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The Role of Low Impact Herbicide Treatments in Ecosystem Management

Charles K. McMahon, James H. Miller, and David F. Thomas

Abstract

Environmentally safe, selective herbicide treatments can be adapted to manage habitats and direct succession toward desired future conditions within the principles of ecosystem management. Six roles for herbicide treatments in ecosystem management are suggested: create and maintain desired habitats; create mixed and uneven-aged stands; restore damaged landscapes; control exotic, noxious, and poisonous plants; maintain recreational areas, trails, and scenic vistas; and manage rights-of-way for multiple use. Low impact, selective herbicide treatments include tree injection, cut-stump sprays or wipes, basal sprays or wipes, directed sprays, and soil-spot sprays. Selective control can also be achieved using broadcast (aerial and ground) applications of selective herbicides. Currently less than 0.1 percent of national forest lands are treated with chemical herbicides in a typical year. The six roles and treatment methodologies are consistent with the desire of the current administration to decrease pesticide use, to use safer pesticides, and to emphasize integrated pest management programs.

Introduction

As the debate on the initial concept of New Perspectives and the current concept of ecosystem management for national forests began a few years ago, some of our public and private sector colleagues would raise the question . . . "Will there be a role for herbicides in this new ecological approach to multiple-use management of the national forests?" Some would quickly answer their own question and say, "probably no role for herbicides" . . . because of the widespread disapproval of herbicide use on public lands. Others would say . . . "probably no role for herbicides" . . . when new regulatory issues dealing with threatened and endangered species, water quality, State Best Management Practices, etc., are factored into ecosystem management strategies. Others would say . . . "probably no role for herbicides" . . . because they see herbicides as only benefiting commodity production . . . "and there would be little room for that" . . . based on their limited understanding of ecosystem management goals. And finally, some environmental organizations would say . . . "probably no role for herbicides" . . . because they pose unnecessary risks to human and ecosystem health and safety, and they are socially unacceptable.

Our own response to the "herbicide question" involved more careful deliberation and was brought to a head by our research mission review process that took place thii year within the USDA Forest Service, Southern Station. From that review and from other reviews of Forest Service programs at the regional and national level, it became obvious to us that the Forest Service will need a carefullydevised and publicly-accepted integrated vegetation management program to meet many ecosystem management goals. Access to the full menu of vegetation management alternatives (biological, chemical, manual, mechanical, and prescribed burning) would be required to reach desired future conditions related to the structure, composition, and function of ecosystems and their aesthetic acceptance. Moreover, as we sorted fact from fiction, and real needs from rhetoric, we concluded that low impact selective herbicide treatments would often be the most cost-effective, environmentally sound, efficacious, and timely option for meeting many of the multiresource needs of forest and grassland ecosystems.

Conceptually, we see a continued role for chemical herbicides in ecosystem management with a decrease in the amount of active ingredient used per acre in most situations. Keep in mind that many newer herbicide formulations coupled with low impact selective application technology now permit effective treatment with only ounces of active ingredients per acre. Also, keep in mind that less than 0.1 percent of our National Forest System lands currently receive a herbicide treatment in any one year (USDA 1993a). Positive control, a high degree of selectivity, and cost-effectiveness are what make modern herbicides ideal for meeting many ecosystem management needs. Clearly, further research will be required to refine prescriptions for all situations, but usable techniques and approaches could be applied today.

Project Leader and Research Forester, respectively, USDA Forest Service, Southern Forest Experiment Station, Auburn, AL; and Pesticide Specialist, USDA Forest Service, Forest Pest Management, Washington, DC.

Role of Herbicides in Ecosystem Management

Ecosystem management is the operating philosophy of the Forest Service for stewardship of lands and resources to achieve environmentally sensitive, socially responsive, economically feasible, and scientifically sound multiple-use management of the National Forest System. Ecosystem management means using an ecological approach to achieve the multiple-use management of National Forests and Grasslands by blending the needs of people and environmental values in such a way that National Forests and Grasslands represent diverse, healthy, productive, and sustainable ecosystems (Bartuska 1993). Conceptual uses of low impact forest herbicides which are consistent with this operating philosophy will be outlined in this paper.

Low impact, selective herbicide treatments include tree injection, cut-stump sprays or wipes, basal sprays or wipes, directed foliar sprays, and soil-spot sprays. These methods are described by Kidd (1987), Miller and Mitchell (1988), and Williamson and others (1989), except for the innovative wipe techniques that can further minimize application rates. These treatments have the potential to control or suppress the full range of sizes and species of plants when the appropriate individual herbicide or tank mixture is used. Selective control can also be achieved using broadcast applications of selective herbicides with aerial and ground systems. Selectivity can often be enhanced by changing application rate, timing, additives, and herbicide formulation.

These proposed roles are logical extensions of current uses and silvicultural practices that have been reported elsewhere (USDA 1983, 1988, 1989, and 1992; Cantrell and others 1985) and will not be reviewed in this paper. Our primary focus is to describe roles that enhance noncommodity values, while still supporting wood and forage production. The discussion of these roles and ideas for specific treatments represent research inputs into adaptive management and will warrant experimental and operational monitoring and testing to refine these uses.

1. Create and maintain desired plant and animal habitat

Herbicides in concert with other vegetation management treatments, such as prescribed fire, can play a vital role in creating and managing habitat for threatened, endangered, and sensitive plants and animals. Wildlife and game animal habitat can also be created and maintained with selective herbicide treatments.

The structure of old-growth stands can be mimicked to some degree in younger stands by midstory control, gap formation, and creation of standing and down coarse woody debris for the assemblage of species dependent on older forests.

In the South, herbicides are being used to selectively remove midstory and understory hardwoods from older pine stands to develop the parklike nesting habitat required by the endangered red-cockaded. woodpecker. This practice is being used operationally in the USDA Forest Service, Southern Region and has been approved by the U.S. Fish and Wildlife Service.

Periodic creation of standing and down woody structure through tree injection can also improve stand composition while benefiting a wide array of organisms from bark-foraging birds, raptores and hole-nesters, to arthropods and microorganisms (McComb and Hurst 1987).

Food plants for game and nongame wildlife can be encouraged by their release from plant competition using selective herbicide treatments. Food plots created for animal species can be managed by removing woody invaders with single stem herbicide treatments so that costly reestablishment procedures will not be required. Woody browse can be created by basal sprays that deaden tops and yield resprouts. Fruiting shrubs can be released from low-value midstory and understory components- Woody plant encroachment into traditional grassland habitat of elk and antelope can be suppressed with selective control treatments to perpetuate critical wildlife populations as a supplement to the natural role of fire in these ecosystems. Additionally, on some landscapes forest livestock grazing can be enhanced with increased forage production by controlling species composition to favor more desirable plants.

2. Create mixed and uneven-aged stands

Regeneration of a variety of stand types, including both mixed conifer-hardwood, hardwood, and uneven-aged stands is the challenge facing Forest Service silviculturists, wildlife biologists, and other resource managers. Completely new silvicultural systems will have to be developed to meet these challenges, which is underway at several ecosystem management research sites across the United States. Natural regeneration will play an increasing role, which will require innovative vegetation control strategies for establishment and management through succession.

Through selective removals by herbicides of individual and component plants early in the regeneration phase, successional development can be positively directed, releasing desired conifer and hardwood species, and other desirable components. Wood and fiber outputs cannot be overlooked in ecosystem management and can be optimally produced using selective application technology. The management of stand structure, composition, and even function (e.g., increasing nitrogen fixers) can be accomplished through removals by selective cutting and selective control with forest herbicides.

Chemical herbaceous plant control will be needed in lieu of burning treatments in smoke sensitive zones to prepare seed beds for fire subclimax conifer species. Also, uneven-aged mixed stands will probably not tolerate periodic burns, thus herbaceous control treatments can be efficiently applied in single-tree gaps or larger openings to foster both conifer and hardwood regeneration.

Edges between adjoining stands, streamside management zones, and wildlife openings can be blended from early successional (low-stature) species, to shrubs, and to arborescent species by using selective periodic removals. These blended edges of harvest units will create a more favorable aesthetic appearance, provide more habitat options for wildlife, and higher recreational values.

3. Restoration and rehabilitation of damaged landscapes

A full array of natural and human induced factors have resulted and will result in extensive areas of damaged landscapes and ecosystems. Pest epidemics, wildfires, hurricanes, ice-snow storms, and widespread drought cause different patterns of perpetual disturbance to forest and range landscapes. Human induced factors such as fire exclusion and overgrazing can also contribute to damage and loss. Some past harvesting practices and reforestation efforts also have resulted in undesirable monocultures, and off-site genotypes, some of which may require restoration to natural vegetation.

Landscape rehabilitation will demand a full array of forest vegetation management tools including herbicides. Broadcast applications of selective herbicides may be required for extensive landscape restorations to accelerate forest canopy development to protect fragile sites, reverse or prevent invasion of exotic species, enhance aesthetics, and reclaim critical habitat.

4. Control of exotic, noxious, and poisonous plants

The Office of Technology Assistance in the U.S. Congress recently published a comprehensive report which describes the current and future threat to the United States from 4,500 harmful nonindigenous plant and animal species (U.S. Congress 1993). The report indicates just 15 potentially high-impact plants, insects, and aquatic invertebrates could cause as much as $134 billion in losses over the next 50 years. This is a growing economic and environmental burden for the entire wuntry, and a major wncern on many forest and grassland ecosystems.

There is much discussion and desire to use biocontrol measures to address these concerns. We also see the need for expanding research efforts for the development of biological pesticides and biocontrol programs for exotic plant species. However, these methods are generally not available at this time and will require years to develop and at very high costs. The need to suppress or eradicate nonindigenous species in some areas calls for immediate action with tools that are readily available. Selective chemical herbicide treatments are often the only effective means to meet this urgent national need.

Forest Service strategic plans for both landscape restoration and management of introduced forest pests have been recently presented in "Healthy Forests for America's Future-a Strategic Plan" (USDA 1993b) and the "Strategic Plan for Pesticide Use, Management and Coordination" (to be published in 1994). While the primary focus in these plans is on insect pests, plant pests are noted as serious problems on most national forests. Because of the unrelenting aggression of these exotic plants with no endemic predators, herbicides must be a part of any cost-effective integrated pest management approach. In most cases, there is no substitute for herbicide's positive control of these persistent and spreading pests. Some of the most pervasive imports are purple loosestrife, knapweeds, salt cedar, and kudzu-each dominate millions of acres. Exotic pests, besides detracting from forest development and recreational uses, often represent severe threats to native plant and wildlife diversity in critical habitats.

Poisonous plants represent continued threats to human and animal health. Poison ivy and oak in campgrounds and recreation sites place severe restriction on recreational opportunities for sensitive individuals. Poisonous plant control has been a long-term activity on national grasslands to prevent livestock mortality and these integrated pest management programs will require herbicides to play a continuing role.

5. Maintain recreation areas, **trails, and scenic vistas**

Woody regrowth that hinders recreational activities or impairs vistas in high-use sites can be controlled with herbicide treatments that minimize unsightly brownout and yield long-term control. Slow-acting herbicides and selective application techniques can be used in this role. Maintenance on the expanding Forest Service trail system, which already exceeds 120,000 miles will demand low-cost innovative treatments.

Resprouting woody species immediately adjacent to trails are typically manually cut each and every year. They could be selectively treated once after cutting with a very small amount of herbicide, eliminating the need for successive treatments. The cost savings would be dramatic and the environmental impacts negligible.

Creation and maintenance of vistas can greatly enhance the recreational value of mountainous areas. Vistas can be effectively managed through the periodic control of the tall-growing woody component by treating cut stumps with herbicides or by using selective, nonbrownout herbicide treatments. This results in the promotion of low-growing, protective, and/or flowering communities, This will protect the site and prolong the periods between treatments compared to the common frequent recutting of woody resprouters. Vista openings can also present new opportunities for creating and maintaining habitat for songbirds and small mammals.

The beauty of highly visible forest stands and trails can be enhanced by encouraging flowering and fruiting plants through selective removals of competitors by low-impact herbicide treatments. Continued cutting would only result in continued resprouting in most cases.

6. **Multiuse** management of rights-of-way

The 369,000 miles in the Forest Service road system, with 6,000 miles of scenic byways, demands roadside management for safety and aesthetic values. There is growing recognition that rights-of-way (ROW) which were initially created to protect roads, power lines, and pipelines must be managed for more than the inanimate Yoad-bed, wire, and pipe." ROW management strategies are developing that incorporate enhancement of "woodlands, wildlife, and people" values.

Natural flowering plants and wildflowers can be encouraged with selective herbicides and selective applications to improve the aesthetic. appearance and biological diversity of ROW's. Some herbicide-treated ROW's can be used as refuge areas for threatened and endangered species, which are dependent on disturbance.

The vegetation corridors resulting from power transmission, telephone, and pipeline ROW's can be managed as multiple-use habitat (Bramble and Byrnes 1983, Bramble and others 1985, 1992a, 1992b). Tall woody plants are undesirable under wire corridors and deep woody roots can penetrate pipes on pipeline corridors. Low-growing perennials for wildlife and/or aesthetic value can be encouraged and maintained through selective control of unwanted woody invaders. Parallel to this low profile, vegetation can be a zone of shrub species, again perpetuated by hardwood control. A parallel zone of midstory tree species (if present in the ecosystem) can then be blended into the adjacent stands. The architecture and shape of these corridor tiers would be customized to blend with the adjacent stand management objectives. Also, ROW's will be increasingly used for recreational access by hikers, bikers, and off-roaders. Their needs can be evaluated, and where possible, incorporated into ROW vegetation management strategies.

These same principles of "edge management" with ROW can be employed across the landscape. The extensive edges that separate stands or within-stand management zones, can be blended and smoothed to increase habitat and aesthetics, by creating size gradients in woody plants through selective control.

Forestry Herbicides are Environmentally Safe

Chemicals used in modern forestry herbicide formulations are "safe" when used properly. They have negligible risks to the environment and human health when used in accordance with label directions and applied by qualified applicators. There are several factors associated with herbicide properties, modern application technology, forest use patterns and risk assessments that support this conclusion (USDA 1988, 1989, 1992).

Chemical herbicides are among the most vigorously tested consumer products on the market today. Herbicides must meet strict standards of environmental safety and human health protection before they are registered for use. Very few products make it through the more than 100 safety related studies required by the Environmental Protection Agency (EPA).

Modern forestry herbicides have relatively low toxicity as compared to older herbicides and other pesticides such as insecticides and fungicides. As measured by the lethal dose criteria, most of the active ingredients in forestry herbicide formulations have toxicity levels below household chemicals, food additives, and nonprescription drugs. Table 1 shows toxicity categories for pesticides and table 2 compares the toxicity of forestry herbicides with some household chemicals.

Unlike insecticides, the newer forestry herbicides act on biochemical processes such as photosynthesis, amino acid pathways, and growth regulators that are unique to plants and do not occur in animals. This is why wildlife species are not directly affected by these chemicals (McComb and Hurst 1987, Miller and Witt 1991). However, wildlife may be influenced by the habitat shifts that can occur with broadcast herbicide treatments or from other vegetation management activities. The use of selective herbicide treatments should help to minimize habitat impacts.

Modern forestry herbicides have low bioconcentration factors and, therefore, do not bioaccumulate when ingested by humans or wildlife. Unlike many older chemical pesticides that build up in fatty tissues, modern herbicides are water soluble and quickly excreted by animals. According to Isensee (1991), 'most existing herbicides as well as many of the newer insecticides, have relatively short half-lives and possess properties that are indicative of low bioconcentration factors."

Most forestry herbicides in use today biodegrade relatively quickly. They do their job on the target species and then break down from exposure to sunlight, soil micro-organisms, and plant enzymes. The few herbicides that are persistent in the soil, such as picloram and tebuthiuron, can be used effectively in prescriptions that require residual control of reinvading target species.

Biologically significant amounts of forest herbicides are unlikely to reach ground water by runoff or by leaching through the soil. Herbicide degradation by hydrolysis, microbial decay, photodecomposition, and plant metabolism limits off-site movement. Another major factor which limits the amount of herbicide available for off-site transport is the infrequent use pattern of forestry herbicides. Even in agricultural systems, runoff of pesticides from treated areas to aquatic sites is limited to 3 to 5 percent of the amount applied under "worst case" situations, e.g., high intensity rainfall shortly after application (Isensee 1991). On occasions, trace amounts of forestry herbicides have been found in surface water on or near a site in brief pulses during and following the first three storm events after

Table I-Toxicity categories for pesticides

Toxicity category	Signal word	Acute oral LD_{50} person	Acute dermal LD_{50}	Acute inhalation LD_{50}	Eye effects	Skin effects	Estimated amount needed (orally) to kill the average person
		(mg/kg)	(mg/kg)	(mg/kg)			
I	DANGER	<50	<200	<0.2	Corrosive; corneal opacity not reversible within 7 days	Corrosive	A taste (<7 drops) to a teaspoonful
II	WARNING	50-500	200-2,000	0.2-2.0	Corneal opacity reversible within 7 days; irritation persisting for 7 days	Severe irritation at 72 hours	A teaspoonful to an ounce
III	CAUTION	500-S ,000	2,000-20,000	2.0-20	No corneal opacity; irritation reversible within 7 days	Moderate irritation at 72 hours	An ounce to a pint
IV	CAUTION	>5,000	>20,000	>20	No irritation	Mild or slight irritation at 72 hours	Greater than a pint

> = Greater than.
< = Less than.

Table S-Toxicities of forest herbicides and other products for comparison. Small amounts for acute oral LD_{50}'s indicate a higher toxicity

Trade name	Approximate acute oral LD_{50}[a]	Toxicity category	Signal word
	(mg/kg)		
	Other products for comparison		
Gasoline	150	II	--
Caffeine	200	II	--
Aspirin	1,240	III	--
Baking soda	3,500	III	--
Table salt	3,000	III .	--
Herbicides			
AAtrex 4L	1,886	III	CAUTION
AAtrex Nine-O	1,600	III	CAUTION
Accord	5,400	IV	CAUTION
Acme Brush Killer	2,010	III	CAUTION
Arsenal AC	>5,000	IV	CAUTION
Banvel CST	>5,000	IV	CAUTION
Banvel 720	1,707	III	CAUTION
Banvel	2,629	III	CAUTION
Chopper RTU	>5,000	III	CAUTION
Escort	>5,000	III	CAUTION
Garlon 4	2,460	III	CAUTION
Garlon 3A	2,830	III	DANGER[b]
Krenite	24,000	IV	CAUTION
Krenite S	>5,000	IV	WARNING[b]
oust	>5,000	IV	CAUTION
Pathway	8,000	IV	WARNING[b]
Pronone 10G	>5,000	IV	CAUTION
Tordon K	5,000-6,000	IV	CAUTION
Tordon 101 Mixture	3,000	III	CAUTION
Velpar L	7,080	IV	DANGER[b]
Weedone CB	2,140	III	WARNING[b]
Weedone 170	2,000	III	CAUTION
Weedone 2,4-DP	2,200	III	CAUTION

[a] Unless otherwise indicated, values are for the formulated product (as in the container before any additional mixing).

[b] Severe eye irritant, which increases the severity of the signal word.

> = Greater than.

application (Michael and Neary 1993). As might be expected, this will occur more often from broadcast applications as compared to selective single stem, cut surface, or soil-spot applications. Typically, the concentrations of herbicides found are well below known toxicity levels and EPA's drinking water standards and health advisories.

The trend toward efficacy at low application rates continues to lower the overall environmental risk of modern forestry herbicides. Today, many prescriptions call for ounces rather than pounds of active ingredient per acre to achieve the desired effects. When low rate prescriptions and selective application methods are coupled with the patterns of herbicide use in forestry, the result is an overall negligible risk to the environment.

The forestry herbicide formulations available today provide many options for selectivity that can be factored into site specific prescriptions that will insure effectiveness and also safeguard the environment. Options for selectivity may be associated with: the use of a foliar versus a soil acting chemical; a granular versus a liquid formulation; the timing of the application; and the application methodology (broadcast, directed spray, soil-spot, injection, etc.). The use of two or more herbicides in a tank mix, the rate of application, and/or the use of additives such as surfactants are other ways to enhance activity on certain species and components while promoting others.

The frequency and patterns of use of forestry herbicides is probably the most compelling but one of the least known factors that helps to safeguard forest ecosystems from negative impacts. In a typical year, less than 0.1 percent of national forest lands are treated with a herbicide (USDA 1993a). In most silvicultural applications, a site will be treated only once or twice in a 30- to 90-year rotation. This contrasts sharply with household (lawns and gardens) and agricultural use of herbicides where a given site may receive six or more applications each and every year. According to Pimentel and Levitan (1986), 75 percent of household lands and 58 percent of agricultural (crop) lands are treated with herbicides each year while only 0.7 percent of all forest lands are treated with herbicides in a typical year. Infrequent use, low levels of active ingredient applied, and fragmented treatment patterns allows the natural resiliency of forest ecosystems to overcome temporary disturbances to nontarget species and their habitat.

Forestry herbicide-use statistics are easy to understand when one looks at the growth patterns of trees and competing vegetation in a forest ecosystem compared to agricultural crops and lawns. Still, many in our forestry community and most of the general public assume herbicides are constantly being applied to our forests at high levels each and every year. For example, more than half of the nonindustrial private forest owners in Alabama mistakenly believe that forest industries spray their pine plantations annually with herbicides (Alabama Cooperative Extension Service 1993).

There have been numerous herbicide and vegetation management environmental impact statements and risk assessments conducted in recent years (USDA 1988, 1989, 1992). However, it is obvious we need to do a better-job of communicating the use patterns and risk findings to the forestry sector and the general public. We also need to inform and educate Forest Service line officers of the relative risks associated with all tools available for implementing ecosystem management strategies. This open communication will be needed if we expect to build partnerships and reach informed consent (and/or support) for the continued role of herbicides in ecosystem management. Central to this task will be the following: a clearer explanation of the. overall role of vegetation management strategies in ecosystem management; why we sometimes use herbicides in lieu of alternatives; the multiresource benefits to be derived over the long run; the frequency and patterns of use on an ecosystem or landscape basis; and a clear explanation of potential risks to human health and environmental safety.

Concluding Remarks

Since the current administration took office in January 1993, and with the release of the National Academy of Science study "Pesticides in the Diets of Infants and Children" (Landrigan and others 1993), the emphasis on pesticide safety has increased dramatically. The administration has proposed significant reform for pesticide safety by endorsing reduced pesticide use and the use of "safer" pesticides. This reform is strongly endorsed by EPA, USDA, and the Food and Drug Administration. Legislation will be introduced in 1994 to modify the Federal Insecticide, Fungicide and Rodenticide Act which supports "safer" pesticides, and for the introduction of integrated pest management strategies an all agricultural lands.

Consistent with this national trend of “safer” pesticide use, selective herbicide applications can be tailored to direct vegetation succession and manage habitat to support the principles of ecosystem management. Soil productivity can be safeguarded and fertility improved through low-impact removals of selected components and the encouragement of soil-forming leguminous species. Creation of coarse woody debris and snags can enrich species diversity on upland and riparian habitats. Recreational values on Forest Service lands can be greatly improved and efficiently maintained with judicious herbicide use. The selective removal of individual plants through quick and simple applications of modern forestry herbicides represents a sophisticated and safe management tool for ecosystem scale management.

Forestry herbicides offer selectivity through both directed applications and the inherent selective nature of all modern herbicides where some undesirable plants are controlled, others are suppressed, and the desirable plants are released. Herbicide applications can and should be used as part of an integrated vegetation management approach employing other treatments such as manual cutting and prescribed fire to reach multiresource ecosystem management objectives. This wise-use, low-impact approach will require a well-trained cadre of knowledgeable applicators under competent supervision and contract monitoring.

The six roles briefly outlined in this paper are not necessarily a complete list of all possible roles for herbicides in ecosystem management. However, they serve to illustrate how this readily available silvicultural tool can be used for more than just economically driven objectives. Moreover, describing the use of selective herbicide treatments for the protection of noncommodity values may help overcome some of the myths and misperceptions that have long surrounded the use of herbicides in forestry.

The traditional role of forestry herbicides to enhance commodity outputs will continue on many landscapes in the United States, especially in areas of mixed public and private ownerships and in the East where most of the forest lands are in the private sector. In many areas of the United States, herbicide use in the private sector has not been as regulated or constrained as in the public sector. Balancing natural resource values associated with ecosystem management with traditional national values (i.e., private property rights), will require building new partnerships and new lines of communication between the public and private sectors. In order to maintain a viable working partnership with the private forestry sector, it would appear essential that natural resource agencies retain chemical herbicides in their vegetation management programs. In that way, the forestry community and the general public will not receive “mixed signals” about what are safe and acceptable ecosystem management practices.

Literature Cited

Alabama Cooperative Extension Service. 1993. Alabama nonindustrial private forest owners • snapshots from a family album. Circular ANR-788, Auburn, AL: Auburn University. 19 p.

Bartuska, A.M. 1993. Ecosystem management. Ecosystem management internal memo, January 12, 1993. U.S. Department of Agriculture, Forest Service. 2 p.

Bramble, W.C.; Bymes, W.R. 1983. Thirty years of research on development of plant cover on an electric transmission right-of-way. Journal of Arboriculture. 9: 6-13.

Bramble, W.C.; Byrnes, W.R.; Hutnik, R.J. 1988. Effects of a special technique for right-of-way maintenance for deer habitat. Journal of Arboriculture. 11: 278-284.

Bramble, W.C.; Yahner, R.H.; Byrnes, W.R. 1992a. Breeding-bird population changes following right-of-way maintenance treatments. Journal of Arboriculture. 18: 23-32.

Bramble, W.C.; Yahner, W.R.; Byrnes, W.R.; Liscinsky, S.A. 1992b. Small mammals in plant cover types on an electric transmission right-of-way. Journal of Arboriculture. 18: 316-321.

Cantrell, R.L. [and others]. 1985. A guide to silvicultural herbicide use in the southern United States. Auburn University School of Forestry, Alabama Agricultural Experiment Station. 517 p.

Isensee, A.R. 1991. Bioaccumulation and food chain accumulation. In: Grover, R.; Cessna, A.J., eds. Environmental Chemistry of Herbicides Vol. II. Boca Raton, FL: CRC Press. 187-199. Chapter 5.

Kidd, F.A. 1987. Application and use of herbicides in forest and industrial right-of-way sites. In: Methods of applying herbicides, monograph series, Weed Science Society of America No. 4. 297312.

Landrigan, P.J. [and others]. 1993. Pesticides in the diets of infants and children. National Academy Press. 386 p.

McComb, W.C.; Hurst, G.A. 1987. Herbicides and wildlife in the southern forests. In: Managing southern forests for wildlife and fish—A proceedings; 1986 October 8; Birmingham, AL. Gen. Tech. Rep. SO-65. New Orleans, LA: US. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 28-39.

Michael, J.L.; Neary, D.G. 1993. Herbicide dissipation studies in southern forest *ecosystem*. Environmental Toxicology and Chemistry. 12(1993): 405-410.

Miller, J.H.; Mitchell, R.J., eds. 1988. A manual on ground applications of forestry herbicides. Manage. Bull. R8-MB-21. U.S. Department of Agriculture, Forest Service. 316 p.

Miller, K.V.; Witt, J.S. 1991. Impacts of forestry herbicides on wildlife. In: Coleman, SS.; Neary, D.G., eds. Proceedings of the sixth biennial southern silvicultural research conference: 1990 October 30-November 1; Memphis, TN. Gen. Tech. Rep. SE-70. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 795-800.

Pimentel, D.; Levitan, L. 1986. Pesticides: Amounts applied and amounts reaching pests. BioScience. Vol. 36, No.2(1986): 86-91.

U.S. Congress. 1993. Harmful non-indigenous species in the United States. OTA-F-866. U.S. Congress Office of Technology Assistance. 1993 September. 390 p.

U.S. Department of Agriculture. 1983. Forest Management Chemicals. Agric. Handb. 585. Washington, DC: U.S. Department of Agriculture, Forest Service, Forest Pest Management. Revised May 1983.645 p.

U.S. Department of Agriculture. 1988. Managing competing and unwanted vegetation. Final Environmental Impact Statement. U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 1988 November.

U.S. Department of Agriculture. 1989. Vegetation management in the coastal plain/piedmont. Final Environmental Impact Statement. Vol. II. Manage. Bull. R8-MB-23. U.S. Department of Agriculture, Forest Service, Southern Region. 1989 January.

U.S. Department of Agriculture. 1992. Risk assessment for herbicide use in Forest Service Regions 1,2,3,4, and 10 and on Bonneville Power Administration Sites. U.S. Department of Agriculture, Forest Service contract 53-3187-9-30. Prepared by Labat-Anderson Incorp., Arlington, VA. 1992 May.

U.S. Department of Agriculture. 1993a. Report of the Forest Service Fiscal Year 1992. Washington, DC: U.S. Department of Agriculture, Forest Service. 214 p.

U.S. Department of Agriculture. 1993b. Healthy forest for America's future-a strategic plan. Manage. Plan MP-1513. US. Department of Agriculture, Forest Service:, 58 p.

Williamson, IK.; Miller, J.H.; Mistretta, P.A. 1989. Hand application methods for commonly used forestry herbicides in the South. Training Manual. Atlanta, GA: U.S. Department of Agriculture, Forest Service. 14 p.