

**EFFECTS OF MID-ROTATION RELEASE ON
FOREST STRUCTURE, WILDLIFE HABITAT, AND PINE YIELD**

by

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(ABSTRACT)

The effects of two forms of mid-rotation release on thinned, fertilized loblolly pine (*Pinus taeda* L.) plantations in Virginia were examined: aerial imazapyr and basal triclopyr application. Imazapyr measurement plots were installed in nine Piedmont and twelve Coastal Plain plantations operationally released with imazapyr, and triclopyr measurement plots were installed within a controlled fertilization/release study spanning both regions. No differences in volume were detected following triclopyr release. All release dates combined, Piedmont released areas averaged 0.06 m³/tree (18%) greater than the control and Coastal Plain released areas averaged 0.05 m³/tree (14%) greater than the control. Reductions in hardwood basal area, stem density, and shrub stratum cover were observed for both forms of release. Reductions in shrub stratum richness and diversity were also documented for imazapyr release; however, trends indicate that richness and diversity, as well as stem density and shrub stratum cover, may recover to pre-treatment levels. Herbaceous vegetation was increased on triclopyr sites, which was reflected in an elevated turkey (*Meleagris gallopavo sylvestris* L.) food/brood index. Following imazapyr release, habitat suitability index (HSI) values for pine warblers (*Dendroica pinus* L.) and black-capped chickadees (*Parus atricapillus* L.) increased due to reductions in canopy hardwoods and increases in snags. Reduced shrub stratum density resulted in a lower bobwhite quail (*Colinus virginianus* L.) cover index on imazapyr-released areas.

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INTRODUCTION AND JUSTIFICATION

The forests of the Southern United States currently contain half of the nation's commercial timberland. In Virginia, forestry employs nearly 64,000 people and contributes nearly three billion dollars of value-added to the Commonwealth's economy (Thompson and Johnson 1994). As we move into the 21st century, demand for wood products from Southeastern forests will continue to increase. Specifically, harvest restrictions in the Pacific Northwest can be expected to place further pressure on Southern forests to produce softwood lumber (Wiedenbeck and Araman 1993).

In 1986 the USDA Forest Service's inventory of Virginia's forests reported the first-ever documented decline in timberland acreage in the state, with 0.4 million acres of timberland converted to other land uses. Although the 1992 forest inventory showed only an additional 1% decline in timberland, 61% of the land taken out of timber production was diverted into urban and residential development, a use from which it will likely never revert (Thompson and Johnson 1994).

Under these circumstances, intensive silviculture will be essential to meeting growing timber demand without substantial price increases. Much research has been conducted on the intensive management of loblolly pine (*Pinus taeda* L.), including the use of herbicides to control competing vegetation. Mid-rotation chemical release, a fairly new technique, has the potential to significantly enhance yield after stand closure (D'Anieri and Zedaker 1986, Pienaar et al. 1983, Oppenheimer et al. 1989, Shriver and Daniel 1994, Fortson et al. 1996, Zutter et al. 1998, Zutter 1999a). However, the effects of mid-rotation release on non-timber values such as forest structure and wildlife habitat have not been investigated.

Forest structure and wildlife habitat are especially important to non-industrial private forest (NIPF) landowners, who currently control 68% of the softwood market in Virginia (Thompson and Johnson 1994). According to a survey by Hodge and Southard (1992), the top three reasons for NIPF landownership include preservation of nature, maintenance of scenic beauty, and wildlife viewing opportunities. For mid-rotation release to become a viable option for increasing timber supplies, its effect on forest structure and wildlife habitat must be considered.

Goal and Objectives

Goal

The goal of this study was to assess changes in wildlife habitat, forest structure, and pine yield resulting from mid-rotation release of thinned, fertilized loblolly pine plantations. Two forms of mid-rotation release were considered: aerial application of imazapyr (2-[4-isopropyl-4-methyl-5-oxy-2-imidazolin-2-yl]-3-pyridinecarboxylic acid) and basal application of triclopyr ([3,5,6-trichloro-2-pyridinyl)oxy]acetic acid). These two methods were chosen for analysis because they offer two extremes in vegetation management, large-scale industry-level and small-scale management more typical of many NIPF landowners.

Objectives

Specific objectives of this mid-rotation release study were to:

1. Evaluate changes in forest structure in terms of canopy, shrub, and ground stratum vegetation. The canopy stratum was examined in terms of hardwood basal area, percent hardwood in the canopy, canopy cover, snag density, species richness, and species diversity. Shrub stratum variables included percent shrub cover, stem density, species composition, species richness, and species diversity. Percent cover of herbaceous vegetation and percent cover of herbaceous growth forms were used to evaluate the ground stratum.
2. Characterize general changes in wildlife habitat by applying a selected set of wildlife habitat suitability (HSI) models for species associated with canopy, shrub, and ground stratum resources.
3. Quantify changes in pine yield on per-tree and per-hectare bases by applying a single tree volume equation developed for thinned plantations planted on cut-over, site-prepared areas.

LITERATURE REVIEW

Mid-Rotation Release

Mid-rotation release refers to the use of herbicides to reduce competing woody vegetation in pine plantations following stand closure. Although this technique has only been operationally applied for approximately five years, it appears to be gaining industrial acceptance quickly throughout the Southeast, with hundreds of thousands of acres of southern pine stands released annually.

Despite the apparent utility of mid-rotation hardwood control, the majority of research published on pine release deals with plantation establishment (Gonzales 1986, Gnegy 1988, Boyd et al. 1995, Haywood 1995, Miller and Edwards 1996). In 1982, D'Anieri and Zedaker established a mid-rotation release study in the Coastal Plain of Virginia. This study revealed that the diameter increments of both 20-year-old and 60-year-old loblolly pine plantations were significantly increased over a three-year period by controlling competing woody vegetation (D'Anieri and Zedaker 1986). They compared chemical control of undesirable woody vegetation via picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid) injection and foliar mist-blown glyphosate (n-phosponomethyl glycine) to traditional prescribed burning. Diameter increment showed a consistent trend between treatments, increasing from plots that had been burned once, to plots receiving a single herbicide application, to sites that had been annually released with herbicides. No significant differences in hardwood basal area, pine height increment, or percent ground cover between treatments were found.

The University of Georgia's Plantation Management Research Cooperative (PMRC) initiated a mid-rotation release study in 10- to 12-year-old slash pine (*Pinus elliottii* Engelm) stands in 1976 and 5- to 9- and 12- to 16-year-old loblolly pine stands in 1984 (Shriver and Daniel 1994). In both cases, competing woody vegetation was completely controlled via cutting and direct glyphosate application. Ten years after the release of the slash pine stands, Oppenheimer et al. (1989) reported significant increases in individual tree and stand characteristics. Shriver and Daniel (1994) evaluated both the slash and loblolly pine studies, reporting gains of 0.25 cords/ac/yr (1.57 m³/ha/yr) after 14 years for slash pine and gains of 0.35 cords/ac/yr (2.20 m³/ha/yr) after 8 years for loblolly pine. Fortson et al. (1996) also

examined the 8-year response of the loblolly pine stands to detect differences in pine response among age groups and topographic positions. They found that topographic position did affect volume but age class did not; average gains of 1.24 cords/ha/yr (3.14 m³/ha/yr) were estimated for all ages and topographic positions.

Similar volume gains were reported by Zutter et al. (1998) following the aerial release of 14-year-old loblolly stands with varying rates of imazapyr. Averaging all imazapyr treatments, they found an increase of 8.5 m³/ha over control levels 2 years after release. In addition, Zutter (1999a) documented volume gains 4 years after the release of a 12-year-old slash pine stand with varying formulations of hexazinone (3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1H,3H)-dione). No significant differences were detected among formulations, and volume gains averaged 2.80 m³/ha/yr for all release treatments.

First-year response of understory vegetation was documented by Zutter and Glover (1997) following the release of a 10-year-old loblolly pine stand with imazapyr and metsulfuron (methyl 2-[[[(4-methoxy-6-methyl-1,3,5-triazine-2-yl)amino]carbonyl]amino]sulfonyl] benzoate). One year after application, the vine and shrub component was reduced from original density. However, where the shrub component remained low, vines began to increase, attributed to the reduction in competition for sunlight (Zutter and Glover 1997).

As a follow-up to this study, Zutter (1999b) examined the effectiveness of imazapyr and metsulfuron in controlling hardwoods. Hardwood stem density and stand basal area were reduced to 25 and 22 percent of control levels two growing seasons after treatment. In terms of average height reduction, black cherry (*Prunus serotina* Ehrh.), dogwood (*Cornus florida* L.), persimmon (*Diospyros virginiana* L.), and sweetgum (*Liquidambar styraciflua* L.) were affected more than water oak (*Quercus phellos* L.) and southern red oak (*Quercus falcata* Michx.). The mean heights of eastern redcedar (*Juniperus virginiana* L.) and Florida maple (*Acer barbatum* Minchx.) were increased.

Herbicides and Wildlife

Direct Effects

Numerous studies have been conducted on the toxicity of herbicides to wildlife species (Newton and Norris 1968, Morrison and Meslow 1983, Weed Science Society of

America 1989). Because herbicides are designed to control plants by altering physiological pathways, and animals share few physiological pathways with plants, the toxic effect of herbicides to wildlife is low. In addition, herbicides are applied at relatively low doses, do not bio-accumulate, and have relatively short half-lives (Morrison and Meslow 1983).

Research has also been conducted on the effect specific herbicides have on wildlife food preference. Newton and Norris (1968) found that black-tailed deer (*Odocoileus hemionus* Rafineque) did not leave areas which had been treated with 2,4,5-T (2,4,5-trichlorophenoxy acetic acid). Sullivan and Sullivan (1979) documented no change in black-tail feeding behavior in glyphosate-treated areas. Campbell et al. (1981) found no significant reduction in black-tailed deer browsing in areas treated with 2,4-D ((2,4-dichlorophenoxy) acetic acid), 2,4,5-T, atrazine (6-chloro-N-ethyl-N'-(1-methylethyl)-1,3,5-triazine-2,4-diamine), dalapon (2,2-dichloropropionic acid), or fosamine (ethyl hydrogen (aminocarbonyl) phosphonate), although there appeared to be an initial preference toward water and 10% diesel carrier solutions over 100% diesel carrier solutions. They did note a reduced acceptance of glyphosate-treated Douglas fir (*Pseudotsuga menziesii* Mirb.) seedlings by black-tailed deer due to phytotoxic effects.

Indirect Effects

Herbicides affect wildlife mainly through alteration of vegetation structure and composition, primary factors governing the distribution and abundance of wildlife species. The variation in plant responses following herbicide application produces a variety of wildlife responses dependent upon where each wildlife species falls along the continuum from generalist to specialist (Morrison and Meslow 1983). Howell et al. (1996) published a bibliography of research since 1954 pertaining to herbicides and wildlife habitat. Of the 376 U.S. and Canadian documents reviewed, 141 dealt with timber management practices. The majority of the research focused on the impacts chemical site preparation and early release have on deer (*Odocoileus spp.*) and moose (*Alces alces* L.) forage, small mammal populations, and avian communities, respectively. Following this intensive review, Howell et al. (1996) concluded that herbicides can affect wildlife positively or negatively depending on the chemical used and the habitat requirements of the particular wildlife species.

Goodrum (1960) addressed the issue of herbicide use in Southern forests and its potential effects on wildlife habitat. He acknowledged that herbicides may be either beneficial or detrimental to wildlife depending on the purpose and method of application. The removal of the hardwood mast producers could eliminate an important wildlife food source; however, preliminary studies showed that single applications of certain chemicals increased the availability of some deer forage species. Goodrum concluded that it was important to determine what level of hardwood control would benefit pine production and still retain basic wildlife values.

More recently, McComb and Hurst (1987) reported on the status of herbicide use in Southern forests and its effect on wildlife habitat. They discussed the implication of herbicide use for site preparation, seedling release, and timber stand improvement. They reported that site preparation with herbicides and prescribed fire produced an open environment ideal for ground-feeding quail (*Colinus virginianus* L.) and dove (*Zenaida macroura* L.), but too harsh for many other species until the vegetation became thicker in the second growing season. In addition, they found that chemical release at age 4 to 8 years tended to increase the grass, forb, vine, and preferred woody white-tailed deer (*Odocoileus virginianus* Zimmerman) forage. Timber stand improvement practices that released the pine component of mixed pine-hardwood stands were found to alter forest structure and diversity through decreases in hard and soft mast-producing trees and increases in woody shrubs, grasses, forbs, vines, woody debris, and snags (McComb and Hurst 1987).

The role of herbicides in snag creation has been a specific topic of interest. The quality and availability of snags used as nesting, foraging, perching, and roosting sites affects the abundance and diversity of cavity nesters (Conner 1978). Warren et al. (1984) reported that site preparation with herbicides (mistblowing 2,4,5-T and injection of 2-4-D) following clearcutting created many snags. According to Conner et al. (1981), the growth of heartwood- and sapwood-decaying fungi is promoted in herbicide-killed trees, thus providing suitable substrate conditions for nest cavity excavation. They suggested that injection or spraying of herbicides may produce snags quicker and easier than traditional girdling practices; however, they also noted that herbicide-killed trees tend to fall within 3-4 years, potentially reducing the long-term snag resources of a site. Conner et al. (1983) found

that southern red oaks injected with 2,4-D exhibited extensive bark splitting within one month and were affected faster by decay fungi than trees that had been girdled.

The Role of Specific Herbicides

In a site preparation study in the Georgia Piedmont, Witt et al. (1993) examined the response of wildlife food plants to mechanical and chemical site-preparation methods. Herbicides included in the study were imazapyr, triclopyr, picloram plus triclopyr, and hexazinone. They found that imazapyr treatments, mechanical treatments, and control areas supported the greatest amount of quail foods two years post-treatment. Legumes accounted for 63% of quail foods on imazapyr sites. Quail foods were less abundant on picloram plus triclopyr and hexazinone treatments. Soft mast species (primarily *Rubus* spp. and *Smilax* spp.) were lowest on hexazinone-treated areas two years post-treatment and triclopyr sites three years post-treatment. Soft mast species were abundant on imazapyr sites. The presence of legumes and soft mast species on imazapyr treatments led Witt et al. (1993) to suggest that imazapyr applications may be an option for enhancing habitat for seed-foraging animals. Similarly, Hurst (1987) and Watkins et al. (1989) observed increases in legumes when imazapyr was used for early release of loblolly pines.

Witt et al. (1993) also noted that white-tailed deer winter browse was lower on the control areas than on any of the mechanical or chemical treatments. However, among the chemically treated plots, hexazinone sites had the highest available white-tailed deer browse. Hurst and Blake (1987) found a similar increase in white-tailed deer browse following hexazinone site preparation. They attributed this increase to an increase in the occurrence of woody vines. In contrast, Hurst and Watkins (1988) reported that white-tailed deer forage biomass was lower on imazapyr sites than on untreated sites for the first two years following treatment.

McNease and Hurst (1991) found that skidder application of imazapyr prior to seed tree harvest of a 50-year-old natural loblolly stand increased white-tailed deer forage for two years following the harvest. Forage enhancement was due primarily to significant increases in vines (mainly *Rubus* spp.) and forbs. No difference in grass and woody browse was found between imazapyr and control plots.

Brooks et al. (1993) compared the diversity and abundance of certain wildlife food plants among hexazinone, picloram, and imazapyr treated sites one year after site preparation. They found both hexazinone and imazapyr produced an abundance of quail food plants. However, the hexazinone-treated sites produced the most white-tailed deer browse and the most favorable habitat conditions over all due to a higher proportion of annual and perennial grasses which provide potential nesting and brood rearing habitat for bobwhite quail. Studies conducted by Hurst and Palmer (1988) and Miller et al. (1989) also reported an abundance of legumes on hexazinone-treated sites.

Miller et al. (1989) examined the redevelopment of wildlife habitat following upper Coastal Plain site preparation. They found that grasses, primarily *Cynodon dactylon* L., *Panicum* spp., and *Andropogon* spp., were the predominant vegetation types on sites which were chemically treated (picloram plus fluroxypyr (4-amino-3, 5-dichloro-6-fluro-2-pyridyloxy-acetic acid] and hexazinone) and burned. They noted that total forb and woody browse production was less on chemically treated sites; however, hexazinone-treated areas supported higher legume production. They concluded that the grass cover on chemically treated sites may provide good rodent habitat and summer foraging sites for wild turkey (*Meleagris gallopavo* L.), the legume abundance on hexazinone sites may be valuable to quail, and snags created through the chemical application may improve habitat for cavity nesters, bark foragers, and raptors.

Thinning

Thinning, defined as intermediate cutting to control the growth of a stand by adjusting stand density or species composition, has been used for centuries to increase usable wood from stands (Smith et al. 1997). Reductions in stand density allow remaining crop trees to exploit more growing space and resources, thus shifting volume growth to the more desirable trees. In addition to stimulating crop tree growth, the increase in available resources, especially sunlight, can promote the growth of understory vegetation (Blair and Enghardt 1976, Blair 1982).

The control of understory hardwood vegetation is especially important to pine plantation management because in the absence of disturbance, natural succession favors

transformation into a hardwood cover type. Shriver and Daniel (1994) noted that even in well-established pine plantations, a considerable amount of competing vegetation may develop. Prescribed burning has traditionally been used to reduce this hardwood competition in thinned plantations. Growth rates of overstory pine may be increased by prescribed burning if adequate understory control is achieved or soil fertility is improved (Waldrop et al. 1987). Mid-rotation chemical release offers an alternative to traditional burning practices which may provide better hardwood control and eliminate the air quality concerns associated with burning.

Thinning and Wildlife Habitat

Due to unique habitat requirements, an alteration in forest structure due to thinning can be expected to elicit species-specific responses. Thinning is generally recognized as enhancing understory development; therefore, species that depend on well-developed herbaceous and low woody vegetation for food and cover such as deer, quail, and turkey may benefit (Blair and Enghardt 1976, Hayes et al. 1997). Nutrient-rich herbaceous vegetation generally increases immediately after thinning, then declines as woody vegetation increases. The leaves, twigs, and buds of woody vegetation provide an important source of browse for species such as white-tailed deer and cottontail rabbit (*Sylvilagus floridanus* Allen).

Hurst and Warren (1982) found that pre-commercial thinning of a 7-year-old loblolly pine stand in west-central Alabama increased white-tailed deer forage 42% and 360% three and 12 months after thinning, respectively. During this time there was a 125% increase in grass forage and a 56% increase in vine forage (mainly *Rubus* spp. with some *Smilax* spp.).

Profuse growth of mid-story hardwoods may reduce browse and herbage availability once they have grown beyond lower feeding zones and begin to shade ground stratum vegetation (Blair and Enghardt 1976). For this reason, thinning is frequently followed by prescribed burning to reduce mid-story competition and maintain herbaceous and low woody vegetation (Stransky and Harlow 1981). Again, mid-rotation chemical release, which has been shown to significantly reduce hardwood basal area (Zutter 1999b), may provide an alternative means of wildlife habitat maintenance following thinning.

Fertilization

Mid-Rotation Fertilization

Mid-rotation fertilization has both biological and economic benefits. Unless extreme nutrient deficiencies exist, nitrogen (N) availability is generally lowest in older stands after the available growing space has become limited and nutrients have become tied up in living and dead organic matter (Harding and Jokela 1994). Therefore, fertilization at mid-rotation can stimulate growth by supplying a limiting resource. Smith et al. (1997) pointed out that fertilization at mid-rotation offers a simple economic benefit over fertilization at establishment because, although approximately the same amount of volume growth is promoted at mid-rotation as at establishment, mid-rotation fertilization adds volume to older trees, which are inherently worth more.

Between 1984 and 1987, the North Carolina State Forest Nutrition Cooperative established a study (NCSFC Region-wide 13 Study) to specifically address mid-rotation fertilization of loblolly pine plantations. The objectives of this study were to quantify the response of loblolly pines (grown on a wide range of sites) to mid-rotation N and phosphorus (P) fertilization, develop diagnostic methods to help identify nutrient deficiencies, and determine the desired combination of N and P application rates (North Carolina State Forest Nutrition Cooperative 1995). The cooperative found mid-rotation fertilization to be economically viable at reasonable stumpage prices ($> \$14.13/\text{m}^3$) and fertilization costs (\$35-\$90/acre) (North Carolina State Forest Nutrition Cooperative 1995) and recommend a rate of 224 kg/ha N and 28 kg/ha P for one-time applications (North Carolina State Forest Nutrition Cooperative 1997).

North Carolina State Forest Nutrition Cooperative's 10-year analysis of findings revealed that fertilization with 224 kg/ha N plus 28 kg/ha P resulted in a 25% average increase in growth, which translates into a 2.5-year increase in stand development. Cumulative volume response ranged from 21.68 m^3/ha to 96.86 m^3/ha , while annual gains of 5.24 $\text{m}^3/\text{ha}/\text{year}$ and 4.83 $\text{m}^3/\text{ha}/\text{year}$ were reported for poorly drained and well drained sites, respectively (North Carolina State Forest Nutrition Cooperative 1997).

The Cooperative's results also indicated the importance of combining N fertilization with P fertilization, especially on well drained sites. In both poorly drained and well drained

areas, the addition of 28 kg/ha P to 224 kg/ha N increased growth over N alone; however, the response was 24.47 m³/ha greater in well-drained areas. In addition, on 25% of their sites fertilization with N alone resulted in significant reductions in foliar P levels, further supporting the need to combine N fertilization with P fertilization (North Carolina State Forest Nutrition Cooperative 1997).

Fertilization Combined with Thinning and Competition Control

Fertilization following thinning has been found to produce greater volume gains than fertilization alone, and because these gains are realized by fewer, larger stems, the added growth is even more valuable (Ballard 1981). In 1983, the North Carolina Forest Fertilization Cooperative (now the North Carolina State Forest Nutrition Cooperative) presented the results of a five-year study focused specifically on thinning and N fertilization in loblolly pine plantations. Their data revealed that the net volume response to fertilization was greatest in thinned stands and the net volume response of crop-trees to thinning was weaker in the absence of fertilization. The greatest gains in net volume and crop tree response occurred on sites that were fertilized and thinned (a response that was, in general, greater than the additive effects of the treatments applied separately). However, they also found that the degree of response was extremely variable among sites, making site-specific interpretations of their results difficult (North Carolina State Forest Fertilization Cooperative 1983).

In contrast to the results presented by the North Carolina State Forest Fertilization Cooperative, Stearns-Smith et al. (1992) reported inconsistent trends in N and P fertilization plus thinning interactions on a cubic meter per hectare basis in slash and loblolly pine stands. Only two out of eight tests showed significant positive interactions when fertilization and thinning were combined. Thinned stands did not respond as well as the unthinned stands in one test and displayed a negative response to fertilization plus thinning in another. However, dramatic increases in volume realized on plots thinned and fertilized with a combination of N and P led them to conclude that significant growth responses may be dependent on the presence of P in the fertilization regime.

The effects of fertilization can also be enhanced by competition control. Jokela and Morris (1998) examined 27 experiments established by the Forest Biology Research

Cooperative (University of Florida) and the Silvicultural Herbicide Cooperative (Auburn University) designed to quantify the interaction between fertilization and herbicide treatments at stand establishment in loblolly and slash pine plantations. They found that the percentage of sites that exhibited significant volume responses five years after establishment was greater when both treatments were combined (81%) than when fertilization or competition control treatments were applied separately (48% and 43% respectively). Three types of interaction responses were identified: interactive but greater than additive, additive, and interactive but less than additive. Seventy-six percent of the interactions were additive, and two examples of greater than additive effects were documented for loblolly pine.

The synergistic effects of fertilization and competition control are not uncommon. For example, McKee and Wilhite (1988) found a three-fold increase in aboveground biomass for seedlings treated with a pre-emergent herbicide and fertilized with N. However, the lack of this response on two other trials indicated that site conditions, including soil moisture and mineralization, may be an important determinant of response. Powers (1983) also documented that growth gains of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) following weeding and fertilization increased from additive on good sites to greater than additive on poorer sites.

Fertilization and Understory Vegetation/Wildlife Habitat

The primary productivity of biological communities is increased by nutrient enrichment (Abrams and Dickmann 1983). Abrams and Dickmann found that the total live shoot biomass of understory vegetation nearly doubled by the middle of the second growing season following fertilization in both clearcut and mature jack pine (*Pinus banksiana* Lamb.) stands.

Hurst et al. (1982) found that pre-commercial thinning and N fertilization significantly increased white-tailed deer forage in a seven-year-old loblolly pine stand in west-central Alabama over a period of three years following treatment. In the summer and winter following a spring application of 368.76 kg/ha urea, there was a significant increase in total forage in both thinned and unthinned stands, and the fertilized thinned stands supported a significantly larger amount of total forage than the fertilized unthinned stands.

They found that fertilization significantly affected total white-tailed deer forage for only one growing season; however, thinning effects appeared to continue.

In terms of species composition, Abrams and Dickmann (1983) noted that no single species exhibited a dominant response; therefore, there was no loss in species richness. These findings contradict Bakelaar and Odem's (1978) review of nutrient enrichment studies from a variety of ecosystems. They found a general trend for the reduction of overall diversity due to the expansion of established opportunistic species into the niche space of subordinates. Kellner (1993) also attributed a shift in plant composition in Sweden's boreal zone to competitive relationships related to nutrient availability following repeated N fertilization. Prescott et al. (1995) also documented the reduction of understory vegetation (mainly ericaceous vegetation) following repeated fertilization of a jack pine stand with N, P, and potassium (K). However, they did not find competitive relationships to be a factor, suggesting instead that a reduction of mycorrhizal colonies may be a factor.

Diversity

The concept of biodiversity has become an important consideration in resource management. At least 29 federal statutes and numerous state and local ordinances mention the maintenance of biodiversity within their guidelines (Zedaker 1991). Three prime examples of this legislation include the National Environmental Policy Act, the Endangered Species Act, and the National Forest Management Act. The National Forest Management Act specifically calls for on-site conservation of "a diversity of plant and animal communities" (Zedaker 1991).

A major obstacle in the enforcement of statutes that include provisions for biodiversity stems from the lack of clear definitions and quantification methods. The Chief of the Forest Service defined biodiversity as "the variety of life in an area, including the variety of genes, species, communities, and regional ecosystems" (Fenwood 1992). Diversity can be considered at three basic levels: within a community (alpha diversity), between communities (beta diversity), and at a landscape scale (gamma diversity) (Kimmins 1987). Our study was concerned with alpha diversity of understory and overstory woody plants within loblolly pine stands.

Alpha diversity is commonly quantified in terms of proportional abundance of species and species richness. Proportional abundance indices provide information about a community's population distribution, while species richness is a simple count of the number of different species encountered in a community. The Simpson's index and Shannon's index (or Shannon's-Wiener index) are two of the more popular proportional abundance indices (Margurran 1988). The terms "evenness" and "dominance" refer to the emphasis placed on these attributes in computation of the diversity index. Formulas for these diversity indices are:

$$\text{Simpson's index (SI):} \quad \text{SI} = 1 - \sum p_i^2$$

$$\text{Shannon's index (H')}: \quad \text{H}' = -\sum p_i \ln(p_i)$$

$$\text{Species richness (S):} \quad \text{S} = \text{number of species encountered per unit area}$$

where p_i = the proportional contribution of species i to the total number of individuals of all species.

Herbicides and Diversity

Herbicide application is initially intended to reduce species evenness in order to release crop trees from competitors and re-direct site resources. Just as the degree of control is important to crop yield, the scope and duration of species changes is important to the maintenance of biological diversity and wildlife habitat. Several studies have documented trends in diversity and richness following chemical site preparation and early release treatments (Zutter and Zedaker 1988, Swindel et al. 1989, Neary et al. 1990, Fredricksen et al. 1991, Brooks et al. 1993, Wilkins et al. 1993, Boyd et al. 1995, Schabenberger 1999).

The degree of diversity and richness change induced by herbicide application is highly dependent on the intensity and duration of treatment. Swindel et al. (1989) reported that unlike mechanical site preparation, repeated chemical applications have the potential to significantly reduce plant species diversity. Zutter and Zedaker (1988) found that the woody plant diversity in loblolly pine stands decreased with increasing hexazinone rate for two years after application. Neary et al. (1990) documented dramatic decreases in diversity of herbaceous vegetation on plots site-prepared and subsequently treated annually with sulfometuron methyl (methyl 2-[[[(4,6-dimethyl-2-pyrimidinyl)amino]carbonyl]amino]

sulfonyl]benzoate), glyphosate, and triclopyr. They noted that annual maintenance applications resulted in significantly fewer species than June and October applications alone; however, a single-species system was still not produced.

The persistence of herbicide effects has been addressed by several studies (Lewis et al. 1984, Blake et al. 1987, Zutter and Zedaker 1988). Boyd et al. (1995) found no significant reduction in plant community or species diversity seven years after broadcast release of two- to three-year-old pine stands. Following an evaluation of understory vegetation and white-tailed deer forage response to hexazinone, Blake et al. (1987) found that the number of herbaceous species did not change or was slightly higher during the second growing season after application.

Due to the selectivity of herbicides, shifts in plant community composition have been documented. Frederickson et al. (1991) noted that chemical site preparation affected community composition at the species level rather than at the growth form level, as with mechanical site preparation. Boyd et al. (1995) found that imazapyr significantly decreased the prevalence of persimmon in the overstory and increased *Rubus argutus* Link and legumes in the understory seven years after broadcast release. Brooks et al. (1993) also noted a first-year increase in legumes on hexazinone and imazapyr-treated sites compared to other site preparation treatments. Blake et al. (1987) reported that in general, legumes were more abundant on herbicide-treated sites.

Quantification of Wildlife Habitat Changes -- HSI Models

Wildlife Habitat Suitability Index (HSI) models represent a formalized synthesis of species-specific biological and habitat information intended to be a practical tool for assessing the impact of habitat changes. HSI models weight and combine habitat variables that are considered to be highly correlated with the basic life requisites of the selected species to produce an overall index value that describes the suitability of the habitat for that species. Habitat variables included in the models are quantified by determining where the measured value of each variable falls along the species' predicted response curve for that variable (Figure 1). HSI models are scaled to produce indices between 0.0 and 1.0, with 0.0 indicating unsuitable habitat conditions and 1.0 indicating optimum conditions.

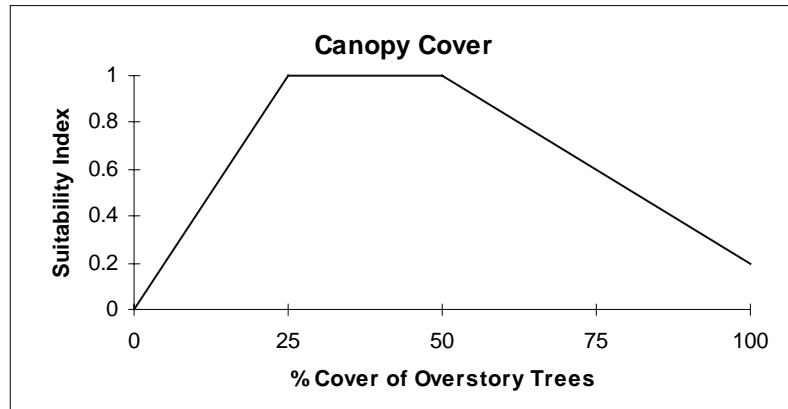


Figure 1. Suitability index curve for canopy closure in the eastern cottontail (*Sylvilagus floridanus* Allen) habitat suitability index model (Allen 1984).

HSI models are compiled by the USDI Fish and Wildlife Service and are intended to be practical operational planning models or research models. They are not intended to be used as population predictors, carrying capacity models, or considered to be comprehensive and all-inclusive. Models can be modified or selectively applied to suit specific purposes. Modification via adding or deleting variables, changing the form of variables, adjusting the suitability index curves, or changing variable weightings may make a model more site-specific and improve the overall performance of the model (Schroeder 1985c). Selective application of model components that quantify specific life-requisites can also be helpful in pinpointing changes in highly correlated habitat attributes.

The evaluative capabilities of HSI models make them especially useful tools for investigating the effects of timber management practices on wildlife habitat. Coupled with information on loblolly pine yield, application of HSI models in areas released at mid-rotation will provide insight into potential wildlife community responses and provide a framework for trade-off analysis.

METHODS

This evaluation of forest structure, wildlife habitat, and pine yield following mid-rotation release consisted of two independent studies: (1) a survey of operationally released loblolly pine plantations treated with an aerial application of imazapyr (Arsenal AC®); and (2) evaluation of a controlled fertilization/release study installed by the Virginia Department of Forestry which included a basal release treatment with triclopyr (Garlon 4®). For both methods of mid-rotation release, crop tree growth response was quantified by applying the single tree volume equation developed by Tasissa et al. (1997) for thinned loblolly pine plantations planted on cut-over site-prepared areas. Forest structure was analyzed by examining changes in basal area, richness, diversity, and percent cover of species and structural components. Wildlife habitat was evaluated by applying HSI models for wildlife species which were highly correlated with ground stratum, shrub stratum, and canopy stratum resources (Table 1).

Table 1. Habitat Suitability Index models and model components¹ used to quantify changes in wildlife habitat within the ground, shrub, and canopy stratum of loblolly pine (*Pinus taeda* L.) plantations released from woody competition at mid-rotation.

Species	Forest Stratum	Component of Model Used
eastern wild turkey (<i>Meleagris gallopavo sylvestris</i> L.)	ground	summer food/brood index (Schroeder 1985a)
eastern cottontail (<i>Sylvilagus floridanus</i> Allen)	ground	winter cover/food index (Allen 1984)
bobwhite quail (<i>Colinus virginianus</i> L.)	shrub	cover index (Schroeder 1985b)
brown thrasher (<i>Toxostoma rufum</i> L.)	shrub	complete model (Cade 1986)
scarlet tanager (<i>Piranga olivacea</i> Gmelin)	canopy	forest maturity index (Stauffer 1994)
pine warbler (<i>Dendroica pinus</i> L.)	canopy	complete model (Schroeder 1985c)
downy woodpecker (<i>Picoides pubescens</i> L.)	canopy (snag resources)	complete model (Schroeder 1983a)
black-capped chickadee (<i>Parus atricapillus</i> L.)	canopy (snag resources)	complete model (Schroeder 1983b)

¹ Because models were selected to evaluate specific forest strata, only the relevant portions of the models were used.

Site Description

Imazapyr Sites

All imazapyr study sites were located in operationally thinned, released, and fertilized loblolly pine plantations in the Piedmont and Coastal Plain of Virginia owned by Chesapeake Forest Products Corporation. Release consisted of a fall aerial application of imazapyr as Arsenal AC® (53.1% isopropylamine salt of imazapyr) at a rate of 0.73 l/ha plus 0.25% TS-90 surfactant. All stands were fertilized the following spring with 222 kg/ha N as urea.

In total, 21 sites were examined. Nine sites were located in the Piedmont, three in each of three different release dates (Table 2), and 12 sites were located in the Coastal Plain, three in each of four different release dates (Table 3). All Piedmont sites were evaluated in July of 1998 and all Coastal Plain sites were evaluated in July of 1999.

On each site, two treatments were considered:

1. Control -- areas that had been thinned and fertilized with 222 kg/ha N but not released, located in buffer zones along stand boundaries and roads.
2. Release -- areas that had been fertilized with 222 kg/ha N and released with 0.73 l/ha plus 0.25% TS-90 surfactant, located in stand interiors.

Table 2. Release date, location, and age of imazapyr mid-rotation release study sites in the Piedmont of Virginia.

Tract	Release Date	County	Age at Measurement (yrs)
Island Ford	1995	Amelia	30
Pollard	1995	Charlotte	26
Shook-Womack	1995	Prince Edward	23
Barrow	1996	Amelia	23
Campsotella	1996	Charlotte	26
J.A. Bishop	1996	Lunenburg	24
Lipscomb	1997	Charlotte	28
Munger	1997	Fluvanna	24
Vaughan-setliff	1997	Lunenburg	20

Table 3. Release date, location, and age of imazapyr mid-rotation release study sites in the Coastal Plain of Virginia.

Tract	Release Date	County	Age at measurement (yrs)
Newington	1995	King & Queen	28
Ryfield	1995	King & Queen	29
Westvaco-Harris	1995	Essex	29
Henrico-Edgehill	1996	Richmond	30
Roadview	1996	King William	29
Whitehall	1996	King William	32
Kean	1997	Northumberland	25
Nelson	1997	Mathews	31
Smithfield	1997	King & Queen	31
Lightwoodneck	1998	Caroline	28
Newbills	1998	King & Queen	23
Providence-Baynham	1998	King & Queen	27

Triclopyr

All triclopyr study sites were part of a fertilization/release study installed by the Virginia Department of Forestry on operationally thinned loblolly pine plantations in the Piedmont and Coastal Plain of Virginia (Table 4). Thinning operations included the removal of all hardwoods greater than 10 cm dbh. Any hardwoods greater than 10 cm dbh which were not removed during thinning operations were manually cut in order to equalize hardwood competition levels prior to treatment.

Three treatments were considered in our study which should not be confused with imazapyr treatment categories:

1. Release - a 19.48 % solution of Garlon 4® (butoxyethyl ester of triclopyr, 61.6% AI) in diesel fuel, applied to all woody stems ≥ 1 in basal diameter with application rate (not exceeding 75.70 l/ha) plus fertilization with 224 kg/ha N and 28 kg/ha P as diammonium phosphate and urea.
2. Fertilization - fertilization with 224 kg/ha N and 28 kg/ha P
3. Control - plots which received no release or fertilization

Table 4. Release date, location, and age of triclopyr mid-rotation release study sites in the Piedmont and Coastal Plain of Virginia.

Tract	Release Date	Region	County	Age at measurement (yrs)
Cumberland	1996	Piedmont	Cumberland	23
Appomattox-Buckingham	1996	Piedmont	Buckingham	20
Falkland	1996	Piedmont	Halifax	21
Layfield	1997	Coastal Plain	Charles City	24
Motley	1997	Coastal Plain	Essex	17
Robinson	1997	Coastal Plain	Southampton	21
Upshaw	1997	Coastal Plain	King William	16

All fertilization and release treatments were applied in the spring (March-April) within one year after thinning. Plots were measured at the end of the second growing season following treatment (July).

Plot Design and Sampling Procedures

To accommodate installation of control plots within the narrow non-released buffer zones on imazapyr sites, a strip transect sampling method was chosen to evaluate pine yield, hardwood basal area, and snag resources. Along the center line of the strip transect a point intercept sampling method was employed to gather wildlife habitat and forest composition data. This plot design and sampling procedure (Figure 2) was used for both the imazapyr and triclopyr studies.

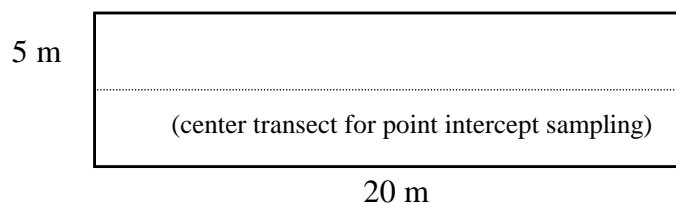


Figure 2. Strip transect sampling design with interior point-intercept sampling line used to evaluate imazapyr and triclopyr release sites in the Piedmont and Coastal Plain of Virginia.

Strip Transect Sampling

Within the entire 5 m x 20 m plot, the following information was collected: dbh of all loblolly pines, height of all loblolly pines, species and dbh of all hardwoods and miscellaneous conifers ≥ 5 m, and snags ≥ 10 cm dbh. Table 5 lists the measurement method, degree of accuracy, and use of each of these variables.

Table 5. Description, measurement method, accuracy, and use of variables measured in the 5 m x 20 m plot which were used to quantify crop tree volume, forest structure, and wildlife habitat in Virginia loblolly pine (*Pinus taeda* L.) plantations released at mid-rotation.

Variable	Measurement Method	Accuracy	Use
loblolly pine dbh	metric dbh tape	to the nearest 0.1 cm	<ul style="list-style-type: none"> • crop tree volume • HSI- downy woodpecker¹
height of loblolly pines	clinometer	to the nearest 0.15 m	<ul style="list-style-type: none"> • crop tree volume • HSI- chickadee² & tanager³
hardwood & misc. conifer dbh	metric dbh tape	to the nearest 0.1 cm	<ul style="list-style-type: none"> • forest structure • HSI- downy woodpecker
tally of snags in three dbh classes (cm) $\geq 10-15$, $>15-25$, and >25	metric dbh tape	to the nearest 1.0 cm	<ul style="list-style-type: none"> • HSI- chickadee & downy woodpecker

¹ *Picoides pubescens* L., ² *Parus atricapillus* L., ³ *Piranga olivacea* Gmelin

Point Intercept Sampling

The following data were taken at 1-m intervals along the 20-m transect: presence of leaf litter, presence of herbaceous vegetation, type of herbaceous vegetation, persistence of herbaceous vegetation, average height of herbaceous vegetation, presence of shrub stratum, shrub stratum species, presence of canopy, presence of overstory pines, and presence of hardwoods in the upper one-third layer of canopy (Table 6).

Table 6. Variable description, measurement method, and use of the point intercept variables used to quantify forest structure and wildlife habitat in Virginia loblolly pine (*Pinus taeda* L.) plantations released at mid-rotation.

Variable	Variable Description	Measurement	Use
leaf litter	herbaceous, shrub, and tree litter ≥ 1 cm deep	metric ruler presence/absence	% ground covered by litter • HSI: brown thrasher ¹
herbaceous vegetation	growth form categories: 1. grass 2. sedges/rushes 3. legumes 4. other broad-leaved forbs	presence/absence and growth form	% cover of herbs • HSI: cottontail ² , turkey ³ • Forest structure % cover by growth form • Forest composition
persistent herbaceous vegetation	all grasses and sedges plus fibrous and/or strong stemmed upright forbs	presence/absence	% canopy cover of persistent herb. veg. • HSI: cottontail
height of herbaceous vegetation	total height to nearest 0.5 cm	metric ruler	Average height of herb layer • HSI: turkey
shrub stratum	genus and species of all woody and semi-woody vegetation < 5m in height	presence/absence and species	% shrub cover, • HSI: quail ⁴ , cottontail • Forest structure % cover by species & diversity indices • Forest composition
canopy	woody vegetation ≥ 5 m in height	presence/absence	% tree canopy cover • HSI: cottontail, thrasher, chickadee ⁵ , tanager ⁶ • Forest structure
pine canopy	pine ≥ 5 m in height	presence/absence	% pine cover • HSI: pine warbler ⁷ • Forest composition
hardwoods in upper 1/3 of canopy	hardwoods reaching the upper 1/3 of mean canopy height	presence/absence	% hardwoods in upper 1/3 of canopy • HSI: pine warbler • Forest composition

¹*Toxostoma rufum* L.; ²*Sylvilagus floridanus* Allen; ³*Meleagris gallopavo sylvestris* L.; ⁴*Parus atricapillus* L.; ⁵*Parus atricapillus* L.; ⁶*Piranga olivacea* Gmelin; ⁷*Dendroica pinus* L.

Woody Stem Sampling

The density of woody stems ≥ 1.0 m tall was determined via the installation of a nested 1 m x 20 m plot centered within the larger 5 m x 20 m plot. All woody stems that crossed through the plane of the plot at a height of 1 m were tallied. Stem density information was used in the brown thrasher (*Toxostoma rufum* L.) model and for forest structure analysis.

Plot Location

Imazapyr Sites

Within each replicate site, four control plots were established in non-released buffer areas. In an effort to minimize variation between control and release plots, buffers were chosen which had received the same thinning rate as the stand interior and which supported a similar species composition (subjective evaluation). Buffers were variable in size, with the minimum buffer size being approximately 10 m x 100 m. Four release plots were paired with the control plots and located within the adjacent released area at randomly selected distances from the control plots (Figure 3). Plots were not laid directly in thinning corridors, logging decks, or other areas lacking loblolly pines.

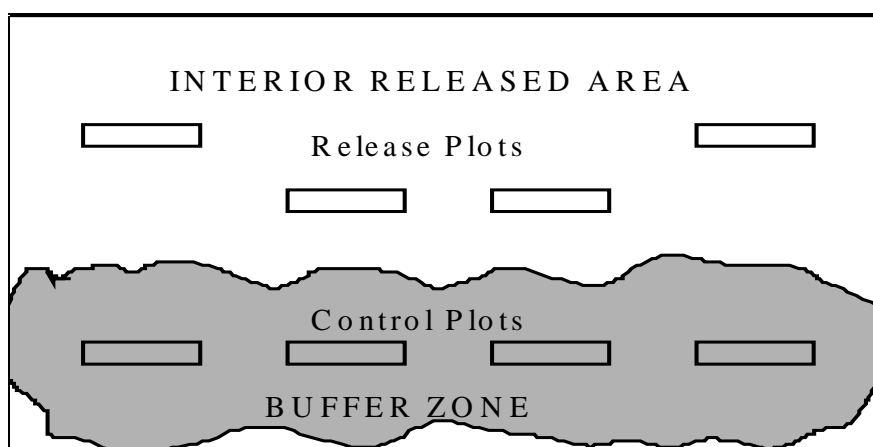


Figure 3. Illustration of paired plot location within release and control areas of loblolly pine (*Pinus taeda* L.) plantations. Released areas were treated at mid-rotation with imazapyr (Arsenal AC®) and fertilized with N; control areas were fertilized with N but not released.

Triclopyr Sites

At each of the seven triclopyr sites, four 5 m x 20 m measurement plots were placed within the existing 0.2 ha treatment blocks installed by the Virginia Department of Forestry. Again, the treatments included were a non-released and non-fertilized control, triclopyr release plus fertilization, and fertilization without release.

Dimensions of the treatment blocks were either 40.2 x 40.2 m or 20.1 x 80.4 m, depending on stand conditions. Within the 20.1 x 80.4 m blocks, four plots were located evenly throughout the area (Figure 4). Within the 40.2 x 40.2 m blocks, four plots were spaced randomly along evenly located transects (Figure 4).

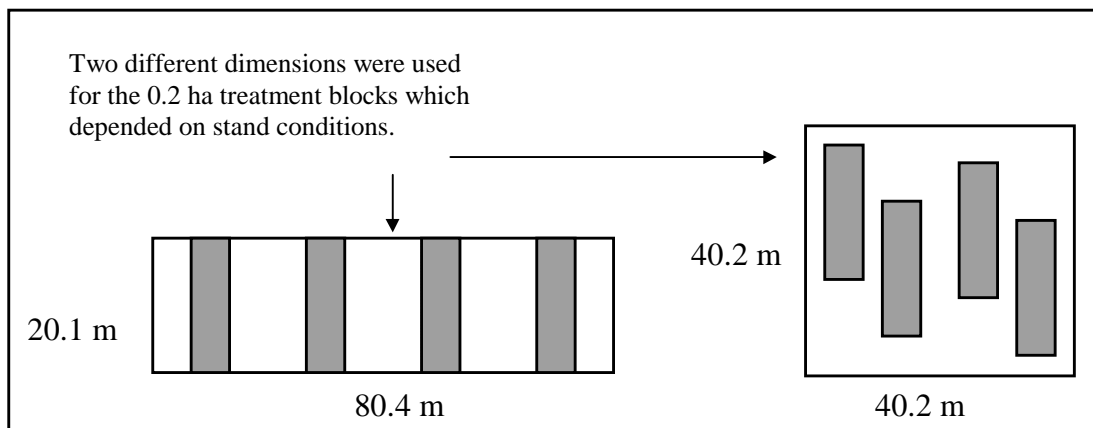


Figure 4. Illustration of measurement plots (shaded areas) within the 0.2 ha fertilization/release treatment blocks installed by the Virginia Department of Forestry. Measurement plots were installed in three different treatment blocks per tract (control, fertilization, and release). Control plots received no fertilization or release, fertilization plots received N and P fertilization at mid-rotation, and release plots received N and P fertilization plus basal application of triclopyr (Garlon 4®).

Data Analysis

Volume Equation

The single-tree volume equation developed by Tasissa et al. (1997) for thinned loblolly pine plantations planted on cut-over site-prepared areas was used to determine the average crop tree volume per tree and per hectare. The volume equation is as follows:

$$V_t = 0.25663 + 0.00239 (D^2H)$$

where: V_t = total outside bark volume
 D = diameter at breast height (in)
 H = total height of tree (ft)

Diversity Index Formulas

Simpson's diversity index (SI), Shannon's diversity index (H'), and species richness (S) were calculated for canopy and understory woody vegetation according to the following equations:

$$\text{Simpson's index (SI): } SI = 1 - \sum p_i^2$$

$$\text{Shannon's index (H'): } H' = -\sum p_i \ln(p_i)$$

where p_i = the proportional contribution of species i to the total number of individuals of all species (Magurran 1988).

Species richness (S): S canopy stratum = average number of species per 0.01 ha
 S shrub stratum = average number of species per 20 m transect

HSI Calculations

Following data collection, the suitability index value for each HSI model variable was determined with the aid of the linear interpolation function in the Quattro®Pro spreadsheet program. This function allowed the determination of a y-axis value (suitability index value) for a known x-axis value (value of variable measured in the field) based on the specified x-y pairs of the predicted species response curves (Appendix A). These suitability index values (scaled from 0 to 1, with 0 indicating unsuitable conditions and 1 indicating optimum conditions) were then entered into HSI equations (Table 7). The HSI equations weighted and combined the suitability index values of each variable to produce an overall habitat suitability index (0 being unsuitable and 1 being optimum).

Table 7. Habitat Suitability Index (HSI) models or model components used and their respective variables and equations. In the following table the letters “SI” preceding the variable code refer to the suitability index value for that particular variable (i.e. SIV1 = the suitability value for variable 1)

Model Component	Variables	HSI equation
eastern wild turkey (<i>Meleagris gallopavo sylvestris</i> L.) summer food/brood index	Variable 1 (V1) - % herbaceous canopy cover Variable 2 (V2) - ave. ht. of herbaceous canopy (cm)	$HSI = (SIV1 \times SIV2)^{1/2}$
eastern cottontail (<i>Sylvilagus floridanus</i> Allen) winter cover/food index	Variable 1 (V1) - % shrub cover Variable 2 (V2) - % tree canopy cover Variable 3 (V3) - % cover of persistent herbaceous vegetation	$HSI = \left[\frac{4(SIV1) + SIV2}{5} \right] + SIV3$ * If equation produces a value > 1 then HSI value = 1
bobwhite quail (<i>Colinus virginianus</i> L.) cover index	Variable 1 (V1) - % shrub cover	$HSI = SIV1$
brown thrasher (<i>Toxostoma rufum</i> L.) complete model	Variable 1 (V1) - density of woody stems (thousands of stems per hectare) Variable 2 (V2) - % tree canopy cover Variable 3 (V3) - % ground covered by litter \geq 1 cm deep	$HSI = SIV1 \times SIV2 \times SIV3$
scarlet tanager (<i>Piranga olivacea</i> Gmelin) forest maturity index	Variable 1 (V1) - % tree canopy cover Variable 2 (V2) - mean tree height (m)	$HSI = (V1 \times V2)^{1/2}$
pine warbler (<i>Dendroica pinus</i> L.) complete model	Variable 1 (V1) - % tree canopy cover Variable 2 (V2) - % cover of hardwood in the upper third of the canopy Variable 3 (V3) - mean tree height (m)	$HSI = (SIV1 \times SIV2 \times SIV3)^{1/3}$
downy woodpecker (<i>Picoides pubescens</i> L.) complete model	Variable 1 (V1) - basal area (ft ² /ac) Variable 2 (V2) - # snags >15 cm per 0.4 ha	$HSI = \text{the lower suitability index value}$
black-capped chickadee (<i>Parus atricapillus</i> L.) complete model	Variable 1 (V1) - % tree canopy over Variable 2 (V2) - ave. height of overstory trees (ft) Variable 3 (V3) - # snags 10-25 cm dbh per 0.4 ha	$HSI = \text{lower of the following:}$ $(V1 \times V2)^{1/2}$ or V3

Statistical Analysis

Imazapyr

Paired t-tests were used to examine differences in crop tree volume and forest structure between all paired release and control sites in each region (n = 9 in the Piedmont and n = 12 in the Coastal Plain). Data from the four sub-plots were averaged to produce one mean value for each treatment per tract. The non-parametric Wilcoxon signed-rank test was used in place of the paired t-test to evaluate richness, diversity, and HSI index values because the distribution of these variables was considered to be non-normal (Sall and Lehman 1996).

Two-way analysis of variance (ANOVA) was used to examine the interaction effects of treatment and release date (Sall and Lehman 1996). Due to the inherently robust nature of this statistical analysis method, two-way ANOVAs were used to characterize interaction effects of all parameters including richness, diversity, and HSI index values.

An alpha level of 0.10 was used to detect significance between treatments. This liberal alpha level was chosen to compensate for the high level of variability associated with this survey design.

Triclopyr

The triclopyr study was set up as a randomized complete block design with seven blocks, representing the seven individual tracts, and three treatments per block: control, fertilization, and release. Due to the small number of sites included in the triclopyr study, Piedmont and Coastal Plain data were not separated. Data were analyzed via one-way ANOVA. The Kruskal-Wallis test, a non-parametric alternative to the one-way ANOVA, was used to evaluate richness, diversity, and HSI values. In both cases the Fisher's LSD test, which uses a comparisonwise alpha level, was used to identify significant differences between individual treatment means (Sall and Lehman 1996).

An alpha level of 0.10 was also used to determine the significance of treatment effects in the triclopyr study. This liberal alpha level was chosen to compensate for small sample size, regional differences, and to facilitate the comparison with imazapyr results.

RESULTS AND DISCUSSION

Pine Yield

Imazapyr

Pine yield was examined on a per-tree as well as a per-hectare basis to compensate for the relatively small plot size and variable number of trees per plot in this survey of operational mid-rotation release. When all release dates were combined for analysis, volume per tree was greater in the released areas of both the Piedmont (8 df, $t = 2.65$, $P = 0.03$) and the Coastal Plain (11 df, $t = 2.07$, $P = 0.06$). In the Piedmont, volume averaged over all release dates was 0.06 m^3 ($SE = 0.02$) (18%) per tree greater in released areas than control areas and in the Coastal Plain per tree volume was 0.05 m^3 ($SE = 0.03$) (14%) greater in released areas than control areas. No difference in volume per hectare was found in the Piedmont (8 df, $t = 1.16$, $P = 0.28$); however, when all release dates were averaged, the Coastal Plain had $21.99 \text{ m}^3/\text{ha}$ ($SE = 13.67$) more volume than control areas, representing a 10.99% increase over the control (11 df, $t = 1.93$, $P = 0.08$).

The magnitude of volume gains realized in this study is in accordance with past mid-rotation release and fertilization research. Zutter et al. (1998) found that aerial applications of imazapyr increased volume an average of $8.5 \text{ m}^3/\text{ha}$ over control levels two years after release. In addition, several studies have documented the additive or synergistic effects of release plus fertilization (Powers 1983, McKee and Wilhite 1988, Jokela and Morris 1998). Fertilization with N following thinning has produced gains of 18.75 m^3 in five years, or approximately $3.75 \text{ m}^3/\text{ha}/\text{yr}$ (North Carolina Forest Fertilization Cooperative 1983). Based on the magnitude of gains realized in past studies, the average volume gain of approximately $8.17 \text{ m}^3/\text{ha}/\text{yr}$ realized in the Coastal Plain is what might be expected following release and fertilization.

Two-way ANOVA revealed no interaction between release date and treatment in terms of volume per tree for the Piedmont (2,12 df, $F = 0.33$, $P = 0.73$) or Coastal Plain (3,16 df, $F = 0.238$, $P = 0.869$). However, combining data from both regions increased the sample size enough to examine changes in volume by release date via paired t-tests. A difference in volume was detected in areas that had been released two years ago (5 df, $t = 3.38$, $P = 0.02$), but no difference was detected in areas released one or three years ago (5 df, $t = 0.00$, $P = 1.0$).

and $df = 5$, $t = 1.77$, $P = 0.14$ respectively) (Figure 5). The lack of significant volume growth in areas one year after release is consistent with past research. In fact, Cain (1991) and Yeiser and Earl (1995) documented reductions in loblolly pine height growth during the first growing season following aerial release with imazapyr. The lack of significant volume differences on sites three years since release was surprising but is likely due to site variability and the low statistical power of the test.

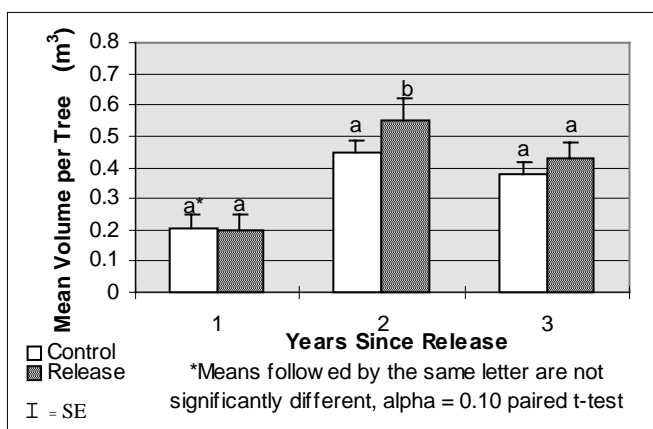


Figure 5. Average loblolly pine (*Pinus taeda* L.) volume (total outside bark) for areas which were released one, two, and three years ago, Virginia Piedmont and Coastal Plain data combined. Released areas were treated at mid-rotation with imazapyr (Arsenal AC®) and fertilized with N, control areas were fertilized with N but not released.

Triclopyr

No treatment effect was detected in per-tree or per-hectare volume (2,18 df, $F = 0.51$, $P = 0.61$ and 2,18 df, $F = 0.86$, $P = 0.44$ respectively) or among any of the individual treatments ($\alpha = 0.10$ in all cases, Fisher's LSD) (Table 8). However, in a separate study by the Virginia Department of Forestry which involved the repeated measurement of these same sites, Scrivani (personal communication) reported a significant fertilization effect. Averaging all fertilization treatments they found a 57% increase in basal area growth two years after treatment. In contrast to fertilization, the effect of release was not consistent across sites and no significant overall trend was detected.

Table 8. Mean loblolly pine (*Pinus taeda* L.) volume (total outside bark) by treatment. Control plots received no fertilization or release, fertilization plots received N and P fertilization at mid-rotation, and release plots received N and P fertilization plus basal application of triclopyr (Garlon 4®).

Volume	Control		Fertilization		Release	
	Mean	SE	Mean	SE	Mean	SE
Per Tree (m ³)	0.33 a*	0.03	0.30 a	0.03	0.34 a	0.03
Per Hectare (m ³ /ha)	97.41 a	16.00	98.96 a	10.30	123.32 a	19.43

*Means in the same row followed by the same letter are not significantly different at the alpha 0.10 level comparisonwise, Fisher's LSD.

Forest Structure

Canopy Stratum

Imazapyr

Both Piedmont and Coastal Plain areas that were released at mid-rotation supported a lower basal area of overstory hardwoods than control areas (8 df, $t = 2.82$, $P = 0.02$ and 11 df, $t = 5.90$, $P = 0.00$ respectively) (Figure 6). These results are similar to those obtained by Zutter et al. (1998). They found that hardwood basal area was substantially reduced by a mid-rotation application of imazapyr and that the percentage decrease increased with increasing pre-treatment stem density.

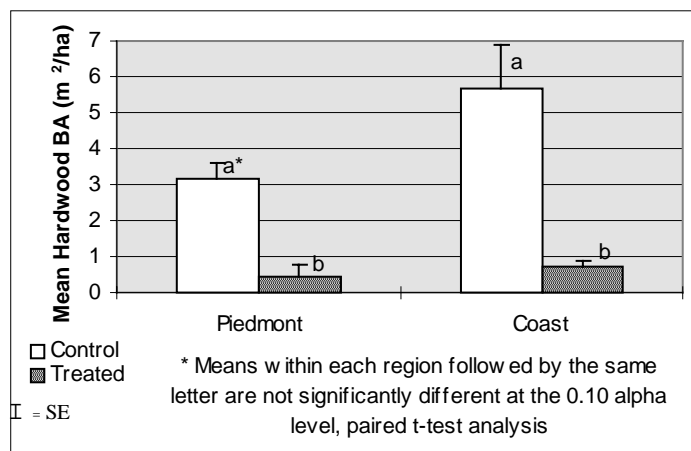


Figure 6. Comparison of hardwood basal area in control and released areas of loblolly pine plantations (*Pinus taeda* L.) in the Piedmont and Coastal Plain of Virginia. Released areas were treated at mid-rotation with imazapyr (Arsenal AC®) and fertilized with N, control areas were fertilized with N but not released.

In addition to a reduction in overall basal area, the percentage of hardwoods in the upper third of the canopy was reduced to zero in both the Piedmont (8 df, $t = 2.82$, $P = 0.02$) and the Coastal Plain (11 df, $t = 4.10$, $P = 0.00$), a reduction of 11 percentage points (SE = 4) and 13 percentage points (SE = 3), respectively. This removal of overstory hardwoods may have contributed to the reduction in canopy cover in both regions, with the canopy reduced an average of 6 percentage points in the Piedmont and 8 percentage points in the Coastal Plain (8 df, $t = 3.77$, $P = 0.00$ and 11 df, $t = 1.97$, $P = 0.07$ respectively). Similar reductions in canopy cover were observed by Zutter (personal communication) two years after the release of a 10-year-old loblolly pine plantation with imazapyr and metsulfuron. Despite the significant reduction in canopy cover detected in our study, cover was not reduced below 77% in either region.

Snags were more abundant on released areas than on control areas in both the Piedmont and Coastal Plain (8 df, $t = 2.86$, $P = 0.02$ and 11 df, $t = 2.24$, $P = 0.05$ respectively) (Figure 7). These results are in accordance with McComb and Hurst's (1987) review of the effects of herbicides on wildlife habitat. They found that timber stand improvement practices which released the pine component of mixed pine-hardwood stands generally increased the number of snags. Conner et al. (1981) suggested that trees injected or sprayed with herbicides may produce snags more quickly and easily than traditional girdling practices. However, they also noted that herbicide-killed trees tended to fall within three to four years, potentially reducing the long-term snag resources of a site. No interaction between treatment and release date was found for the snag resources in either the Piedmont (2,12 df, $F = 2.86$, $P = 0.02$) or the Coastal Plain (3,16 df, $F = 1.08$, $P = 0.39$).

Overstory richness was reduced in the released areas of both the Piedmont (8 df, signed-rank = 18, $P = 0.01$) and Coastal Plain (11 df, signed-rank = 39, $P = 0.00$). The mean number of species encountered per 0.01 ha plot in the released areas of the Piedmont and Coastal Plain were 0.71 (SE = 0.15) and 0.57 (SE = 0.23) respectively, while control areas in the Piedmont and Coastal Plain supported 1.89 (SE = 0.12) and 1.92 (SE = 0.17) species respectively. There was no interaction between treatment and release date in the Piedmont (2,12 df, $F = 0.71$, $P = 0.51$) or Coastal Plain (3,16 df, $F = 1.02$, $P = 0.41$).

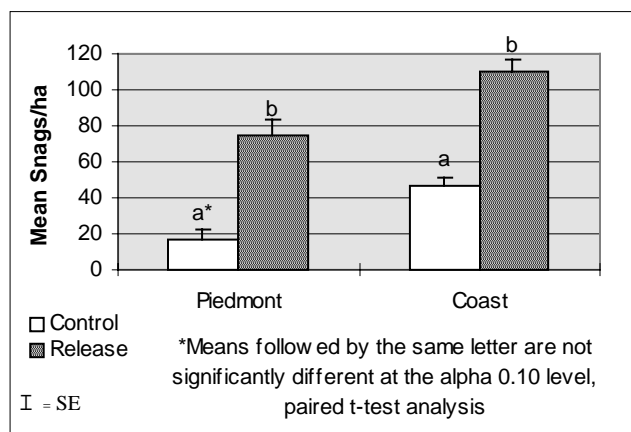


Figure 7. Mean number of snags per hectare in control and released areas of Virginia Piedmont and Coastal plain loblolly pine (*Pinus taeda* L.) plantations. Released areas were treated at mid-rotation with imazapyr (Arsenal AC®) and fertilized with N, control areas were fertilized with N but not released.

Diversity as measured by the Simpson's and Shannon's indices was also reduced in the released areas of both the Piedmont and Coastal Plain (Table 9). As with species richness there were no interactions between treatment and release date for either diversity index ($p > 0.10$ in all cases, two-way ANOVA).

Table 9. Mean overstory diversity index values for control and released areas of loblolly pine (*Pinus taeda* L.) plantations in the Piedmont and Coastal Plain of Virginia. Released areas were treated at mid-rotation with imazapyr (Arsenal AC®) and fertilized with N, control areas were fertilized with N but not released.

Diversity Index	Piedmont				Coastal Plain			
	Control		Release		Control		Release	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Simpson's	0.75 a*	0.04	0.38 b	0.12	0.77 a	0.02	0.40 b	0.10
Shannon's	1.66 a	0.10	0.70 b	0.24	1.72 a	0.07	0.74 b	0.18

* Means for each index within the same region which are followed by the same letter are not significantly different at the alpha = 0.10 level, Wilcoxon signed-rank test

Similar reductions in richness and diversity have been documented following early release and site preparation with herbicides (Zutter and Zedaker 1988, Swindel et al. 1989, Boyd et al. 1995, Schabenberger 1999). However, the lack of interaction between treatment

and release date suggested that, unlike the early release study by Boyd et al. (1995), canopy diversity and richness may not recover to pre-treatment levels within the rotation.

Triclopyr

There was no overall effect of treatment on hardwood basal area; however, there was an effect of treatment on the percent cover of hardwoods reaching the upper third of the canopy (2,18 df, $F = 2.97$, $P = 0.08$). According to Fisher's LSD test, there was more hardwood cover on the fertilized plots than either the control or released plots ($\alpha = 0.10$, Fisher's LSD) (Figure 8).

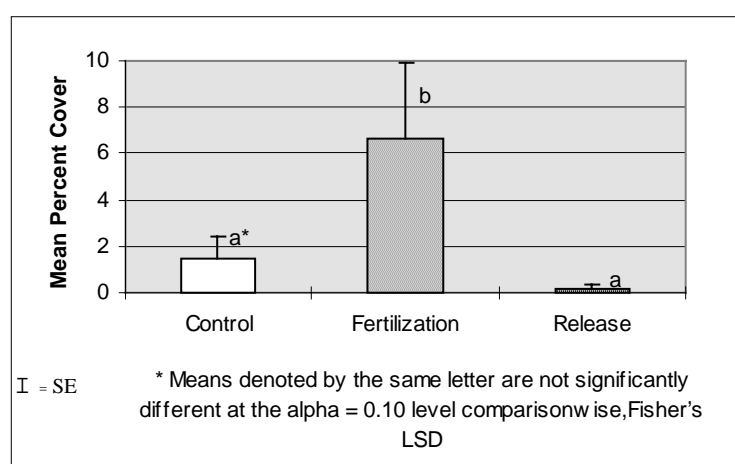


Figure 8. Mean percent hardwood cover in the upper third of the canopy in control, fertilization, and release plots of Virginia loblolly pine (*Pinus taeda* L.) plantations. Control plots received no fertilization or release, fertilization plots received N and P fertilization at mid-rotation, and release plots received N and P fertilization plus basal application of triclopyr (Garlon 4®).

Snag resources were not different among treatments as they were in the imazapyr study (2,18 df, $F = 0.14$, $P = 0.87$). However, this is likely due to the specified removal of hardwoods >10 cm dbh during thinning operations.

In contrast to the imazapyr study, there were no differences among treatments in terms of overstory richness (2 df, $X^2 = 0.89$, $P = 0.64$) or Simpson's (2 df, $X^2 = 1.83$, $P = 0.40$) and Shannon's (2 df, $X^2 = 1.61$, $P = 0.45$) diversity. The relatively low number of species found on triclopyr plots prior to treatment may partially account for this lack of difference in richness and diversity between treatments (average number of species found

per plot on control and release plots were 1.03 (SE = 0.37) and 0.50 (SE = 0.11) respectively).

Shrub Stratum

Imazapyr

Percent cover of all woody and semi-woody vegetation in the shrub stratum (including *Rubus* spp. and vines) was lower in the released areas of the Piedmont (8 df, $t = 4.36$, $P = 0.00$) and Coastal Plain (11 df, $t = 4.14$, $P = 0.00$) (Figure 9). In the Piedmont, stem density was also significantly lower (8 df, $t = 5.611$, $P = 0.00$) (Figure 9). Similarly, Zutter and Glover (1997) documented a reduction in the shrub and vine component of loblolly pine stands four months after mid-rotation release with imazapyr and metsulfuron. In a follow-up study, Zutter et al. (1998) found stem density levels were still significantly lower in the released area two years after treatment. In contrast, Boyd et al. (1995) found no significant difference between areas released with imazapyr and control areas in terms of rootstock densities and stem counts seven years after broadcast release of a young pine plantation, suggesting the shrub stratum may recover in time.

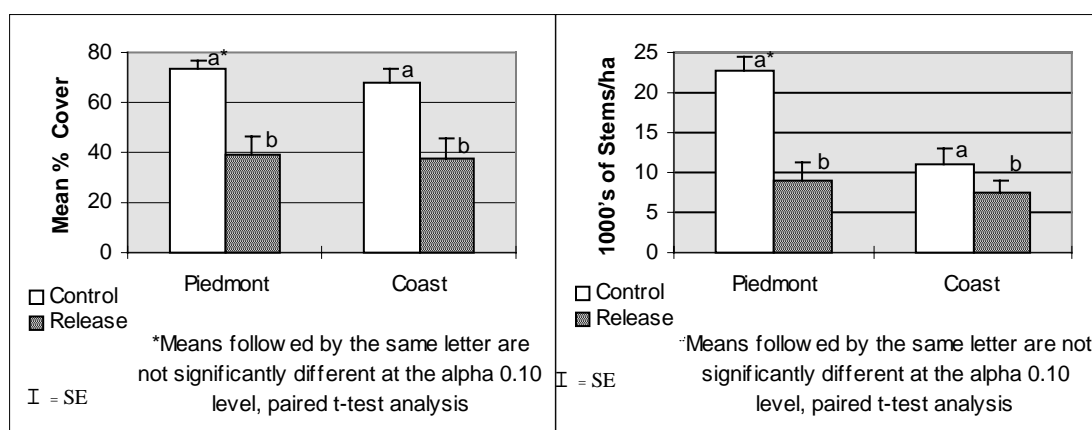


Figure 9. Shrub stratum cover and stem density in control and released areas of loblolly pine (*Pinus taeda* L.) plantations in the Piedmont and Coastal Plain of Virginia. Released areas were treated at mid-rotation with imazapyr (Arsenal AC®) and fertilized with N; control areas were fertilized with N but not released.

Analysis of the interaction between treatment and release date lends some support to the concept of shrub stratum recovery. A significant interaction between release date and treatment was detected in both Piedmont (2,12 df, $F = 5.70$, $P = 0.02$) and Coastal Plain

(3,16 df, $F = 3.16$, $P = 0.05$) areas. Although this study did not follow the development of a set of sites over time, the interaction between release date and treatment suggested that cover may be increasing at a faster rate in the released areas than in control areas, possibly indicating a recovery to pre-release levels (Figure 10). This hypothesis is supported by Zutter and Glover (1997) and Hurst and Blake (1987), who documented increases in the semi-woody vine component of pine plantations after mid-rotation release and chemical site-preparation, respectively. Additionally, unpublished follow-up data on the study by Zutter and Glover (1997) showed a recovery of vine and non-arborescent semi-woody plant cover (*Rubus spp.*) to approximately control levels 1.5 years after release (personal communication).

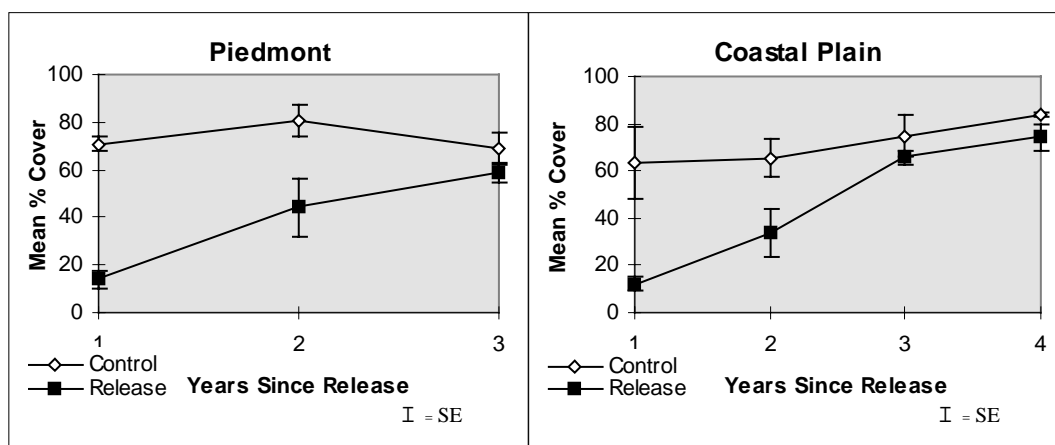


Figure 10. Trends in mean shrub stratum cover with years since release in control and released areas of loblolly pine (*Pinus taeda* L.) plantations in the Piedmont and Coastal Plain of Virginia. Released areas were treated at mid-rotation with imazapyr (Arsenal AC®) and fertilized with N; control areas were fertilized with N but not released.

Increases in percent cover of several shrub stratum species following release contributed to the overall increase in cover with years since treatment. Natural loblolly pine seedlings, freed from woody competitors, were found in greater abundance in released areas of both the Piedmont (8 df, $t = 2.83$, $P = 0.06$) and the Coastal Plain (11 df, $t = 3.02$, $P = 0.00$) (Table 10). In addition, percent cover of *Rubus* spp. was higher in Piedmont released areas (8 df, $t = 2.61$, $P = 0.03$) and percent cover of devils-walkingstick (*Aralia spinosa* L.) was higher in released areas of the Coastal Plain (11 df, $t = 2.03$, $P = 0.07$) (Table 10). This

dominance of *Rubus* spp. following release was not surprising in light of several other studies that documented the resistance of this genus to imazapyr (McNease and Hurst 1991, Boyd et al. 1995). The enhancement of devils-walkingstick was in contrast with the results of a study by Cain (1991) which examined the effect of imazapyr on woody competitors. Cain found that devils-walkingstick was successfully controlled at the lowest rates of imazapyr application. In light of this research, our results may simply reflect the ability of this species to quickly re-colonize an area following disturbance.

In the Coastal Plain, percent cover of American holly (*Ilex opaca* Ait.) in the shrub stratum did not differ between treatments (11 df, $t = 0.61$, $P = 0.55$) and it was one of the top five cover species in released areas (Table 10). The resistance of this waxy-leafed species to imazapyr was also documented by Cain (1991). In the Piedmont, mockernut hickory (*Carya tomentosa* (Poir.) Nutt.) was one of the top five cover species, not differing significantly between treatments (8 df, $t = 1.58$, $P = 0.15$) (Table 10). Again, Cain (1991) reported similar results, finding that imazapyr release treatments did not result in acceptable topkill of hickories (*Carya spp.*) In addition, Japanese honeysuckle (*Lonicera japonica* Thunb.), considered a shrub stratum species in this study, was one of the top five cover species in both the Piedmont and the Coastal Plain, not differing significantly between treatments in either case (9 df, $t = 0.48$, $P = 0.64$ and 11 df, $t = 1.20$, $P = 0.25$ respectively). Similarly, Zutter and Glover (1997) documented the recovery of this genus seven months after mid-rotation release with imazapyr.

Table 10. Mean percent cover of primary shrub stratum species by region and treatment in Virginia Piedmont and Coastal Plain loblolly pine (*Pinus taeda* L.) plantations. Released areas were treated at mid-rotation with imazapyr (Arsenal AC ®) and fertilized with N; control areas were fertilized with N but not released.

Species	Mean Percent Cover							
	PIEDMONT				COASTAL PLAIN			
	Control		Release		Control		Release	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
red maple (<i>Acer rubrum</i> L.)	12.64 a*	2.44	1.39 b	0.44	10.94 a	3.15	2.60 b	1.19
yellow poplar (<i>Liriodendron tulipifera</i> L.)	12.22 a	0.37	0.83 b	0.06	2.92 a	0.02	2.5 a	0.02
sweetgum (<i>Liquidambar styraciflua</i> L.)	9.86 a	3.71	2.5 a	1.16	8.33 a	2.57	1.46 b	0.96
blackgum (<i>Nyssa sylvatica</i> Marsh.)	7.50 a	2.86	0.28 b	0.18	3.02 a	1.25	1.25 a	0.77
dogwood (<i>Cornus florida</i> L.)	6.53 a	1.60	0.83 b	0.47	5.21 a	2.36	0.63 b	0.33
blackberry (<i>Rubus</i> spp.)	4.17 a	0.14	19.86 b	0.61	3.13 a	0.18	7.71 b	0.25
Japanese honeysuckle (<i>Lonicera japonica</i> Thunb.)	6.53 a	0.47	5.56 a	0.32	1.35 a	0.09	3.96 a	0.24
mockernut hickory (<i>Carya tomentosa</i> (Poir.) Nutt.)	5.14 a	1.94	1.67 a	1.04	0.63 a	0.42	0.31 a	0.22
greenbriar (<i>Smilax</i> spp.)	2.22 a	1.41	0.83 a	0.47	14.48 a	4.53	2.19 b	0.94
American holly (<i>Ilex opaca</i> Ait.)	0.28 a	0.28	0.42 a	0.42	0.17 a	3.88	14.48 a	4.61
blueberry (<i>Vaccinium stamineum</i> L.)	1.67 a	0.59	0.14 b	0.14	5.73 a	2.95	0.17 a	0.77
loblolly pine (<i>Pinus taeda</i> L.)	0.28 a	0.28	1.11 b	0.33	0.83 a	0.52	5.83 b	1.85
devils-walkingstick (<i>Aralia spinosa</i> L.)	0.0 a	0	0.0 a	0	2.71 a	1.66	3.85 b	1.90

* Means followed by the same letter are not significantly different at the alpha = 0.10 level comparisonwise, paired t-test analysis

Shading indicates that the species is one of the top five cover species in that treatment

In addition to composition shifts, shrub stratum species richness was lower in the released areas of both the Piedmont (8 df, signed-rank = 18.00, $P = 0.00$) and the Coastal Plain (11 df, signed-rank = 32.00, $P = 0.01$). However, there was an interaction between treatment and release date in both the Piedmont (2,12 df, $F = 5.94$, $P = 0.02$) and the Coastal Plain (3,16 df, $F = 5.51$, $P = 0.01$), indicating a possible recovery in richness levels similar to that found in the early release study by Boyd et al. (1995) (Figure 11). They found overstory and understory plant species richness was not decreased seven years after the early release of a pine plantation, although species composition was shifted.

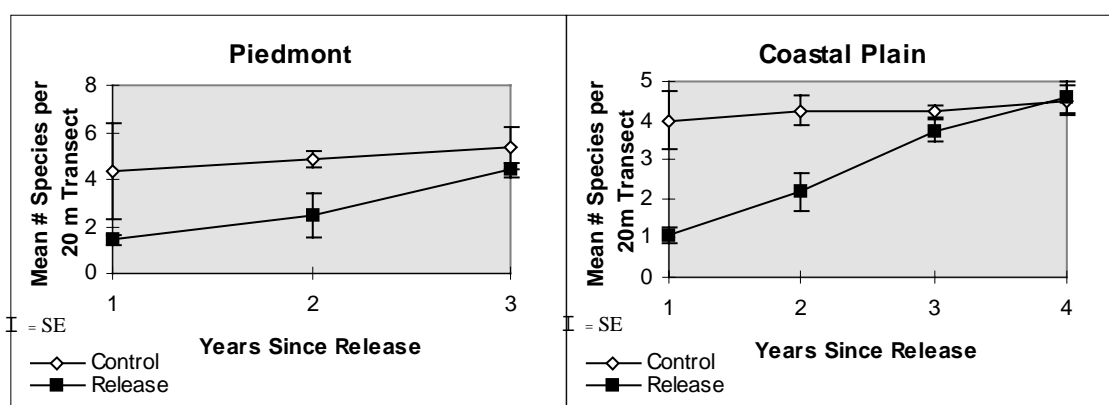


Figure 11. Trends in shrub stratum richness with years since release in control and released areas of Virginia Piedmont and Coastal loblolly pine (*Pinus taeda* L) plantations. Released areas were treated at mid-rotation with imazapyr (Arsenal AC®) and fertilized with N; control areas were fertilized with N but not released.

Shannon's and Simpson's diversity indices were also lower in the released areas of both the Piedmont and the Coastal Plain (Table 11). As was the case with richness levels, there was an interaction between treatment and release date in the Coastal Plain for both Simpson's (3,16 df, $F = 4.84$, $P = 0.01$) and Shannon's (3,16 df, $F = 4.60$, $P = 0.02$) diversity indices, suggesting a recovery of diversity with time. However, this pattern was not repeated in the Piedmont, where there was no interaction between treatment and release date in either the Simpson's (2,12 df, $F = 0.41$, $P = 0.67$) or Shannon's index (2,12 df, $F = 0.62$, $P = 0.55$). Figure 12 illustrates these trends in diversity by release date in both regions.

Table 11. Shrub stratum Simpson's and Shannon's diversity index values for control and released areas of Virginia Piedmont and Coastal Plain loblolly pine plantations. Released areas were treated at mid-rotation with imazapyr (Arsenal AC®) and fertilized with N; control areas were fertilized with N but not released.

Diversity Index	Piedmont				Coastal Plain			
	Control		Release		Control		Release	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Simpson's	0.88 a*	0.01	0.76 a	0.03	0.85 a	0.01	0.76 b	0.03
Shannon's	2.55 a	0.08	1.86 a	0.13	2.28 a	0.08	1.76 b	0.17

* Means followed by the same letter are not significantly different at the $\alpha = 0.10$ level, Wilcoxon signed-rank test

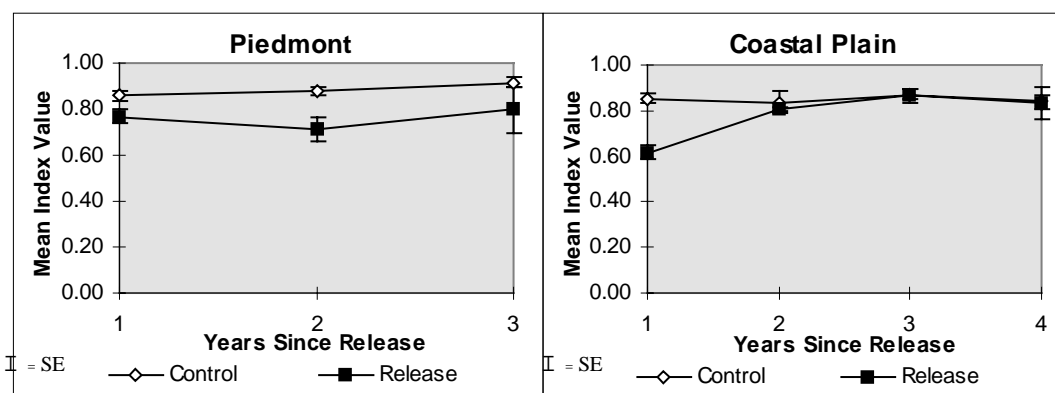


Figure 12. Trends in shrub stratum diversity with years since release in Piedmont and Coastal Plain loblolly pine (*Pinus taeda* L.) plantations as measured by Simpson's diversity index. Simpson's index is on a scale from zero to one, indicating optimum diversity and zero indicating no diversity. Released areas were treated at mid-rotation with imazapyr (Arsenal AC®) and fertilized with N; control areas were fertilized with N but not released.

Triclopyr

Both shrub stratum cover and stem density were affected by treatment (2,18 df, $F = 6.51$, $P = 0.01$ and 2,18 df, $F = 3.57$, $P = 0.05$, respectively) (Figure 13). Released plots supported lower shrub stratum cover than either control or fertilized plots ($\alpha = 0.10$, Fisher's LSD). Stem density in the released plots was not different from the control; however, released plots supported a lower stem density than fertilized plots ($\alpha = 0.10$, Fisher's LSD). The contrast between release and fertilization plots was not surprising because fertilization has been shown to increase understory vegetation biomass. Abrams and

Dickmann (1983) found that the total live shoot biomass of understory vegetation nearly doubled by the middle of the second growing season after fertilization of mature jack pine stands.

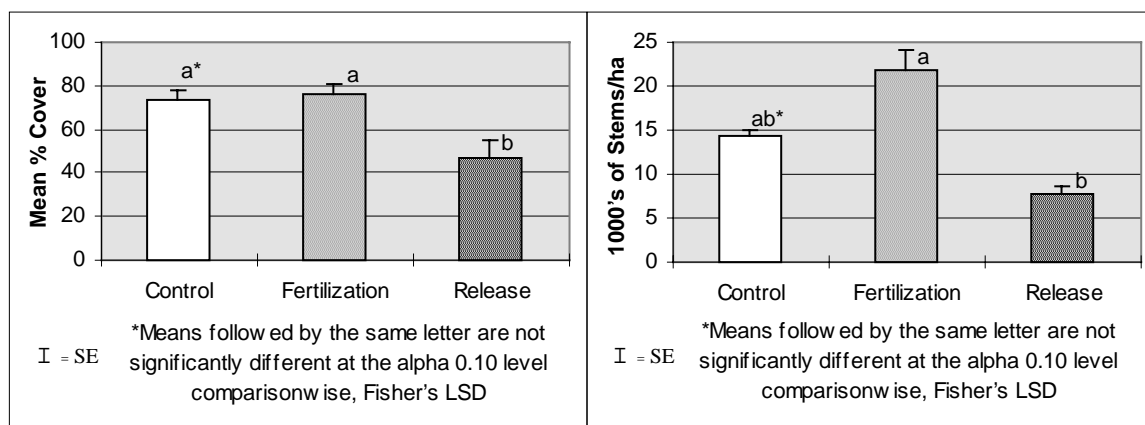


Figure 13. Mean shrub stratum cover and stem density in control, fertilization, and release plots of Virginia loblolly pine (*Pinus taeda* L.) plantations. Control plots received no fertilization or release, fertilization plots received N and P fertilization at mid-rotation, and release plots received N and P fertilization plus basal application of triclopyr (Garlon 4®).

Species composition was very similar between treatments, and red maple (*Acer rubrum* L.) was the only species that differed significantly, with mean percent cover in released plots being lower than in fertilized plots (alpha = 0.10, Fisher's LSD) (Table 12). In addition, four of the five top cover species in all treatments were the same (Table 12).

Species richness did not differ between control, fertilization, and release plots (2 df, $X^2 = 0.33$, $P = 0.85$), supporting an average of 2.25 (SE = 0.84), 2.55 (SE = 0.86), and 1.75 (SE = 0.69) species, respectively. Diversity levels were also not affected by any of the treatments (2 df, $X^2 = 0.02$, $P = 0.99$ and 2 df, $X^2 = 0.32$, $P = 0.85$ for Simpson's and Shannon's indices, respectively). These results are in contrast to the changes in richness and diversity induced by imazapyr release; however, direct comparisons cannot be made due to differing experimental design and sample size.

Table 12. Mean percent cover of primary shrub stratum species by treatment in Virginia loblolly pine (*Pinus taeda* L.) plantations. Control plots received no fertilization or release, fertilization plots received N and P fertilization at mid-rotation, and release plots received N and P fertilization plus basal application of triclopyr (Garlon 4®).

Species	Mean Percent Cover					
	Control		Fertilization		Release	
	Mean	SE	Mean	SE	Mean	SE
Sweetgum (<i>Liquidambar styraciflua</i> L.)	21.43 a*	6.61	13.75 a	5.88	5.54 a	3.07
red maple (<i>Acer rubrum</i> L.)	10.48 ab	3.10	12.68 a	3.94	3.39 b	2.24
Japanese honeysuckle (<i>Lonicera Japonica</i> Thunb.)	7.14 a	3.02	3.04 a	5.39	10.89 a	1.76
blackgum (<i>Nyssa sylvatica</i> Marsh.)	5.89 a	2.91	4.29 a	2.59	3.04 a	1.93
blackberry spp. (<i>Rubus</i> spp.)	4.82 a	0.21	7.14 a	0.29	8.04 a	0.28
yellow poplar (<i>Liriodendron tulipifera</i> L.)	3.39 a	1.58	5.00 a	2.94	3.93 a	3.13

* Means for each species followed by the same letter are not significantly different at the alpha = 0.10 level comparisonwise, Fisher's LSD

Shading indicates that the species is one of the top five cover species in that treatment

Ground Stratum

Imazapyr

Herbaceous cover did not differ between control and released areas in either the Piedmont (8 df, $t = 0.63$, $P = 0.54$) or the Coastal Plain (11 df, $t = 0.97$, $P = 0.35$). Results obtained by Blair (1971) and Zutter (personal communication) are contrary to these findings. Blair found that removal of hardwoods in an all-aged pine-hardwood stand increased herb abundance within the first two to four years before it began to decline as the growth of pine seedlings increased. Preliminary second-year results provided by Zutter on the response of understory vegetation to mid-rotation release with imazapyr and metsulfuron revealed a decrease in grasses directly after treatment, followed by an increase to levels above the control within one year (23% versus 13 %).

The proportions of forbs, grasses, and sedges/rushes were also not different in either the Piedmont or the Coastal Plain ($p > 0.10$ in all cases, paired t-test analysis). However, when both regions were combined, a pattern of greater forb cover in the released areas was revealed (2 df, $t = 2.16$, $P = 0.04$) (Figure 14). These results were similar to those obtained by Miller et al. (1995), who found that control of woody vegetation with triclopyr and glyphosate increased the relative proportion of forbs one to two years after release. Frederickson et al. (1991) also reported on the abundance of ruderal forbs and shortage of grasses in areas treated annually with herbicides. Legume percent cover did not differ between release and control areas in either the Piedmont (8 df, $t = 1.38$, $P = 0.17$) or Coastal Plain (11 df, $t = 1.15$, $P = 0.28$). This was contrary to previous studies which reported an abundance of legumes on sites treated with imazapyr (Watkins et al. 1989, Brooks et al. 1993, Witt et al. 1993, Boyd et al. 1995).

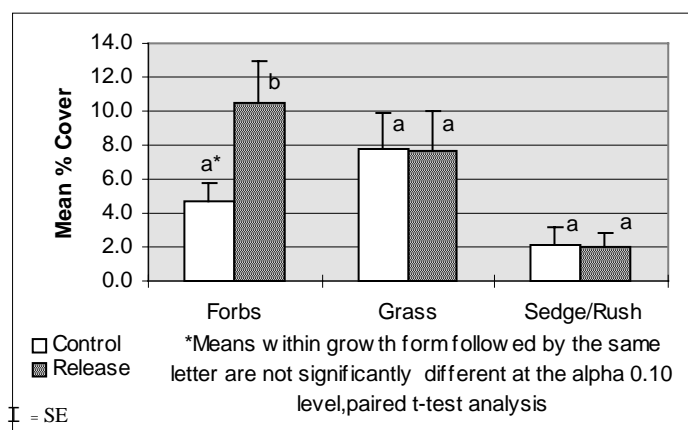


Figure 14. Mean percent cover by growth form in control and release areas of loblolly pine (*Pinus taeda* L.) plantations in the Piedmont and Coastal Plain of Virginia (data from both regions combined). Released areas were treated at mid-rotation with imazapyr (Arsenal AC®) and fertilized with N; control areas were fertilized with N but not released.

Triclopyr

Herbaceous cover was different among treatments (2,18 df, $F = 2.67$, $P = 0.09$), with release plots supporting a higher percent cover than control plots and fertilization plots ($\alpha = 0.10$, Fisher's LSD) (Figure 15). This increase in herbaceous cover following basal

release with triclopyr was not surprising. In contrast to broadcast aerial application of imazapyr, basal application of triclopyr allowed woody stems to be targeted without greatly impacting the herbaceous layer. The reduction of woody cover allowed more sunlight to reach the forest floor, stimulating growth of existing herbs. Additionally, unlike imazapyr, which controls a wide variety of annuals and perennials and has a high residual soil activity, most grasses are tolerant to triclopyr and its residual soil activity is low (Weed Science Society of America 1989).

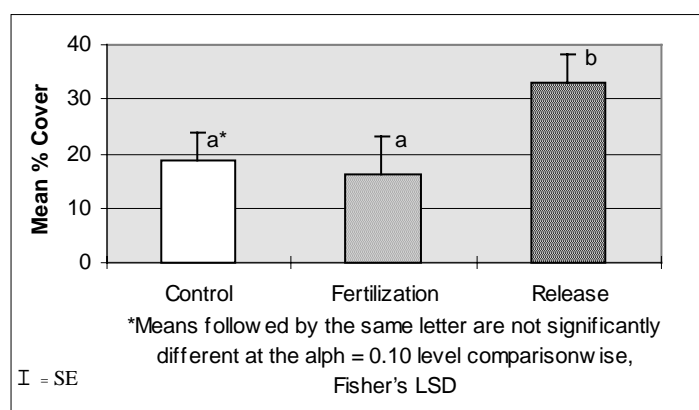


Figure 15. Herbaceous cover on control, fertilization, and release plots of Virginia loblolly pine (*Pinus taeda* L.) plantations. Control plots received no fertilization or release, fertilization plots received N and P fertilization at mid-rotation, and release plots received N and P fertilization plus basal application of triclopyr (Garlon 4®).

There were no significant differences in the percent cover of growth forms among treatments (alpha = 0.10, Fisher's LSD). Treatment also did not affect legume cover (218, df, F = 0.87, P = 0.44).

Wildlife Habitat

Canopy Stratum

Imazapyr

Four HSI models were used to evaluate the effects of mid-rotation release on canopy stratum resources: scarlet tanager (*Piranga olivacea* Gmelin), pine warbler (*Dendroica*

pinus L.), black-capped chickadee (*Parus atricapillus* L.), and downy woodpecker (*Picoides pubescens* L.). Of these four models, two indicated a change in habitat suitability between the control and release areas (Table 13). Pine warbler habitat suitability was higher in the released areas of both the Piedmont (8 df, signed-rank = 16.50, $P = 0.06$) and Coastal Plain (3 df, signed-rank = 31.00, $P = 0.01$) due to the reduction in canopy hardwoods. This canopy foraging species is restricted to pine and cedar trees for both its nesting and foraging needs (Ehrlich et al. 1988); therefore, it is an indicator of canopy composition rather than structure. However, the pine warbler is quite unique in its preference for a pure pine canopy, and therefore these results cannot be expanded to reflect general increases in habitat suitability for canopy stratum species.

Table 13. Mean habitat suitability index (HSI) by treatment for wildlife species related to canopy stratum resources in Virginia Piedmont and Coastal Plain loblolly pine (*Pinus taeda* L.) plantations. Released areas were treated at mid-rotation with imazapyr (Arsenal AC ®) and fertilized with N; control areas were fertilized with N but not released.

Species	Piedmont		Coastal Plain	
	Control	Release	Control	Release
scarlet tanager (<i>Piranga olivacea</i> Gmelin)	0.95 a*	0.94 a	0.89 a	0.84 a
pine warbler (<i>Dendroica pinus</i> L.)	0.76 a	0.87 b	0.70 a	0.80 b
chickadee (<i>Parus atricapillus</i> L.)	0.06 a	0.42 b	0.33 a	0.50 a
downy woodpecker (<i>Picoides pubescens</i> L.)	0.03 a	0.16 a	0.18 a	0.23 a

*Means for each species within each region which are followed by the same letter are not significantly different at the 0.10 alpha level, Wilcoxon signed-rank test.

In contrast to the pine warbler model, the scarlet tanager model is an indicator of canopy structure. Scarlet tanagers, which nest and forage in the canopy of both deciduous and coniferous trees, are mainly found in mature forest stands. In this model, tree height and canopy cover were used as an index of forest maturity. Although the complete model contained a variable related to forest patch size, the scale of our study allowed us only to apply the forest maturity index. The lack of a statistically significant difference in this index

between control and released areas in both the Piedmont (8 df, signed-rank = 1.50, $P = 0.84$) and the Coastal Plain (11 df, signed-rank = 12.50, $P = 0.16$) suggested that the removal of overstory hardwoods may not result in a biologically significant reduction in canopy cover.

Habitat suitability for the black-capped chickadee was higher in the released areas of the Piedmont than in control areas of the Piedmont (8 df, signed-rank = 14.00, $P = 0.02$). This increase was primarily due to the greater number of snags on released sites, which are used for nesting and foraging purposes. In a study designed to evaluate the effect of vegetation structure on breeding bird diversity, Balda (1975) found that the number of cavity nesters did increase as the number of available snags increased. Although this suggests that release may improve habitat conditions for many cavity nesting species, the quality of snag resources must also be taken into account. Studies have shown that treating trees with herbicides is a viable way to produce snags suitable for nest cavity excavation (Conner et al. 1981, Conner et al. 1983); however, the mere presence of herbicide-killed trees will not insure ample cavity resources for all species. For example, although chickadee habitat was improved, the habitat suitability for downy woodpeckers was not altered following release in either the Piedmont (8 df, signed-rank = 5.00, $P = 0.13$) or Coastal Plain (11 df, signed-rank = 3.00, $P = 0.73$). This was due to the lower number of snags in the >15 cm category versus the 10-15 cm category in both the Piedmont (8 df, $t = 3.46$, $P = 0.01$) and the Coastal Plain (11 df, $t = 5.27$, $P = 0.00$). Therefore, although mid-rotation release has the ability to improve snag resources, the impact it will have on cavity nesters will hinge on pre-existing stand conditions, intermediate thinning operations, and individual species preferences.

Triclopyr

In contrast to the imazapyr study, no differences in the index values for canopy stratum species were detected among treatments (Table 14). The lack of significant change in the chickadee model and downy woodpecker model was likely due to the pre-treatment removal of hardwoods >10 cm dbh. This hardwood removal also reduced the number of deciduous trees reaching the upper third of the canopy in all treatments, limiting the potential for pine warbler habitat improvement following release.

Table 14. Mean habitat suitability index (HSI) by treatment for wildlife species related to canopy stratum resources in Virginia loblolly pine (*Pinus taeda* L.) plantations. Control plots received no fertilization or release, fertilization plots received N and P fertilization at mid-rotation, and release plots received N and P fertilization plus basal application of triclopyr (Garlon 4®).

Species	Control	Fertilization	Release
scarlet tanager (<i>Piranga olivacea</i> Gmelin)	0.62 a*	0.56 a	0.66 a
pine warbler (<i>Dendroica pinus</i> L.)	0.69 a	0.64 a	0.68 a
chickadee (<i>Parus atricapillus</i> L.)	0.18 a	0.18 a	0.18 a
downy woodpecker (<i>Picoides pubescens</i> L.)	0.14 a	0.18 a	0.04 a

*Means for each species which are followed by the same letter are not significantly different at the 0.10 alpha level comparisonwise, Fisher's LSD.

Shrub Stratum

Imazapyr

Two models were used to evaluate the shrub strata: the brown thrasher and the cover index for the bobwhite quail model. The brown thrasher requires a well-developed shrub layer for nesting, and quail depend on low dense woody vegetation for protective cover. The brown thrasher HSI did not differ between treatments in either the Piedmont (8 df, signed-rank = 11.00, $p = 0.13$) or Coastal Plain (11 df, signed-rank = 16, $p = 0.23$). The quail cover index was lower in Piedmont released areas (8 df, signed-rank = 11.00) (Table 15); however, no difference was detected in the Coastal Plain (11df, signed-rank = 4.00, $p = 0.77$).

The reduction in quail cover suitability detected in the Piedmont was mainly due to reductions in shrub stratum cover that occurred directly after release. There was an interaction between treatment and release date for the quail cover index in the Piedmont (2,12 df, $F = 10.09$, $P = 0.00$), which directly reflected changes in shrub stratum percent cover. This suggests that the suitability of the habitat in terms of providing cover for quail and other ground stratum species may increase with time following release (Figure 16).

Table 15. Mean habitat suitability index (HSI) by treatment for wildlife species related to shrub stratum resources in Virginia Piedmont and Coastal Plain loblolly pine (*Pinus taeda* L.) plantations. Released areas were treated at mid-rotation with imazapyr (Arsenal AC ®) and fertilized with N; control areas were fertilized with N but not released.

Species	Piedmont		Coastal Plain	
	Control	Release	Control	Release
brown thrasher (<i>Toxostoma rufum</i> L.)	0.21 a*	0.16 a	0.23 a	0.18 a
bobwhite quail (<i>Colinus virginianus</i> L.)	0.96 a	0.69 b	0.90 a	0.73 a

*Means for each species within each region which are followed by the same letter are not significantly different at the 0.10 alpha level, Wilcoxon signed-rank test.

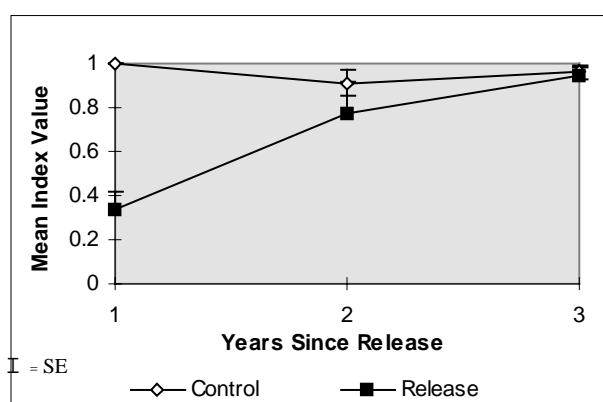


Figure 16. Trends in mean bobwhite quail (*Colinus virginianus* L.) cover suitability with years since release in loblolly pine (*Pinus taeda* L.) plantations in the Piedmont of Virginia. Released areas were treated at mid-rotation with imazapyr (Arsenal AC ®) and fertilized with N; control areas were fertilized with N but not released.

As previously described, much of the recovery in shrub strata can be attributed to an increase in *Rubus* spp.. Although species richness was reduced following release, this increase in soft mast producers may be beneficial to some wildlife species. In addition, the dense thorny thickets of *Rubus* spp. may enhance nesting and protective cover for some species. McNease and Hurst (1991) pointed out that the removal of hardwoods via herbicide application may be beneficial to wildlife because hardwoods often prevent the growth of more desirable wildlife vegetation such as vines and forbs.

Triclopyr

Treatment was found to be a significant factor influencing brown thrasher suitability values (2 df, $X^2 = 12.73$, $P = 0.00$); however, the treatments did not alter bobwhite quail cover index values (2 df, $X^2 = 0.29$, $P = 0.86$) (Table 16). Mean thrasher habitat suitability was lower on released plots than on fertilized or control plots ($\alpha = 0.10$, Fisher's LSD). As was the case with imazapyr release, these lower suitabilities reflected the reduction in stem density following release.

Table 16. Mean habitat suitability index (HSI) by treatment for wildlife species related to shrub stratum resources in Virginia loblolly pine (*Pinus taeda* L.) plantations. Control plots received no fertilization or release, fertilization plots received N and P fertilization at mid-rotation, and release plots received N and P fertilization plus basal application of triclopyr (Garlon 4®).

Species	Control	Fertilization	Release
brown thrasher (<i>Toxostoma rufum</i> L.)	0.39 a*	0.46 a	0.13 b
bobwhite quail (<i>Colinus virginianus</i> L.)	0.93 a	0.91a	0.80 a

*Means for each species which are followed by the same letter are not significantly different at the 0.10 alpha level comparisonwise, Fisher's LSD.

Ground Stratum

Imazapyr

Selected portions of two HSI models were used to evaluate changes in ground stratum habitat resources: the winter cover/food index for the eastern cottontail and the summer food/brood index of the eastern wild turkey. The cottontail winter/food index was chosen for analysis because of its inclusion of a mix of woody and herbaceous cover requirements which may be helpful in the extrapolation of these results to other ground stratum wildlife species. According to this index, cottontails require at least 20% shrub cover, but at levels of shrub cover greater than 50%, habitat quality begins to decline due to the reduced area available for herbaceous vegetation. Canopy cover is also included as an indicator of winter cover, with some trees being beneficial but levels of canopy cover greater

than 50% considered to be undesirable due to resultant declines in shrub stratum cover. This model also considers persistent herbaceous vegetation to improve cover resources when woody material is in short supply.

The summer food/brood index is one of four detailed model components comprising the turkey HSI model and was included strictly to evaluate changes in herbaceous resources. Despite the cover type restriction which deems it inapplicable in evergreen forests, this component was included in the study due to the potential for herbaceous stratum improvement following mid-rotation brush control with Arsenal® (American Cyanamid 1995). According to this index, herbaceous densities between 60% and 80% will provide adequate insect populations for young turkeys while still allowing free movement at ground level. Herbaceous heights of 20.0 cm to 60.0 cm are also considered ideal in this index.

No differences in the cottontail winter food/cover index were observed between treatments in either the Piedmont (8 df, signed-rank = 1.00, P = 0.91) or the Coastal Plain (11 df, signed-rank = 4.00, P = 0.77) (Table 17). The turkey food/brood index was also not different between treatments (8 df, signed-rank = 6.00, P = 0.46 and 11 df, signed-rank = 0.00, P = 1.00 for the Piedmont and Coastal Plain respectively) (Table 17). The lack of change in the cottontail winter food/cover index was likely due to the presence of suitable shrub resources in both the release and control areas. Low herbaceous cover levels and insignificant changes in herbaceous cover contributed to the absence of difference in the turkey food/brood index.

Table 17. Mean habitat suitability index (HSI) by treatment for wildlife species related to ground stratum resources in Virginia Piedmont and Coastal Plain loblolly pine (*Pinus taeda* L.) plantations. Released areas were treated at mid-rotation with imazapyr (Arsenal AC®) and fertilized with N; control areas were fertilized with N but not released.

Species	Piedmont		Coastal Plain	
	Control	Release	Control	Release
eastern cottontail (<i>Sylvilagus floridanus</i> Allen)	0.84 a*	0.82 a	0.76 a	0.76 a
eastern wild turkey (<i>Meleagris gallopavo sylvestris</i> L.)	0.26 a	0.40 a	0.08 a	0.10 a

*Means for each species within each region which are followed by the same letter are not significantly different at the 0.10 alpha level comparisonwise, Wilcoxon signed-rank test.

Triclopyr

No significant treatment effects were found for either the cottontail (2 df, $X^2 = 0.93$, $P = 0.63$) or turkey summer food/brood index (2 df, $X^2 = 4.41$, $P = 0.11$) (Table 18). These results were counter to what had been anticipated following the removal of understory hardwood cover. The increases in herbaceous cover that were detected following triclopyr release were expected to improve habitat suitability for species such as the turkey and cottontail, which are dependent on a well-developed herbaceous layer. These results indicate that although the herbaceous cover was increased in the released area by an average of 15.71% (SE = 0.88) over control and fertilized areas, the magnitude of change may not be large enough to significantly improve habitat.

Table 18. Mean habitat suitability index (HSI) by treatment for wildlife species related to ground stratum resources in Virginia loblolly pine (*Pinus taeda* L.) plantations. Control plots received no fertilization or release, fertilization plots received N and P fertilization at mid-rotation, and release plots received N and P fertilization plus basal application of triclopyr (Garlon 4®).

Species	Control	Fertilization	Release
eastern cottontail (<i>Sylvilagus floridanus</i> Allen)	0.25 a*	0.20 a	0.46 a
eastern wild turkey (<i>Meleagris gallopavo sylvestris</i> L.)	0.87 a	0.83 a	0.88 a

*Means for each species followed by the same letter are not significantly different at the alpha = 0.10 level comparisonwise, Fisher's LSD.

SUMMARY AND CONCLUSIONS

Mid-rotation release, a new silvicultural technique in practice throughout much of the Southeast, has the potential to enhance pine yield and alter forest structure. Wildlife species that utilize pine plantations as habitat may be positively or negatively affected by these alterations depending on their individual habitat requirements. I found that the volume per tree on operationally thinned, fertilized loblolly pine plantations was increased following aerial imazapyr release an average of 0.06 m^3 (18%) over three years in the Piedmont and 0.06 m^3 (14%) over four years in the Coastal Plain. In the Coastal Plain, volume per hectare was increased an average of $8.17 \text{ m}^3/\text{ha}/\text{yr}$.

Both aerial imazapyr release and basal triclopyr release reduced the percentage of hardwoods reaching the upper third of the canopy, and imazapyr significantly reduced hardwood basal area. The reduction in hardwood basal area on imazapyr sites was accompanied by a reduction in both richness and diversity.

Shrub stem density and percent cover were reduced following both imazapyr and triclopyr release. A significant interaction between release date and treatment was identified for shrub stratum cover values on imazapyr sites, suggesting a possible recovery to pre-release conditions. Richness and diversity were reduced following imazapyr release but not triclopyr release.

Herbaceous cover was increased following basal triclopyr release, but there was no significant difference in herbaceous cover detected on imazapyr sites. Evaluation by growth form revealed an increase in forbs following imazapyr release, but no changes were found following triclopyr release.

Although these alterations in forest structure should be examined on a species-specific basis, several generalizations can be made based on our findings. The increase in snags and corresponding increase in black-capped chickadee habitat suitability following release indicates that mid-rotation release of stands with moderate hardwood basal area component ($\geq 10\%$) can improve habitat for some cavity nesting species. The removal of hardwoods from the upper canopy does not appear to reduce canopy cover enough to affect species such as the scarlet tanager, which prefers closed canopy mature stands, and it may improve habitat for species such as the pine warbler, which favors pure pine stands.

Shrub stratum reductions may temporarily reduce habitat suitability for species that require low woody vegetation for nesting and protective cover, such as the brown thrasher and bobwhite quail. However, evaluation of imazapyr results by release date suggests that shrub stratum cover may recover in a relatively short period of time. A primary factor in this increased shrub stratum cover was the expansion of *Rubus* spp. following release. *Rubus* spp. may enhance wildlife habitat through the increased availability of soft mast and protective cover; however, this alteration in composition should be evaluated on an individual species basis.

In terms of herbaceous layer enhancements, our data suggests that no significant increase in herbaceous cover occurs following broadcast release with imazapyr; however, directed basal application of triclopyr may increase cover. Species which depend on a well-developed herbaceous layer may respond positively to these enhancements; however, we detected no significant increases in the cottontail winter cover/food index or turkey summer food/brood index.

This ex-post facto examination of mid-rotation release augments the results of past studies that documented pine yield gains and provides a preliminary look at the effects of this practice on forest structure and wildlife habitat. Future research initiatives should include the controlled investigation of forest structure in pine plantations released at mid-rotation and the evaluation of wildlife populations which they support.

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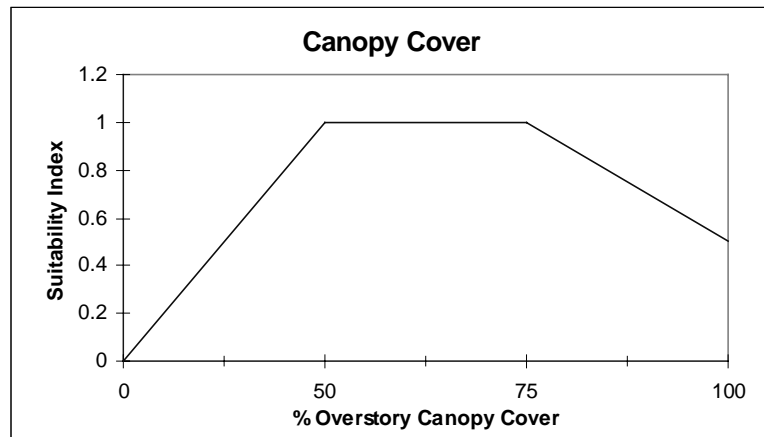
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APPENDIX A

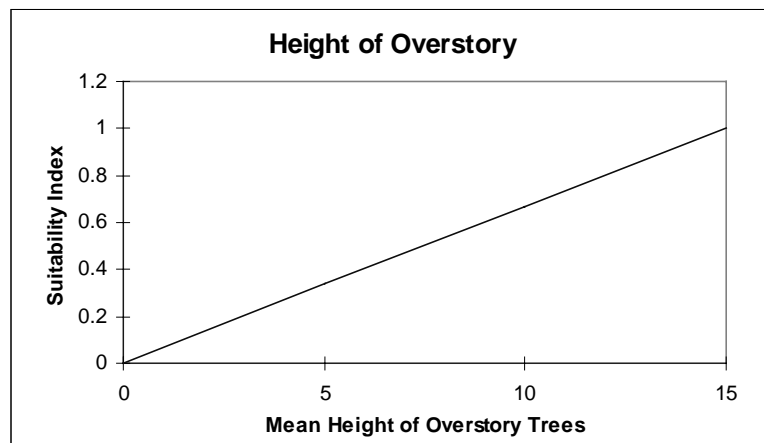
HSI SUITABILITY INDEX CURVES

BLACK-CAPPED CHICKADEE HSI

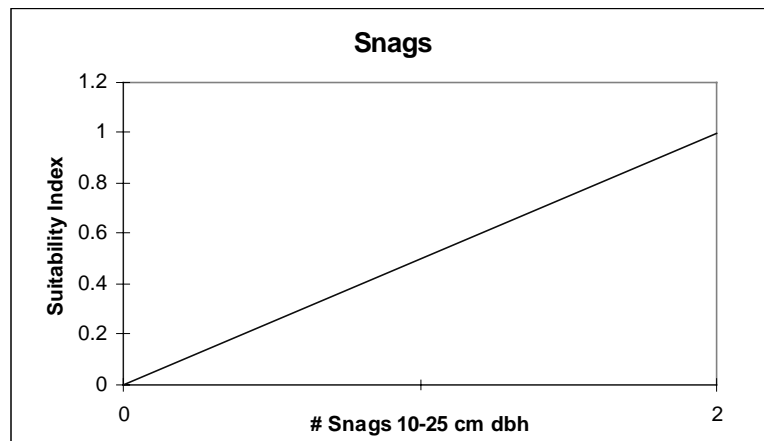
Variable 1



Variable 2

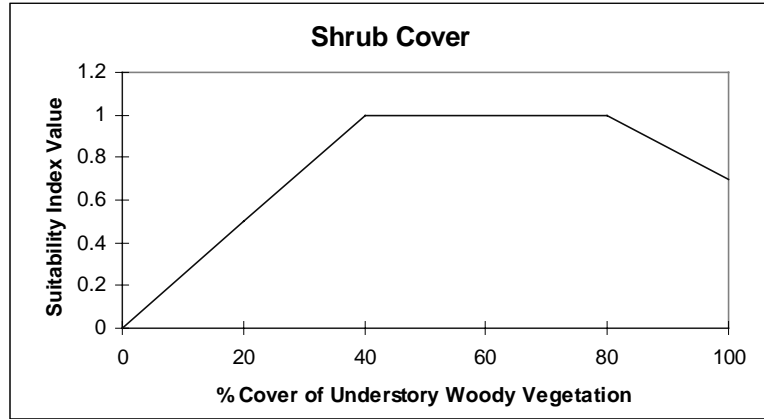


Variable 3



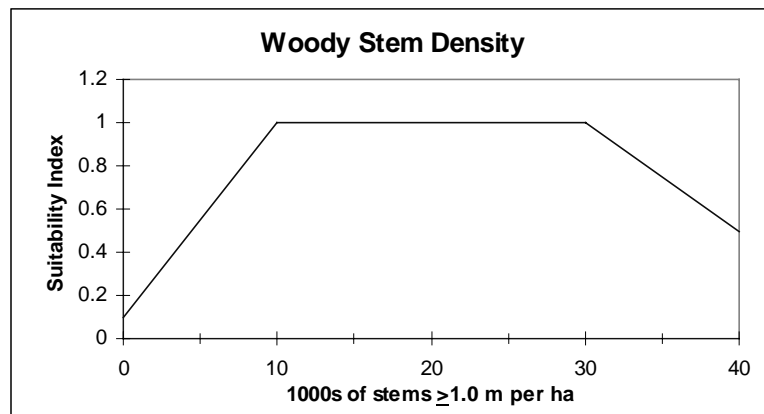
BOBWHITE QUAIL COVER INDEX

Variable 1

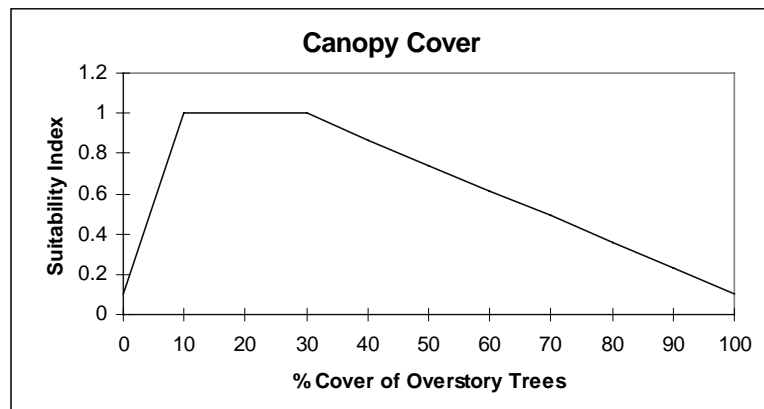


BROWN THRASHER HSI

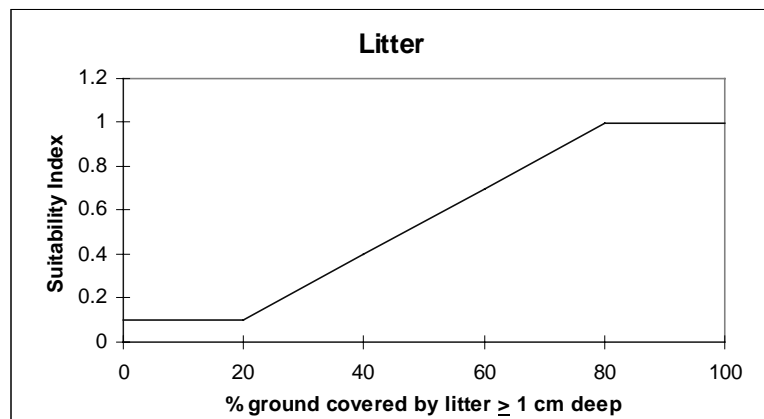
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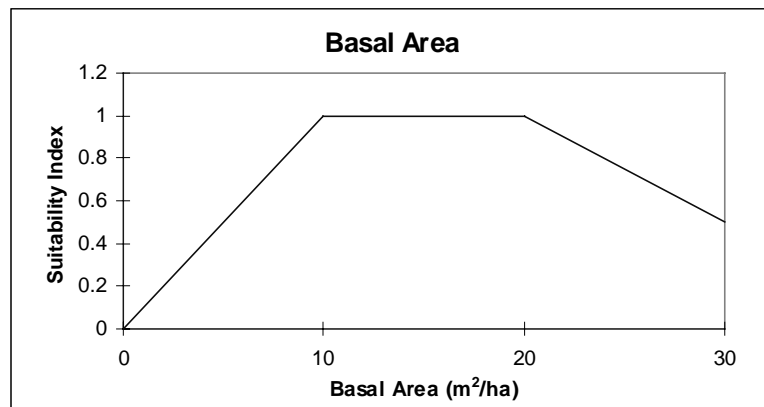


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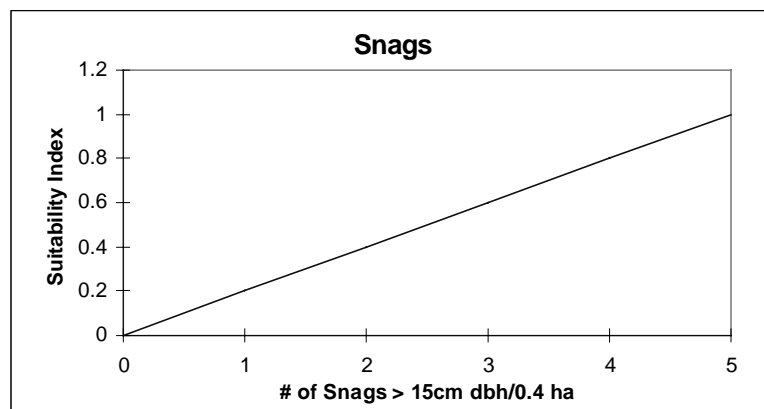


DOWNY WOODPECKER HSI

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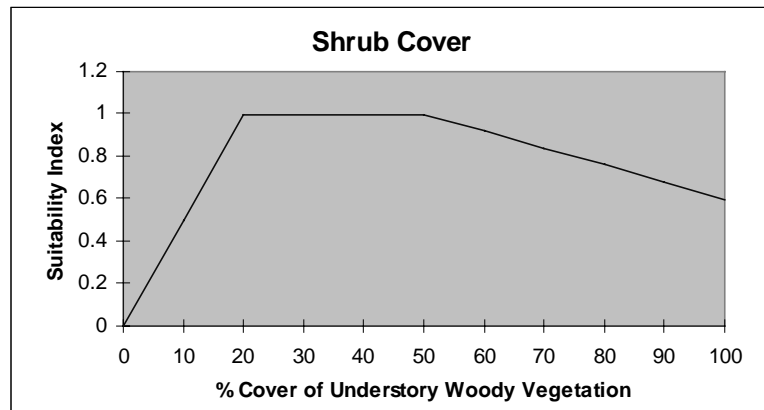


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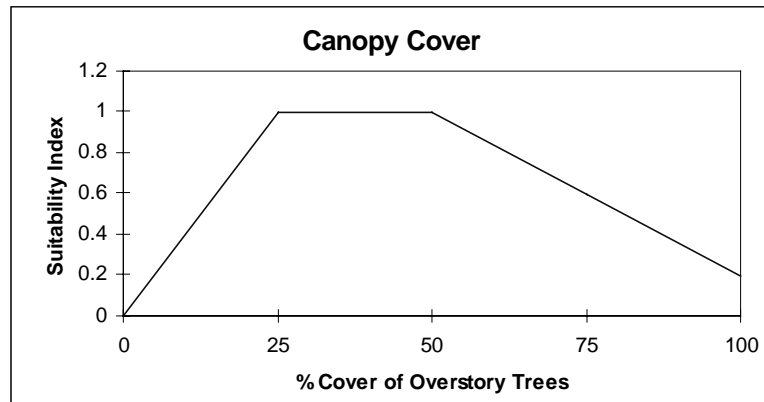


EASTERN COTTONTAIL WINTER COVER/FOOD INDEX

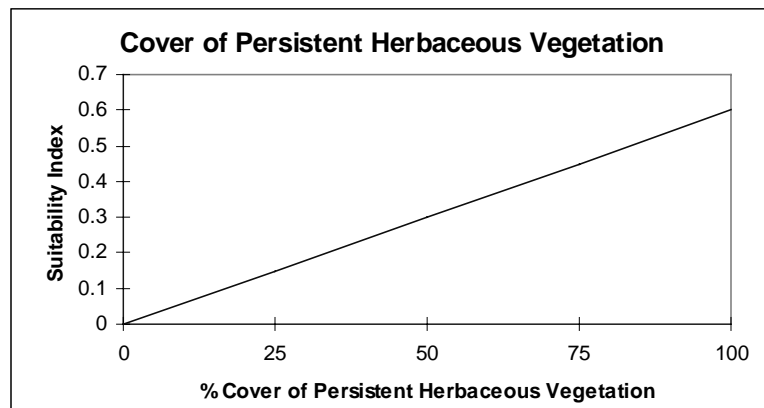
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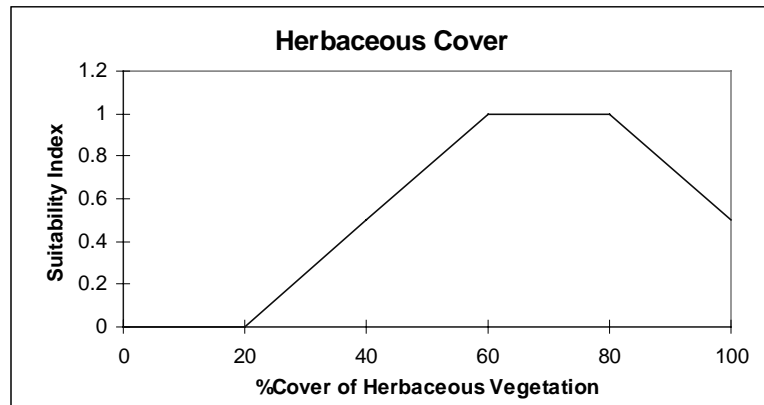


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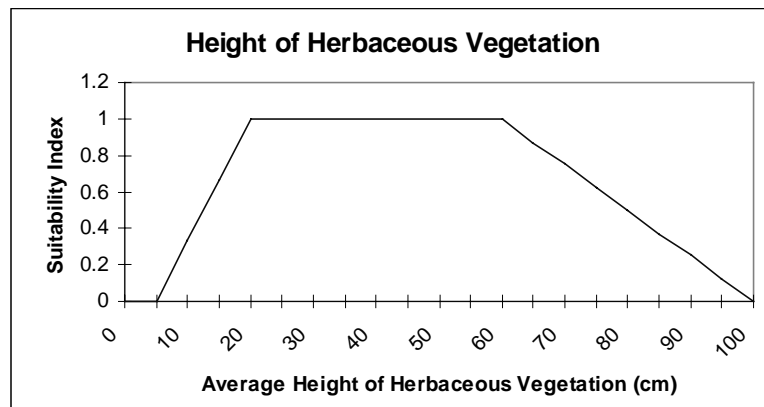


EASTERN WILD TURKEY SUMMER FOOD/BROOD INDEX

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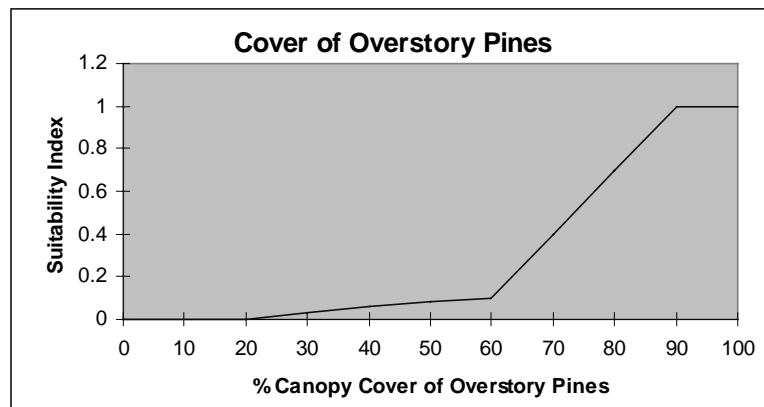


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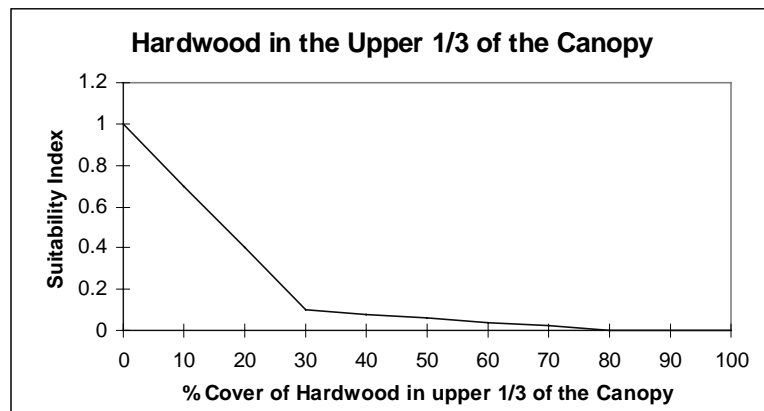


PINE WARBLER HSI

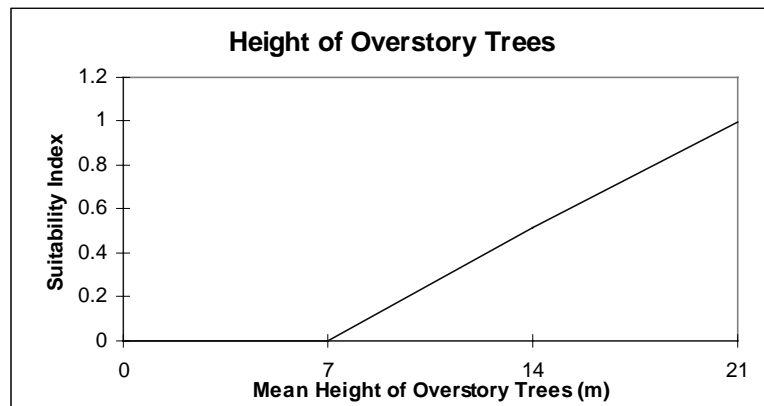
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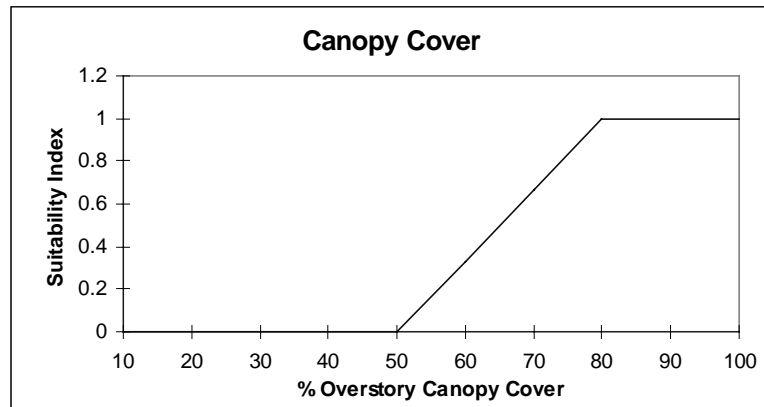


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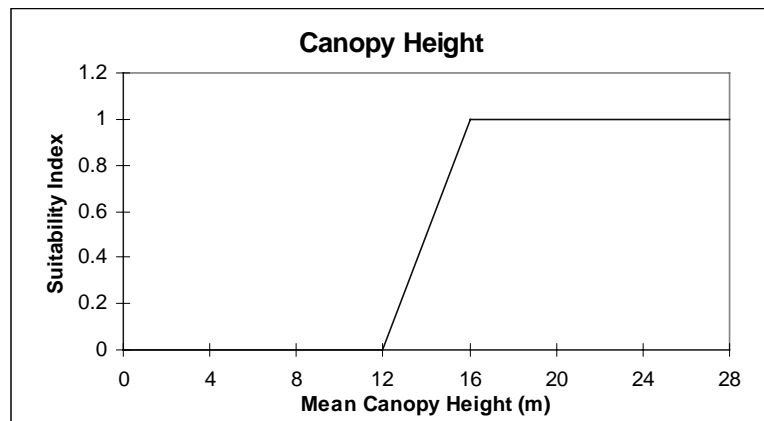


SCARLET TANAGER FOREST MATURITY INDEX

Variable 1



Variable 2



VITA

Kyla Ingeborg Cheynet, daughter of George and Ruth Lacy, was born March 22, 1972, in Riverside, California. Following her graduation in 1990 from Blacksburg High School, she attended North Carolina State University, where she played on their nationally ranked women's soccer team and majored in Zoology. In 1992 she transferred to Virginia Tech and majored in Wildlife Management, graduating Summa Cum Laude in 1994. In 1995 Kyla married John A. Cheynet and moved to the Coastal Plain of Virginia, where she worked as a research technician, wildlife habitat consultant, and resource management assistant. In 1998 she returned to Virginia Tech as a graduate research and teaching assistant in the Department of Forestry. After graduation in December 1999, she begins work with Westvaco as a Cooperative Forest Management Forester in Covington, Virginia.