THE EFFECTS OF FIRE AND FIRE SURROGATE FOREST MANAGEMENT PRACTICES ON COLEOPTERANS IN THE CLEMSON EXPERIMENTAL FOREST

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ABSTRACT

Impacts of the forest management practices, prescribed burning, mechanical thinning, prescribed burning and thinning combined, and untreated areas on ground active beetle communities was monitored in the Clemson Experimental Forest in 2002. Main plot treatments consisted of forestry management treatments: mechanical thinning, prescribed burn, mechanical thinning and prescribed burn, and an untreated control. Subplot blocking factors of pulpwood-sized trees (dbh 15-25 cm), pulpwood to sawtimber-sized trees (dbh >258 cm), and sawtimber -sized trees were evaluated. Pitfall traps were used to sample beetle communities in alternating months, for 48-hour periods. All captured beetles were identified to family. Species were identified in Scarabaeidae, Carabidae, and Erotylidae. Identified genera with large catch numbers, Scarabaeidae: *Bolbocerus*, Carabidae: *Cyclotrachelus*, and Erotylidae: *Triplax* were examined. Impacts of forest management practices on beetles were unique to the identification level of captured specimens.

Effects of time, treatment type, or treatment/time interactions on order, family, genera, and species representatives were determined using ANOVA and least squared mean analysis. Impacts of time and time/treatment interactions on the presence or absence of beetle families and species were examined using ANOVA and PROC GLM. A Dunnett's test examined differences of selective thinning and row thinning methods on beetle captures.

DEDICATION

This thesis is dedicated to my sister, best friend, and hero Katey Staeben.

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CHAPTER I

INTRODUCTION

The continual suppression of fire, poor timber production practices, climatic changes, pest infestations, and farmland and abandonment has altered the vegetational composition and structure in southern forest ecosystems. As a result, the forest ecosystems of today have reduced floral and faunal diversity, compacted stands of dense, basally small trees, and often an excess of litter, or fuel accumulation. These conditions have resulted in an increased risk of large-scale wild fires in woodlands. To reduce the risk of wild fires, the management practices of prescribed burning and mechanical thinning have been used. Prescribed burning and thinning practices reduce excessive fuel loads and alter the age structure and under story vegetation of stands. Altered stands have younger trees and ground vegetation that is more likely to resist wild fire ignition. When it occurs, ignition of the altered stands results in low temperature burns that are characteristic of the short-interval, low - moderate - severity fire regimes that historically occurred in southeastern states.

The Clemson Experimental Forest (CEF) in Anderson, Oconee, and Pickens Counties in South Carolina offers a unique opportunity for a Fire/Fire Surrogate study. Located on the Piedmont Physiographic region, the topography of the forest floor was shaped by historical use as farmland and the erosion of Cecil-Lloyd-Madison associated soil.

CEF is a mixed - stand community representative of both the abandoned farmland of southeastern forests, which began in the 1930s, and timber harvesting programs that originated during the Great Depression. It contains dense vegetation composed of spatially uniform stands of small trees and, historically has short-interval, low – moderate severity fires occurring in warm months at one - three - year intervals. Vegetation mainly consists of second- or third-growth short leaf (*Pinus echinata* Mill.) or loblolly (*P. taeda* L.) pine with a hardwood mixed mid- and understory.

The majority of studies examining the impact of burning and thinning on beetle communities have occurred in Canada, Finland, Australia and the western United States (Bailey and Covington 2002, Cole, et al. 1998, Feeney, et al. 1998, Holliday 1984,1991, Kaye and Hart 1998, Niemela 1996, Oliver et al. 2000, Peters et al. 2002, Wikars and Schimmel 2001). In the southeastern United States, little is known about the impact of prescribed burning and thinning on beetle communities.

This study evaluated the impact of prescribed burning, mechanical thinning and combined burning and thinning treatments on the presence, abundance, and richness of ground active beetles.

Hypotheses

In this study the following hypotheses were considered when comparing treatments of prescribed burning, mechanical thinning, and thin/burn to an untreated control.

H1: The abundance of coleopterans within treatment areas will be significantly different from those in the control areas.

H2: Family and species diversity of coleopteran communities within treatment areas will be significantly different from those in the control areas.

H3: Family and species evenness of coleopteran communities within treatment areas will be significantly different from those in the control areas.

H4: The presence or absence of families and species of coleopteran communities within treatment areas will be significantly different from those in the control areas.

CHAPTER II

LITERATURE REVIEW

Use of Pitfall Traps as a Sampling Method

The following discussion of pitfall traps is broad in context and presents information gathered from several studies that have used pitfall trapping. The various trap designs reported in previous studies will not be discussed in detail. Instead this discussion focuses on factors affecting efficiency, application, and assessment of catches.

The ideal sampling method to use in this project design is the pitfall trap. It is used to gather data to qualitatively compare similar species, similarity quotients, and the spatial heterogeneity of diversity within different (Blumberg and Crossley 1988) or isolated habitats (Blumberg and Crossley 1983). Pitfall traps have been used to gather data to estimate seasonal incidences and population data and spatial distribution of carabids (Greenslade 1964). However, pitfall trapping does not allow inference of population densities on a per unit area basis (Richardson and Holliday 1982) because immigration and emigration of individuals is not controlled within the study site (Rickard 1970).

Pitfall trap data have been used to compare relative numbers, spatial distribution, seasonal occurrence and activity level of the arthropod communities (Paquin 1997). Rykken (1997) used pitfall traps to determine the relative species activity, but did not examine the true density and diversity of beetles (Carabidae) present.

Pitfall trapping has been used in entomological studies to estimate population density (Gist and Crossley 1973). Catches from pitfall traps can be quantified by removal and mark-recapture techniques (Blumberg and Crossley 1988). It is a sampling method enabling the investigator to survey population density, and calculate both diversity and abundance of feeding guilds in different habitats (Greenslade 1964, Baars 1979, McCullough, Werner and Neumann 1998). The mean density of a population can be based on the number of individuals captured during a pitfall sampling period only if capture efficiency, natural mortality, and activity period of a species is known (Baars 1979). However, a measure of the relative abundance of a beetle community can be estimated using pitfall traps if captures are collected over a full activity period, begining at emergence and concluding when an individual dies.

A pitfall trap is an effective method to compare different habitats (Blumberg and Crossley 1983). Continual trapping provides a reliable relative measure of density in different habitats (Baars 1979, Richardson and Holliday 1982). The assumption that continual trapping demonstrates a reliable and relative measure of a species density enables an investigator to compare the population differences of a single species in varied locations. However, pitfall trapping may not capture each species equally (Richardson and Holliday 1982).

Beetle population density has been noted to impact individual beetle activity due to a potential increase of interspecies competition for limited resources. A contention for limited resources can force individuals to increase searching activity and expand their spatial distribution across the landscape. Activity increases and spatial distribution of beetle assemblages is reflective in only a small proportion of the pitfall catch (Baars

1979). However, measurements of the relative density of individuals across the landscape, can be estimated if all pitfall traps are installed in areas of uniform vegetation (Blumberg and Crossley 1983).

Beetle assemblages are most often affected by microclimate moisture levels, although trap placement and intraspecific interaction (Richardson and Holliday 1982, Rkken et al. 1997). The reduction of vegetation following a fire, which alters the microclimate and may act as one of several environmental factors that determine carabid distributions throughout an ecosystem (Richardson and Holliday 1982).

The activity of ground-dwelling species may vary seasonally with an activity increase in summer months and decreased activity in winter months (Williams 1959). Baars (1979) noted that data from pitfall trapping could be used to compare seasonal activity in different time periods. However, other authors have found this to be true only if the investigator uses pitfall traps throughout a study (Gist and Crossley 1973, Richardson and Holliday 1982). The pitfall trapping technique is often criticized due to the number of biotic factors that can impact efficiency. Pitfall trapping is a passive capture method, dependent on collected species activity (Greenslade 1964). The distribution, population density, and activity of individuals are affected by weather and temperature (Richardson and Holliday 1982, Rickard 1970). Beetle activity can be influenced by the vegetation surrounding a trap (Greenslade 1964, Richardson and Holliday 1982). If vegetation is dense and allows only limited movement, then an aggregated insect population of certain species will exist only in exclusive pockets of land (Blumberg and Crossley 1983) that support reproductive or feeding areas. This is notably true of the distribution of carabid beetles across a landscape of dense vegetation

(Greenslade 1964). Pitfall trap captures might often under-represent the presence of invertebrate species (Rykken et al. 1997). Despite pitfall sampling deficiencies, it is often the only sampling method applicable to carabid studies (Greenslade 1964).

Use of Coleoptera as Indicator Organisms

At least a single indicator organism is needed to quantify the effects of different management practices (Villa-Castillo and Wagner 2002). Indicator organisms should be highly sensitive to changes in the environment and serve as a food source for a broad range of predatory species (Gagne and Belanger 1999). Therefore, to assess forest management techniques, ecological indicator taxa should be identified. This study examines if the presence, abundance, and species richness of selected coleopterans can be used as ecological indicators to determine the effects of specific forest management practices.

Over one fourth of all animals described on earth are in the order Coleoptera (Arnett and Thomas 2001). They are important components of ecological function and community composition (Burke and Goulet1998). Beetles are among the most diverse soil-inhabiting invertebrate organisms in a forest system (Wikers and Schimmel 2001). They include decomposers, predators, herbivores, and they occur in a wide range of habitats (Burke and Goulet 1998). Beetle assemblages are sensitive to environmental changes associated with forest management practices. Villa-Castillo and Wagner (2002) used soil coleopterans as indicator organisms to assess the forest condition. Burke and Goulet (1998) found poor forest management practices caused a reduction of beetle biomass by negatively altering nutrient cycling, decomposition, prey availability to large invertebrates and vertebrates, and the overall function of the local ecosystem.

Fire History of the Southeastern United States

The fire history of the southeastern United States predates the 1800s, when fire was commonly applied to eliminate under story vegetation on pine plantations to form woodland savannas. Native Americans used fire to open forested areas and facilitate the growth of desired plants, increase wildlife habitat, ease travel difficulties, and increase visibility within forested areas. Americans cleared and burned numerous small tracts of forested land to create farmland in the 1920s. In the 1930s, farmlands were being abandoned and land managers and private landowners encouraged the conversion of agricultural fields into forested ecosystems. In the 1980s, prescribed burning applications were encouraged as a technique of wildfire suppression (Pyne 1997).

Forest managers in the southeastern United States have recognized the importance of prescribed fire in the establishment and health of the mixed conifer forests native to the southeast. Without fire applications, the native mixed forests of loblolly pine (*Pinus taeda* L.), longleaf pine (*P. palustris* Mill.), slash pine (*P. elliottii* Engelm.), and short leaf (*P. echinata* Mill.) would succumb to the encroachment of hardwood species (Harris and Whitcomb 1974). Forest managers can successfully apply prescribed fire to restore modern forested areas to the natural state that occurred prior to human disturbance (Kalisz and Powell 2000).

The Clemson Experimental Forest (CEF) is an experimental unit within the Piedmont Forest and Mountain Physiographic Regions of the Carolinas. The topography of the CEF was shaped both by geography and the farmers who terraced the land early in the beginning of the nineteenth century for cotton production. The CEF is like other forests in the southeastern states because it is established on land that includes various streams and bodies of water, bordering small tracts of land managed for timber (Walker and Oswald 1999). The CEF was established in the mid 1940s by the federal government in an effort to stop the degradation of abandoned farmland (Sorrells 1984).

Prescribed Burning

Prescribed burning is an artificially ignited blaze that mimics the frequent, naturally occurring low-intensity fires that would have burned forest habitats (Peters et al. 2002). It is an anthropogenic practice (Bailey and Covington 2002) that impedes wild fire, improves wildlife habitat (Weber and Taylor 1992) and positively augments the ecological health of a stand that has been subject to fire suppression (Peters et al. 2002). As the heat intensity of a fire increases, the layers of duff are consumed, causing a reduction in the infiltration rate of the soil. Soil subject to a severe burn becomes hydrophobic, increasing erosion rates (Robichaud, 2000). The design of a prescribed burning emphasizes a low-intensity burn, so the water infiltration rates of the soil surface are not compromised. Prescribed burning removes slash and vegetation, which reduces live or dead fuel and improves charge conditions in the soil (Weber and Taylor 1992). It facilitates plant regeneration by increasing the production of flowering plants and allowing the reintroduction of fire into an ecosystem (Peters et al. 2002).

Prescribed burning often can be done for a more reasonable cost per unit area than mechanical thinning. As the area requiring burn application increases, the cost to administer the fire decreases (Weber and Taylor 1992).When applied within a forested area, prescribed burning enables a landowner, hired forester, or land manager to accomplish specific ecologic and economic goals. Burning is often used in conjunction habitat and watershed reclamation, stand rehabilitation, wild fire hazard reduction (Weber and Taylor 1992), and timber management (silviculture). The risk of wild fire is reduced in areas that have prescribed burn treatment applications due to the regular removal of live or dead fuel (Kalisz and Powell 2000). Fuel consumption reduces risk of a wild fires ability, to ignite, spread, and resist control (Weber and Taylor 1992).

Today, the association of prescribed burning with increased biological diversity has popularized the application of prescribed burning (Wikars and Schimmel 2001). Fire is an ecological process that maintains landscape integrity and plant-associated communities (Griffis and Crawford 2001, Weber and Taylor 1992, Wikers and Schimmel 2001). Prescribed burning, as a management practice, changes the habitat and biotic structure of a forest ecosystem (Wikers and Schimmel 2001). Prescribed burning enhances timber productivity and restores a mosaic pattern of diversified stand composition in a forest system (Weber and Taylor 1992). Prescribed burning prepares forested areas for regeneration of native plant species by reducing plant competition (Peters et al. 2002), over story shading, under-story competition, and build up of an excessive organic layer. It promotes plant succession and advances stand composition conversion to native plant species (Weber and Taylor 1992). It opens the habitat (Richardson and Holliday 1982), providing seed-bedding areas for shade-intolerant tree species (Peters et al. 2002); and it deters the establishment of unwanted hardwood tree species when a multiple aged forest or a pure coniferous stand is desired (Harris and Whitcomb 1974).

Fire behavior, intensity, and stability are dependent upon several factors, including the distribution and amount of fuel as well as the orientation of wind and topography. Fire intensity can be affected by the amount or dispersion of moisture within the layers of leaf litter and soil layers. Each factor can significantly contribute to the mosaic pattern of burned and unburned areas in a forested area after a blaze (McCullough el al. 1998). As fire intensity increases, the risk of burning deep into the organic soil also increases. Drought seasons often lead to fire capable of burning the organic soil layer. A drought may cause both the upper layers of the soil surface and the leaf-litter layer to dry. As layers of the forest floor lose moisture the floor itself becomes a fuel source that can support an increasingly intense fire (Wikars and Schimmel 2001).

An intense fire is likely to consume the entire pine litter layer on the forest floor and reduce the population of carabid beetles in the environment (French and Keirle 1969). Despite the loss of existing populations, the overall abundance of carabid beetles may not be drastically reduced due to the colonization of pyrophilus species. Immediate colonization is demonstrated by the individuals in the carabid genus, *Agonum*, which immediately immigrate into a burning area due to an affinity for smoke and heat (Holliday 1984, Richardson and Holliday 1982).

Prescribed Fire and Invertebrates

Ecological stability of an environment is directly related to its abundance of biological diversity (Blumburg and Crossley 1983). The desired environmental stability of a forest ecosystem is incorporated into the forest management plans. Inclusive management of a forest requires prescribed burning knowledge of the impacts on diversity and abundance of insects (McCullough et al. 1998).

If prescribed burning is used for pest management coordination of weather conditions, pest life stage and location are required for a prescribed burn to effectively control undesired pests. The weather must support a fire temperature that reduces the density of the pest population without damaging standing trees. A fire that is too hot may destroy all leaf litter (French and Keirle 1969), that is the microhabitat of many arthropods. Trees suffering burn wounds are less resistant to bark beetle attack (McCullough et al. 1998). Forest succession could be directed or disrupted by an insect outbreak following a burn (McCullough et al. 1998).

Previous studies have determined when fire application would improve biotic diversity of a forested area or serve as a pest control method (McCullough et al. 1998). Prescribed burning can decrease insect populations by producing excessive heat and smoke (Richardson and Holliday 1982). It is used to control insect pests of seeds and cones (McCullough et al. 1998) and successfully reduces populations of bark beetles (McCullough et al. 1998, Weber and Taylor 1992).

Insects survive fire disturbances by finding safety *in situ*, and immigrating or emigrating either after or during the blaze (Holliday 1991). Wikars and Schimmel (2001) determined the major cause of invertebrate mortality during a blaze was depth at which the organic layer is consumed. The organic soil layer of the forest floor was described as a moist insulation layer that protects its inhabitants from the heat of a blaze. Insects found after a blaze are frequently previous residents that reemerge from an insulating layer of soil, or are colonists from surrounding forested areas that have similar vegetation (Ferris and Humphrey 1999). McCullough et al. (1998) stated that the majority of pine beetle populations present after a burn are colonists.

Fire has a significant role in the establishment and composition of invertebrate and vegetation species in the southeastern United States (Harris and Whitcomb 1974). Fire exclusion in forested landscapes has been a popular practice for decades, but preventing fire has reduced the habitat of species that require burned habitats. Wikers and Schimmel (2001) reported that although fire-favored species have been lost there are still those that persist. Some organisms require a habitat where forest fires periodically recur for their long-term survival (Wikers and Schimmel 2001). Fire produces charred substrates, which is required by some arthropod species in their environment (Niemela 1996).

The attraction of arthropods to a burned site may occur during or immediately following a blaze (McCullough et al. 1998). Pyrophilous species are attracted to and breed within vegetation that has been burned. Unburned trees suffering from weather damage, adverse weather conditions or lightening strike are used by pyrophilous beetle species during fire-free periods. (Evans 1971). In a time of almost emphatic fire exclusion, Wikers and Schimmel (2001) conjectured that pyrophilous species have been forced to use forested areas that have been treated with the clear-cut method of timber harvest. The clear-cut method has been the only harvesting method to closely simulate the vegetative alterations caused by fire treatments.

Mechanical Thinning

Nyland (2002) defined mechanical thinning as the removal of trees within a fixed spatial arrangement. It is an intermediate harvesting method applied in hardwood, conifer, or mixed-tree stands. Thinning is a silviculture practice applied in a number of ways to meet specific ecological and economical goals. A clear cut is the removal of all trees within a stand and is often excluded from this discussion of thinning.

There are a variety of mechanical thinning techniques, each alters the density of a forest stand to fulfill economic, wildlife, or various ecological goals. It includes the removal of dead, diseased, pest infested or undesired tree species. It is applied to dense stands of green or dry timber where fire suppression has been encouraged and the growing space of individual trees is compromised (Peters et al. 2002). It is often the preferred type of site preparation used to facilitate forest regeneration into aged stands of trees (Peters et al. 2002, Weber and Taylor 1992).

Historically, it has been used to increase wood fiber production and tree growth to reestablish ecosystem health (Peters et al. 2002). It improves the resource uptake of the remaining trees. Improved resource intake results in increased trunk diameter, leaf toughness (Wikars and Schimmel 2001), total body mass growth, and improved resistance to insect infestations (Freeney and Kolb 1998). However, timber harvest does not substitute for a natural disturbance (Niemela 1996).

Mechanical thinning reduces vegetation competition by cutting and removing unwanted trees and undesirable sprouts that would otherwise compete for resources in order to gain height (Feeney and Kolb 1998). Mechanical thinning changes the vegetation structure, so remaining trees have the opportunity to develop into a high-value stand (Hicks 1998 and Peters et al. 2002). The reduction in competition increases tree growth, wood fiber production, and a stand's ability to resist insect and disease attacks. If used as a preventative measure, mechanical thinning may eliminate the need for using an insecticide (Walker and Oswald 1999). Thinning is most often used on dense stands of large, well-aged, shade tolerant trees that have been unaltered by fire suppression (Hicks 1998, Peters et al. 2002).

Despite the positive effects of mechanical thinning on timber growth and ecosystem restoration, the actual process of thinning can harm the overall health of a forest habitat. The harvesting of timber requires road construction that causes erosion and increases sediment delivery into streams (Nyland 2002 and Peters et al. 2002). Roads also cause an increase in soil compaction that reduces trunk basal area increments, resin flow and the level of moisture and nitrogen in the soil (Feeney and Kolb 1998). Furthermore, the reduction of understory plants aids in the reintroduction of fire to a forested ecosystem (Peters et al. 2002) by increasing the amount of heat absorbed by the forest floor, which reduces the available moisture content of the soil. This alteration of microclimate increases the risk of wild fire (Nyland 2002 and Peters et al. 2002).

Mechanical thinning makes an artificial impact on the environment that is unique to any natural disturbance (Niemela 1996). Invertebrate communities are assumed to survive most natural disturbances, but can not likely survive ill-planned management treatment applications. Therefore, a thinning treatment must be applied to simulate the impact of a natural disturbance (Niemela 1996).

Butterfield (1997) used pitfall traps, five years after a row thinning treatment, to collect 'fast moving' carabid species that were present at low densities in pine plantations. He determined that carabid populations peaked, in terms of species-abundance and diversity, at the beginning of the plantation cycle, which begins once a stand is completely felled (often in the form of a strip-row thinning method). Butterfield (1997) noted that the burst of carabid diversity and species-abundance coincided with the ground vegetation recovery period. It is during the recovery period that the plant composition and structural variances of the ground vegetation is most diverse. He also reported that the recovery period promoted large population densities of various soil-dwelling macro-invertebrates and suggested that the increased collection of larger bodied carabid species (>5.9mm) in young pine plantation stands 1 to 4 years after a row thinning treatment may reflect an increase in prey availability.

Thin /Burn Treatment

Prescribed burning in combination with mechanical thinning are silviculture practices that are often applied to a harvested site to prepare the areas for regeneration. Conversely, the application of prescribed burning can renew a stand after it has been thinned by removing logging slash, competitive vegetation, and excessive organic layers. Fires applied after tree removals are often cool and smolder close to the ground as timber slash is consumed (Weber and Taylor 1992).

In a thin/burn study conducted by Wikars and Schimmel (2001) pyrophilus insects colonized stands that had been uncut, selectively cut, or clear-cut and exposed to various burn intensities. Stands that were colonized most frequently by fire-favoring species had not been thinned and were severely burned. Wikars and Schimmel (2001) found that invertebrates with a thick cuticle layer are more likely to survive a fire and the warmer soil conditions of the charred soil surface. The authors further discussed the importance of a thick cuticle layer that may improve the rate of survival for individuals that persist in a thin/burn treatment area. Individuals that remain in thin/burn stands have a higher risk of desiccation because they are subject to weather and temperature extremes that occur due to the loss of vegetation caused by thinning and burning. Furthermore, as Wikars and Schimmel (2001) stated, the thermal inertia of invertebrates is so minute that the cuticle layer could only serve to reduce desiccation, not act as a protective barrier that resists the heat of a fire. Wikars and Schimmel (2001) noted, within sixty-days following a blaze, the abundance of invertebrate species in thin/burn stands were lower than in the burned and uncut stands. The composition of beetles collected in burned and uncut stands consisted of a few fire-favoring species.

Biotic organism abundance and diversity is increased in forested ecosystems in which vegetation is structurally diverse (McCullough et al. 1998). Authors have found evidence that habitat has a significant impact on the richness and abundance of carabid beetle communities (Apigianans Wheelwright 2000, Ings and Hartley 1999). The structure and composition of stand vegetation and the amount of invertebrate prey determines if the environment can support a carabid population. Ings and Harley (1999) found the richness of carabid communities was correlated with tree size. As the average dimension of trees increased, the mean number of individuals captured increased; however the richness of the carabid community sampled decreased.

The application of thinning, burning, and thin/burn to a forest in northern Arizona (Villa-Castillo et al. 2002) proved to significantly impact carabid beetle assemblages. Carabid richness increased as the level of disturbance increased, resulting in low species diversity in areas of forest where treatment had been excluded. Also the genera *Harpalus* and *Amara* both have a preference for dry habitats; they prefer an open habitat of little vegetation (Villa-Castillo et al. 2002).

Coleoptera: Carabidae and Silviculture Treatments

The application of forestry management practices does not ensure that a decrease in the number of species present within the habitat will occur. There are certain arthropod species that require disturbed stand habitats, like those caused by forest management practices. Disturbed environments offer a fragmented habitat conducive to generalist arthropod species. Generalist carabid beetle species are likely to immigrate into a disturbed forest. According to Niemela's (1996) six-year study, carabid beetle and spider richness was highest in regenerating stands that had been thinned 10 years prior to the study. The positive correlation between the richness of strictly forest-dwelling carabids and the size of an undisturbed forest habitat (Niemela 1996) demonstrates that carabid beetle community structure is impacted by the forest habitat.

The stability of an environment and the ability of individuals to disperse across short and long distances determine a population's chance of survival (Den Boer 1970). Rykken (1997) reported the dispersal range of carabid beetles to be 5 to 10 meters daily. Individual carabid beetles often travel throughout a 10-meter area over a 24 hour period. Therefore, carabid beetle communities often consist of an aggregation of individuals in small areas existing at random throughout the landscape (Greenslade 1964). Kirk (1971) observed carabid beetle activity often occurs near or at the soil surface layer during daylight hours. The population density of carabid beetles increased in May or early July. A second population peak occurred within the same year, from August to October and coincided with late summer prey activity (Kirk 1971).

In Holliday's (1991) boreal forest study in Winnipeg, Mantobia the median body mass and number of brachypterous carabids captured after a prescribed fire increased with time, while the body mass and number of brachypterous individuals captured in a climax forest was independent of time. The trend of larger bodied carabids increasing in population with time was assumed to be associated with increased prey accessibility in mature forest. Holliday's (1991) species captures immediately following a blaze had small body mass and relatively long-wing length. Holliday (1991) also found that small, long winged individuals were present only in initial stages of forest regeneration; and a trend in the number of individuals that have a larger body mass increased consistently after a blaze had been extinguished. Holliday (1991) speculated that the increase in body mass of individuals within the beetle community over time was due to an increase of the amount of prey items available after a blaze. However, this trend was evident only in early stages of forest regeneration. Of the species captured by Holliday (1991) members of the *Harpalus* genus were most common.

The number of captured carabid individuals is likely to be influenced by a several environmental factors. A combination of microclimate, vegetation, and edaphic factors affect both beetle population density and individual activity (Richardson and Holliday 1982). Beetle communities located in habitats that are conducive for reproduction are more likely to be represented in catches due to increase local activity, not dispersing activity (Baars 1979).

The proportion of individuals trapped in a specific area is dependent on the activity of those individuals. Baars (1979) stated that locomotory activity, or the dispersal of individuals, is often motivated by reproduction or adverse conditions in the environment (Baars 1979, Holliday 1991). Furthermore, the distribution of beetle activity is influenced by weather conditions. The locomotion of beetles increases as the ambient temperature rises. However, species of Carabid beetles increase locomotory activity, despite environmental temperature, following a period of diapause or little mobility in search of food or a reproductively active mate (Baars 1979). Harris (1974) found in his study of the mixed pine forests in Florida that carabid beetles actively move about the soil surface year round.

Rykken (1997) demonstrated that carabid species are habitat generalists. He found the distribution of ground beetle species across varied forest landscapes was independent of the ecological land type in which the collections occurred. Of the 35 species commonly collected, Rykken considered two species to have an affinity for high soil moisture while all others to have no habitat preference. Apigian and Wheelwright (2000) found carabids to be habitat generalists that establish high populations in areas of continuous forest.

Coleoptera: Staphylinidae and Silviculture Treatments

Wikars and Schimmel (2001) focused on the short-term impact that fire has on species abundance in a forested area. They attributed the survival of Staphylinidae in burned boreal stands to the immediate colonization of the burn area as well as the *in situ* survival of the blaze. Staphylinidae were assumed to have survived *in situ* because the pliability of their body allowed locomotion through ground substrates. The mobility of individual beetles had a positive correlation with the body size of an individual. Wikars and Schimmel (2001) found a correlation between body size and the structure of vegetation to increase the probability of beetle survival, especially Staphylinidae present in a thin/burn treatment stand. The large body mass of one species of Staphylinidae was found to increase the chance for blaze survival due to an increased ability to move throughout soil substrates.

Coloeptera: Erotylidae *Triplax thoracica* Say

Ten genera containing forty-nine species of Erotylidae, commonly called pleasing fungus beetles, are found in moist forested areas north of Mexico. *Triplax* Herbst is the largest genus of Erotylidae in North America, represented by nineteen species in the United States. *Triplax thoracica* Say occurs in moist deciduous forests in central North America east of the Rocky Mountains, and in the eastern United States (Goodrich 1993).

Goodrich (1993) collected Erotylidae specimens, using pitfall and UV light traps, and by hand under decaying bark or within the pileus of mushrooms. However, Goodrich (1993) collected *T. thoracica* exclusively within the fungus *Pleurotus ostreatus*, the oyster-mushroom (Wiley and Sons 1962).

CHAPTER III

MATERIALS AND METHODS

The impacts of the management practices of prescribed burning, mechanical thinning, prescribed burning and thinning combined, and untreated areas on Coleoptera were monitored.

Experimental Design

Study Sites

The study sites were located in the Clemson Experimental Forest (CEF) and selected based on homogenous vegetative, structural, and compositional stand elements. The stands within each study site were 15 to 60 years of age with a pine canopy and hardwood understory. The pine canopy is a mixture of *Pinus echinata* Mill. and *P. taeda* L. and ranged from saw timber (>25 cm DBH) to pulpwood (<25 cm DBH). The CEF has utisol soil, steep sloping gullies, and little or no topsoil layer, which is characteristic of the topography of abandoned farmland in the southeastern United States (Sorrells 1984).

Treatments were applied within 14 study sites, ranging in size from 14 to 36 ha. The study sites were 10 hectares enclosed with a buffer area of at least one tree length (approximately 20 m) (Fig. 4). Within each treatment area, 36 grid points were established and marked by a rebar stake, driven 30 cm into the ground. The stakes were tagged with a numbered aluminum label and spray painted pink for ease of location. The first grid point was in the northeastern corner of the treatment area, and the second grid point placed 50 m west of the first point; the third was placed west of the second and so on. When the grid approached the western edge of the study site, the following numbered point was installed 20m south of the previous point. The following point was then positioned 50m directly east and began another line of grid points parallel to the first grid line. Subplot blocking factors of pulpwood-sized trees (dbh 12-15 cm), pulpwood to sawtimber trees (dbh 15-25 cm), and sawtimber (dbh >25 cm) trees were evaluated.

Collection Plots

Collection plots were established within Modified Whittaker Vegetation Plots (MWVP) placed at the second, and every following fourth, grid point in the treatment plot. A MWVP is a 20x50m area, containing ten 10x10m collection plots. All MWVP were placed in cardinal alternating directions. The MWVP placed on the second grid point was oriented in a north/south direction the following MWVP, at grid point six, was established in an east/west direction, the alternating of cardinal orientation continues throughout the treatment area. One 50m side of the MWVP was chosen at random, and a single pitfall trap was placed within each 10x10m collection plot, bordered by the chosen 50m side. Each treatment plot was sampled using five pitfall traps in each of the four collection plots, resulting in a total of 20 pitfall traps within each 10-hectare treatment plot (Fig. 5).

Beetle Sampling

To establish each pitfall trap, an auger was used to form a hole in the soil deep enough to accommodate a 473-ml (16 oz.) Solo © plastic cup (Solo Cup Company, Urbana, Illinois, USA). The 473-ml cup was placed so that the open end was flush with the soil surface when placed in the hole. This cup was used to maintain the structural integrity of the hole throughout the study and to support a second cup placed within it. The second cup was a 288-ml (9 oz.) Solo © plastic cup (Solo Cup Company, Urbana, Illinois, USA) containing 75% ethanol that serves to kill and preserve captured beetles.

A 22 cm diameter Styrofoam Hefty plate ™ (Pilex Corporation, Lake Forest, Ill., USA) was used as a protective cover to keep rain, and leaf litter from entering the cups. These also enabled me to quickly locate traps in dense vegetation. Three small holes were made in each plate approximately 1.5 cm from the edge and the upper head of the three 16d 3-1/2" Bright Duplex Nails (Grip Rite Fas'ners TM, Primesource Building Products, INC., an Itochu Company, Dallas, Texas) were placed through these holes. The nails supported the plate above the soil surface and acted as weights to prevent the plates from being removed by wind or other natural forces. The cover was placed above the pitfall trap and the nails were pushed into the soil surface. During trapping, the cover was left approximately 3 to 4 cm above the soil surface to allow the arthropods to enter the trap. Between trapping periods, the cover plate was placed close to the soil surface to protect the 473-ml cup and facilitated location of traps when returning to collect again.

Beginning in January, sampling occurred during the first week of alternate months for twelve months during 2002. Traps remained active for 48 hrs during each trapping period. After trapping, the trap was opened and the capture cup removed. All contents were poured into a plastic storage container. The capture cup was examined in the field to ensure that all arthropods had been placed in the storage container. The lid to the storage container was applied and labeled with the date of collection, treatment plot type, and number of the collection plot. Once all capture cups had been collected, the material was taken to the laboratory for identification using published keys (Dillion 1961, Ciegler 2000, Harpootlian 2001). Beetles collected from the pitfall traps were identified to family, and those belonging to the families Carabidae and Scarabaeidae were determined to species. The presence of each beetle within a treatment was recorded.

Comparisons of Beetle Captures in Thin Treatment Areas

Thin treatment areas, thin two, thin three, thin four, and thin five were naturally regenerated stands. A selective thinning was applied to remove insect-infested, diseased, small, or merchantable (28-32 dbh) trees. Slash caused by the thinning was not removed from thinning sites. The residual basal area of remaining tree was approximately 18 m^2ha. Stands in the thin one treatment area were dense and $\leq$ 25 dbh, planted in rows with little understory vegetation. A row thinning was applied to thin one and corridors were cleared of trees but supporting opportunistic grass and brush were formed between the dense stands. All thinning treatments were applied in December 2000, or in January, February, March, or April of 2001.

A Dunnett's test was used to determine if selective thinning or row thinning significantly impacted beetle captures in thin treatment areas (Zar 1984). The Dunnett's test compared the group mean of beetle captures in thin two, thin three, thin four, and thin five to the total means of captured beetles in the thin one treatment area (SAS Institute 1999).

Comparisons of Beetle Captures in Burn Treatment Areas

Prescribed burning was applied to all burn areas in April 2001, 8 months before the first collection period occurred. Flanking and strip fires were ignited manually on the ground when weather conditions were at the 80th percentile. The goal of the burn application included the survival of 80% of the overstory trees, and suppression and top kill of intermediate canopy and understory vegetation.

Comparisons of Beetle Captures in Thin/Burn Treatment Areas

The burn application occurred in thin/burn treatment areas after the January collection period. All beetle captures in thin/burn areas after January demonstrated the immediate impact of prescribed burning. The immediate impact and of prescribed burning and peaks of captures in thin/burn areas were examined by comparing the mean number of beetle captures in each collection period, using ANOVA and least-squared-mean analysis (SAS Institute 1999).

Statistical Analysis

Family, Genus, and Species Abundance Analysis

A split plot time model was used to examine the mean number of beetle family and species captures because the outcomes of trap catches were likely to be dependent on trap placement, or catches that occurred in prior collection periods. The interdependence of captures among sampling dates required the use of the split plot time design for appropriate statistical analysis.

All family and species data were examined for normality using an ANOVA. Zar (1984) suggested a square root transformation model for biological data analysis, because the data are often randomly collected and may incur small or zero counts. The square root transformation model promoted a normal distribution of sample data despite the occurrence of zeros in the data. A square root transformation model altered data with non-normal distributions.

Only species or families that were represented by at least 20 individuals were assessed so that there were enough observations for statistical analysis. The value of statistical significance for all recorded data was a ≤ 0.05.

Order, Family, Genus, and Species Analysis: Comparisons of Collection Periods

The effects of time, treatment type, or treatment/time interactions on order, family, genera, and species representatives were determined using the mean number of captures in treatment areas. The mean number of captures was compared among collection periods using ANOVA and least-squared-mean analysis (SAS Institute 1999).

The significant peaks in the mean number of beetle captures among collection periods were also examined by comparing the mean number of captures in treatment areas during collection periods. ANOVA and least squared means were used (SAS Institute 1999).

Family and Species Presence and Absence Analysis

Family and species presence/absence analysis determined if a time/treatment interaction or treatment impacted the presence of a family or identified species in treatment areas. Beetle captures were recorded as either a 1 ($\geq$ one family or species representative was captured) or 0 (a representative was not captured) based on the capture of beetle families or identified species in treatment areas. The first analysis examined the presence or absence of a beetle using both treatment-type and time of collection as model factors. The second analysis considered the presence or absence beetles using only treatment-type in the model. All presence/absence analysis was conducted using ANOVA (SAS Institute 1999).

Family and Species Diversity Analysis

Family and species diversity within each type of treatment area was determined using the Shannon index of diversity. The Shannon index assumes that sampling occurred at random (Zar 1984) and that all species present in the treatment areas were represented in the samples (Magurran 1988). Evenness was calculated using the Shannon index, presented by Magurran (1988) (SAS Institute 1999).

After diversity values for each treatment site were compared, the significant differences were determined between treatment sites using a t-test (SAS Institute 1999).

CHAPTER IV

RESULTS AND DISCUSSION

Pitfall Trap Samples

Twenty-five species of Carabidae, twenty-two species of Scarabaeidae and one species of Erotylidae were captured. Members of 25 other families were collected, but species were not identified (Appendix C). The largest numbers of individuals captured during the study were the carabids *Pasimachus punctulatus* Haldeman (66 specimens) and *Cyclotrachelus spoliatus* (Newman) (61 specimens), the scarabaeids *Bolboceras thoracicornis* (Wallis) (69 specimens) and *Ateuchus histeroides* Weber (65 specimens), and the erotylid *Triplax thoracica* Say (282 specimens).

In this study, 893 beetles were identified to species and, 1,810 to the family level. Only 12 species and 9 families had enough representatives to allow statistical analysis. In studies such as this it is not uncommon for only a few species or families to be examined (Muona 1994, Niwa and Peck 2002, Villa-Castillo and Wagner 2002).

Pitfall Trap Results

In my study, beetle captures occurred more often in some traps while other traps in the same transect captured very few. Variation within a transect is likely to be determined by the mobility and behavior of individuals within the habitat (Greenslade 1964). Surface movement of beetle species impacts the efficacy of traps and determines the proportion of beetle species captured. Muona (1994) noted that pitfall trap captures are likely influenced by the lack of vegetation after a blaze.

A decrease in ground cover could force beetle species to roam more often in search of resources. Muona (1994) proposed that capture rates in a burned area may increase after a blaze due to an increase in beetle activity, not an increase in the population density of beetles.

Effects of Thinning Techniques

Captures of beetle families *(df=4, F=1.19, p=0.342)* and species *(df=4, F=1.14, p=0.363)* in thin one were not significantly different from captures in the thin two, thin three, thin four, and thin five treatment areas. These data would suggest that the effects of thinning did not differ in row or selective thinning.

Family and Species Analysis

ANOVA output indicated that the captures of Carabidae, Scarabaeidae, Nitidulidae, Scolytidae, and Tenebrionidae were normally distributed, while the captures of Erotylidae, Curculionidae, Staphylinidae, and Leiodidae were non-normal and were examined using a square root transformation. However, the transformation did not significantly change the overall p-value of the non-normal distributions.

Data for *Cyclotrachelus spoliatus* (Newman), *Harpalus pensylvanicus* (DeGeer), *Pasimachus puntulatus* Haldeman, *Dichaelus dilatatus dilatatus* Say, *Triplax thoracica* Say, *Cotinis nitida* (Linnaeus), and *Onthophagus subaeneus* (Beauvois) were not normally distributed and required transformation. Data for *Cyclotrachelus sigillatus* (Say) and *Trox tuberculatus* (DeGeer) did not require transformation.

Carabidae

The abundance of Carabidae was not impacted by treatments overall (d.f. =3, *F* =0.56, *P* =0.652). Time (d.f.=5, *F* =0.05, *P* =1.000) and treatment type (d.f. =3, *F* =44.41, *P* =0.172) did not significantly impact captures among collection periods. Captures did not reflect a time/treatment interaction (d.f. =15, *F* =1.43, *P* =0.172). Captures in burn (d.f. =5, *F* =4.39, *P* =0.0007), thin (d.f. =5, *F* =5.58, *P* =0.001), and control (d.f. =5, *F* =3.18, *P* =0.031) areas peaked significantly in June and October (Fig. 1). Carabidae captures in thin/burn treatment areas did not significantly differ among collection periods (d.f. =5, *F* =0.00, *P* =1.000).

Carabidae were captured during all six sampling periods, the number of individuals captured peaked in warmer weather (Fig. 1). Baars (1979) also observed increased carabid activity with warmer temperatures.

The lack of treatment effect on carabid abundance may indicate that carabidae are impacted by alterations within the microhabitat. The movement of species within the sampled area determines the proportion of beetle species within catches (Greenslade 1964). The total traveling range of most adult Carabidae is 5-10 meters (Rykken et al. 1997) within a twenty-four hour period (Greenslade 1964). Traps placed in areas of cleared or little leaf litter are likely to have larger numbers of catches. Therefore, as catches were taken from increased leaf-litter depth the surface movement of certain species was possibly hindered while other species increased movement activity. Carabidae populations generally remain aggregated and restrict themselves to favorable habitats (Greenslade 1964).

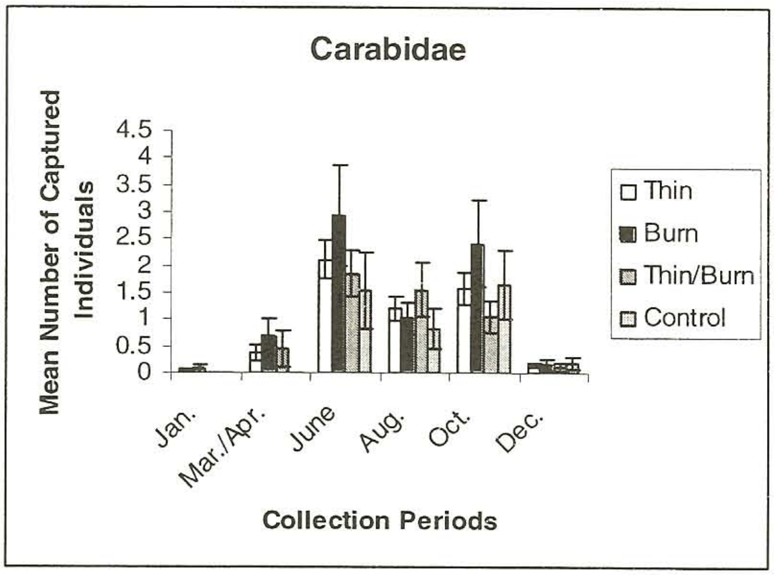


Figure 1. The mean number of Carabidae captures in each treatment per collection period in the Clemson Experimental Forest in 2002.

Muona and Rutanen (1994) believed their collections of ground active beetles in a burned Scandinavian boreal forest indicated that prescribed burning impacts arthropods for decades. They further speculated that burning impacts the mobility and abundance of various beetle species. Harris and Whitcomb (1974) identified prescribed burning as a means to manipulate carabid beetle populations. In the CEF, I speculate that prescribed burning does not impact carbaidae populations more or less than other forest management techniques.

Carabidae, often hide within leaf litter, loose tree bark, and under stones during the day and are active at night (Headstrom 1977). Adult carabids generally capture insect larvae that feed within burrows, though a few species are agricultural pests that feed on seeds (Dillon and Dillon 1972). The diverse feeding habits likely enhance the survival of

Carabidae within various habitats. Therefore, the family Carabidae is adapted to areas where low or high levels of disturbance have occurred.

Carabidae: *Cyclotrachelus spoliatus* Say

The abundance of *Cyclotrachelus spoliatus* did not differ among treatment or control areas overall (d.f. =3, F =0.52, P =0.675) The time of capture significantly influenced the mean number of captures (d.f. =5, F =3.00, P = 0.020). Captures among collection periods of *C. spoliatus* were not impacted by the type of treatment (d.f. =3, F =0.73, P = 0.539), or treatment/time interactions (d.f. =15, F =0.32, P =0.991). However, significant peaks of capture in burn (d.f. =5, F =6.05, P =0.001) and thin (d.f. =5, F =0.52, P =0.051) treatment areas did occur among collection periods (Fig. 2). In thin/burn (d.f. =5, F =0.04, P =0.999) and control (d.f. =5, F =0.09, P =0.994) areas captures rates did not significantly increase among collection periods. Capture peaks in thin treatment and burn treatment areas suggest that the amount of plant material on the forest floor is not a limiting factor for populations of *C. spoliatus* within stands. Thinned areas have logging slash on the forest floor, while the duff layers in burned areas were decreased.

Cyclotrachelus spoliatus is a large-bodied beetle (13.4-18.3 mm) that is attracted to lights and can be found in leaf litter or under logs (Ciegler 2000). Also larger carabid species travel farther and are likely to be captured in pitfall traps more often (Greenslade 1964).

C. spoliatus is nocturnal and seeks daytime shelter under logs and within leaf litter (Larochelle and Lariviere 2003). I captured 61 specimens, which reflects an overall low population density of *C. spoliatus* in the CEF. *C. spoliatus* has limited dispersal ability, the pitfall traps may have not been installed in areas near aggregations of *C. spoliatus*, resulting in low capture numbers.

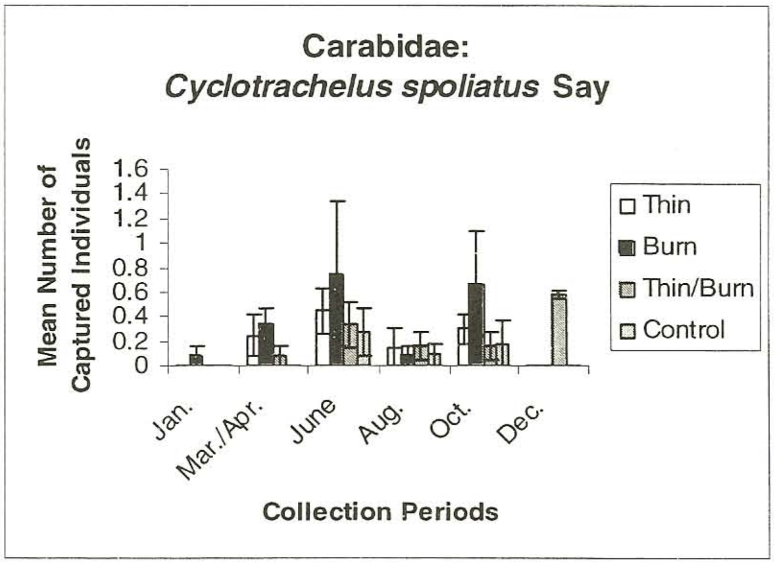


Figure 2. The mean number of *C. spoliatus* Say captures in each treatment per collection period in the Clemson Experimental Forest in 2002.

Carabidae: *Pasimachus subsulcatus* Say

The abundance of *Pasimachus subsulcatus* was not impacted by treatment type (d.f. =3, *F* =1.64, *P* =0.243). There was not a significant time (d.f. =5, *F* =1.87, *P* =0.118) or treatment effect (d.f. =3, *F* =0.75, *P* =0.530) on *P. subsulcatus* captures among collection periods. A time/treatment interaction effect was not found (d.f. =15, *F* =0.31, *P* =0.992). Significant capture peaks occurred in June and August in thin (d.f. =5, *F* =6.68, *P* =<0.0001) and burn (d.f. =5, *F* =3.26, *P* =0.011) areas; though treatment type did not significantly impact captures among collection periods (d.f. =3, *F* =0.75, *P* =0.530). Significant peaks of capture did not occur in control (d.f. =5, *F* =1.00, *P* =0.426) or thin/burn (d.f. =5, *F* =0.96, *P* =0.458) areas. The lack of significant captures in thin/burn areas, suggest the prescribed burn application in thin/burn stands in March may have deterred *P. subsulcatus* from the thin/burn treatment areas until October (Fig.16).

Larochelle and Lariviere (2003) stated that *P. subsulcatus* is found in open forests, in lowland areas of sandy soil covered sparsely by vegetation. In thin areas an open canopy habitat was present due to tree removal but logging debris and ground vegetation remained. In burn treatment areas ground vegetation was reduced and an open understory canopy was present due to the burning of underbrush. My data suggest *P. subsulcatus* is captured in stands that have open canopies or reduced ground vegetation.

The total captures of *Pasimachus subsulcatus*, though low (65), were relatively high compared to other ground active beetle species captured in the CEF. The frequency of captures suggest that populations of *P. subsulcatus* in the CEF are large, relative to other ground active beetle species.

P. subsulcatus are solitary, brachytoperous species that move slowly across the ground but actively burrow into soil (Larochelle and Lariviere 2003). The limited dispersal ability reduces trapping frequency due to a lack of mobility. Therefore, populations of *P. subsulcatus* in the CEF must be substantial because a high number of individuals were captured.

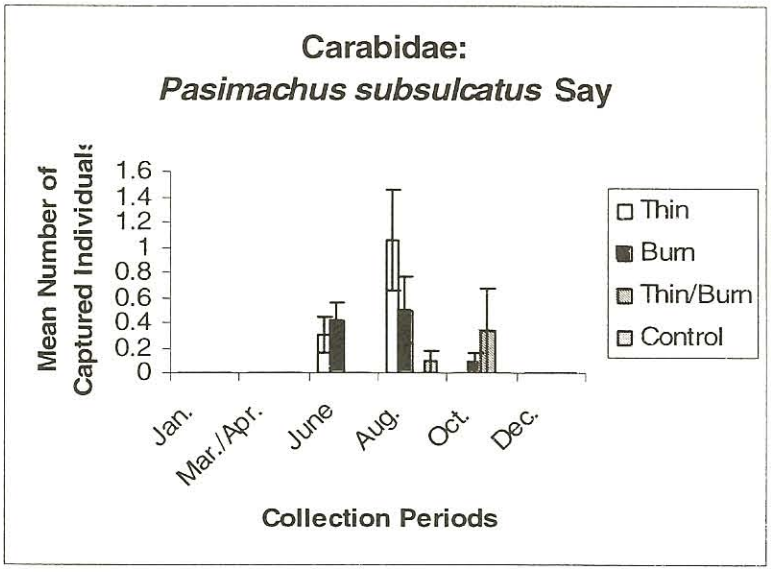


Figure 3. The mean number of *P. subsulcatus* Say captures in each treatment per collection period in the Clemson Experimental Forest in 2002.

P. subsulcatus feeds on eggs and adult grasshoppers and the seasonality of *P. subsulcatus* is year round; mating pairs are active during spring and fall months in Florida (Larochelle and Lariviere 2003). In the CEF captures occurred primarily in June and August (Fig. 15); therefore, activity of adult *P. subsulcatus* maybe restricted to summer months in the Piedmont in South Carolina.

Scarabaeidae

The total abundance of captures was not impacted by treatment (d.f. =3, *F* =0.17, *P* =0.913). Scarabaeidae were captured during each collection period (Fig. 4). Time (d.f. =5, *F* =2.05, *P* =0.088) and time/treatment interactions (d.f. =15, *F* =1.6, *P* =0.111) did not significantly affect Scarabaeid captures among collection periods. Treatment type did significantly affect the mean number of scarab captures among collection periods (d.f. =3, *F* =4.04, *P* =0.012). Captures increased in March/April, peaked in June, and decreased in the fall in thin (d.f. =5, *F* =0, *P* =1.000), burn (d.f. =5, *F* =1.02, *P* =0.414), and control (d.f. =5, *F* =1.37, *P* =0.249) areas. Captures significantly increased following the burn application in the thin/burn treatment areas (d.f. =5, *F* =2.42, *P* =0.040) in March/April (Fig. 4).

The feeding function of Scarabaeidae is largely unknown, with species speculated to be myrmecophilous or detritivous (Vaz De Mello 1998) while other Scarabaeidae feed on pollen, decaying vegetation, larvae of other insects in trees, carrion, feces, feathers and animal skin (Headstrom 1977). The disturbance in the thin/burn treatment appeared to promote scarabaeid populations after the prescribed burning application. It is possible that the disturbance caused by the thin/burn treatment immediately provided a habitat in which dead vegetation or animals were present. Also stands in burned areas were likely to be weakened by the blaze and susceptible to insect larvae infestation.

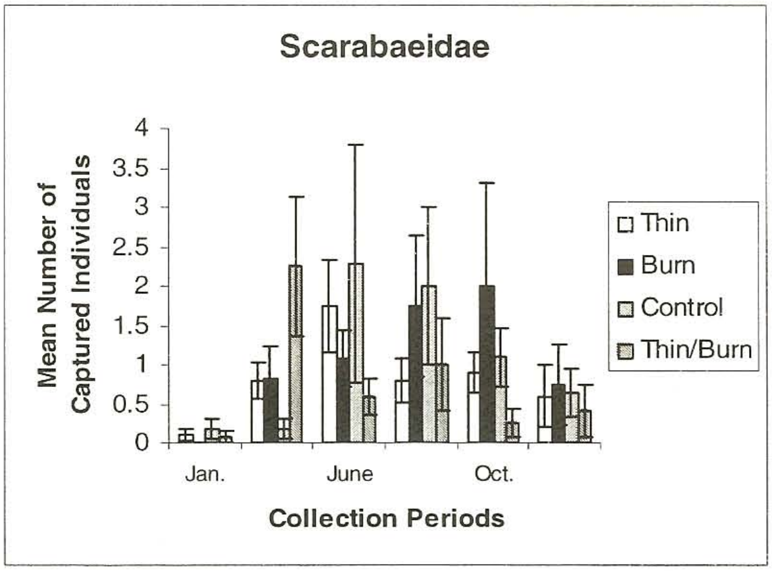


Figure 4. The mean number of Scarabaeidae captures in each treatment per collection period in the Clemson Experimental Forest in 2002.

Scarabaeidae: *Ateuchus histeroides* Weber

Ateuchus histeroides was captured most often in June and October (Fig. 5). The abundance of *A. histeroides* was statistically insignificant overall (d.f. =3, *F* =0.95, *P* =0.454). *A. histeroides* captures were not significantly impacted by time (d.f. =5, *F* =1.77, *P* =0.137), treatment (d.f. =3, *F* =1.38, *P* =0.261), or time/treatment interactions (d.f. =15, *F* =0.93, *P* =0.543). The lack of significant treatment or time effects was likely due to the low number of *A. histeroides* captured overall.

Significant peaks of *Ateuchus histeroides* did not occur in burn (d.f. =5, *F* =0.94, *P* =0.460) or control (d.f. =5, *F* =1.74, *P* =0.140) areas. The greatest number of *A. histeroides* captures appeared in the thin treatment areas (Fig. 5). However, capture peaks did not occur in thin treatment areas at the a=0.05 level of significance (d.f. =5, *F* =2.12, *P* =0.067). After the prescribed burn treatment, insignificant numbers of *A. histeroides* were captured in the thin/burn treatment areas *(d.f. =5, F =0.96, P =0.458)*. The prescribed burn application in thin/burn areas may have negatively affected *A. histeroides* populations.

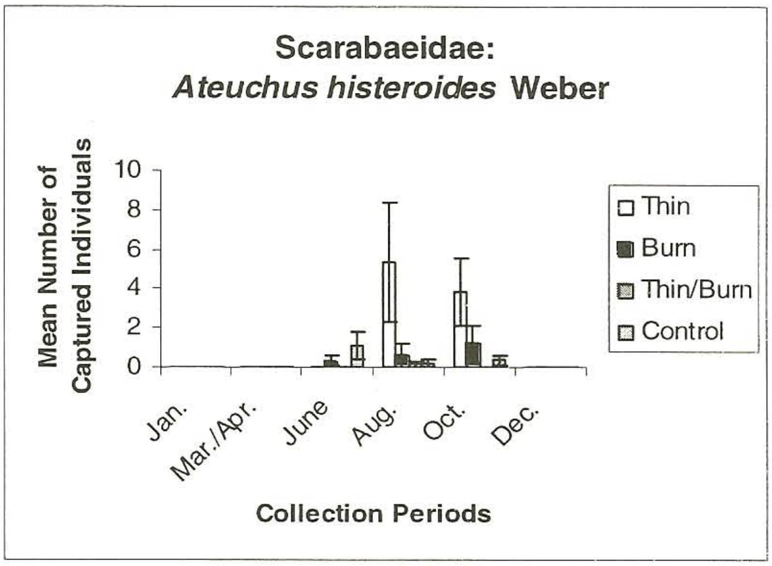


Figure 5. The mean number of *A. histeroides* Weber captures in each treatment per collection period in the Clemson Experimental Forest in 2002.

Ateuchus has been collected in the eastern United States in habitats where cow dung or dead fish are present (Headstrom 1977). The preferred foods of *A. histeroides* were not present in the study areas. Cattle grazing did not occur in the CEF and treatment areas were not located near bodies of water. It is likely that an alternative food source promotes *A. histeroides* populations in the CEF.

Scarabaeidae: *Bolbocerus thoracicornis* (Wallis)

The abundance of *Bolbocerus thoracicornis* did not differ among treatment areas (d.f. =3, *F* =1.23, *P* =0.349). Captures were not effected by time of collection (d.f. =5, *F* =0.01, *P* =1.000) or time/treatment interactions (d.f. =15, *F* =0.02, *P* =1.000). Treatment-type did effect the mean number of captures among collection periods (d.f. =3, *F* =5.15, *P* =0.004). The mean number of *B. thoracicornis* captures did not significantly differ among collection periods in burn (d.f. =5, *F* =1.17, *P* =0.333), thin/burn (d.f. =5, *F* =0.96, *P* =0.458), or control (d.f. =5, *F* =2.30, *P* =0.056) areas at the a=0.05 level of significance. However, the mean number of *B. thoracicornis* captures did differ between collection periods in thin (d.f. =5, *F* =2.63, *P* =0.027) treatment areas.

Bolbocerus thoracicornis captures in thin treatment areas occurred in June and August, while in control areas captures occurred in October and December (Fig.). *B. thoracicornis* may have been more active in summer months in the thin areas, but became more prevalent in the leaf litter of control areas, as temperatures cooled and over wintering sites were desired.

Ciegler (2000) depicted *B. thoracicornis* as a spring and fall active beetle species and noted observations of *B. thoracicornis* burrowing into wet soil near wooded paths after rain storms in South Carolina. My data suggest *B. thoracicornis* activity occurs in the spring, summer, and fall.

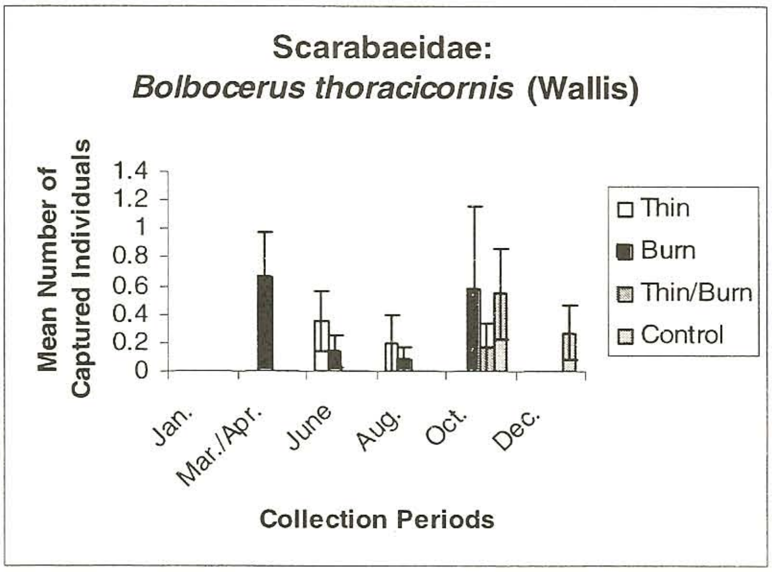


Figure 6. The mean number of B. thoracicornis (Wallis) captures in each treatment per collection period in the Clemson Experimental Forest in 2002.

Erotylidae: *Triplax thoracica* Say

Captures of Tr*iplax thoracica* appeared to occur primarily in the thin treatment and control (Fig. 6); though the abundance of captured *T. thoracica* did not differ significantly among treatment areas (d.f. =3, *F* =0.96, *P* =0.450). There was not a significant treatment (d.f. =3, *F* =1.59, *P* =0.203) or time/treatment interaction effect (d.f. =15, *F* =0.94, *P* =0.527) on *T. thoracica* captures. Although significant peaks of capture occurred in thin treatment (d.f. =5, *F* =2.96, *P* =0.015) and control (d.f. =5, *F* =3.29, *P* =0.011) areas in August and October (Fig. 6). Captures in burn treatment areas (d.f. =5, *F* =2.23, *P* =0.062) were not significant at a=0.05. Capture totals in thin/burn treatment areas were too low for treatment analysis (d.f. =5, *F* =., *P* =.). The low rate of captures in areas that burn treatments suggest that burning deters the establishment of *T. thoracica* populations, unlike thin only and control areas. However, a significant time effect on captures among collection periods was found (d.f. =5, F =3.19, P =0.014).

Triplax thoracica was not captured before August. Captures peaked in October and decreased in December (Fig. 6). Therefore it is likely that *Triplax thoracica* adults are inactive in the CEF prior to August or late summer. Goodrich (1993) found that *T. thoracica* populations increase during the spring and fall months but can be found year round, except in February, in Illinois (Goodrich 1993). If treatment type had been a significant determining factor of *T. thoracica* captures, population samples would have occurred in January, March/April and June collection periods.

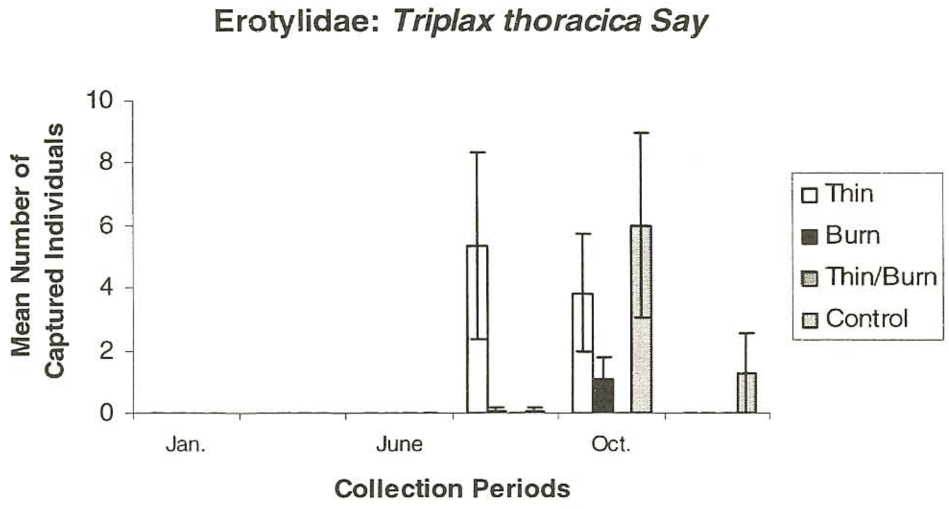


Figure 7. The mean number of *T. thoracica Say* captures in each treatment per collection period in the Clemson Experimental Forest in 2002.

Triplax species feed upon the fleshy portion of the oyster mushroom, *Pleurotus ostreatus* Fries, that develops under tree bark (Dillion and Dillion 1972), by digesting fungal proteins (Martin 1981). *Pleurotus ostreatus* was used by Goodrich (1993) to rear *T. thoracica* larvae. In the CEF the establishment of *P. ostreatus* may be hindered by burning in the burn or thin/burn areas but encouraged in control or mechanically thinned areas. Muona (1994) postulated that alterations of a single habitat feature, caused by a forest management technique, could impact only certain taxa.

Scolytidae

The abundance of Scolytidae was not impacted treatment (d.f. =3, F =0.60, P =0.630) overall. Among collection periods captures were not significantly effected by time (d.f. =5, F =0.90, P =0.488), treatment (d.f. =3, F =0.47, P =0.705), or thin/treatment interactions (d.f. =15, F =1.06, P =0.412). Peaks of capture did occur in burn (d.f. =2, F =2.27, P =0.057) and thin (d.f. =5, F =2.36, P =0.044) treatment areas. In control areas (d.f. =5, F =1.39, P =0.241) or thin/burn treatment areas (d.f. =5, F =0.84, P =0.532) significant capture peaks did not occur.

Captures of Scolytidae in the thin/burn treatment areas of the CEF did not occur until after the prescribed burn had been applied (Fig. 8). Data suggest that Scolytidae were positively, though insignificantly, impacted by the prescribed burn treatment in June (Fig. 8). Scolytidae were not initially attracted to the recently burned thin/burn areas, indicating that the immediate habitat alterations caused by the prescribed burn did not support a scolytid population (Fig. 8). Werner (2002) found scolytids in treated stands in the first year following treatment application. Five years after the thin/burn the scolytid population fell below populations levels in untreated stands.

Stands infested by scolytid beetles were excluded from treatment areas in the initial collection periods. However, the number of stands infested with Scolytidae increased throughout the CEF in 2002. The increased mean number of captures was likely caused by the increased scolytid infestations in stands that bordered the treatment areas.

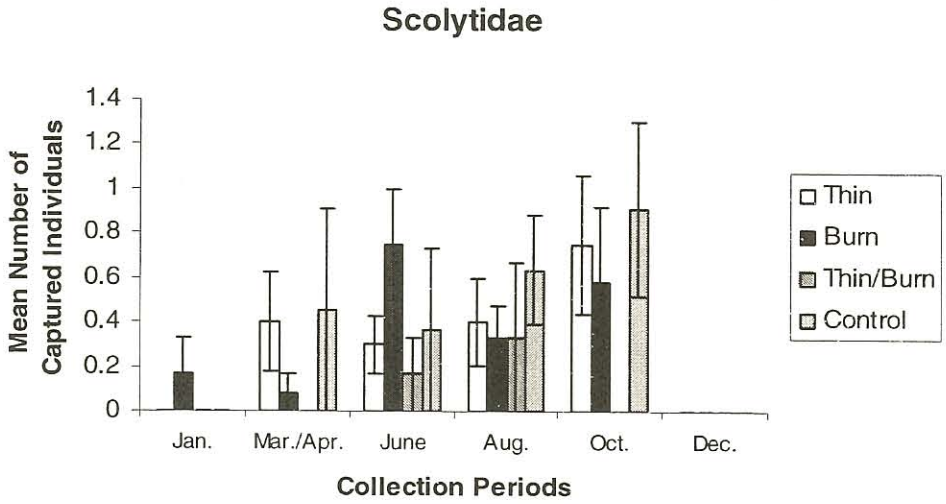


Figure 8. The mean number of Scolytidae captures in each treatment per collection period in the Clemson Experimental Forest in 2002.

Nicolai (1997) described scolytid beetles as "pioneer species", acting as 'keystone recycling' organisms in forested ecosystems that initially decompose tree trunks and essentially enable other taxa to utilize the organic matter of fallen trees. Engraver beetles excavate galleries within the bark and hart wood of healthy or dying trees. Schowalter

(1981) attributes the southern pine beetle, *Dendroctonus frontalis*, with a historical forest regeneration interaction that increases forest productivity and community diversity. Schowalter (1981) believes *D. frontalis* infestations in forested stands forms patches of dead trees that can act as kindling for wildfires. Historically, these patches induced wildfire that causes pine regeneration and the reduction of nutrient loss within the forest ecosystem. Werner (2002) identified the application of thin/burn treatments, following a timber harvest in Alaska, provided an ideal habitat for Scolytidae species. In the first year following the application of thin/burn treatments Werner (2002) found scolytids in treated stands. However, five years after the initial thin/burn application population levels of scolytids within treated stands decreased below populations in untreated areas.

Nitidulidae

The abundance of Nitidulidae beetles was not significantly different overall (d.f. =3, F =1.26, P =0.340). Time/treatment interactions did not affect beetle captures (d.f. =15, F =0.75, P =0.722). The time of trapping did not affect captures (d.f. =5, F =1.25, P =0.303). There was a significant increase in the mean number of nitidulids captured in burn (d.f. =5, F =6.12, P =0.0001), thin (d.f. =3, F =2.97, P =0.015), and control (d.f. =5, F =4.73, P =0.001) areas, although treatment type did not impact captures overall (d.f. =3, F =1.94, P =0.137). The mean number of nitidulid captures in thin, burn, and control treatment areas was low in spring and winter months, but peaked in June and October (Fig. 33).

The mean number of captured Nitidulidae in thin/burn treatment areas did not differ between collection periods (d.f. =5, F =1.61, P =0.187). Nitidulidae did not occur in the thin/burn treatments until after the prescribed burn treatment was applied (Fig. 9). Nitidulidae activity is limited to under the bark of trees and bark disturbance may not have occurred before the prescribed burn was conducted in the thin/burn treatment areas.

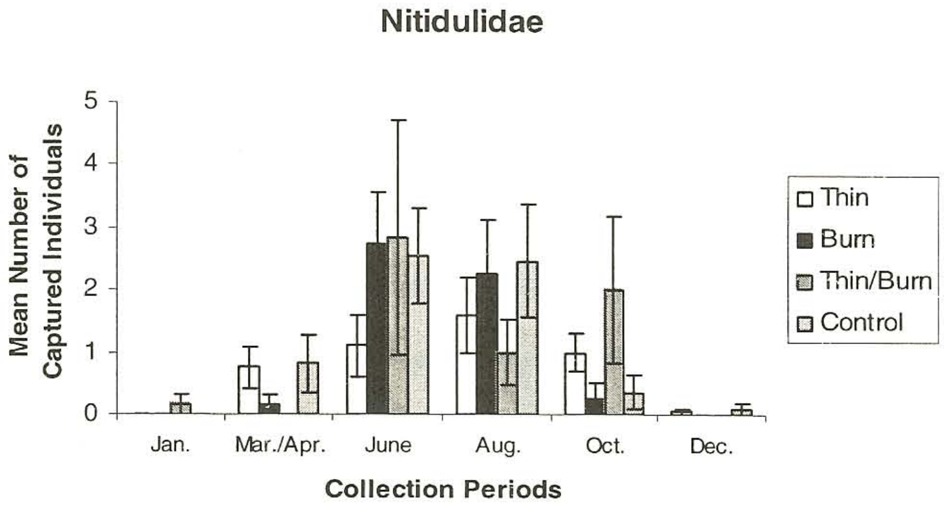


Figure 9. The mean number of Nitidulidae captures in each treatment per collection period in the Clemson Experimental Forest in 2002.

Nitidulids generally feed on fruit juices and sap relinquished from damaged trees. Few species have other feeding preferences for carrion, fungi, pollen and nectar (Headstrom 1977). Nitidulids will copulate in fresh or deteriorating carcasses and certain species are inclined to eat scolytid larvae (Headstrom 1977). In Nicolai ‘s (1997) trophic beetle study, conducted in European /pine stands, Nitidulidae were valuable predators of Scolytidae.

Staphylinidae

Staphylinidae were captured in all collection periods, with captures notably increasing in June, August and December (Fig. 10). The abundance of Staphylinidae was not significantly impacted by treatments overall (d.f. =3, F =3.21, P =0.07). The mean number of captures in thin (d.f. =5, F =1.48, P =0.203) and control (d.f. =5, F =1.20, P =0.319) areas did not differ among collection periods.

The mean number of Staphylinidae captures in thin/burn treatment areas did not differ between collection periods (d.f. =5, F =1.00, P =0.435) because the mean number of captures was low in each collection period. Staphylinid captures were not made prior to the prescribed burn in thin/burn treatment areas. Unlike Muona (1994) and Wikar and Schimmel (2001), I did not find burning to immediately increase the mean number of captured staphylinids. Captures of Scolytidae after the burn treatment did not occur until August (Fig.10).

The mean number of staphylinids captures was significantly different between collection periods in burn treatment areas (d.f. =5, F =7.56, P =0.0001). Captures of staphylinids in burn areas peaked in August and notably decreased in October (Fig. 36). However, the decrease in staphylinid captures in burn areas occurred during the same collection period that capture means decreased in all treatment areas. Therefore captures of Staphylinidae may reflect the activity trends of Nitidulidae in the CEF. Over twenty thousand species of Staphylinidae, are described. Staphylinids are attracted to fermenting tree sap and fungi, decaying vegetation, feces, and animal remains.

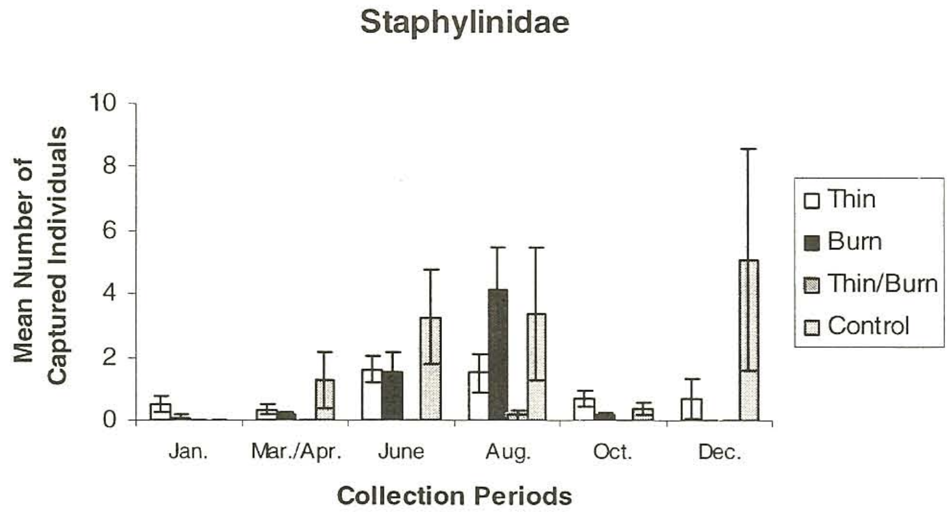


Figure 10. The mean number of Staphylinidae captures in each treatment per collection period in the Clemson Experimental Forest in 2002.

Family and Species Presence and Absence Results

Treatments, time, and time/treatment interactions, were found to not significantly impact the presences or absence of any beetle family or species in a treatment area.

Diversity Analysis

Family Diversity

Family diversity was greatest in thin/burn treatments (H'=0.903) and little variation occurred among thin (H'= 0.891), burn (H'=0.865), and control (H'=0.893) areas. The evenness of beetle families among treatments was also greatest in thin/burn treatment areas (J'=0.326). However, neither family diversity nor evenness differed significantly among treatment areas (Figure 11). The total family diversity measures of coleopterans captured within each treatment type were compared to the total diversity measures of all other treatments using a t-test.

My results are similar to Muona's (1994) findings of environmental alterations contributing to increased diversity, complexity, and structure of the stands in which silviculture treatments occurred. Beetle species captures in thin/burn treatments were significantly different from captures in stands in which thin treatments alone had occurred (Table 1). In Sweden, Ljungberg (2002) found Carabidae fauna to be most diverse in open areas of sparse, short vegetation, maintained by fire, drought, and other factors. Castillo and Wagner (2002) found beetle community diversity to increase as habitat disturbance increased. Therefore, it is likely that prescribed burning, applied with or without mechanical thinning, caused greater habitat disturbance in the CEF than mechanical thinning treatments alone.

Species Diversity

However, there was significant species diversity of coleopterans captured between certain treatment sites (Figure 12). Species diversity was significant between the burn sites and control treatment sites (d.f. =344.956, P = 0.000), burn and thin treatment sites (d.f.=553.730, P = 0.000), and the burn and thin/burn sites (d.f. =249.104, P = 0.003). Species diversity significantly differed between the thin/burn and thin treatment sites (d.f.=341.370, P = 0.004). The species diversity of captured coleopterans in the control treatment sites did not significantly differ from species diversity in the thin treatment sites (d.f.=459.854, P = 0.413) or the thin/burn treatment sites (d.f. =317.094, P =0.062).

Treatment One vs. Treatment Two	H Prime Treatment One vs. Treatment Two	Degrees of Freedom	Test Statistic	p-value a ≤ 0.05
Burn vs. Control	0.865 vs. 0.893	802.47	-1.041	0.298
Burn vs. Thin	0.865 vs. 0.891	735.47	-1.047	0.295
Burn vs. Thin/burn	0.865 vs. 0.903	526.66	-1.143	0.254
Control vs. Thin	0.893 vs. 0.891	1041.98	0.086	0.931
Control vs. Thin/burn	0.893 vs. 0.903	488.56	-0.304	0.761
Thin vs. Thin/burn	0.891 vs. 0.903	417.42	-0.388	0.698

Figure 11. ANOVA summary of the effects of forest management treatment and control areas on the diversity of beetle families captured in pitfall traps in the CEF in 2002.

Treatment One vs. Treatment Two	H Prime Treatment One vs. Treatment Two	Degrees of Freedom	Test Statistic	p-value a ≤ 0.05
Burn vs. Control	1.276 vs. 1.020	344.96	5.045	0.000
Burn vs. Thin	1.276 vs. 0.976	553.73	6.620	0.000
Burn vs. Thin/burn	1.276 vs. 1.128	249.10	3.053	0.003
Control vs. Thin	1.020 vs. 0.976	459.85	0.820	0.413
Control vs. Thin/burn	1.020 vs. 1.128	317.03	-1.873	0.062
Thin vs. Thin/burn	0.891 vs. 1.128	341.37	-2.887	0.004

Figure 12. ANOVA summary of the effects of forest management treatment and control areas on the diversity of beetle species captured in pitfall traps in the CEF in 2002.

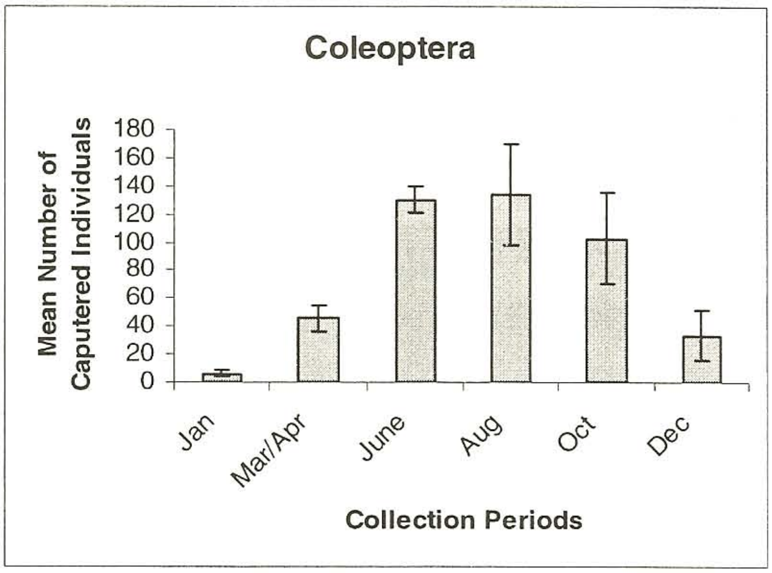


Figure 13. The mean number of coleopteran captures in the Clemson Experimental Forest in 2002.

Comparisons of Total Coleoptera Captured

The treatments had no impact on the mean number of captured Coleoptera in the CEF (d.f. =3, F =1.40, P =0.210), though data show greater numbers of capture in thin treatment areas (Fig). The time of capture significantly impacted the mean number of coleopterans captured (d.f. =5, F =12.83, P =<0.0001). Captures were low in cooler months, and increased in June, peaking in August (Fig. 13). A time/treatment interaction was found (d.f. = 15, F =1.03, P =0.426).

Thin treatment areas consistently harbored greater numbers of coleopterans (Fig. 14). Butterfield (1997) found the plant community and leaf litter layers are reduced by prescribed burning and prescribed burning alters soil chemistry in burned, not thinned treatment areas (Robichaud 2000). The removal of leaf litter and soil alterations likely promoted negative habitat changes for ground active coleopterans. The lower number of captures in burn treatment areas compared to thinned areas demonstrates a biological trend of increased ground active coleopteran populations in thinned habitats.

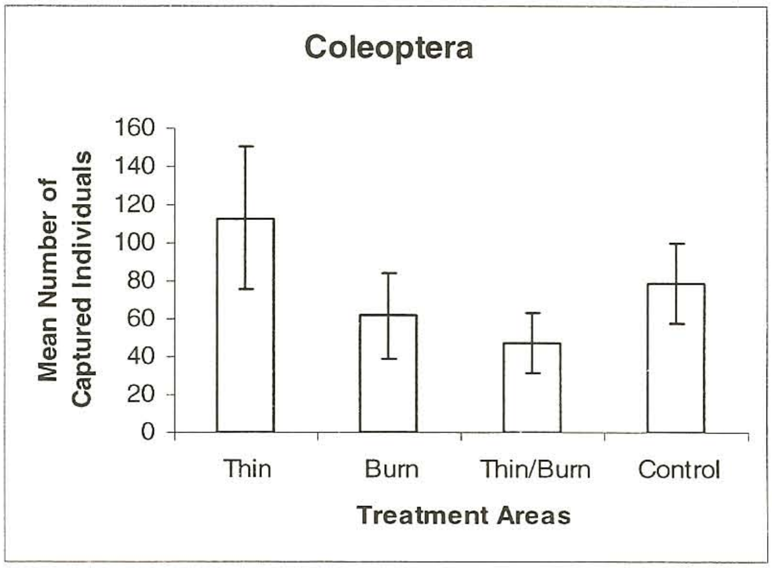


Figure 14. The mean number of coleopteran captures in treatment areas in the Clemson Experimental Forest in 2002.

<u>Comparisons of Beetle Genus Captures</u>

Carabidae: *Cyclotrachelus*

The overall abundance of Cyclotrachelus was not significantly impacted by treatments (d.f. =3, *F* =0.65, *P* =0.602). Captures among collection periods were not significantly impacted by treatments (d.f.=3, *F* =2.45, *P* =0.075) (Fig. 16). Time/treatment interactions (d.f.=15, *F* =2.55, *P* =0.007) and time of trapping (d.f.=5, *F* =6.99, *P* =<0.0001) significantly impacted beetle captures (Fig. 15).

Scarabaeidae: *Bolbocerus*

Treatment type did not impact the abundance of *Bolbocerus* overall (d.f. =3, *F* =1.5, *P* =0.375). There was no time/treatment interaction (d.f.= 15, *F* =0.63, *P* =0.839), or treatments (d.f.= 3, *F* =1.77, *P* =0.165) effect that impacted genera captures among collection periods. Data of the mean number of *Bolbocerus* genera illustrate the insignificant differences of capture means in treatment areas (Fig. 18). However, captures of *Bolbocerus* in the CEF were significantly affected (d.f.= 5, *F* =7.61, *P* =<0.0001) by time of collection (Fig. 17).

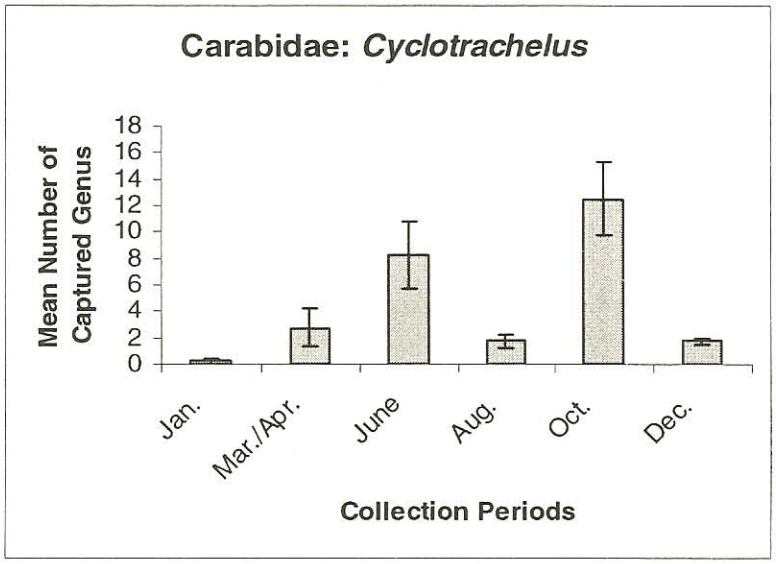


Figure 15. The mean number of *Cyclotrachelus* captures in the Clemson Experimental Forest in 2002.

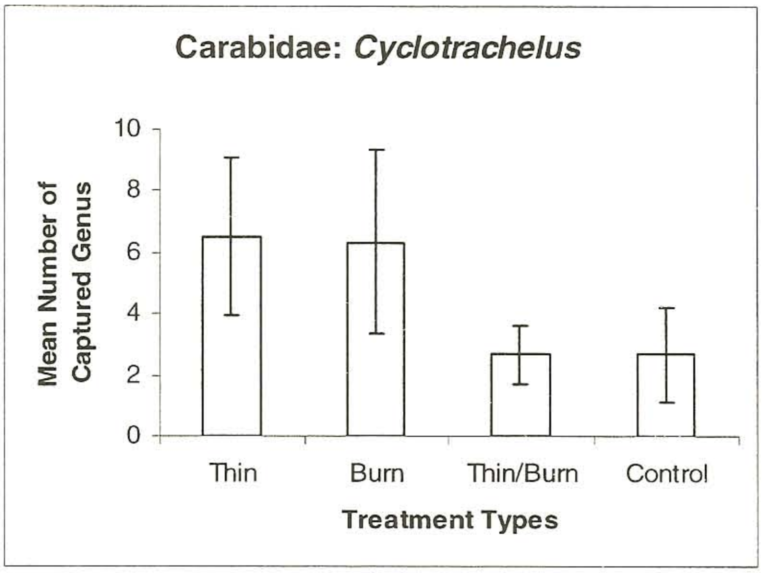


Figure 16. The mean number of *Cyclotrachelus* captures in treatment areas in the Clemson Experimental Forest in 2002.

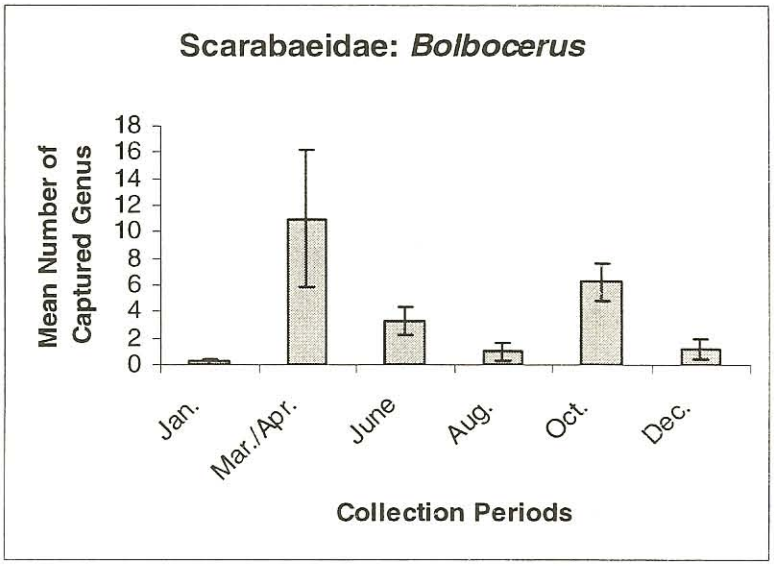


Figure 17. The mean number of *Bolbocerus* captures in the Clemson Experimental Forest in 2002.

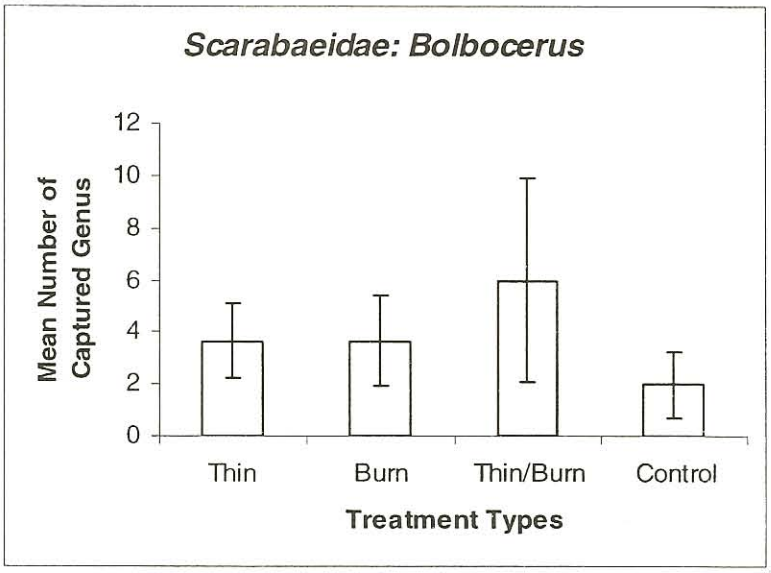


Figure 18. The mean number of *Bolbocerus* captures in treatment areas in the Clemson Experimental Forest in 2002.

CHAPTER V

CONCLUSIONS

In this study, prescribed burning, mechanical thinning, prescribed burning and thinning combined and untreated areas were found to have little impact on beetle communities in the CEF. The average Carabidae captures per pitfall trap in the CEF was much lower than Holliday's (1991), average trap catches in Manitoba, Canada. The low mean number of beetle captures are likely due to a number of factors. Beginning in June, 1998, levels of precipitation were less than normal in the South Carolina piedmont (Kiuchi 2002). Drought conditions occurred throughout the state for at least three years before the first collection period. The lack of precipitation in the piedmont reduced moisture conditions on the forest floor and stressed or reduced beetle communities.

Secondly, it is possible that the historic use of the CEF has decreased forest resources needed to support large populations of large beetle populations. The CEF is second-third growth stands that were reforested on abandoned farmland after the Great Depression. The land of the CEF was originally terraced for crop production and pesticide applications. Residual pesticide levels and steep landscapes are still common within stands of the CEF. These anthropogenic impacts may cause overall reductions of beetle populations.

Finally, low beetle captures may have resulted from the sampling scheme used in this study. Twenty pitfall traps sampled beetle populations in each 10 ha treatment area for 48 hours on alternating months. This study may be improved by increasing both number of pitfall traps and the number of collection periods.

The impacts of forest management practices in the CEF were unique to the identification levels of captured specimens. The family Scarabaeidae was impacted by treatments (d.f. = 3, *F* =4.04, *P* =0.01) and thinned areas significantly affected captures. Significant impacts on *Bolbocerus*, were significantly impacted only by time of collection (d.f. =5, *F* =7.61, *P* =<0.0001). The species *Bolbocerus thoracicornis*, was effected by treatments (d.f. = 3, *F* =5.15, *P* =0.004).

Scarabaeidae beetles were effected by thin (d.f. =5, *F* =2.42, *P* = 0.04) treatment areas, while *Bolboccerus* was impacted by thin/burn treatments, and *B. thoracicornis* captures were impacted by thin (d.f. =5, *F* =2.63, *P* =0.01).

Carabid beetle captures were impacted by treatment type (d.f. =3, *F* =44.14, *P* =0.0001). *Cyclotrachelus* members were significantly effected by time (d.f. =5. *F* =6.99, *P* =0.0<0.0001) and time/treatment interactions (d.f. =15, *F* =2.55, *P* =0.007). However, *C. spoliatus* was effected by time (d.f. =5, *F* =3.00, *P* =0.020). This data suggests that time of collection period, treatments, and time-treatment interactions are unique to the level that a beetle is identified.

APPENDIX

Appendix A

Table A- I

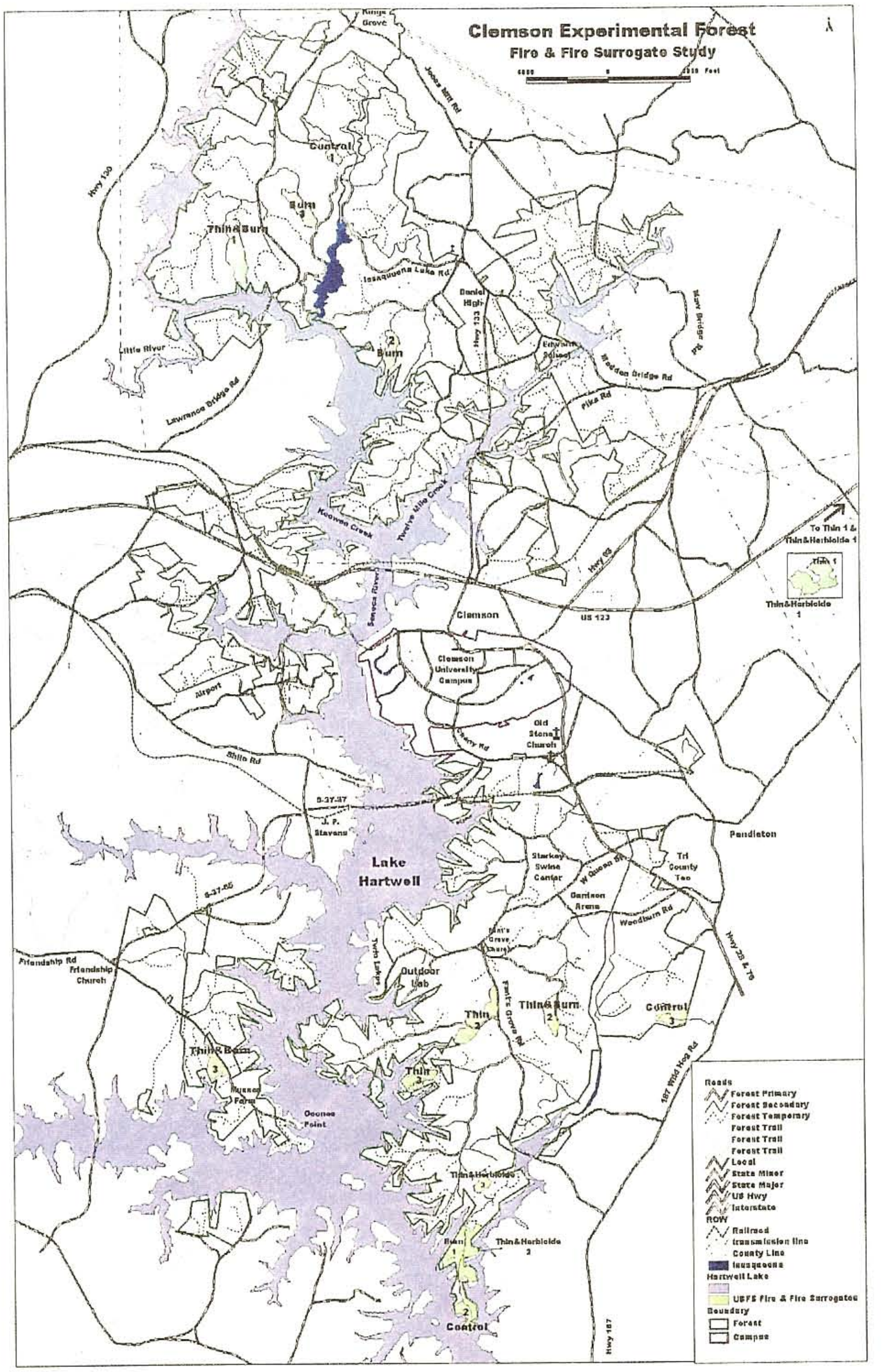
Dates of Prescribed Burn and Mechanical Thinning Applications in the Clemson Experimental Forest

Burn 1: 10 April 2001
Burn 2: 12 April 2001
Burn 3: 11 April 2001
Thin 1: 8 March – 4 April 2001
Thin 2: 18 December 2000– 18 January 2001
Thin 3: 5 – 21 February 2001
Thin/burn 1: Thinned 3 – 18 January 2001, Burned early March
Thin/burn 1: Thinned 25-31 January 2001, Burned 25 March 2002
Thin/burn 1: Thinned 26 February – 7 March 2001, Burned April 20

APPENDICES

Figure B-I

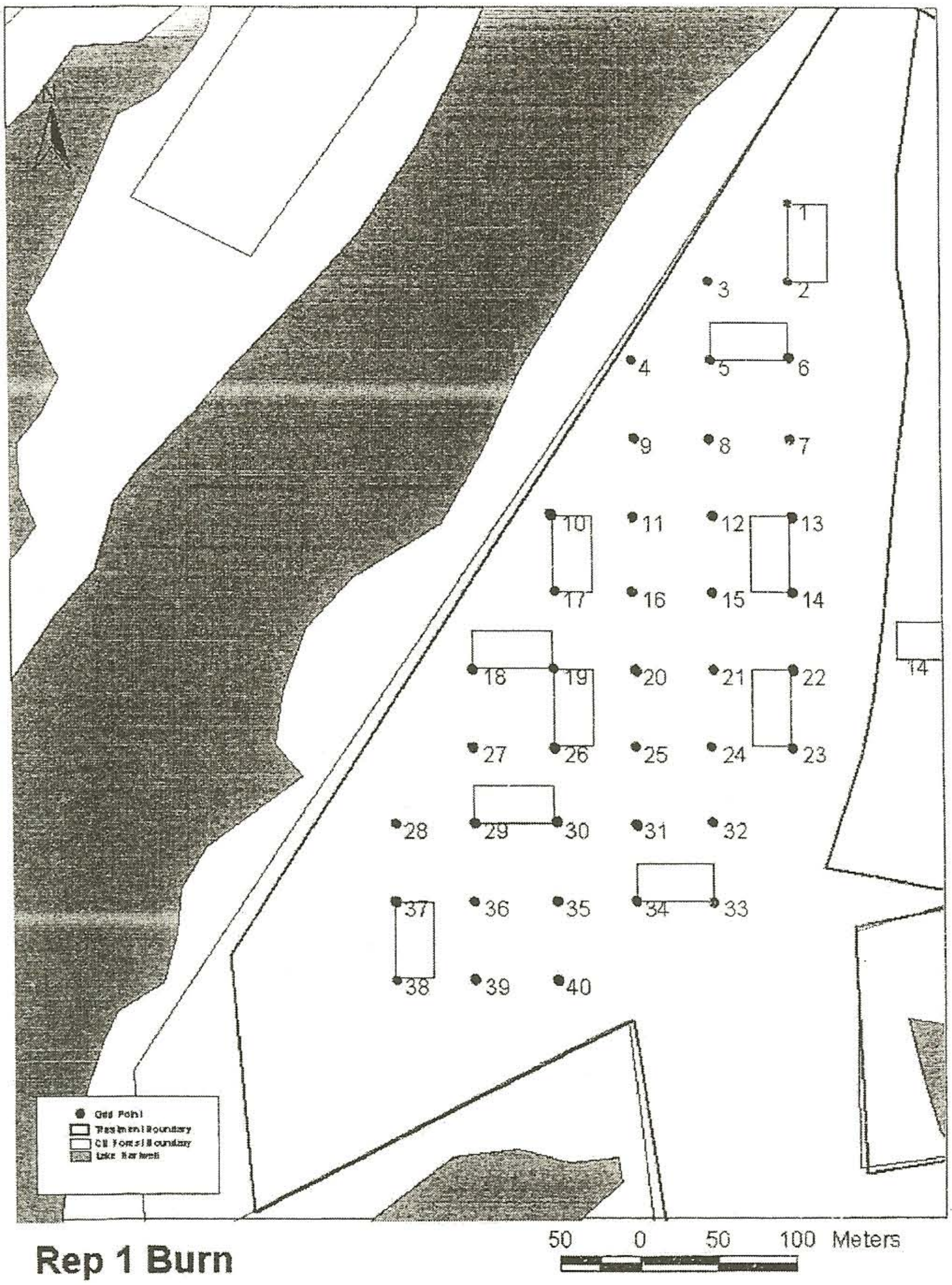
Map of the treatment areas in the Clemson Experiemental Forest in 2002.



Appendix B

Figure B-II

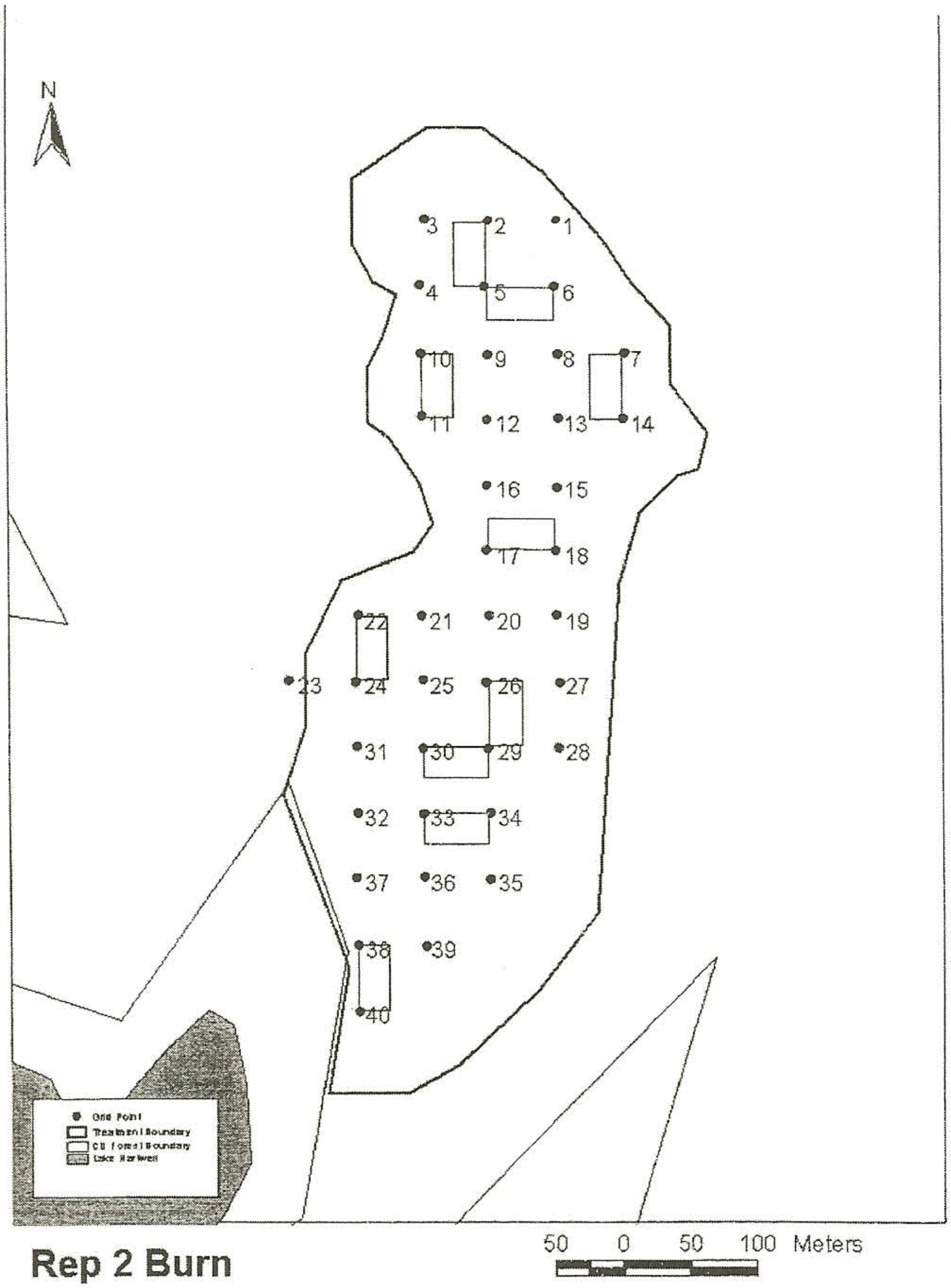
Map of the Treatment Area Burn One in the CEF



Appendix B

Figure B-III

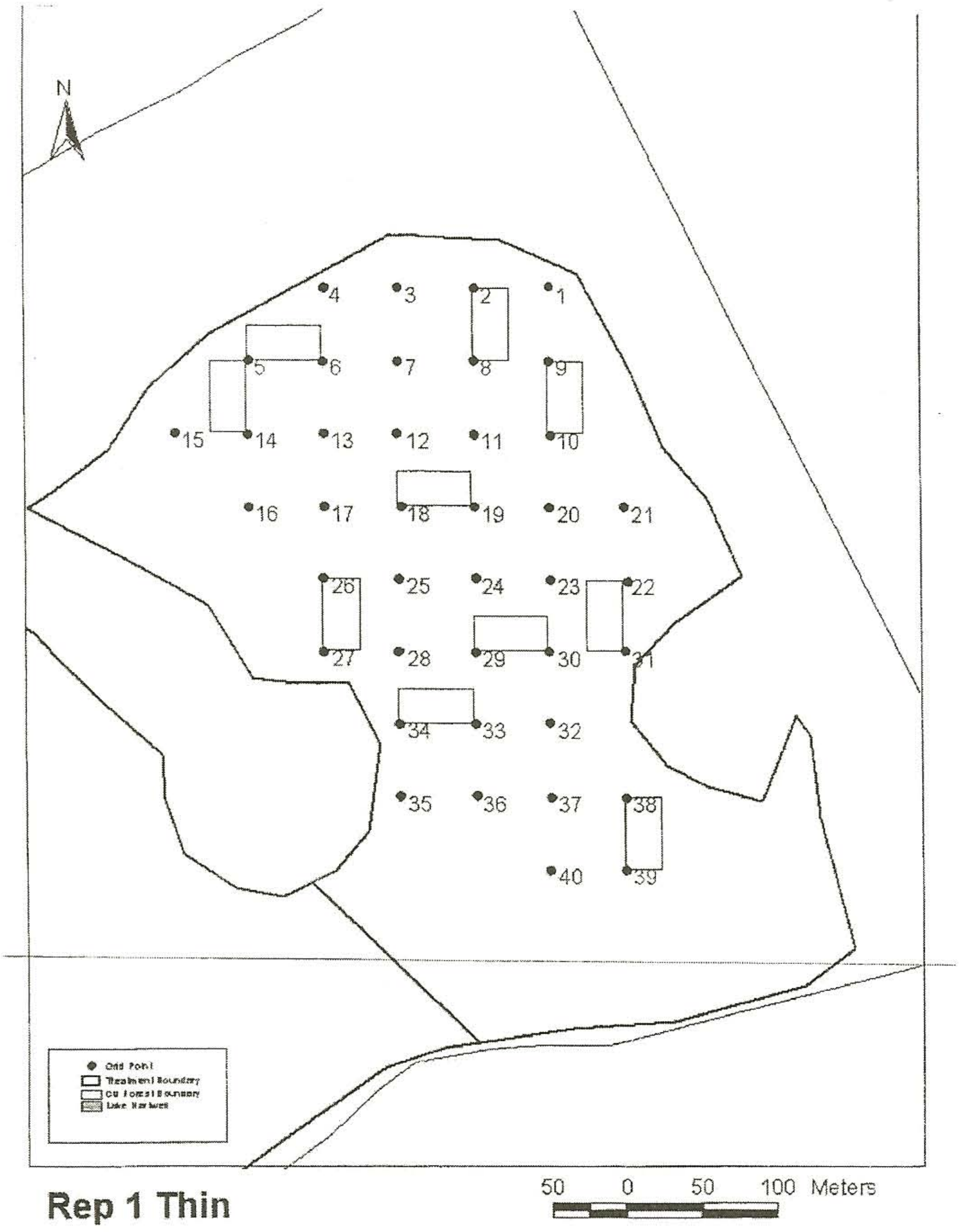
Map of the Treatment Area Burn Two in the CEF



Appendix B

Figure B-IV

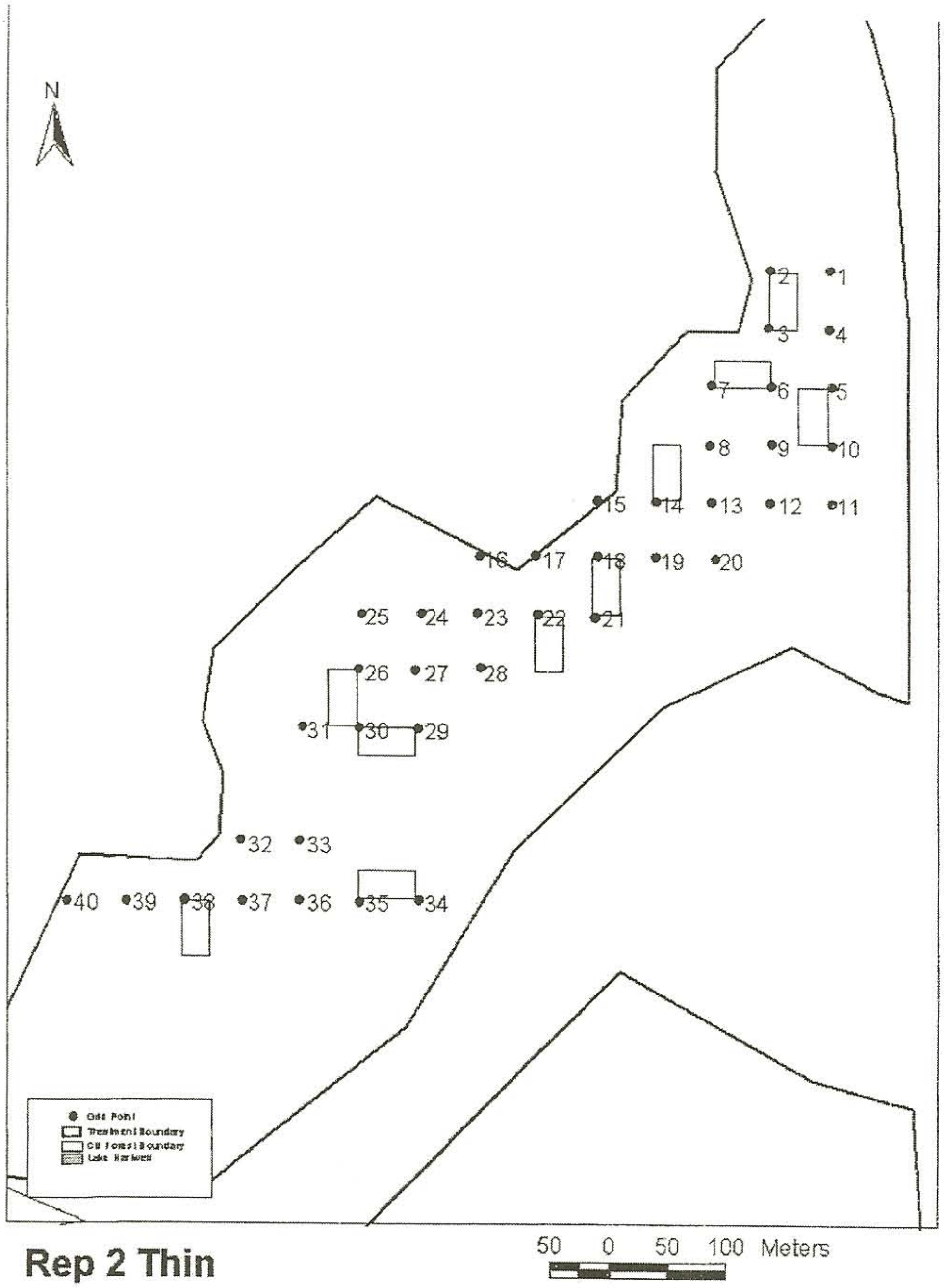
Map of the Treatment Area Thin One in the CEF



Appendix B

Figure B-V

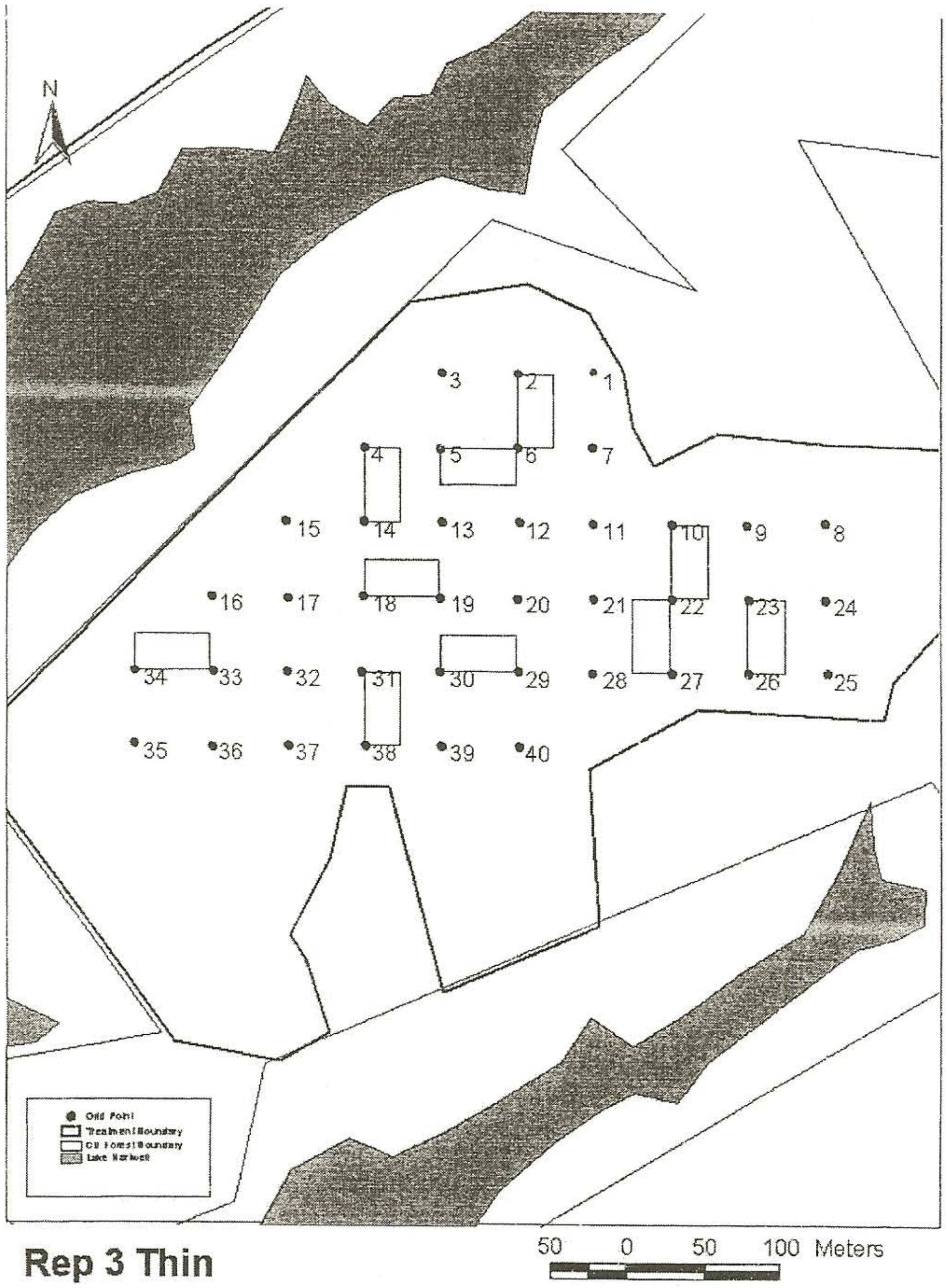
Map of the Treatment Area Thin Two in the CEF



Appendix B

Figure B-VI

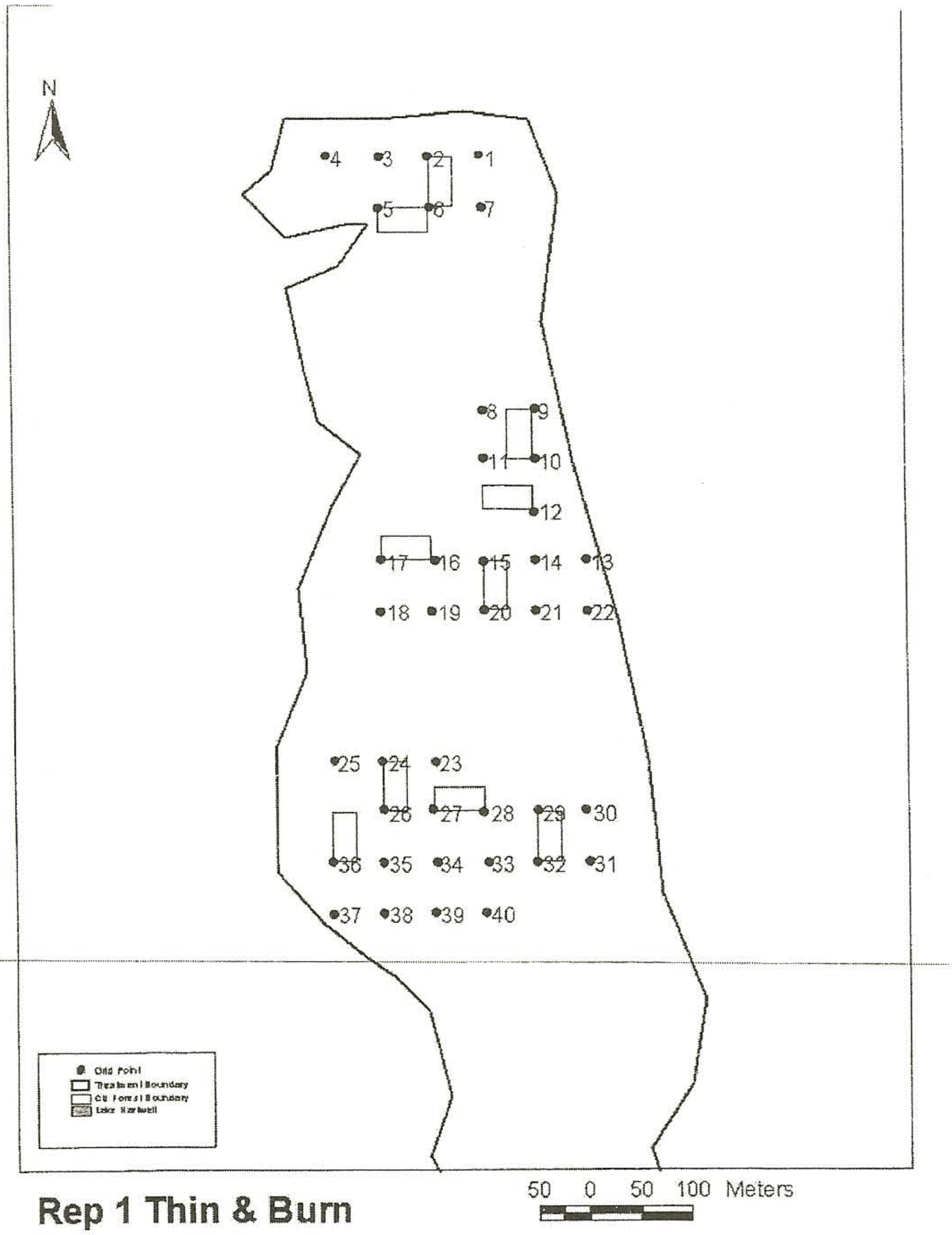
Map of the Treatment Area Thin Three in the CEF



Appendix B

Figure B-VII

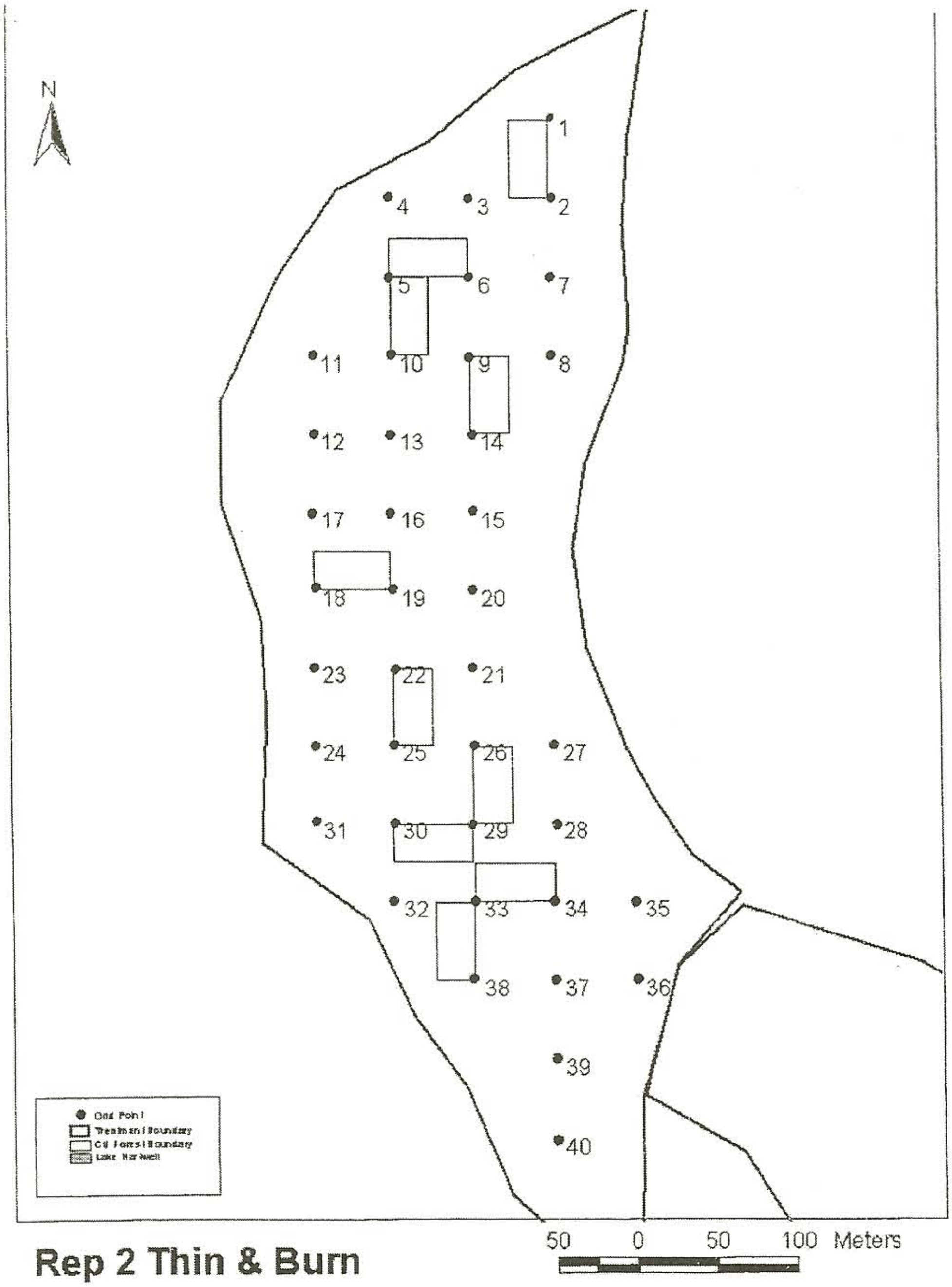
Map of the Treatment Area Thin/Burn One in the CEF



Appendix B

Figure B-VIII

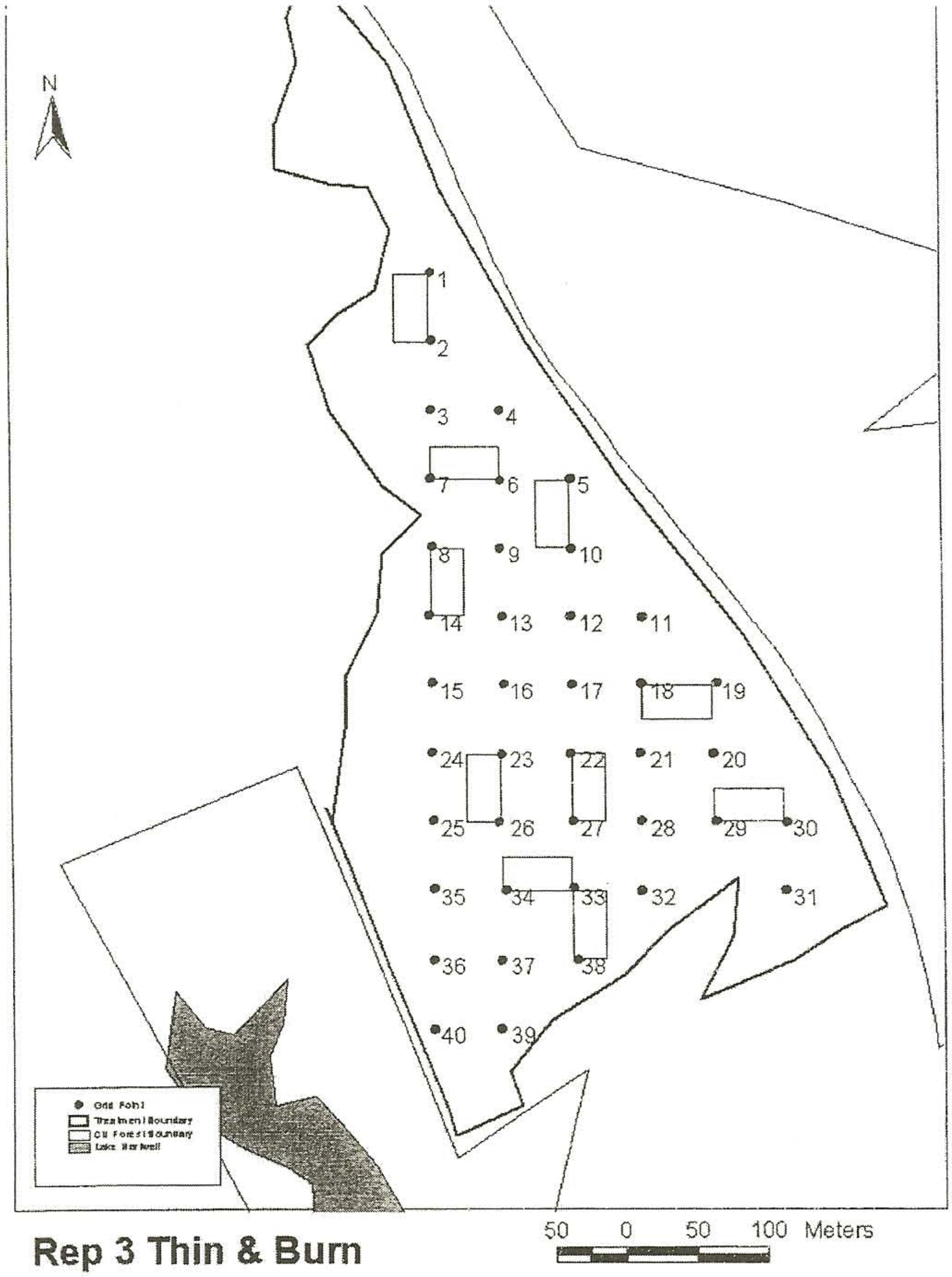
Map of the Treatment Area Thin/Burn Two in the CEF



Appendix B

Figure B-IX

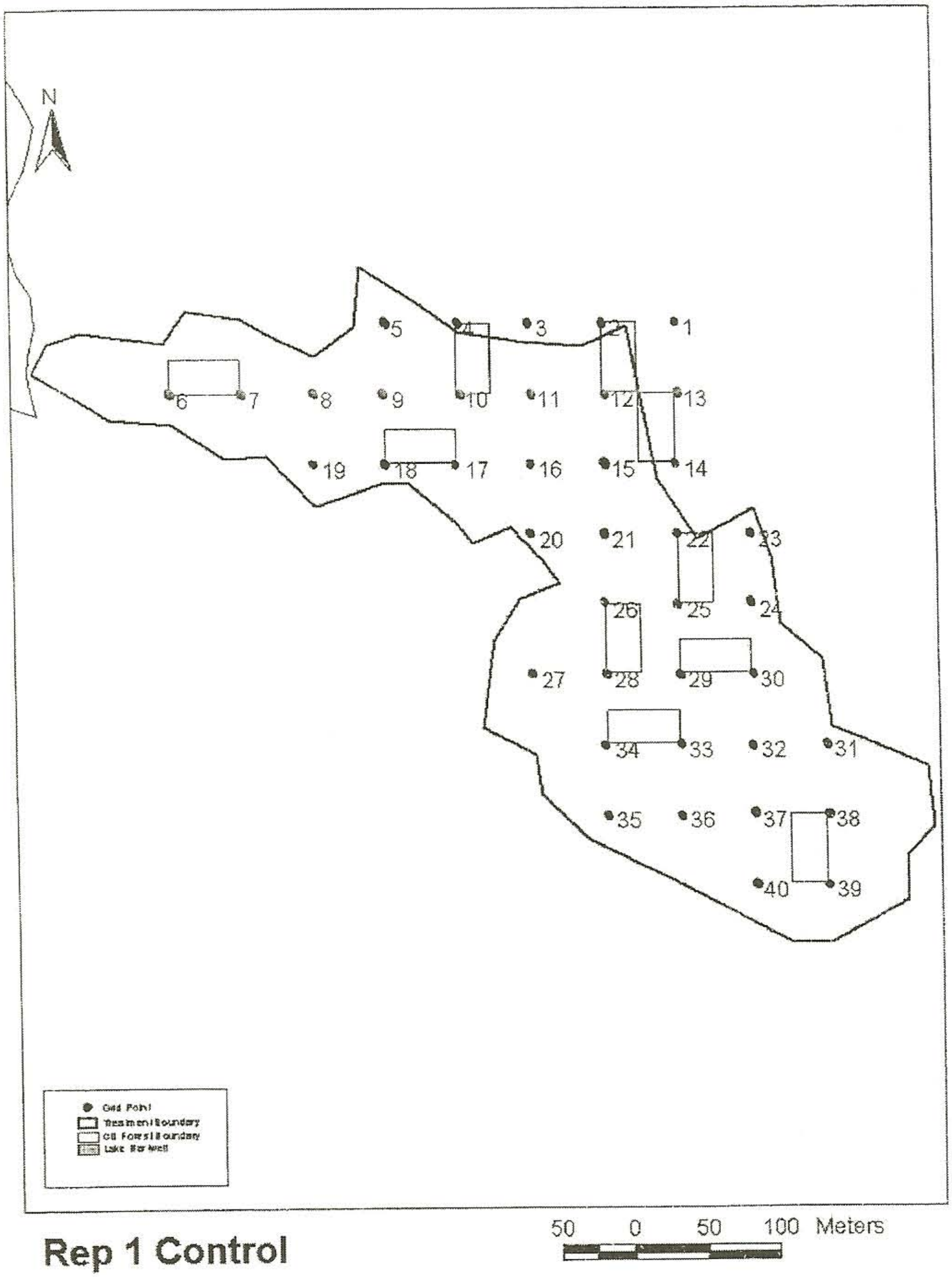
Map of the Treatment Area Thin/Burn Three in the CEF



Appendix B

Figure B-X

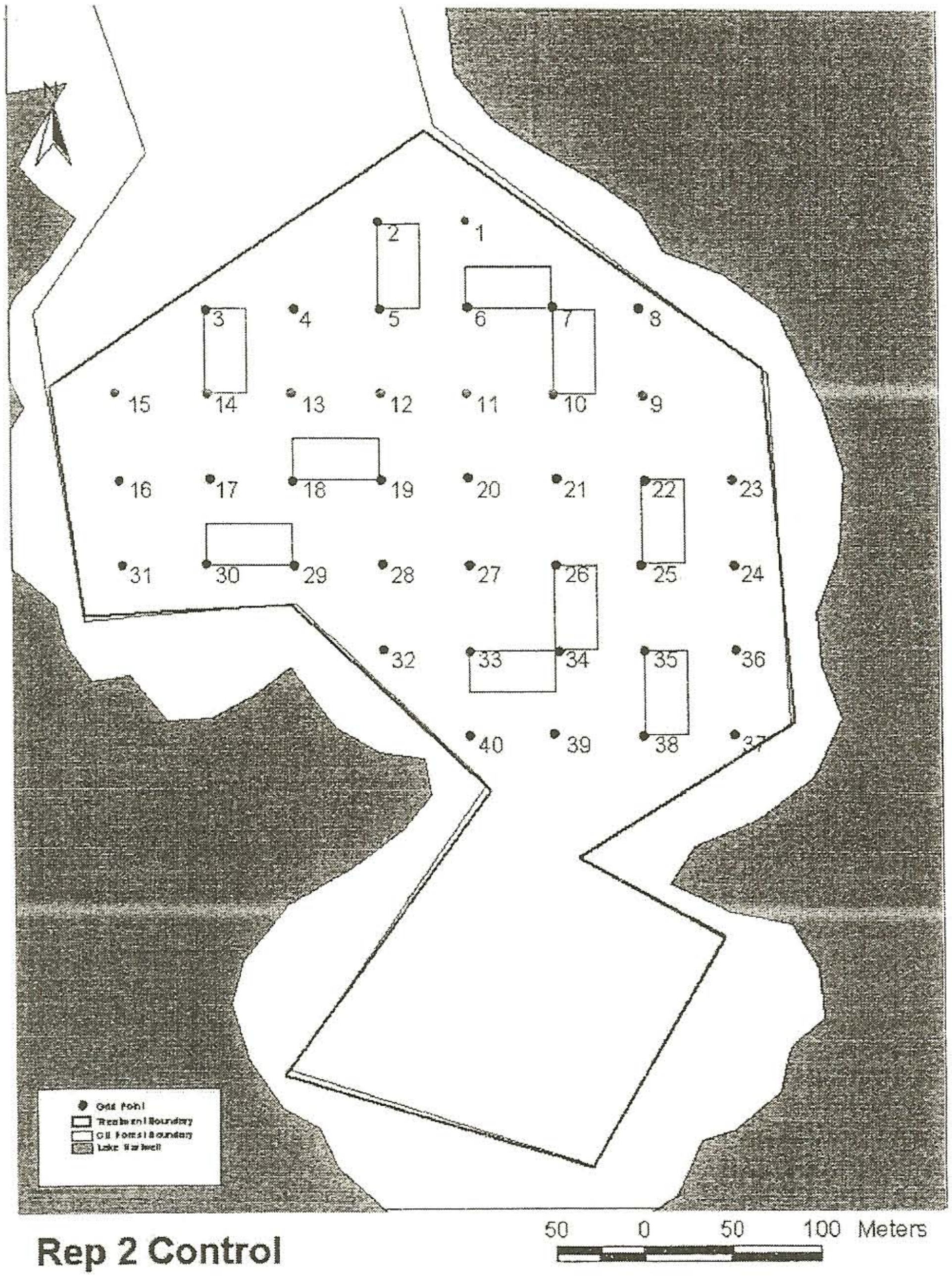
Map of the Treatment Area Control One in the CEF



Appendix B

Figure B-XI

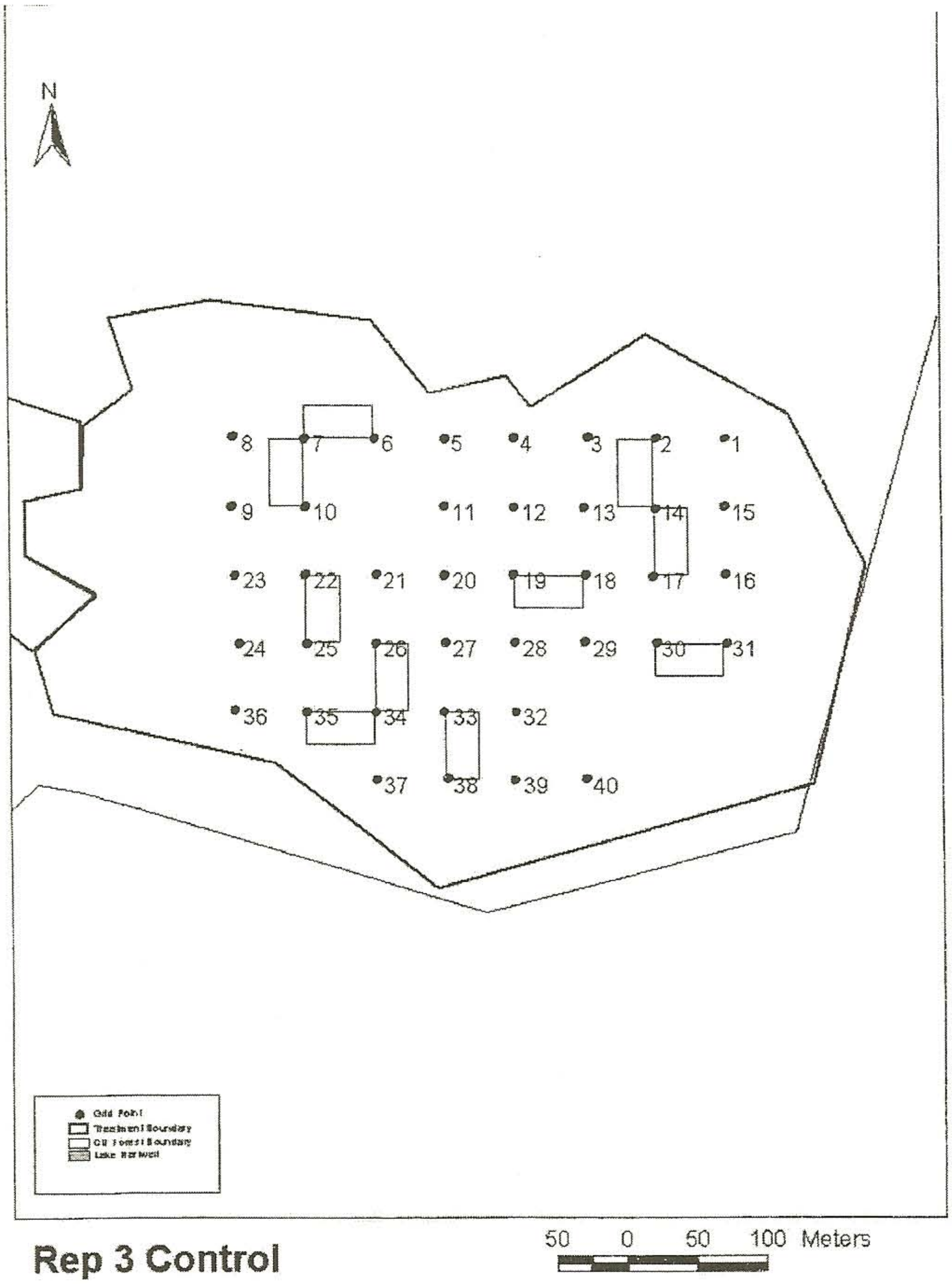
Map of the Treatment Area Control Two in the CEF



Appendix B

Figure B-XII

Map of the Treatment Area Control Three in the CEF



Appendix B

Figure B-XIII

Coordinates of Grid Points Marking Collection Plots in Treatment Areas

Treatment Area	Grid Point	Latitude	Longitude
Burn One	2	34 34 57.56603	-82 50 02.12413
Burn One	10	34 34 52.61030	-82 50 07.90202
Burn One	14	34 34 51.07638	-82 50 01.98154
Burn One	34	34 34 44.52773	-82 50 05.76208
Burn Two	2	34 43 55.01550	-82 50 58.57213
Burn Two	6	34 43 53.42297	-82 50 56.57082
Burn Two	14	34 43 50.20810	-82 50 54.53344
Burn Two	30	34 43 42.00676	-82 51 00.24797
Burn Three	2	34 45 13.73490	-82 52 08.85900
Burn Three	6	34 45 12.17290	-82 52 04.89115
Burn Three	10	34 45 10.52039	-82 52 06.82025
Burn Three	14	34 45 08.95835	-82 52 02.85247
Thin One	14	34 42 33.35339	-82 44 54.12480
Thin One	26	34 42 30.13664	-82 44 52.09181
Thin One	34	34 42 26.91990	-82 44 50.05885
Thin One	38	34 42 25.38194	-82 44 44.13073
Thin Two	6	34 37 14.63912	-82 49 41.41675
Thin Two	22	34 37 08.03172	-82 49 49.12439
Thin Two	30	34 37 04.69848	-82 49 54.94058
Thin Two	38	34 36 59.74279	-82 50 00.72096
Thin Three	10	34 36 34.10183	-82 50 28.70333
Thin Three	14	34 36 33.98324	-82 50 36.55241
Thin Three	34	34 36 30.64943	-82 50 42.36738
Thin Three	38	34 36 29.11604	-82 50 36.44477
Thin Four	2	34 35 01.10080	-82 49 57.67604
Thin Four	10	34 34 56.41964	-82 49 53.54083
Thin Four	14	34 34 49.71439	-82 49 59.38824
Thin Four	18	34 34 48.15091	-82 49 55.42946
Thin Five	2	34 35 35.12893	-82 49 47.31834
Thin Five	6	34 35 31.88411	-82 49 47.24717
Thin Five	10	34 35 30.32052	-82 49 43.28785
Thin Five	14	34 35 28.58039	-82 49 51.09971

Appendix B

Figure B-XIV

Coordinates of Grid Points Marking Collection Plots in Treatment Areas

Treatment Area	Grid Point	Latitude	Longitude
Thin/Burn 1	6	34 44 59.04661	-82 52 53.18836
Thin/Burn 1	9	34 44 52.61802	-82 52 49.11017
Thin/Burn 1	24	34 44 41.17063	-82 52 54.74899
Thin/Burn 1	32	34 44 38.01707	-82 52 48.77918
Thin/Burn 2	2	34 37 18.41624	-82 48 56.54880
Thin/Burn 2	14	34 37 13.51974	-82 48 58.40532
Thin/Burn 2	22	34 37 08.62324	-82 49 00.26177
Thin/Burn 2	30	34 37 05.37841	-82 49 00.19106
Thin/Burn 3	6	34 36 42.04660	-82 53 01.90464
Thin/Burn 3	10	34 36 40.45453	-82 52 59.90570
Thin/Burn 3	18	34 36 37.24009	-82 52 57.87019
Thin/Burn 3	38	34 36 30.72035	-82 52 59.68582
Control 1	6	34 45 48.10903	-82 51 55.92305
Control 1	10	34 45 48.22949	-82 51 48.05953
Control 1	18	34 45 46.57705	-82 51 49.98895
Control 2	2	34 34 18.65748	-82 49 59.30735
Control 2	14	34 34 15.35369	-82 50 03.15884
Control 2	22	34 34 13.87855	-82 49 53.31641
Control 2	26	34 34 12.22669	-82 49 55.24216
Control 3	10	34 37 11.92390	-82 47 35.30116
Control 3	14	34 37 12.06808	-82 47 25.48831
Control 3	26	34 37 08.70787	-82 47 33.26881
Control 3	30	34 37 08.82318	-82 47 25.41862

APPENDICES

Appendix C

Figure C-I

Treatment Area and Collection Periods for All Captured Individuals

Carabidae	Treatment Area	Jan.	Mar./Apr.	June	Aug.	Oct.	Dec.
C. sigillatus	Thin	*	1	3	*	6	2
	Burn	*	*	3	*	7	1
	Thin/Burn	*	1	*	*	4	1
	Control	*	*	*	*	6	2
C. spoliatus	Thin	*	5	9	3	6	*
	Burn	1	4	9	1	8	*
	Thin/Burn	*	*	4	2	2	*
	Control	*	*	3	1	2	*
H. pensylvanicus	Thin	*	*	*	1	3	*
	Burn	*	*	2	*	*	*
	Thin/Burn	*	*	2	*	7	*
	Control	*	*	4	*	7	*
C. sylvosus	Thin	*	*	4	*	*	*
	Burn	*	*	3	*	*	*
	Thin/Burn	*	*	*	*	*	*
	Control	*	*	*	*	*	*
G. bicolor	Thin	*	*	*	1	*	*
	Burn	*	*	*	*	*	*
	Thin/Burn	*	*	*	*	*	*
	Control	*	*	*	*	*	*
U. unipunctata	Thin	*	*	1	*	*	*
	Burn	*	*	1	1	*	*
	Thin/Burn	*	*	*	*	*	*
	Control	*	*	*	*	*	*
H. herbivagus	Thin	*	*	*	*	*	*
	Burn	*	*	1	1	1	*
	Thin/Burn	*	*	*	*	4	*
	Control	*	*	*	*	*	*
N. novemstriatus	Thin	*	*	*	*	1	*
	Burn	*	1	*	*	*	*
	Thin/Burn	2	*	*	*	1	*
	Control	*	*	*	*	1	*
C. unicolor	Thin	*	*	*	*	*	*
	Burn	*	*	1	*	*	*
	Thin/Burn	*	*	*	*	*	*
	Control	*	*	*	*	*	*

Appendix C

Figure C-III

Treatment Area and Collection Periods for All Captured Individuals

Carabidae	Treatment Area	Jan.	Mar./Apr.	June	Aug.	Oct.	Dec.
S. opalinus	Thin	*	*	*	*	*	*
	Burn	*	*	2	*	*	*
	Thin/Burn	*	*	*	*	*	*
	Control	*	*	*	*	*	*
N. sayi	Thin	*	*	*	*	*	*
	Burn	*	*	*	*	7	*
	Thin/Burn	*	*	1	*	1	*
	Control	*	*	*	*	*	*
C. brevoorti	Thin	*	*	*	*	2	*
	Burn	*	*	*	*	*	*
	Thin/Burn	*	*	*	*	*	*
	Control	*	*	*	*	*	*
H. faunus	Thin	*	*	*	*	1	*
	Burn	*	*	*	*	*	*
	Thin/Burn	*	*	*	*	*	*
	Control	*	*	*	*	*	*
P. acutipes	Thin	*	*	*	1	*	*
	Burn	*	*	*	*	*	*
	Thin/Burn	*	*	*	*	*	*
	Control	*	*	*	*	*	*
C. emarginatus	Thin	2	3	*	*	*	*
	Burn	2	*	*	1	3	*
	Thin/Burn	*	*	*	1	*	*
	Control	*	1	1	3	2	*

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Figure C-IV

Treatment Area and Collection Periods for All Captured Individuals

Scarabaeidae	Treatment Area	Jan.	Mar./Apr.	June	Aug.	Oct.	Dec.
G. blackburnii	Thin	*	*	*	*	*	*
	Burn	*	*	*	2	*	*
	Thin/Burn	*	*	1	1	*	*
	Control	*	*	*	2	*	*
A. hsteroides	Thin	*	1	*	2	7	*
	Burn	*	*	4	7	14	*
	Thin/Burn	*	*	11	1	1	*
	Control	*	*	12	2	4	*
C. nitida	Thin	*	*	*	*	*	*
	Burn	*	*	*	*	*	*
	Thin/Burn	*	*	*	*	*	*
	Control	*	*	*	2	*	*
B. liebecki	Thin	1	2	1	*	2	*
	Burn	*	2	1	*	1	*
	Thin/Burn	*	4	3	3	*	*
	Control	*	*	1	*	2	*
O. orpheus orpheus	Thin	*	*	*	*	*	2
	Burn	*	*	*	*	*	6
	Thin/Burn	*	*	*	*	*	*
	Control	*	*	*	*	*	*
C. viridis	Thin	*	*	*	*	*	*
	Burn	*	*	*	2	*	*
	Thin/Burn	*	*	1	*	*	*
	Control	*	*	*	*	*	*
O. hectate hectate	Thin	*	*	*	3	*	*
	Burn	*	*	*	*	*	*
	Thin/Burn	*	*	1	*	*	*
	Control	*	*	*	1	*	*
O. subaeneus	Thin	*	*	*	2	*	*
	Burn	*	*	1	1	*	*
	Thin/Burn	*	*	2	*	*	*
	Control	*	*	*	*	*	*
O. gazella	Thin	*	*	7	4	*	*
	Burn	*	*	1	2	*	*
	Thin/Burn	*	*	1	6	*	*
	Control	*	*	3	6	*	*
O. taurus	Thin	*	*	7	1	*	*
	Burn	*	*	1	2	*	*
	Thin/Burn	*	*	1	6	*	*
	Control	*	*	3	7	*	*

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Figure C-V

Treatment Area and Collection Periods for All Captured Individuals

Scarabaeidae	Treatment Area	Jan.	Mar./Apr.	June	Aug.	Oct.	Dec.
T. foveicollis	Thin	*	3	*	*	*	*
	Burn	*	*	*	*	*	*
	Thin/Burn	*	*	*	*	*	*
	Control	*	*	1	*	*	*
B. thoracicornis	Thin	*	7	2	*	5	*
	Burn	*	8	2	1	7	*
	Thin/Burn	*	21	3	*	2	*
	Control	*	*	*	*	6	*
G. egerai	Thin	*	*	*	*	*	3
	Burn	*	*	*	*	*	8
	Thin/Burn	*	*	*	*	*	2
	Control	*	*	*	*	*	1

Erotylidae	Treatment Area	Jan.	Mar./Apr.	June	Aug.	Oct.	Dec.
T. triplax	Thin	*	*	*	107	77	*
	Burn	*	*	*	1	13	*
	Thin/Burn	*	*	*	2	1	*
	Control	*	*	*	1	66	14

Appendix C

Figure C-VI

Treatment Area and Collection Periods for All Captured Individuals

Beetle Family	Treatment Area	Jan.	Mar./Apr.	June	Aug.	Oct.	Dec.
Carabidae	Thin	1	6	35	31	21	*
	Burn		8	35	12	29	2
	Thin/Burn	1	3	27	13	19	4
	Control	*	*	17	9	18	2
Scarabaeidae	Thin	2	2	35	16	18	12
	Burn	*	16	16	21	24	9
	Thin/Burn	1	9	9	12	3	5
	Control	2	27	27	22	12	7
Erotylidae	Thin	*	*	*	107	18	*
	Burn	*	*	*	1	13	*
	Thin/Burn	*	*	*	2	1	*
	Control	*	*	*	1	66	14
Nitidulidae	Thin	*	15	22	32	20	1
	Burn	*	2	33	27	3	*
	Thin/Burn	*	2	9	9	*	*
	Control	*	9	28	27	4	1
Cucujidae	Thin	*	*	*	2	1	*
	Burn	*	*	*	3	2	*
	Thin/Burn	*	*	1	2	1	*
	Control	*	*	*	7	1	*
Melandryidae	Thin	*	2	1	*	*	*
	Burn	*	*	*	*	*	*
	Thin/Burn	*	*	*	*	*	*
	Control	*	*	*	*	*	*
Histeridae	Thin	*	*	*	1	1	*
	Burn	*	*	2	2	1	*
	Thin/Burn	*	*	*	*	*	*
	Control	*	*	3	2	*	*
Endomychidae	Thin	*	*	1	1	4	*
	Burn	*	*	*	*	*	*
	Thin/Burn	*	*	*	*	*	*
	Control	*	*	*	*	*	*
Curculionidae	Thin	1	5	1	*	9	2
	Burn	*	2	4	1	*	*
	Thin/Burn	*	2	2	*	2	1
	Control	*	*	10	5	2	*
Staphylinidae	Thin	10	7	32	30	14	14
	Burn	1	2	18	50	2	*
	Thin/Burn	4	13	8	7	*	5
	Control	*	14	36	37	4	56

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Figure C-VII

Treatment Area and Collection Periods for All Captured Individuals

Beetle Family	Treatment Area	Jan.	Mar./Apr.	June	Aug.	Oct.	Dec.
Silphidae	Thin	*	*	*	*	*	*
	Burn	*	*	*	*	*	*
	Thin/Burn	*	*	*	*	*	*
	Control	*	*	1	*	*	*
Elateridae	Thin	*	*	*	*	*	*
	Burn	*	*	*	*	*	*
	Thin/Burn	*	3	*	*	*	*
	Control	*	*	*	*	*	*
Phengodidae	Thin	*	*	*	*	*	*
	Burn	*	*	*	*	*	*
	Thin/Burn	*	*	*	*	*	*
	Control	*	*	*	*	1	*
Scolytidae	Thin	*	8	6	8	15	*
	Burn	2	1	9	4	7	*
	Thin/Burn	*	4	5	19	8	*
	Control	*	*	4	7	8	*
Cryptophagidae	Thin	*	*	*	*	1	*
	Burn	*	*	*	*	*	*
	Thin/Burn	*	*	*	*	*	*
	Control	*	*	*	*	2	*
Rhizophagidae	Thin	*	*	*	*	*	*
	Burn	*	*	*	2	*	*
	Thin/Burn	*	*	*	*	*	*
	Control	*	*	*	*	*	*
Phalacridae	Thin	*	*	*	*	1	*
	Burn	*	*	*	*	*	*
	Thin/Burn	*	*	*	*	*	*
	Control	*	*	*	*	*	*
Tenebrionidae	Thin	1	2	5	*	*	*
	Burn	*	*	6	*	*	*
	Thin/Burn	*	*	5	*	*	*
	Control	*	2	4	*	*	*
Alleculidae	Thin	*	*	*	*	*	*
	Burn	*	*	1	*	*	*
	Thin/Burn	1	*	1	*	*	*
	Control	*	*	1	2	*	*
Leiodidae	Thin	*	3	12	*	4	*
	Burn	*	*	1	*	1	*
	Thin/Burn	*	1	2	1	1	*
	Control	*	*	5	2	1	*

Appendix C

Figure C-VIII

Treatment Area and Collection Periods for All Captured Individuals

Beetle Family	Treatment Area	Jan.	Mar./Apr.	June	Aug.	Oct.	Dec.
Cerambycidae	Thin	*	*	*	*	*	*
	Burn	*	*	*	*	*	*
	Thin/Burn	*	*	*	*	*	*
	Control	*	1	*	*	*	*
Eucnemidae	Thin	*	*	*	*	*	*
	Burn	*	*	1	*	*	*
	Thin/Burn	*	*	*	*	*	*
	Control	*	*	*	*	*	*
Meliodidae	Thin	1	*	*	*	*	*
	Burn	*	*	*	*	*	*
	Thin/Burn	*	*	*	*	*	*
	Control	*	*	*	*	*	*
Lampyridae	Thin	*	*	*	*	*	*
	Burn	*	*	*	*	*	*
	Thin/Burn	*	1	*	*	*	*
	Control	*	*	*	*	*	*
Cleridae	Thin	*	*	*	*	1	1
	Burn	*	*	*	*	1	*
	Thin/Burn	*	*	6	*	*	*
	Control	*	1	*	*	*	*
Mordellidae	Thin	*	*	*	1	*	*
	Burn	*	*	2	2	*	*
	Thin/Burn	*	*	2	*	*	*
	Control	*	*	*	*	*	*
Ptinidae	Thin	*	*	*	1	*	*
	Burn	*	*	*	*	*	*
	Thin/Burn	*	*	*	*	*	*
	Control	*	*	*	*	*	*
Throscidae	Thin	*	*	*	*	*	*
	Burn	*	1	*	*	*	*
	Thin/Burn	*	*	*	*	*	*
	Control	*	*	*	*	*	*

LITERATURE CITED

Apigian, K., and Nathaniel T. Wheelwright. 2000. Forest ground beetles (coleoptera: carbidae) on a boreal island: habitat preferences and the effect of experimental removals. The Canadian Entomologist 132:627-634.

Alexopoulos, C. J. 1962. Introductory mycology, 2nd ed. John Wiley & Sons, Inc., New York p.517.

Arnett R. H. and Michael C. Thomas. 2001. American beetles archostemata, myxophaga, adephaga, polyphaga: staphyliniformia Vol I. CRC Press, Boca Raton. 32-132, 272-418 pp.

Arnett R. H. and Michael C. Thomas. 2001. American beetles polyphaga: scarabaeoidae through curculionoindae, Vol II. CRC Press, Boca Raton. 348-353 pp.

Baars, M. A. 1979. Catches in pitfall traps in relation to mean densities of carabid beetles. Oecologia 41(1):25-46.

Bailey, J. D. and William Wallace Covington. 2002. Evaluating ponderosa pine regeneration rates following ecological restoration treatments in northern Arizona, USA. Forest Ecology and Management 155(1-3):271-278.

Blanche, K. R., Alan N. Anderson, and John A. Ludwig. 2001. Rainfall-contingent detection of fire impacts responses of beetles to experimental fire regimes. Ecological Applications 11(1):86-96.

Blumberg, A. Y. and D. A. Crossley, Jr. 1983. Comparison of soil surface arthropod populations in conventional tillage, no-tillage and old-field systems. Agro-Ecosystems 8:247-253.

Blumberg, A. Y. and D. A. Crossley, Jr. 1988. Diurnal activity of soil-surface arthropods in agroecosystems: design for an inexpensive time-sorting pitfall trap. Agriculture, Ecosystems and Environment 20:159-164.

Brust, G. E. 1990. Direct and indirect effects of four herbicides on the activity of carabid beetles (coleoptera: carbidae). Pesticide Science 30(3):309-320.

Butterfield, J. 1997. Carabid community succession during the forestry cycle in conifer plantations. Ecography 20:614-625.

Burke, D. and Henri Goulet. 1998. Landscape and area effects on beetle assemblages in Ontario. Ecography 21:472-479.

Ciegler, J. C. 2000. Ground beetle and wrinkled bark beetles of south carolina (coleoptera: geadephaga: carabidae and rhysodidae). Biota of south carolina. Vol. I. Clemson university, Clemson, S.C. 149 pp.

Cole, E. C., William C. McComb, Michael Newton, J. P. Leeming and Carol L. Chambers. 1998.Response of small mammals to clear cutting, burning, and gyphosate application in the Oregon coast range. Journal of Wildlife Management 62(4):1207-1217.

Cowell, C. M. 1993. Environmental gradients in secondary forests of the piedmont, USA. Journal of Biogeography 20:199-207.

Danks, H. V. and R. G. Foottit 1989. Insects of the boreal zone of Canada. The Canadian Entomologist 121(8):625-690.

Den Boer, P. J. 1970. On the significance of dispersal power for populations of carabid-beetles (coleoptera, carabidae). Oecologia 4 (1):1-28.

Dillion, E. S. and Lawrence S. Dillion 1961. A manual of common beetles of eastern north America.

Eisenbeis, Gerhard and Wilfried Wickard. 1987. Atlas on the Biology of Soil Arthropods.

Evans, W.G. 1971. The attraction of insects to forest fires. Proceedings Tall Timbers Conference on Ecological Animal Control by Habitat Management Feb 25-27 (3): 115-127.

Feeney, S. R., Thomas E. Kolb, W. Wallace Covington and Michael R. Wagner. 1998. Influence of thinning and burning restoration treatments on presettlement ponderosa pines at Gus Pearson natural area. Canadian Journal of Forest Research 28(9):1295-1306.

Ferris, R. and J. W. Humphrey. 1999. A review of potential biodiversity indicators for application in british forests. Forestry 72(4):313-328.

French, J. R. J. and Rosalie M. Keirle 1969. Studies in fire-damaged radiata pine plantations. Australian Forestry 33(3):175-180.

Forest Fire, Context Paper, Canadian Forest Service. 2001. Forest fire-emerging issues. The Forestry Chronicle 77(3):407.

Gagne, N., Louis Belanger and Jean Huot. 1999. Comparative responses of small mammals, vegetation, and food sources to natural regeneration and conifer release treatments in boreal balsam fir stands of Quebec. Canadian Journal of Forest Research 29(7):1128-1140.

Gist, C. S. and D. A. Crossley, Jr. 1973. A method for quantifying pitfall trapping. Environmental Entomology: Entomological Society of America 2(5):951-952.

Goodrich, M. A. and Paul E. Skelley. 1993. The pleasing fungus beetles of Illinois (coleoptera: erotylidae) part II. triplacinae. *triplax* and *ischyrus*. Transactions of the Illinois state academy of science. 86(3&4):153-171.

Greenslade, P. J. M. 1964. Pitfall trapping as a method for studying populations of carabidae (coleoptera). The Journal of Animal Ecology 33(22):301-310.

Griffis K. L., Julie A. Crawford, Michael R. Wagner and W. H. Moir. 2001. Understory response to management treatments in northern Arizona ponderosa pine forests. Forest Ecology and Management 146(1-3):239-245.

Harpootlian, P.J. 2001. Scarab beetles (coleoptera: scarabaeidae) of south carolina. Biota of south carolina. Vol. 2 Clemson University, Clemson, S.C. 157pp.

Harris, D. L. and W. H. Whitcomb. 1974. Effects of fire on populations of certain species of ground beetles (coleoptera: carabidae). The Florida Entomologist 57(1):97-103,

Hicks, R. R. 1998. Ecology and Management of Central Hardwood Forests.

Hirsch, K., Victor Kafka, Cordy Tymstra, Rob McAlpine, Brad Hawkes, Herman Stegehuis, Sherra Quintillo, Sylvie Gauthier and Karl Peck. 2001. Fire-smart management: a pragmatic approach to sustainable forest management in fire-dominated ecosystems. Forestry Chronicle 77(2):357-363.

Holliday, N. J. 1984. Carabid beetles (coleoptera: carabidae) from a burned spruce forest (*picea* spp.). The Canadian Entomologist 116:919-922.

Holliday, N. J. 1991. Species responses of carabid beetles (coleoptera: carabidae) during post-fire regeneration of boreal forest. The Canadian Entomologist 123:1369-1389.

Humphrey, J. W., C. Hawes, A. J. Peace, R. Ferris-Kaan, and M. R. Jukes. 1999. Relationships between insect diversity and habitat characteristics in plantation forests. Forest Ecology and Management 113:11-21.

Ings, T. C. and S. E. Hartley. 1999. The effect of habitat structure on carabid communities during the regeneration of a native Scottish forest. Forest Ecology and Management 119(1-3):123-136.

Kalisz, P. J. and Janet E. Powell. 2000. Effects of prescribed fire on soil invertebrates in upland forests on the Cumberland and plateau of Kentucky, USA. Natural Areas Journal 20(4):336-341.

Kaye, J. P. and Stephen C. Hart. 1998. Ecological restoration alters nitrogen transformations in a ponderosa pine-bunchgrass ecosystem. Ecological Applications 8(4):1052-1060.

Kirk, V. M. 1971. Biological studies of a ground beetle, *pterostichus lucublandus*. Annals of the Entomological Society of America 64(3):540-544.

Kiuchi, M. 2002. Multiyear-drought impact on hydrologic conditions in South Carolina, wateryears 1998-2001. South Carolina Department of Natural Resources, Land, Water and Conservation Division

Kjaer, C. and Niels Elmegaard. 1996. Effect if herbicide treatment on host plant quality for a leaf-eating beetle. Pesticide Science 47:319-325.

Landers, J. David H. Van Lear, and William D. Boyer. 1995. The longleaf pine forests of the southeast: requiem or renaissance?. Journal of Forestry 95(11):39-44.

Larochelle, A. and M. C. Lariviere. 2003. A Natural History of the Ground-Beetles (Coleoptera: Carabidae) of America North of Mexico.

Lavelle, P. 2001. Suspected side effects of a herbicide on dung beetle populations (coleoptera: scaraeibaeidae). Comptes Rendus de l'Academie des Sciences 324(11):989-994.

Lindgren, P. M. F. and Thomas P. Sullivan. 2001. Influence of alternative vegetation management treatments on conifer plantation attributes: abundance, species diversity, and structural diversity. Forest Ecology and Management 142(1-3):163-181.

Martel, J., T. Mauffette and S. Tousignant. 1991. Secondary effects of canopy dieback: the epigeal carabid fauna in Quebec Appalachian maple forests. The Canadian Entomologist 123(4):851-859.

Martinez, I. M., Jean-Pierre Lumaret and Magdalena R. Cruz. 2001. Suspected side effects of a herbicide on dung beetle populations (coleoptera: scarabaeidae). Comptes Rendus del'Academie des Sciences- Series III- Sciences de la Vie 324(11):989-994.

McCullough, D. G., Richard A. Werner and David Neumann 1998. Fire and insects in northern and boreal forest ecosystems of north America. Annual Review of Entomology 43:107-127.

Mississippi State University Extension Service. 2001. Forest herbicide safety: environmental concerns and proper handling. Available: http://msucares.com/pubs/pub1874.html

Mississippi State University Extension Service. 2001. Prescribed burning in the southern pine forest: fire ecology techniques, and uses for wildlife management. Available: http://msucares.com/pubs/p2283.html

Mississippi State University Extension Service. 2001. When will prescribed burn help my pine stand? Available: http://msucares.com/pubs/p2262.html

Morrill, W. L. 1975. Plastic pitfall trap. Environmental Entomology: Entomological Society of America 4(4):596.

Muona, J. and Ilpo Rutanen. 1994. The short-term impact of fire on the beetle fauna in boreal coniferous forest. Annales Zoologicic Fennici 31:109-121.

Niemela, J. 1996. Invertebrate and boreal forest management. Conservation Biology 11(3):601-610.

Nyland, R. D. 2002. Silviculture concepts and applications second edition. McGraw-Hill series in forest resources. The McGraw-Hill Companies, Inc. New York, NY.

Oliver, I., Ralph Mac Nally, and Alan York. 2000. Identifying performance indicators of the effects of forest management on ground-active arthropod biodiversity using hierarchical partitioning and partial canonical correspondence analysis. Forest Ecology and Managemnet 139:21-40.

Paquin, P. and Daniel Coderre 1997. Deforestation and fire impact on edaphic insect larvae and other macroarthropods. Environmental Entomology 26(1):21-30.

Penev, L. 1996. Large-scale variation in carabid assemblages, with special reference to the local fauna concept. Annales Zoologici Fennici 33(1):49-63.

Peters, R. L., Evan Frost and Felice Pace. 2002. Managing for forest ecosystem health: a reassessment of the "forest health crisis". Available: http://www.defenders.org/bio-fh06.html

Purrington, F. F., John E. Bater, Maurizio G. Paoletti and Benjamin R. Stinner 1989. Ground beetles from a remnant oak-maple-beech forest and its surroundings in northeastern Ohio (coleoptera: carabidae). The Great Lakes Entomologist 22(3):105-110.

Pyne, S. J. 1997. America's Fires Management on Wildlands and Forests.

Reynolds, P. E., Naresh V. Thevathasan, James A. Simpson, Andrew M. Gordon, R. A. Lautenschlager, Wayne F. Bell, Donald A. Gresch and Donald A. Buckley. 2000. Alternative conifer release treatments affect microclimate and soil nitrogen mineralization. Forest Ecology and Management 133(1-2):115-125.

Richardson, R. J. and N. J. Holliday. 1982. Occurrence of carabid beetles (coleoptera: carabidae) in a boreal forest damaged by fire. The Canadian Entomologist 114(6):509-514.

Rickard, W. H. 1970. Ground dwelling beetles in burned and unburned vegetation. Journal of Range Management 23(4):293-294.

Robichaud, P. R. 2000. Fire effects on infiltration rates after prescribed fire in northern rocky mountain forests USA. Journal of Hydrology 231-232:220-229.

Rykken, J. J., David E. Capen and Sean P. Mahabir. 1997. Ground beetles as indicators of land type diversity in the green mountains of Vermont. Conservation Biology 11(2):522-530.

Sorrells, R. T. 1984. The Clemson Experimental Forest Its First Fifty Years (A History).

Sullivan, T. P., Christopher Nowotny and R. A. Lautenschlager. 1998.Silvicultural use of herbicide in sub-boreal spruce forest: implications for small mammal population dynamics. The Journal of Wildlife Management 62(4):1196-1206.

Sullivan, T. P., Robert G. Wagner, Douglas G. Pitt, R. A. Lautenschlager and Din G. Chen. 1998. Changes in diversity of plant and small mammal communities after herbicide application in sub-boreal spruce forest. Canadian Journal of Forest Research 28(2):168-177.

Villa-Castillo, Jamie and Michael R. Wagner. 2002. Ground beetle (coleoptera: carabidae) species assemblages as an indicator of forest condition in northern Arizona ponderosa pine forest. Enviromental Entomology 31(2):1-14.

Walker, L. C. and Brian P. Oswald 1999. The Southern Forest Geography, Ecology, and Silviculture. pp. 67-175.

Weber, M. G., and S. W. Taylor. 1992. The use of prescribed fire in the management of Canada's forested lands. The Forestry Chronicle 68(3):324-333.

Wikars, L. and Johnny Schimmel. 2001. Immediate effects of fire-severity on soil invertebrates in cut and uncut pine forests. Forest Ecology and Management 141(3):189-200.

Wildlife Neighbors Web Page (2002). Loblolly pine. Available: http://www.baylink.org/wpc/loblolly.html

Wiley, J. & Sons, Inc. 1962. Introductory mycology second edition. P. 517.

Williams, G. 1959. The seasonal and diurnal activity of the fauna sampled by pitfall traps in different habitats. The Journal of Animal Ecology 28(1):1-13.

Zar, J. H. 1984. Biostatistical analysis 2nd ed. Prentice-Hall, Inc., Englewood Cliffs, N.J. 33-38, 146-148, 241 pp.