# Herbicides as an Alternative to Prescribed Burning for Achieving Wildlife Management Objectives

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Abstract.—Prescribed burning is used for many silvicultural and wildlife management objectives. However, the use of prescribed burning can be constrained due to difficulties in obtaining burning permits, concerns about liability, potential effects of scorch on growth and survival of crop trees, its sometimes ineffective results, limited burning days, and the costs of applying, controlling, and monitoring burns. For some landowners, herbicides offer a cost-effective alternative to prescribed burning for manipulating plant communities and wildlife habitat, especially when the boundaries of application are closely defined and the focus is on individual habitat components. Although the ecological effects of fire and herbicides sometimes differ, when used alone or with other management practices herbicides offer an opportunity to meet many wildlife management objectives. In this paper, we discuss and provide examples of wildlife management objectives that have been met by using herbicides, and factors that should be evaluated when considering use of either prescribed burning or herbicides.

## Introduction

Wildlife habitat is "an area with the combination of resources (like food, cover, water) and environmental conditions (temperature, precipitation, presence or absence of predators and competitors) that promotes occupancy by individuals of a given species (or population) and allows those individuals to survive and reproduce" (Morrison et al. 1992:11). Achieving management objectives for single wildlife species, or communities of wildlife species often involves manipulating in space and time the structure, composition, and distribution of plant communities and special habitat features such as snags, down and dead wood, and mast-producing vegetation.

Fire has long been used for managing plant communities. Native Americans burned forest land periodically to improve game habitat, facilitate travel, reduce insect pests, remove cover for potential enemies, and enhance native food production (MacCleery 1992, Day 1953). Early European settlers used fire to improve habitat for livestock and game species such as white-tailed deer (*Odocoileus virginianus*), wild turkey (*Meleagris gallopavo*), and northern bobwhites (*Colinus virginianus*) (Komarek 1981). Currently, foresters and wildlife managers prescribe fire to reduce fuels, prepare sites for natural or artificial regeneration, control competing vegetation in mid-rotation stands, control certain insects and diseases, enhance development of forage resources, obtain desired structural characteristics (e.g., development/promotion of herbaceous and shrub layers), create specialized habitat components (e.g., snags and logs), and restore desired plant species composition in some ecosystems, e.g., longleaf pine (*Pinus palustris*).

As recently as 20 years ago, prescribed burning was used extensively to manage plant communities on private lands (Mobley and Balmer 1981), which represents the majority of lands in the United States (USDA Forest Service 2000). However, in many states the use of prescribed burning appears to have been relatively stable or slightly declining over the past 20 years, although data related to these trends are limited. In a survey of southern state forestry agencies by the Georgia Forestry Commission, 6 responding states indicated that the area burned over the past 2 decades has remained relatively stable and 2 states reported a significant decline in area burned (R. Ferris, Georgia Forestry Commission, personal communication). Trends in states not responding are unknown. Data from South Carolina provides an example of a state where the area burned annually has been slightly declining over the past 20 years (Figure 1). In areas where use of prescribed burning is constrained or declining, managers have begun to search for alternative technologies to achieve wildlife management objectives.

During the latter half of the 20th century, herbicides emerged as a tool for manipulating plant communities. Herbicide products (generally the active ingredient and one or more surfactants mixed in water) are used extensively to manipulate the species composition and structure of vegetation in agriculture, along roads and utility rights-of-way, in urban settings, and in forest management (Walstad and Kuch 1987, Brennan et al. 1998). However, data describing trends in herbicide use in forested ecosystems in the United States are limited.

The recent registration of more selective herbicides increases the potential to use herbicides for achieving wildlife management objectives, especially when these objectives cannot be achieved through prescribed

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Figure 1.—Area treated with prescribed fire in South Carolina during 1973-1999 (source, South Carolina Forestry Commission annual reports).

burning or in forest systems where fire is not a natural ecological force. In this paper, we discuss the use of herbicides to address wildlife-related objectives within forested ecosystems, with an emphasis on the eastern United States. We will describe herbicides commonly used in forest management, silvicultural objectives for which they are used, habitat components affected, and wildlife objectives that can be met with their use. We also will discuss considerations for determining which tool to use. Our manuscript benefitted from reviews by R. A. Lautenschlager and D. H. Van Lear.

## Ecological Functions of Fire

Can the judicious use of herbicides lead to conditions similar to those created by fire? The answer depends upon the specific ecological response in question. Fire has myriad effects in forested ecosystems. Fire influences plant and animal species richness, plant reproduction and development, insect outbreak and disease cycles, wildlife habitat relationships, soil functions, and nutrient cycling (SNEP Science Team and Special Consultants 1996). The ecological effects of fire (Figure 2) are complex, interrelated, and sometimes undesirable when fire is intense or occurs across large areas (Agee 1993). Pyne et al. (1996), based on information in Wright and Heinselman (1973), suggested that depending upon intensity fire may:

- Trigger the release and germination of seeds in some plant species;
- Stimulate flowering and fruiting of some shrubs and herbs;
- Alter seedbeds by removing litter and humus and creating bare soil;
- Stimulate vegetative reproduction of woody and herbaceous species through overstory reduction;
- Temporarily reduce competition for moisture, nutrients, and light, thereby favoring some species;
- Selectively eliminate part of a plant community;
- Influence community composition and successional stage; and
- Regulate susceptibility of forests to blowdowns.

Fire has countless other ecological effects some of which depend upon the ecosystem in which it occurs. Fire may kill or injure above- and below-ground portions of plants, volatize nitrogen, improve conditions for nitrogen mineralization, cause elements/nutrients to become more available for uptake by plants, and dramatically change micro-climates (Wright and Heinselman 1973). In oak ecosystems, fire creates favorable conditions for acorn caching by squirrels (*Sciurus* spp.) and blue jays (*Cyanocitta cristata*), reduces populations of insects that prey on acorns and young oak seedlings, xerifies mesic sites through consumption of surface organic matter and exposure of the soil to greater solar radiation, and reduces understory and midstory competition from fire-intolerant species (Van Lear and Watt 1993). Fire scarifies the seed coat of some plants and enhances their germination, and reduces debris loading following natural disturbance or harvesting.

Clearly, use of herbicides also results in some of these ecological effects. Herbicides can injure or kill the above-ground portion of plants, selectively eliminate part of a plant community, influence community composition and successional stage, and temporarily reduce competition among plants for resources. In such cases, herbicides may provide an appropriate substitute for prescribed burning. However, herbicides cannot perform every ecological function of fire. For instance, herbicides cannot directly and immediately alter a seedbed by removing litter and humus and creating bare soil, although herbicides can contribute to this indirectly over time. Herbicides cannot scarify leguminous seeds to enhance germination or stimulate seed release in plants such as jack pine (*Pinus banksiana*).

Herbicides may be more effective at eliciting some ecological effects if used in combination with other management tools. For example, mechanical site preparation could be used in combination with herbicides to remove litter and humus and create bare soil. Herbicides and fire already are commonly used in combination for site preparation to reduce debris loading and control competing competition. However, approaches for combining herbicides and other tools to meet wildlife and ecological objectives need more thorough investigation.

## Herbicide Use in Forestry

Wildlife habitat management is commonly achieved in conjunction with or as a corollary of other land management activities such as forestry. Often, the decision of whether to use fire or herbicides for wildlife

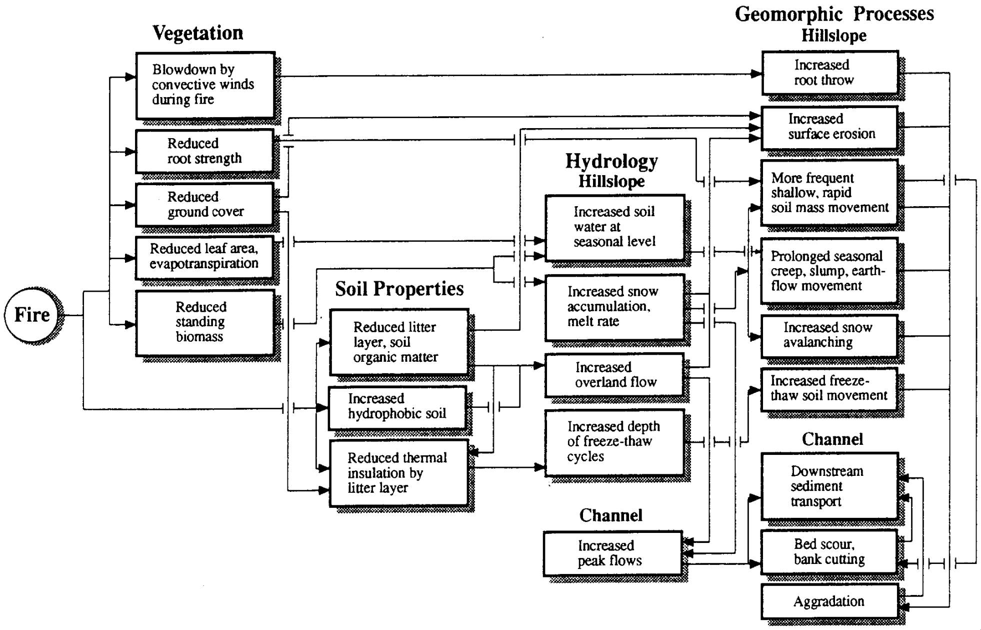


Figure 2.—The effects of fire on vegetation, soils, hydrology, and geomorphic processes (from Swanson 1981 and Agee 1993). Excerpted from *Fire Ecology of Pacific Northwest Forests* by James K. Agee. Copyright © 1993 by James K. Agee. Reprinted by permission of Island Press, Washington, DC and Covelo, CA.

management in forested ecosystems depends upon which tool is most effective at achieving other landowner objectives (e.g., a forestry objective). Because herbicides are increasingly a preferred tool for achieving forestry objectives, we will briefly describe forestry-related uses of herbicides. Each of these forestry-related uses represents opportunities for biologists to interact with foresters and discuss modifications to herbicide prescriptions that would also achieve wildlife management objectives.

Herbicides are used in forestry for site preparation, release of crop trees from competition with herbaceous and non-commercial woody plants, and timber stand improvement (Lautenschlager 2000). The reduction of competing vegetation can significantly increase tree growth well into mid-rotation (e.g., Zutter and Miller 1998), and controlling both woody and herbaceous vegetation provides the greatest increase in tree growth (Figure 3). Herbicide applications typically are tailored according to soils, structure and composition of the plant community, and management objectives. Table 1 provides an overview of herbicides commonly used in forest management.

Depending upon topography and soil conditions, site preparation may be accomplished using herbicides alone or in combination with mechanical methods or fire. When applied for site preparation, herbicides generally are broadcast. Thus, using herbicides alone for site preparation (especially when they are aerially broadcast) generally results in minimal soil disturbance and erosion potential.

To control herbaceous vegetation, herbicides often are broadcast or applied in bands or spots during the first year or two following stand establishment. Some herbicides, such as sulfometuron can be sprayed over the top of the seedlings of selected tree species (e.g., southern pines) without adversely affecting their growth. Following stand establishment and through mid-rotation, herbicides are commonly used to release crop trees from the influence of competing vegetation. Sometimes herbicide applications for this purpose follow thinnings or precede applications of fertilizer.

As an intermediate treatment (timber stand improvement), hebicides often are applied to individual woody stems in the midstory and overstory to improve the composition, structure, condition, and growth of the stand. Herbicides can be applied during much of the year to individual woody stems through injection (herbicide applied to a wound in the tree bole), basal spraying (herbicide sprayed at the base of the tree close to the ground), or soil treatment (herbicide applied to ground), although there may be some seasonal constraints on these treatments. Treatment of individual stems is labor intensive, but the ability to do so provides significant opportunities for selective habitat enhancement without impacting the entire plant community.

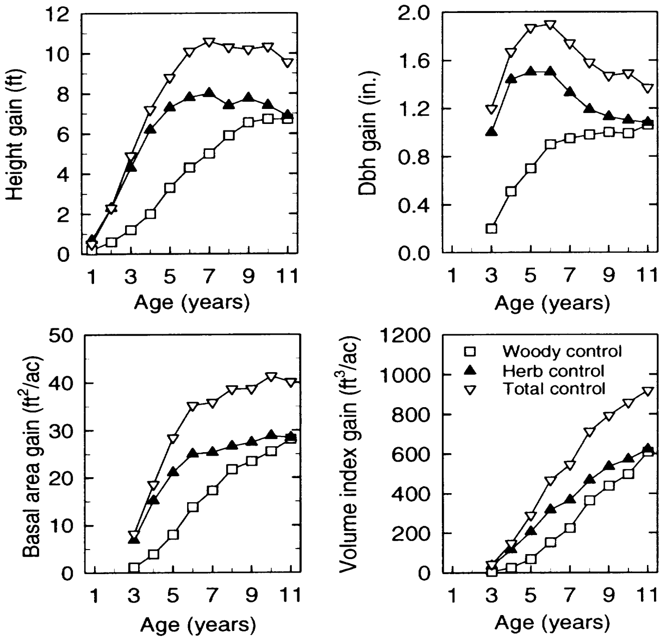


Figure 3.—Gains in average loblolly pine height, dbh, stand basal area, and stand volume index over no-treatment control through 11 growing seasons by vegetation control method (from Zutter and Miller 1998). Reprinted from the Southern J. Appl. For. 22[2]:93 published by the Society of American Foresters, 5400 Grosvenor Lane, Bethesda, MD 20814-2198. Not for further reproduction.

The various herbicides registered for forestry use typically affect different plant species and species groups. Some herbicides such as glyphosate are broad spectrum and affect virtually all plant species, although timing and application rates may alter selectivity of many herbicides. Other herbicides are more selective and affect only certain species or plant growth forms (Table 2). For example, metsulfuron is highly effective for controlling plants in the genus *Rubus*. In contrast, legumes and *Rubus* spp. generally are tolerant to imazapyr (Table 3). Fluazifop-P and sethoxdim are grass-specific chemicals and have little impact on broadleaf species, while triclopyr has little effect on grasses and sedges. Sulfometuron methyl (as Oust®) has been used in northern hardwood forests to control hay-scented (*Dennstaedtia punctilobula*) and New York (*Thelypteris noveborancensis*) ferns but was found to have no effect on woody plants (Horsley 1988a).

Sometimes different configurations of the same herbicide have different effects, due either to differences in the nature of the active ingredient (i.e., ester or amine) or additives (e.g., type of surfactant). For example, Miller and Mitchell (1990) found that applications of triclopyr in the form of Garlon® resulted in 40-80 percent mortality in dogwoods (*Cornus* spp.), while applications of triclopyr in the form of Pathfinder® resulted in >80 percent mortality of the same species. This selectivity enhances a manager's ability to manipulate plant communities. Of course, because of this differing selectivity, foresters sometimes mix two or more herbicides in the same tank to enhance the number of species controlled during an application. However, some herbicides are not compatible in tank-mixes and the number of species controlled by such mixtures may actually decrease (Ezell 1998).

## Using Herbicides to Meet Wildlife Management Objectives

Although the ecological effects of herbicides and fire sometimes differ, herbicides can be used to meet many wildlife management objectives related to plant species composition and structure, special habitat features (e.g., snags, down wood), and the temporal and spatial distribution of selected habitat components. In fact, herbicides are more effective than fire for achieving some wildlife management objectives and can perform some functions that fire cannot. Numerous studies have evaluated the potential of using herbicides for specific wildlife management objectives (Table 4). In reviewing many of these studies, Lautenschlager et al. (1995) suggested that, by choosing appropriately (active ingredient, time of application, application technique), herbicides can be used to: (1) reduce densities of invading non-native plants (restoring native populations and associated wildlife); (2) create snags, dead and down woody material, and "drumming logs" in early or later successional stands (providing "old growth" characteristics); (3) create small, intermediate, or large early-successional openings within older vegetation types; (4) change shrub-dominated areas to earlier successional grassy, or herb/grass-dominated communities; (5) favor male aspen clones; (6) release patches or expanses of conifers; and (7) keep woody and herbaceous "browse" within reach of browsing animals.

### Managing Vegetative Species Composition and Structure

By using newer, more selective herbicides or regulating time of application, managers can manipulate understory plant species composition and structure. For example, dense mats of hay-scented fern and New York fern can interfere with development of woody seedlings and the shrub layer in northern hardwood forests (DeGraaf et al. 1992, Horsley 1988b). This reduces food resources (fruits from shrubs, woody browse from seedlings) and vertical structure (shrub and midstory layers) for many wildlife species, especially songbirds. Applying herbicides during late summer and early fall generally will control ferns and result in little if any damage to desirable woody seedlings or to spring ephemeral herbs, which already have completed their annual reproductive cycles and senesced (Ristau and Horsley 1999)

**Table 1.—Characteristics of common silvicultural herbicides and herbicide formulations**

| Herbicide | Trade Name | Site Preparation | Conifer Release | Herbaceous weed control | Tree Injection | Cut Stump Application | Hardwood Weed Control | Basal Bark Applications | Activity | Behavior in soil | Toxicity |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Dicamba | Vanquish | X | | | X | X | | | Foliar; Soil | Weakly adsorbed | Low |
| Fluazifop-P | Fusilade DX | | | X | | | | | Foliar | Readily adsorbed, low mobility | Very low |
| Glyphosate | Accord, Roundup | X | X | X | X | X | | | Foliar | Rapidly adsorbed to soil | Very low |
| Hexazinone | Pronone 10G, 25G, and MG | X | X | X | | | | | Soil | Relatively mobile | Low |
| Hexazinone | Velpar L | X | X | X | X | | | | Soil; Foliar | Relatively mobile | Low |
| Hexazinone | Velpar ULW | X | X | | | | | | Soil; Foliar | Relatively mobile | Low |
| Imazapyr | Arsenal AC | X | X | X | X | X | | | Foliar; Soil | Weakly adsorbed to soil | Very low |
| Imazapyr | Chopper | X | X | | X | X | | X | Foliar; Soil | Weakly adsorbed to soil | Very low |
| Imazaquin | Scepter | | | X | | | X | | Foliar: Soil | Weakly adsorbed in high pH soils | Verylow |
| Metsulfuron | Escort | | | X | | | | | Foliar; Soil | Moderately mobile | Verylow |
| Pendimethalin | Pendulum | | | X | | | X | | Soil | Strongly adsorbed to soil | Very low |
| Picloram | Tordon K | X | | | | | | | Foliar | Weakly adsorbed by clays | Low |
| Picloram + 2,4-D | Pathway | | | | X | X | | | N/A | Weakly adsorbed by clays | Low |
| Picloram + 2,4-D | Tordon 101M | X | | | X | X | | | Foliar | Weakly adsorbed by clays | Low |

Continued

| Herbicide | Trade Name | Site Preparation | Conifer Release | Herbaceous weed control | Tree Injection | Cut Stump Application | Hardwood Weed Control | Basal Bark Applications | Activity | Behavior in soil | Toxicity |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sethoxdim | Vantage | | | X | | | | | Foliar | Adsorption varies with organic material | Very low |
| Sulfometuron | Oust | | | X | | | X | | Foliar; Soil | Not tightly bound (especially high pH) | Very low |
| Triclopyr | Garlon 3A | X | X | | X | X | | | Foliar | Not tightly bound | Low |
| Triclopyr | Pathfinder II | | | | | X | | X | N/A | Not tightly bound | Low |
| Triclopyr | Garlon 4 | X | X | | | X | | X | Foliar | Not tightly | Low |

**Table 2.—Susceptibility[1] of selected woody plant species to forestry herbicides. Data obtained from product labels and Miller and Mitchell (1990)**

| | | Woody plant species | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Herbicide | Trade Name | *Abies* sp. | *Acer* spp. | *Alnus* spp. | *Amelanchier* spp. | *Betula* spp. | *Carpinus* sp. | *Carya* spp. | *Chamaecyparis* sp. | *Corylus* spp. | *Cornus* spp. | *Crataegus* spp. | *Diospyros* sp. | *Fraxinus* spp. | *Juglans* sp. | *Juniperus* spp. | *Larix* spp. | *Liquidambar* sp. | *Liriodendron* sp. | *Lonicera* spp. | *Morus* spp. | *Oxydendrum* sp. | *Picea* spp. | *Pinus* spp. | *Populus* spp. | *Prunus* spp. | *Quercus* spp. | *Rhus* spp. | *Ribes* sp. | *Rosa* spp. | *Rubus* spp. | *Salix* spp. | *Sambucus* sp. | *Toxicodendron* spp. | *Tsuga* sp. | *Ulmus* spp. | *Vitis* spp |
| Dicamba | Vanquish; Banvel | | I | S | S | S | S | S | | | S | S | T | S | | | | T | | S | | I | S | S | S | I | I | S | | S | S | S | | S | S | S | S |
| Glyphosate | Accord; Roundup | T | I | S | | S | | T | | S | S | S | I | T | | | | S | I | S | | I | T | T | S | I | S | I | | S | S | S | S | S | T | I | |
| Hexazinone | Pronone 10G, 25G, and MG | T | I | | | S | | T | | S | T | S | T | I | | | | S | T | S | | T | T | T | S | I | S | T | | | S | S | | | | S | |
| Hexazinone | Velpar L and Velpar ULW | T | I | | | S | | I | | S | I | S | T | I | | | | I | T | I | | T | T | T | S | I | S | I | | | S | S | | | | S | S |
| Imazapyr | Arsenal AC | | S | | | | | I | | | I | T | S | S | | | | S | S | S | S | | T | T | S | I | S | S | | S | S | S | | S | | T | S |
| Imazapyr | Chopper RTU | | S | | | | | S | | | S | S | | S | | | | | | | | | | | S | S | S | S | | S | | S | | | | | |
| Metsulfuron | Escort | S | S | S | | | | | | | | S | | S | | S | | | S | S | S | | S | | S | S | S | | | S | S | S | | | | S | S |
| Pendimethalin | Pendulum | T | T | T | | T | | | T | | T | T | | T | T | T | | | T | | | T | T | T | T | T | T | | | | | T | | | T | T | |
| Picloram | Tordon K | S | S | | | | | I | | | I | S | I | | | S | | I | | | | | S | I | S | I | S | S | | | S | S | | | S | | |
| Picloram + 2,4-D | Pathway | S | S | S | S | S | S | S | | | S | S | | S | | S | | | | | | | | | S | S | S | | | | | | | | | S | |
| Picloram + 2,4-D | Tordon 101M | S | I | S | | S | | S | | | | | S | | | | | I | S | S | | S | S | I | S | S | S | S | | | S | S | | | S | I | |
| Sethoxdim | Vantage; Poast | T | T | | | T | | | T | | T | | | T | T | | | T | | | | | T | T | T | T | T | | | | | T | | | T | | |
| Sulfometuron | Oust | | R | | | | | | | | | | | T | | | R | | | | | | R | R | T | | R | I | | | I | | | | | | |
| Triclopyr | Garlon 3A | T | I | S | | S | | I | | S | I | T | | S | | | | I | S | | S | | | I | S | I | I | S | | | S | S | S | S | | I | |
| Triclopyr | Garlon 4 | | I | S | | S | | S | | S | I | T | T | I | | | | I | S | | S | | I | I | S | I | I | T | | | S | S | S | S | | S | |
| Triclopyr | Pathfinder II | | S | S | | S | | S | | S | S | | S | S | | S | S | S | S | | | | I | I | S | I | S | I | | | S | S | | S | | I | |

[1]S=Susceptible species (>80 percent control); I=Marginally or variably controlled species (40-80 percent control); T=Tolerant species (<40 percent control); blank = No data available).

**Table 3.—Plant species that are tolerant to imazapyr or that commonly recolonize a site following an application of imazapyr (from American Cyanamid Company 1999)**

| Tolerant | | Recolonize | |
|---|---|---|---|
| Scientific name | Common name | Scientific name | Common name |
| *Amorpha fruticosa* | Indigo bush | *Amaranthus hybridus* | Pigweed |
| *Amphicarpa bracteata* | Hog peanut | *Ambrosia artemisifolia* | Common ragweed |
| *Apios americana* | Ground nut | *Ambrosia trifida* | Giant ragweed |
| *Cassia fasciculata* | Partridge pea | *Andropogon* spp. | Broomsedges |
| *Cassia nictitans* | Small partridge pea | *Bidens spp.* | Beggar ticks |
| *Centrosema virginianum* | Butterfly pea | *Callicarpa americana* | American beautyberry |
| *Cercis canadensis* | Redbud | *Campsis radicans* | Trumpet vine |
| *Clitoria mariana* | Butterfly pea | *Ceanothus americanus* | New Jersey tea |
| *Desmodium nudiflorum* | Beggarweed | *Chenopodium album* | Lambsquarters |
| *Desmodium rotundifolium* | Beggarweed | *Croton capitatus* | Wooly croton |
| *Desmodium tortuosum* | Florida beggarweed | *Croton glandulosus* | Dove weed |
| *Ephrosia virginiana* | Goats rue | *Cuscuta gronovii* | Lovevine |
| *Galactia volubilis* | Erect milk pea | *Diodia teres* | Poor-joe |
| *Indigofera caroliniana* | Wild indigo | *Epilobium angustifolium* | Fireweed |
| *Lespedeza bicolor* | Bicolor lespedeza | *Euphorbia corollata* | Flowering spurge |
| *Lespedeza capitata* | Roundhead lespedeza | *Geranium carolinianum* | Wild geranium |
| *Lespedeza hirta* | Hairy lespedeza | *Ipomoea purpurea* | Morningglory |
| *Lespedeza intermedia* | Wand lespedeza | *Mollugo verticillata* | Carpet-weed |
| *Lespedeza japonica* | Japonica lespedeza | *Oenothera biennis* | Evening primrose |
| *Lespedeza procumbens* | Prostrate lespedeza | *Oxalis stricta* | Yellow wood sorrel |
| *Lespedeza striata* | Common lespedeza | *Panicum* spp. | Panic grasses |
| *Lespedeza thunburgii* | Thunburg lespedeza | *Parthenocissus quinquefolia* | Virginia creeper |
| *Psoralea psoralioides* | Samson snakeroot | *Passiflora incarnata* | Maypop |
| *Rhynchosia reniformis* | Dollar weed | *Physalis virginiana* | Ground cherry |
| *Rhynchosia tomentosa* | Hairy rhynchosia | *Phytolacca americana* | Pokeweed |
| *Robinia pseudo-acacia* | Black locust | *Polygonum pennsylvanicum* | Pennsylvania smartweed |
| *Rubus argutus* | Blackberry | *Rhus copallina* | Winged sumac |
| *Rubus trivialis* | Dewberry | *Rhus glabra* | Smooth sumac |
| *Schrankia microphylla* | Sensitive briar | *Rhus radicans* | Poison ivy |
| *Sesbania macrocarpa* | Sesbania | *Richardia scabra* | Florida purslane |
| *Strophostyles helvola* | Milk pea | *Rumex hastatulus* | Sheep-sorrel |
| *Strophostyles umbellata* | Trailing wild bean | *Smilax bona-nox* | Greenbrier |
| *Stylosanthes biflora* | Pencil flower | *Trichostema dichotomum* | Blue curls |
| *Tephrosia spicata* | Spike tephrosia | *Viola* spp. | Violets |
| *Vicia dasycarpa* | Narrowleaf vetch | *Vitis rotundifolia* | Muscadine grape |
| *Vigna suteola* | Wild pea | | |

**Table 4.—Examples of wildlife habitat objectives achieved or resulting through use of herbicides**

| Objective | Location | Citation |
|---|---|---|
| Reduce live emergent vegetation in wetlands | North Dakota<br>South Dakota | Blixt (1993)<br>Solberg and Higgins (1993) |
| Reduce abundance of parasites in small mammals | Oklahoma | Boggs et al. (1991) |
| Increase selected wildlife foods and cover, and habitat interspersion | Pennsylvania | Bramble and Byrnes (1983) |
| Create snags to accelerate development of old-growth characteristics | Oregon | Cole (1996) |
| Manage hardwood midstory in red-cockaded woodpeckers (*Picoides borealis*) cluster areas | Texas<br>Georgia | Conner (1989)<br>Jones (1992) |
| Reduce habitat suitability for northern pocket gophers (*Thomomys talpoides*) to control damage to lodgepole pine (*Pinus contorta*) seedlings | Unknown | Engeman et al. (1997) |
| Establish food plots | Wisconsin | Hamilton and Buckholtz (1953) |
| Control undesirable emergent vegetation and promote waterfowl food plants in impoundments | Georgia | Wood et al. (1996) |
| Manipulate lesser prairie chicken (*Tympanuchus pallidicinctus*) habitat | Texas | Doerr and Guthery (1983) |
| Improve elk (*Cervus elaphus canadensis*) and mule deer (*Odocoileus hemionus*) range | Colorado | Kufeld (1977) |
| Restore herbaceous understory in pine stands managed for northern bobwhite (*Colinus virginianus*) | Florida | Welch (2000) |
| Create habitat for cavity-nesting songbirds | Kentucky | McComb and Rumsey (1983) |
| Provide openings and increase deer (*Odocoileus virginianus*) forage | Oklahoma | Thompson et al. (1991) |

Directed application of herbicides also can be used to suppress some woody species from the shrub and midstory layers, thus promoting growth and development of species with more desirable structural features. For example, shrub-nesting songbirds prefer the finer and multiple-branching twigs produced by species such as American beech (*Fagus grandiflora*) and birches (*Betula* spp.) to the more simplified branching of larger twigs represented by striped maple (*Acer pensylvanicum*) (D. S. deCalesta, USDA Forest Service, unpublished data). Herbicides can be used to selectively reduce the abundance of striped maple in the shrub and midstory, which competes with species such as beech and birches. Such application can be expensive, however, and uneconomical when treatment levels exceed 400 stems per acre (R. D. Nyland, State University of New York, School of Environmental Science and Forestry, personal communication).

Annual or biennial prescribed burning during the dormant season has been unable to effectively control understory hardwood invasion in some open pine forests managed for red-cockaded woodpeckers (*Picoides borealis*) and northern bobwhite (*Colinus virginianus*). Welch (2000) reported that a one-time application of imazapyr alone or combined with prescribed burning could significantly reduce hardwood invasion without adversely impacting habitat conditions or food production for northern bobwhites and allow future management with prescribed fire during the growing season. This strategy sometimes is used by federal agencies (Ralph Costa, U.S. Fish and Wildlife Service, personal communication).

Herbicides can be used in conjunction with regeneration techniques, such as a shelterwood harvest, to alter overstory species composition and structure through management of advanced regeneration. A combined shelterwood harvest and herbicide application increases sunlight to the forest floor and stimulates germination and growth of seeds thrown by the overstory. If conditions are appropriate, prescribed burning also can be used for similar purposes (Brose et al. 1999).

### Managing Special Habitat Features

The availability of snags and coarse woody debris is a key factor influencing the abundance and composition of wildlife communities. Snags and down wood are created by a number of factors, including shearing winds, rot associated with insect and disease attack, lightning strikes, and wild fire. However, these natural processes produce somewhat variable and unpredictable results in terms of the abundance and characteristics of created snags (e.g., species composition, dbh, height,). Light prescribed burnings may not cause enough damage to the cambium to lead to tree mortality and create snags, especially for tree species that are resistant to fire-induced mortality. Thus, snags and down wood may not be created from all species.

Herbicides have been used to create snags for a variety of wildlife-related purposes (Conner et al. 1983, Bull and Partridge 1986). Because they can be applied selectively to individual trees, herbicides can be used to regulate the species composition, dbh, and height of snags and resulting logs. Snags created with some herbicides (e.g., 2,4-D) may decay more rapidly than snags created through other means such as girdling (Conner et al. 1983; Bull and Partridge 1986). However, ongoing research in Oregon (Michael Newton, Oregon State University, personal communication) suggests that the life span of snags created through mechanical means (e.g., girdling, topping) and herbicides such as MSMA and triclopyr can be very similar.

### Managing Spatial and Temporal Arrangement of Habitat

Herbicides can be used to manage the spatial and temporal availability of habitat, a prime determinant of the diversity and productivity of wildlife communities (Morrison et al. 1992). For example, herbicides can be used to create snags and down wood where desired within the landscape and in a variety of seral stages. Managers can use herbicides to retain and regulate the distribution of conifers in riparian ecosystems in order to provide nesting and foraging habitat for bird species such as blackburnian warbler (*Dendroica fusca*), Swainson's thrush (*Catharus ustulatus*), and Acadian flycatcher (*Empidonax virescens*). Herbicides can be used in selected locations to produce patches of early-successional habitats and change overstory species composition. Overstory species composition can be changed directly by killing undesired overstory trees or indirectly and over a long period of time by altering species composition of advanced regeneration as previously discussed.

## Considerations When Choosing Between Fire and Herbicides

As vegetation management tools, herbicides and fire each have a unique set of advantages and disadvantages. The decision to use fire or herbicides is complex and involves many variables. We recommend that biologists and managers consider the following factors when deciding when and where to apply these tools.

### Effectiveness

Obviously, managers should weigh the relative capabilities of prescribed burning and herbicides to achieve desired vegetative conditions. For some conditions, prescribed burning is most appropriate (e.g., promotion of fire-adapted understory vegetation). Sometimes, however, herbicides can be equally or more effective at eliciting desired vegetative responses. For example, herbicides are a unique and effective tool for accelerating the development of late-successional habitat, specific old-growth components (e.g., large snags and logs, large live trees of specified species composition), and associated wildlife species (e.g., Cole 1996). This can be accomplished by turning some live overstory trees first into snags of desired species, dbh, and spatial distribution, and later into logs when they fall. Herbicides are a unique tool for controlling populations of some non-native species. For example, Grilz and Romo (1995) found that smooth brome (*Bromus inermis*) was most effectively controlled by spring burning combined with glyphosate applications. Herbicides are particularly well suited for regulating plant communities in early successional habitats where regenerating trees would be damaged by fire.

### Historical Disturbance Regime

In selecting whether to use prescribed burning or herbicides, managers also should consider disturbance regimes of the ecosystem being managed. Generally, prescribed burning is most appropriate in fire-associated or fire-dependent ecosystems such as pine and oak ecosystems that historically were disturbed on a regular basis by non-lethal understory fires (Abrams 1992; Waldrop and Van Lear 1989). However, even in these forest types fire was not the only form of historical disturbance. For example, in southern pine forests, hurricanes, ice storms, and southern pine beetles (*Dendroctonus frontalis*) also helped shape forest structure, species composition, and habitat for species such as red-cockaded woodpeckers (*Picoides borealis*) (Coulson et al. 1995; Hooper and MacAdie 1995; Conner and Rudolph 1995). These disturbance factors created important habitat features (e.g., snags, dead down wood) not readily created through low-intensity fires with short return intervals.

In some forest ecosystems, historical fires affected small areas, were infrequent, or occured primarily as stand-replacing fires or mixed and variable fires (Brown 1994, Runkle 1985). Historical return intervals of fire in some forest ecosystems in North America are estimated to be as long as 500-1,000 years, e.g., northern New England (800 years), upper elevation conifer forests in eastern Canada (1,000 years), coastal redwood forests in California (500-600 years) (Oliver and Larson 1990). In such situations, prescribed burning may not be the most appropriate tool for achieving habitat objectives and could cause damage to trees that are not fire-adapted. For example, in the Northeast, management for species such as chestnut-sided warblers (*Dendroica pensylvanica*), bluebirds (*Sialia sialis*), and bobolinks (*Dolichonyx oryzivorus*) requires development of early-successional habitat (Braile 2000). However, before timber harvest can be used to create these habitats, the density of ferns, grasses, blackberries (*Rubus* spp.), and undesirable woody species often must be reduced to allow sufficient stocking of advanced regeneration of desirable (ecologically and commercially) tree species. This objective may best be achieved using herbicides, particularly in ecosystems where fire is not the dominant source of disturbance. Where oaks are not fire-adapted, managers may choose to promote oak regeneration by top-clipping oak seedlings and treating the remaining vegetation with a herbicide such as glyphosate. The top-clipped oak seedlings, which will not have absorbed the herbicide, will sprout and grow vigorously in the absence of competing vegetation (Wright et al. 1985).

### Risk to Other Resources

Managers sometimes choose to use herbicides because fire can damage other resources. For example, extremely hot fires can alter the physical properties of soils, accelerate erosion rates, volatize nutrients, and slow successional recovery (Pyne et al. 1996, Lautenschlager et al. 1998). Crown scorch can cause mortality and loss of diameter and height growth in crop trees (Waldrop and Van Lear 1984). Johansen and Wade (1987) reported that even slightly scorched trees showed a 15 percent loss of radial growth. Because managed forests represent a signficant financial investment, many landowners are hesitant to risk such losses.

### Administrative Considerations

Herbicides may be an appropriate tool if administration of fire is difficult or impossible. For example, fuel loads may be extremely high, the location may present difficulties (e.g., near a highway where smoke would present a hazard to motorists), or labor to administer the burn may be unavailable. Increasingly, people live in or near managed forests (Cohen 2000; Egan and Luloff 2000), and because of complaints about smoke and concerns about potential damage, managers increasingly are reluctant to burn or are having more difficulties obtaining burning permits.

Prescribed burnings that escape control are of special concern to landowners. For example, the May 2000 "Cerro Grande" fire that destroyed a large number of houses in Los Alamos and White Rock, New Mexico, began as a prescribed burn on the north rim of the Grand Canyon. Private landowners often have been the target of litigation related to unintended consequences of prescribed burning, and since the passage of the federal Tort Claims Act, even federal agencies are not immune from litigation over such matters. In contrast, drift of herbicides can be minimized by pre-planning applications using recently developed modeling tools such as AgDRIFT® (Teske 2000).

Regulations and guidelines at the local, state, and federal levels also may constrain a manager's ability to use fire. Many states have stringent requirements regarding weather conditions under which prescribed burning can and cannot be used. For instance, regulations in Texas prohibit the use of fire under conditions when smoke will present a hazard on any "pubic road, landing strip, or navigable water" or when it will affect a "sensitive receptor" (e.g., a residence, business, farm building, or greenhouse) (Texas Natural Resource Conservation Commission 2000). At the federal level, EPA's interim air quality policy on wildland and prescribed fire (Environmental Protection Agency 1998) also constrains the use of fire in order to regulate emissions of particulate matter and visibility impairments in the 156 mandatory Class 1 federal areas ("Areas of Great Scenic Importance"). Regional haze regulations that eventually will be promulgaed by EPA may further complicate prescribed burning. When air quality is an administrative concern, EPA's Interim Air Quality Policy on Wildland and Prescribed Burnings (Environmental Protection Agency 1998) explicitly states that "chemical treatments may be appropriate tools."

### Economics

Costs obviously are an important consideration when selecting a habitat managment tool. Generally, prescribed burning costs less to apply per unit area than do herbicides. Average costs in the South during 1998 were $40.97/ha for prescribed burning and $178.70/ha for herbicide applications (Dubois et al. 1999). However, several other factors also should be considered when evaluating the cost of fire and herbicides. Multiple applications of prescribed burning over years or decades sometimes are required to achieve the same level of vegetation control that can achieved with one application of herbicides (Lautenschlager et al. 1998). Although liability costs and loss of growth do not occur every time a forest is burned, they could significantly affect the cost of prescribed burning in some situations and were not incorporated into estimates by Dubois et al. (1999). Even without considering these factors, the cost of applying fire has increased dramatically relative to the cost of applying herbicides. A cost index calculated by Dubois et al. (1991) for prescribed burning increased at an average annual rate of 10 percent between 1952 and 1988, over twice the rate for herbicide applications (Dubois et al. 1999).

### Operability at Desired Spatial and Temporal Scales

In deciding whether to use fire or herbicides, managers also should consider factors related to time and space. For example, herbicides can be applied to individual plants, patches of vegetation within stands, and at the stand scale or larger. In contrast, fire is most easily applied at the stand or community levels. Herbicides sometimes immediately produce desired responses in plant communities (e.g., reduction of non-native species), while multiple applications of fire over several years may be required.

## Conclusion

The choice of whether to use prescribed burning or herbicides for achieving wildlife management objectives depends upon many factors. For achieving some habitat objectives, herbicides probably are a preferred or partial alternative to fire. In other cases, fire is the most appropriate tool. However, prescribed burning sometimes cannot or will not be used because of concern about liability, smoke management difficulties, availability of labor, limited burning days, or other reasons. In such cases, herbicides may be the only tool available and must be used if biologists are to even partially address a wildlife-related objective. Generally, herbicides are most useful from a wildlife management prespective for shaping individual habitat components in well-defined areas. However, no habitat management tool, whether prescribed burning or herbicides, is best or even capable of addressing every wildlife management objective. Thus, we urge managers to retain access to an assortment of tools, including herbicides, and to use them in an integrated fashion.

## Literature Cited


Abrams, M. D. 1992. **Fire and the development of oak forests.** Bioscience. 42: 346-353.

Agee, J. K. 1993. **Fire ecology of Pacific Northwest forests**. Island Press. Washington, DC. 493 p.

American Cyanamid Company. 1999. **Habitat release herbicide**. American Cyanamid Company, Parsippany, NJ. 7 p.

Blixt, D. C. 1993. **Effects of glyphosate-induced habitat alteration on birds, using wetlands**. M.S. Thesis, North Dakota State University, Fargo. 127 p.

Boggs, J. F.; McMurry, S. T.; Leslie, D. M., Jr.; Engle, D. M.; Lochmiller, R. L. 1991. **Influence of habitat modification on the community of gastrointestinal helminths of cotton rats.** Journal of Wildlife Diseases. 27: 584-593.

Braile, R. 2000. **In twist, reforestation threatens some species**. Boston Globe Online. <http://www.boston.com/dailyglobe2/226/newhampshire/In_twist_reforestation_threatens_some_species-.shtml>.

Bramble, W. C.; Byrnes W. R. 1983. **Thirty years of research on development of plant cover on an electric transmission right-of-way.** Journal of Arboriculture. 9: 67-74.

Brennan, L. A.; Engstrom, R. T.; Palmer, W. E.; Hermann, S. M.; Hurst, G. A.; Burger, L. W.; Hardy, C. L. 1998. **Whither wildlife without fire?** Transactions North American Wildlife and Natural Conference. 63: 402-414.

Brose, P.; Van Lear, D.; Cooper, R. 1999. **Using shelterwood harvests and prescribed fire to regenerate oak stands on productive upland sites.** Forest Ecology and management. 113: 125-141.

Brown, J. K. 1994. **Fire regimes and their relevance to ecosystem management**. In: Proceedings Society of American Foresters Conference, Bethesda, MD: Society of American Foresters. 171-178.

Bull, E. L.; Partridge, A. D. 1986. **Methods of killing trees for use by cavity nesters**. Wildlife Society Bulletin. 14: 142-146.

Cohen, J. D. 2000. **Preventing disaster: home ignitability in the wildland-urban interface**. Journal of Forestry. 98(3): 15-21.

Cole, E. C. 1996. **Managing for mature habitat in production forests of western Oregon and Washington**. In: Role of forest and rangeland vegetation management in conservation biology. Seattle, WA: Proceedings of a WSSA symposium: 422-429.

Conner, R. N. 1989. **Injection of 2,4-D to remove hardwood midstory within red-cockaded woodpecker colony areas**. Res. Pap. SO-251. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 4p.

Conner, R. N.; Kroll, J. C.; Kulhavy, D. L. 1983. **The potential of girdled and 2,4-D injected southern red oaks as woodpecker nesting and foraging sites**. Southern Journal of Applied Forestry. 7: 125-128.

Conner, R. N.; Rudolph, D. C. 1995. **Wind damage to red-cockaded woodpecker cavity trees on eastern Texas national forests**. In: D. L. Kulhavy, R. G.

Hooper, and R. Costa, eds. Red-cockaded woodpecker: recovery, ecology and management. Nacogdoches, TX: Center for Applied Studies, College of Forestry, Stephen F. Austin State University: 183-190.

Coulson, R. N.; Fitzgerald, J. W.; Oliveria, F. L.; Conner, R. N.; Rudolph, D. C. 1995. **Red-cockaded woodpecker habitat management and southern pine beetle infestations**. In: D. L. Kulhavy, R. G. Hooper, and R. Costa, eds. Red-cockaded woodpecker: recovery, ecology and management. Nacogdoches, TX: Center for Applied Studies, College of Forestry, Stephen F. Austin State University: 191-195.

Day, G. M. 1953. **The Indian as an ecological factor in the northeastern forest**. Ecology. 34(2): 329-346.

DeGraaf, R. M.; Yamasaki, M.; Leak, W. B.; Lanier; J. W. 1992. **New England wildlife: management of forested habitats**. Gen. Tech. Rep. NE-144. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 271 p.

Dubois, M. R.; McNabb, K.; Straka; T. J. 1999. **Costs and trends for forestry practices in the South**. Forest Landowner. 58(2): 3-8.

Dubois, M. R.; Straka, T. J.; Watson, W. F. 1991. **A cost index for southern forest practices**. Southern Journal of Applied Forestry. 15: 128-133.

Doerr, T. B.; Guthery, F. S. 1983. **Effects of tebuthiuron on lesser prairie-chicken habitat**. Journal of Wildlife Management. 47: 1138-1142.

Egan, A. F.; Luloff, A. E. 2000. **The exurbanization of America's forests: research in rural social science**. Journal of Forestry. 98(3): 26-31.

Engeman, R. M.; Barnes, V. C., Jr.; Anthony, R. M.; Krupa, H. W. 1997. **Effect of vegetation management for reducing damage to lodgepole pine seedlings from northern pocket gopher**. In: Crop protection. Oxford, England: Elsevier Science Ltd. 407-410.

Environmental Protection Agency. 1998. **Interim air quality policy on wildland and prescribed fires**. <http://www.epa.gov/ttncaaa1/t1/meta/m27340.html>.

Ezell, A. W. 1998. **Tank mixtures of forestry site preparation herbicides can be antagonistic**. Mississippi Cooperative Extension Service, Information Sheet 1574. <http://www.ext.msstate.edu/pubs/is1574.htm>.

Grilz, P. L.; Romo, J. T. 1995. **Management considerations for controlling smooth brome in fescue prairie**. Natural Areas Journal. 15: 148-156.

Hamilton, K. C.; Buckholtz, K. P. 1953. **Use of herbicides for establishing food patches**. Journal of Wildlife Management. 17: 509-516.

Hooper, R. G.; McAdie, C. J. 1995. **Hurricanes and the long-term management of the red-cockaded woodpecker**. In: D. L. Kulhavy, R. G. Hooper, and R. Costa, eds. Red-cockaded woodpecker: recovery, ecology and management. Nacogdoches, TX: Center for Applied Studies, College of Forestry, Stephen F. Austin State University: 148-166.

Horsley, S. B. 1988a. **How vegetation can influence regeneration**. In: Smith, H. C., A. W. Perkey, and W. E. Kidd Jr., eds. Workshop: Guidelines for regenerating Appalachian hardwood stands. Society of American Foresters Publication 88-03. 38-55.

Horsley, S. B. 1988b. **Control of understory vegetation in Allegheny hardwood stands with Oust**. Northern Journal of Applied Forestry. 5: 261-262.

Johansen, R. W.; Wade, D. D. 1987. **Effects of crown scorch on survival and diameter growth of slash pines**. Southern Journal of Applied Forestry. 11: 180-184.

Jones, E. P., Jr. 1992. **Silvicultural treatments to maintain red-cockaded woodpecker habitat**. In: J. C. Brissette, ed., Proceedings Seventh Southern Silvicultural Research Conference. Gen. Tech. Rep. SO-93. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 627-632.

Komarek, E. V. 1981. **History of prescribed fire and controlled burning in wildlife management in the South**. In: G. W. Wood, ed., Prescribed fire and wildlife in southern forests. Georgetown, SC: Baruch Forest Science Institute, Clemson University: 1-14.

Kufeld, R. C. 1977. **Improving gambel oak ranges for elk and mule deer by spraying with 2,4,5-TP**. Journal of Range Management. 30: 53-57.

Lautenschlager, R. A. 2000. **Can intensive silviculture contribute to sustainable forest management in northern ecosystems?** The Forestry Chronicle. 76(2): 283-295.

Lautenschlager, R.A.; Crawford, H. S.; Stokes, M. R.; Stone, T. L. 1997. **Forest disturbance type differentially affects seasonal moose forage.** Alces. 33: 49-73.

Lautenschlager, R. A.; Sullivan, T. P.; Wagner, R. G. 1995. **Using herbicides for wildlife management in northern ecosystems**. In: R. E. Gaskin and J. A. Zabkiewicz, compilers, Bulletin Number 192. Second International Conference on Forest Vegetation

Management. Rotorua, New Zealand: New Zealand Forest Research Institute: 152-154.

Lautenschlager, R. A.; Bell, F. W.; Wagner, R. G.; Reynolds, P. E. 1998. The Fallingsnow Ecosystem Project: **Documenting the consequences of conifer release alternatives.** Journal of Forestry. 96(11): 20-27.

MacCleery, D. W. 1992. **American forests: a history of resiliency and recovery.** FS-540. Washington, DC: U.S. Department of Agriculture, Forest Service. 59 p.

McComb, W. C.; Rumsey, R. L. 1983. **Characteristics of cavity-nesting bird use of picloram-created snags in the central Appalachians**. Southern Journal of Applied Forestry. 7: 34-37.

Miller, J. H.; Mitchell, R. J.; eds. 1990. **A manual on ground applications of forestry herbicides.** Management Bulletin R8-MB21. Atlanta, GA: U.S. Department of Agriculture, Forest Service. 358 p.

Mobley, H. E.; Balmer, W. E. 1981. **Current purpose, extent and environmental effects of prescribed fire in the South**. In: G. W. Wood, ed., Prescribed fire and wildlife in southern forests. Georgetown, SC: Baruch Forest Science Institute, Clemson University: 15-22.

Morrison, M. L.; Marcot, B. G.; Mannan, R. W. 1992. **Wildlife-habitat relationships: concepts and applications**. University of Wisconsin Press, Madison. 364 p.

Oliver, C.D.; Larson, B.C. 1990. **Forest stand dynamics.** McGraw-Hill, Inc., New York, NY. 467 p.

Pyne, S. J.; Andrews, P. L.; Laven, R. D. 1996. **Introduction to wildland fire**. Second edition. John Wiley and Sons, Inc. New York, NY. 769 p.

Ristau, T. E.; Horsley, S. B. 1999. **Impact of glyphosate and sulfometuron methyl on diversity of plants and wildlife in Allegheny hardwoods. Part I: Assessing short-term impacts on understory plant communities.** Progress Report 4110-FS-4152-163, Northeastern Research Station, Forestry Sciences Laboratory, Irvine PA: U.S. Department of Agriculture, Forest Service.

Runkle, J. R. 1985. **Disturbance regimes in temperate forests**. In: S. T. A. Pickett and P. S. White, eds. The ecology of natural disturbance and patch dynamics. New York, NY: Academic Press, Inc.: 17-34.

SNEP Science Team and Special Consultants. 1996. **Sierra Nevada Ecosystem Project: Final report to Congress Volume I: Assessment summaries and management strategies**. Wildland Resources Center Report No. 36. Centers for Water and Wildland Resources, University of California, Davis. <http://ceres.ca.gov/snep/pubs/web/v1/v1_default.html>.

Solberg, K. L.; Higgins, K. F. 1993. **Effects of glyphosate herbicide on cattails, invertebrates, and waterfowl in South Dakota wetlands**. Wildlife Society Bulletin. 21: 299-307.

Swanson, F. J. 1981. **Fire and geomorphic processes**. In: H. Mooney, et al., eds. Fire regimes and ecosystem properties: proceedings of the conference. General Technical Report WO-26. Washington Office: U.S. Department of Agriculture, Forest Service: 401-420.

Teske, M. E. 2000. **Stream model assessment with AgDRIFT**. Technical Bulletin No. 808. Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc. 25 p.

Texas Natural Resources Conservation Commission. 2000. **Local government guide to the TNRCC. Chapter 22 - Outdoor Burning**. <http://www.tnrcc.state.tx.us/catalog/gi/145/ch22.html>.

Thompson, M. W.; Shaw, M. G.; Umber, R. W.; Skeen, J. E.; Thackston, R. E. 1991. **Effects of herbicides and burning on overstory defoliation and deer forage production**. Wildlife Society Bulletin. 19: 163-170.

USDA Forest Service. 2000. **Southern Region Forest Inventory and Analysis Home Page**. USDA Forest Service, Southern Research Station. http://www.srsfia.usfs.msstate.edu/Fiab.htm

Van Lear, D. H.; Watt, J. M. 1993. **The role of fire in oak regeneration**. In: D. Loftis, C. E. McGee, eds. Oak regeneration: serious problems, practical recommendations. General Technical Report SE-84. Ashville, NC: U.S. Department of Agriculture, Forest Service: 66-78.

Waldrop, T. A.; Van Lear, D. H. 1989. **History, uses, and effects of fire in the Appalachians**. General Technical Report SE-54. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 20 p.

Waldrop, T. A.; Van Lear, D. H. 1984. **Effect of crown scorch on survival and growth of young loblolly pine**. Southern Journal of Applied Forestry. 8: 35-40.

Walstad, J. D.; Kuch, P. J., eds. 1987. **Forest vegetation management for conifer production.** John Wiley and Sons, New York, NY. 523 p.

Welch, J. R. 2000. **Evaluation of chemical and mechanical treatments to enhance southeastern pine forest habitat for northern bobwhite**. M.S. Thesis, University of Georgia, Athens. 78 p.

Wood, D.E.; Miller, K. V.; Forster, D. L. 1996. **Glyphosate and fluridone for control of giant cutgrass (*Zizaniopsis miliaceae*) in waterfowl impoundments**. Proceedings Annual Conference Southeastern Association of Fish and Wildlife Agencies 50: 592-598.

Wright, G. M.; Pope, P. E.; Fischer, B. C.; Holt, H. A.; Byrnes, W. R. 1985. **Chemical weed control to establish natural and artificial oak regeneration in a mechanically thinned upland hardwood stand.** In: E. Shoulders, ed. Proceedings third bienniel southern silvicultural research conference. Gen. Tech. Rep. SO-54. New Orleans, NO: U.S. Department of Agriculture, Forest Service: 266-272.

Wright, H. E., Jr.; Heinselman, M. L.; eds. 1973. **The ecological role of fire in natural conifer forests of western and northern America**. Quaternary Research. 3: 317-513.

Zutter, B. R.; Miller, J. H. 1998. **Eleventh-year response of loblolly pine and competing vegetation to woody and herbaceous vegetation to woody and herbaceous plant control on a Georgia flatwoods site**. Southern Journal of Applied Forestry. 22: 88-95.