ROLE OF HERBICIDES IN LONGLEAF PINE FLATWOODS RESTORATION: PINE GROWTH, UNDERSTORY VEGETATION RESPONSE AND FATE OF APPLIED HERBICIDES

By

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To my beloved parents, sisters and Jenny.

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Longleaf pine ecosystems, once dominant in the southeastern Coastal Plain, have been drastically reduced in acreage by excessive logging, land use changes and fire suppression. Increased understory competition is a primary cause for inadequate regeneration of longleaf pine. In pine flatwoods understory competition is heightened due to the dense shrub understory. Effective vegetation control is achieved in flatwoods with the use of intensive mechanical and chemical site preparation methods. Although these methods are successful in increasing pine growth, they are also detrimental to native plant diversity. The renewed interests in restoration of longleaf ecosystems are often guided by multiple objectives. Protecting the rich biodiversity of these unique ecosystems is of great importance. Therefore, intensive site preparation methods may not be appropriate in vegetation control in areas concerned with restoration. As an alternative low intensive site preparation followed by over the top application of herbicides is suggested.

In this study the application of three commercially available herbicides (hexazinone, sulfometuron and imazapyr) following site preparation by single drum chopping and burning was investigated. Pine growth and survival were measured after one growing season. Effect on understory vegetation was assessed three and nine months after herbicide application. In addition, fate of applied herbicides was determined 16, 90 and 240 days after treatment at 0-15, 15-30 and 45–60 cm soil depths. A bioassay was used to determine herbicide concentrations in soil.

Herbicide applications significantly reduced longleaf seedling survival compared to control with the exception of hexazinone. However, imazapyr treatment significantly increased pine seedling growth compared to the control. Sulfometuron treatment displayed a stunting effect by reducing seedling growth compared to control. Imazapyr treatment resulted in significant control of overall shrub species, with other treatments exhibiting no effect. Species diversity increased with imazapyr application compared to other treatments. However, sulfometuron significantly reduced species diversity compared to control. Hexazinone and sulfometuron dissipated to very low concentrations 240 days after treatment. Imazapyr was found in very low concentrations 16 days after treatment and indicated persistence, as it did not dissipate rapidly with time.

CHAPTER 1
LONGLEAF PINE ECOSYSTEMS AND THEIR RESTORATION IN FLATWOODS

Longleaf Pine Ecosystems and Their Decline

Longleaf pine (*Pinus palustris* Mill) ecosystems once occupied an estimated 37 million ha in the south and southeastern United States (Frost 1993). These forests dominated the Coastal Plain areas ranging from Virginia to Texas through central Florida (Croker 1979, Landers, Van Lear and Boyer 1995), occupying a variety of sites ranging from xeric sandhills to wet poorly drained flatwoods (Carter et al. 1998, Brockway and Outcalt 2000, Boyer 1990). The extent of longleaf pine ecosystems has greatly declined since European settlement. At present, they occupy less than 2 million ha, about 5% of the original acreage (Kelly and Bechtold 1990, Busby et al. 1995). Excessive logging in the early 20th century cleared vast areas of virgin longleaf forests with minimal effort in regeneration. As the demand for timber increased, land that was once under longleaf pine was converted to other faster growing pine species such as slash pine (*Pinus elliottii* Engelm.) and loblolly pine (*Pinus taeda* L.). Conversion of forestland in to agriculture reduced the longleaf acreage further more.

Throughout its natural range, longleaf ecosystems are faced with many disturbances such as periodic fires and hurricanes, which play a very important ecological role. Through these disturbances and varying site conditions, longleaf ecosystems are comprised of a mosaic of community types that sustains a variety of flora and fauna (Brockway and Outcalt 2000, Croker 1979). The canopy gaps and the open midstory created by these disturbances allows more sunlight to reach the forest floor, thus inducing understory vegetation growth.

Longleaf ecosystems have one of the richest species diversities outside the tropics (Peet and Allard 1993). Although the overstory is dominated by one species, the understory is host to a plethora of plant species. The diversity among the herbaceous plants is the main contributor to its high biodiversity. The composition of the understory is site specific, but is mainly dominated by grass species. In the western Gulf Coastal Plain, the understory is comprised mainly of bluestem grasses. In Florida and along the Atlantic Coast wiregrass (*Aristida beyrichiana)* is dominant, with *Aristida stricta* occurring from central South Carolina through North Carolina (Peet 1993). One of the significant causes for the reduction of longleaf regeneration was the interruption of natural fire cycles in the understory.

Role of Fire, Mechanical and Chemical Site Preparation as Restoration Techniques

Prior to European settlement, periodic fires were a frequent phenomenon in longleaf ecosystems and were ignited by lightning and native Americans (Croker 1979). Such frequent fires promoted longleaf dominance limiting the less fire adapted hardwood species to more mesic sites. Fire also created a forest structure with open midstory and a savanna like understory. The understory, mainly comprised of grasses, provided the necessary fuels and facilitated the spread of these fires.

Understanding the role of fire and the autecology of longleaf pine is vital for the restoration of this ecosystem. Longleaf pine is a very intolerant pioneer species (Landers et al. 1995) and does not compete well for site resources with other more aggressive species (Brockway and Lewis 1997). With the removal of fire, the less fire adapted shrub species were allowed to spread into the understory. The encroaching hardwoods compete for site resources and light with the longleaf seedlings and hinder their growth and regeneration. Research shows that simulating the natural fire regime by applying frequent growing season burns increases the growth and survival of longleaf pine seedlings (Grelen 1978, 1983). Longleaf seedlings undergo an extended stem-less phase without height initiation. This phase, also known as the “grass stage”, varies in length depending on site resources and competition and may last as long as 10-15 years. Increased competition from the shrubs hinders height initiation of regenerating longleaf seedlings. The shrub species also outcompete the native grass and herbaceous species for site resources such as light. Studies show a significant increase in species diversity and richness on sites under a frequent fire regime (Brockway and Lewis 1997). In addition, the dangers of catastrophic fires are increased with the encroachment of shrub and other hardwood species. The shrubs and hardwoods occupy the once open midstory and provide ladder fuels that could cause crown fires and damage entire forests (Brockway and Lewis 1997). In addition to competition for light some hardwood scrub species display allelopathy against native pines including longleaf pine and native herbaceous species (Richardson 1985).

Compared to other pine species, longleaf pine is not a prolific seeder. Longleaf pine seeds require over three years for their physiological development (Pederson et al. 1999). Thus good seed crops are infrequent and may arise once every 4-5 years. The seeds are large and heavy and do not disperse a great distance (Landers et al. 1995). The short dispersal of the seeds prevents longleaf pine from colonizing and establishing in areas far from the seed source. Longleaf seeds require a seedbed of exposed mineral soil free of surface litter. Fire exclusion results in accumulation of forest litter that hinders proper germination of longleaf pine seeds (Croker 1975). The number of regenerating seedlings is further lowered through predation by non-native feral hogs. One study done on the impact of feral hogs demonstrated that exclusion of hogs resulted in 500 seedlings in the fenced area compared to 8 seedlings in non fenced areas (Lipscomb 1989).

Due to its rapid and continuing decline, longleaf forests are considered an endangered ecosystem. Therefore, there is heightened interest in developing techniques to restore longleaf pine ecosystems. Better understanding of the silvicultural requirements of longleaf pine has enabled foresters and landowners to successfully establish and manage longleaf forests. With the alarming increase of endangered species, there is also great amount of interest in maintaining the biodiversity of these ecosystems.

The use of prescribed fire has greatly enhanced longleaf restoration efforts. The use of prescribed fire is suggested prior to seed fall to improve seedbed conditions. In areas sensitive to burning, mechanical scarification methods are suggested (Croker 1975). Fire is also used effectively to eliminate hardwood shrubs thus releasing regenerating pines from vegetation competition. Unfortunately, prescribed fire may not be applicable in some sites. The use of fire in forests near residential or commercial properties bears the risk of damaging human lives and property. Prescribed fire may only be used under favorable weather conditions and proper authorization. Forest fires also increase the potential for soil erosion, and prescribed fire should be used with caution on sites prone to erosion. With concern for catastrophic crown fires, sites with heavy fuel loads should not be burned until fuel loads are reduced by other methods. Due to such limitations of prescribed fire, alternative vegetation control methods are used.

Understory shrub control could also be achieved through mechanical site preparation and vegetation removal. Intensive site preparation such as disking, harrowing and bedding has been successful in temporarily reducing understory shrub vegetation. On sites concerned with understory restoration such as wiregrass establishment, intensive site preparation should be limited. Research shows that intensive site preparation may adversely effect wiregrass populations (Clewell 1989). Excessive soil disturbance through mechanical site preparation may also increase the risk of soil erosion. Chemical treatments in the form of herbicides have been widely used to control understory vegetation. Herbicides are found in many forms, which differ in their mode of action, and target species. Therefore, herbicides can be used at different stages of stand development to selectively control undesired species.

Longleaf Pine Flatwoods Restoration

Pine flatwoods constituted a major forest type in the southeastern Coastal Plain and occupied nearly 50% of the Florida peninsula (Davis 1967). The soils within pine flatwoods are poorly drained saturated sandy soils with seasonal flooding (Stout and Marion 1993). Historically, this landscape was dominated by longleaf and slash pine depending on site conditions. Longleaf pine dominated the upland and moderate to poorly drained sites, frequented by fires. Slash pine was limited to the wetter sites where fires were not prevalent (Stout and Marion 1993). Flatwoods ecosystems are also characterized as having relatively dense understories, typically comprised of shrubs such as gallberry (*Ilex glabra*), saw palmetto (*Serenoa repens*), runner oak (*Quercus pumila*), fetterbush (*Lyonia lucida*), blueberry (*Vaccinum myrsinites*) and hairy wicky (*Kalmia hirsuta*) (Huck 1987).

The predominantly shrub understory amplifies the challenges faced by young longleaf seedlings due to the increased competition for site resources. Restoration techniques such as prescribed fire have been widely used to control understory shrub vegetation resulting in successful establishment of longleaf pine forests on many sites (Provencher et al 2001). However, vegetation control by prescribed fire is short-lived on flatwood sites due to the vigorous resprouting of the shrubs. Typical shrubs and herbaceous species of flatwoods sites have extensive rootstock systems that enable the vegetation to resprout rapidly following fire (Abrahamson 1984). Therefore, alternative restoration tools are required for successful establishment of longleaf pine on flatwood sites.

Alternative vegetation control methods such as mechanical and chemical site preparation and pine release treatments have been widely studied on flatwood sites with slash pine (Kline et al 1994, Shiver et al 1991, Shiver et al 1990, Burger et al 1988). For example, Shiver et al (1990) reported significant growth increases in planted slash pine seedlings with site preparation methods such as chopping and bedding. Burger et al (1988) compared low intensity (chopping, burning) and high intensity (blading and harrowing) site preparation methods on flatwood sites and reported significant early growth gains with intensive site preparation. A majority of the flatwood studies used bedding as a standard site preparation method for better growth. Research done by Shiver et al (1991) on the use of picloram-triclopyr mixtures at site preparation rates reported 70 % control of gallberry, saw palmetto, wax myrtle and blueberry species. The study also reported 70% or greater control of blueberry species and staggerbush with imazapyr at site preparation rates. A similar study done by Kline et al (1994) using triclopyr and imazapyr mixtures at site preparation rates achieved good control over a majority of the shrub species. However, both studies found that even at high rates none of the herbicides yielded equal control on all flatwood species.

The recent increase of interest in longleaf pine restoration is with multiple objectives such as biodiversity protection and enhancement of wildlife habitat. Therefore, the effect of restoration activities on native plant diversity is of concern. Mechanical site preparation such as bedding, disking and harrowing causes extensive soil disturbances. Although these methods are very effective in providing better growth gains among planted pine seedlings, they are detrimental to the native plant diversity. For instance, wiregrass a keystone species within longleaf pine ecosystems is very sensitive to ground disturbance. According to Clewell (1989), wiregrass is a poor seed producer and relies on vegetative propagation for its expansion. Wiregrass is also easily uprooted and once uprooted it is rarely successful in propagation. Therefore, intensive site preparation should not be used in areas concerned with understory restoration with wiregrass.

Information regarding the effect of herbicides on the groundcover vegetation of natural flatwoods and sandhill communities is scarce (Litt et al 2001). An extensive literature review done by Litt et al (2001) on published research regarding herbicide effects on groundlayer vegetation found only 3 and 7 studies, respectively, on natural flatwoods and sandhill sites. A study done by Neary et al (1990) on a flatwood site in Florida found nearly 75% reduction in species richness following an intensive weed management regime with repeated application of sulfometuron, glyphosate and triclopyr treatments and mowing. Brockway et al (1998) studied the effects of hexazinone applied at 1.1 and 2.2 kg/ha with different application techniques on a sandhill site. They reported significant decrease in the cover of oak species and shrub control at the higher rate. Moreover, the higher rate application of hexazinone induced an 86% increase in biomass of wiregrass in the first growing season after treatment. With the broadcast application of hexazinone, a short-term reduction of forb species was also reported. The continuance of herbicide effects appears to be dependent on the rate and method of application. However, most treatment applications seem to cause only short-term changes in species diversity and composition. A long-term study of herbicide effect on understory plant diversity and richness was conducted by Boyd et al (1995) with one-time broadcast applications of imazapyr, glyphosate, and hexazinone. The reported results 7 years after treatment showed no significant herbicide effect on species diversity and richness.

Fate of Applied Herbicides

The application of herbicides creates a contamination risk of ground and surface water bodies. Extensive research has been conducted on the offsite movement of applied herbicides and the risk of contamination. Studies done by Michael and Neary (1993) with multiple herbicides on industrial forestry sites near a watershed reported levels of contamination less than the Health Advisory Levels (HAL). On some sites, herbicide concentrations exceeded HAL and drinking water standards when herbicide applications were directed onto surface water bodies, but did not persist for an extended period of time (Michael 2000, Neary et al. 1996). The groundwater level in flatwoods sites is prone to seasonal fluctuations and may rise as high as the soil surface level. On such sites, the application of herbicide may seem to involve high risk. In contrast, a study done on a flatwoods site by Neary et al. (1989), reported low levels of offsite movement and contamination of ground water using sulfometuron methyl.

Phytotoxic effects of herbicide residue on non-target species are also of concern. Herbicide residue on agricultural fields has displayed phytotoxic effects on rotational crops (Brewster and Appleby 1985). Movement and persistence of forestry herbicides depend on weather, edaphic conditions, herbicide characteristics, method and time of application and site characteristics (Norris 1981).

The majority of aforementioned research involved intensive mechanical and chemical site preparation treatments. Such methods may not be appropriate on most flatwoods sites with high water table and where multiple management objectives, including understory species richness and diversity, are of great concern. As a shrub control method in flatwoods, low-rate, over the top application of herbicide following less intensive site preparation could serve s an alternative to high intensity site preparation. In our study, three commonly used forestry herbicides, hexazinone, sulfometuron and imazapyr were used and their efficacy was examined. These herbicide treatments were applied following single drum chopping and prescribed burning. The three major research objectives addressed in this study were:

- Determine the extent of pine seedling response
- Quantify the fate of applied herbicides in the soil
- Determine the effect of applied herbicides on understory species diversity and composition

CHAPTER 2
LONGLEAF PINE SEEDLING AND UNDERSTORY VEGETATION RESPONSE TO HERBICIDAL VEGETATION CONTROL AND FATE OF APPLIED HERBICIDES IN FLATWOODS

Introduction

Pine Flatwoods

Pine flatwoods constituted a major forest type in the southeastern Coastal Plain and occupied nearly 50% of the Florida peninsula (Davis 1967). These landscapes were mostly dominated by longleaf pine (*Pinus palustris* Mill.) or slash pine (*Pinus elliottii* Engelm.) depending on site conditions. Longleaf pine dominated the upland and moderate to poorly drained sites, frequented by fires. Slash pine was limited to the wetter sites where fires were not prevalent (Stout and Marion 1993). Due to excessive logging and inadequate regeneration, the extent of longleaf pine ecosystems including flatwoods has greatly declined since European settlement. At present, longleaf pine forests occupy less than 2 million ha, about 5% of the original acreage (Kelly and Bechtold 1990, Busby et al. 1995).

Due to the high demand for timber and the rise of plantation forestry, many longleaf dominated sites were converted to slash pine and loblolly pine (*Pinus taeda* L.) (Croker 1979). Longleaf pine was replaced by other pines because of the slow early growth characteristic of the species. It is a poor seed producer with infrequent seed crops (Boyer 1990, Pederson et al. 1999) and requires scarified seedbed with exposed mineral soil for adequate germination (Croker 1979). Once established, longleaf seedlings exhibit a slow growth phase with little to no height initiation for several years. This slow juvenile growth phase, also known as the "grass stage" is extended with increased competition for site resources (Haywood 2000, Jose et al. 2003). Such challenges are exacerbated on flatwoods sites due to the characteristic heavy understory of shrub species. These understories are typically comprised of shrubs such as gall berry (*Ilex glabra* L.), saw palmetto (*Serenoa repens* Bartr.), runner oak (*Quercus pumila* Walt.), fetterbush (*Lyonia lucida* Lam.), blueberry (*Vaccinum myrsinites* Chapman.) and hairy wicky (*Kalmia hirsuta* Walt.) (Huck 1987).

Vegetation Control and Pine Response

Prescribed fire has been widely used to control understory woody vegetation resulting in successful establishment of longleaf pine forests on many sites (Provencher et al. 2001). Vegetation control by prescribed fire is short-lived on flatwoods sites due to the vigorous resprouting of the vegetation. Typical shrubs and herbaceous species of flatwoods sites have extensive rootstock systems that enable the vegetation to resprout rapidly following fire (Abrahamson 1984).

Alternative vegetation control methods such as mechanical and chemical site preparation and pine release treatments have been widely studied on flatwoods sites with slash pine (Kline et al. 1994, Shiver et al. 1990, 1991, Burger et al. 1988). For example, Shiver et al. (1990) reported significant growth increases in planted slash pine seedlings with site preparation methods such as chopping and bedding. Burger et al. (1988) compared low intensity (chopping, burning) and high intensity (burning, blading and harrowing) site preparation methods on flatwoods sites and reported significant early growth gains with intensive site preparation. A majority of the flatwoods studies used bedding as a standard site preparation method for better growth. Research done by Shiver et al. (1991) on the use of picloram-triclopyr mixtures at site preparation rates reported 70 % control of gallberry, saw palmetto, wax myrtle and blueberry species. The study also reported 70% or greater control of blueberry species and staggerbush with imazapyr at site preparation rates. A similar study done by Kline et al. (1994) using triclopyr and imazapyr mixtures at site preparation rates achieved good control over majority of the shrub species. However, both studies found that even at high rates none of the herbicides yielded equal control on all flatwoods species. The importance of site specific applications of herbicide treatments depending on the prevalent shrub species was emphasized by both studies.

The aforementioned research on methods of vegetation control conducted on industrial forestry sites with slash pine may be applicable to the establishment of longleaf pine stands in flatwoods. However, the recent interests in restoring longleaf pine ecosystems are with multiple objectives in addition to increased seedling growth. In areas concerned with native biodiversity, sensitive plant populations and groundwater quality, intensive site preparation and high-rate herbicide applications may not be applicable. For example, wiregrass is reported as very sensitive to site disturbance. Therefore, on sites concerned with wiregrass regeneration intensive site preparation methods should be avoided (Clewell 1989).

Fate of Applied Herbicides

The offsite movement and persistence of applied herbicides and the risk of contamination has been widely studied. Movement and persistence of forestry herbicides depend on weather, edaphic conditions, herbicide characteristics, method and time of application and site characteristics (Norris, 1981). Studies done by Neary and Michael (1989) with sulfometuron methyl on a flatwoods site reported low levels of off-site movement and contamination of ground water. The study also reported that the high acidity (average pH = 4) of flatwoods sites further impedes the mobility of herbicides such as sulfometuron methyl. Michael and Neary (1993) reported on the off site movement of hexazinone, imazapyr, picloram and sulfometuron on industrial forestry sites in the south. Results from 23 studies showed levels of contamination less than the Health Advisory Levels (HAL) for all herbicides tested. On some sites, herbicide concentrations exceeded HAL and drinking water standards when herbicide applications were directed onto surface water bodies, but did not persist for an extended period.

Phytotoxic effects of herbicide residue on non-target species are also of concern. Herbicide residue on agricultural fields has displayed phytotoxic effects on rotational crops (Brewster and Appleby 1985). Thus, persistent herbicides may impact seasonal variation in plant communities. Due to site specificity of herbicide behavior, care should be taken in estimating herbicide movement and persistence based on data from other sites (Michael 2000).

Research on herbicidal vegetation control on flatwoods sites has focused primarily on pre-plant site preparation treatments. Information regarding the effect of over-the-top herbicide applications on longleaf pine seedlings and the understory vegetation of flatwoods sites is scarce. This study examined use of three commercially available herbicide treatments (hexazinone, sulfometuron and imazapyr) following low-intensive site preparation. The specific questions researched were:

- What is the response of longleaf pine seedling survival and growth to the applied treatments?
- What is the impact of herbicide application on major understory species foliar cover and density?

- What is the mobility and persistence of the applied herbicides in flatwoods soils?

Materials and Methods

Study Area Description

This study was conducted on a flatwoods site at the Point Washington State Forest in Walton County, Florida ($30^0$20’16.04” N, 86^0 4’19.22” W). Average annual high and low temperatures were 25.5^0C and 12^0C respectively. Annual precipitation was about 1640mm (2002) with most received in the late summer months (Figure 2-1). Soils were of low pH (pH <5) and sandy texture with low nutrient content (Table 2.1). The study area soils were mapped as sandy, siliceous, thermic aeric alaquods belonging to the Leon series, which is characterized by deep, poorly to very poorly drained soils. Soils of the flatwoods pinelands are formed on sandy quaternary formations derived from marine deposits (Stout and Marion 1993).

Prior to study establishment the overstory was a planted slash pine stand with intermittent longleaf pine saplings. The average age of the stand was 26 years with a basal area of 1.85 m^2 and an average dbh of 19.1 cm. The understory was comprised mainly of species such as gallberry, saw palmetto, runner oak, dangleberry (*Gaylussacia frondosa* L.), hairy wicky, wiregrass (*Aristida beyrichiana* Trin.and Rupr.) and bluestem grasses. Dormant season fires were used on a three-year burn cycle to mitigate fuel build up.

Experimental Design and Treatments

Prior to site preparation, the overstory was harvested (August 2001). The harvest debris and the understory were roller chopped once and prescribed burned in October 2001. A randomized complete block design was used to examine the effects of herbicidal vegetation control methods on pine seedling growth and survival. The study incorporated six blocks with five treatment plots within each block. All treatment plots were 36.6m x 24.4 m, including a > 3m buffer strip between plots. In December 2001, one year old containerized longleaf pine seedlings were hand-planted at 3.1m x 1.8m spacing. Seedlings were planted in rows to facilitate the application of treatments. Each treatment plot included 100 seedlings amounting to 3000 seedlings for the entire study. In March 2002, four herbicide treatments [Sulfometuron (0.26 ai kg/ ha), Hexazinone (0.56 ai kg/ ha), Sulfometuron (0.26 ai kg/ ha) + Hexazinone (0.56 ai kg/ ha) mix, Imazapyr (0.21 ae kg/ ha)] were applied in a 1.2 m band over the top of seedlings via a knapsack sprayer. In each block, one treatment plot was kept herbicide free as a control.

Measurements

Pine survival and growth

Pine survival was monitored six and 12 months (respectively, June 2002 and Dec 2002) after planting. Pine growth was measured after the first growing season (Dec 2002). Seedling height and root collar diameters (RCD) were measured as growth parameters on all planted seedlings. Seedling height was measured using a ruler, from soil surface to the top of the bud and RCD was measured using a digital caliper. Stem volume index (SVI) was calculated with the measured RCD and height data. Initial RCD of seedlings were also recorded prior to planting as baseline data. Within our study, post-planting burial was observed among the majority of the dead seedlings. In addition to growth measurements, the extent of post planting burial was estimated for each seedling.

Vegetation control assessment

A preliminary vegetation survey was conducted (June 2001) prior to overstory harvest and site preparation to assess the initial presence and percent cover of understory species. Following site preparation and herbicide application, two vegetation surveys were conducted. These surveys were done six and eleven months (June and Nov 2002) after pine planting. In each plot six randomly selected $1m^2$ quadrats were sampled in the herbicide treated bands and were revisited for subsequent surveys. Percent cover was ocularly estimated for all species using the modified Daubenmire scale (Daubenmire 1959). Stem number and average stem heights were recorded for all shrub species.

Herbicide dissipation assessment

Soil was sampled over time in the hexazinone, sulfometuron and imazapyr plots in three blocks to monitor the persistence and movement of the herbicides. Soil samples were collected 16, 90 and 240 days after treatment. In each treatment plot, six random points within treated bands were sampled and the general location was revisited for subsequent sampling. Samples were collected at 0-15, 15-30 and 45-60cm depths. In each block, soil collected within a treatment plot was composited by depth to a single sample. Samples were kept frozen until the time of analysis. A bioassay was used to determine the herbicide concentration in soil samples (Ramsey et al 2004). Standard curves were established for each herbicide by subjecting brown top millet (*Panicum ramosum* L.) seeds to a known concentration of each herbicide. Three herbicide concentration ranges, 1-10 ppb at 1 ppb interval, 10-100 ppb at 10 ppb interval and 100-1000 ppb at 100 ppb interval were tested. The seeds were grown in a growth chamber with 16 hours of daylight (1800 μmol m^{-2}) at 30 ± 1^0C and 8 hours of darkness at 15 ± 1^0C. Growth chamber conditions were set as described by Hernandez-Sevillano et al. (2001). Plants were harvested after 13 days and dry plant weight was measured. The field soils was thawed at room temperature and brown top millet seeds were grown under the same growing conditions as the standards.

Statistical Analysis

Pine survival and growth

Pine survival, RCD, height and SVI data after one growing season were analyzed using analysis of variance (ANOVA) within the framework of a randomized complete block design (RCBD) using SAS version 8.0 (SAS 2000). Significant treatment effects (α=0.1) were separated using Duncan's multiple range test. The initial RCD and the extent of post planting burial were used as covariates in the ANOVA model.

Vegetation control

The effect of treatments on stem counts and heights of major shrub species were analyzed using ANOVA for a randomized complete block design. Pre harvest uniformity of stem counts for each shrub species were tested prior to analysis. Only those shrub species with uniform stem counts prior to treatment application were considered for analysis. Percent control on shrub stem number and heights were calculated. Significant differences (α=0.1) between treatments were detected by Duncan's multiple range test.

ANOVA was not used in the analysis of percent cover data, as it did not conform to the assumption of normality. Therefore, the Kruskal-Wallis test was used with PROC NPAR1WAY as a nonparametric alternative to ANOVA. Pre harvest percent cover uniformity of shrubs, grasses, forbs and major understory species were tested. Treatment effects on overall percent cover changes in shrubs, grasses and forbs were analyzed for both survey dates. Five major understory species that showed pre harvest uniform percent cover were used to test for treatment effects on percent cover of individual species. Percent control was calculated for each vegetation class and major species.

Treatment plots were compared to the untreated control plots to establish significant differences (α=0.1).

Herbicide persistence analysis

A power model was developed to predict herbicide concentration (Y) using the plant dry weight (X) as follows:

$$Y= aX^b$$

The quality of fit of the model was tested for each herbicide by calculating R^2 value. Dry whole plant weight from seeds grown in the herbicide contaminated field soil was used in the power model to predict the herbicide concentrations in the field soil. The predicted concentrations were analyzed using ANOVA for differences in concentrations between sampling days and depths. Duncan's multiple range test was used to detect significant differences between days and depths at a significance level of α=0.1.

Results

Pine Survival

Analysis of variance revealed a significant treatment effect on pine seedling survival after one growing season ($P<0.0001$). The control and hexazinone treatments had the highest survival (85.3% and 85% respectively) and were significantly greater than sulfometuron (78.3%), sulfometuron+hexazinone mix (67.8%) and imazapyr (65.6%) treatments (Fig 2-2a).

Pine RCD, Height and SVI

Analysis of first growing season RCD data revealed a significant treatment effect on RCD growth ($p<0.0001$). Initial RCD and extent of post-planting burial were significant as covariates ($p<0.0001$). Imazapyr treatment yielded the highest RCD (12.17mm) and was significantly larger than all other treatments. The RCD in hexazinone (11.75mm) and sulfometuron-hexazinone mix (11.25mm) treatments showed significant differences between the two treatments but did not differ from the control (11.65mm). Sulfometuron treatment resulted in the lowest RCD growth (10.80mm)and was significantly lower than all other treatments (Fig 2-2b).

Analysis of height data showed significantly taller seedlings in the imazapyr (1.35cm) and sulfometuron+hexazinone mix (1.29cm) compared to other treatments. Hexazinone (1.18cm) did not significantly affect seedling height compared to the control (1.10cm). Sulfometuron (1.04cm) again resulted in lower growth and had the lowest height compared to all other treatments (Fig 2-2c).

The SVI showed a similar trend as RCD and height. Imazapyr treatment resulted in the largest mean SVI of 2.46cm^3 and was significantly greater than all other treatments. Sulfometuron (1.59cm^3) yielded lowest SVI compared to all other treatments. Hexazinone and sulfometuron+hexazinone mix treatment did not significantly affect SVI compared to the control (Fig 2-3).

Vegetation Control

Imazapyr resulted in significant overall reduction of the percent cover of shrubs in both 3 MAT and 9 MAT surveys (66% and 59% control respectively). None of the other herbicide treatments was effective in reducing the overall percent cover of shrubs. Overall, percent cover of grasses and forbs were not reduced by any of the treatments.

Analysis of major flatwoods species showed no treatment effect on wiregrass and saw palmetto percent cover. Imazapyr was successful in significantly reducing the percent cover of gallberry in the June 2002 survey (78% control) and showed sustained control through November 2002 survey (70% control). Gallberry percent cover was unaffected by the other treatments except in sulfometuron+hexazinone mix treatment where it increased in both surveys. None of the treatments reduced the percent cover of runner oak by June 2002 survey. However runner oak exhibited a delayed response to hexazinone (37% control), imazapyr (69% control) and sulfometuron+hexazinone mix (46% control) treatments as its percent cover was significantly reduced in the Nov 2002 survey. Bluestem species were not adversely affected by the applied treatments. The percent cover of bluestem species increased in the sulfometuron treatment plots by the Nov 2002 survey.

Shrub stem counts and heights were analyzed for gallberry, runner oak and saw palmetto species (table 2-3). Gallberry and runner oak stem counts and heights were unaffected by the herbicide treatments except for imazapyr. Imazapyr significantly reduced (58%) the amount of resprouting stems of gallberry in June 2002 survey. An increased amount of control of gallberry was found (79%) in Nov 2002 and a significant reduction in the number of runner oak stems (65%). The effect on stem heights followed a similar trend with only imazapyr yielding reduced stem heights. In the June 2002 survey, imazapyr significantly reduced the stem heights of gallberry and runner oak species (64% and 40% respectively). The significant reduction in stem heights of gallberry and runner oak species by imazapyr was sustained in the Nov 2002 survey (37% and 29% respectively). None of the herbicide treatments significantly affected the stem counts or heights of saw palmetto species.

Herbicide Dissipation

Three predictive power models were developed for imazapyr, sulfometuron and hexazinone with pseudo R^2 values of 0.89, 0.65 and 0.60 respectively. The analysis of the predicted concentrations for the herbicide contaminated soils revealed no significant difference among soil depths and days (Fig 2-4). Herbicide concentrations of the entire sampled soil profile were analyzed over the three sampling dates. Hexazinone and sulfometuron showed significant decrease in herbicide concentrations between 16 DAT and 240 DAT. Imazapyr concentrations were not significantly different among the three dates (Fig 2-5).

Discussion

Successful establishment, survival and improved growth of pine seedlings on flatwoods sites rely on the efficacy of applied vegetation control methods. The majority of the studies reporting improved survival and growth were associated with intensive site preparation and high rate pre-plant herbicide applications which provide significant release from competition stress (Shiver et al. 1991, Kline et al. 1994).

Within our study, overall survival of seedlings was moderate at best including the control. Post planting burial observed among the majority of the dead seedlings may have contributed to the overall seedling mortality. Metcalfe and Cantrell (1986) studied the effect of sulfometuron and sulfometuron+hexazinone treatments on first year survival of longleaf seedlings planted on a sandy soil in Florida. In their study with higher rates of sulfometuron and sulfometuron+hexazinone mix treatments, no significant effect on seedling survival was found compared to the control. Our results are contrary to the above findings as sulfometuron and sulfometuron+hexazinone mix treatments significantly lowered seedling survival compared to the control. Although imazapyr and sulfometuron+hexazinone mix treatments resulted in lowest survival, they both significantly increased seedling height with imazapyr also increasing RCD growth. Our results reveal an evident “trade off” in benefits of using herbicide applications such as imazapyr against control, providing forest managers the choice between increased survival of pine seedlings or increased growth depending on their silvicultural objectives.

Application of sulfometuron displayed a stunting effect on seedling growth by yielding the lowest RCD and height. Our findings agree with previous research done by Gjerstad et al. (1983) where they reported detrimental effects such as stunting of pines by sulfometuron in sandy soils.

Analysis of understory vegetation revealed significant reduction in foliar cover of shrubs by imazapyr treatment. However, imazapyr did not reduce the foliar cover of grasses and forb species. Runner oak displayed a delayed response to hexazinone, sulfometuron+hexazinone mix and imazapyr treatments. The benefits of runner oak percent cover reduction may be realized the following growing seasons. Although imazapyr had poor control over grasses and forbs, it resulted in increased growth of longleaf pine seedlings by controlling the shrub component alone. This result suggests an important competitive relationship between the flatwoods understory shrub species and planted longleaf seedlings. Our observations reiterate the importance of effective shrub control for improved growth of longleaf seedlings on flatwoods sites. Imazapyr was the only treatment to effectively reduce the resprouting of major flatwoods shrub species such as gallberry and runner oak by reducing the stem number and their heights. Interestingly, none of the treatments reduced the percent cover of wiregrass. Thus, in flatwoods areas concerned with restoration of longleaf-wiregrass ecosystems, the tested herbicide treatments at the specified rates may be applied for longleaf pine establishment without any detrimental effects on wiregrass.

Bioassays are widely used to detect herbicide concentrations in soil. With the existing limitations of analytical methods due to inefficient residue extraction methods, bioassays provide a good alternative (Hernandez-Sevillano et al. 2001). They are effectively used to detect biologically active levels of herbicide residue at lower concentrations in soil (Anon 2000). Therefore, a bioassay is best suited for our study due to the relatively low herbicide rates applied. A study done by Hollaway et al. (1999) comparing different detection methods reported that bioassays were more accurate than high performance liquid chromatography (HPLC) when used to detect residues at lower concentrations. Many studies have also reported on the efficacy of bioassays in detecting herbicide residue concentrations as small as 1 ppb (Stork and Hannah 1996, Hollaway et al. 1999, Hernandez-Sevillano et al. 2001).

The three predictive models developed through the bioassays had relatively high pseudo R^2 values indicating good predictive strength. However, bioassay results did not show significant differences in herbicide concentrations between soil depths for all herbicides. Although nonsignificant, the results reveal a trend in herbicide movement as concentrations increase in lower depths with time (fig 2.4). Lack of significance may be attributed to the large amount of variation encountered within the bioassay. For future studies, additional field sampling and increased replications within the bioassay are suggested to account for high variation. Herbicide dissipation analysis over the entire sampled soil profile reveals a significant decrease in herbicide concentrations of hexazinone and sulfometuron between 16 DAT and 240 DAT. Imazapyr was persistent in the soil at low concentrations for an extended period of time. Soil adsorption of imazapyr is improved with increased organic matter and low pH in soil (Dickens and Wehtje 1986). The accumulation of debris from the site preparation burn and low pH of the site may have contributed to the low predicted imazapyr concentrations by increasing its adsorption to soil. Herbicide concentrations less than 50 ppb were found for all three herbicides 240 DAT.

Conclusion

Within the first growing season after treatment application imazapyr treatment resulted in a significant decrease in seedling survival. However, it resulted in greater overall growth by significantly increasing RCD and height of seedlings. Imazapyr also resulted in significant reduction of shrub foliar cover, stem density and stem heights. The decrease in understory dominance of shrubs with imazapyr induced increased growth of longleaf seedlings. Application of hexazinone, sulfometuron and sulfometuron+hexazinone mix treatments failed to yield significant vegetation control and improve overall pine seedling growth and survival. Sulfometuron resulted in lowest RCD growth and its application is not recommended on sandy flatwoods soils.

Applied herbicides did not significantly impact the understory grasses and forb species. More importantly, none of the herbicide treatments was detrimental or augmented wiregrass foliar cover. However, with the decline of shrub dominance the potential for improvement in wiregrass cover is increased.

Hexazinone and sulfometuron do not seem to persist for extended periods. Imazapyr was present in very low concentration soon after application and exhibited a slower dissipation. However all three herbicides dissipated to very low concentrations less than 75ppb, 240 days after treatment.

Overall, imazapyr provided the best-desired results with significant increase in pine growth and better control of shrub species with no significant effect on other understory species.

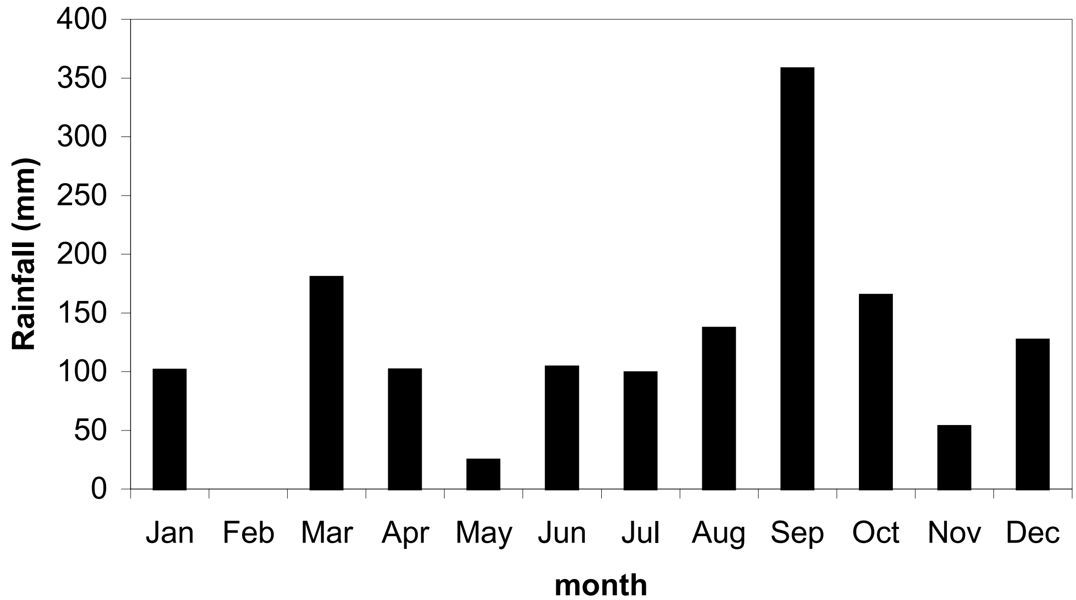


Figure 2-1. Monthly rainfall data for year 2002 at Point Washington State Forest, Walton County, Florida.

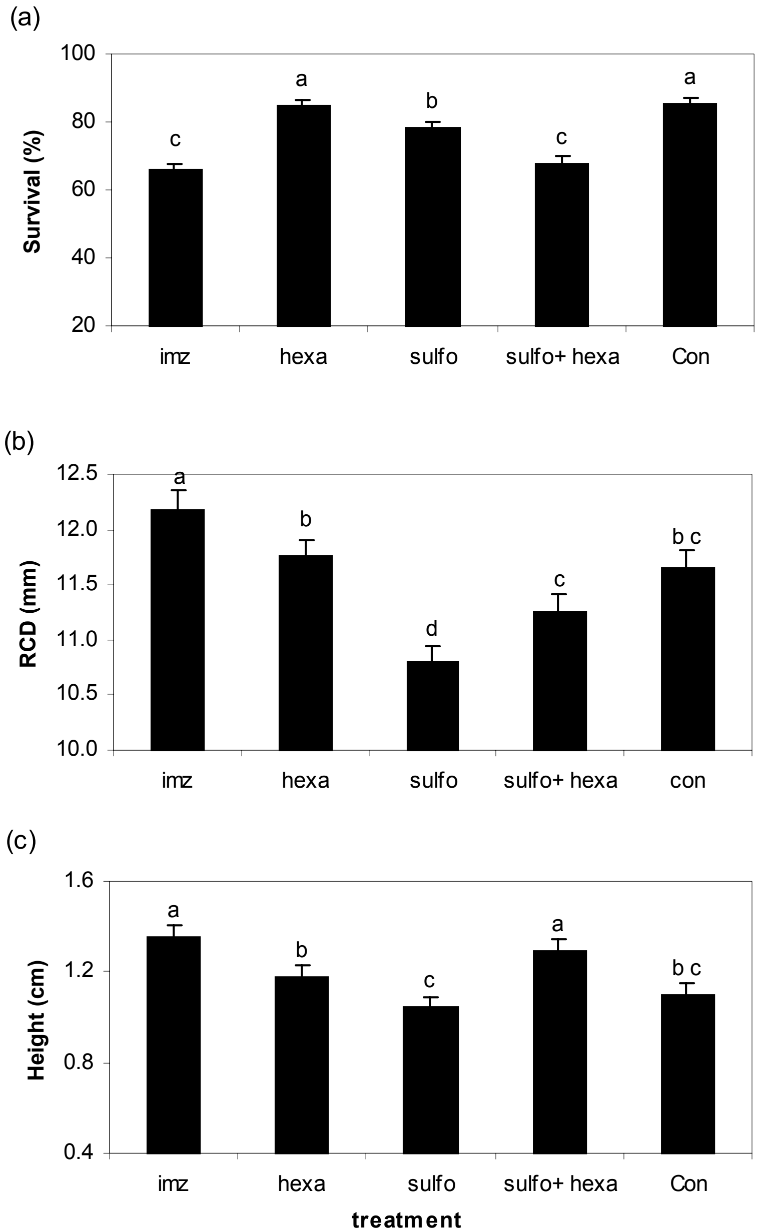


Figure 2-2. Longleaf pine seedling survival and growth. (a) mean survival, (b) mean root collar diameter (RCD), (c) mean seedling height by treatment. Means followed by the same letter are not significantly different (α=0.1). (imz: imazapyr; hexa: hexazinone; sulfo: sulfometuron; sulfo+hexa: sulfometuron+hexazinone mix; con: control)

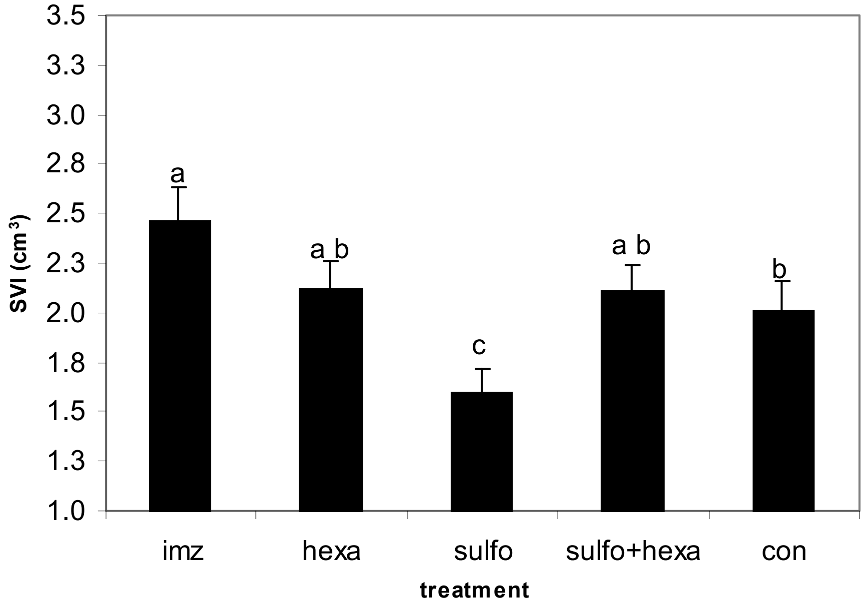


Figure 2-3. Stem volume index of longleaf seedlings after one growing season by treatments. Means associated with the same letters are not significantly different (α=0.1). (imz: imazapyr; hexa: hexazinone; sulfo: sulfometuron; sulfo+hexa: sulfometuron+hexazinone mix; con: control)

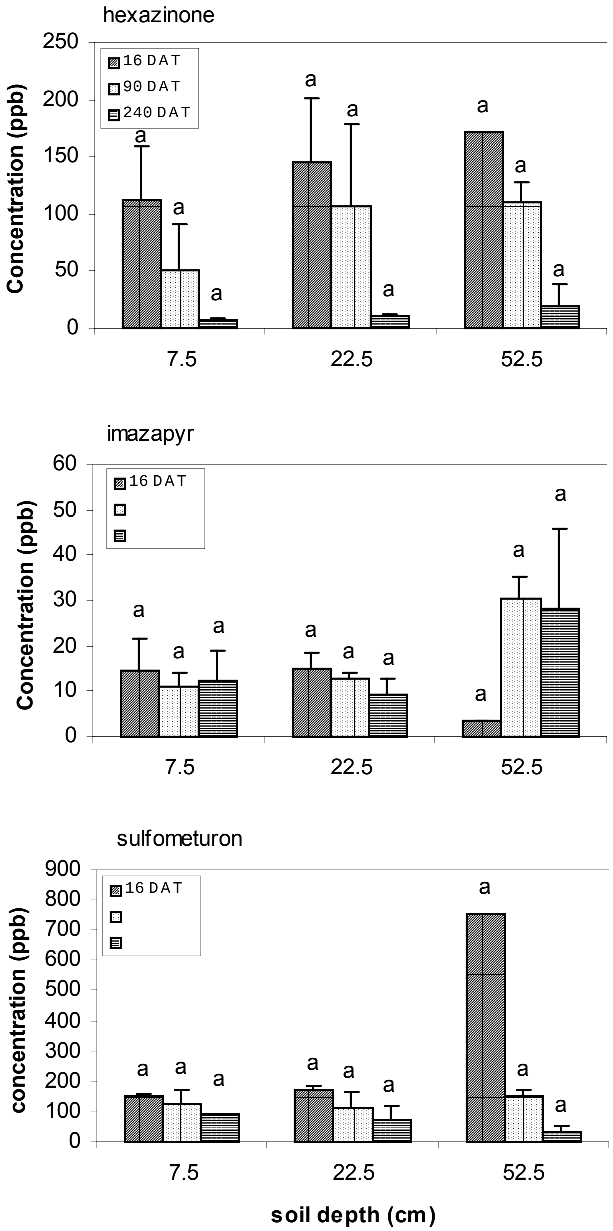


Figure 2-4. Mean herbicide concentrations in part per billion (ug kg $^{-1}$) by depth. Values associated with the same letters are not significantly different (α=0.1). Significance established with duncan's multiple range test.

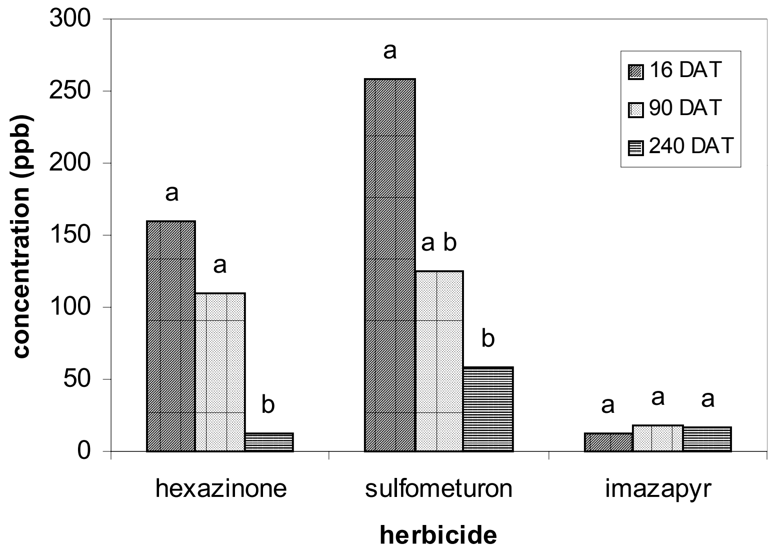


Figure 2-5. Change in herbicide concentration over time across soil profile (60 cm). Concentration values followed by different letter are significantly different from other dates for the respective herbicide. Significance declared at α=0.1 using Duncan's multiple range test.

Table 2-1. Soil description at four depths of Point Washington State Forest, Walton County, Florida.

Soil property	Soil depths (cm)			
	0-15	15-30	30-45	45-60
Texture	sandy	sandy	sandy	sandy
Soil pH	4.40	4.60	4.80	4.60
CEC (meq/100g)	3.80	2.20	2.50	2.50
Organic matter (%)	1.38	0.62	0.58	0.37
Phosphorus (kg ha^{-1})	16.67	4.44	4.44	4.44
Potassium (kg ha^{-1})	42.23	14.44	10.00	8.89
Magnesium (kg ha^{-1})	60.02	12.22	10.00	8.89
Calcium (kg ha^{-1})	330.11	50.01	44.46	33.33

Table 2-2. Mean foliar cover for major understory species and the total foliar cover of vegetation types by treatment.

	Control	Sulfometuron	Hexazinone	Sulfo+Hexa[1]	Imazapyr
Species					
Wiregrass					
June 2002	4.50± 0.9	6.02± 1.1	6.5± 1.4	5.00± 1.0	5.81± 1.7
Nov 2002	11.5± 2.5	13.97±2.7	13.65± 2.6	12.86± 2.1	12.40± 1.4
Bluestem spp					
June 2002	0.96± 0.2	1.05± 0.3	1.08± 0.2	1.00± 0.2	0.50
Nov 2002	4.75± 1.8	2.04± 0.5[a]	3.80± 0.6	5.16± 1.3	3.83± 1.2
Gallberry					
June 2002	9.15± 1.7	10.32± 1.2	10.91±1.5	13.34± 1.9 [a]	2.10± 0.4 [a]
Nov 2002	14.20± 2.1	15.21± 2.2	17.13± 1.9	19.12± 2.4 [a]	4.31± 0.9 [a]
Runner oak					
June 2002	19.09± 4.6	21.60± 4.9	12.55± 3.3	10.89± 1.5	6.12± 1.6
Nov 2002	29.21± 4.2	32.20± 5.4	18.50± 3.2[a]	15.96± 2.0 [a]	9.25± 2.0 [a]
Saw palmetto					
June 2002	11.22± 4.1	8.04± 2.3	8.70± 2.3	7.94± 4.1	11.30± 3.6
Nov 2002	10.83± 3.9	11.50± 2.4	9.62± 2.4	13.64± 4.5	10.75± 2.1
Veg-type					
All shrub					
June 2002	50.79±13.6	44.58±11.6	34.28±4.9	36.93±6.8	23.26±4.2[a]
Nov 2002	68.65±10.1	67.91±12.4	57.2±6.1	60.42±6.7	34.41±2.6[a]
All grasses					
June 2002	11.46±2.2	8.08±1.7	8.99±1.0	7.93±1.7	7.5±1.4
Nov 2002	26.00±2.7	18.63±3.9	24.92±5.8	20.65±3.6	22.48±3.4
All forbs					
June 2002	4.60±1.5	3.02±0.6	4.22±1.2	3.10±1.3	5.52±2.3
Nov 2002	8.36±4.7	7.10±1.0	6.22±1.2	6.50±2.3	12.32±4.1

Note: Values followed by letter “a” are significantly different from the control along rows at $\alpha = 0.1$.
1 Sulfometuron+Hexazinone mix treatment

Table 2-3. Stem numbers and stem heights for three understory shrub species by treatment.

Species	Control	Sulfometuron	Hexazinone	Sulfo+Hexa[1]	Imazapyr
			Shrub stem numbers (stems/ m^2)		
			3 MAT		
Gallberry	18.37± 2.6	20.60± 2.7	16.93± 1.5	16.60± 1.8	7.60± 0.9 **b**
Runner oak	31.40± 5.3	31.29± 5.9	23.14± 3.9	20.32± 2.5	17.62± 3.6
Saw palmetto	2.20± 0.5	2.45± 0.4	2.00± 0.4	2.55± 0.6	2.90± 0.6
			9 MAT		
Gallberry	34.50± 4.9	39.80± 5.3	38.33± 3.7	43.00± 5.9	7.03± 1.6 **b**
Runner oak	52.07± 7.8	59.20± 12.1	37.57± 6.4	36.57± 4.7	18.04± 3.3 **b**
Saw palmetto	2.75± 0.5	3.44± 0.8	2.00± 0.6	3.28± 1.3	3.33± 0.8
			Shrub heights (cm)		
Species	Control	Sulfometuron	Hexazinone	Sulfo+Hexa[1]	Imazapyr
			3 MAT		
Gallberry	18.89± 1.1	18.64± 0.7	20.57± 1.0	19.52± 1.1	6.72± 0.4 **b**
Runner oak	22.92± 1.9 **a b**	22.66± 1.6 **a**	19.40± 1.4 **b**	18.00± 0.8 **b**	13.66± 0.2**c**
Saw palmetto	36.00± 5.5	30.45± 5.0	51.20± 6.3	25.11± 4.8	36.10± 4.0
			9 MAT		
Gallberry	25.24± 1.5	26.71± 1.4	28.16± 1.5	27.66± 1.6	15.85± 1.6 **b**
Runner oak	29.92± 2.1**a**	26.37± 2.2**a b**	26.00± 1.7**a b**	23.82± 1.3**b**	21.16± 1.8 **c**
Saw palmetto	24.81± 4.2	26.11± 5.9	35.75± 9.0	30.85± 6.1	30.25± 5.4

Note: values followed by different letters are significantly different along rows (α=0.1)

[1] Sulfometuron+Hexazinone mix treatment

CHAPTER 3
UNDERSTORY SPECIES DYNAMICS FOLLOWING HERBICIDAL PINE RELEASE TREATMENTS ON A LONGLEAF FLATWOODS SITE

Introduction

Prior to European settlement in the United States, the southeastern coastal plain was dominated by large tracts of longleaf pine forests, covering an estimated 37 million ha (Frost. 1993). These forests ranged from southeastern Virginia to eastern Texas through central Florida (Croker 1979, Landers et al. 1995), occupying a variety of sites ranging from xeric sandhills to wet poorly drained flatwoods (Boyer 1990, Carter et al.1998). At present, longleaf acreage has been reduced to less than 5% of its former range with an estimate of less than 2 million ha remaining (Kelly and Bechtold 1990, Busby et al. 1995).

The longleaf pine range within the southeastern Coastal Plain is prone to many natural disturbances such as tropical storms and forest fire (Delcourt et al 1993). Coupled with these disturbances and varying site conditions, longleaf ecosystems included a mosaic of community types that sustained a high diversity of flora and fauna (Croker 1979, Brockway and Outcalt 2000). Longleaf pine ecosystems are well adapted to such natural calamities and were dependent on them to maintain their structure and functions. The frequent fires that swept through these forests prevented the encroachment of less fire-adapted hardwood species and maintained an open midstory. These natural disturbances coupled with competition intolerance of longleaf pine created a widely spaced overstory. Such structural characteristics of these forests facilitated increased light transmitance facilitating understory plant growth.

Longleaf ecosystems have one of the richest species diversities outside the tropics (Peet and Allard 1993). Although the overstory is mostly monospecific, the understory is host to a plethora of plant species. The composition of the understory is site specific and mainly dominated by grass species (Outcalt 2000). In the western gulf Coastal Plain, the understory is comprises mainly of bluestem grasses. In Florida and along the Atlantic Coast wiregrass (*Aristida beyrichiana* Trin and Rupr) is dominant with *Aristida stricta* Michx., occupying from central South Carolina through North Carolina (Peet 1993). Some of the common forb species include *Asclepias* spp., *Aster* spp., *Liatris* spp., *Rhexia* spp., *Carphephorus* spp. and *Eupatorium* spp. among others. (Platt et al. 1988, Huck 1987). On the more mesic flatwoods sites the understory is comprised of a variety of shrub species such as gallberry (*Ilex glabra* L.), runner oak (*Quercus pumila* Walt.), fetterbush (*Lyonia lucida* Lam.), saw palmetto (*Seronoa repens* Bartr.), blueberry (*Vaccinum myrsinites* Chapman.) and hairy wicky (*Kalmia hirsuta* Walt.) (Huck. 1987). The forests of the southeastern Coastal Plain also include a large number of rare plants (Collins et al. 2001).

With the decline of these forests and changes in land use and development activities, some of the rare and native plant populations were fragmented and eliminated reducing genetic diversity (Collins et al. 2001). Due to the rapid loss of these forests and the associated highly diverse understory, its restoration has gained importance. In restoration efforts focus on controlling the understory shrub dominance has gained importance. Shrub dominance increases resource competition stress of longleaf pine seedlings and suppresses the ground-layer understory vegetation. On flatwoods sites, the competition for site resources and shrub dominance is elevated due to the characteristic dense understory. Prescribed fire has been widely used to control understory vegetation resulting in successful establishment of longleaf pine forests on many sites (Provencher et al. 2001). Vegetation control by prescribed fire is short-lived on flatwoods sites due to the vigorous resprouting of many species. Typical shrub and herbaceous species of flatwoods sites have extensive rootstock systems that enable them to resprout rapidly following fire (Abrahamson 1984).

The uses of mechanical and chemical site preparation and release treatments are suggested as alternatives to reduce the understory dominance of shrub species. Although intensive mechanical site preparation provides good shrub control (Burger et al. 1988), it also causes extensive ground disturbance that may be detrimental to desired native species. For instance, wiregrass, one of the keystone understory species of longleaf pine ecosystems, is reported to be very sensitive to ground disturbance (Clewell 1989).

Chemical vegetation control methods are widely used as site preparation and pine release treatments. Herbicide applications at high rates (site preparation) were studied by Kline et al. (1994) and Shiver et al. (1991) on industrial flatwoods sites, with significant reduction of the understory shrub component. Information regarding the effect of herbicides on the ground-layer vegetation of natural flatwoods and sandhill communities is scarce (Litt et al. 2001). An extensive literature review done by Litt et al. (2001) regarding herbicide effects on groundlayer vegetation found only 3 and 7 studies respectively, on natural flatwoods and sandhill sites. A study done by Neary et al. (1990) on a flatwoods site in Florida found nearly 75% reduction in species richness following an intensive weed management regime with repeated applications of sulfometuron, glyphosate and triclopyr mowing. Brockway et al. (1998) studied the effects of hexazinone applied at 1.1 and 2.2 kg ha^{-1} with different application techniques on a sandhill site. They reported significant decreases in the cover of oak species and increases in shrub control at the higher rate. Moreover, the higher rate application of hexazinone induced an 86% increase in biomass of wiregrass in the first growing season after treatment. With the broadcast application of hexazinone, a short-term reduction of forbs species was also reported. A long-term study of herbicide effect on understory plant diversity and richness was conducted by Boyd et al (1995) on sandhill and piedmont site with one-time broadcast applications of imazapyr, glyphosate, and hexazinone. The reported results seven years after treatment showed no significant herbicide effect on species diversity and richness.

Our study was conducted to examine the effects of three common forestry herbicides (imazapyr, hexazinone and sulfometuron) on the understory species of a flatwoods site. The specific questions addressed were:

- The effect of herbicides on the overall vegetation composition and species diversity;
- The effect of herbicides on cover and density of major understory shrub species;
- The effect of herbicides on the percent cover of wiregrass.

Materials and Methods

Study Area Description

This study was conducted on a flatwoods site in Point Washington State Forest, Walton County, Florida ($30^0$20’16.04” N, 86^0 4’19.22” W). Average annual highest and lowest temperatures were 25.5^{0}C and 12^{0}C, respectively. Annual precipitation was about 1640mm (2002) with most received in the late summer months (Figure 2.1). Soils are of low pH (pH <5) and sandy texture with low nutrient content (Table 2.1). The study area soils were mapped as sandy, siliceous, thermic aeric alaquods belonging to the Leon series, which is characterized by deep, poorly to very poorly drained soils. Soils of the flatwoods pinelands are formed on sandy quaternary formations derived from marine deposits (Stout and Marion 1993).

Prior to study establishment the overstory was a stand dominated by slash pine with the occasional longleaf pine saplings. The average age of the stand was 26 years with a basal area of 1.85m^2 and an average dbh of 19.1cm. The understory was comprised mainly of species such as gallberry, saw palmetto, runner oak, dangleberry, hairy wicky, wiregrass and bluestem grasses. Dormant season fires were used on a three-year burn cycle to mitigate fuel build up.

Experimental Design and Treatments

Prior to site preparation, the overstory was harvested (August 2001). The harvest debris and the understory were roller chopped once and prescribed burned in October 2001. A randomized complete-block design (RCB) with five replicates was used to examine the effect of four herbicidal vegetation control methods on the understory vegetation of the site. The study included five treatment plots within each block. All treatment plots were 26.6m x 24.4 m, and included a > 3m buffer strip between plots. In December 2001, one year old containerized longleaf pine seedlings were hand-planted at 3.1m x 1.8m spacing. Seedlings were planted in rows to facilitate the application of treatments. In March 2002, four herbicide treatments [Sulfometuron (0.26 ai kg ha^{-1}), Hexazinone (0.56 ai kg ha^{-1}), Sulfometuron (0.26 ai kg ha^{-1}) + Hexazinone (0.56 ai kg

ha^{-1}) mix, Imazapyr (0.21 ae kg ha^{-1})] were applied in a 1.2 m band over the top of seedlings using a knapsack sprayer. In each block, one treatment plot was kept herbicide free as a control plot.

Measurements

A preliminary vegetation survey was conducted (June 2001) to assess the initial species composition and diversity, prior to harvesting and site preparation. The experimental blocks and treatment plots were demarcated and within all plots, three randomly selected $1m^2$ sampling quadrats were sampled. After study establishment and herbicide application, two more vegetation surveys were conducted. These surveys were done three and nine (June and Nov 2002) months after herbicide treatment (MAT) and sampling was done on the herbicide applied strips along pine seedlings rows. In each treatment plot six randomly selected $1M^2$ quadrats were sampled and the same location was revisited for subsequent survey. In every survey, all plants found within a quadrat were assigned to vegetation class of shrubs, grass, forbs, vines and ferns. Percent cover was ocularly estimated for all species using the modified Daubenmire scale (Daubenmire 1959). Stem number and average stem heights were recorded for all shrub species.

Statistical Analysis

Uniformity of percent cover of understory species and stem counts of major shrub species was tested within the pre-harvest survey data. Only species that displayed uniformity in percent cover and stem counts were used in comparison with post-treatment survey data. Percent cover data did not conform to the assumption of normality even after data transformation. Therefore, comparison of percent cover between treatments and the control plots for each survey date was performed with Kruskal-Wallis test at a significance level of $\alpha=0.05$. Treatment effects on stem counts were analyzed using analysis of variance (ANOVA) techniques within the framework of a randomized complete block design (RCBD) using SAS version 8.0 (SAS 2000). Significant treatment effects were separated using Duncan's multiple range test. Importance value (IV) was calculated for shrubs, grasses and forbs. Shrub species IV was calculated as an average of relative frequency, relative cover and relative density. Average of relative frequency and relative cover was used as IV for grass and forb species. IV values were log transformed before analysis. Differences of IV values between treatments were tested with Duncan's multiple range test at a significance level of α=0.05.

Species diversity was calculated using Shannon-Wiener diversity indices, which incorporate species richness and evenness of the species. Species diversity was calculated for all three vegetation surveys using percent cover data and were analyzed using Multivariate Statistical Package (MVSP) version 3.1 (Kovach 1999).

Canonical Correspondence Analysis (CCA) was used to examine the overall distribution of species among the study plots. CCA is a direct gradient analysis which constraint the species distribution along specified environmental variables (Palmer 1993). The applied treatments were used as nominal environmental variables and time since treatment was used as a quantitative environmental variable in CCA analysis. CCA analysis was performed for each survey separately. Monte Carlo permutation test was used to detect significant (α=0.05) environmental variables.

Results

Species Composition and Diversity

CCA analysis with pre-harvest survey and control plots revealed a change in species composition with time without the effect of herbicides (Figure 3-1 a). Monte

Carlo permutation tests showed time (p= 0.015) as a significant factor. The compositional change may be attributed to the seasonal variation within the plant community and the effects of site preparation. Analysis of 3 MAT vegetation survey data showed no significant changes in the species composition and distribution between the treatments (Fig 3-1 b). Monte Carlo permutation tests also revealed that 3 MAT none of the treatments were significant. However, 9 MAT data showed a distinct separation between herbicide treatment and the control (Fig 3-2 c). The first axis was highly correlated with absence of herbicides and the second axis although nonsignificant was correlated with imazapyr treatment. Monte Carlo permutation revealed absence of herbicide (P= 0.04) to be the most significant factor for the separation of sample plots within the ordination. The permutation tests did not reveal any significant herbicide treatment effect.

A total of 81 species were recorded within the duration of the study. A larger number of species was found within post-treatment surveys compared to the survey done prior to harvest. The applied herbicides had no significant effect on species richness 3 and 9 MAT.

Within post-treatment surveys, overall species evenness increased across all treatments (Table 3-1). However, in both surveys none of the herbicides significantly changed species evenness among the treatments. Although non-significant, imazapyr treatment resulted in the highest evenness in both surveys with sulfometuron resulting in the lowest evenness values.

Species diversity increased 3 MAT across all the treatments compared to pre-harvest vegetation (Figure 3-2). However, none of the herbicide treatments had a significant effect on the understory species diversity 3 MAT (Figure 3-2). Further increase in diversity was observed across all treatments 9 MAT. The largest increase occurred with imazapyr treatment and was significantly greater than all other treatments, including control. Sulfometuron markedly reduced species diversity 9 MAT and was significantly lower than imazapyr, hexazinone treatments and control (Figure 3-2).

Overall, shrub foliar cover was not significantly affected in both 3 and 9 MAT surveys in all treatments except imazapyr (Table 3-2). Imazapyr resulted in a reduction of 65% of shrub foliar cover 3 MAT and 58% reduction 9 MAT compared to control (Table 3-2). Overall grass and forb foliar cover were not significantly affected by any of the herbicides (Table 3-2).

Understory Shrub Cover and Density

Prior to harvest and site preparation, the understory was dominated by gallberry, runner oak, and saw palmetto. These species were abundantly found with percent frequency of 76, 56 and 42, respectively. These species were used to examine herbicide effects. Among the major understory shrub species, saw palmetto cover was not significantly affected by any herbicides in both post-treatment surveys (Table 3-2). Runner oak cover was not affected by the herbicides 3 MAT (Table 3-2). However, it showed a delayed response to imazapyr, hexazinone and sulfometuron+hexazinone mix treatments with a foliar cover reduction of 67%, 36% and 45%, respectively, compared to the control, 9 MAT (Table 3-2). The greatest reduction of cover occurred in gallberry in the imazapyr treatment with 77% reduction 3 MAT and 70% reduction 9 MAT. Gallberry cover was not affected by any other treatments (Table 3-2).

Shrub density differences between treatments were analyzed for gallberry, runner-oak and saw palmetto, which showed uniform density across the study site prior to treatment application. Saw palmetto density was not affected by any of the applied treatments. The density of runner oak was not affected by any herbicides 3 MAT but showed delayed response to imazapyr with a 65% reduction of stem density 9 MAT (Table 3-3). Gallberry density was unaffected by the applied treatments except imazapyr. Within the imazapyr treatment gallberry density reduced by 58% and 79% 3 and 9 MAT, respectively.

Analysis of mean importance values revealed no significant change due to applied herbicides except imazapyr (Table3-4). Imazapyr treatment significantly reduced the importance value of gallberry 3 MAT (> 50%) and was further reduced (>60%) 9 MAT.

Wiregrass Cover

Prior to harvest, wiregrass was the dominant grass species with 63 percent frequency. Interestingly none of the herbicide treatments negatively affected the foliar cover of wiregrass.

Discussion

Ecological disturbance such as periodic fires, hurricanes and plant mortality due to pathogens or insects influence the species diversity within an ecosystem by changing dominance, interspecific competition and initiating succession (Perry 1994). Herbicide application through its selective activity may also influence dominance of species, interspecific competition and species composition. Thus, with herbicide application changes in species diversity, richness and composition can be expected.

CCA ordination on pre-harvest vegetation and the control plots revealed a change in species composition with time. The difference in compositional change may be a response to site disturbance and seasonal variation within the plant community. For instance, an increase in number of forb species such as *Aster tortifolius*, *Liatris tenuifolia* and *Sabatia brevifolia* were found in the latter survey conducted in late fall. The ordination analysis for 9 MAT vegetation data showed a significant separation of treatments due to the absence of herbicide. The separation between herbicide treatments and the control reveals a herbicide effect on overall species composition.

In our study, post harvest vegetation surveys included a higher number of species compared to the pre harvest vegetation. The increase in species richness occurred in all treatment plots and may be attributed to the disturbances brought forth by site preparation treatments and prescribed burning. Similarly, Brockway et al. (1997) found increases in species richness following disturbances such as prescribed fire. Species richness did not change between the herbicide treatments indicating no apparent effect of treatments on species richness. This is contrary to published research, which shows a decline in species richness within the first growing season after herbicide application. A study done by Wilkins et al. (1993) with hexazinone on a flatwoods site reported significant reduction in species richness with increasing application rates within the first year. A similar study by Brockway et al. (1998) on a sandhill site with a broadcast application of hexazinone at 1.1 ai kg/ha reduced the species richness by 28%. It should be noted that both the above studies used site preparation rates of hexazinone and used broadcast application methods. The relatively lower rate application of herbicides and the banded application method used in our study did not significantly affect species richness.

The increase in species diversity across the study site is a characteristic response to site disturbances. Usually a decrease in species diversity within the first growing season after herbicide treatments is common. Brockway et al. (1998) reported an overall reduction in species diversity on a sandhill site treated with high rates of hexazinone.

With the exception of imazapyr and sulfometuron, the herbicide treatments used in our study did not significantly impact understory species diversity at the applied rates. Imazapyr was the only treatment to significantly increase species diversity 9 MAT. In addition, an increase in species evenness was also observed. Species evenness measures the similarity of abundance between species found within a given area. Higher evenness values signify a lack of dominance by a fewer species and reveals similar proportions of abundance. The significant reduction of shrub foliar cover and density by imazapyr may have reduced the dominance of shrub species, thereby increasing resource availability to other species. The absence of shrub dominance may have facilitated similar distribution of abundance among other species increasing species evenness and in turn improving species diversity. In contrast to imazapyr, sulfometuron resulted in a significant decrease in species diversity. The decrease in diversity is attributable to the lower species richness and evenness found in the sulfometuron treatment.

Although imazapyr showed significant control over the dominant shrub species, it did not cause a reduction in species richness within the treated area. This reveals the selectivity of imazapyr on its target species and its inability to severely damage or eliminate them from the understory at the applied rate. The herbicide application method used in our study may also have contributed to the lack of severity of herbicide effect on species diversity and richness. In contrast to broadcast application, the band application method provides a herbicide free buffer between treatment bands. The buffer strips provide a suitable seed source for re-colonization within the treated plots. Studies done with broadcast and spot application treatments have reported greater decline in species richness and diversity with the broadcast application of herbicides compared to the spot application method (Brockway et al. 1998).

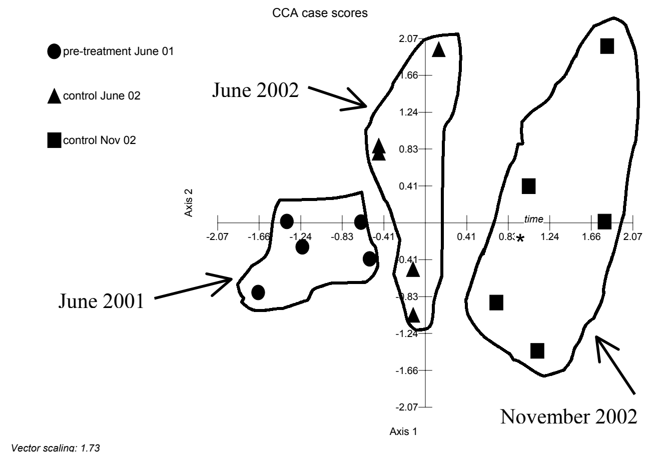
One of the important concerns with longleaf pine restoration techniques is their effect on wiregrass regeneration and growth. Clewell (1989) reported on the detrimental effects of soil disturbance on wiregrass. In his research 85% reduction in wiregrass density was found with soil disturbance in flatwoods. In addition, the negative impact of site preparation methods such as chopping was also reported. In contrast to the above findings, the site preparation chopping performed in this study did not have any negative effect on wiregrass foliar cover. However, the damaging effects of soil disturbances is lessened along an increasing moisture gradient (Clewell 1989). Thus, the recovery of wiregrass following site disturbances may be site specific. A study done on a sandhill site reported an increase in wiregrass cover in a linear relationship with increasing application rates of hexazinone within the first growing season (Wilkins et al. 1993). They also reported a significant reduction in the dominant oak species that may have led to the increase in wiregrass cover. A similar study done by Brockway et al. (1998) reported an 86% increase in wiregrass cover following a 93% reduction in dominant shrub cover. The above research indicates a positive response of wiregrass to reduction of shrub dominance within the first growing season. In our study, the herbicide treatments did not significantly effect the cover of wiregrass. However, imazapyr resulted in a significant reduction in gallberry cover and runner oak showed delayed significant reduction to hexazinone, imazapyr and sulfometuron+hexazinone mix treatments. Thus, the reduced shrub competition may yield greater wiregrass cover in the following years. Wiregrass is also reported to experience a lag time and requires at least two growing seasons to respond to reduced competition (Brockway et al. 1998).

Overall, imazapyr yielded the most desirable results by reducing the shrub dominance while improving the understory biodiversity. Imazapyr was also successful in yielding improved growth of planted pine seedlings. Hexazinone yielded a delayed control of runner oak with no significant impact on the understory biodiversity. The benefits of hexazinone with its delayed control of runner oak may be realized in the coming years. However after one growing season hexazinone did not yield greater benefits compared to control. Sulfometuron yielded poor results by reducing the biodiversity with no significant control over shrub dominance. The application of sulfometuron was also found detrimental to planted longleaf pine seedlings on flatwoods sites as described in chapter two. The sulfometuron+hexazinone mix treatments did not result in any improved benefits.

Conclusions

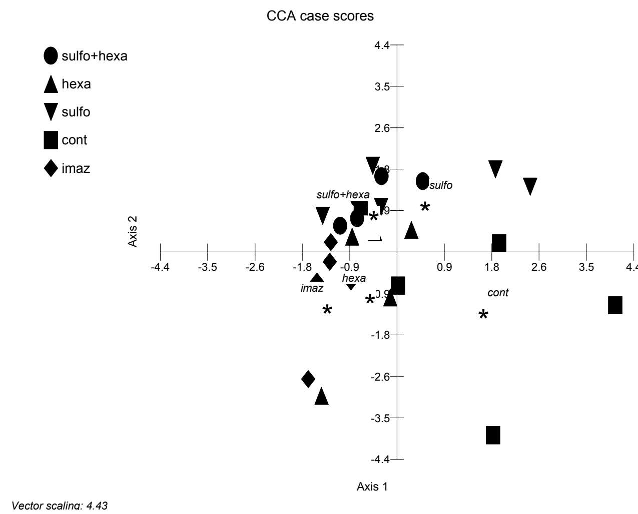
Within the first growing season, imazapyr treatment significantly increased the species diversity while increasing evenness. In contrast, sulfometuron decreased the species diversity and reduced species evenness. None of the other herbicides significantly impacted the understory plant diversity. Imazapyr treatment resulted in an overall reduction of shrub foliar cover with a significant reduction of gallberry and runner oak. However, shrub species such as saw palmetto and huckleberry species displayed resistance to imazapyr at the applied rate. Imazapyr caused a higher mortality rate of pine seedlings compared to control, but resulted in a significant increase in growth. Hexazinone was not effective in the control of major understory shrub species with the exception of runner oak. Runner oak displayed a delayed response to hexazinone by significant reduction of foliar cover 9 MAT. None of the other herbicide treatments was effective in reducing shrub dominance. Therefore, on flatwoods sites with an understory dominated by gallberry and runner oak, application of imazapyr seems to yield the best control of shrub dominance one-year after treatment. The use of sulfometuron at the above-applied rates is not recommended on flatwoods sites as it decreased understory species diversity while hindering longleaf pine seedling growth.

Figure 3-1. Canonical correspondence analysis (CCA) ordination for understory vegetation. (a) CCA ordination with pre harvest and post treatment control plots. (b) CCA ordination of vegetation 3 months after treatment (MAT). (c) CCA ordination of vegetation 9 MAT. The tested nominal variables are plotted as centroids.



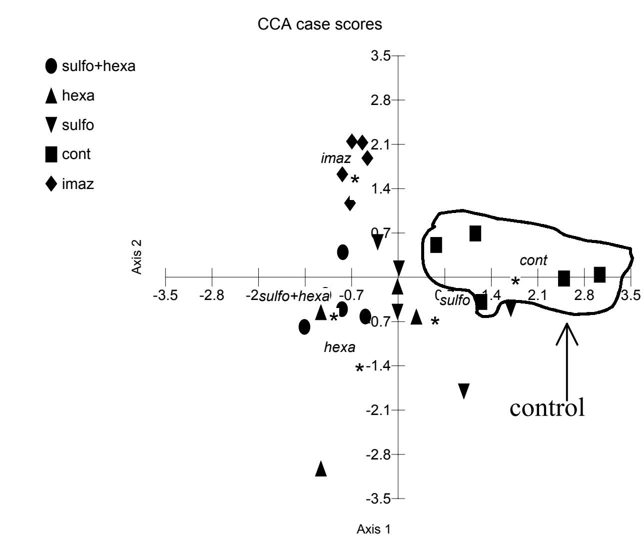
CCA case scores
pre-treatment June 01
control June 02
control Nov 02
June 2002
June 2001
November 2002
time
Axis 1
Axis 2
Vector scaling: 1.73

(a)



CCA case scores
sulfo+hexa
hexa
sulfo
cont
imaz
Axis 1
Axis 2
Vector scaling: 4.43

(b)



CCA case scores
sulfo+hexa
hexa
sulfo
cont
imaz
control
Axis 1
Axis 2
Vector scaling: 3.33

(c)

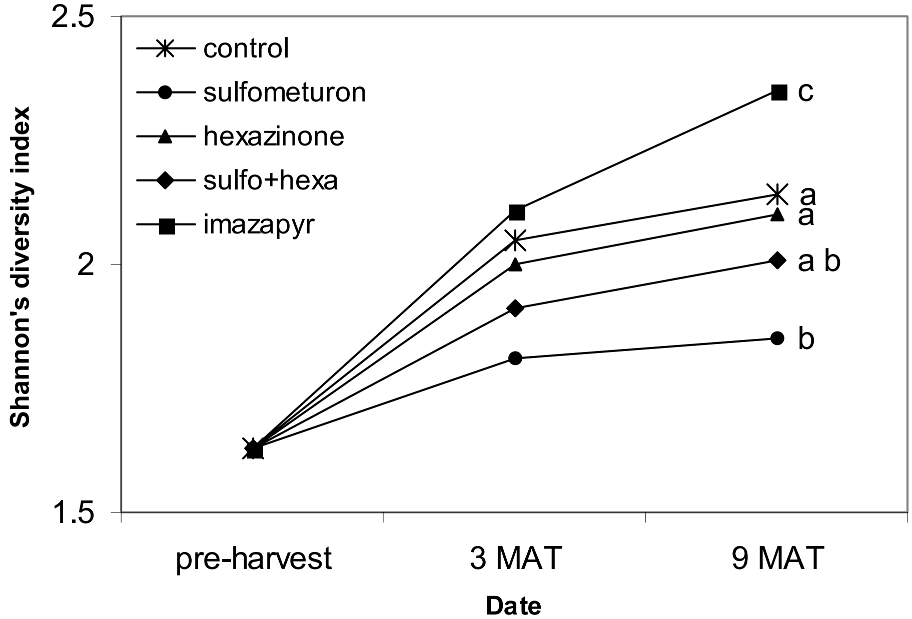


Figure 3-2. Mean Shannon diversity index for each treatment by date. Shannon's index values for each treatment followed by a different letter is significantly different from other treatments within each date. Significance established through Duncan's multiple range test at α=0.1. (sulfo+hexa: sulfometuron+hexazinone mix treatment)

Table 3-1. Mean species evenness and richness of three vegetation surveys

Treatment	Evenness	Richness
Pre harvest survey	0.70	10.40
3 MAT[2] survey		
Control	0.76	14.80
Sulfometuron	0.74	11.60
Hexazinone	0.78	13.00
Sulfo+Hexa[1]	0.77	12.40
Imazapyr	0.81	13.80
9 MAT[2] survey		
Control	0.83	13.00
Sulfometuron	0.77	11.20
Hexazinone	0.83	12.60
Sulfo+Hexa[1]	0.81	12.80
Imazapyr	0.87	14.80

[1]Sulfometuron+Hexazinone mix treatment
[2]Months after treatment

Table 3-2. Percentage change in foliar cover (% cover) of major understory species and vegetation classes by treatment

Species/ Vegetation class	Sulfometuron	Hexazinone	Sulfo+Hexa	Imazapyr
Wiregrass				
June 2002	33.86 +	44.44 +	11.11 +	29.29 +
November 2002	21.53 +	18.69 +	11.82 +	7.82 +
Bluestem spp				
June 2002	9.27 +	12.14 +	3.51 +	48.24 -
November 2002	56.93 - [a]	19.83 -	8.77 +	19.29 -
Gallberry				
June 2002	12.80 +	19.27 +	45.79 +	77.04 - [a]
November 2002	7.16 +	20.65 +	34.68 +	69.61 - [a]
Runner oak				
June 2002	13.17 +	34.22 -	42.93 -	67.91 -
November 2002	10.26 +	36.66 - [a]	45.34 - [a]	68.33 - [a]
Saw palmetto				
June 2002	28.29 -	22.45 -	29.19 -	0.71 +
November 2002	6.18 +	11.12 -	25.97 +	0.73 +
All shrub				
June 2002	12.22 -	32.50 -	27.28 -	54.20 - [a]
November 2002	1.07 -	16.67 -	11.98 -	49.87 - [a]
All grasses				
June 2002	29.49 -	21.55 -	30.80 -	34.55 -
November 2002	28.34 -	4.15 -	20.57 -	13.53 -
All forbs				
June 2002	34.34 -	8.26 -	32.60 -	20.00 +
November 2002	15.07 -	25.59 -	22.24 -	47.36 +

[1]sulfometuron+hexazinone mix treatment

\+ and – indicate increase and decrease of foliar cover in relation to control

[a] significantly different from control within rows. Significance established with Kruskal-Wallis test at $\alpha = 0.1$

Table 3-3. Mean stem numbers for three major understory shrub species by treatment

	Shrub stem numbers (stems/m^2)				
Species	Pre harvest				
Gallberry	22.42±2.1				
Runner oak	32.16±3.8				
Saw palmetto	2.22±0.2				
	Control	Sulfometuron	Hexazinone	Sulfo+Hexa	Imazapyr
	3 MAT[1]				
Gallberry	18.37±2.6	20.60±2.7	16.93±1.5	16.60±1.8	7.60±0.9 [a]
Runner oak	31.40±5.3	31.29±5.9	23.14±3.9	20.32±2.5	17.62±3.6
Saw palmetto	2.20±0.5	2.45±0.4	2.00±0.4	2.55±0.64	2.90±0.6
	9 MAT[1]				
Gallberry	34.50±4.9	39.80±5.3	38.33±3.7	43.00±5.9	7.03±1.6 [a]
Runner oak	52.07±7.8	59.20±12.1	37.57±6.4	36.57±4.7	18.04±3.3 [a]
Saw palmetto	2.75±0.5	3.44±0.8	2.00±0.6	3.28±1.3	3.33±0.8

[1] Months after treatment

[a] significant differences between treatment within rows. Significance established by Duncan's multiple range test at $\alpha = 0.1$

Table 3-4. Importance values (IV) for major understory species in three vegetation surveys by treatment.

Treatment	Species[1]								
	Blue	Arbe	Gadu*	Ilgl*	Kahi*	Limi*	Pani	Qupu*	Sere*
Pre harvest	0.79	0.60	0.99	1.05	1.02	1.11	0.70	1.05	0.954
3 MAT									
Control	0.70	0.54	1.65	1.22	1.65	1.68	0.88	1.32	1.32
Sulfometuron	0.85	0.48	1.51	1.26	1.68	0.23	0.71	1.12	1.23
Hexazinone	0.92	0.62	1.50	1.21	0.40	1.54	0.17	1.13	0.78
Sulfo+Hexa[2]	0.73	0.52	0.92	1.27	0.39	0.89	0.65	1.06	0.95
Imazapyr	N/A[3]	0.45	N/A[3]	0.45[a]	N/A[3]	1.06	0.29	0.63	1.20
9 MAT									
Control	0.60	0.47	1.59	1.12	2.38	1.22	1.04	1.41	1.11
Sulfometuron	0.53	0.58	1.61	1.24	N/A[3]	N/A[3]	0.46	1.24	1.45
Hexazinone	0.60	0.65	1.03	1.35	N/A[3]	1.39	0.28	1.09	0.73
Sulfo+Hexa[2]	0.77	0.63	0.57	1.42	0.37	1.13	0.10	1.07	1.05
Imazapyr	0.71	0.56	1.26	0.36[a]	1.07	1.06	0.34	0.51	1.18

[1] Blue:Bluestem spp, Arbe:Wiregrass, Gadu:Dwarf huckleberry, Ilgl:Gallberry, Kahi:Hairy wicky, Limi:Gopher apple, Pani:Panicum spp, Qupu:Runner oak, Sere:Serenoa repens

[2] Sulfometuron+Hexazinone mix treatment

[3]N/A: Not present in treatment plots at the time of survey

* IV values calculated as an average of relative frequency, cover and density

[a] Significantly different along rows. Significance established with Duncan's multiple range test at $\alpha = 0.1$

CHAPTER 4
SUMMARY AND CONCLUSIONS

Successful restoration of longleaf ecosystems and their associated understory may depend on the control of competing vegetation. On flatwoods sites, the need for vegetation control is magnified due to the dense shrub understory that smothers young longleaf seedlings and the herbaceous vegetation. Although prescribed fire is an effective restoration tool in many longleaf sites, in flatwoods its shrub control is short lived due to the vigorous sprouting of the shrub vegetation (Abrahamson 1984). Intensive mechanical site preparation, while yielding enhanced growth of seedlings (Burger et al. 1988), may cause extensive damage to the understory vegetation (Clewell 1989).

In our study, we examined the effects of over the top application of herbicides following site preparation with chopping and burning. The use of herbicides such as imazapyr exhibited an evident trade off between non-application and application of herbicides. Herbicide treatments such as imazapyr, which resulted in significantly higher growth within the first growing season, also resulted in significantly lower survival. Where as in control, higher survival was observed but seedling growth was significantly lower compared to imazapyr treatment. On the other hand hexazinone had no effect on survival and did not improve longleaf pine seedling growth. The use of sulfometuron on flatwoods is not recommended as it significantly lowered survival and growth of planted longleaf pine seedlings. The sulfometuron+hexazinone mix treatment did not yield any additional benefit. Imazapyr was the only treatment that yielded significant control of the overall shrub foliar cover with no effect on the herbaceous component of the understory. The significant increase in seedling growth by controlling the shrub component alone reiterates the importance of shrub vegetation control on flatwoods sites. Hexazinone yielded delayed control of runner oak which was one of the dominant shrub species and may yield desirable results in the coming years.

The understory species composition exhibited a change without the influence of herbicide treatments. These changes could be attributed to the seasonal changes in the vegetation and the site preparation activities. However, the herbicide treatments as a whole showed a distinct influence on the overall species composition. The understory species diversity was increased across all treatments compared to pre harvest vegetation. The herbicide treatments did not have a significant effect on the species diversity with the exception of imazapyr and sulfometuron. Imazapyr increased species diversity 9 MAT with nonsignificant increases in species evenness and richness. In contrast, sulfometuron decreased species diversity while resulting in lowered evenness and richness.

Contrary to published research, the site preparation conducted in our study did not significantly affect the foliar cover of wiregrass. The herbicide treatments also had no significant affect on wiregrass.

In conclusion, imazapyr yielded the best-desired effects with increased longleaf pine seedling growth, significant shrub control and improved understory plant diversity. In contrast, sulfometuron resulted in lower survival, growth and species diversity. Therefore, application of sulfometuron for shrub control on flatwoods sites is not recommended.

APPENDIX
SPECIES LIST

Scientific name	Code	Common name
Shrubs		
Asimina incana	Asin	Wooly paw paw
Cyrilla racemiflora	Cyra	Ti ti
Gaylussacia dumosa	Gadu	Drawf huckleberry
Gaylussacia frondosa	Gafr	Dangleberry
Ilex cariacea	Ilca	Large gallberry
Ilex glabra	Ilgl	Gallberry
Ilex vomitoria	Ilvo	Yaupon
Kalmia hirsuta	Kahi	Hairy wicky
Licania michauxii	Limi	Gopher apple
Lyonia lucida	Lylu	Fetterbush
Magnolia virginiana	Mavi	sweet bay
Myrica cerifera	Myce	Wax myrtle
Photinia pyrifolia	Phpy	Red choke berry
Quercus pumila	Qupu	Runner oak
Seronoa repens	Sere	Saw palmetto
Stillingia sylvatica	Stsy	Queens delight
Vaccinium spp	*Vacc*	Blueberry spp
Grasses		
Bluestem spp	Blue	Bluestem grasses
Arisitida beyrichiana	Arbe	Wiregrass
Calamovilfa curtissii	Cacu	Curtis sandgrass
Ctenium aromaticum	Ctar	Toothache grass
Cyperus	Cype	Sedge spp
Eragrostis spectabilis	Ersp	Purple lovegrass
Panicum	Pani	Panicun spp
Panicum erectifolium	Paer	Erect leaf witchgrass
Panicum laxiflorum	Pala	Velvet Witchgrass
Scleria	Scle	Nutrush spp
Xyris caroliniana	Xyca	Yellow eyed grass
Forbs		
Asclepias viridula	Asvi	Southern milkweed
Aster adnatus	Asad	Scaleleaf aster
Aster eryngiifolius	Aser	Thistleleaf aster
Aster reticulatus	Asre	White top aster
Aster tortifolius	Asto	Dixie aster

Species list continued

Carphephorous pseudoliatris	Caps	Bristleleaf chaffhead
Carphephorus odoratissimus	Caod	Deer tounge
Chrysopsis	Chry	Silkgrass spp
Conyza canadensis	Coca	Canadian horseweed
Coreopsis linifolia	Coli	Texas tickseed
Desmodium rotundifolium	Dero	Tricklyfoil
Drosera capillaris	Drca	Pink sundew
Elephantopus tomentosus	Elto	Devils granmother
Eupatorium capillifolium	Euca	Dog fennel
Eupatorium compositifolium	Euco	Yankee weed
Eupatorium mohrii	Eumo	Mohr's thoroughwort
Eupatorium pilosum	Eupi	Rough Boneset
Euthamia graminifolia	Eugr	Flat top goldenrod
Gelsemium sempervirens	Gese	Yellow jessamine
Gratiola hispida	Grhi	Rough Hedgehyssop
Hypericum hypericoides	Hyhy	St. Andrews cross
Hypoxis sessilis	Hyse	Glossyseed yellow stargrass
Hypoxis spp	Hypo	Stargrass spp
Lachnanthes caroliana	Laca	Carolina redroot
Lechea	Lech	Pineweed spp
Lechea pulchella	Lepu	Leggett's pineweed
Liatris gracilis	Ligr	Slender gayfeather
Liatris tenuifolia	Lite	Shortleaf gayfeather
Mimosa quadrivalvis	Miqu	Sensitive brier
Oenothera fruticosa	Oefr	Evening primrose
Opuntia humifusa	Ophu	Prickly pear
Pityopsis graminifolia	Pigr	Silkgrass
Pterocaulon pycnostachyum	Ptpy	Blackroot
Rhexia alifanus	Rhal	Meadow beauty
Rhexia petiolata	Rhpe	Fringed meadow beauty
Sabatia brevifolia	Sabr	Shortleaf Rosegentian
Seymeria cassioides	Seca	Yaupon Blacksenna
Smilax laurifolia	Smla	Laurel green brier
Smilax pumila	Smpu	Green brier
Solidago odora	Sood	goldenrod
Stylisma patens	Stpa	Coastal plain dawn flower
Tragia urens	Trur	Wavyleaf noseburn
Verbena brasiliensis	Vebr	Brazilian vervain
Viola septemloba	Vise	Blue violet
Vitis rotundifolia	Viro	Muscadine

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BIOGRAPHICAL SKETCH

Sanjaya Ranasinghe was born on December 26th 1975, in Colombo, Sri Lanka. In 1996 he came to the United States to pursue an undergraduate degree at Luther College Decorah, Iowa. Upon graduation in 2000 with a B.A. in Biology he was employed at Tidewater Inc., an environmental consultant company based in Columbia, Maryland. In 2001 he was accepted to pursue a master's degree with the School of Forest Resources and Conservation at University of Florida.