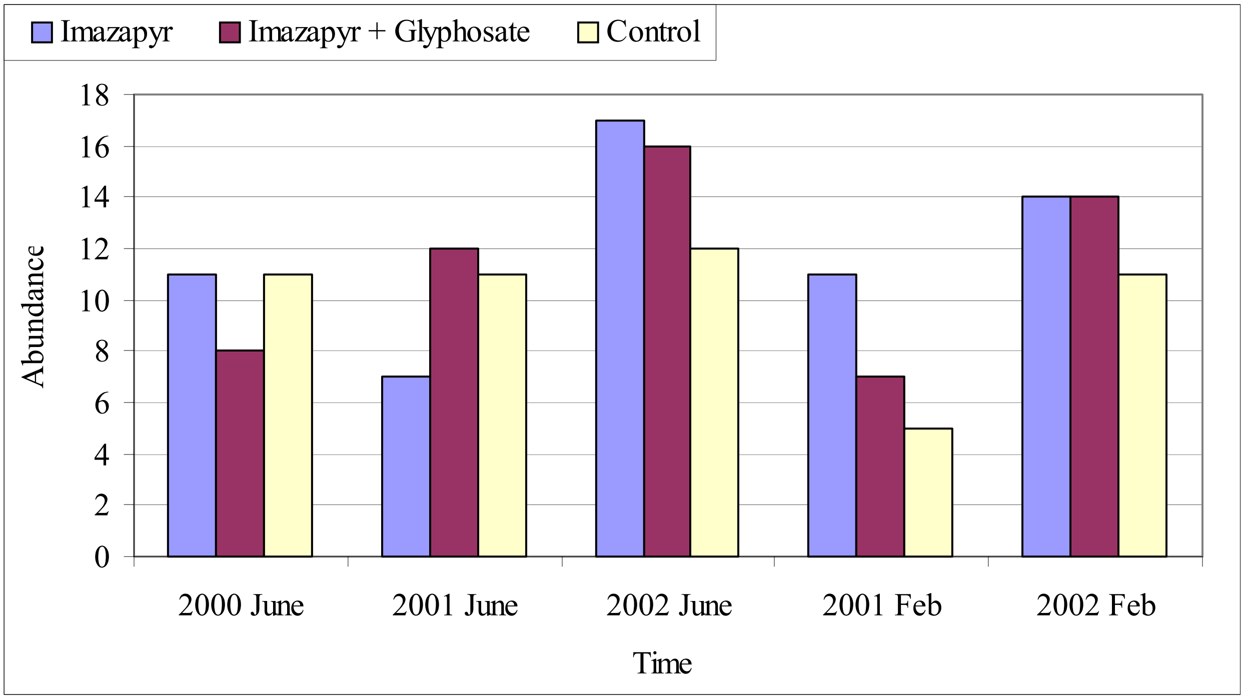

Figure 12. Relative abundance of small mammals per year and treatment prior to herbicide application in 2000 and post–treatment years 2001–2002 on 75–85 year–old uneven aged pine stands in east central Louisiana.

control plots (imazapyr 15, imazapyr + glyphosate 9, control 26) (Table 19) and 3–9 % of the 900 possible trapping occurrences were successful (Table 20).

First Year Post–Treatment

Relative abundance was variable across treatments (Table 18 and Figure 12). Animals were not trapped on 2 of 9 plots (control and imazapyr + glyphosate) in February. We captured 23 animals in February and 30 in June. Eleven individuals were trapped on imazapyr plots, 7 on imazapyr + glyphosate plots, and 5 on control plots in February. Seven individuals were trapped on imazapyr plots, 12 on imazapyr + glyphosate plots, and 11 on control plots in June. Percent change in June abundance was greatest on imazapyr + glyphosate plots (imazapyr –36.4%, imazapyr + glyphosate +50%, control 0%, Table 21). Species richness was similar across treatments in February (1 / treatment) and greater on control plots in June (imazapyr 1, imazapyr + glyphosate 2, control 3). Trapping success was higher on imazapyr plots in February (imazapyr 14, imazapyr + glyphosate 10, control 8) and higher on imazapyr + glyphosate plots in June (imazapyr 15, imazapyr + glyphosate 23, control 17) (Table 19). Of 900 possible trapping occurrences in February, 3 – 5 % were successful and 5 – 8 % were successful in June (Table 20).

Second Year Post–Treatment

Relative abundance was similar on herbicide treatments in February and variable across treatments in June (Table 18 and Figure 12). Animals were not trapped on 1 of 3 imazapyr plots in February. We captured 39 animals in February and 45 in June. Fourteen individuals were trapped on imazapyr plots, 14 on imazapyr + glyphosate plots, and 11 on control plots in February. Percent change in February abundance was greatest on control plots (imazapyr –27.3%, imazapyr + glyphosate +100%, control +120%) (Table 21). Seventeen individuals were

Table 19. Trapping success for small mammals prior to herbicide application 2000 and post-treatment (2001–2002) on 75–85 year–old uneven aged pine stands in east central Louisiana.

Year / Season	Treatment		
	Imazapyr (n)	Imazapyr + Glyphosate (n)	Control (n)
2000 June	15	9	26
2001 February	14	10	8
2001 June	15	23	17
2002 February	18	29	19
2002 June	39	32	22

Table 20. Percent of small mammal traps (300 possible trapping occurrences per treatment) that were successful during each trapping period prior to herbicide application (2000) and post–treatment (2001–2002) on 75–85 year-old uneven aged pine stands in east central Louisiana.

Year / Season	Treatment		
	Imazapyr (%)	Imazapyr + Glyphosate (%)	Control (%)
2000 June	5	3	9
2001 February	5	3	3
2001 June	5	8	6
2002 February	6	10	6
2002 June	13	11	7

Table 21. Percent change per treatment, year, and season for small mammal abundance prior to herbicide treatment (2000) and post–treatment years (2001–2002) on 75–85 year–old uneven aged pine stands in east central Louisiana.

Treatment	Imazapyr			Imazapyr + Glyphosate			Control		
Year	2000	2001	2002	2000	2001	2002	2000	2001	2002
June Abundance (n)	11	7	17	8	12	16	11	11	12
% Change		- 36.4	+142.9		+ 50.0	+ 33.3		0	+ 9.1
February Abundance (n)		11	14		7	14		5	11
% Change			+ 27.3			+100			+ 120

trapped on imazapyr plots, 16 on imazapyr + glyphosate plots, and 12 on control plots in June. Percent change in June abundance was greatest on imazapyr plots (imazapyr +142.9%, imazapyr + glyphosate +33.3%, control +9.1%). Species richness was greater on imazapyr plots in February (imazapyr 4, imazapyr + glyphosate 2, control 1) and greater on control plots in June (imazapyr 1, imazapyr + glyphosate 1, control 2). Trapping success was higher on imazapyr + glyphosate plots in February (imazapyr 18, imazapyr + glyphosate 29, control 19) and higher on imazapyr plots in June (imazapyr 39, imazapyr + glyphosate 32, control 22) (Table 19). Of 900 possible trapping occurrences in February, 6 – 10 % were successful and 7 – 13 % in June (Table 20).

DISCUSSION

Herbicide application used with prescribed burning to promote early successional habitats in mature southeastern pine forests may affect small mammal abundance and species richness by altering plant communities, structural diversity, and associated invertebrates. Small mammals that typically inhabit mature southeastern pine forests are white–footed mice (*Peromyscus* spp.), golden mice (*Ochrotomys nuttalli)*, short–tailed shrews (*Blarina brevicauda),* southern flying squirrels *(Glaucomys volans),* hispid cotton rats (*Sigmodon hispidus*)*,* eastern harvest mice (*Reithrodontomys fulvescens*)*,* eastern woodrats (*Neotoma floridanus*)*,* and woodland voles (*Microtus pinetorum*; Lowery 1974). Most of these small mammals are granivorous and supplement their diet with invertebrates. Effects of herbicides on small mammals are species–specific whereby species may avoid, select, or are unaffected in treated areas (Lautenschlager 1993). Additionally, changes in small mammal abundance and species richness may be from indirect effects of herbicides that cause changes in vegetation structure and composition (Cole et al. 1998). Specifically, decreases in cover can decrease abundances of some small mammal

species (Santillo et al. 1989, Ritchie et al. 1987). Increases in herbaceous growth associated with structural diversity and increased slash on forest floor also can increase small mammal abundance (McMurry et al. 1996, Kirkland 1977).

Small mammal abundance was similar on imazapyr and control plots prior to herbicide application and species richness was greater on imazapyr + glyphosate plots prior to application. Plant species diversity and invertebrate orders (Hemiptera and Thysanura) were greater on pre–imazapyr treatments and control plots, potentially resulting in higher habitat quality. Although species richness was greater on imazapyr + glyphosate treatments, only one animal represented other species on all plots. *Peromyscus* spp. was the most common species trapped on all plots during our study. Other studies reported similar results in South Carolina, British Columbia, Oklahoma, and Oregon (Cole et al. 1998, Sullivan et al. 1998, McMurry et al. 1996, O'Connel and Miller 1994).

Small mammal abundance was greater on imazapyr + glyphosate treatments during the first year post treatment, but species richness was greater on control plots. However, abundance was greater on imazapyr treatments in February and greater on imazapyr + glyphosate treatments in June. McMurry et al. (1996) reported greater white–footed mice abundance using removal–trapping methods on unburned tebuthiuron treatments in December in late and early successional hardwood forests in Oklahoma. Conversely, Sullivan and Boateng (1996) reported greater abundances of deer mice (*Peromyscus maniculatus*) on control plots versus glyphosate using live trapping methods for first–year post treatment following clear–cutting on sub–boreal spruce biogeoclimatic zone in British Columbia. Other studies reported similar results using glyphosate in the first post–treatment summer in coniferous forests of British Columbia (McMurry et al. 1993, Sullivan et al. 1997).

Peromyscus spp. are the most common small mammal that typically inhabit wooded areas (Lowery 1974) where they and are mostly granivorous and insects comprise < 10 % of their diet (Linzey and Linzey 1973). Greater plant diversity combined with greater percentages of woody vegetation and hardwood midstory on control plots during first year post–treatment may have created conditions for higher *Peromyscus* abundance. Higher invertebrate diversity and greater numbers of orders Homopteran and Diptera could explain why several hispid cotton rats were trapped on control sites, because animal matter makes up a large portion of their diet (Lowery 1974).

Small mammal abundance and species richness were greater on imazapyr treatments during the second–year post–herbicide treatment. Sullivan et al. (1997) reported greater small mammal abundance in the second year post–treatment winter following glyphosate treatment in the sub–boreal spruce zone of British Columbia. McMurry et al. (1996) reported greater white–footed mice abundance in herbicide / burn treatments in the second post–treatment winter in late and early successional hardwood forests in Oklahoma. Contrastingly, Sullivan et al. (1998) reported similar small mammal abundance on herbicide and control in sub–boreal spruce zone of British Columbia. Higher percentages of *Rubus* spp., bobwhite food plants that produce seeds and legumes, higher invertebrate species diversity, and light litter depth on imazapyr treatments may have provided cover (Santillo et al. 1989, Ritchie et al 1987) and food for greater numbers of small mammals. McMurry (1996) reported that abundance of *Peromyscus leucopus* increased as herbaceous and grassy vegetation increased in upland pine forests with grasslands–cedar savannas of Oklahoma.

MANAGEMENT IMPLICATIONS

Small mammal abundance appeared to improve on both herbicide treatments designed to improve habitat quality for bobwhites. Corresponding increases in small mammal abundance on herbicide treatments is likely attributable to changes in vegetational characteristics and communities, along with increased plant and invertebrate diversity on imazapyr treatments. *Peromyscus* species was the most common animal trapped on all plots. Managers using herbicides to improve bobwhite habitat in forests should be aware that herbicide application and subsequent vegetational changes might affect abundances of some small mammal species.

CHAPTER 5 CONCLUSION

Our study has provided valuable information for other researchers and managers on the effects of 2 types of selective herbicides (imazapyr and imazapyr- glyphosate) in combination with prescribed burning. Imazapyr provided the most benefit towards improving bobwhite brood – rearing and nesting habitat by increasing plant and invertebrate diversity, and increasing percentages of bobwhite food plants in the understory. Furthermore, both herbicide applications improved vegetative structure for bobwhites, although the greatest net improvement occurred following a renovating fire prior to the second growing season following application. Overstory mast producing hardwoods essential for winter food were not affected by herbicide application. Neither herbicide treatment effectively increased bare ground, a critical habitat component for bobwhites during brood-rearing. Changes in vegetation and invertebrate communities appeared to benefit small mammal communities, as abundance increased following application of herbicides.

Managers interested in manipulating mature pine – hardwood forests with herbicides to improve habitat for bobwhite should consider canopy conditions across management sites. Relatively high canopy closure (> 90%) on our sites likely limited vegetative response, and drought conditions prior to and during the initial phases of our study potentially affected plant response to herbicide application. Future research is needed to test effects of different percentages of canopy closure on understory vegetation and invertebrates. Furthermore, managers interested in improving the condition of brood-rearing habitat should recognize the likely inability of herbicide application similar to that in our study to create and maintain adequate proportions of bare ground. Therefore, the use mechanical methods (i.e., discing) may be necessary.

Long–term effects of imazapyr application on vegetation, invertebrates, and small mammal communities is unclear. Additionally, it is possible that managers could reduce application rates and still achieve desired results (improving bobwhite habitat). Small landowners would benefit if lower rates were determined to be beneficial because of the relatively high cost associated with the application of imazapyr per acre. Future research is needed to determine effects of different application rates on vegetation and invertebrate communities.

Our findings demonstrate that the application of selective herbicides can be a valuable tool for improving bobwhite habitat in pine forests. However, managers should recognize that bobwhites require a diverse, patchy matrix of habitats across the landscape. Therefore, future evaluations of herbicide application should determine the efficacy of using selective chemicals at the landscape-scale, in conjunction with other established methods for managing bobwhite habitat (fire, mechanical disturbance).

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VITA

Judy Diane James Jones was born in 1959 at Barksdale Air Force Base by Bossier City, Louisiana. She has lived in England, Wyoming, and North Dakota, as a child when her father was transferred by the Air Force. Judy lived most of her childhood in the suburbs of Bossier City just outside of Barksdale Air Force Base, Louisiana, where she would watch Air Force aircraft maneuvers at a park in the back of her neighborhood. Judy began to hunt with her father as a child and learned to value the outdoors and wildlife.

Judy's interest in drawing sent her to Oklahoma, in 1976 where she graduated from Oklahoma State University Technical College in Okmulgee, Oklahoma, in 1979 with a diploma in industrial drafting. Judy then moved to Hahnville, Louisiana, near New Orleans after she was hired by Union Carbide Corporation as a piping designer in the Engineering Department. Judy met her husband, Allan, and decided to settle down in Hahnville and help raise his two children, Angela and Charlie. Judy and her family enjoyed the outdoors of the southern United States by camping, fishing, hunting, and off-road excursions. Judy's interest in the outdoors eventually culminated in thoughts of changing her career to wildlife, so she started going to school at night in 1994 at Nicholls State University in Thibodaux, Louisiana, in pursuit of a Bachelor of Science degree in biology. Judy also got involved in wetland restoration and environmental issues by joining and chairing her company's employee environmental advisory committee, and volunteering at Audubon's center for research of endangered species. After three long years of night school, Judy quit Union Carbide in 1997 after 17.5 years of service as a piping designer and engineering technician to attend college full time. Judy graduated college in May 1999 and took an internship position for 4 months at Aududon's Center for Research of Endangered

Species where she worked with endangered cranes, storks, small cats, Mexican gray wolves, tapirs, and bongos.

In 1999, Judy decided to attend Louisiana State University in Baton Rouge, Louisiana, as a non-degree graduate student. She was accepted as a Master of Science student in Spring 2000 under Dr. Vernon Wright in the School of Renewable Natural Resources. Dr. Wright helped Judy get a research assistantship under Dr. Michael Chamberlain soon after. Judy's interests in habitat and wildlife restoration were well aligned with the research project she accepted concerning bobwhite quail habitat restoration. Near the completion of her degree, Judy was hired as a contractor for the Louisiana Wildlife and Fisheries Department Natural Heritage Program to work with landowners to conserve rare, threatened, and endangered species.