

Forestry herbicide influences on biodiversity and wildlife habitat in southern forests

by Karl V. Miller and James H. Miller

Abstract In the southern United States, herbicide use continues to increase for timber management in commercial pine (*Pinus* spp.) plantations, for modifying wildlife habitats, and for invasive plant control. Several studies have reported that single applications of forestry herbicides at stand initiation have minor and temporary impacts on plant communities and wildlife habitat conditions, with some reports of enhanced habitat conditions for both game and nongame species. Due to the high resiliency of floral communities, plant species richness and diversity rebound rapidly after single herbicide treatments, with short- and long-term compositional shifts according to the selectivity and efficacy of the herbicide used. Recently, however, a shift to the Southeast in North American timber supplies has resulted in increased forest management intensity. Current site-preparation techniques rely on herbicide combinations, often coupled with mechanical treatments and ≥ 1 years of post-planting applications to enhance the spectrum and duration of vegetation control. This near-total control of associated vegetation at establishment and more rapid pine canopy closure, coupled with shortened and repeated rotations, likely will affect plant diversity and wildlife habitat quality. Development of mitigation methods at the stand and landscape levels will be required to minimize vegetative and wildlife impacts while allowing continued improvement in pine productivity. More uncertain are long-term impacts of increasing invasive plant occupation and the projected increase in herbicide use that will be needed to reverse this worsening situation. In addition, the potential of herbicides to meet wildlife management objectives in areas where traditional techniques have high social costs (e.g., prescribed fire) should be fully explored.

Key Words biodiversity, habitat, herbicide, release treatment, site preparation, Southeast, wildlife

More than 70 years ago, Leopold (1933) listed the habitat manager's tools for controlling or reversing plant succession as the "cow, plow, axe, and fire," and abundant research since then has demonstrated the utility of these

tools to manage various habitats. However, each of these tools, when wielded by the land management practitioner, has the potential to enhance or degrade wildlife habitat conditions depending on the objectives, scope, intensi-

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ty, and extent of the treatment. For example, prescribed fire is requisite for maintenance of many pyrophytic habitats (Van Lear and Harlow 2001), but extensive damage from unmanaged fire has led to numerous programs to eliminate fire dating from as early as the 1910s (Johnson and Hale 2001). Similarly, seasonal harrowing of fallow openings is an important tool for management of northern bobwhite (*Colinus virginianus*) habitats in the Southeast (Stoddard 1931), whereas conventional row-

ing site preparation, release of crop trees from noncommercial woody or herbaceous competition, and mid-rotational management of overstory and understory vegetation (Wigley et al. 2002). Site preparation with herbicides can increase loblolly pine (*Pinus taeda*) yields by >5 fold vs. untreated stands in the southern United States (Glover and Zutter 1993). Although data detailing trends in herbicide use in southern pine forests are limited, current estimates suggest that herbicide treatments are

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applied to approximately 1 million ha annually (Dubois et al. 2003), primarily to aid in plantation establishment.

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crop agricultural systems often do not have sufficient insect abundance to meet daily foraging requirements of northern bobwhite chicks (Palmer 1995).

Leopold's list predates the advent of modern herbicides by several decades. However, had he been a contemporary, we wonder what his opinion of these and other modern forestry tools would be. Herein, we review pertinent literature and focus on the role of silvicultural herbicides in forest management in the Southeast, the impacts of these herbicides on plant and animal communities, and the potential uses of herbicides to aid in the management of wildlife habitats in forested areas. Because DeLong (1996) identified problems with conflicting definitions of biodiversity, we focus our discussion on stand-level impacts to species diversity and species richness.

Trends in silvicultural herbicide use in the Southeast

In the southern United States, timber production is a multi-billion dollar industry, with an increasing amount of fiber provided by intensively managed pine (*Pinus* spp.) plantations. Timber production more than doubled between 1952 and 1997, and the share of United States production rose from 41–58% (Wear and Greis 2002). The area in pine plantations is forecast to rise by 67%, from a little more than 12.1 million ha in 1999 to 21.6 million ha by 2040 (Wear and Greis 2002). Simultaneously, financial considerations coupled with shifting policy on public lands and concerns about future timber supplies are driving a trend of increasing intensity of management (Sedjo and Botkin 1997).

Intensive management of southern pines for timber production commonly employs herbicides for pre-plant-

ing site preparation, release of crop trees from noncommercial woody or herbaceous competition, and mid-rotational management of overstory and understory vegetation (Wigley et al. 2002). Site preparation with herbicides can increase loblolly pine (*Pinus taeda*) yields by >5 fold vs. untreated stands in the southern United States (Glover and Zutter 1993). Although data detailing trends in herbicide use in southern pine forests are limited, current estimates suggest that herbicide treatments are applied to approximately 1 million ha annually (Dubois et al. 2003), primarily to aid in plantation establishment.

Concurrent with the increase in treated acreage is a trend toward using tank mixes of herbicides to increase the spectrum of competing vegetation controlled, followed by ≥ 1 herbaceous release treatments within the first 1 or 2 growing seasons after planting (Shepard et al. 2004). Use of herbicides to control herbaceous weed competition on industrial forests in the South is increasing rapidly. In 1991 >25% of industrial regenerated pine stands in the South were treated, and >33% are projected to be treated annually in the future (Teeter et al. 1993) because of increases in yield and associated financial returns (Dangerfield and Merck 1990).

Influence of silvicultural herbicides on plant diversity

The richness and diversity of plants associated with pine plantations vary considerably across the numerous physiographic provinces of the southern United States. Distinct forest communities inhabit each physiographic province and vary within each province according to topographic and landform variation. Localized studies in several states have contributed to our understanding of plant diversity responses to herbicide site preparation. However, the influence of plantation establishment techniques on floristic diversity has been studied in only a few situations and in general has not been well reported.

Although plant communities differ across the South, a common flora does exist of species that range throughout the region, especially in provinces where pine plantations are predominantly grown. Thus, there is a pressing need to understand the micro- and macro-effects of plantation management on biodiversity in all situations where they occur. The regional Competition Omission Monitoring Project (COMP) is monitoring pine growth and plant succession in response to intensive woody and/or herbaceous control treatments at 13 locations in 7 states across the

South. In general, intensive woody control treatments have increased richness and abundance of understory plants over a 15-year measurement period while herbaceous control without woody control has released hardwoods that shade out shrubs and herbaceous plants, decreasing understory diversity (Miller et al. 2003). Control of both woody and herbaceous plants for a 3–5-year establishment period continues to suppress floristic diversity through 15 years.

The various herbicides registered for forestry use typically affect different plant species and species groups. Some herbicides (e.g., glyphosate) are broad-spectrum, whereas others affect only certain species or plant growth forms. For example, imazapyr generally enhances legume (Fabaceae) and blackberry (*Rubus* spp.) presence, while picloram, metsulfuron, and triclopyr reduce legumes and blackberries (Wigley et al. 2002). Glyphosate controls huckleberries (*Vaccinium* spp.), whereas hexazinone releases these commonly occurring shrubs. These changes in composition can greatly influence wildlife habitat value (Boyd et al. 1995, Miller et al. 1999).

Site preparation

Most studies that have evaluated the effects of silvicultural herbicides at stand initiation have focused on single pre-planting applications either with or without complementary mechanical treatments. These studies typically have been short-term (<5 years) due to the ephemeral nature of these early-successional communities as well as the rapid changes in forest regeneration technologies. For example, a series of studies in Mississippi evaluated early-successional floristics among a variety of chemical and mechanical site-preparation treatments. Blake et al. (1987) reported no differences in plant species richness between chemically (hexazinone) and mechanically site-prepared (shear, rake, disk, and bed) areas in east-central Mississippi. Similarly, Hurst et al. (1994) reported no differences in species richness between imazapyr-treated sites and areas that had received a mechanical site-preparation treatment (roll-chop). Hurst and Blake (1987) reported that hexazinone-treated sites had more species of legumes, grasses, and vines, but fewer species of other plants, than an untreated site. In the Sandhills province of South Carolina, O'Connell and Miller (1994) found few differences in plant species diversity measures between sites prepared with hexazinone or mechanical treatments (shear and windrow) at 2 and 3 years post-treatment, but greater herbaceous diversity and richness on the mechanically treated areas at 5 years post-treatment.

More recent research has evaluated floristic responses among a variety of common silvicultural chemicals at

operational scales. This research includes the Tazewell study in southwestern Georgia and the Savannah River Site (SRS) study in west-central South Carolina.

Tazewell study. Three forest herbicide site-preparation treatments were compared at 0–5 years post-treatment on a 158-ha study site in Georgia. Detailed study descriptions, treatment methodologies, and sampling protocols are provided in Brooks (1992), Rodrigue (1994), and Moore (1996). Treatments were replicated 3 times in a randomized complete block design and included Pronone 10G® (hexazinone; DuPont, Wilmington, Del.) @ 3.4 kg a.i./ha; Tordon 101® (picloram+2,4-D; Dow AgroSciences, Indianapolis, Ind.) @ 0.6+2.2 kg a.e./ha+ Garlon 4® (triclopyr; Dow AgroSciences, Indianapolis, Ind.) @ 2.2 kg a.e./ha; and Arsenal® (imazapyr; BASF Forestry Products, Research Triangle Park, N.C.) @ 0.84 kg a.e./ha. The hexazinone treatment was broadcast in May 1990 and the other treatments in August 1990. All treatments were prescribe-burned in late October 1990. Woody vegetation was assessed at 1 year pre-treatment and annually for 5 years post-treatment on permanently marked 4-m² quadrats while frequency of occurrence of herbaceous species and vines was assessed at points systematically located on a 2.9 × 29-m grid. Woody-species richness and diversity declined during the first year post-treatment, but during the subsequent years post-treatment, they recovered to approximately pre-treatment levels (Figure 1); the only exception was that woody-species richness on the imazapyr sites remained below pre-treatment levels throughout the study. Herbaceous species richness and diversity also were not differentially affected by site-preparation chemical, although species richness was consistently lowest on hexazinone treatments.

SRS study. Because the Tazewell study only evaluated plant responses among herbicide treatments, a follow-up study in west-central South Carolina incorporated a mechanical site-preparation treatment for comparison to chemical treatments. Detailed study descriptions, treatment methodologies, and sampling protocols are provided in Sparling (1996) and Branch (1998). Treatments were replicated 3 times in a completely randomized block design on individual 33-ha study blocks. Specific treatments included Velpar ULW® (hexazinone; DuPont, Wilmington, Del.) @ 4.63 kg a.i./ha; Tordon K® (picloram; Dow AgroSciences, Indianapolis, Ind.) @ 2.24 kg a.e./ha+ Garlon 3A® (triclopyr; Dow AgroSciences, Indianapolis, Ind.) @ 3.36 kg a.e./ha; Arsenal® (imazapyr; BASF Forestry Products, Research Triangle Park, N.C.) @ 1.12 kg a.e./ha; and a mechanical treatment (root rake and windrow). Hexazinone treatments were applied using backpack spreaders in April 1992; the other chemical treatments were applied by boom sprayer on a

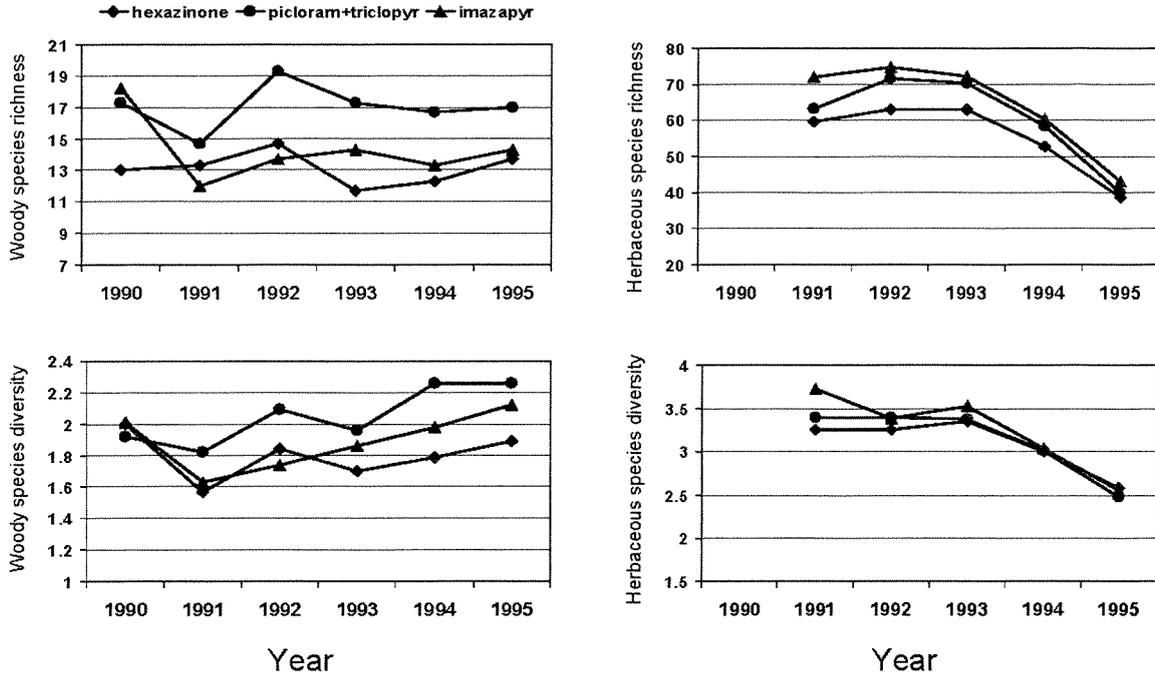


Figure 1. Mean plant species richness (number of species/4-m² plot) and diversity (Shannon index) on chemically site-prepared sites near Tazewell, Marion County, Georgia. Site-preparation treatments occurred during summer 1990. Pre-treatment woody vegetation was assessed in April 1990, and post-treatment vegetation was assessed during late summer 1991–1995.

crawler tractor in May 1992, and mechanical treatments occurred in October 1992. All plots were broadcast-burned in October 1992. Woody vegetation was assessed for 4 years post-treatment on permanently marked 4-m² quadrats, and herbaceous species were recorded in nested 1-m² subplots. Results of this study were similar to

those of the Tazewell study, although both woody and herbaceous species richness were lower due to the poor site quality and less diverse early-successional plant communities of the SRS treatment areas (Figure 2). As with the Tazewell sites, few differences in floristic diversity and richness occurred among treatments, although

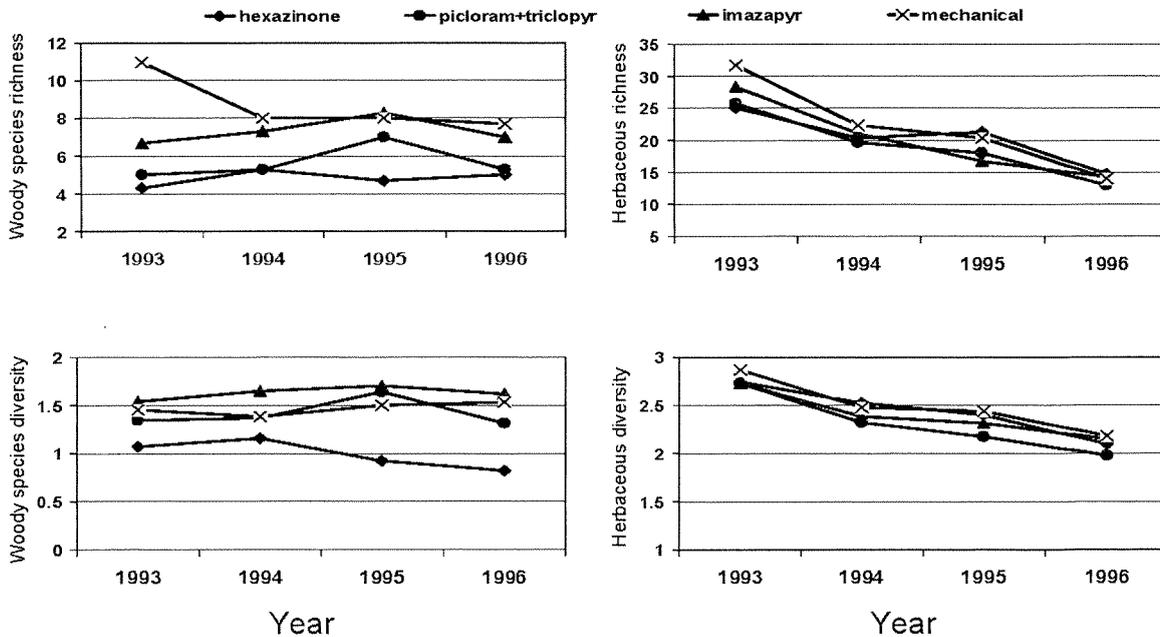


Figure 2. Mean plant species richness (number of species/4-m² plot) and diversity (Shannon index) on chemically site-prepared sites on the Savannah River Site, Barnwell County, South Carolina. Site preparation occurred during 1992, and vegetation was assessed in August 1993–1996.

woody-species richness and diversity were lowest on the hexazinone-treated areas.

To evaluate the longer-term impacts of chemical site preparation on plant communities across a variety of soil types, a study was established in 1984 on 4 study sites in 3 physiographic provinces in central Georgia (Miller et al. 1999). At each study site, 6 herbicide treatments and 1 untreated control were established. Treatment plots averaged 0.4 ha and included Roundup® (glyphosate; Monsanto, St. Louis, Mo.) @ 3.4 kg a.e./ha and Garlon 4® (triclopyr) @ 4.4 kg. a.e./ha. Picloram (Tordon®) was applied as a granule at 3.4 kg a.e./ha. Two herbicides containing dicamba and 1 containing 2,4-D (Banvel® and Banvel 720®; BASF Forestry Products, Research Triangle Park, N.C.) were applied at 4.5 kg a.e./ha dicamba+4.5 kg a.e./ha 2,4-D. Application rates for Velpar L® and Pronone 10G® (hexazinone; DuPont, Wilmington, Del.) varied from 2.8 kg a.i./ha to 3.9 kg a.i./ha according to soil type requirements. At 11 years post-treatment, there were no differences in species richness or diversity among the chemically treated sites and the untreated control (Figure 3), although there were minor differences in the composition of the plant community (primarily woody species) among the various treatments, reflecting differing selectivities among the treatments.

The results of the Tazewell, SRS, and Miller et al. (1999) studies, along with other studies in the southern United States (e.g., Neary et al. 1990, O'Connell 1993, Hurst et al. 1994, Boyd et al. 1995), suggest that although silvicultural herbicides have differing selectivities for plant groups, overall floristic diversity and species richness vary little in response to a single herbicide application at stand initiation. Furthermore, floristic responses to single chemical treatments approximate those in response to mechanical disturbances, or to communities on untreated sites. However, plant community responses to forestry herbicides certainly are impacted by the specificity of the herbicide used as well as site-specific factors such as soil fertility and texture.

To date, only Wilkins et al. (1993) have compared responses of plant communities to herbicide site-preparation treatments

across broad soil types. In their study plant community dynamics were evaluated in response to increasing rates of hexazinone application on an edaphic gradient (xeric sandhill, mesic flatwoods, and hydric hammock). With increasing application rates, herbaceous diversity decreased on the xeric sandhill, did not vary on the mesic flatwoods, and increased on the hydric hammock. They concluded that plant community responses to hexazinone were a function of application rate, edaphic factors, adaptive strategies of resident plant species, and the presence or absence of hexazinone-tolerant species.

Although they have not been similarly evaluated, differential responses to rate and environmental factors certainly occur for other silvicultural herbicides as well. For example, plant community responses to imazapyr application on acidic coastal plain soils with high organic content differ markedly than those on soils with higher clay content (K. V. Miller, University of Georgia, unpublished data). Clearly, additional field studies are required to fully discern plant community responses to individual herbicide site-preparation treatments.

Release treatments

Herbicides also are used following site preparation to release crop trees from competition with other woody species and from herbaceous vegetation. The few studies that have evaluated plant responses to herbicide release treatments have found minor reductions in the diversity of woody species (hexazinone; Zutter and Zedaker 1988) or no differences in plant richness or diversity at 7 years post-treatment (imazapyr, glyphosate or hexazinone; Boyd et al. 1995). In the latter study, individual plant species increased or decreased in abundance depending on selectivity of the species to the different herbicides.

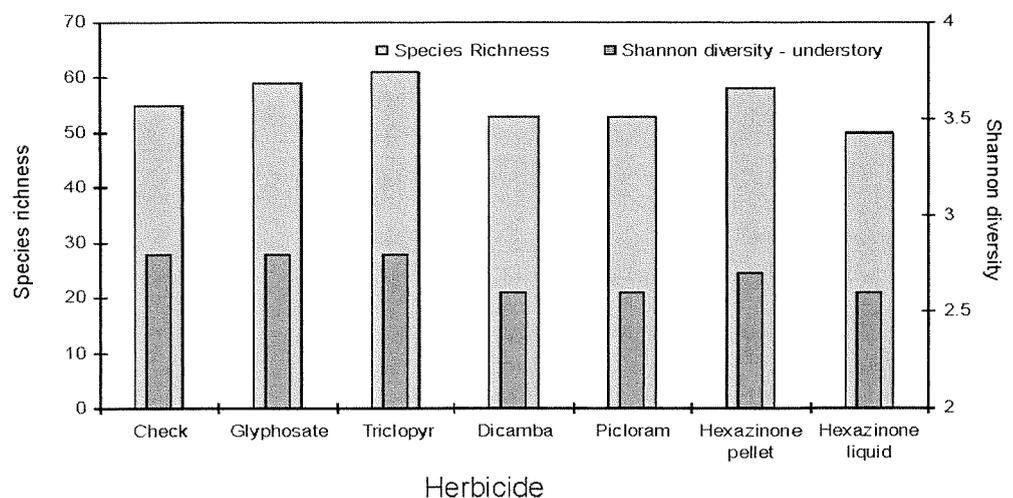


Figure 3. Treatment means for total plant species richness and Shannon diversity among 6 herbicide treatments at 4 sites in central Georgia, evaluated 11 years after treatment. Data from Miller et al. (1999).

In an evaluation of plant responses to herbaceous release treatments (Oust®), Keyser et al. (2003) reported that although total herbaceous coverage and species richness declined in the first year after application on many locations, these vegetation measurements rebounded in the second or third year. Few differences were observed in the abundance of wildlife forage plants or plant species diversity.

Future trends

Although single herbicide applications have minor or temporary impacts on plant communities at current application rates, stand-level management intensity has increased dramatically in recent years. Increased use of herbicides, coupled with fertilization and genetically improved seedlings have shortened rotation lengths. Current site-preparation herbicide prescriptions often include tank mixes of ≥ 2 herbicides to eliminate hardwood competition, often combined with some form of mechanical tillage, followed by ≥ 1 year of herbaceous release treatments at 1 or 2 years post-planting.

When applied as broadcast treatments, herbaceous releases clearly can alter the plant community and reduce plant diversity, although definitive research is lacking. However, when applied selectively, such as in bands over the crop trees, release treatments could functionally enhance the diversity of plant species on a site by placing portions of the overall stand in different seral stages. However, the rapidly emerging technologies to maximize growth of crop trees have resulted in a shortened interval between planting and canopy closure (Borders and Bailey 1997), and thus reduced the time interval for establishment of early-successional plant species. Additionally, increased competition control may result in reduced seed rain of early-successional species, thereby impacting potential plant community responses following subsequent disturbances. Clearly, additional field studies are needed to determine means of maintaining plant communities and wildlife habitat values in intensively managed stands.

Influence of silvicultural herbicides on avian communities

Early seral stages of pine plantations, before canopy closure, provide excellent habitat for a number of early-successional songbirds (Meyers and Johnson 1978, Hunter et al. 2001). However, few studies have investigated the response of avian communities to site-preparation methods. Kilgo et al. (2000) compiled and evaluated the results of a series of studies in west-central South Carolina (SRS study as described above). In a study that

compared hexazinone-treated areas with mechanically prepared sites (O'Connell 1993), avian species diversity was greater on the chemical treatments at 2 and 3 years post-treatment, but not different at 5 years. The few observed differences in avian communities were attributed to differences in vegetative components, particularly the retention of residual snags on the chemically prepared sites. Thus, cavity-nesting songbirds such as the eastern bluebird (*Sialia sialis*) and perching species such as the brown-headed cowbird (*Molothus ater*) and mourning dove (*Zenaidura macroura*), were more common on the chemically treated areas, whereas shrub-scrub species such as the Carolina wren (*Thryothorus ludovicianus*) and the yellow-breasted chat (*Icteria virens*) were more common along windrows of woody debris in the mechanically treated sites. In the SRS studies that compared several chemical treatments and a mechanical treatment (Sparling 1996, Branch 1998), breeding-bird diversity and richness did not differ among treatments during 4 years post-treatment (Figure 4). Similarly, on the Tazewell sites, avian diversity, species richness, and indices of abundance did not differ among the 3 chemical site-preparation treatments when monitored at 4 and 5 years post-treatment (Moore 1996).

The combined SRS studies, along with similar studies in other regions of the southern United States (e.g., Warren 1980), demonstrate that there are few differences in avian responses to a variety of chemical or mechanical treatments. However, because of the ephemeral nature of these successional habitats and the rapid developments in site-preparation technologies, other results are possible with different herbicides, application rates, or application timing. Additionally, the trend toward increased use of herbicide tank mixtures to achieve greater competition control combined with repeated herbicide treatments for control of herbaceous competition and fertilization of young pines (Miller et al. 1995) likely will reduce food availability and structural diversity for avian communities. Additionally, the time that the site is available to successional-scrub species may be reduced because more intense vegetation control often removes habitat for ≥ 1 year and fertilization accelerates the speed at which canopy closure excludes successional plants. More complete competition control also will reduce the abundance of potential snags during subsequent rotations. However, stand rotation age also will be shortened, resulting in an increased frequency of returns to early-successional habitat.

The response of early-successional songbirds to the increased rate of successional change is unknown. However, on a landscape scale, a shortened period of suitable habitat and lower snag abundance may reduce

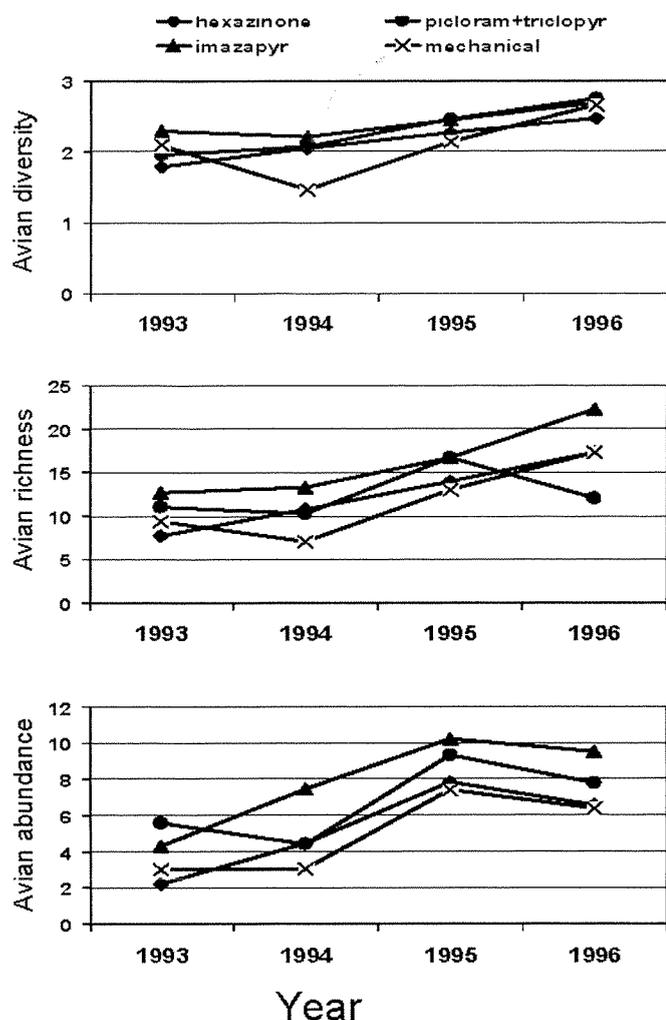


Figure 4. Mean avian diversity (Shannon index), species richness (number species detected/plot), and index to abundance (number detected/census plot) on chemically site-prepared sites on the Savannah River Site, Barnwell County, South Carolina. Site preparation treatments occurred during 1992, and avian censuses were conducted during June 1993–1996.

populations of some disturbance-associated species (Freemark et al. 1995). Clearly, additional research is requisite to verify the general trends observed and to investigate avian responses to increased intensity of silvicultural treatments at stand initiation.

Influence of silvicultural herbicides on small-mammal communities

Although responses of small mammals to chemical site preparation has received considerable research attention in the northern coniferous ecosystems of southern Canada and northern portions of the United States (see Lautenschlager 1993, Sullivan et al. 1998, Lautenschlager and Sullivan 2002), few studies have

investigated small-mammal responses in southern pine systems. To date only the Tazewell study and the SRS study described above have monitored responses of small mammals to herbicide site-preparation treatments.

Tazewell study

Herbicide application followed by a prescribed fire initially reduced the abundance of small mammals, although population recovery was apparent 18 months post-treatment (Figure 5a). In subsequent years small-mammal populations typified successional changes in developing pine plantations, with rapid turnover of species dominance reflecting changes in the ephemeral early-successional communities and declines in abundance as the stand moved toward canopy closure (Atkeson and Johnson 1979). There was little indication of species-specific treatment effects.

SRS study

As with the Tazewell study, small-mammal abundance was depressed initially during the year of treatment but recovered during the year after treatment, except on the mechanically treated sites (Figure 5b), perhaps due to the elimination of most coarse woody debris via mechanical piling into windrows. The dynamics of microsite components including stumps and leaf cover can affect small-mammal populations (Dueser and Shugart 1978) and capture rates (Planz and Kirkland 1992).

It has long been established that peak populations of seed-eating rodents and shrews typically occur during the first year after loblolly pine stands are clearcut (Trousdel 1954). The Tazewell and SRS studies, when combined with the findings of others (e.g., O'Connell and Miller 1994), suggest that small-mammal population responses to clearcutting may be delayed by 1–2 years by chemical site preparation. However, peak population responses may be greater on chemically treated sites than on mechanically treated sites. Thus, although chemical site preparation can influence small-mammal populations immediately through habitat alteration, herbicide-specific effects appear to be short-lived.

Influence of silvicultural herbicides on game species

The response of important wildlife forage plants to herbicide site preparation has been studied on a variety of sites across the southern states. For example, a series of studies established in Mississippi revealed that herbicide site-preparation treatments (hexazinone, imazapyr) typically decreased total white-tailed deer (*Odocoileus virginianus*) forage 1 year after treatment, but by the second

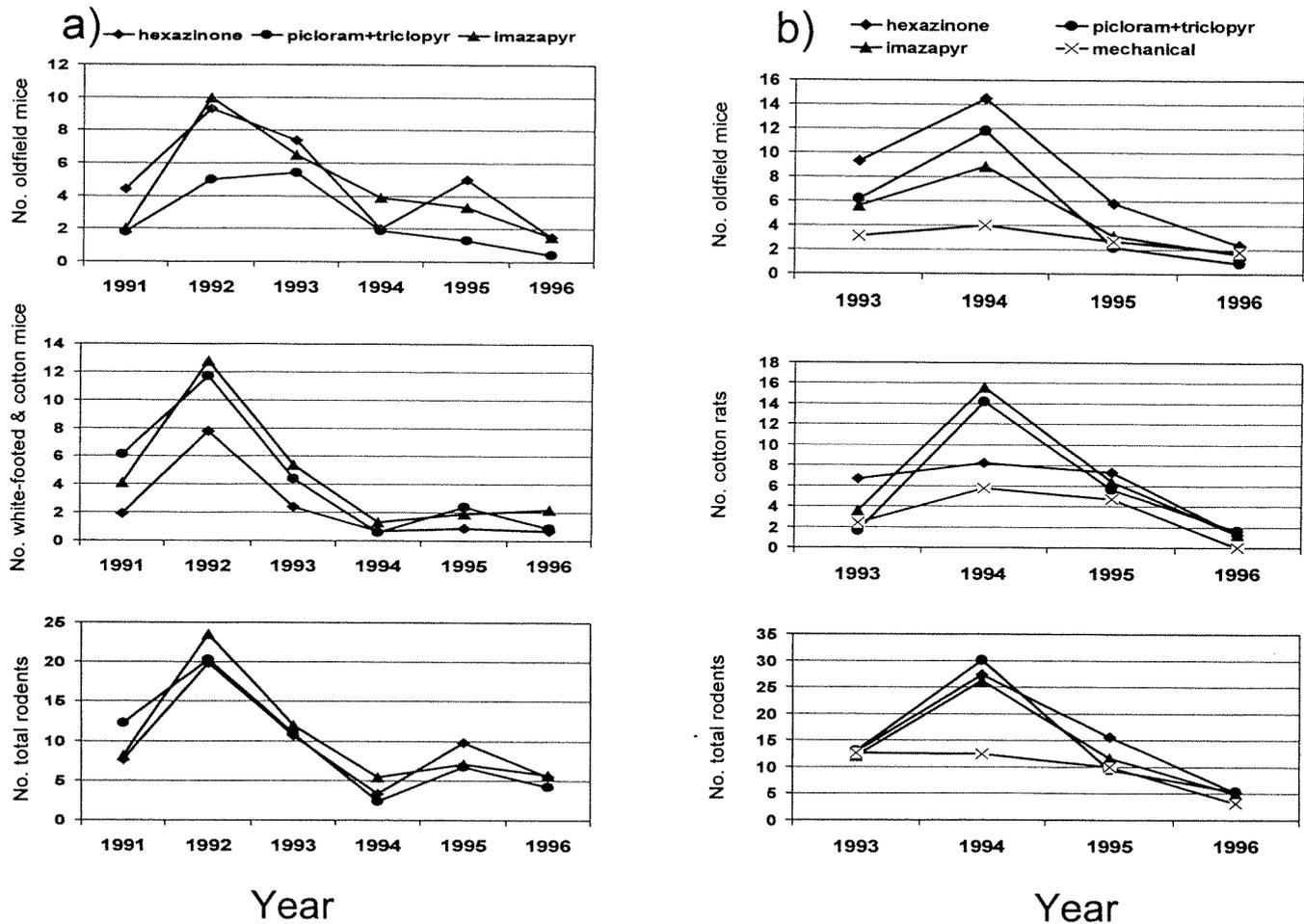


Figure 5. Capture rates of small mammals (per 100 trap-nights) on chemically site-prepared sites. A) February captures of oldfield mice (*Peromyscus polionotus*), white-footed and cotton mice (*P. leucopus* and *P. gossypinus*), and total rodents on chemically site-prepared sites near Tazewell, Marion County, Georgia. Site-preparation treatments occurred during summer 1990. B) December captures of oldfield mice, cotton rats (*Sigmodon hispidus*), and total rodents on sites at the Savannah River Site, Barnwell County, South Carolina. Site preparation treatments occurred during 1992.

year no differences occurred between treated and untreated plots (Copeland 1986, Hurst and Warren 1986, Blake et al. 1987, Hurst 1987, Hurst and Watkins 1988, McNease and Hurst 1991). Similar studies in South Carolina (Gassett et al. 2000) and in Georgia (Witt et al. 1993, Moore et al. 1997) indicated that the application of certain forestry herbicides may concurrently suppress undesirable woody vegetation and provide short-term benefits to deer forage production.

Similarly, production of food plants for northern bobwhites typically is reduced in the year following chemical treatment but recovers in subsequent years post-treatment (Hurst and Palmer 1988, Witt et al. 1993). In a South Carolina study, Feken (1995) reported that imazapyr treatment enhanced production of quail foods and increased nesting cover at 1 year post-treatment. However, the imazapyr treatment reduced the abundance of woody vegetation important for escape cover.

Concurrently, Hawkes (1995) found decreased quail use of the study sites the year following imazapyr treatments but no difference in quail use of the treatment or reference sites during the second summer post-treatment.

As with other aspects of single-application site-preparation treatments, production of wildlife forage species across broad geographic areas likely is influenced by a variety of factors including herbicide specificity, rate, timing of application, and edaphic variables. Additionally, to date no comprehensive studies have evaluated the impacts of tank mixtures of herbicides, multiple herbicide treatments for site preparation and release, or the combined impacts of herbicides, mechanical tillage, and fertilization. Clearly, long-term field trials are necessary to thoroughly evaluate the impacts of emerging silvicultural technologies and mitigation techniques for potential negative effects (Miller et al. 2003).

The role of silvicultural herbicides in wildlife habitat management

Lautenschlager et al. (1995), and more recently Wigley et al. (2002), reviewed literature and provided guidelines for using herbicides to improve habitat conditions for a variety of wildlife. According to Lautenschlager et al. (1995), herbicides can be a beneficial tool to reduce invasive nonnative plants, create snags, create early-successional openings, change shrub communities to grass or herbaceous communities, favor aspen (*Populus tremuloides*) clones, release conifers, and manage browse resources.

In the southern United States, herbicide use has been evaluated as a tool to achieve numerous wildlife habitat objectives. For example, both Conner (1989) and Jones (1992) reported using herbicides to manage hardwood midstories in red-cockaded woodpecker (*Picoides borealis*) cluster areas. Several studies have evaluated use of herbicides to create snags for cavity-nesting songbirds (Conner et al. 1981, 1983; McComb and Rumsey 1983; Schulz et al. 1992). Welch et al. (2004) successfully controlled hardwood invasion in open pine stands without negatively impacting habitat conditions or food production for northern bobwhites. Edwards et al. (2003) reported that an application of imazapyr in open pine stands could enhance deer forage production more cost-effectively than the establishment of warm-season food plots. In a Mississippi study, Hood et al. (2002) reported that small-mammal populations (primarily *Peromyscus* spp.) in thinned, mid-rotation loblolly pine stands responded favorably to prescribed burning and burning-plus-herbicide (imazapyr) treatments at 1 and 2 years following treatment. Herpetofauna communities were not affected by the treatments, although fence lizard (*Sceloporus undulatus*) capture rates were higher on treatment sites. On the same study area, Thompson (2002) reported that areas treated with imazapyr and prescribed fire contained greater forb cover and lower mid-story basal area than control sites. Avian species associated with open pine stands were more common on herbicide and burn treatments, whereas species associated with a dense mid- and understory were most common on the control area.

Through the proper selection of herbicide, rates, timing of application, and application methods, herbicides can be used to create a variety of habitat characteristics for many wildlife species. However, the key to designing herbicide treatments to benefit wildlife is to thoroughly understand the habitat requirement of the particular wildlife species (Lautenschlager et al. 1995) as well as site-specific plant community responses to herbicide treatments.

Control of nonnative invasive plants

Nonnative and native invasive plants are decreasing floristic diversity at an increasing rate in the Southeast, not only in pine plantations but in every land-use sector. The spread of invasive plants is the greatest current threat, besides human development, to native plant communities globally and in the Southeast (Simberloff et al. 1997, Mack et al. 2000) and attacks specifically the richest communities (Stohlgren et al. 1999). Initially, invasive nonnative plants add to richness by their entry into native communities, but they inevitably restrict richness and diversity due to their competitive invasive habits. Herbicide applications, both selective and broadcast, offer one of the most effective means of combating these invasions, especially when combined with other tools into integrated approaches to vegetation management and plant restoration (Miller 2003).

Management of forest plant communities in the future

Because plantation area is expected to increase in the South (Wear and Greis 2002), pine plantations will play an increasing role in biodiversity conservation within the landscape matrix of agricultural lands, natural and plantation forests, rights-of-way, and urban-suburban community forests. Plant communities associated with pine plantations influence nutrient increment and conservation, wildlife communities, wildfire intensity, and the productivity of a stand. Yet, little is known about the conservation capabilities of pine plantations as they interplay with other land uses or the contributions of associat-



When used at appropriate application rates and methods, herbicides can provide land managers with a valuable vegetation management tool for altering habitat conditions or controlling exotic invasive species such as kudzu (*Pueraria montana*).

ed plant communities to the long-term health and sustainability of forestlands. More long-term, detailed research is needed to evaluate plant and animal species responses following herbicide, mechanical, burning, and fertilization treatments for pine plantation management and how the resulting plant communities interact with other landscape components. Detailed studies on influences of silvicultural treatments, including herbicides, on amphibian and reptile communities are especially needed.

Intensive forest management tools such as herbicide use and their relationship with plant communities and wildlife habitat values are coming under increased scrutiny from regulatory agencies (Salwasser 1990), and in sustainable forestry programs such as the Forest Stewardship Council and the Sustainable Forestry Initiative®. Thus, in the future, vegetation management expenditures must be not only justified by increases in the growth and yield of crop trees but also weighed against changes in the amenity values of wildlife and noncrop species maintenance (Miller et al. 1995).

Developments in plant community management are essential to protect species richness, to sustain and improve soil health and productivity, and to maintain wildlife habitat. Herbicides are one of several "ecological tools" available for meeting many natural resource objectives. In addition to enhancing commodity outputs, vegetation management techniques and technology can create and maintain desirable plant and animal habitats, restore damaged forest landscapes, control invasive plants, maintain recreational areas, and maintain rights-of-way for multiple uses. However, herbicides often are perceived by the public to cause harm to the environment, and as a result, many public land managers are hesitant to use them. A major problem in managing natural resources in today's sociopolitical environment is that there have been too few integrated comparisons of forest vegetation management alternatives and too few syntheses of information to provide a scientific basis for decision-making.

Clearly, herbicides can be used to enhance habitat conditions for a variety of wildlife. However, just as any of the habitat management tools described by Leopold can be used for the benefit or detriment of wildlife, when wielded indiscriminantly or with little understanding of or concern for wildlife impacts, herbicides have the potential to significantly alter plant communities and wildlife habitat. As pine plantation management increases in intensity, increases in the efficacy and duration of control of associated vegetation with multiple herbicide applications may reduce habitat quality significantly. On a landscape scale, this shortened period of suitable habitat and reduction in habitat quality may reduce popula-

tions of disturbance-dependent songbirds (Freemark et al. 1995) and game species. However, the scale of application and the landscape context of the treated areas will determine effects on local or regional populations. Even minor changes in design and management of pine plantation forests could enhance habitat quality and the conservation of biodiversity without negatively impacting forest productivity (Hartley 2002). Specific activities that may enhance diversity include varying herbicide prescriptions among stands, designing "skips" of untreated areas during application, retaining leave-trees and snags to enhance structural diversity, protecting special habitat features or habitat types, and use of alternative vegetation management techniques such as silvopastures.

As with all tools, selection of appropriate chemicals, application rates, timing, and methods of application must be made with a keen understanding of historical disturbance patterns, land-use history, localized plant community responses, herbicide selectivities, and overall objectives. No vegetation management tool is capable of addressing every habitat management objective, and in some cases, herbicides may be the only effective management tool available. Retention of all available tools allows for maximum flexibility when addressing any habitat management need.

Acknowledgments. Funding for this research was provided by McIntire-Stennis Project GEO-0093-MS. We thank D. A. Osborn, S. H. Mily, and J. P. Carroll for editorial comments.

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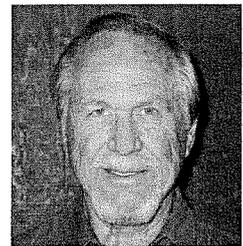
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