Interaction of fire and insects in the restoration and management of longleaf pine

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INTERACTION OF FIRE AND INSECTS IN THE RESTORATION AND MANAGEMENT OF LONGLEAF PINE

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The interactions of insects and fire on the health and restoration of longleaf pines in Louisiana were investigated. Insects found to be economically and ecologically important were considered, primarily bark beetles and weevils. First, insect populations in an area of fire exclusion of the Palustris Experimental Forest within the Kisatchie National Forest were quantified using baited flight intercept and pitfall traps. The possible influence of temperature and precipitation on insect abundance also was studied. Insects were most abundant during March and April and with correlating temperatures from 10 – 20 °C. Precipitation was not found to have an effect on insect abundance. Second, the roles of fire and insects and tree health were examined. As an indicator of tree health, 24-hour resin production was sampled from trees in the study area. Insects responded differentially to prescribed fire by season and feeding guild. Dormant season burns attracted significantly more root feeding than bark feeding insects. Growing season burns attracted significantly fewer insects than dormant season burns. Last, a portable propane burner was utilized to conduct semi-controlled burning of trees, simulating dormant and growing season burns of long and short duration of low and high intensity, respectively. Trees subjected to non-traditional prescriptions (high intensity dormant season fires and low intensity growing season fires) produced significantly less resin than trees burned under traditional prescriptions (low intensity dormant season fires and high intensity growing season fires). Overall, my research indicated that longleaf pine should be managed with prescribed burning during the growing season for stand maintenance. Growing season burns minimize

insect response and have been shown to mimic natural burning patterns and be more effective at reducing understory competition. Depending upon management objectives, managers should consider insect response and the effect of fire on tree health when developing prescriptions.

INTRODUCTION

The abundance of longleaf pines (*Pinus palustris* Mill.) in the South has been on the decline for many years (Outcalt 1997). A once vast, contiguous forest (Figure 1) of 37 million hectares stretching from the Atlantic Coastal Plain through the Gulf Coastal Plain has been reduced to less than 2 million hectares (USDA Forest Service, Forest Inventory and Analysis 1994, Means and Grow 1985, Noss 1989).

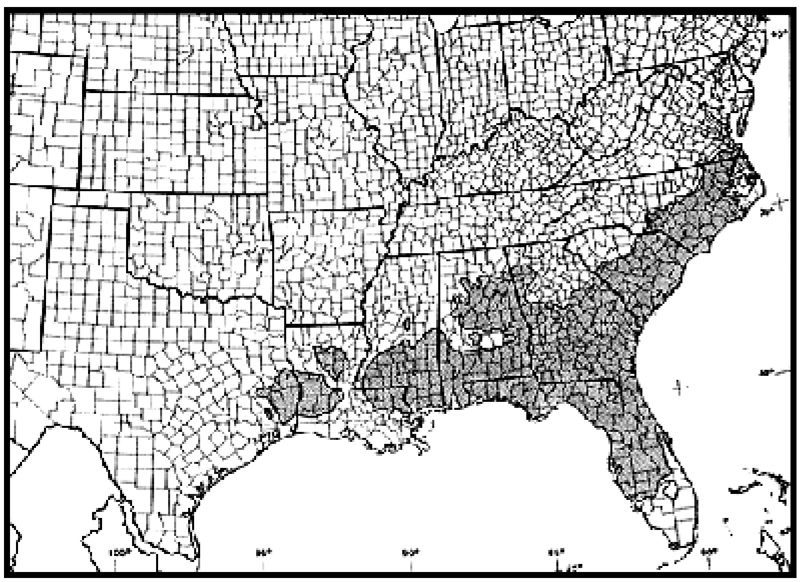

Figure 1 – Natural longleaf pine range in Southeastern United States, from Boyer, (1990b).

Of the remaining acreage, Louisiana has a total of about 94 thousand hectares. The loss of acreage is due in part to the exclusion of fire from stands which encouraged competition by other pines and hardwoods (Boyer 1990b, and Gilliam and Platt 1999). Fire determined the species composition and diversity of the longleaf forest and prevented succession.

Fire also produces complex interactions with insects that help to prevent stand replacement by competitive species. McCullough et al. (1998) reviewed

many papers regarding these interactions in northern and boreal forest systems, They concluded that fire suppression greatly changed the composition and structure of forest species, making the forests more vulnerable to insects. Fire suppression has altered forest composition throughout the United States, particularly longleaf pine forests (Gilliam and Platt 1999). Using fire-scarred trees and a combination of physiographic factors, Frost (1998) determined that before settlement by Europeans, fires occurred in the longleaf habitat of the south at a frequency of every one to three years or four to six years, depending upon location. Heavy clear-cutting of old growth forests at the turn of the 20th century and the lack of longleaf regeneration led to its replacement with faster growing loblolly (*Pinus taeda* L.) and slash pine (*Pinus elliottii* Engelm.). Destruction of seedlings by feral hogs (Lipscomb 1989), low seed production, regeneration failure and the need for fire to manage stands also contributes to the decline of longleaf forestland (Outcalt 2000b). The effective Smoky Bear campaign by the Forest Service put society in opposition to using fire and the need to comply with the Clean Air Act and Clean Water Act further complicated using fire as a management tool.

In the past, many different management techniques have been investigated in longleaf pine. Until the 1980's, management objectives were primarily for production of saw logs and poles and occasionally for grazing (Wolters 1981), wildlife and pine straw harvesting (Haywood et al. 1998). Currently, initiatives are being proposed to return remaining degraded longleaf stands to pre-settlement conditions where trees are spaced in a park-like setting with open

ground lacking underbrush and dominated by grasses (Heyward 1938, Kush et al 1998, Walker 1999). This ecosystem is desirable for its unique habitat, the preservation of rare and endangered species, and the increased biodiversity associated with the longleaf system.

Prescribed fire is used to remove the unwanted competitive species of trees from longleaf stands and to reduce the amount of fuel present. Burning controls many understory plant species, supports some grasses, and prevents midstory development (Brockway and Lewis 1997). However, fire behavior and its effects with altered stand conditions must be considered, as different management practices may cause differential fire effects when reducing fuel loads (Brose and Wade 2001). Degraded and overgrown longleaf stands will not create the same fire effects as the desired 'pre-settlement' stand (Johnson and Miyanishi 1995) and the arbitrary re-introduction of fire may result in catastrophic fires with high mortality in stands with high fuel loads. Vose (2000) promotes a more ecological viewpoint, favoring ecosystem health and sustainability.

Longleaf is adapted to frequent fire cycles and demonstrates characteristics typical of this type of adaptation. Stands are open-canopied, and uneven-aged due to recruitment into openings. Longleaf can be slow-growing compared to other southern pines. It is often found on nutritionally poor sites and invests energy into building carbohydrate reserves in the roots of seedlings before stem elongation begins (Platt et al. 1988). This may delay height growth for years, depending upon site quality and competition. Once stem elongation is initiated, the seedling rapidly gains height, referred to as bolting. This allows the tree to

reach heights that will be above the low intensity fire lines, preventing crown damage to the young tree. Thick bark prevents damage to the bole. The natural cycle of longleaf is dependent upon fire to facilitate release of the longleaf seedling from the grass stage and encourages reproductive success by reducing competition and removing the forest floor litter (Haywood et al. 2001). During a low intensity fire, a thick tuft of needles that surround the terminal bud protects the seedling. Fire also reduces the incidence of brown-spot needle blight (*Scirrhia acicola* Dearn.) on longleaf seedlings (USDA 1985). Fahnestock and Hare (1964), and Hare (1965a,b) found that the comparatively thick longleaf bark provides a good insulating layer, preventing damage from fire in mature trees. However, increased mortality has been shown in mature stands following prescribed burns (Otrosina et al. 1999). In this study, Otrosina et al. found an increasing incidence of blue stain fungi and root feeding insects after prescribed burns. Boyer (1990a) found that while longleaf pines in the 12.7 to 38.1 cm d.b.h. class did not suffer mortality from a first summer re-introduction fire, 13 percent of trees larger than 39.4 cm were killed. He postulated the losses may have been due to excessive fuels at the root collar of these trees, causing damage to the cambial tissues. Kush et al (1998) lost 91% of old growth longleaf in a low intensity surface fire. Prescribed burning also may affect tree growth, and is especially important where the management objective includes timber production. Johansen and Wade (1987) determined that prescribed fire reduced diameter growth in slash pine by as much as 60%, depending upon the amount of crown scorch. Boyer (1987) found up to 33% increased growth in longleaf

trees on an unburned check as opposed to trees subjected to biennial burning regimes. Van Lear et al. (1977) failed to show any effect of prescribed burning on growth. It became obvious from these and other studies that a better understanding of how fire affects tree health is necessary in order to achieve the stand condition desired.

Longleaf pine is a long-lived conifer and is considered to be resistant to, or tolerant of, most diseases and insects that affect southern pines (Boyer 1990b, Barnard et al. 1993). This resistance may be compromised by an inappropriate use of fire. Fire causes at least a temporary increase in the resin flow of longleaf, (Harper 1944). Stands that have had fire excluded for several years have a buildup of fuels both in the understory and at the ground level. This high fuel load can produce extremely high fire temperatures and intense fires at the ground level and above, that might not have occurred under a natural burning condition (Heyward 1938). Frequent burns eliminate surface fuels and maintain a low intensity fire that quickly consumes fine fuels such as needles and grasses. High fuel loads can lead to greater crown scorch and root injury, adversely affecting growth and survival (Chambers et al. 1986, Johansen and Wade 1987) and ladder fuels can produce catastrophic crown fires. In the restoration of ponderosa pine, *Pinus ponderosa* Dougl., Covington et al. (1997) showed that prescribed fire used to reduce fuel loads caused up to 60% mortality in pre-settlement trees. Root injury also may predispose trees to pathogenic fungi as well as increased stress (Littke and Gara 1986, Otrosina 1998). These fungi often are vectored by bark beetles, and are found to increase in association with

increased occurrence of bark beetles in declining stands of pines (Klepzig et al. 1991, Erbilgin and Raffa 2002, Otrosina et al. 1999, 1997 and Witcosky et al. 1986).

Major disturbances in stands such as fire, hurricane, harvesting practices, flood, wind and ice storms all have the potential to increase bark beetle populations. Greenberg and Thomas (1995) showed an increase in mean proportion of herbivorous beetles following burn-salvage compared to other management techniques. Volatiles produced by stressed pines are used by beetles to locate potential host trees (Flechtmann et al.1999, Fox and Hill 1973, Santoro et al. 2000). Some insects, such as reproduction weevils, may prefer hosts already under attack by other insects (Fox and Hill 1972). Resin produced by pine trees under attack prevents successful colonization by beetles, causing the beetles to retreat or be drowned in the exuding resin (Witanachchi and Morgan 1981). Under high population conditions, *Ips* spp. have been shown to overcome tree defenses and kill healthy trees (Ayres et al. 1999 and Santoro et al. 2000). Coleopteran pests such as reproduction weevils (*Hylobius* and *Pachylobius* sp.), *Ips* spp. engraver beetles, black turpentine beetles (*Dendroctonus terebrans* Olivier), and *Hylastes* spp. are some of the ecologically important pests that attack longleaf pine. These pests cause mechanical damage and may introduce pathogenic fungi to attacked trees, further taxing the trees' resources and reducing growth. High temperature fires in the early growing season may damage trees and attract large numbers of these pests, resulting in more frequent attacks. Increased beetle attacks and the associated

presence of pathogenic fungi may result in the loss of significantly more trees than by fire disturbance alone.

Burning may have an effect on soil nutrient availability. The use of fire is often associated with improved nitrogen availability in the soil, due to the greening effect of plants afterward. Hot fires and frequent fires have been shown to cause a loss of soil moisture holding capacity (Boyer and Miller 1994). There also can be a loss of nutrients and a total consumption of organics remaining in the soil, decreasing their availability in the long run (Tiedemann et al. 2000). The use of prescribed fire in mature hardwoods has not been shown to alter the canopy foliar suitability for insect herbivores and resulted in little change in phytochemistry (Rieske et al. 2002). The effect on longleaf pine has not been investigated.

Determining the best time to use fire in the restoration and management of longleaf also is in question. Dormant season, or cool fires, may not achieve the desired reduction of fuel loads and understory (Olson and Platt 1995). Dormant season and growing season fires have different intensities and durations associated with them (Wright and Bailey 1982). Heavy fuel loads may necessitate using cooler fires (reduced ambient temperature), until fuels are at more acceptable levels and growing season fires can be utilized. The physiological condition of plants at the time of burn also may affect the degree of understory control. Undesirable species burned during the dormant season may suffer top kill or crown reduction, but may sprout prolifically during the growing season (Boyer 1990a). Some oaks tolerate dormant season fires with few

effects (Jacqmain et al. 1999), but have high mortality in growing season fires (Glitzenstein et al. 1995).

How a fire behaves can be very important to its impact on trees. While dormant season fires may not achieve high temperatures, the slow movement of the fire may expose trees to an increased temperature for a longer period of time. Ferguson and Thatcher (1960) showed that in loblolly, *Pinus taeda*, and shortleaf, *Pinus echinata* Mill., a “cool” fire of long duration caused severe cavitation near the ground and death of the tree more than a year after the fire.

Boyer and Croker (1979) and Boyer (1975), provide a good methodology for the natural regeneration of longleaf. In order to restore longleaf on degraded sites, successful regeneration must occur. The seed must contact soil in order to germinate (Boyer 1990b), which does not occur when periodic fire is suppressed and a thick litter layer accumulates on the forest floor. Fire removes this layer and eliminates competition for seedling resources. I have personally observed a lack of regeneration in areas where fire has been suppressed and a heavy understory has become established.

In addition to the use of prescribed fire, researchers have investigated using herbicides instead of, or with prescribed fire to manage and restore longleaf. Longleaf seedlings are relatively intolerant of vegetative competition and herbicides can reduce competition and, thus, the amount of time that seedlings are in the grass stage (Nelson et al. 1982). Use of herbicides also increases stem growth over areas where no herbaceous vegetative control is used (Creighton et al. 1987).

There has been a great deal of research regarding the use of prescribed fire and Southern pines. Both the ecological and economical benefits associated with longleaf make it a desirable ecosystem to preserve and expand. Prescribed fire simulates natural fire disturbance in the longleaf system and is an inexpensive and necessary tool from both a management and ecological viewpoint (Palik et al. 2002). Work very similar to this study is underway in longleaf areas burned by dormant season fire, wildfire, and similar work is being conducted in northern forests. Other comparative studies are focusing on longleaf performance against that of other southern pines, such as loblolly (Bales et al. 1999). The U.S.D.A. Forest Service has directives to expand the longleaf forest type, provide voluntary incentives for state and private landholders to increase longleaf acreage (Walker 1999), and to expand research programs concerning restoration/conservation activities of longleaf stands (McMahon et al. 1998). However, my research focuses on the effect of fire, both prescribed and wildfire, on tree health. While the use of prescribed fire is considered beneficial in longleaf pine stands, it may also have negative effects on the health of trees. Many questions regarding fire and its interactions with insects and tree health are still unanswered. This research further investigates tree physiological responses to dormant and growing season prescribed fires, insect response to burned stands, and the relationship between fire intensity and tree injury in longleaf pines.

CHAPTER 1
SEASONAL OCCURRENCES OF BARK AND ROOT FEEDING INSECTS IN CENTRAL LOUISIANA

Introduction

Bark, root feeding and ambrosia beetles (Scolytidae) and weevil (Curculionidae) species cause economic loss by damaging and/or killing southern pine trees intended for harvest. In addition, forests that are managed primarily for habitat for associated animals and plants also may be at risk from these insects, due to the insects' aggressive colonization and vectoring of pathogenic fungi (Otrosina et al.1997 and Otrosina et al. 1999). The most notorious of the southeastern bark beetles is the southern pine beetle (SPB), *Dendroctonus frontalis* Zimmermann. While most species attack dead and dying trees, the SPB will attack and kill healthy trees, causing the loss of millions of board feet during outbreaks (Price et al. 1996). However, their cryptic behavior has made it difficult to study the biology of many species of bark beetles. Bark and ambrosia beetles live most of their life cycle in either the phloem or xylem tissue of trees, respectively (Anderson, et al. 2002.). Weevils affecting pines feed on roots and are often active only at night. In addition, exotic species of Scolytidae are appearing with increasing frequency in the United States (Rabaglia 2001). Exotics pose a two-fold threat since little is known about their biology in their natural habitat and even less is known about how they may affect new habitats they invade.

The most economically and ecologically important pest insects of southern pines are considered to be the southern pine beetle (*Dendroctonus frontalis* Zimm.), black turpentine beetle (*Dendroctonus terebrans* Olivier), *Ips* spp., *Hylastes* spp., the pales weevil, *Hylobius pales* Herbst and the pitch-eating weevil, *Pachylobius picivorus* Germar. Recent publications link these pest insects and other scolytids with

pathogenic fungi, possibly causing the decline of southern pines (Otrosina et al. 1997 and Otrosina et al. 1999). This association makes these and even the less important insect pest species of concern for forest managers. Also, climatic patterns are known to influence the initiation of bark beetle population cycles (Kalkstein 1976).

Many of the scolytids use allelochemicals in order to locate a suitable host plant (Person 1931). Raffa and Berryman (1982) showed that pine resin induced by bark beetle attack was different from constituitive resin. These differences also are affected by environmental conditions in loblolly pine (Lombardero et al. 2000). Correlations between temporal volatile release from felled loblolly pines and arrival patterns of bark and ambrosia beetles also have been studied (Flechtmann et al. 1999). Many of these pests show an attraction to areas where tree disturbance has occurred, either due to management methods or natural disturbance (Fox and Hill 1973, Corneil and Wilson 1984, and Flamm et al. 1993). Traps using volatiles emitted from disturbed host trees are effective in capturing both weevils and bark and ambrosia beetles (Phillips et al. 1988, Fatzinger et al. 1987 and Oliver and Mannion 2001). Some species, particularly those in the tribe Ipinae, also use aggregation pheromones to encourage further colonization of the host (Phillips et al. 1989).

In this study, I employed ethyl alcohol and turpentine baited traps in order to identify the yearly cycle of emergence and abundance of weevils and bark and ambrosia beetles in an unburned mixed pine and hardwood forested area of Louisiana. The possible influence of weather conditions on insect activity also was investigated. The ultimate goal was to compare these seasonal activity patterns with those in nearby areas receiving prescribed burns for fuel reduction and longleaf restoration (see Chapter 2).

Methods and Materials

Study Site

Figure 2 – Location of the Longleaf Tract in the Palustris Experimental Forest in Rapides Parish Louisiana indicated by arrow.

The study site was in the Palustris Experimental Forest, located within the Kisatchie National Forest in Rapides Parish, Louisiana (Figure 2). The site was about 56 km south of Alexandria, Louisiana. The study was set up on the South Unit of the Longleaf Tract. This area had not been burned for more than 10 years and could be considered typical of areas of former longleaf pine habitat undergoing restoration with a heavy understory of woody plants and competing pines and hardwoods (Figure 3). Ruston, McKamie and Gore are the major soil types and are well drained. The site was clearcut prior to 1930 and after being designated as a National Forest in 1935, the site was re-planted in the 1930's. The trees are 60 to 65 years old and average 20 m in height and 38 cm in diameter. Basal area (BA) of longleaf is less than 20 on the unit and there are many mature loblolly, BA 70, and scattered slash pine present in the stand as well. The stand was part of a grazing study from the 1950's through the 1980's and was

frequently burned to maintain grazing pastures. Fire management was stopped in the late 1980's and the stand has undergone natural succession to present.

Figure 3 – Typical area of fire exclusion with a heavy understory and competing pines at Palustris Experimental Forest, Louisiana, 2000-2002.

Competing species of pine, including loblolly and slash were present as well as hardwood species such as dogwood (*Cornus florida* L.), red maple (*Acer rubrum* L.), water oak (*Quercus nigra* L.), southern red oak (*Quercus falcata* Michx.) and blackjack oak (*Quercus marilandica* Muench.). A heavy understory of woody plants also was present including American beauty bush, (*Callicarpa americana* L.), sassafras (*Sassafras albidum* [Nutt] Nees.), yaupon (*Ilex vomitoria* Ait.), and vines such as yellow jessamin (*Gelsemium sempervirens* L.), rataan vine (*Berchemia scandens* [Hill] Koch) and Smilax (*Smilax bona-nox* L.). A dedicated control research area was established within the Palustris Experimental Forest. In this study, control refers to an area of fire exclusion.

Insect Sampling

Flight intercept and pitfall traps were used to sample insects in the control area. A flight interception trap (after Klepzig et al., 1991) was constructed using a one-gallon plastic milk jug (Figure 4).

Figure 4 – Flight intercept (left) and pitfall (right) traps used at Palustris Experimental Forest, Louisiana, 2000-2002.

The sides of the jug were cut away and the remaining frame was attached inverted on a stake, about 0.5 meters above ground. A 118ml "specimen" cup was attached to the threaded neck to collect intercepted insects. The trap was baited with ethyl alcohol (95%) and Klean Strip® turpentine, distilled from southern pines. The baits were placed in two, two-dram vials that were attached with wire to the back of the trap. Insects responding to the bait would strike the back of the jug and fall into the cup. In order to capture apterous insects, a pitfall trap (Figure 4) was employed (after Klepzig et al. 1991). Pitfall traps (Figure 4) were constructed from 10.1cm PVC pipe measuring 20 cm in length. An end cap was glued to the bottom of the trap and drain holes drilled into it to allow water to escape. An inner PVC cup, called an end cap, was placed inside the pipe, again with drain holes drilled into the bottom. The top cap was not glued to allow

for removal. Two, two-dram vials were suspended by wire from the lid cap and filled with the same ethyl alcohol and turpentine baits used in the flight interception traps. A five-to-eight cm long and one-to-two cm diameter segment of loblolly pine stem was placed in the bottom of the pitfall trap as a substrate for insect attack/breeding. The pitfall traps were placed in the ground with openings drilled at intervals around the circumference of the pipe at ground level to allow crawling insects to enter. Thirty collection stations were placed 30 to 50 meters apart, near 30 longleaf pines in the study area. Each station consisted of one pitfall and one flight intercept traps, for a total of 60 traps. Traps were initially installed in May 2000 and remained until August 2002. Insects were collected, identified and counted weekly, except when temperatures dropped below freezing. The baited vials also were refilled at each collection period.

In order to construct correlations with insect abundance, weather conditions were monitored. Precipitation amounts and air temperature at 1.5 m above the soil were taken from the weather station log on the Palustris Experimental Forest.

Statistical Analysis

It should be noted that the most economically important pest, the SPB, was not detected in Louisiana during this study. *Dendroctonus terebrans, Ips grandicollis* (Eichhoff), *Ips avulsus* (Eichhoff), *Hylastes salebrosus* (Eichhoff), *Hylastes tenuis* (Eichhoff), *Pachylobius picivorus* and *Hylobius pales* were assumed to be the most economically and ecologically important pine pest species for this study. Therefore, these insect abundances were analyzed to determine monthly patterns and correlations with temperature and weather conditions.

Insects known or suspected to have had an impact on the health of southern pines (i.e. Curculionidae and Scolytidae spp.) were analyzed for correlations in monthly

abundance. Monthly precipitation and average weekly temperature readings were used in correlation analyses to determine any trends between insect presence and abundance and weather conditions. A weekly temperature average was determined by averaging all hourly readings for the entire week in C°. Precipitation was calculated as totals for the month in millimeters. Insect tally data for years 2001 and 2002 showed no significant differences in abundance and were used for correlation analysis between weather trends and insect occurrences. Significance for the model was determined using SAS© proc GLM and proc REG (SAS 2001). SAS© proc CORR Kendall was used to determine any correlations between temperature or rainfall and insect abundance.

Results

Climate Variables

No significant difference was found for monthly rain totals between years 2001 and 2002 ($p<0.052$; $F = 6.39$). Monthly rainfall totals for 2000 were significantly lower than 2001 ($p<0.0016$; $F = 0.1078$) and 2002 ($p<0.011$; $F = 0.053$). No significant differences were found among weekly average temperatures (of the same weeks) over the three years of this study, though daily high temperatures in the second week of July of 2000 exceeded 38°C for nine consecutive days. Insect species of interest (*Dendroctonus* sp., *Ips* spp., *Hylastes* spp., and pales and pitch-eating weevils) were most abundant during the months of March and April for both 2001 and 2002 (Figure 5). The corresponding temperatures during this period averaged between 10° and 20°C. Significant differences were found for insect abundance between the years and by season (Table 1). Similar to Taylor and Franklin's (1970) findings in Georgia with *Hylobius pales*, as the season progressed into summer, insect abundance decreased. No correlation was

found between rainfall totals and insect abundance, nor was there a significant interaction between rainfall and temperature.

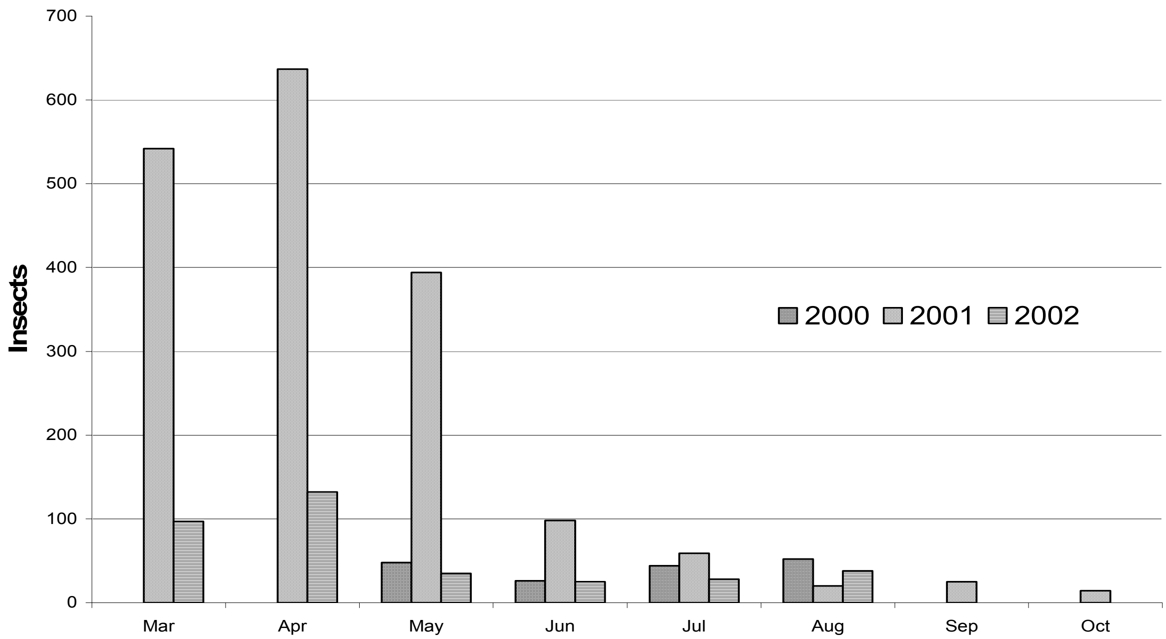

Figure 5 – Monthly insect abundance for Black Turpentine Beetle, *Ips* spp., *Hylastes* spp., pales and pitch-eating weevils combined. Palustris Experimental Forest, Louisiana 2000-2002.

Table 1 – Statistical analysis of the influence of year and season (spring or summer) on insect abundance, Palustris Experimental Forest, Louisiana, 2000-2002.

Source	DF	F Value	Pr > F
year	2	12.34	<.0001
season	1	43.46	<.0001

Table 2 – Percent abundance of insects of major importance to longleaf pine health by year, Palustris Experimental Forest, Louisiana 2000-2002.

	2000	***2001***	***2002***
BTB	4.3	0.53	0.28
Hylastes	39.1	81.3	25.3
Ips	37.8	12.1	40.7
Weevils	18.6	6.0	33.7
Totals	99.8	99.93	99.98

Insects

Dendroctonus terebrans (BTB)

More commonly referred to as the black turpentine beetle (BTB), this large scolytid was not abundant in the three years of this study (Figure 6). Less than 20 were collected from 2000 to 2002 in the control area. Percent abundance decreased over the three years of the study (Table 2). BTB was captured infrequently, and no conclusions

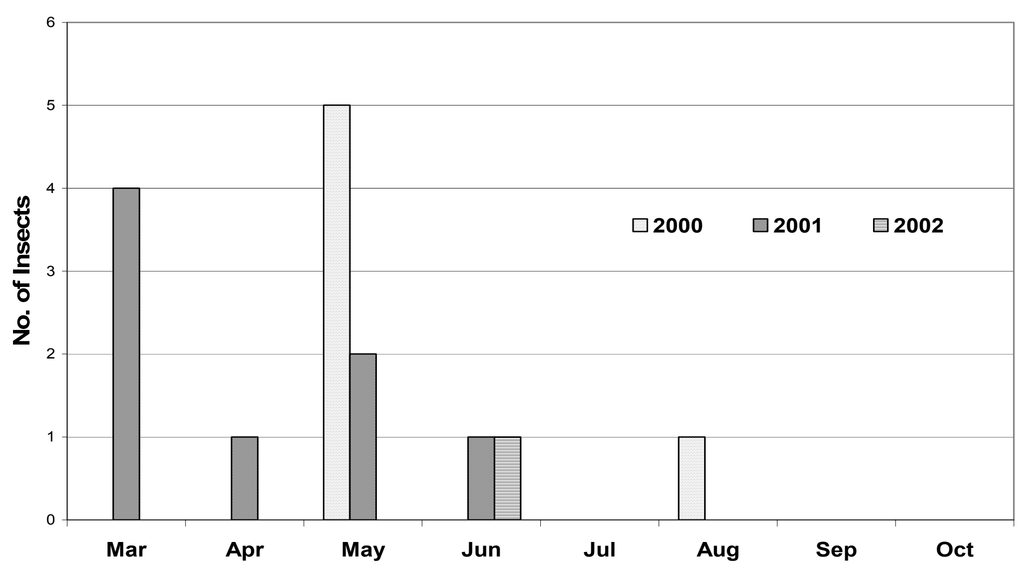

Figure 6 – BTB abundance by year, Palustris Experimental Forest, Louisiana, 2000-2002.

can be made in this study regarding trap preference or monthly abundance.

Hylastes spp.

Hylastes spp. (Figure 7) were most often collected in pitfall traps and were commonly found feeding on the phloem of the stem segments. *Hylastes* spp. were much more prevalent in 2001 than in 2000 or 2002, and were most abundant in the months of March, April and May in both 2001 and 2002. *Hylastes* spp. accounted for more than 80% of the insect abundance for 2001 (Table 2). It is not known if populations cycle by year, warranting further investigation. *Hylastes salebrosus* was collected more often than *Hylastes tenuis* (1349 vs. 207 insects, respectively).

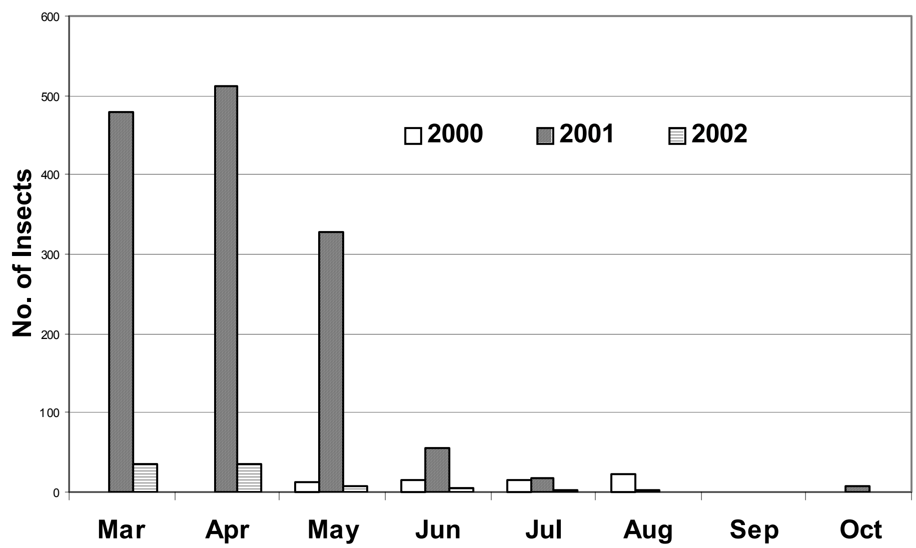

Figure 7 – Hylastes abundance by year, Palustris Experimental Forest, Louisiana, 2000-2002.

Bark Beetles

The most commonly collected bark beetle was *Ips grandicollis* (Eichhoff). *Ips grandicollis* was common in both types of traps, and frequently developed galleries with eggs and/or larva in the stem segments of the pitfall traps. *Ips avulsus* (Eichhoff) also

was found, though less frequently than *I. grandicollis*, and *Ips calligraphus* (Germar) was rarely collected, with only two specimens captured throughout the study (Figure 8). *Ips* were found from March through May and generally declined in abundance for the rest of the year. Percent abundance decreased from 2000 to 2001, but then increased in 2002 (Table 2).

Also in the tribe Ipini, *Orthotomicus caelatus* Eichhoff was trapped regularly in 2002, rarely in 2001, and not at all in 2000. Though found in both flight and pitfall traps, *O. caelatus* generally occurred in much higher numbers in pitfall traps when many would be found in the phloem of the pine segment.

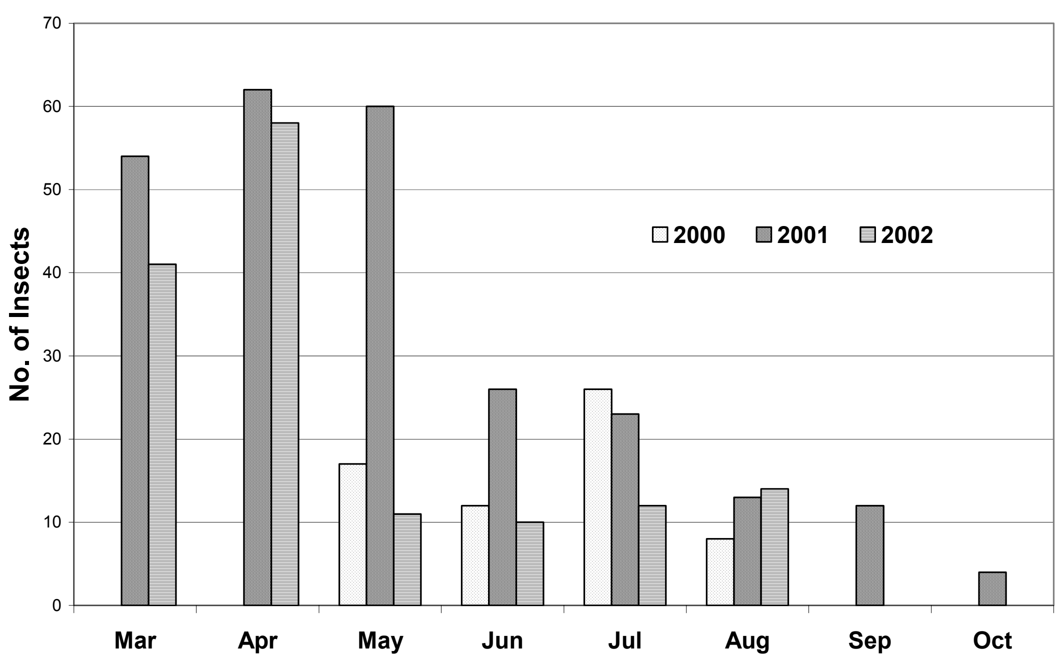

Figure 8 – Ips abundance by year, Palustris Experimental Forest, Louisiana, 2000-2002.

This was most likely due to aggregation pheromones (Phillips et al. 1989), and larvae were nearly always observed in stem segments with more than one beetle.

Weevils

Pachylobius picivorus (Germar) was most often found in pitfall traps and occasionally found in flight interception traps. *P. picivorus* was found throughout the year, with no one month notably higher for abundance. *Hylobius pales* (Herbst) also was found throughout the year, but more often when there were fewer *P. picivorus* captured (Figure 9). Whether or not temporal or spatial exclusion occurs between the species is not known, but these data suggest the possibility exists. Percent abundance of weevils decreased from 2000 to 2001, then increased dramatically from 2001 to 2002 (Table 2).

Though not generally considered a pest, *Cossonus corticola* (Say) was quite

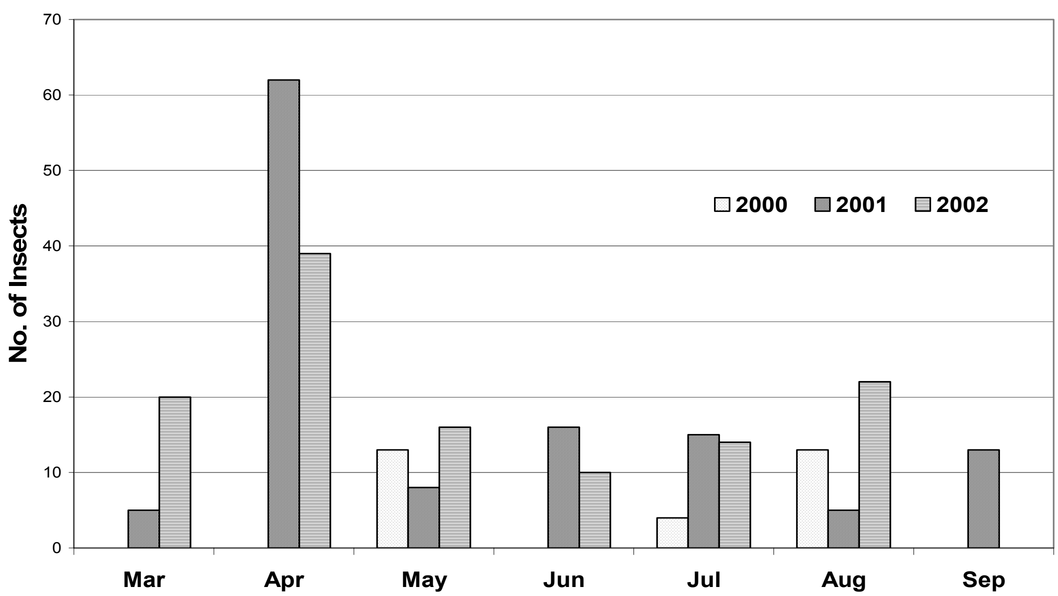

Figure 9 – Weevil abundance by year, Palustris Experimental Forest, Louisiana 2000-2002.

prevalent, being most abundant in 2000 and in the months of May, June and July for all three years. Though readily found in flight interception traps, C. corticola was rarely found in pitfall traps.

Ambrosia Beetles

Several species of ambrosia beetles were collected (Table 3). *Xylosandrus compactus* (Eichhoff) is an introduced species, most likely from southeast Asia, and was first recorded in the United States in Florida in 1941 (Ngoan et al. 1976). It has since become widespread and was trapped at the study site in all three years. *X. compactus* was most abundant in 2002, in the months of March and April, and readily made galleries in the stem segments of the pitfall traps. It is likely an opportunist, with a wide range of host trees and woody plants.

Table 3 – Ambrosia beetle collections by year and month on Palustris Experimental Forest, 2000-2002.

2000		Xylosandrus compactus	Xylosandrus crassiusculus	Xyleborus ferrugineus	Xyleborinus saxeseni	Xyleborus affinis	Xyleborus pubescens	Gnathotrichus sp.	Hypothenemus sp.	Dryoxylon sp.
	May	0	0	0	0	0	0	0	0	0
	Jun	8	4	1	9	0	0	0	0	0
	Jul	5	0	1	1	0	0	0	0	0
	Aug	0	0	1	2	0	0	0	0	0
2001	Mar	0	0	0	0	0	0	0	0	0
	Apr	11	7	1	5	0	0	0	0	0
	May	0	5	1	41	3	11	0	2	0
	Jun	0	2	1	14	0	6	0	0	0
	Jul	0	3	0	5	1	18	0	0	0
	Aug	1	1	0	1	0	8	0	0	0
	Sep	11	0	0	0	2	22	0	0	0
	Oct	29	0	0	2	2	9	3	0	0
2002	Mar	330	36	1	28	1	45	4	54	12
	Apr	481	31	0	11	4	117	0	48	11
	May	1	9	0	0	0	0	0	0	0
	Jun	1	27	31	13	0	0	0	1	0
	Jul	58	0	0	0	0	0	0	2	0
	Aug	2	0	0	0	0	9	0	0	0

Whether or not *X. compactus* can successfully complete its life cycle in *Pinus* spp. is not known. *Xylosandrus crassiusculus* (Motschulsky) also was captured, but in very low

numbers. Like *X. compactus*, it was most abundant in March and April 2002. *Xylosandrus crassiusculus* was found with larvae in sapwood of the pine stem segments on two occasions, but whether the larvae would have completed development in *Pinus* spp. is unknown.

Xyleborinus saxeseni (Ratzeburg) was collected in all three years. *X. saxeseni* was not very abundant and varied in abundance from year to year. Highest trap catches were in June 2001 and March 2002. This beetle often was found boring into the sapwood of the stem segments but no larvae were observed.

Xyleborus pubescens (Zimmermann) was found commonly in 2001 and 2002. It was most abundant in April 2002 but was trapped in every month that year and in all but March and April 2001. *X. pubescens* was readily found in the sapwood of the pine bolts. No larvae were observed. *X. affinis* (Eichhoff) was captured in flight traps but in relatively low numbers.

Xyleborus ferrugineus (Fabricius), *Dryoxylon onoharaensum* (Murayama) and *Gnathotrichus materiarius* (Fitch) were rarely captured and in very few numbers. These beetles were almost always collected in flight interception traps. *Hypothenemus* sp. was most common in March and April and was quite abundant in March and April of 2002. *Hypothenemus* sp. was most frequently found in pitfall traps. *Xyleborus californicus* was trapped on the study site and was a new state record for 2001 (Rabaglia 2001), the first time reported in Louisiana.

In summary, the abundance and emergence patterns of pales and pitcheating weevils, bark beetles, *Dendroctonus* and *Hylastes* species are of concern to forest managers. My data suggest that management practices that may attract these insects such as prescribed burning, harvesting and thinning, should be minimized in the months

of March and April. Insect abundance should be carefully monitored when the average weekly temperature is between 10° and 20°C and when management activities may make stands more susceptible to insect attack. These insects may also vector pathogenic fungi. Since the role of these fungi in causing tree decline is not well understood, it is even more important to minimize the relative attractiveness of forests to these insects through properly timed management practices.

CHAPTER 2
EFFECTS OF PRESCRIBED BURNING FOR RESTORATION AND MANAGEMENT OF LONGLEAF PINE ON INSECT ABUNDANCE AND TREE HEALTH

Introduction

Pre-settlement fire regimes for the United States have been well established by Frost (1998) and Outcalt (1997). Native Americans used fire to burn forests for agricultural and hunting purposes, supplementing the frequency of lightning strike-initiated fires. Longleaf pine, *Pinus palustris* Mill., is well adapted to fire and depends upon fire to maintain its unique ecosystem. Fire suppression in the national forests after World War II began a period of decline in longleaf acreage. In the late nineteenth and early twentieth centuries, extensive logging of old growth forests in the south and east further reduced longleaf forests. Factors such as damage by feral hogs and intolerance to competition drastically reduced seedling numbers on longleaf sites. Re-planting of stands with other pine species such as loblolly, *Pinus taeda* L., also contributed to the loss of acreage. In addition, the need for fire to manage and maintain longleaf has reduced the attractiveness of longleaf as a crop tree. Longleaf has declined from more than 90 million acres in the pre-settlement Atlantic and Gulf Coastal Plains to less than 3 million acres today (USDA Forest Service, Forest Inventory and Analysis 1994, Means and Grow 1985, Noss 1989). Louisiana has lost between 85 and 98% of its longleaf habitat (Outcalt 1997). The remaining forests often are highly fragmented and degraded.

Longleaf pine is considered relatively resistant to diseases and insects that afflict southern pines (Wahlenberg 1946). It is a superior timber tree and will grow on lower quality sites with poor soils (Barnett 1999). In addition, the longleaf ecosystem is unique and is associated with many rare and endangered species and a highly diverse understory composition, making it a desirable system to preserve and expand. Essential to the restoration and management of longleaf and its associated diverse understory is the use of prescribed fire (Barnett 1999). Periodic fire improves stand condition and improves the understory vegetation (Outcalt 2000a) compared to longleaf stands where fire has been suppressed. There are many problems linked to the re-introduction of fire, including mortality in mature trees. Boyer (1990a) found that while longleaf pines in the 12.7 to 38.1cm d.b.h. class did not suffer mortality from a first summer re-introduction fire, 13 percent of trees larger than 39.4cm were killed. The site had undergone regular dormant season burns, but hardwoods survived and a mid-story of hardwoods had developed. Kush et al. (1998) found that feeder roots will invade a heavy needle accumulation at the base of mature longleaf pines. A subsequent fire in May resulted in the death of 91% of the stand.

Trees damaged by fire are often attacked by bark beetles and root feeding beetles. The volatiles released by stressed trees are used by beetles to locate potential host trees (Fletchmann et al. 1999, Fox and Hill 1973, Santoro et al. 2000). The beetles cause mechanical damage to the trees by excavating galleries in and consuming phloem tissues, as well as potentially introducing

pathogenic fungi (Otrosina et al. 1997 and Otrosina et al. 1999). Trees felled for salvage operations may become a refuge for these insects and Ips spp. may attack trees within one week after felling (Berisford and Franklin 1971).

This study sought to identify key mortality factors for longleaf pine to assist managers in making decisions about individual tree health. Annual mortality rates differ in the literature. Quicke et al. (1997) gave an annual survival rate of more than 99% for longleaf trees over 15.2 cm in diameter. This shows that a small percentage of large trees have a possibility of mortality each year. However, this does not reflect the higher mortality observed in trees subject to restoration regimes (Varner et al. 2000). Boyer (1994) found an overall mortality rate of 0.4 % across 27 mature regeneration sites from North Carolina to Louisiana, while Palik and Pederson (2002) found a 1.9% annual mortality rate in mature stands in Georgia. Ryan (1998) and Reinhardt (1988a, b) developed mortality indices using several morphological parameters. This study also investigated the interactive effects of insects and prescribed fire on tree health and survival.

Methods and Materials

<u>Prescribed Burns</u>

Study Site

The study site was in the Longleaf Tract of the Palustris Experimental Forest, located within the Kisatchie National Forest in Rapides Parish, Louisiana (Figure 2). The site was about 56 km south of Alexandria, Louisiana. Ruston, McKamie and Gore are the major soil types and are well drained. The site was clearcut

prior to 1930 and after being designated as a National Forest in 1935, the site was re-planted in the 1930's. The mature trees were 60 to 65 years old and averaged 20 m in height and 38 cm in diameter. Regeneration is present depending upon stand condition and varies from grass stage seedlings to sapling. Basal area (BA) of longleaf varies from less than 2 m^2/ha on some of the Longleaf Tract units to more than 5 m^2/ha and there are many mature loblolly (BA 16 m^2/ha) and scattered slash pines present in the stand as well. Parts of the stand were used in a grazing study from the 1950's through the 1980's and were frequently burned to maintain grazing pastures. Prescribed burning has been used to control hardwoods and reduce fuels about every two years on most of the units, depending upon opportunity and conditions.

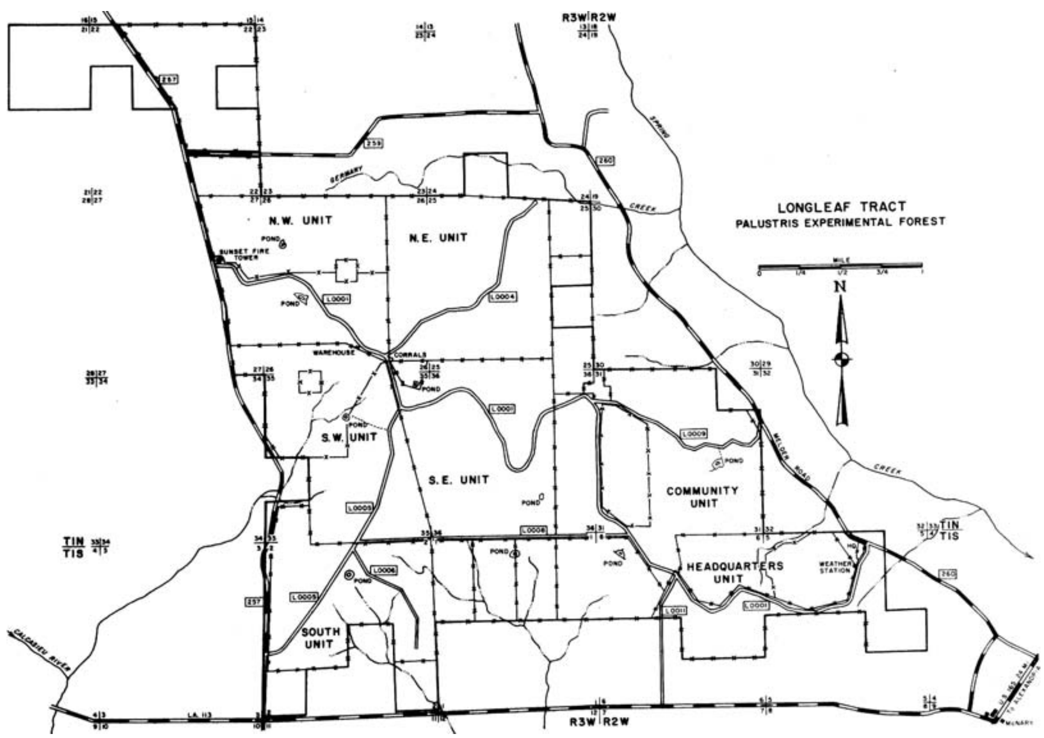

Figure 10 – Map of the Longleaf Tract of the Palustris Experimental Forest in Rapides Parish, Louisiana. Red arrows indicate treatment areas where prescribed burns were conducted.

Four growing season and three dormant season prescribed burns (Table 4) were investigated over three calendar years, in similar stands of longleaf pine on the Longleaf Tract (Figure 10). Treatment areas varied in size from 12 ha to more than 200 ha. Thirty trees were selected within each treatment area by apparent uniformity of health, including live-crown ratio (0.3-0.5), diameter (30-63 cm), and distance to nearest test tree > 10 m. The trees were marked with numbered aluminum tags for identification. Thirty trees also were selected and marked in an adjacent unburned (control) area, located in the South Unit. Diameter at breast height, bark thickness, and any injuries were noted using Forest Health Monitoring Protocols and Quality Assurances (USDAFIA, 2000).

On the day of the prescribed burn, environmental conditions such as ambient temperature and relative humidity, duff and soil moisture, bark moisture, fuel load and wind speed and direction were recorded. Relative humidity was determined using a Bacharach model 12-9015 sling psychrometer at hourly intervals before and during the burn. Bark moisture was measured with a Protimeter model "mini", with two readings taken on opposite sides of each sample tree. Duff and soil moisture were ascertained at the start of the burn with a Lincoln soil moisture meter. The fuel load of the plot to be burned was quantified as 1-hour, 10-hour, 100-hour and 1000-hour fuels. This amount then was converted into megatons per hectare of fuel. Wind and ambient temperature were measured with a Kestral model 3000 weather station. No fires were conducted when Keetch-

Byram Drought Indices were above 600 (Melton 1996). Drought conditions in 2000 caused the postponing of several burns until 2001.

To monitor fire intensity, each study tree had two thermal paint strips affixed to it at 0.33 meters above the duff layer, one each on the predicted windward and leeward sides (direction of fire movement) of the tree (Fig. 11).

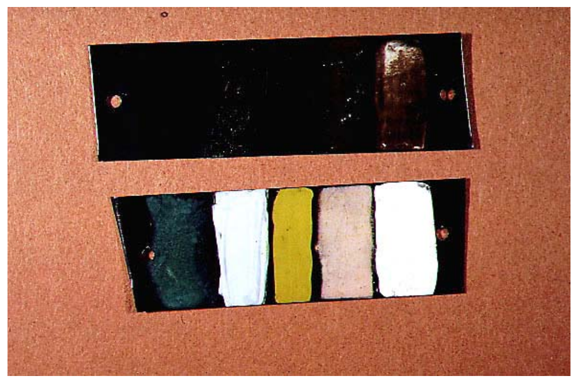

Figure 11 – Temperature indicating lacquer strips affixed to tree bole (left) and before and after fire (right).

The paint strips were 2.5 X 15 cm steel strips that had Omega LAQ temperature indicating lacquer paints applied to them at melting levels of 65.6, 197.8, 315.6, 550, 773.9, 926.7 and 1093.3 °C (Omega, 1999 after Clinton et al. 1998). The lacquer strips were removed from the trees after the fire treatment and the maximum temperature achieved was recorded for each tree. To ensure accurate interpretation of the melting point temperature, the strips were tested in a Thermodyne 2000 furnace. Each lacquer was tested beginning at 10 °C below the indicated reaction temperature (lowered by 10 °C if a reaction occurred) and

in 10 °C increments until a reaction was observed. Duration of exposure was five minutes at each temperature.

A regression model for paint temperature and bole char was developed using a test prescribed burn. A prescribed burn was conducted at the Idlewild Research Station near Clinton, Louisiana in March of 2002. Thermal paint strips were affixed to random trees within the stand prior to burning as described above. Stephens and Finney (2002) showed that mortality increases with increasing bole char height, though no temperature is associated with this measurement. Quantifying mortality temperatures occurring outside the tree can provide managers with a tool to make decisions concerning tree health. I was unable to generate a mortality model, as no tree mortality occurred in the prescribed burns conducted for this study. Fire behavior characteristics of flame length, height, and flame movement in meters per minute were visually estimated and recorded. The trees in the treated and untreated areas were monitored weekly during insect sampling, at six months and then yearly intervals, for symptoms of decline and insect attacks. Resin flow (see Resin Sampling below) also was tested after treatment. Bole char was used in concert with the lacquer strips to determine an individual tree's fire intensity exposure. A relationship between the height of bole char and the corresponding lacquer temperature was investigated by regression analysis.

The insect sampling and resin flow results from the dormant season burns were compared to those from the growing season burns using SAS© (2001) Proc GLM and Reg to determine risk level for the effect of timing and intensity of

the burn on tree health and predisposition to insect attack. Evaluation of both the resin flow characteristics (see below) and the actual presence of known or potentially damaging insects were used to predict tree vulnerability or risk for these two burning regimes.

Wildfire

In addition to prescribed burns, this work also examined the effects of wildfires on tree health. The Longleaf Vista is a wilderness area and prescribed burning is not used to manage it. Fuels are allowed to accumulate. Using the July 2000 wildfire in the Kisatchie Longleaf Vista area, trees were selected based upon

Figure 12 – Site of July 2000 wildfire on the Longleaf Vista of the Kisatchie National Forest indicated by arrow.

degree of crown scorch and classified either light to moderate scorch (< 75%) or heavy scorch (>75%) categories. There were 30 trees in each category as well as 30 control trees that were not burned and separated by a paved road from the burned area. Any damage, such as basal cavitation, bole char, crown scorch or

root damage, was noted. Trees were inspected at one-, four- and ten- months (or next season) post-fire for symptoms of decline, insect attack and mortality.

Insect Response

Insect response to prescribed fire was investigated using both flight interception and pitfall traps placed in both the control and treatment areas. See *Insect Sampling* in chapter 1 (p. 14) for description of traps and technique. The traps were installed one week after fire treatment in the dormant season fire studies, and for varying times before and/or one week after fire treatment in the growing season fire studies. Insects were collected and counted weekly. The bait vials were refilled each week after collection. Number of insects that were collected and known to, or suspected to have had an impact on the health of southern pines (i.e. Scolytid spp.), were used in correlation analyses of relative abundance, fire intensity and season of burn.

In addition, trees involved in the study were inspected weekly for insect attacks during the trapping period after treatment and at one month, six months, and one year intervals thereafter. Evidence of attack included the presence of pitch tubes, boring dust and insect emergence holes. Attacked trees with symptoms of decline were monitored, and any tree that died was examined post-mortem to determine cause of death, if possible.

Resin Sampling

Oleoresin flow is the primary defense of pines against insect attack (Popp et al. 1991 and Strom et al. 2002). Either 15 or 30 trees in the control and treatment areas were resin sampled for 24-hour resin production before and/or

after treatment, depending upon season. To obtain a resin sample, a 1.25 cm metal punch was used to remove the bark and phloem at about breast height on the bole of the tree (Fig 13). A line of silicon caulk was placed beneath the punch in a funnel shape to direct resin into a pre-weighed, plastic bag. The bag was affixed to the tree beneath the punch hole

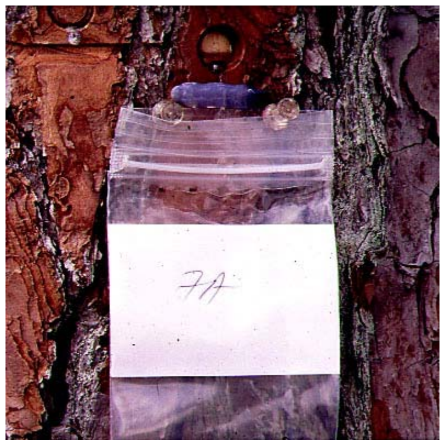

Figure 13 – Resin sample being taken from longleaf pine tree bole to determine 24-hour resin production. Palustris Experimental Forest, Louisiana, 2000-2002.

to catch the resin flow. At the onset of the study, each tree was sampled on opposing faces of the tree (north and south). Strom et al. (2002) determined that within tree resin production varied significantly, and so all samples were subsequently taken on the south face of the tree. After 24 hours, the bag(s) were retrieved from the trees and weighed, using a Mettler PC180 balance to determine the 24- hour flow rate. Resin flow was sampled at about one month after treatment. The rate of resin production for each tree sampled was determined. Results of the resin sampling were compared using ANOVA, and for correlations with timing of fire treatment (dormant or growing season fire), and for duration and intensity of fire treatment.

Results

Prescribed Burns

Fuel loading was not measured for all burns, but was very similar on all sites (Table 4). A light understory of hardwood and woody plant growth had developed on sections of all sites to a height of 1.5 meters. Grasses and pine straw lightly covered the surface. Nearly all fuels were removed by the fires. Drip torches were used to start backfires around the ploughed perimeter of all fires. As the backfires were ignited, incendiary devices dropped from a helicopter above the burn site started strip headfires. A positive correlation was found between height of bole char and fire temperature (Figure 14). As temperature increased, bole char height increased.

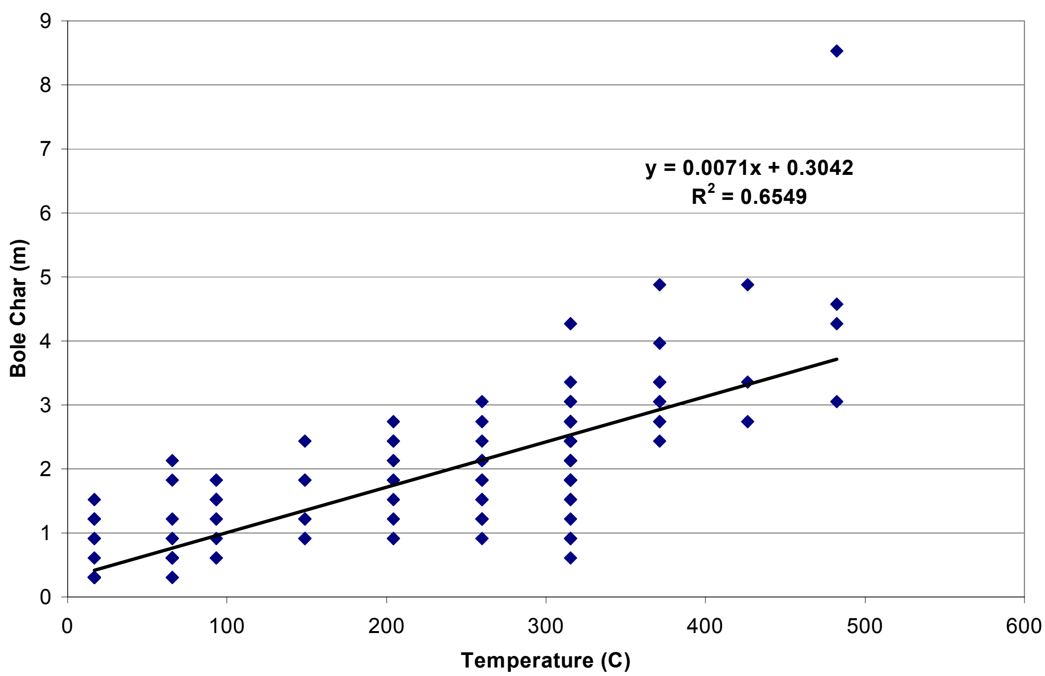

Figure 14 – Positive correlation between temperature of fire and height of bole char on the bole of mature pines. Palustris Experimental Forest, 2002.

Table 4 – Fire data for all prescribed fires conducted on the Longleaf Tract of Palustris Experimental Forest from July 2000 to June 2002. Temperatures are in ° C.

Burn	*Ambient Temp*	*Relative Humidity*	*Mean Resin (g)*	*Mean Paint Temp*	*Mean Fuel Mg/ha*	*Bark Moisture %*	*Soil Moisture %*	*Wind (Kts)*
So.unit 7/5/00	85-93	58-80	3.9	227	40	14	45	0-3
RCW 1/10/01	3-6.1	60-74	4.1	N/A	N/A	N/A	N/A	0.4-0.9
SWU 1/25/01	10-12.7	46-61	2.4	698	N/A	N/A	N/A	0.8-3.9
NEU 5/7/01	23-26	76-84	N/A	377	N/A	12	25	0-1.2
L009 5/7/01	23-26	80-84	N/A	532	30	14	20	0-1.2
RCW II 3/7/02	19.5-24.4	55-74	N/A	329	N/A	12	35	3.9-11.7
Mat 6/4/02	29-32	65-75	N/A	402	N/A	N/A	N/A	1-2.1

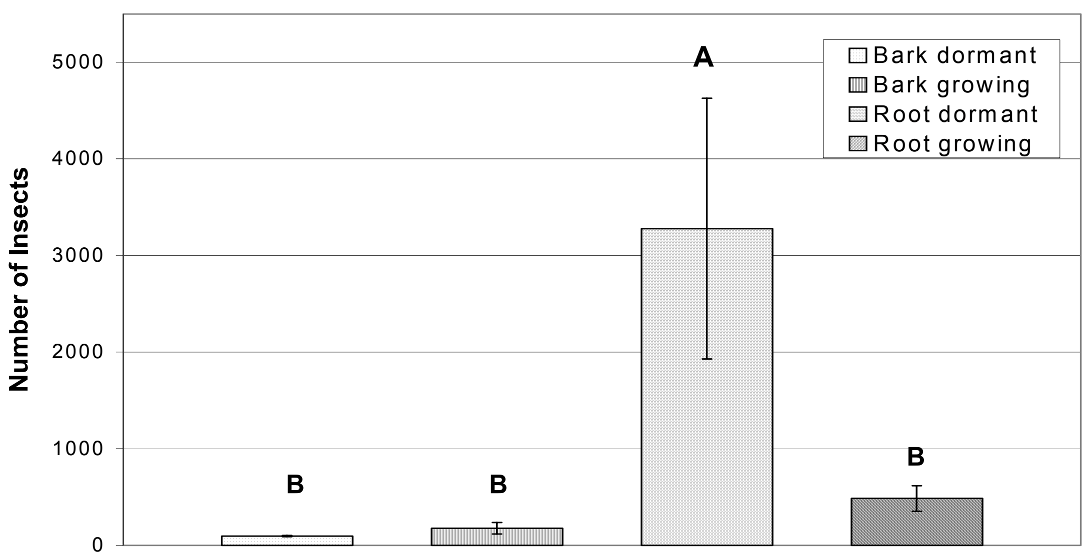

Figure 15 – Insect Guild and Season of Burn. Insects were trapped on Palustris Experimental Forest, 2000-2002 following 7 prescribed burns (3 dormant vs. 4 growing). Same letters indicate no significant difference in insect abundance.

Insect Response

More root feeding insects, *Hylastes* spp. and reproduction weevils, *Hylobius pales* and *Pachylobius picivorus,* were associated with dormant season burns than with growing season burns (Figure 15). A significant increase in the number of root feeding insects occurred

with dormant season burns ($F_{1,14}$=9.99; p=0.0069). Bark feeding insect, (i.e. *Ips* spp and BTB), abundance did not differ significantly by season of burn. The abundance of these aboveground beetles did not significantly differ from the abundance of root feeding insects following growing season burns.

These data suggest that growing season burns are not associated with a relative increase in abundance of either root- or stem-feeding insects. Peak insect flight periods occur prior to the initiation of growing season burns. These findings also indicate that managers should be aware of a greater potential for root-feeding insects responding to stands that have been subject to dormant season, prescribed burns. The cryptic behavior of root-feeding insects and their potential as vectors of pathogenic fungi make these findings important to maintaining forest health.

Wildfire

As scorched trees declined they were attacked by wood borers and bark beetles. All trees in the burned area were examined one month after the fire for insect attack, bole char, basal damage and crown scorch (Table 5). 10% were found to be under attack by bark feeding insects. 30% of the trees were exuding resin in response to the fire stress and 53% showed injury to roots and/or basal

cavitation. At four months after the fire, 13% showed signs of insect attack and 61% were exuding resin. Two trees had died and had evidence of extensive insect attacks by bark feeding insects (i.e. boring holes, frass and dust). At 10 months after the fire, six trees (10%) were dead. Insect attacks were observed on 15% of the trees and the percent of live crown had been reduced on 90% of the trees. It is likely that mortality will increase over time due to insect attack.

Table 5 – Longleaf pine mortality after the Longleaf Vista wildfire in July of 2000, Kisatchie National Forest, Louisiana. A is <75% crown scorch, B is >75% crown scorch.

Scorch # of trees		**Average bole Char (m)**		**Mortality at 1 month # of trees**		**Mortality at 4 months # of trees**		**Mortality at 10 months # of trees**	
A	B	A	B	A	B	A	B	A	B
30	30	6.7	9.89	0	0	0	2	0	6

No insect attacks were observed on unburned trees in the control area, and these trees suffered no mortality during the time of this study. The control area underwent a prescribed burn in February of 2001 that appeared, as of March 2001, to have had no deleterious effects.

Resin Sampling

Because of rain diluting the samples, we were unable to gather accurate resin samples from all of the treatment areas. The samples we were able to collect were inadequate to make comparisons for burning regimes, but fell within the

range reported by Strom et al. (2002) for loblolly. See Chapter 3 for resin sampling after burning under semi-controlled conditions.

Depending upon the season conducted, fuel loading, fire behavior and stand characteristics, prescribed burning can have wide ranging effects on tree health. Insect response to burned areas differs significantly depending upon the season and intensity of fire. Forest managers should carefully consider all effects a prescribed burn can have upon a stand before developing a prescription.

CHAPTER 3
EFFECTS OF SEASONAL BURNING USING A SEMI-CONTROLLED BURNING METHOD IN LONGLEAF PINE

Introduction

Longleaf pine (*Pinus Palustris Mill.*) is the key species in a unique subclimax forest ecosystem that supports many rare and endangered species, such as the Red-cockaded Woodpecker (*Picoides borealis* Vieillot). These qualities make the longleaf system attractive for preservation and restoration efforts designed to prevent the continued loss of longleaf acreage in the southeastern United States. This system is dependent upon fire to prevent the invasion of hardwoods and competitive pine species such as loblolly (*Pinus taeda* L.) and slash pines (*Pinus elliottii* Engelm.). Periodic fire has many benefits in the longleaf system, including the increase of species richness (number of species present) and diversity of plant composition on the forest floor (Brockway and Lewis 1997). In the last century, man has excluded fire from the forest systems in an effort to prevent timber loss and damage to homes and property. The past 70 years or so of fire exclusion, along with extensive clearcutting and competition from other species, has resulted in a reduction in area of longleaf pine from as much as 37 million to 3.8 million hectares by the 1990's (USDA Forest Service, Forest Inventory and Analysis 1994). In the mid-1990's, longleaf acreage continued to decline in most of the Gulf Coastal Plain (Outcalt 1997). Landers et al. (1995) suggested management options and methods to reverse this trend. Central to any attempt to restore longleaf is the re-introduction of fire, and its continued use to manage and maintain the longleaf system. According to Frost (1998), much of the Gulf Coast Plain burned naturally every one to three or four to six years, depending upon location.

Recent efforts to restore longleaf forests to conditions preceding the arrival of European settlers have met with varying levels of success. There has been some question in the scientific community about the exact definition of ‘pre-settlement condition’ and whether or not today’s demands on forests system make suchrestoration goals realistic (Vose 2000, Tiedemann et al. 2000). Nevertheless, pre-settlement conditions are considered important in restoration, since the pre-settlement period saw man’s influence begin to greatly alter the stand composition and health of longleaf pine forests. Management goals must be well planned and decisions involving fire must be well informed before fire is implemented as a restoration tool.

There have been varying results using fire in longleaf restoration efforts, depending upon the season of use. ‘Growing season fires’ are defined here as occurring after stem elongation has begun (usually March in Louisiana) and before the cessation of growth in the fall/winter (usually October in Louisiana). ‘Dormant season fires’ are those occurring between the cessation of growth in the fall/winter and before stem elongation the spring. Dormant season burns are considered effective in removing fuels and are often the first step taken in restoration of longleaf. However, Jacqmain et al. (1999) reported that dormant season burns may have the opposite effect than desired, by increasing the density of oaks in the stand. Growing season burns more closely mimic the natural burn pattern, but may have deleterious effects on longleaf trees. Another consideration when re-introducing fire to the system is how the current stand condition will affect fire behavior. Glitzenstein et al. (1995) found that stand dynamics seemed more affected by fire behavior than by season of burn. There are also concerns over smoke management issues and attempts to comply with the Clean Air Act. Boyer

(1990) discovered high mortality of mature trees after fire was implemented to control hardwoods. Conner (1991) found fire to be the primary cause of mortality in red-cockaded woodpecker trees, perhaps because altered fuel loads on the forest floor allowed fires to reach higher up the tree bole and ignite resin exuded from woodpecker cavities. The re-introduction of fire also can affect many aspects of the longleaf system: stand dynamics, stand composition, soil nutrients and increased longleaf mortality (Varner et al 2000). Covington et al. (1997) used fire and understory removal techniques to successfully achieve restoration efforts of ponderosa pine. The lack of information regarding the effects of fire on tree health in the existing longleaf system led to this investigation.

With regard to tree and stand health, resin production is thought to be the primary defense mechanism of pines against attack by many pest insects, especially bark beetles (Popp et al. 1991 and Strom et al. 2002). The amount of resin a tree produces can be considered an indicator of that tree's ability to withstand insect attack and, consequently, of tree health. Bark beetles respond to the amount of resin produced by a tree (Krawielitzki et al. 1983) and burning can temporarily increase the amount of resin produced by longleaf (Harper 1944). By contrast, if phloem injury occurs, the resin production can be severely depressed and result in increased susceptibility to bark-boring insects. Resin production was used in my study to indicate an individual tree's response to burning.

To better understand the effects of season and intensity of burn on tree health and resin production, experimentation was employed using a propane burner (after Sackett and Ward 1972). By varying the amount of heat and duration of treatment, I simulated a

low temperature dormant season fire, a high temperature dormant season fire, a low temperature growing season fire and a high temperature growing season fire. Sackett and Haase (1992) used thermocouples to monitor cambial temperature during prescribed burns. I implemented a similar system for my experiment, to indicate whether or not temperatures during treatment reached lethal temperature (68°C), (Hare 1965a).

The focus of this experiment was to compare the impact of fire duration and intensity on individual trees, using resin production as an indicator of tree response, or health, under semi-controlled conditions.

Methods and Materials

A large study area was established with 30 longleaf pine trees selected in each of four treatment areas and 30 control longleaf pine trees in an adjacent, untreated area (a total of 150 trees). Trees were selected within the study area by apparent uniformity of health, including live-crown ratio (0.3-0.5), diameter (30-63 cm), and distance to nearest test tree > than 10 m. The trees were marked with numbered aluminum tags for identification. Diameter at breast height, bark thickness, percentage of crown on the south side of the tree and any injuries were noted using Forest Health Monitoring Protocols and Quality Assurances (USDAFIA, 2000). Treatment was assigned by season of burn: 60 trees in the growing season burn and 60 trees in the dormant season burn. In each season, trees were assigned, 30 each, to either four-minute or ten-minute burn durations. Trees were burned using a Red Dragon® (Forestry Suppliers) propane torch with a Victor® SR461B pressure regulator to equalize the flame intensity (Figure 16).

Figure 16 – Propane torch with regulator used to treat individual trees in semi-controlled burning study in Palustris Experimental Forest, 2001-2002.

One set of trees was burned for four minutes, to simulate a high-intensity fast-moving fire, and had a propane gas flow rate of 100 pounds. Treatment was applied to one-half the circumference of the bole, usually the south-facing side. A second set of trees was burned for ten minutes, to simulate a low-intensity, slow-moving fire and had a gas flow rate of 25 pounds. The flame head of the torch was maintained at a uniform distance of approximately 0.33m from the tree bole during treatment. Treatment was applied to one half the circumference of the bole, (usually the south side for uniformity) at 0.5 to 0.75 m above the root collar. Two holes were drilled with a hand drill 15-24 cm apart and angled forty-five degrees to the bark surface. Depth varied according to bark thickness, but holes were drilled through the bark to the phloem layer. Thermocouples were inserted into the tree via the drilled holes to the cambial interface and loose soil was packed into the holes to insulate the thermocouple from hot gases. Using a model CR10X Campbell Scientific® (Logan, Utah) datalogger and PC208W version 3.01 Campbell computer program, the internal temperature and duration during treatment

were monitored. To calculate internal temperature, the average temperature measured by the two thermocouples for each tree/duration of burn was used. Occasionally, a thermocouple would be improperly placed resulting in a spurious recording and in this case, only one temperature was available for calculations. Burn simulations were conducted on days with similar National Weather Service Fire Weather Forecast Category Days. Weather conditions, including wind speed and ambient temperature, were recorded on site during the treatment. Bark moisture also was noted. Trees were monitored after treatment for symptoms of decline and insect attack. This included 24-hour resin flow rate at one month post-treatment (see 'Resin Sampling' in chapter 2), presence of insects, emergence holes and pitch tubes.

Statistical Analysis

Resin flow rate was analyzed using a SAS© (2001) one-way ANOVA and Proc Mixed. Average cambial temperature was analyzed as a 2X2 factorial design. Fisher's LSD was used as a Post-ANOVA technique. Average cambial temperature and resin flow rate also were analyzed for correlation(s) with bark thickness and diameter at breast height, employing simple linear regression. One data point was determined to be an outlier and was excluded from analysis. Bark thickness was used as a covariable for the factorial design.

Results

<u>Temperature</u>

Burns for both four- and ten-minute duration treatments at the prescribed intensity for both seasons achieved internal temperatures higher than the accepted lethal temperature, 68°C, for plant cambial tissues (Hare 1965a) (Table 6).

Table 6 – Results by treatment for semi-controlled burning of mature longleaf pine trees on Palustris Experimental Forest, Louisiana, 2001-2002.

Treatment	Mean Bark Thickness cm	Mean DBH cm	Mean High Cambial Temp °C	Wind Range kts	Ambient Temp Range °C	Bark Moisture Range %
Dormant Short	1.87 ± 0.05	40.3 ± 0.89	64.63 ± 3.2	0 – 2.5	6.1 – 22.9	12 – 14
Dormant Long	1.78 ± 0.04	37.4 ± 0.94	79.21 ± 4.5	0 – 2.4	6.1 – 22.9	12 - 15
Growing Short	1.65 ± 0.08	35.74 ± 0.51	63.77 ± 0.76	0 – 2.2	21.0– 30.8	10 - 14
Growing Long	1.64 ± 0.06	37.60 ± 0.76	90.1 ± 12.64	0.5 - 3	23.9 – 30.4	10 - 15

Significantly higher cambial temperatures were found by season ($F_{1,85}$=11.10; p=0.0013. Even though fire intensity was lower (25 lbs. of gas pressure as opposed to 100 lbs.), the 10-minute durations achieved the highest average cambial temperatures (Figure 17). The 4-minute dormant season controlled burns averaged 66.83°C and 10-minute dormant season fires had a mean high temperature of 79.61°C (Figure 17). Growing season fires had 4-minute and 10-minute mean high temperatures of 61.46°C and 77.39°C, respectively. It also was observed that trees subjected to the 10-minute treatment, whether growing or dormant season, took longer to return to ambient temperature than trees exposed to the 4-minute treatments. This may indicate that slow-moving, lower intensity fires heat trees to higher internal temperatures than fast moving, higher-intensity fires, and trees sustain that higher temperature for a longer period of time. It should be noted, however, that when samples of phloem tissue were removed from the treated trees one week post-treatment, only two trees had obvious

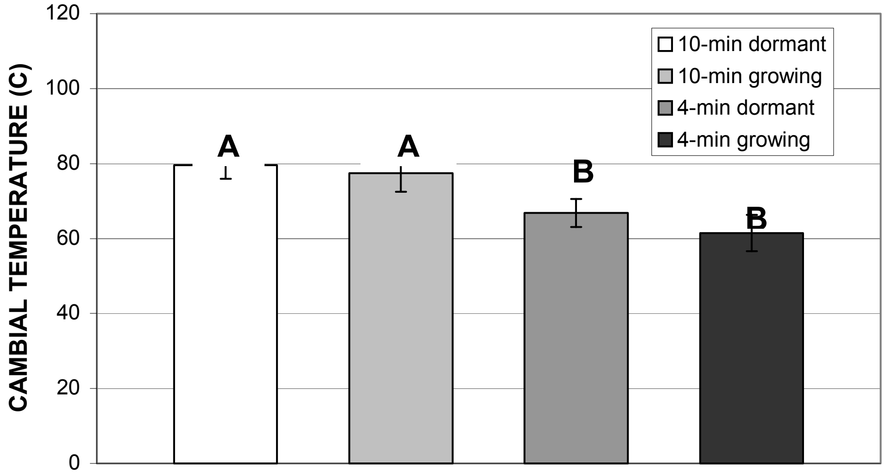

Figure 17 – Average high temperatures for season and duration of burning treatments in longleaf pine. Same letters indicate no significant difference at $p<0.05$; means are adjusted for bark thickness. Palustris Experiemental Forest 2001-2002.

discoloration, indicating damaged tissue. All other sampled trees appeared to have healthy phloem, regardless of treatment. This may be due, in part, to procedure of treating only one-half the circumference of the tree bole or the relatively short sampling interval.

Bark thickness was significantly correlated with average cambial temperature ($F_{1,89}$=11.87; p=0.0009). As bark thickness increased, average cambial temperature decreased (Fig. 18). The R^2 value was relatively low, indicating a lack of fit for the model.

Resin

Mean resin production was significantly lower in the growing season 10-minute treatment as compared to all other treatments and the control (Fig. 19) ($F_{4,125}$=4.00; p=0.0043). These data support the hypothesis that longleaf is adapted to fast moving

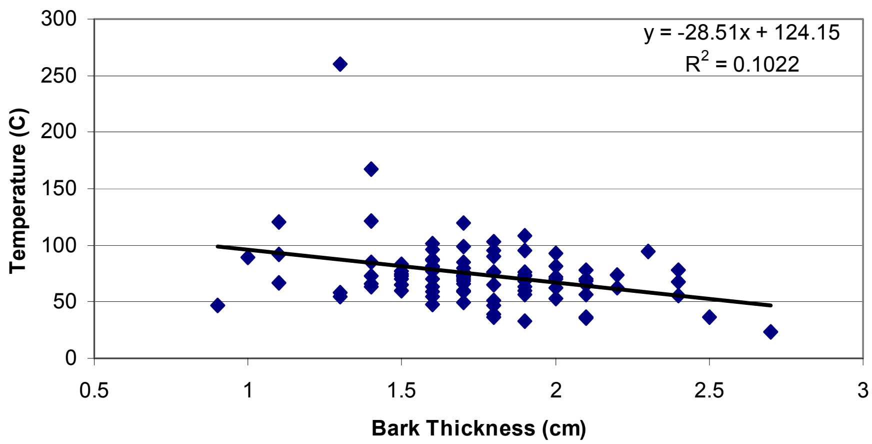

Figure 18 – Regression analysis of longleaf bark thickness and heating of cambial tissue after treatment with a propane burner under semi-controlled conditions.

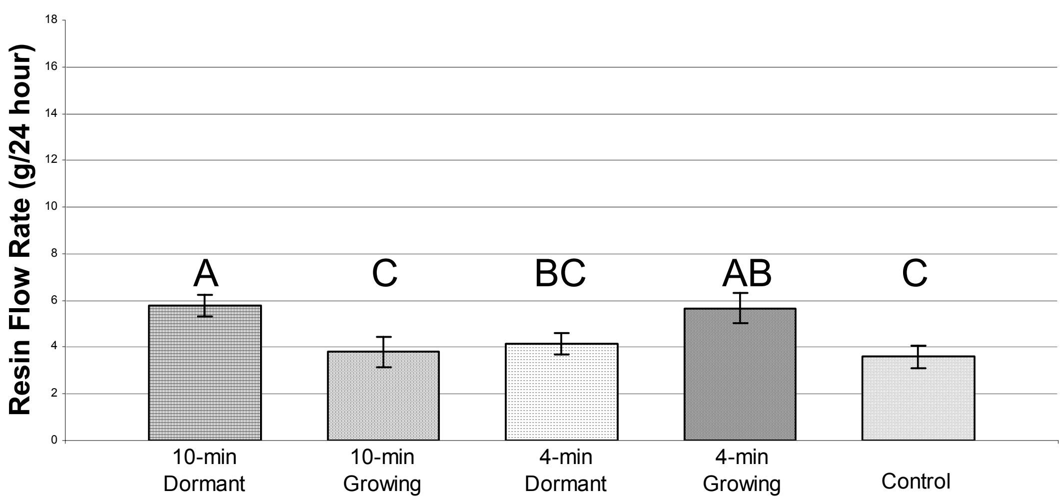

Figure 19 – Analysis of 24-hour resin flow rate in longleaf pine by treatment type. Times indicate duration of semi-controlled burn. Different letters indicate significant differences at the 0.05 level using Fisher's LSD.

low intensity fires during the growing season. A significant difference was observed between treatment means ($F_{4,125}$=4.00; p=0.0043). Trees subjected to 10-minute burns for dormant season produced significantly more resin than 10-minute growing season

burns. This response was not significantly different from the 4-minute growing season burns, possibly demonstrating that the same physiological response is triggered by slow-moving, low-intensity fires during the dormant season and fast-moving, high-intensity fires in the growing season. Both of these treatments, however, showed higher resin production than controls. Resin flow in 10-minute growing season and 4-min dormant season burns did not significantly differ. Neither of these treatments produced more resin than the controls. This may indicate slow-moving, low-intensity fires in the growing season, and fast-moving high-intensity fires in the dormant season, do not elicit a physiological response in longleaf pine. This may have implications for forest managers, should these trees be attacked by insects, post-fire. Factors such as drought stress may compound this problem. It should be noted, again, that there were no active SPB infestations statewide for the three years of this study. When plotted against bark thickness, resin production in trees with greater than 2 cm bark thickness showed identifiable trends by season and duration of fire (Figure 20). Trees with less than 2 cm of bark thickness had highly variable resin production responses to the various treatments. Trees with greater than 2 cm bark thickness burned for 10-minutes during the growing season showed a decrease in resin production, though it was not significant. Again, this may indicate that trees subjected to slow moving low intensity fires in the growing season may have less resistance to insect attacks. The other three treatments resulted in increased resin production, though none of these significantly differed from one another. This is comparable to Hodges and Johnson (1997) who found that tree stem size was the strongest predictor of resin production in slash pine (*Pinus elliottii*). It is likely that a complex interaction occurs between bark thickness,

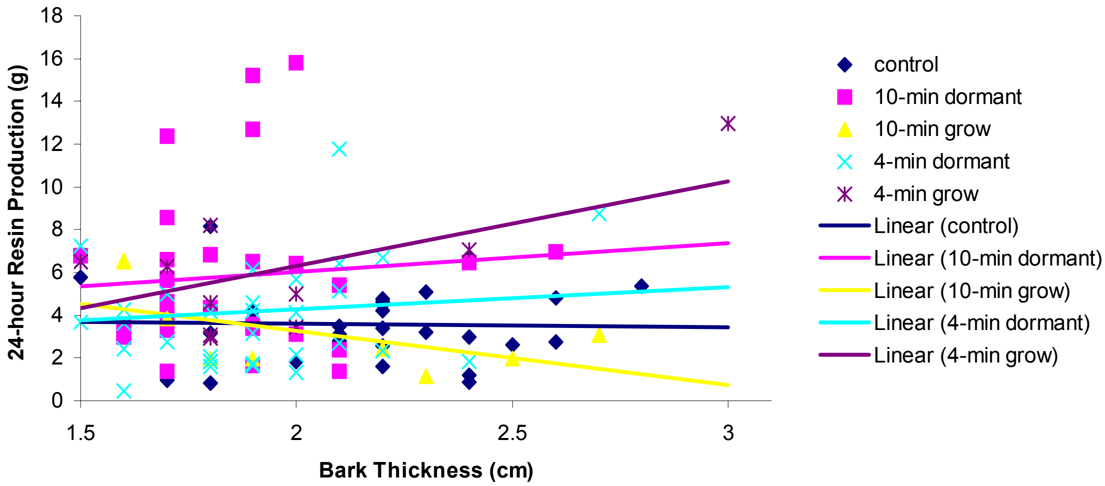

Figure 20 – The influence of bark thickness on resin production in longleaf pine for various semi-controlled treatment regimes.

diameter and resin production as well as other parameters. It would be logical to consider that thicker bark and a larger diameter indicate thicker phloem and thus, higher resin output. However, this was not confirmed in my study.

My research indicates that trees burned out of the natural cycle, i.e. low- intensity slow-moving fires in the growing season or high-intensity fast moving fires in the dormant season, do not produce as much resin as trees burned with slow-moving low-intensity fires in the dormant season and fast-moving high-intensity fires in the growing season. The implications for management are important, as trees burned on these prescriptions may be more susceptible to insect attack. With the current prescription for fuel reduction fires conducted during the dormant season, managers must consider spring insect population peaks. Trees should be carefully inspected for symptoms of damage post-fire that could increase their chance of being attacked by insects. This is especially true in the spring.

SUMMARY/CONCLUSIONS

Chapter 1

One objective of the study was to identify the yearly cycle of emergence and abundance of weevils and bark and ambrosia beetles in the Palustris Experimental Forest of the Kisatchie National Forest in central Louisiana. For this study, fit was anticipated that the most ecologically and economically important species of insects were southern pine beetle (*Dendroctonus frontalis* Zimm.), black turpentine beetle (*Dendroctonus terebrans* Olivier), *Ips* spp., *Hylastes* spp., the pales weevil (*Hylobius pales* Herbst) and the pitch eating weevil (*Pachylobius picivorus* Germar). However, the southern pine beetle was not detected in Louisiana during my study.

The possible influence of temperature and precipitation as indicators of weather conditions on insect abundance also was investigated. Average weekly temperatures showed no significant difference over the three years of my study. Insects were most abundant during the months of March and April when temperatures ranged from 10° to 20°C. As the season shifted from Spring to Summer, insect abundance significantly decreased. Monthly precipitation was significantly lower in 2000 than in 2001 or 2002. 2000 was considered a drought year. Precipitation did not have an effect on insect abundance, though a general trend toward fewer insects with increased precipitation was observed. More research is needed to further investigate the effects of weather on bark colonizing insects in pine.

Percent abundance of insect species varied from year to year. In 2000, *Ips* spp. and *Hylastes* spp. were the most abundant, at 38 and 39% of total insects captured, respectively. In 2001, *Hylastes* spp. comprised over 81% of total insects. My research did not show why populations of *Hylastes* increased so markedly for 2001. In the final year of the study, 2002, insects of interest were more evenly distributed in abundance. *Ips* spp. were 40%, weevils 33% and *Hylastes* spp. 25%, of total catches.

Several species of ambrosia beetles were also collected, many of which are exotics. A new state record for Louisiana was set in 2001 with the beetle *Xyleborus californicus*. This beetle was trapped on the study site during 2001. Exotic insects pose a two-fold threat to forests: their biology is not well understood, nor is it known how they will affect novel habitats they invade.

My research indicated that important pests of southern pines are most abundant during the months of March and April in Louisiana. This becomes very important for forest managers who will want to minimize the relative attractiveness of forests to these insects. Management practices, such as prescribed burning, should be planned to avoid periods of peak insect activity, i.e. burning during the growing season when insect abundance decreases. These insects are known to vector pathogenic fungi that may play a role in tree decline. Tree vigor should be maximized to decrease stand attractiveness to these insects.

Chapter 2

For the second objective, I investigated the interactions of fire and insects and their roles in the health of mature longleaf pine stands. Dormant season and growing season burning prescriptions were used to identify which, if any,

management practices might lead to decreased stand health. Insect responses were sampled and compared by burning regime and insect feeding guild (bark or root feeders). Finally, a wildfire occurred in July of 2000 in the Longleaf Vista of the Kisatchie National Forest. I investigated fire effects upon tree mortality over ten months after the fire.

Using temperature-indicating paints attached to tree boles during prescribed burns I developed a linear model for the positive correlation between bole char and temperature. For each 1°C of temperature, bole char increased by 0.0071 meters. This relationship will assist managers in knowing the external heat an individual tree was subjected to, and can be used to identify potential tree stress.

Insects responded differentially in abundance to fire by season and feeding guild (stem versus root feeders). Dormant season burns attracted significantly more root feeding insects than stem feeding insects. Growing season burns attracted significantly fewer insects of both feeding guilds. Forest managers will want to be aware of the potential for increased abundance of root feeding insects following dormant season burns, as these insects are cryptic and may be difficult to detect. These insects not only cause mechanical damage to trees, but may also vector pathogenic fungi associated with tree decline.

The July 2000 wildfire at the Longleaf Vista in the Kisatchie National Forest was devastating. At ten months after the fire, the forest had a 10% mortality rate. Insects had attacked 15% of the trees and this appeared to be on the increase over time. Trees showed signs of physiological stress, with 61% exuding resin and more than 90% had reduced crown volume. It is strongly suggested that a

management regimen incorporating prescribed burning to reduce fuel loads is implemented for the remaining trees.

My research indicates that fire and insects play important roles in the health of longeaf pine stands. Proper timing of prescribed burns is central to maintaining stand vigor. Growing season burns for the management of longleaf are recommended to maintain tree health and avoid increased insect abundance.

Chapter 3

The third objective of my work was to investigate how burning affects the health of trees using resin production as an indicator parameter. Resin flow is the primary defense of pine against bark beetle attack. I employed a propane burner and flame torch to simulate growing season and dormant season burns of two durations, 4 and 10 minutes. Trees were resin sampled for 24 hours to determine tree response to the various burning regimes.

Duration of treatment had a differential effect on average cambial temperatures. The 10-minute long treatments at lower fire intensity achieved higher cambial temperatures than 4-minute treatments at higher fire intensity. Trees subjected to the 10-minute treatments were observed to take a longer period of time to return to ambient temperature. This may indicate that slow-moving fires of low intensity create more heat in tree tissues than fast moving fires of high intensity.

I also found bark thickness to be negatively correlated with average cambial temperature during treatment. As bark thickness increased, average cambial temperature decreased. This reinforces the importance of tree vigor in maximizing growth and production.

Trees subjected to particular burning regimes produced significantly less resin. Trees burned during the dormant season for 4 minutes and during the growing season for 10 minutes produced significantly less resin than trees burned for 10 minutes during the dormant season and 4 minutes during the growing season. These data suggest that trees burned out of the natural cycle may be more susceptible to insect attack. Burning prescriptions that fall into this category should be avoided.

My research indicates that, when possible, longleaf should be burned during the growing season for stand maintenance. Growing season burns minimize insect response, are more effective at reducing competition and mimic natural burning patterns. Managers whose primary objective is habitat and biodiversity are strongly recommended to employ growing season burns. Management objectives focused on production will have to consider the effects of fire on tree growth when developing prescriptions and minimize practices that may increase tree vulnerability to insect attack. For initial fuel reduction, combinations of mechanical removal of understory, herbicides and prescribed burning show the greatest promise for restoration of longleaf pine forests (Haywood; Brose and Wade 2002, Brockway and Outcalt 2000, Provencher et al. 2001).

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APPENDIX: RAW DATA

Appendix A. Monthly insect collection totals by species for fire excluded plot on Palustris Research Station, Louisiana, 2000-2002. BTB – *Dendroctonus terebrans*, H Sal – *Hylastes Salebrosus*, H ten – *Hylastes tenuis*, Ips a – *Ips avulsus*, Ips g – *Ips grandicollis*, Ips c – *Ips calligraphus*, H pales – *Hylobius pales*, P pici – *Pachylobius picivorus*, Platy – *Platypus* sp., Coss – *Cossonus corticola*, com – *Xylosandrus compactus*, crass – *Xylosandrus crassiusculus*, Xe fer – *Xyleborus ferrugineus*, Sax – *Xyleborinus saxeseni*, O. cal – *Orthotomicus caelatus*, X. aff – *Xyleborus affinis*, X.pub – *Xyleborus pubescens*, G. mat – *Gnathotrichus materiarius*, Deod – *Pissodes nemorensis*, Hypo – *Hypothenemus* sp., Dryox – *Dryoxylon onoharaensis*

		BTB	H Sal	H Ten	Ips a	Ips g	Ips c	H pales	P pici	Platy	Coss	com	crass	Xe fer	Sax	O. cal	X.aff	X.pub	G.mat	Deod	Hypo	Dryox
2000	May	5	13	0	2	15	0	6	7	41	268	0	0	0	0	0	0	0	0	0	0	0
	Jun	0	14	1	2	9	1	0	0	25	364	8	4	1	9	0	0	0	0	0	0	0
	Jul	0	13	1	2	24	0	1	3	7	136	5	0	1	1	0	0	0	0	0	0	0
	Aug	1	4	18	2	6	0	4	9	1	72	0	0	1	2	0	0	0	0	0	0	0
2001	Mar	4	440	39	4	50	0	1	4	1	0	0	0	0	0	0	0	0	0	0	0	0
	Apr	1	469	43	2	60	0	18	44	0	0	11	7	1	5	0	0	0	0	0	0	0
	May	2	294	34	4	51	1	4	4	1	113	0	5	1	41	0	3	11	0	0	1	0
	Jun	1	35	20	0	26	0	6	10	2	73	0	2	1	14	0	0	6	0	0	0	0
	Jul	0	7	11	2	21	0	7	8	1	25	0	3	0	5	0	1	18	0	0	0	0
	Aug	0	0	2	0	13	0	3	2	0	3	1	1	0	1	1	0	8	0	0	0	0
	Sep	0	0	0	1	11	0	11	2	2	11	11	0	0	0	1	2	22	0	0	0	0
	Oct	0	3	4	0	4	0	2	1	2	25	29	0	0	2	2	2	9	3	3	0	0
2002	Mar	0	28	8	3	38	0	20	0	1	3	330	36	1	28	12	1	45	4	0	54	12
	Apr	0	17	18	0	58	0	34	5	0	4	481	31	0	11	0	4	117	0	0	48	11
	May	0	9	4	0	11	0	7	9	30	30	1	9	2	1	32	1	6	0	0	0	0
	Jun	1	2	2	1	9	0	6	4	10	96	16	10	0	3	94	0	29	0	0	1	0
	Jul	0	0	1	1	11	0	3	11	1	54	9	5	0	2	30	7	38	0	0	2	0
	Aug	0	1	1	0	14	0	2	20	2	28	12	1	0	2	16	0	21	0	0	0	0

Appendix B Results of thermal paints used to determine individual tree exposure to fire temperature by site. In °F

South Unit	SWU	L009	NEU	Melder	Johnson	RCWII	RCW II	Mat
750	1022	600	600	100	100	100	150	800
388	600	600	600	388	600	150	700	300
150	1022	600	600	100	150	500	600	700
388	1022	600	100	600	100	500	300	800
388	600	600	388	150	388	150	200	900
100	600	600	600	388	100	600	100	300
388	600	600	600	388	600	100	900	150
388	600	600	600	388	388	100	100	700
388	600	600	600	100	388	600	100	600
388	600	600	600	388	100	700	800	700
388	600	1022	388	150	100	100	800	600
388	1022	600	1022	388	388	100	200	300
100	600	600	600	600	388	200	600	600
388	600	600	600	600	100	600	150	150
100	600	1022	600	388		600	600	200
100	1022	600	600	600		500	500	200
100	600	600	600	388		100	150	900
388	600	600	600	388		900	600	400
100	1022		600	388		400	150	300
100	1022		600	600		900	100	700
150	600		600			600		700
100	600		388			150		400
750	600		388			500		200
	600		388			600		600
	1022		600			600		600
	600		100			300		600
	600		600			600		600
	600		388			600		700
	600		388			600		600
	600		100			700		700

Appendix C Thermal paint and total insect abundance results for prescribed burns on Palustris Research Station, Louisiana, 2000-2002.

Site	Mode Temp ºF	Mean Temp ºF	# of Insects	Season g=growing d=dormant
South Unit	388	298.6	268	g
SWU	600	728.4	4962	d
L009	600	646.9	763	d
NEU	600	572.1	1267	d
Melder	388	374	465	g
Johnson	100	277.9	228	g
RCWII	100	397.8	1082	d
Mat	700	504.3	927	g

Appendix Table D Results of semi-controlled burning of longleaf pine trees to determine individual tree response to fire regimes. Palustris Experimental Forest, Louisiana, 2001-2002.

Tree #	Mean temp	Bark thick	DBH	Resin	Ambient Temp	Duration	Season
182	46.45	1.8	.	4.35	18.9	l	d
183	68.67	1.9	.	6.12	19.3	s	d
184	119.6	1.7	.	8.54	19.4	l	d
185	69.8	1.5	.	7.25	19.9	s	d
186	68.45	1.7	.	3.87	20.1	l	d
187	95.15	1.8	.	2.05	19.5	s	d
188	95.8	1.9	.	12.6	20.6	l	d
189	76.15	1.8	.	4.15	20.2	s	d
190	71.75	2	.	3.1	19.6	l	d
191	65.35	1.8	.	1.61	12.7	s	d
192	99.1	1.7	.	12.3	12.9	l	d
193	56.65	2.1	.	11.7	14.9	s	d
194	84.55	1.7	.	5.63	14.9	l	d
195	62.3	2.2	.	2.35	13.5	s	d
196	77.85	2.4	.	6.47	16.3	l	d
400	67.45	2.4	.	1.85	17.3	s	d
401	58.6	1.7	.	1.36	17.7	l	d
402	103.4	1.8	.	1.83	17.4	s	d
403	63.25	1.6	.	3.03	21.3	l	d
404	69.85	2	.	5.67	22.9	s	d
405	60.2	1.7	.	4.5	22.9	l	d
407	56.2	1.9	14.9	3.38	8.3	l	d
408	70.15	2.1	16	5.15	7.8	s	d
409	68.6	2.1	15.5	1.38	10.7	l	d
410	47.75	1.6	16.3	0.46	11.7	s	d
412	77.1	1.6	15	4.26	11.1	s	d
413	74.1	1.7	15.4	3.3	14.6	l	d

Appendix Table D continued

Tree #	Mean temp	Bark thick	DBH	Resin	Ambient Temp	Duration	Season
414	60.1	1.9	15.5	3.15	14.8	s	d
415	72.65	1.7	13.9	5.74	14.6	l	d
416	68.15	1.9	14.4	4.59	14.4	s	d
417	96.2	1.6	15.2	2.98	15.2	l	d
418	32.6	1.9	17.6	4.19	16	s	d
419	77.75	2.1	16.2	2.39	14.1	l	d
420	66.3	1.7	18.1	5	14.1	s	d
421	35.5	2.1	16.4	5.41	14.4	l	d
422	64.75	2.1	15	6.43	15.4	s	d
423	101.3	1.6	12.7	3.15	14.6	l	d
424	52.5	2	16.7	4.11	6.1	s	d
425	73.5	1.9	17	3.57	6.1	l	d
426	23.5	2.7	17.5	8.73	5.7	s	d
427	87	1.6	14.2	3.51	6.8	l	d
428	76	1.9	16.1	1.63	6.8	s	d
429	81.5	2	12.4	15.7	8.3	l	d
430	36.5	1.8	19.1	1.84	7.2	s	d
431	73	1.7	16.3	6.58	7.4	l	d
432	70	1.6	15.1	2.41	7	s	d
433	76	1.7	14.2	4.62	8.7	l	d
434	72.5	1.4	17.1	9.1	7.7	s	d
435	167	1.4	12.8	8.34	8.5	l	d
436	36	2.1	15.2	2.68	8.1	s	d
437	63	1.4	13.4	4.22	7.3	l	d
438	80	1.7	14	2.76	7.3	s	d
439	92.5	2	17.5	6.39	7.2	l	d
440	59.5	1.5	13.8	3.65	6	s	d
441	83	1.5	12.6	6.75	6.3	l	d
442	81.5	1.6	13.3	3.63	6.1	s	d
R120	58.5	1.3	12	5.98	26.9	s	g
R121	55	1.6	15.1	6.56	28.3	l	g

Tree #	Mean temp	Bark thick	DBH	Resin	Ambient Temp	Duration	Season
R122	39	1.8	14.4	8.2	28.1	s	g
R123	63.5	1.9	13.6	1.95	29.4	l	g
R124	49.5	1.7	14.4	6.27	28.4	s	g
R125	90	1.8	14.7	1.96	28.7	l	g
R126	75	1.5	13.7	6.52	30.6	s	g
R127	67	1.1	12.1	5.44	29.7	l	g
R128	55	1.3	11.9	3.41	31.1	s	g
R129	121	1.4	15.7	3.88	29.2	l	g
R130	51.5	1.8	14.4	3.07	30	s	g
R131	74	2.2	14.7	2.42	30.4	l	g
R132	69.8	1.7	13.9	4.99	27	s	g
R133	108.6	1.9	16	3.06	27.2	l	g
R134	77.5	1.5	14	2.94	27.6	s	g
664	92.15	1.1	16.2	3.94	28	l	g
665	80.95	1.6	16.4	3.07	29.2	s	g
666	120.2	1.1	15.6	3.65	28.6	l	g
667	73.2	1.5	15.7	8.83	29.7	s	g
668	260	1.3	14.3	2.48	30.8	l	g
669	89.3	1	13.5	5.05	31.4	s	g
670	64.8	1.5	14.2	2.67	32.4	l	g
671	47.1	0.9	14.5	5.67	29.9	s	g
672	59.15	1.6	16.3	6.17	32.4	l	g
673	85.2	1.4	14.7	4.36	31.4	s	g
674	66.1	1.4	16.1	6.93	30.3	l	g
R201	76.7	1.8	14.2	4.57	27.4	s	g
R202	87.2	1.6	12.8	6.49	27.7	l	g
R203	37.55	3	13.7	12.9	28.4	s	g
R204	36.6	2.5	14.9	1.98	28.4	l	g
R205	55.7	2.4	14.9	7.06	30.8	s	g
R206	94.25	2.3	14.6	1.13	30.4	l	g

VITA

Tessa Bauman was born in Orange, Texas, on August 2, 1967. In 1968 her family moved to New Orleans, where she spent most of her life. She completed her Bachelor of Science degree in biological sciences at Louisiana State University in Shreveport in 2000. She completed her Master of Science in forestry with a minor in entomology at Louisiana State University in Baton Rouge under Dr. Richard A. Goyer and graduated in May 2003.