

**Arthropod assemblages on longleaf pines: a possible link between
the red-cockaded woodpecker and groundcover vegetation**

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Thesis submitted to the Faculty of the Virginia Polytechnic Institute and State University in
partial fulfillment of the requirements for the degree of

Master of Science

in

Biology

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February 26, 2003

Blacksburg, Virginia

Keywords: Red-cockaded woodpecker, arthropod, fire, groundcover

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(Abstract)

Little is known about arthropod communities inhabiting longleaf pines in the southeastern United States. This information is of particular importance because arthropods serve as the food base for the federally endangered red-cockaded woodpecker (RCW). In a recent study, this arthropod community has been suggested to be the mechanism by which RCW reproductive success is linked to the groundcover composition of the forest (which is a reflection of the forest's fire history). This is possible because it has been shown that much of the arthropod community found on longleaf pines originates from the forest floor. If the arthropod community is the link between the ground cover and the RCWs' reproductive success then higher amounts of arthropods should be found in areas with groundcover that is indicative of frequent burning. I conducted a one year study at three sites containing RCWs to determine whether the ground cover of the forest influences the abundance and mass of the arthropod communities on longleaf pines. I focused on impacts of groundcover on arthropods by controlling for tree species, tree age, soil type, hardwood midstory density, and overstory basal area. My results show that arthropod biomass was positively and significantly correlated to the percent coverage of herbaceous and graminoid vegetation and was negatively and significantly correlated to the percent coverage of woody vegetation. Arthropod biomass and abundance was also observed to vary seasonally with a peak occurring during spring and summer. Additionally, prescribed fire was not found to have a negative short-term impact on arthropod biomass.

Acknowledgements

I thank Jeff Walters, Jim Fraser, Bob Jones, and Scott Salom for their ideas and assistance during my project. Thanks to the Virginia Tech Avian Ecology Lab for their help in reviewing and editing my writing and answering my endless questions. Thanks to Pete Johnston and Brady Simmons for their assistance with the arthropod trapping. Special thanks to my family for their unending support. Special thanks to Jeff Walters for the many opportunities he has provided me and for his thoughtful insight at all stages of my project. Funding was provided by the Department of Energy-Savannah River Operations Office through the U.S. Forest Service Savannah River under Interagency Agreement DE-IA09-00SR22188. The Savannah River Site is acknowledged as a National Environmental Research Park.

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Chapter 1

Introduction

The Longleaf Pine Ecosystem

Formerly covering a broad swath of the southeastern U.S., the longleaf pine (*Pinus palustris* Miller) ecosystem has become one of the most endangered ecosystems in the northern hemisphere. Dominated by unique vegetation types and maintained by frequent fires, the longleaf pine ecosystem ranged from southern Virginia to eastern Texas along the coastal plain and covered approximately 24 million hectares prior to European colonization. Currently approximately 1.6 million hectares remain, indicating a decline of almost 93 percent (Boyer 1990). The decline of the longleaf pine ecosystems is due to several different factors: regeneration failure of longleaf pines following logging in the 1800's (Frost 1993), the prevalence of feral hogs which feed voraciously on longleaf seedlings (Frost 1993), and the period of fire suppression that characterized land management in the 1900's (Frost 1993, Landers et al. 1995). As a result, very little old growth exists and much of the remaining forest is in fragmented patches. The majority of the remaining longleaf pine ecosystem, mostly second growth, exists on federal government installations operated by the U.S. Department of Defense, U.S. Department of Agriculture, and the U.S. Department of Energy with smaller amounts found on state and private land.

The longleaf pine ecosystem is characterized by a vegetative structure that has evolved in response to the frequent fires caused by lightning strikes, which are common during the spring and summer growing seasons in the southeastern U.S. Estimates of historical fire frequency in this system range from 1 to 8 years (Christensen 1981, Frost 1998) depending on soil conditions, geographic location, fuel load, and fuel moisture (Christensen 1981). The nature of the disturbance caused by fire has resulted in a vertically stratified vegetative community with an overstory composed of large, well spaced pines and a speciose understory vegetation layer composed of forbs and grasses. Later successional hardwoods are typically absent in frequently burned areas due to exclusion by growing season fires (Vogl 1973, Langdon 1981, Kush et al. 1999) resulting in a forest that has been described as park-like in appearance. Traditionally, the

overstory is composed of large longleaf pines with other pine species such as loblolly (*P. taeda* Linnaeus), shortleaf (*P. echinata* Miller), slash (*P. elliotii* Engelman), and pond pine (*P. serotina* Michaux) present depending on geographic location and soil conditions. In many managed areas however, these other pine species have been planted in place of longleaf pines.

The frequent growing season fires that historically have swept through longleaf forests help to prevent hardwoods such as turkey oaks (*Quercus laevis* Walt.) from successionaly dominating this ecosystem. Fires were traditionally of low intensity and were confined to the understory vegetation, and caused little damage to the overstory pines. The important role fire plays in this ecosystem was not recognized by early land managers and a period of fire suppression began at the beginning of the 20th century (Frost 1993). This suppression of growing season fire led to the establishment of a hardwood midstory which, due to its shading effect, contributed to the decline of the species-rich understory. An additional negative effect of the establishment of hardwoods is the potential for more intense wildfires because the hardwoods provide a means for flames to spread to the crown of the overstory pines. Traditionally, pine needles that are shed by the overstory pines accumulate on the understory vegetation. However when hardwoods are established, the pine needles are collected by the branches of the hardwoods and provide a fuel ladder for fire to leave the understory and advance into the crown of the overstory pines. While the overstory pines experience low levels of mortality from low intensity fires that are confined to the understory, high levels of mortality result from fires that are spread up through hardwoods and into the overstory pine canopy. The importance of fire in this ecosystem is now recognized, however concerns over perceived negative effects of fire such as air pollution and the inherent public fear of fire have limited the use of fire in restoring or maintaining longleaf pine forests.

Longleaf pines are found throughout the Southeast in a range of xeric and mesic soil conditions. More adapted to frequent fire than other species, longleaf pines have several unique life history characteristics that help them to thrive in this frequently burned ecosystem. Removal of vegetation and fine litter by fire creates the bare mineral soil conditions necessary for germination of longleaf seed (Boyer 1990). Newly germinated seedlings take advantage of the

lack of competition created by the temporary removal of the groundcover and of the increased nutrient availability (nitrogen, calcium, potassium, magnesium, phosphorus) caused by vegetation incineration (Christensen 1977, McKee and Lewis 1982). Following germination, the seedling enters what is termed the 'grass stage' during which growth of an extensive root system occurs, while the aboveground portion remains stemless (Boyer 1990). During this stage, longleaf seedlings are very resistant to fire. Once the root collar reaches approximately 2.5cm in diameter, rapid vegetative growth commences (Boyer 1990). This rapid vegetative growth helps to elevate the meristem above the damaging heat caused by fire. However, the seedling is very susceptible to fire damage until it reaches a height of 0.6 to 0.9m (Boyer 1990). Later, as the pine matures, very thick bark develops which helps to insulate the tree from the heat caused by fire passing through the understory vegetation. In addition to being fire resistant, longleaf pines create conditions that are conducive to frequent fires by the shedding of their long 30cm needles which add to the amount of combustible vegetative matter in the understory. Because of their special adaptations to frequent fires, the presence of multiple age classes of longleaf pines is usually indicative of high fire frequencies.

Because of the historical frequency of fire in this system, many of the plants comprising the understory vegetation have developed special adaptations in response to fire. These adaptations include structural features such as underground rhizomes and stolons (Vogl 1974), as well as reproductive responses such as stimulation of flowering and seed production by burning (Ahlgren and Ahlgren 1960, White and Terry 1979, Platt et al. 1988). Additionally, many species have evolved synchronous production of flowering stems following fires (Platt et al. 1988). In particular, wiregrass (*Aristida* sp.), a large bunchgrass, has several adaptations that enable it to respond favorably to frequent fire conditions as well as to create conditions that encourage fires. Mature clumps of wiregrass contain large amounts of combustible dead vegetative matter that, along with longleaf pine needles, create conditions that are conducive to frequent low intensity fires. Additionally, the high density of wiregrass in undisturbed areas results in overlapping dead vegetation that facilitates the movement of fire through the understory (Clewell 1989). Following the passage of a fire, wiregrass is one of the first plants to initiate growth due to the leaf meristems being protected by their location 1.5 inches

underground (Lemon 1949). These adaptations, along with a shallow but tightly knit mat of roots, allow the plant to take advantage of the release of nutrients and the lack of competing understory vegetation created by the passing of the fire (Clewell 1989). Additionally wiregrass will flower and produce seeds following exposure to stress, most often in the form of summer fires, so as to take advantage of optimal post-fire conditions (Platt et al. 1988, Clewell 1989).

Forest managers, in an effort to prevent hardwoods from competing with desirable pine species, have learned to mimic the effects of natural fires in pine plantations by using prescribed fires to control hardwoods (Langdon 1981). These prescribed fires are also used to remove flammable vegetative debris that accumulates on the forest floor which, if left unchecked, could lead to higher intensity wildfires and potentially higher levels of pine mortality. Because of the emphasis on maximizing timber harvest, prescribed burns in pine plantations were historically conducted in the dormant season to prevent a perceived higher rate of pine mortality. A recent study has shown, however, that if conducted properly, growing season burns do not result in higher than average pine mortality and have little effect on pine growth (Streng et al. 1993). Growing season burns mimic the natural fire regime and promote the reproduction of forbs and graminoids and are more effective in controlling hardwoods by increasing the rate of topkill, increasing the rate of complete kill, and reducing the rate of sprouting (Langdon 1981, Streng et al. 1993).

Recently, interest in the longleaf pine ecosystem has greatly increased because of the precipitous declines in the coverage of this ecosystem and the declines in plant and animal species that are associated with it. A focal point for this interest has been the red-cockaded woodpecker (*Picoides borealis*) which was listed as Endangered under the Endangered Species Act in 1970 (35 Federal Register 16047). This species, once common throughout the southeastern United States, nests exclusively in live, mature pines, primarily longleaf, and is intolerant of a hardwood midstory layer (Van Balen and Doerr 1978, Costa and Escano 1989, Conner and Rudolph 1991). Two of the main reasons for the endangered status of the red-cockaded woodpecker are habitat loss and habitat degradation. As mentioned earlier, the amount of acreage of the longleaf pine ecosystem has greatly diminished as a result of clearing for

agriculture and the creation of pine plantations. The replacement of longleaf pine forests by pine plantations has resulted in the planting of non-native pine species in densities that are greatly above the density preferred by red-cockaded woodpeckers. These pine plantations are also managed in short rotations that do not allow the pines to reach sufficient size and age for use by red-cockaded woodpeckers as cavity trees. On average, pines used for cavity trees must be at least 60-80 years old to have sufficient size and heartwood to accept a red-cockaded woodpecker cavity (DeLotelle and Epting 1988, Hooper 1988). Additionally, a hardwood midstory has been allowed to develop in many of the pine plantations due to fire suppression, which leads to the degradation of the speciose groundcover traditionally associated with this ecosystem.

Natural History of Red-cockaded Woodpeckers

The red-cockaded woodpecker is a non-migratory, cooperatively breeding species that typically lives in extended family groups consisting of a breeding pair and offspring from previous years. These offspring, typically males, temporarily forgo breeding attempts of their own and assist their parents in raising the current year's offspring and help to defend a territory containing the cavity trees in which the birds roost (Ligon 1970, Lennartz and Harlow 1979, Lennartz et al. 1987, Walters et al. 1988). The cavity trees are a valuable resource for the red-cockaded woodpecker due to the length of time that it takes to excavate a cavity in a living pine (Jackson et al. 1979, Rudolph and Conner 1991, Conner and Rudolph 1995, Harding 1997, Harding and Walters 2002). Research into the nature of the cooperative breeding behavior in this species suggests that because of the limited number of cavity trees, it is often a better strategy for offspring to stay on their natal territory until a breeding vacancy becomes available on their natal territory or on a neighboring territory than to disperse in search of other breeding vacancies (Walters 1991).

To prevent predators such as arboreal snakes from climbing the tree, red-cockaded woodpeckers peck small wounds into the cambium of the pine around the cavity entrance. Due to the copious amount of sap that is common in longleaf pines, these wounds create resin flows that surround the cavity entrance and help to prevent predators from climbing the tree (Ligon

1970, Jackson 1974, 1978, Rudolph et al. 1990). As is clear from their natural history, cavities are an important resource for red-cockaded woodpeckers. Efforts to increase the population size by creating new cavities have been successful in areas that contain suitable habitat characteristics but are lacking cavities (Copeyon et al. 1991).

Because of their endangered status, much work has been done on the habitat conditions preferred by red-cockaded woodpeckers. Preferred conditions include open, low basal area forests (40-60 ft²/ac) (Conner et al. 1991) with an overstory composed of large pines and a sparse hardwood midstory layer. Red-cockaded woodpeckers have been observed to abandon cavities when hardwoods reach the height of their cavity entrances (Van Balen and Doerr 1978, Hovis and Labisky 1985, Loeb et al. 1992). This is thought to be an anti-predator strategy since the hardwoods might hide potential avian predators and could provide pathways onto the pine bole for predatory snakes. Recent research has documented a preference by red-cockaded woodpeckers for forests with a speciose groundcover composed primarily of forbs and grasses (Van Balen and Doerr 1978, Hardesty et al. 1997, James et al. 1997, James et al. 2001, Convery 2002). However, the reasons for this preference are unclear since red-cockaded woodpeckers rarely forage on the ground. These preferred habitat conditions (the low basal area, the lack of a hardwood midstory layer, and a speciose groundcover) are created and maintained by the frequent fires that have historically swept through these forests.

Because of the implications to forest management a considerable amount of research has been conducted to determine the tree species and tree characteristics preferred by red-cockaded woodpeckers. The importance of live pines as foraging substrate for red-cockaded woodpeckers is well established (Hooper and Lennartz 1981, Porter and Labisky 1986) and hardwoods are rarely used for foraging (Hooper and Lennartz 1981, Porter and Labisky 1986, Jones and Hunt 1996, Hardesty et al. 1997). Pine species that have been observed as foraging substrate include longleaf, loblolly, pond, shortleaf, slash, and Virginia (*P. virginiana* Miller) pine (Nesbitt et al. 1978, Porter and Labisky 1986, Zwicker and Walters 1999). Information on which species of pine is preferred by red-cockaded woodpeckers for foraging is equivocal. Contrary to Porter and Labisky (1986) and Nesbitt et al. (1978), Zwicker and Walters (1999) observed no difference

between percent use and percent availability for stands composed of longleaf, loblolly, and pond pines. After live pines, dying or recently dead pines are the next most frequently used type of trees (Ligon 1970, Hooper and Lennartz 1981). As noted earlier, hardwoods are rarely ever used as foraging substrate by red-cockaded woodpeckers. Hardesty et al. (1997) observed hardwoods being used by males and females in less than 5% of their foraging observations while Jones and Hunt (1996) observed hardwood use in significantly lower proportion than availability (6.9% and 36.0% respectively). Similarly, Hooper and Lennartz (1981) observed foraging in hardwoods very infrequently (<1%), and only noted one occurrence of foraging on the ground.

Research on foraging habitat selection indicates that red-cockaded woodpeckers prefer to forage on relatively old and large diameter pines (Hooper and Lennartz 1981, Porter and Labisky 1986, Engstrom and Sanders 1997, Hardesty et al. 1997, Zwicker and Walters 1999, Walters et al. 2002). Hooper and Lennartz (1981) observed a preference for pines larger than 23 cm in diameter and avoidance of pines less than 13 cm dbh. Zwicker and Walters (1999) also observed that use of live pines older than 60 years of age exceeded availability, and observed an additional, stronger selection for the oldest age class of trees (>100 years old). Preference was also shown towards trees of larger diameter indicating that large, old growth trees are the preferred foraging habitat of red-cockaded woodpeckers.

The reasons for why red-cockaded woodpeckers prefer to forage on large, old growth pines are not fully understood. Older pines have more surface area than younger trees of the same species, and hence should contain more arthropods per tree than the younger, smaller diameter trees. Therefore selection for these older pines may result from reduced exposure to predators and reduced energy expenditure associated with reduced movement between trees. Additional hypotheses for why older pines are selected include differences in bark texture and/or different arthropod assemblages when compared with younger trees (Zwicker and Walters 1999). However, Hanula and Engstrom (2000) compared nestling diets in old-growth forests to nestling diets in forests with relatively young longleaf pines and observed a high degree of similarity in nestling prey items. Despite an incomplete understanding of why older pines are the preferred foraging substrate, that red-cockaded woodpeckers select these older, larger trees is clear

(Hooper and Lennartz 1981, Porter and Labisky 1986, Engstrom and Sanders 1997, Hardesty et al. 1997, Zwicker and Walters 1999, Walters et al. 2002).

In addition to specific tree characteristics, stand characteristics such as the basal area of particular size classes of pines have been shown to influence the preference of red-cockaded woodpeckers for certain areas as well as to affect measures of their fitness (Hardesty et al. 1997, Walters et al. 2002). Walters et al. (2002) documented that red-cockaded woodpecker use of timber stands in the North Carolina Sandhills was greatest in stands with intermediate densities of medium and large pines. Additionally, timber stands with high densities of large pines and low densities of small pines were associated with increasing woodpecker group size, an important measure of fitness (Walters et al. 2002). The lower habitat quality of stands with high densities of small pines may be related to arthropod abundance since lower densities of pines are correlated with increased arthropod abundance, and since arthropod biomass per tree increases with increasing tree age (Hanula et al. 2000a). Thus arthropod abundance and biomass may play a role in explaining red-cockaded woodpecker preference for certain stand characteristics as well as specific tree characteristics.

Foraging Behavior

As part of the recovery effort, considerable research has been conducted to characterize red-cockaded woodpecker feeding preferences and foraging behavior. Several researchers have examined the diet of nestling and adult red-cockaded woodpeckers in different populations in the Southeast. Their research has revealed that the adults' diet consists mainly of arthropods, especially Hymenopterans, Coleopterans, Blattodeans, Chilopodes, and Araneae, although other arthropods such as Hemipterans, Lepidopterans, and Orthopterans are also taken (Beal 1911, Beal et al. 1916, Harlow and Lennartz 1977, Hooper and Lennartz 1981, Hanula and Franzreb 1995, Hess and James 1998). Depending on the area being studied, ants make up a considerable portion of adult red-cockaded woodpecker diet. Observations by Hess and James (1998) and Beal et al. (1916) revealed that ants and their eggs, larvae, and pupae made up more than half of the adult RCW diet. Of the ants sampled in the Hess and James study, 74% were *Crematogaster ashmeadi*, the dominant arboreal ant at Apalachicola National Forest. This dominance is a result

of *C. ashmeadi*'s ability to competitively exclude other arboreal ant species (Hahn and Tschinkel 1997), indicating that red-cockaded woodpeckers may not be specializing on this species but are instead opportunistically taking the most abundant ant species present.

Percentages of vegetative matter in the diet vary considerably depending on the population being observed, although it typically constitutes only a small percentage (0-23%) (Beal et al. 1916, Harlow and Lennartz 1977, Hooper and Lennartz 1981, Hanula and Franzreb 1995, Hess and James 1998). Species eaten include the fruits and seeds of sweetbay magnolia (*Magnolia virginiana* Linnaeus), wax-myrtle (*Myrica* spp.), poison ivy (*Rhus radicans* Linnaeus), longleaf pine, and blueberry (*Vaccinium* spp.) (Hooper and Lennartz 1981, Hess and James 1998).

The diet of nestling red-cockaded woodpeckers mainly consists of arthropods with prey items fed to nestlings tending to be larger than items that make up the diet of adults (Hanula and Franzreb 1995, Hess and James 1998, Hanula et al. 2000b). Proportions of vegetative matter in the nestling diet are lower than in adult diets. Prey items fed to nestlings include Blattodea, Hymenoptera, Coleoptera, Lepidoptera, Araneae, and Chilopodes (Harlow and Lennartz 1977, Hanula and Franzreb 1995, Hanula and Engstrom 2000, Hanula et al. 2000b) but proportions may vary based on geographic location. In a stomach content study at the Apalachicola National Forest, ants, beetles, spiders, and centipedes were roughly equal in proportion (12-15%) in the nestlings' stomachs (Hess and James 1998) whereas in photo observation studies in Georgia and South Carolina, wood roaches composed the bulk of nestling diet (Hanula and Franzreb 1995, Hanula and Engstrom 2000, Hanula et al. 2000b). It should be noted that the two methods of sampling, stomach flushing and photo observation, each produce biased results. Stomach flushing typically results in higher than normal amounts of hard bodied prey, such as ants, that may take longer to digest whereas photo observations are biased towards larger prey items, such as wood roaches, which are more easily identifiable than smaller prey in photos.

The foraging habits of red-cockaded woodpeckers reflect the distribution of their prey items, which live either under the bark or on the surface of the pines in the crevices of the bark.

Observations of foraging behavior in an old growth pine forest in Georgia revealed that red-cockaded woodpeckers spent 69% of their foraging time excavating into the bark, 15% scaling bark, and 10% “hitching and looking” (Engstrom and Sanders 1997). Unlike other woodpeckers, only rarely do red-cockaded woodpeckers excavate through the bark and into the living tissue of the tree in search of prey. Similar foraging behaviors were observed by Hooper and Lennartz (1981). Both groups of researchers also observed sexual niche partitioning where the males foraged higher on the boles than the females and also made more visits to branches. Recently Rudolph et al. (2002) have documented differences in foraging locations between helper males and breeder males with helper males feeding farther out on branches than breeding males which fed closer to the pine bole. These foraging behaviors are thought to reduce intraspecific food competition and intersexual aggression (Hooper and Lennartz 1981, Pizzoni-Ardemani 1990).

The Arthropod Community

Although the red-cockaded woodpecker’s diet and foraging habits are well studied, there have been few attempts to describe the arboreal arthropod community upon which red-cockaded woodpeckers prey. Much of the research that has been conducted has focused on the abundance and diversity of arthropods in relation to understory and overstory forest vegetation characteristics. However, many of the studies failed to control for certain factors that could potentially affect arthropod abundance and biomass on the pine boles.

The earliest study to address the arboreal arthropod community on southeastern pines in relation to their role as prey for the red-cockaded woodpecker examined arboreal arthropod biomass during the winter season (Hooper 1996). The winter season was chosen because Hooper hypothesized that arthropod populations would be less active and hence be more stable. He found that total arthropod biomass per tree increased with increasing tree age up to age 86, but arthropod biomass per m² decreased with increasing tree age. Among the five sampling areas on each tree, the highest biomass of arthropods was found within dead branches, the presence of which increases with tree age. After dead limbs, the mid-bole contained the highest arthropod biomass, followed by the upper bole, the lower bole, and live limbs. In his study however, factors shown to have an effect on the arboreal arthropod community, such as the

composition of the surrounding groundcover and the basal area of the pines, were not considered. It should also be noted that this study only provides a description of the arboreal arthropod community during the winter months.

Researchers have examined the seasonal abundance of the arboreal arthropod community to determine if prey abundance fluctuates seasonally. Research into seasonality has yielded conflicting results with Hanula and Franzreb (1998) observing that arthropod biomass was highest during the fall while Hanula et al. (2000a) observed arthropod biomass to be highest during winter and spring. This discrepancy may be due to differences in analysis since in the earlier study, data from 3 months were used for each season, while in the later study only one month from each season was used. The discrepancy may also be due to geographic differences in the arthropod community since the earlier study was conducted in South Carolina, while the latter study took place in Florida and Alabama.

One of the most important studies concerning the distribution and abundance of potential red-cockaded woodpecker prey on pine boles examined the source of the arthropods on the pine bole. In their study Hanula and Franzreb (1998) placed crawl traps at various heights on the bole (base, mid-bole, and crown) and pitfall traps in the surrounding forest floor. By placing barriers at the base of half of the trees and observing subsequent declines in arthropod biomass found on these trees, Hanula and Franzreb were able to determine that the arthropods on the bole were moving upward from the ground. In the trees without crawl barriers, they observed a 58% similarity between the arthropods captured on the pine bole and the arthropods captured in the pitfall traps, with the greatest similarity occurring at the lowest height on the tree. By noting the similarity between arthropod communities on the ground and on the bole and by demonstrating a decrease in arthropod biomass on the bole following the placement of barriers to movement, Hanula and Franzreb established that a large portion of the arboreal arthropod community originates from the ground level. In contrast to Hooper, equal numbers of arthropods were found at all three levels of the tree that were sampled.

With the sharp increase in the amount of acreage of managed pine plantations throughout the range of the red-cockaded woodpecker, it is important to know how forest management decisions such as the tree species planted, basal area, and presence/absence of hardwoods may affect the prey base of the red-cockaded woodpecker. Several researchers have worked to address these management issues by looking at differences in arthropod abundance in timber stands that have been subjected to various management techniques.

Hanula et al. (2000a) report that in longleaf pines, arthropod abundance and biomass were positively correlated with increasing stand age, tree diameter, and increasing bark thickness. Overstory pine basal area was negatively related to arthropod abundance and biomass when examined over all size classes of pines. This observation may help explain why red-cockaded woodpeckers prefer stands with a low basal area. When site index, a measure of site quality, was examined, there was no effect on arthropod abundance, biomass, or diversity.

In comparing arthropod densities on loblolly and shortleaf pines, Collins et al. (2002) found that loblolly pines harbored higher densities of arthropods throughout a one year sampling period than did shortleaf pines. They also examined the influence that hardwood midstory has on the arthropod community found on the overstory pines, and observed a significant reduction in arthropod abundance on loblolly pines in stands with an established hardwood midstory compared to stands without a hardwood midstory. The reduction in arthropod abundance was found at all three sampling heights on the pine bole (3, 6, and 9 m). These results should be interpreted cautiously due to problems with pseudoreplication (Hurlbert 1984) in the sampling design. An additional comparison of arthropod communities on different species of pines was conducted by Horn (2000). Horn found that longleaf pines had significantly more arthropods on their surface than loblolly pines. By removing some of the bark surface from longleaf pines and observing a subsequent decrease in arthropod abundance, Horn hypothesized that the rugose bark structure on longleaf pines contributed to their more abundant arthropod fauna. One confounding issue with the Collins et al. and Horn studies is the failure to control for covariates that may affect arthropod abundance such as groundcover coverage and composition, overstory basal area, and soil type.

Horn (2002) also examined the effects of coarse woody debris on the forest floor on the arboreal arthropod community. This issue is important because of the large amount of slash and other debris left behind as a result of current forestry practices. In an experimental study in which the amount of coarse woody debris was manipulated, Horn (2002) found mixed results. Depending on the sampling type, crawl traps or burlap wraps, coarse woody debris had either no effect or a positive effect on the arboreal arthropod community.

As would be expected from the historical frequency of growing season fire, the arthropod community found on longleaf pines exhibit direct and coevolved responses to fire. In a large scale longleaf pine restoration study in Florida, the introduction of growing season prescribed burning was shown to increase the density and biomass of herb layer arthropods. Additionally, groundcover measures indicative of frequent fires were found to be positively correlated with the density and biomass of herb layer homopterans, hemipterans, ants, moths, and grasshoppers (Provencher et al. 2001). These observations, combined with Hanula and Franzreb's (Hanula and Franzreb 1998) observation that the arboreal arthropod community which constitutes the food base of the red-cockaded woodpecker originates from the forest floor, suggest that fire may have a positive impact on red-cockaded woodpeckers through processes other than the suppression of a hardwood midstory, specifically the condition of the groundcover.

Importance of Fire and Fire Maintained Groundcover

The ultimate indicator of habitat quality is not habitat selection, but effects of habitat on fitness. A body of literature has begun to develop that documents an association between red-cockaded woodpecker fitness measures and the composition of the groundcover in the forests they inhabit. As reviewed earlier, historically, groundcover in the longleaf pine ecosystem has been described as a speciose assemblage of forbs and grasses with little woody vegetation. This vegetation assemblage was maintained by the frequent fires that were common to this ecosystem prior to active fire suppression. Although the mechanism is unclear for the relationship between red-cockaded woodpecker fitness measures and groundcover composition, researchers have begun to associate this characteristic fire-maintained understory with cavity tree placement and measures of red-cockaded woodpecker fitness such as group size, clutch size, and number of

fledglings (Van Balen and Doerr 1978, Hardesty et al. 1997, James et al. 1997, James et al. 2001). A foraging preference for areas containing this type of groundcover has also been documented (Convery 2002).

Van Balen and Doerr (1978) first noted the association between red-cockaded woodpeckers and groundcover composition by comparing hardwood stem density near 60 cavity trees and 60 randomly selected trees that would be suitable for cavity excavation. They found lower hardwood stem density around the cavity trees compared with the random trees without cavities. They attributed the decreased hardwood density near the cavity trees to the effects of fire (Van Balen and Doerr 1978).

Researchers have also documented a correlation between red-cockaded woodpecker reproductive success and groundcover composition. In the Apalachicola National Forest, James et al. (2001) observed a significant difference in the percent coverage of wiregrass between two red-cockaded woodpecker populations that had opposite population trends. The Apalachicola Ranger District had a large stable population of red-cockaded woodpeckers and had a much higher percent coverage of wiregrass than did the Wakulla Ranger District, which had a declining population. They also noticed a negative correlation between percent coverage of wiregrass and gallberry (*Ilex glabra* Linnaeus); higher percentages of the former species being indicative of frequent fires. By comparing demographic and vegetation data from the two ranger districts, James et al (2001) were able to relate the difference in percent coverage between wiregrass and woody vegetation to the density of groups ($R^2 = 0.19$) and number of young fledged per group ($R^2 = 0.26$), two measures of red-cockaded woodpecker fitness.

In an earlier study, James et al (1997) observed that red-cockaded woodpeckers tended to have larger clutch sizes in areas that received burns during the previous season. Decreased group size was related to fire-suppressed groundcover containing higher percentages of woody and palmetto vegetation. Thus James et al. (1997, 2001) related effects of groundcover on fitness to fire history. Daniels et al. (2002) observed similar correlations between fire and group size in the Francis Marion National Forest. They observed increased group size correlated with

prescribed burning within the previous 5 years. These findings are supported by the observation by Hardesty et al. (1997) at Eglin Air Force Base in Florida that red-cockaded woodpecker clutch size is positively correlated with increasing forb coverage. Hardesty et al. also observed that group size and the number of fledglings is associated with increasing forb coverage. At Eglin Air Force Base the percentage of forb cover helped explain 35% of the variation in fledgling production (Hardesty et al. 1997). Similar results with respect to fledgling production were obtained by Convery (2002) at Camp Lejeune Marine Corp Base in North Carolina.

Groundcover composition has also been correlated with red-cockaded woodpecker territory size; decreasing territory size is associated with increasing territory quality (U.S. Fish and Wildlife Service 2003). At Apalachicola National Forest, larger, less productive, red-cockaded woodpecker territories were associated with high percentages of gallberry while the smaller, more productive territories had high percentages of wiregrass (James et al. 2001). Similar observations of a correlation between territory size and groundcover composition were noted by Convery (2002) at Camp Lejeune.

Despite the strong and consistent trends indicating that groundcover composition and fire frequency is correlated with red-cockaded woodpecker fitness, the mechanism responsible for this correlation is unknown. Red-cockaded woodpeckers forage almost exclusively on pine boles and only rarely venture down to the understory. James et al. (2001) speculated that the passage of fire may increase the quality and/or quantity of the arthropod community upon which the red-cockaded woodpeckers feed. This speculation is supported by the results of Provencher et al. (2001), in which fire frequency and percent coverage of forbs and grasses were correlated with increased arthropod density and biomass. Further research into the mechanism by which groundcover and fire affect red-cockaded woodpeckers is needed.

Conclusion

Considering the historically frequent fires that helped to shape and maintain the southeastern pine ecosystem, it is hardly surprising that a growing body of literature documents correlations between fire and its effects on the animals and plants that make-up this ecosystem

(Fig 1). The influence of fire in suppressing hardwoods and maintaining the speciose groundcover of the longleaf pine ecosystem, along with the correlations between hardwood abundance, groundcover composition, and red-cockaded woodpecker fitness, indicate that a mechanism may exist linking the historically common fires in this ecosystem to red-cockaded woodpeckers. The mechanism by which this interaction occurs is currently unknown and is subject to speculation. One potential mechanism is the relationship between groundcover composition and the arboreal arthropod community which constitutes the prey base of the red-cockaded woodpecker. Documentation of a correlation between groundcover composition, a reflection of fire history, and the arboreal arthropod community would provide an indication of a potential pathway through which fire in the longleaf pine ecosystem could affect red-cockaded woodpecker fitness.

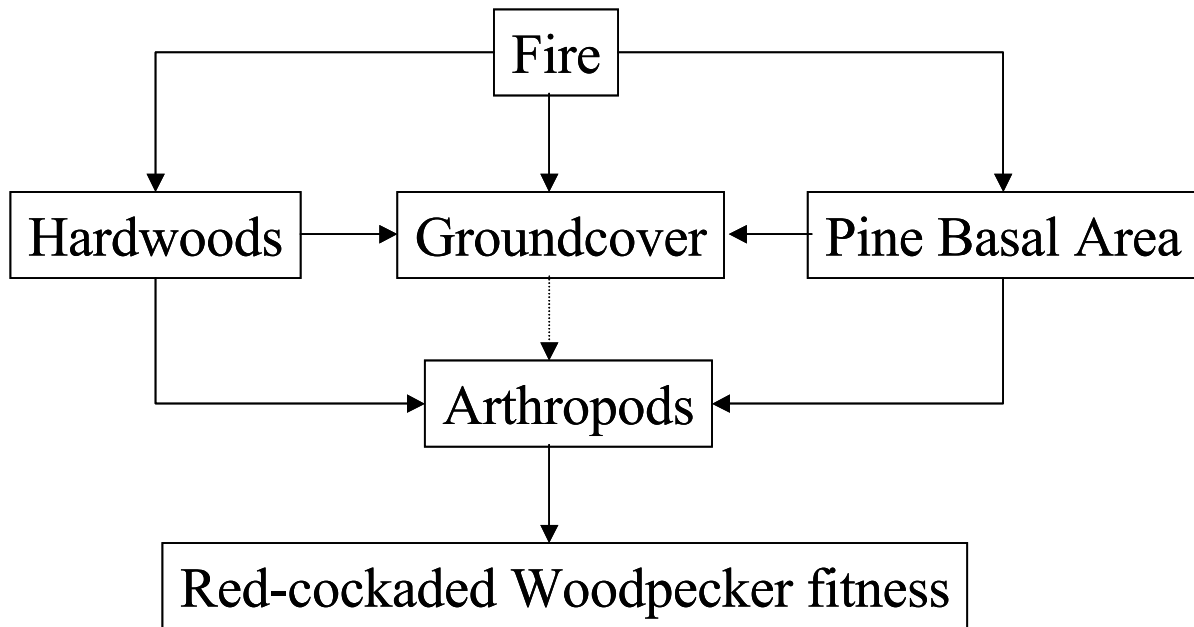


Figure 1.1 Historical fire interactions with floral and faunal components of the longleaf pine ecosystem. The groundcover-arthropod interaction is hypothesized.

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Chapter 2

Influence of Groundcover Composition on the Arthropod Prey Base of Red-cockaded Woodpeckers

INTRODUCTION

Characterized by frequent, lightning caused fires during the spring and summer growing seasons, the southeastern longleaf pine (*Pinus palustris* Miller) ecosystem is home to a diverse assemblage of flora and fauna whose presence is tied closely to the frequency of this pervasive disturbance. Historical fire frequencies in this ecosystem range from 1 to 8 years (Christensen 1981, Frost 1998) and alteration of this frequency has impacts on the flora and fauna that are still being discovered and investigated. A less frequent fire regime and a shift to dormant season burns has had deleterious effects on numerous plant and animal species endemic to the southeastern pine ecosystem. These species include the red-cockaded woodpecker (*Picoides borealis*), gopher tortoise (*Gopherus polyphemus*), Bachman's sparrow (*Aimophila aestivalis*), and wiregrass (*Aristida* spp). Researchers have begun to document a positive relationship between attributes of red-cockaded woodpeckers and the amount of herbaceous and graminoid vegetation in the forest groundcover. Although this relationship has been consistent across the species' range, the mechanism responsible for it is currently unknown. The purpose of this study is to examine the relationship between red-cockaded woodpeckers and the composition of the groundcover and specifically to test whether the biomass of the arthropods on which the woodpeckers feed is greater in areas with higher percent coverages of herbaceous and graminoid vegetation.

One of the most noticeable effects that growing season fire has in the longleaf pine ecosystem is on the structure of the vegetation. Historical descriptions of upland longleaf pine forests describe them as park-like with a vertically stratified vegetation structure (Means and Grow 1985, Boyer 1990). The overstory was composed of large, well spaced pines while the

understory was made up of a speciose groundcover composed primarily of herbs and graminoids. The lack of a hardwood midstory was a noticeable characteristic of this ecosystem.

The presence of a diverse understory in the longleaf pine ecosystem is closely tied to the frequency of growing season fire. Numerous studies have documented a high diversity of plant species in the groundcover of frequently burned areas (Lemon 1949, Christensen 1981, Langdon 1981, Walker and Peet 1983, Walker 1993, Brockway and Lewis 1997, Rodgers and Provencher 1999). This diversity exists because the disturbance created by frequent fires interrupts competition and prevents any one plant species from becoming dominant. The pervasive presence of growing season fire in this ecosystem has resulted in special adaptations such as synchronized reproductive timing and special growth forms that allow understory plants to respond positively to the passage of fire (Allen 1960, Vogl 1974, White and Terry 1979, Platt et al. 1988). The large amounts of dead vegetation associated with these plants species results in a positive feedback loop: the presence of this dead, dry vegetation encourages the frequent passage of fire (Clewell 1989). Because of the close ties that understory vegetation has with growing season fire, the presence of a speciose understory composed of herbs and graminoids is an indicator of frequent growing season fire and is a reflection of the area's fire history.

The lack of a hardwood midstory is another fire influenced characteristic of the longleaf pine ecosystem. Unless frequent growing season burning suppresses them, understory hardwoods such as turkey oak (*Quercus laevis* Walt.) and bluejack oak (*Q. incana* Bartr.) will form a subcanopy layer, the development of which results in the shading and degradation of the groundcover layer (Waldrop et al. 1992). Additionally, hardwoods intercept pine needles falling from the overstory pines and create a fuel ladder. This fuel ladder allows the historically low intensity fires that are typically confined to the understory vegetation to grow in intensity and to reach the overstory pines, possibly resulting in mortality of the pines. The presence of a hardwood midstory is an indication that the forest has not experienced fire in recent years.

Growing season fire also has impacts on the overstory pines that are one of the most dominant characteristics of the longleaf system. Longleaf pines have a unique life history that includes a high level of resistance to fire (Means and Grow 1985, Boyer 1990). They are vulnerable to fire for a period after leaving the grass stage during which the meristem is protected underground, and prior to becoming tall enough to be above the lethal effects of fire (Boyer 1990). As a result, fire thins the pines and helps to maintain a relatively low basal area, enabling ample light to reach the groundcover on the forest floor. Another way that growing season fire affects longleaf pines is by removing vegetative litter from the forest floor and exposing bare mineral soil, the presence of which is necessary for longleaf pine seed germination (Boyer 1990). Therefore the presence of grass stage longleaf pines is an indication of a recent fire event.

Growing season fire also has effects on the fauna of the longleaf pine ecosystem which are often mediated through the effects that fire has on the forest vegetation. In particular, the endangered red-cockaded woodpecker has been found to be especially responsive to features of the vegetative community that are indicative of frequent growing season fires. Through direct observation and correlation analysis, researchers have been able to describe the 'optimal niche gestalt' of the red-cockaded woodpecker (James et al. 2001). James et al. (2001), through their work at Apalachicola National Forest, found that several features of the biology of red-cockaded woodpeckers are related to overstory pine characteristics and the composition of the forest groundcover. They demonstrated that increased numbers of adults per group and young fledged per group were associated with high densities of large pines (>35cm dbh) and low densities of medium pines (15-25cm dbh). These features were also positively related to the percentage of wiregrass in the groundcover minus the percentage of woody vegetation (James et al. 2001). Both the overstory and groundcover conditions that were favored by red-cockaded woodpeckers at the Apalachicola National Forest are indicative of frequent growing season fires. Many other researchers have documented a strong negative association between red-cockaded woodpeckers and a hardwood midstory layer, the presence of which is associated with a lack of frequent fire (Van Balen and Doerr 1978, Hovis and Labisky 1985, Loeb et al. 1992). As one would expect from the historical association of growing season fire with the longleaf pine ecosystem, red-

cockaded woodpeckers appear to prefer forest conditions that are reflective of the frequent passage of fire.

The proximate causes of the red-cockaded woodpeckers' association with the characteristic vegetation structure of the longleaf pine ecosystem are not completely understood. A demonstrated preference by red-cockaded woodpeckers for foraging on larger, older pines (Engstrom and Sanders 1997, Hardesty et al. 1997, Zwicker and Walters 1999, Walters et al. 2002) is thought to be due to increased arthropod abundance on the larger trees, however this theory remains to be adequately tested. By foraging on trees with more abundant food resources, red-cockaded woodpeckers could minimize their energetic costs and their potential exposure to predators as they move from tree to tree. In addition to preferring large, old trees for foraging, red-cockaded woodpeckers require old trees for cavity excavation (Conner and O'Halloran 1987, DeLotelle and Epting 1988, Rudolph and Conner 1991). Red-cockaded woodpeckers are unique among North American woodpeckers in that they only excavate cavities in living pines and will abandon cavities if the tree dies. Only old trees contain sufficient heartwood to house a cavity, and older longleaf pines are often infected with red heart fungus (*Phellinus pini*), which softens the heartwood thereby facilitating cavity excavation (Conner et al. 1976, Conner and Locke 1982). Thus the proximate reason for selection of larger pines for nesting is clear, but the reason for foraging preference for these trees remains to be conclusively determined.

Numerous researchers have documented a negative association between red-cockaded woodpeckers and hardwood midstory, but the mechanism responsible for this association is not fully understood. Red-cockaded woodpeckers will abandon their cavities if the hardwood midstory approaches the height of their entrances (Van Balen and Doerr 1978, Hovis and Labisky 1985, Loeb et al. 1992). This may be a predator avoidance tactic: hardwoods near the cavity entrance may allow snakes and other predators to bypass the resin barrier that the red-cockaded woodpeckers maintain around the cavity entrance (Dennis 1971). However, this idea has not been tested. Additionally, researchers have observed that red-cockaded woodpeckers prefer to forage in areas without a hardwood midstory layer (Jones and Hunt 1996, Rudolph et al. 2002, Walters et al. 2002). This foraging preference may be related to reduced arthropod

abundance on pines in areas with a substantial hardwood midstory (Collins et al. 2002). Perhaps, as a result of evolving in fire-maintained forests without a hardwood midstory, red-cockaded woodpeckers may view forests with an extensive hardwood midstory as being inherently unsuitable habitat (Conner and Rudolph 1991). Although these ideas remain untested, the association between the development of a hardwood midstory layer and subsequent red-cockaded woodpecker avoidance is well documented (Van Balen and Doerr 1978, Hovis and Labisky 1985, Loeb et al. 1992, Jones and Hunt 1996, Rudolph et al. 2002, Walters et al. 2002).

Recently, several researchers have documented red-cockaded woodpecker foraging preferences for, and increases in red-cockaded woodpecker fitness values in areas with groundcover that is indicative of frequent growing season burning, i.e. contains high percentages of graminoids and forbs (Hardesty et al. 1997, James et al. 1997, James et al. 2001, Convery 2002). This association is widespread and has been observed throughout the species' range. The reasons for this association are unclear, as red-cockaded woodpeckers very rarely come into contact with the groundcover and forage primarily on living pines (Hooper and Lennartz 1981).

One hypothesis that has been put forth to explain these associations is that the arboreal arthropod community that serves as the bulk of the diet of the red-cockaded woodpecker is responding positively to groundcover that is indicative of frequent burning (James et al. 1997). The observation by Hanula and Franzreb (1998) that a large percentage of arboreal arthropods were moving up the trees from the forest floor lends support to this hypothesis. Additionally, because of the long term association of growing season fire with the longleaf pine ecosystem, the arthropod community found in it should be adapted to the presence of fire and the effects that fire has on the vegetative community. Red-cockaded woodpeckers sexually partition where they feed with females foraging primarily at the lower levels of the pine bole (Hooper and Lennartz 1981). In the study by Hanula and Franzreb (1998), the strongest positive correlation between arthropods on the forest floor and arthropods on the trees was at the lowest height on the pine bole where female red-cockaded woodpeckers forage. These observations suggest that the arthropods that constitute the bulk of the red-cockaded woodpecker's diet could be responding to changes in

groundcover composition and therefore may be the link between red-cockaded woodpeckers and the composition of the forest groundcover. The purpose of my study was to test this hypothesis.

METHODS

Study Sites

Arthropod abundance and biomass were sampled for one year at three field sites. Results of the arthropod sampling were examined in relation to the results of groundcover sampling that was conducted during the summer months of the study. The field sites were Savannah River Site in New Ellenton, SC, Fort Gordon Army Base in Augusta, GA, and Camp Lejeune Marine Corp Base in Jacksonville, NC.

Located in the upper Atlantic Coastal Plain physiographic province of South Carolina, the Savannah River Site (SRS) contains a rapidly growing population of red-cockaded woodpeckers. Although the facility is operated by the U.S. Department of Energy (DOE), the U.S. Forest Service (USFS) manages the surrounding forests for timber production and wildlife management. The timber stands consist of mainly longleaf, loblolly (*P. taeda* Linnaeus), and slash pine (*P. elliottii* Engelman) although other pine species play a minor role in timber production (Edwards et al. 1999). The groundcover in these timber stands is typically sparse due to intensive timber management and agricultural use prior to the purchase of the site by DOE. Common groundcover species include poison oak (*Toxicodendron pubescens* Miller), various *Vaccinium* species, brackenfern (*Pteridium aquilinum* (L.) Kuhn), sassafras (*Sassafras albidum* Nuttall), and turkey oak.

Fort Gordon U.S. Army Signal Center (FG), approximately 45 km west-northwest of SRS, lies in the Fall Line transition zone between the Coastal Plain and the Piedmont Plateau. FG contains a small but growing population of red-cockaded woodpeckers inhabiting pine plantations managed by the Environmental/Natural Resources Management Office. Pine plantations contain loblolly, longleaf, and slash pine. Although the land comprising FG received considerable agricultural use in the past, the groundcover at FG is generally less degraded, relative to SRS, due to less intensive agricultural use prior to reforestation. Common

groundcover species include beargrass (*Nolina georgiana* Michaux), wiregrass (*Aristida stricta* Michaux), brackenfern, (*Andropogon* spp.), and *Vaccinium* species.

The third study site, Camp Lejeune Marine Corp Base, is located on the Atlantic Coastal Plain. This site contains the largest population of red-cockaded woodpeckers among the three sites chosen for this study. A large portion of the base is covered in plantations of longleaf and loblolly pine with small amounts of pond pine (*P. serotina* Michaux) mixed in. The predominant groundcover at Camp Lejeune is wiregrass, with various *Vaccinium*, *Andropogon*, and other species in lesser abundance.

Study Design

Thirty-five timber stands distributed among the three field sites were chosen for the study. However one stand was dropped because a prescribed burn took place too close to the time of vegetation sampling, resulting in a sample size of 34 timber stands (10 at CL, 12 at FG, and 12 at SRS). Timber stands were chosen based on the presence of overstory habitat characteristics that would support red-cockaded woodpeckers, although the lack of red-cockaded woodpecker nesting cavities in the timber stand did not preclude its inclusion. Timber stands were also chosen to represent a wide variety of groundcover characteristics in order to examine the greatest range of possible effects that groundcover might have on arthropod abundance.

In order to attempt to control for the many variables that may influence arthropods on the pine boles (Figure 2.1), a number of limitations were imposed on the timber stands during the selection process. To control for soil type, timber stands at SRS and FG were restricted to Troup and Lakeland soil types, both of which are common in the upland areas of each site. Both of these are acidic, well drained, permeable soils with the upper horizons composed of loose sand grains (Paulk 1981, Rogers 1990). Due to the uncommon nature of Troup and Lakeland soils at CL, timber stands with Kureb and Alpin soils were chosen due to their similarity in composition to Troup and Lakeland soils (Barnhill 1992).

Because the amount of bark surface area on tree boles varies in relation to bole diameter, the diameter of the trees sampled for arthropods was restricted to a narrow range so that the amount of bark surface area being sampled was similar among all trees. Red-cockaded woodpeckers have been shown to preferentially forage on the oldest and largest pines available (Hooper and Lennartz 1981, Zwicker and Walters 1999). A survey of the size class distribution of the pines in each timber stand was conducted so that the largest commonly abundant tree diameter could be identified. This survey resulted in the selection of pines 25.4 - 30.5cm dbh for sampling.

A study of the arthropod communities on two common southern pines revealed that arthropod abundance on the bole varied based on tree species (Horn and Hanula 2002). Longleaf pines were shown to contain a significantly larger population of arthropods than loblolly pines. Based on this observation, combined with the emphasis by the U.S. Fish and Wildlife Service (2003) on the planting of longleaf pines for red-cockaded woodpecker recovery purposes, I selected longleaf pine as the tree species for arthropod sampling. Other variables depicted in Figure 2.1, such as the amount of hardwood midstory, stand density, and geographic location, were statistically controlled for during the analysis.

Arthropod sampling was conducted continuously for one calendar year with samples collected every 30 days. Arthropod traps were placed at breast height (1.4m) on four randomly selected longleaf pines, within the size criteria described above, in each of the selected timber stands, resulting in 136 arthropod traps. The arthropod traps were a modified version of the trap described by Hanula and New (1996) (Figure 2.2). The trap design consisted of an inverted funnel mounted to the pine bole with a plastic container mounted at the narrow opening of the funnel. Attached to the container was a removable sample cup filled with 1% formaldehyde solution. A small amount of dishwashing detergent was added to the trapping solution to help break the surface tension so arthropods immediately sank when they fell into the sample cup. 3M™ spray adhesive was used to attach sand to the inside of each funnel in order to provide a surface on which the arthropods could climb. To aid in channeling arthropods into the funnel, a 15cm wide band of aluminum flashing was placed around the tree with a gap in the flashing

located at the opening to the funnel. Arthropods entered the funnel and crawled upwards, eventually ending up in the sample cup where they were preserved until the samples were collected. Additional information on the trap design can be found in Hanula and New (1996).

After the sample cups were collected for each 30 day sampling period, each stand's sample was sorted and arthropods were identified to order or morphotype (excluding collembola, mites, and small dipterans that were perceived to be too small to serve as red-cockaded woodpecker forage). After sorting, samples were stored in vials of 70% ethanol until drying. Biomass measurements for each sample were obtained by drying the contents of each sample at 60° C for 24 hours before weighing them.

Groundcover vegetation was sampled during a 2 week period in early August, 2001. Ten, 1m² plots were placed around each longleaf pine being sampled for arthropods as illustrated in Figure 2.3. Groundcover plots were randomly arranged at set distances around each longleaf pine in order to ensure that a proportional amount of groundcover was sampled as the distance from the pine increased. Groundcover measurements consisted of a visual estimation of the percent coverage of various components into 10% coverage categories (1-10%, 11-20%, 21-30%,...91-100%). The use of coverage classes is a well established vegetation survey method (Daubenmire 1959). To aid in estimating percent cover, a 1m² PVC frame was used at each sampling point to define the area being sampled. Additionally, a 0.1m² piece of clear plexiglass was used as a reference tool to help approximate the 10% coverage class. Coverage categories were: graminoids, wiregrass, forbs, ferns, lichens, woody species, vines, bare ground, fine litter, and woody litter (Table 2.1). The woody species category was limited to woody species <1.4m in height. Because of structural overlap among vegetation types within a plot, coverage categories could sum to more than 100%.

To account for effects of a hardwood midstory on the arboreal arthropod community, hardwood midstory was measured. The diameter at breast height (dbh) of all hardwood trees greater than 1.4m in height within 5m of the pines being sampled was recorded.

To account for the effects of pine basal area on the arboreal arthropod community, the basal area surrounding each pine being sampled was determined using a 10 BAF factor (English unit) prism. For trees that were determined to be “borderline”, the dbh of the pine in question and its distance from the pine being sampled were recorded in order to determine whether or not the tree should be counted in determining the basal area.

To account for differences in plant productivity, site index values for each timber stand were obtained from the forestry managers at each of the field sites. For analysis purposes, each tree was assigned the site index value (base 50) of the timber stand within which it was located.

Statistical Analysis

Data for all three sites were combined during the analysis in order to incorporate the full range of groundcover conditions. To account for site differences in the combined data, I employed the PROC MIXED function in SAS (SAS Institute 2001). Mixed models are useful in handling both fixed and random effects and hence are appropriate for dealing with any potential fixed site effects. Because trees being sampled for arthropods were located within the same timber stand and were exposed to the same management practices, the trees within a stand (four trees per stand) were nested within the stand in the mixed model to avoid pseudoreplication.

In order to focus on groundcover variables, the hardwood midstory values and the pine basal area values, although recorded as continuous variables during the vegetation survey, for analysis purposes are used as dummy variables (1 or 0). For hardwood midstory, a value of 1 was assigned when there were hardwood species >2cm dbh within 5 meters of the pine being sampled. Conversely, a 0 was assigned if such trees were absent. For basal area, a value of 1 was assigned for basal areas <11.5m² per hectare (50ft² per acre) and a value of 0 for basal areas >11.5m² per hectare (50ft² per acre).

Percent coverage variables for the vegetation and nonvegetation categories were derived by using the midpoint of each of the 10% coverage classes and then averaging the 10 resulting values for each tree into a single value that represented the percent coverage of each

groundcover category surrounding the pine being sampled. Prior to analysis it became clear that the variables representing the percent coverage of bare ground and fine litter were negatively correlated (Pearson Correlation Coefficient = -0.899) so the variable representing bare ground was removed from the analysis. In order to more fully focus on vegetation classes that are a positive indicator of fire frequency, the vegetation classes of graminoids, wiregrass, and forbs were combined for analysis into the 'HERB_GRASS' variable. Because of the lack of independence in sequential monthly arthropod samples for each tree, autoregression techniques were incorporated into the mixed model analysis.

In order to determine the best fitting model, backwards selection techniques were used to eliminate variables from the full model until the best fitting model was reached. The backwards selection process involved removing the least significant variables following each model run until the model contained only variables for which alpha was <0.1 . The Akaike's Information Criteria (AIC) statistic was used to evaluate each of the reduced models that was created during the selection process to ensure that the removal of variables resulted in a better fitting model. The model with the lowest AIC statistic was considered the best fitting model.

RESULTS

During the one year sampling period, approximately 31,500 arthropods encompassing nineteen orders were collected (Table 2.2). Of the fourteen orders that have been identified in the literature as being prey items of red-cockaded woodpeckers (Beal 1911, Beal et al. 1916, Harlow and Lennartz 1977, Hess and James 1998, Hanula and Engstrom 2000), twelve were collected in this study (Table 2.2). The two orders not collected (Scorpionida, Odonata) make up extremely minor components of the red-cockaded woodpecker diet (Harlow and Lennartz 1977, Hess and James 1998). These results suggest that the arthropods captured in the traps used in this study are a reasonable representation of red-cockaded woodpecker prey.

A wide range of groundcover percentages were present among the three study sites (Table 2.3). The groundcover at the sites ranged from areas with only pine needles to areas with high percentages of wiregrass and forbs, the presence of which is indicative of well burned areas.

The results of the full model are presented in Table 2.4. Of particular interest are the variables HERB_GRASS and WOODY SPECIES which are promoted and inhibited respectively by growing season burning. In the full model, the variable HERB_GRASS was significantly and positively associated with arthropod biomass while the WOODY SPECIES variable was negatively correlated with arthropod biomass (Table 2.4). The positive relationship between arthropod biomass and HERB_GRASS during the red-cockaded woodpecker breeding season at two of the field sites is depicted in Figure 2.4. The significant relationships for the TIME and the TIME*TIME variables indicates that arthropod biomass varies during the year (TIME) and that there is a quadratic relationship among monthly samples (TIME*TIME), as is demonstrated in Figure 2.5. The lack of independence among monthly samples validates the use of the autocorrelation techniques that were incorporated into the mixed model analysis. Monthly biomass results are presented in Figure 2.5. Seasonal abundance and biomass patterns of arthropod orders are presented in greater detail in Chapter 3.

Results of the backwards variable selection process are presented in Table 2.4. The variable HERB_GRASS remained positively and significantly associated with arthropod biomass during the selection process while the relationship between WOODY SPECIES and arthropod biomass remained negative and became significant in the final reduced model ($p=0.03$). All other groundcover variables were removed during the backwards selection process ($p>0.1$). The consistent decline of the Akaike's Information Criteria throughout the model selection process indicates the fit of the model improved throughout the variable selection process (Table 2.4).

DISCUSSION

This study presents evidence that arthropod biomass may be the mechanism relating red-cockaded woodpeckers to groundcover indicative of growing season fire (herbaceous and graminoid vegetation). The positive correlation between increasing arthropod biomass and increasing coverage of herbaceous and graminoid vegetation suggests that growing season fire may help to increase the amount of prey available to red-cockaded woodpeckers. The beneficial effects growing season fire has on nesting habitat by eliminating hardwood midstory are well

established (Garren 1943, Allen 1960, Vogl 1973, Langdon 1981, Kush et al. 1999). The negative correlation between arthropod biomass and percent coverage of woody and shrubby vegetation suggests that the absence of growing season fire also negatively affects the red-cockaded woodpecker prey base. Thus, the results support the idea that the arboreal arthropod community mediates one of the mechanisms responsible for the correlations observed between red-cockaded woodpecker fitness components and the composition of the groundcover (Hardesty et al. 1997, James et al. 1997, James et al. 2001, Convery 2002).

The results of this study help to explain the numerous relationships between red-cockaded woodpeckers and fire influenced habitat. Higher amounts of food resources may help to explain observations of increased red-cockaded woodpecker territory density, group size, clutch size, and fledgling productivity in habitat with herbaceous and graminoid groundcover (Hardesty et al. 1997, James et al. 1997, Convery 2002). Additionally, the increased prey biomass may help to explain the preference by red-cockaded woodpeckers for foraging in habitat with high percentages of herbaceous and graminoid groundcover (Convery 2002). In some cooperatively breeding species, increased food abundance on the natal territory is positively related to territory quality which, in turn, is positively associated with lifetime reproductive success (Komdeur and Edelaar 2001). This suggests that variation in red-cockaded woodpecker reproductive success may be related to differences in arthropod biomass. While territory quality in red-cockaded woodpeckers has traditionally been determined by the presence/absence of cavities and the structure of the vegetation, differences in arthropod biomass may also play a secondary role in determining red-cockaded woodpecker territory quality.

Growing season fire has also been reported to affect arthropod biomass by suppressing hardwoods. Collins et al. (2002) observed arthropod biomass in two loblolly pine timber stands, one with an extensive hardwood midstory and one without, and found that arthropod abundance was greater where hardwoods were absent. These results however, are confounded by a failure to control for the composition of the groundcover, which was qualitatively different in the two timber stands. The forest floor of the timber stand with a hardwood midstory was described as “virtually bare of any herbaceous or hardwood (groundcover) vegetation” as a result of not

having been burned in the previous 50 years and also as a result of the shade produced by the encroaching hardwood midstory. The encroachment of hardwoods in the absence of frequent fire produces shade that groundcover adapted to an open canopy forest cannot tolerate. The timber stand without a hardwood midstory had “a thick herbaceous layer of grasses, forbs, and young woody vegetation” which resulted from the timber stand having been burned three times in the past 20 years (Collins et al. 2002). As the results of this study indicate, differences in arthropod biomass may be due to differences in groundcover composition rather than hardwood midstory.

The hardwood and groundcover vegetation characteristics seen in the two timber stands of the Collins et al. (2002) study represent separate responses to fire frequency that will often co-occur. The timber stand that had vegetation representative of frequent growing season fire (i.e. no hardwood midstory and an herbaceous groundcover) had significantly more arthropods than the timber stand with vegetation that is indicative of a lack of growing season fire (i.e. dense hardwood midstory and no groundcover) (Collins et al. 2002). The positive relationship between fire frequency and arthropod abundance is consistent with the results of my study, indicating that the relationship between the arboreal arthropod community and the passage of growing season fire is not limited to longleaf pines but extends to loblolly pines as well. However, the lack of a correlation between a hardwood midstory and arthropod biomass seen in my study suggests that the correlations found in the Collins et al. (2002) study may be due to the negative shading effect that a hardwood midstory has on groundcover vegetation.

The positive correlations between growing season fire and arboreal arthropod biomass reported in this study are consistent with the observations of Provencher et al. (1998) at Eglin Air Force Base in Florida. In a study evaluating the effects of hardwood midstory reduction techniques, including growing season burning, the abundance and biomass of arthropods located in the groundcover responded positively to growing season fires. This is important in light of the observation that the forest floor is a major source of the arthropods found on pine boles (Hanula and Franzreb 1998). Other midstory management techniques such as herbicide and mechanical felling did not result in similar increases in arthropod densities until the treated stands were

burned the following growing season (L. Provencher, unpublished).

The results of Provencher et al. (1998) suggest that more than one mechanism related to growing season fire may be responsible for increases in red-cockaded woodpecker prey availability. While higher levels of vegetation species diversity may help to increase arthropod species diversity (Folkerts et al. 1993), the lack of a response in arthropod abundance following herbicide and mechanical hardwood removal that was seen by Provencher et al. (1998) suggests that fire related mechanisms other than changes in vegetation structure may also be influencing the arthropod community. The passage of growing season fire releases large quantities of nutrients from the groundcover and forest floor litter (Christensen 1977). Following a growing season fire, there is a period of vigorous plant growth which contains higher levels of nutrients (N, P, K, Ca, and Mg) when compared to vegetation in unburned areas (Christensen 1977). The flush of new growth and increased nutrient levels may stimulate populations of herbivores, which would subsequently increase populations of their predators (Provencher et al. 1998). Additionally, if the increased nutrient levels found in vegetation are passed on to the arthropod community, red-cockaded woodpeckers could be foraging on more nutritious arthropods in areas that have experienced growing season fires, a mechanism that has been suggested by James et al. (1997). Thus, the correlation between increasing arthropod biomass and increasing herbaceous and graminoid coverage found in this study may only be an indication that fire mediated processes such as an increase in nutrient availability have occurred. However, regardless of which mechanism may be responsible for arthropod responses, the results of this study, the Collins et al. study (2002) and the Provencher et al. study (1998) suggest that the frequent passage of growing season fire increases red-cockaded woodpecker prey quality and quantity. This increase in prey resources provides a fire mediated mechanism for the increase in red-cockaded woodpecker group size in areas that have experienced growing season fires within their home range (Daniels et al. 2002).

The results of this study contradict an earlier study by Hanula et al. (2000a) that examined arboreal arthropod biomass on longleaf pines in Escambia Experimental Forest in Alabama and Blackwater State Forest in Florida. Using similar trapping techniques, Hanula et

al. (2000a) did not observe a correlation between arboreal arthropod biomass and the percentage of herbaceous groundcover, the number of herbaceous plant genera, or the number of herbaceous plant stems (Hanula et al. 2000a). Differences in results between the two studies could possibly be due to geographic differences in the location of the studies. However, correlations between red-cockaded woodpecker fitness components and groundcover composition have been observed in both the northern (Convery 2002) and southern (Hardesty et al. 1997, James et al. 1997) portions of the species' range. If the mechanism responsible for this relationship is the same throughout the species' range, then discrepancies in the results of the two studies should not be attributed to geographical differences. Alternatively, the difference in the results of the two studies might be due to differences in groundcover vegetation sampling methodology. Hanula et al. (2000a) sampled groundcover around half of the trees that were sampled for arthropods, and only one, 1m² groundcover sample was taken for each tree that was chosen for groundcover sampling. In this study, ten, 1m² groundcover samples were taken around each tree that was sampled for arthropods. The increased number of vegetation samples in this study may have reduced sampling error, allowing effects of groundcover to emerge.

The results of this study, along with the results of Provencher et al. (1998) and Collins et al. (2002), suggest that growing season burning may be a useful tool for the ecosystem management strategy that many land managers employ. Not only do growing season fires mimic historical disturbance patterns but these fires also help to maintain and restore historical vegetation structure and diversity. Whether or not these vegetation conditions affect arthropod abundance and biomass is yet to be determined, however, the positive correlation between arthropod biomass and groundcover indicative of frequent burning indicates that growing season fires improve foraging conditions for insectivorous birds such as the brown headed nuthatch (*Sitta pusilla*) and the endangered red-cockaded woodpecker. Further research into the effects growing season fire has in maintaining nutrient pathways in longleaf pine ecosystems would be useful in teasing out the mechanisms by which growing season fire may influence red-cockaded woodpeckers.

Table 2.1. Definitions of habitat variables used in mixed model analysis.

Variable	Description
BASAL AREA	Density of overstory pines surrounding each pine being sampled. Dummy variable with '1' entered for stands <50ft ² and '0' for stands >50ft ²
BARE GROUND	Percent coverage of areas not covered by living or dead organic matter. Measured in 10% coverage categories.
COARSE LITTER	Percent coverage of organic debris greater than 1cm in diameter. Measured in 10% coverage categories.
FERN	Percent coverage of ferns. Measured in 10% coverage categories.
FINE LITTER	Percent coverage of organic debris less than 1cm in diameter. Measured in 10% coverage categories.
HARDWOOD	Presence/absence of hardwoods >2cm dbh within 5m of each pine being sampled. Dummy variable with '1' entered for stands with hardwoods >2cm and '0' entered for stands without such trees
HERB_GRASS	Percent coverage of herbaceous and graminoid vegetation. Measured in 10% coverage categories.
LICHEN	Percent coverage of lichens. Measured in 10% coverage categories.
SITE INDEX	Timber stand productivity values provided by each site's forestry division.
VINES	Percent coverage of viney plant species. Measured in 10% coverage categories.
WOODY SPECIES	Percent coverage of woody plant species less than 1.4m tall (breast height). Measured in 10% coverage categories.

Table 2.2. Comparison of arthropod orders collected in this study and orders identified in the diet of Red-cockaded woodpeckers (Beal 1911, Beal et al. 1916, Harlow and Lennartz 1977, Hanula and Franzreb 1995, Hess 1997, Hess and James 1998, Hanula and Engstrom 2000, Hanula et al. 2000b).

	Arthropod Orders Collected in this Study	Arthropod Orders Identified in the Diet of Red-cockaded Woodpeckers
Araenida	+	+
Blattaria	+	+
Coleoptera	+	+
Diploda*	+	
Diptera	+	+
Hemiptera	+	+
Homoptera	+	+
Hymenoptera	+	+
Isoptera	+	
Lepidoptera	+	+
Neuroptera	+	
Odonata		+
Opiliones	+	
Orthoptera	+	+
Pseudoscorpionida	+	+
Psocoptera	+	+
Scolopendromorpha	+	+
Scorpionida		+
Thysanoptera	+	
Thysanura	+	
Trichoptera	+	

* order unknown

Table 2.3. Range of Coverage Categories around each pine. Values are based on an average of the 10 measurements taken around each tree. Each of the 10 measurements is the midpoint of the 10% coverage class that was selected.

	Minimum	Maximum	Mean
HERB_GRASS	0	52.3	14.8
LICHEN	0	8.9	0.2
WOODY SPECIES	1.1	68.5	17.7
BARE GROUND	0	28.5	3.7
COARSE LITTER	1.7	16.5	6.5
FINE LITTER	72.5	95.5	92.9
FERN	0	36.5	1.9
VINES	0	16.3	1.4
SITE INDEX (base 50)	50	110	64.9

Table 2.4. Results of the backwards model selection process for predicting arthropod biomass. The variable with the highest p-value (in bold) was removed each step until all variables were significant to $p < 0.1$. Akaike's Information Criterion (AIC) was used to ensure that model fit improved with each step of the model selection process (the lower the AIC value, the better the fit). Descriptions of habitat variables are found in Table 2.1.

	HERB_GRASS	WOODY SPECIES	TIME	TIME*TIME	COARSE LITTER	BASAL AREA	SITE INDEX	FERN	HARDWOOD	FINE LITTER	VINES	LICHEN	AIC
Full Model	p = 0.01 t = 2.53	p = 0.14 t = -1.50	p < 0.0001 t = 6.83	p < 0.0001 t = -6.95	p = 0.31 t = 1.01	p = 0.24 t = 1.18	p = 0.21 t = 1.25	p = 0.38 t = -0.88	p = 0.58 t = -0.56	p = 0.60 t = 0.53	p = 0.89 t = 0.14	p = 0.94 t = -0.08	-1805.3
	p = 0.01 t = 2.53	p = 0.14 t = -1.50	p < 0.0001 t = 6.83	p < 0.0001 t = -6.96	p = 0.31 t = 1.01	p = 0.24 t = 1.18	p = 0.21 t = 1.26	p = 0.38 t = -0.88	p = 0.57 t = -0.56	p = 0.60 t = 0.52	p = 0.89 t = 0.14		-1814.1
	p = 0.01 t = 2.56	p = 0.14 t = -1.49	p < 0.0001 t = 6.84	p < 0.0001 t = -6.96	p = 0.30 t = 1.04	p = 0.24 t = 1.18	p = 0.21 t = 1.26	p = 0.37 t = -0.89	p = 0.58 t = -0.55	p = 0.61 t = 0.52			-1825.1
	p = 0.009 t = 2.62	p = 0.14 t = -1.46	p < 0.0001 t = 6.84	p < 0.0001 t = -6.97	p = 0.27 t = 1.10	p = 0.26 t = 1.12	p = 0.23 t = 1.19	p = 0.36 t = -0.91	p = 0.74 t = -0.34				-1836.8
	p = 0.007 t = 2.71	p = 0.14 t = -1.47	p < 0.0001 t = 6.84	p < 0.0001 t = -6.97	p = 0.27 t = 1.11	p = 0.28 t = 1.07	p = 0.25 t = 1.15	p = 0.35 t = -0.94					-1844.0
	p = 0.005 t = 2.85	p = 0.12 t = -1.57	p < 0.0001 t = 6.84	p < 0.0001 t = -6.97	p = 0.18 t = 1.35	p = 0.23 t = 1.20	p = 0.26 t = 1.13						-1855.4
	p = 0.005 t = 2.84	p = 0.13 t = -1.53	p < 0.0001 t = 6.84	p < 0.0001 t = -6.97	p = 0.16 t = 1.40	p = 0.35 t = 0.94							-1867.2
	p = 0.003 t = 2.98	p = 0.06 t = -1.88	p < 0.0001 t = 6.85	p < 0.0001 t = -6.98	p = 0.16 t = 1.39								-1873.7
Reduced Model	p = 0.008 t = 2.64	p = 0.03 t = -2.13	p < 0.0001 t = 6.84	p < 0.0001 t = -6.97									-1882.6

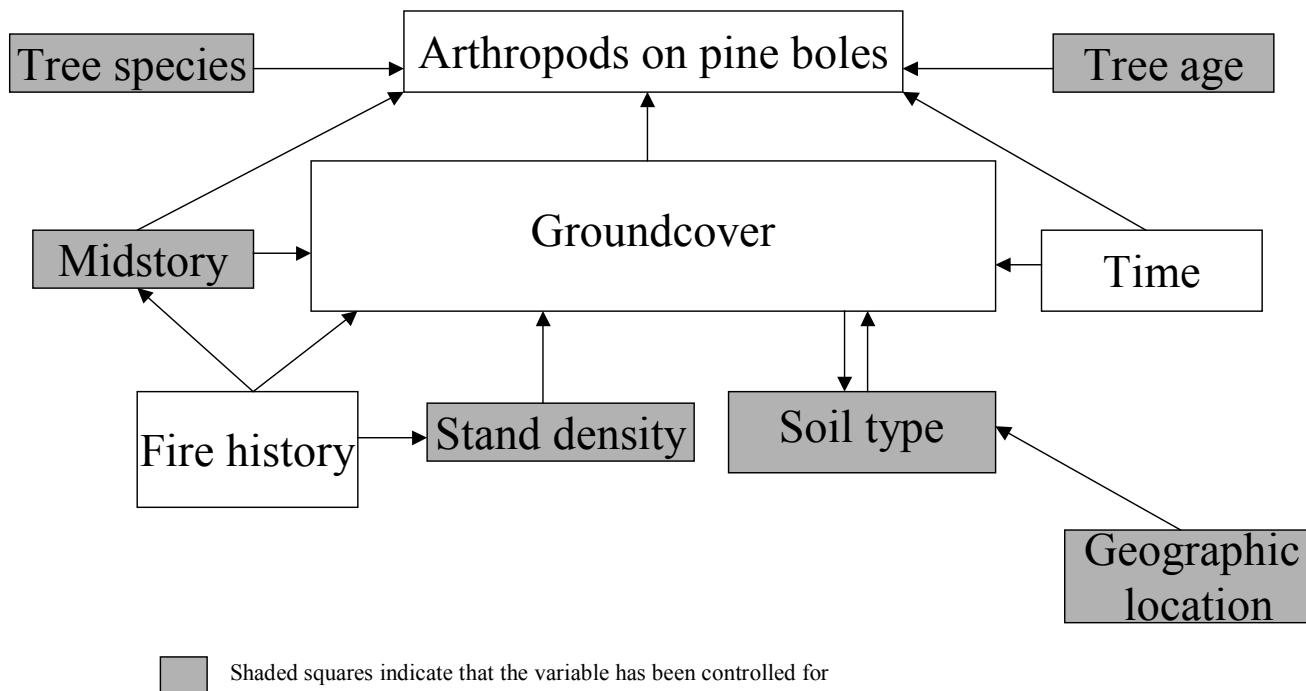


Figure 2.1. Inter-relationship of floral and faunal characteristics that influence the arboreal arthropod community of longleaf pine forests

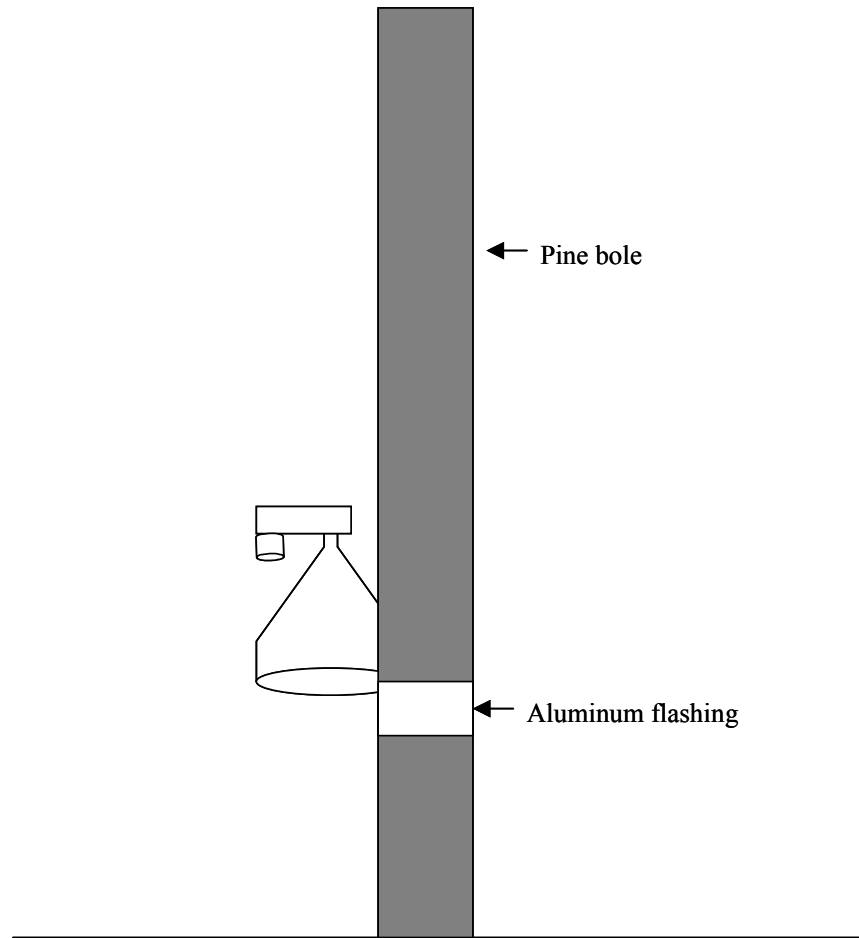


Figure 2.2. Diagram of arthropod trap used in this study. Design is modified from Hanula and New (1996).

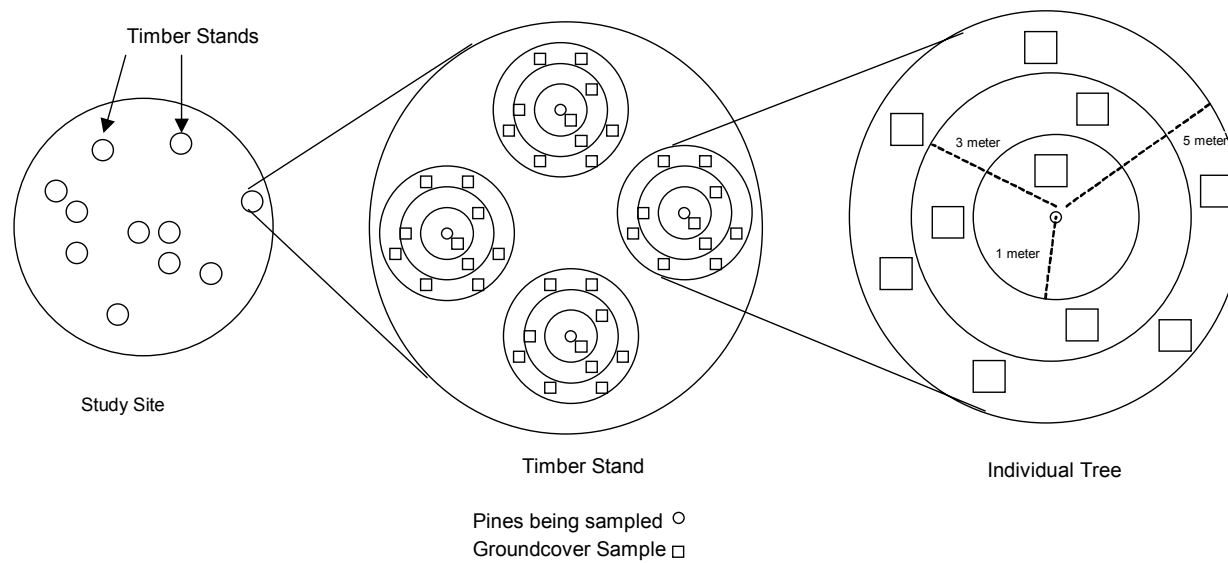


Figure 2.3. Arthropod and groundcover sampling methodology. Three study sites encompassing 34 timber stands were selected. Four longleaf pines from each timber stand were selected for arthropod sampling. Ten, 1m² groundcover samples were taken around each pine.

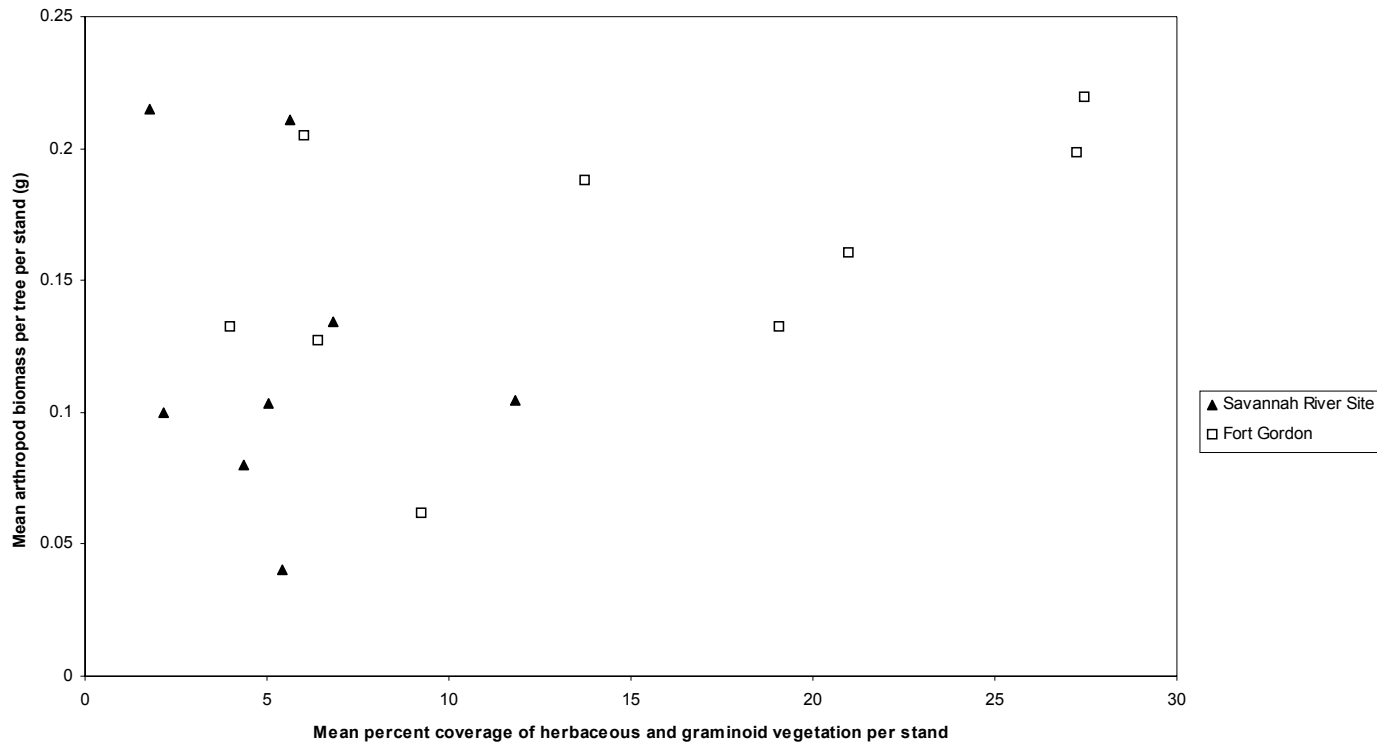


Figure 2.4. Relationship between mean arthropod biomass and the mean percent coverage of herbaceous and graminoid vegetation per timber stand at Savannah River Site, SC and Fort Gordon, GA during the months of April, May, and June, 2001. Data presented are an average of all three months for each timber stand. Data from timber stands burned during these months were excluded. Camp Lejeune, NC data are not included due to the site's distance from the other two sites.

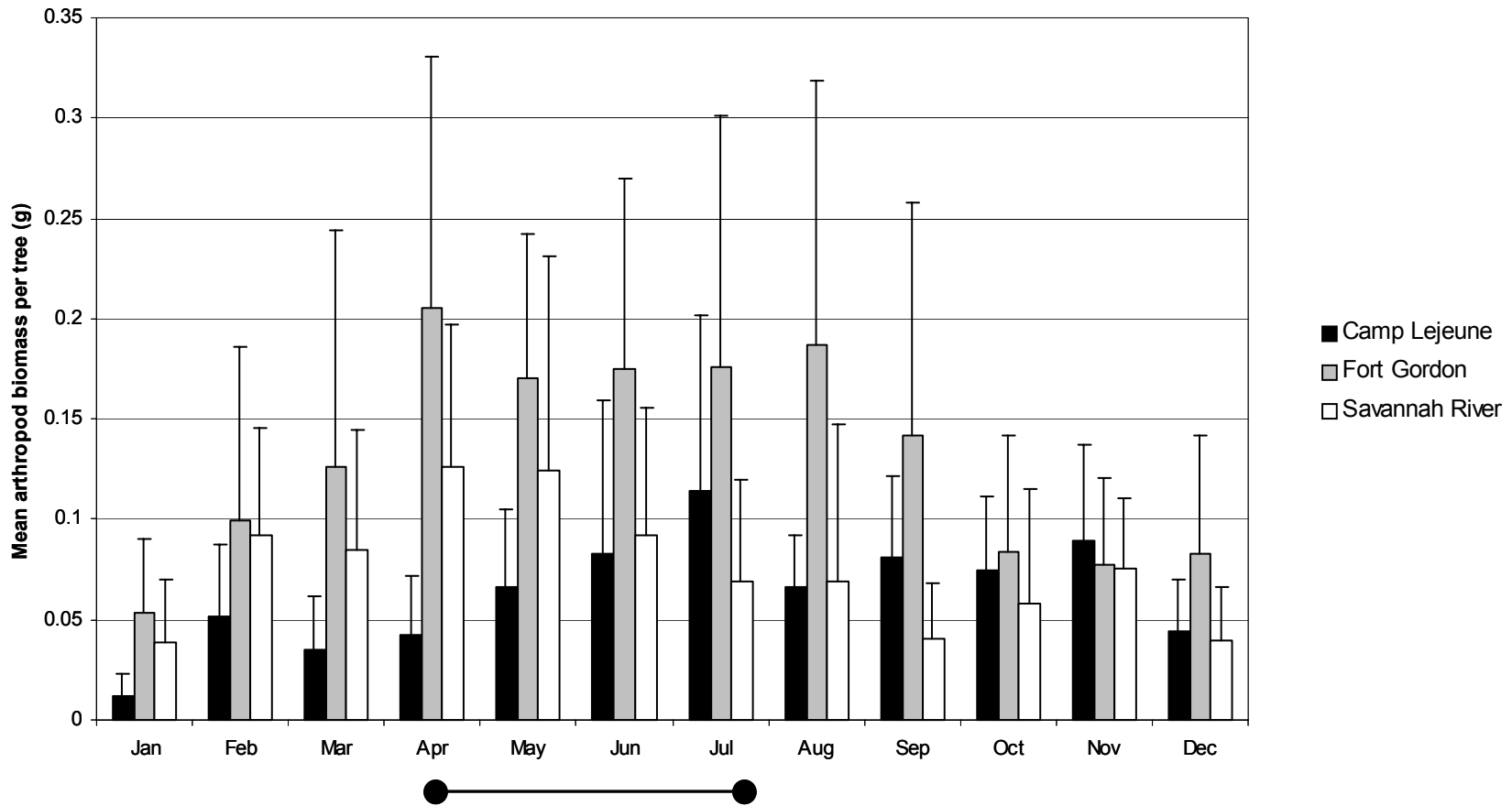


Figure 2.5. Mean arthropod biomass per month by site in 2001. Values are an average of the timber stands at each field site. Values for each timber stand are the mean number of arthropods in the traps located in each timber stand. The duration of the red-cockaded woodpecker nesting season is indicated by the horizontal bar below the x-axis. Standard deviation error bars are shown.

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Chapter 3

Seasonal Abundance and Biomass of Red-cockaded Woodpecker Arthropod Prey

INTRODUCTION

Knowledge of a threatened or endangered species' foraging behavior and diet is critical in the recovery of the species. The endangered red-cockaded woodpecker (*Picoides borealis*) is no exception. A small, cooperatively breeding woodpecker that is endemic to the pine forests of the southeastern United States, the red-cockaded woodpecker's preferred foraging habitat characteristics and diet preferences have been studied extensively (Beal 1911, Beal et al. 1916, Engstrom and Sanders 1997, Hardesty et al. 1997, Hess and James 1998, Zwicker and Walters 1999, Hanula et al. 2000b, Convery 2002, Walters et al. 2002). This research has revealed that the best foraging habitat for red-cockaded woodpeckers mimics pre-colonial vegetation characteristics (Hardesty et al. 1997, James et al. 1997, Zwicker and Walters 1999, James et al. 2001, Convery 2002, Walters et al. 2002). Prior to the arrival of European settlers, much of the southeastern United States was covered by extensive tracts of large longleaf pines (*Pinus palustris* Miller), with a rich groundcover dominated by herbaceous and graminoid plant species (Means and Grow 1985, Boyer 1990). Forests also were characterized by the lack of a successional invading hardwood midstory. These vegetative conditions were maintained by frequent growing season fires ignited by lightning strikes (Lemon 1949, Christensen 1981, Langdon 1981, Walker and Peet 1983, Walker 1993, Brockway and Lewis 1997, Rodgers and Provencher 1999). It is the decline of these fire-maintained pine forests through fire suppression or conversion into agriculture or pine plantations that has led to the decline of the red-cockaded woodpecker (U.S. Fish and Wildlife Service 2003).

Red-cockaded woodpeckers forage primarily on arthropods that they obtain by gleaning from the crevices and flaking bark on the surface of living pines, including longleaf, loblolly (*P. taeda* Linnaeus), shortleaf (*P. echinata* Miller), slash (*P. ellioti* Engelmann), and pond (*P. serotina* Michaux) pines (U.S. Fish and Wildlife Service 2003). Additionally, red-cockaded woodpeckers have been observed foraging on the surface of recently dead pines (Hooper and

Lennartz 1981). Red-cockaded woodpeckers rarely excavate into the living tissue of the pines in search of arthropod prey, although excavating into dead branches is common (Hooper and Lennartz 1981). Research into the specific tree characteristics that red-cockaded woodpeckers prefer indicates that they preferentially forage on the largest and oldest pines that are available, but apparently do not prefer one pine species over another (Hooper and Lennartz 1981, Porter and Labisky 1986, Jones and Hunt 1996, Engstrom and Sanders 1997, Hardesty et al. 1997, Zwicker and Walters 1999, Walters et al. 2002). Red-cockaded woodpeckers rarely forage on hardwoods or in the groundcover vegetation (Hooper and Lennartz 1981, Porter and Labisky 1986, Hardesty et al. 1997).

Arthropods comprise the bulk of the red-cockaded woodpecker's diet, while vegetative matter contributes only a minor portion (Beal 1911, Beal et al. 1916, Harlow and Lennartz 1977, Hanula and Franzreb 1995, Hess 1997, Hess and James 1998, Hanula and Engstrom 2000, Hanula et al. 2000b). In general, nestlings have higher percentages of arthropods in their diet than adults (Harlow and Lennartz 1977, Hanula and Franzreb 1995, Hess and James 1998, Hanula and Engstrom 2000, Hanula et al. 2000b). A list of arthropod orders confirmed in the diet of red-cockaded woodpeckers is presented in Table 2.2. Of particular importance for both adults and nestlings are ants, roaches, spiders, beetles, and centipedes. A wide variety of other arthropod orders are found less commonly in the diet. Diets of adult red-cockaded woodpeckers are dominated by ants, while studies of nestling diet have not consistently revealed one arthropod order to predominate after accounting for biases in sampling methods (Harlow and Lennartz 1977, Hanula and Franzreb 1995, Hess and James 1998, Hanula and Engstrom 2000, Hanula et al. 2000b).

For non-migratory species such as the red-cockaded woodpecker, data on the seasonality of prey abundance and biomass are particularly important to identify periods when food might be limiting or in excess. Timing of reproduction should face selection pressure to occur during or prior to periods of peak prey abundance and biomass (Martin 1987). Consequently, in some altricial bird species, including woodpeckers, variation in food supply during reproduction has been correlated with variability in reproductive success (Brodman et al. 1997, Olsson et al. 1999).

Fluctuations in food abundance have also been suggested to explain differences in reproductive success in red-cockaded woodpeckers (Beyer et al. 1996).

Several studies have examined the seasonality of red-cockaded woodpecker prey abundance and biomass. Hanula et al. (2000a), using passive arthropod traps mounted on longleaf pines, reported that arthropod biomass peaked during the winter and spring in Alabama and Florida. However, in a similar study using the same sampling technique, Hanula and Franzreb (1998) found that arthropod biomass and abundance in South Carolina peaked in the fall. Differences in results were attributed to differences in how abundance and biomass data were reported for each season (Hanula et al. 2000a). Both studies were consistent, however, in that arthropod biomass was lowest during the summer (Hanula and Franzreb 1998, Hanula et al. 2000a). In a study on the impacts of a hardwood midstory on arboreal arthropods in Texas, Collins et al. (2002) reported highest densities of arthropods on loblolly pines during the months of May and July, with a lesser peak occurring in November. Arthropod densities on shortleaf pines in areas without a hardwood midstory also peaked during May, July, and November. It should be noted that the shortleaf and loblolly pines were in the same timber stands, suggesting that intra-stand factors may be partially responsible for the similarity in results. Similarly, Horn (2000) found peak arthropod abundance on loblolly pines during summer months. Results of previous studies do not present a consistent picture of arthropod abundance and biomass, which may be due to differences in sampling methodology or to geographical variation.

Due to the inconsistent seasonal patterns that have been reported for red-cockaded woodpecker prey, additional research is needed. This study examines seasonal patterns in arboreal arthropod biomass at three sites in the southeastern U.S. I hypothesize that arthropod biomass and abundance peaks during the red-cockaded woodpecker breeding season when the increased abundance of food would facilitate the rearing of young.

METHODS

Study Sites

Arthropod abundance and biomass were sampled for one year at three field sites. The

field sites were Savannah River Site near New Ellenton, SC, Fort Gordon Army Base near Augusta, GA, and Camp Lejeune Marine Corp Base near Jacksonville, NC. The selection of three field sites was necessary in order to encompass the full range of timber stand vegetation conditions that are found throughout the range of the red-cockaded woodpecker.

Located in the upper Atlantic Coastal Plain physiographic province of South Carolina, the Savannah River Site (SRS) contains a rapidly growing population of red-cockaded woodpeckers. Although the facility is operated by the US Department of Energy (DOE), the US Forest Service (USFS) manages the forests for timber production and wildlife. The timber stands consist primarily of longleaf, loblolly, and slash pine, although other pine species are present in small numbers (Edwards et al. 1999). The groundcover in these timber stands is typically sparse due to agricultural use prior to the purchase of the site by DOE and intensive timber management since. Common groundcover species include poison oak (*Toxicodendron pubescens* Miller), *Vaccinium* species, brackenfern (*Pteridium aquilinum* (L.) Kuhn), and sassafras (*Sassafras albidum* Nuttall).

Fort Gordon US Army Signal Center (FG), approximately 45 km west-northwest of SRS, lies in the Fall Line transition zone between the Coastal Plain and the Piedmont Plateau. FG contains a small but growing population of red-cockaded woodpeckers inhabiting pine plantations managed by the Environmental/Natural Resources Management Office. Pine plantations contain loblolly, longleaf, and slash pine. Although the land comprising FG received considerable agricultural use in the past, the groundcover at FG is generally less degraded, relative to SRS, due to less intensive timber management. Common groundcover species include beargrass (*Nolina georgiana* Michaux), wiregrass (*Aristida stricta* Michaux), brackenfern, (*Andropogon* spp.), and *Vaccinium* species.

The third study site, Camp Lejeune Marine Corp Base, is located on the Atlantic Coastal Plain. This site contains the largest population of red-cockaded woodpeckers among the three sites chosen for this study. Similar to the other two sites, a large portion of the base is covered in plantations of longleaf and loblolly pine with small amounts of pond pine mixed in. The

predominant groundcover at Camp Lejeune is wiregrass, with *Vaccinium* sp., *Andropogon* sp., and other species in lesser abundance.

Study Design

Thirty-five timber stands distributed among the three field sites were chosen for sampling (10 at CL, 12 at FG, and 13 at SRS). Timber stands were chosen based on the presence of overstory habitat characteristics that would support red-cockaded woodpeckers, although the lack of red-cockaded woodpecker nesting cavities did not preclude a stand's inclusion. Timber stands were chosen to represent a wide variety of groundcover characteristics in order to examine the greatest range of possible effects that groundcover might have on arthropod abundance (see Chapter 2).

In order to control for the many variables that may influence arthropods on the pine boles (Figure 3.1), a number of limitations were imposed on the timber stands during the selection process. To control for soil type, timber stands at SRS and FG were restricted to Troup and Lakeland soil types, both of which are common in the upland areas of each site. Both are acidic, well drained, permeable soils with the upper horizons composed of loose sand grains (Paulk 1981, Rogers 1990). Troup and Lakeland soils are uncommon at CL, so timber stands with Kureb and Alpin soils, which are similar in composition to Troup and Lakeland soils (Barnhill 1992), were chosen.

Because the amount of bark surface area on tree boles varies in relation to bole diameter, the diameter of the trees was restricted to a narrow range. A survey of the size class distribution of the pines in each timber stand was conducted so that the largest commonly abundant tree diameter could be identified, resulting in the selection of pines 25.4-30.5cm dbh for sampling.

A study of the arthropod communities on two common southern pines revealed that arthropod abundance on the bole varied among tree species (Horn and Hanula 2002). Longleaf pines contain a significantly larger population of arthropods than loblolly pines. Based on this observation and the USFWS (2003) emphasis on longleaf pine planting for red-cockaded

woodpecker recovery, I selected longleaf pine as the tree species for arthropod sampling. Other variables depicted in Figure 3.1, such as the amount of hardwood midstory, stand density, and geographic location, were statistically controlled for during the analysis.

Arthropod sampling was conducted continuously for one calendar year with samples collected every 30 days. Arthropod traps were placed at breast height (1.4m) on four randomly selected longleaf pines, within the size criteria described above, in each of the selected timber stands resulting in 136 arthropod traps. The arthropod traps were a modified version of the trap described by Hanula and New (1996). The trap design consisted of an inverted funnel mounted to the pine bole, with a plastic container attached at the narrow opening of the funnel. Secured to the container was a removable sample cup filled with a 1% formaldehyde solution. A small amount of dishwashing detergent was added to the trapping solution to help break the surface tension, allowing arthropods to sink when they fell into the sample cup. 3M™ spray adhesive was used to attach sand to the inside of each funnel to provide a surface on which the arthropods could climb. To aid in channeling arthropods into the funnel, a 15cm wide band of aluminum flashing was placed around the tree with a gap in the flashing located beneath the opening to the funnel. Arthropods entered the funnel and crawled upwards, eventually falling into the sample cup where they were preserved until the samples were collected. A diagram of the funnel trap is found in Figure 2.2.

After the sample cups were collected for each 30 day sampling period, each stand's sample was sorted and arthropods were identified to order or morphotype (excluding collembola, mites, and small dipterans that were perceived to be too small to serve as red-cockaded woodpecker prey). After sorting, samples were stored in vials of 70% ethanol until drying. Biomass measurements for each sample were obtained by drying the contents of each sample at 60° C for 24 hours before weighing.

Statistical Analysis

Abundance

Monthly arthropod abundance values at each site are reported as an average of the number

of arthropods captured per trap in each timber stand. Abundance values for individual orders were derived in the same manner. Abundance values are reported for timber stands instead of individual traps because of presumed lack of independence among samples within the same timber stand. Some monthly averages in some timber stands are based on fewer than 4 traps due to missing traps. No timber stands with less than 3 arthropod traps for any monthly sample were included in the results. Results are not analyzed for individual timber stands during months with wildfires or prescribed burns which resulted in the number of monthly timber stands ranging from 28 to 35 (9-10 at CL, 6-12 at FG, 9-13 at SRS). Arthropod sampling resumed the following month for stands that were burned.

Combined monthly arthropod abundance values for each of the three sites were determined by averaging the stand abundance values. Seasonal abundance values were determined by averaging the mean monthly abundance values for all timber stands during the three months comprising each of the seasons. Months were assigned to seasons in a manner to allow comparisons to existing literature on seasonal abundance (Hanula and Franzreb 1998): Winter - January, February, March; Spring - April, May, June; Summer - July, August, September; Fall - October, November, December. Seasonal monthly timber stand values were analyzed using PROC MIXED in SAS with Tukey's Honestly Significantly Difference (HSD) procedure used for comparisons of least square means setting $\alpha = 0.05$ *a priori* (SAS Institute 2001). Because the three field sites were independent with respect to their arthropod communities, site effects were incorporated into the mixed model analysis.

Biomass

Like abundance values, monthly biomass estimates for each site represent the average of the stand values for that site. The stand values were calculated by averaging the arthropod biomass captured in the traps in the timber stand. Seasonal biomass values were determined by averaging the mean monthly biomass values for all timber stands during the three months comprising each of the seasons. Seasonal monthly timber stand values were analyzed using PROC MIXED in SAS with Tukey's Honestly Significantly Difference (HSD) procedure used for comparisons of least square means, setting $\alpha = 0.05$ *a priori* (SAS Institute 2001).

RESULTS

During the one year sampling period, approximately 31,500 arthropods encompassing nineteen orders were collected in approximately 1600 monthly samples. Of the fourteen orders that have been identified in the literature as being prey items of red-cockaded woodpeckers (Beal et al. 1916, Harlow and Lennartz 1977, Hess and James 1998, Hanula and Engstrom 2000), twelve were collected in this study (Table 2.2). The two orders not collected in this study (Scorpionida, Odonata) make up extremely minor components of the red-cockaded woodpecker diet (Harlow and Lennartz 1977, Hess and James 1998). These results, combined with the opportunistic foraging behavior of the red-cockaded woodpecker (Hanula *In press*), suggest that the arthropods captured in the traps used in this study are a reasonable representation of red-cockaded woodpecker prey.

It is important to note that the arthropod traps used in this study were passive traps and only caught arthropods that were moving up the bark of the pines. The absence of arthropods during a particular time of the year does not necessarily indicate that their populations are low during that sampling period, but could instead indicate that they are not particularly mobile during that period. Trends may reflect temperature influenced levels of mobility or true fluctuations in arthropod abundance.

The number of arthropods that were available to red-cockaded woodpeckers tended to increase during the spring and into the summer, although a late fall peak also occurred (Figures 3.2, 3.3). Peaks during the spring and summer were largely due to increases in Hymenopteran abundance while the early winter peak was due to an increase in aphids (Homoptera).

When seasonal abundance data from all three sites were combined (Table 3.1), spring and summer abundance were not significantly different from each other ($p=0.53$) but were significantly higher than fall and winter abundance (Figure 3.4). Abundance in fall and winter were not significantly different from each other ($p=0.65$).

The abundance of different arthropod orders varied seasonally in different ways, and the nature of this variation frequently was consistent among the three study sites. Spider (Araneae) abundance was bimodal with peaks occurring in April-June and December-February at all three sites (Figure 3.5). Although few wood roaches (Blattaria) were caught, there was a consistent peak during the spring and summer, and very few wood roaches were active during the cooler months of the year (Figure 3.6). Similar to wood roaches, very few centipedes (Chilopoda) were caught during the sampling period. The limited data suggest that centipedes were more active during the warmer months of the year (Figure 3.7). Beetles (Coleoptera), were caught throughout the year and tended to be caught in greater abundance during the winter and spring months at all three field sites (Figure 3.8). Hymenopterans, primarily ants, exhibited strong seasonality with peaks in abundance occurring during the summer months (Figure 3.9). The peak in Hymenopteran abundance during December at Fort Gordon may be an artifact of a reduced number of arthropod traps during that sampling period. Due to an aggressive prescribed burning program, 6 of the 12 timber stands at Fort Gordon were burned during the month of December which eliminated the traps in these stands from analysis.

Arthropod biomass also exhibited seasonality with peaks occurring during the spring and summer months (Figure 3.10). Among the different sites, Fort Gordon had the highest seasonal biomass which occurred over a broad peak from April-August. Savannah River Site had a smaller peak that occurred earlier in the year (April, May) when compared to the other two sites.

When seasonal abundance data from all three sites were combined (Table 3.2), the spring and summer biomass were not significantly different from each other ($p=0.25$) but were significantly higher than fall and winter biomass (Figure 3.11). Fall and winter biomass were not significantly different from each other ($p=0.99$).

DISCUSSION

In their analysis of red-cockaded woodpecker reproduction and foraging habitat, Beyer et al. (1996) speculate that variation in prey abundance may be related to variation in red-cockaded woodpecker reproductive success. Studies of another woodpecker species, the lesser spotted

woodpecker (*Dendrocopos minor*), indicate that food availability during the breeding season has a significant influence on reproductive success (Olsson et al. 1999, Wiktander et al. 2001). As a result, breeding efforts should be selected to occur during times of peak arthropod abundance and biomass. Results of this study indicate that arthropod prey biomass is highest during the red-cockaded woodpecker breeding season, which typically runs from April through July (Figure 3.10). Because energy demands of altricial young increase as they mature (Martin 1987), the sustained increase in arthropod biomass throughout the latter part of the red-cockaded woodpecker breeding season facilitates adults in meeting the increasing food demand. Additionally, arthropod prey abundance increases throughout the breeding season, resulting in a peak during late spring and early summer (Figures 3.3 and 3.4). These results indicate that food availability is greatest when red-cockaded woodpecker demand is greatest. My results also suggest that food is reduced during winter and thus may be a limiting factor affecting survival. There are no data demonstrating that survival is lowest in winter, or linking survival during the winter to food, however.

Red-cockaded woodpeckers exhibit an interesting spatial foraging partitioning in which females feed low on the pine bole and males forage on the upper bole and branches of the tree (Ligon 1970, Hooper and Lennartz 1981, Engstrom and Sanders 1997, Hardesty et al. 1997). Consequently, the results of this study are particularly applicable to female red-cockaded woodpeckers due to the low height of the arthropod traps (" 1.4m). The increasing availability and biomass of arthropods as the breeding season approaches in April and May (Figures 3.2, 3.3 and 3.10) suggests that female red-cockaded woodpeckers receive increased food resources during a critical period for egg production. Levels of food resources prior to egg formation are reflected in the quality or quantity of the year's offspring (Martin 1987). Arthropods located low on the pine bole may be an important source of nutrients prior to egg formation. Prescribed fire and the emergence of new vegetation during the spring have been hypothesized to provide additional nutrients to these arthropods which are then passed on to female red-cockaded woodpeckers (James et al. 1997).

Results of this study indicate that the composition of the arthropod fauna that is available as prey for the red-cockaded woodpecker changes throughout the year. Of particular interest is the increase in availability of ants (Hymenopteran sp.), primarily *Crematogaster* species, at the start of the red-cockaded woodpecker breeding season, which then continues to increase throughout the spring and summer. Previous studies have shown ants constitute a large portion of the adult red-cockaded woodpecker's diet as well as a moderate portion of nestling diet (Hess and James 1998). The seasonal trends seen in this study (Figure 3.9) help explain the decline of ants in the diet of adult red-cockaded woodpeckers during fall (Hess and James 1998). Also of particular interest is the consistent presence of spiders (Araneae sp.) throughout the year. Spiders may constitute an important part of the diet of red-cockaded woodpeckers during the winter months when arthropod biomass and abundance were low.

Previous studies do not present a consistent picture of arthropod abundance in southeastern pine forests. Results of this study substantiate previous findings that arthropod abundance peaks in May and July on loblolly and shortleaf pines in Texas (Collins et al. 2002), but do not agree with results reported by Hanula and Franzreb (1998), who used similar arthropod traps on longleaf pines at one of the three field sites (Savannah River Site) used in my study. Hanula and Franzreb (1998) reported peaks in arthropod abundance during the summer and peaks in arthropod biomass during the winter. During this study arthropod abundance at Savannah River Site peaked in late spring and early summer (Figure 3.2) and arthropod biomass peaked during the spring (Figure 3.10). The differences in results may be due to yearly variations in weather conditions. Another possible reason for this discrepancy is a difference in methodology. Hanula and Franzreb (1998) collected samples for a one week period during each month and extrapolated to the entire month. I sampled arthropods continuously during each 30 day sampling period and used all data collected in the analysis. By sampling continuously, monthly trap results do not reflect potential short term fluctuations in arthropod abundance that may bias shorter sampling periods. The accuracy of the arthropod abundance and biomass trends reported in this study are supported by their consistency across the three field sites that were sampled (Figures 3.2 and 3.10). The correspondence of increases in arthropod abundance and biomass with the red-cockaded woodpecker breeding season also is reassuring.

One limitation of this study that should be noted is that it only quantifies the arthropod community that is crawling up from the forest floor and conclusions cannot be extended to arthropods that fly onto the pine bole. However, Hanula and Franzreb (1998) documented that arthropod biomass on the pine bole was significantly reduced (up to 75%) by the placement of barriers at the base of the tree that prevented arthropods from crawling up the bole from the forest floor. Additionally they noted that these barriers did not completely stop the upward movement of arthropods, suggesting that the reduction in arthropod biomass they observed may be an underestimate. Because of this, they concluded that a significant portion of arthropod biomass is crawling up from the forest floor (Hanula and Franzreb 1998). These observations indicate that the results of this study are applicable for much of the arthropod community that makes up the diet of the red-cockaded woodpecker.

Many factors influence arthropod abundance in southeastern pine forests (Figure 3.1). Coarse woody debris (Horn 2000), hardwood midstory (Collins et al. 2002), and groundcover composition (see Chapter 2) have all been demonstrated to influence arboreal arthropod communities. Because the original purpose of this study was to determine the influence that groundcover composition has on arboreal arthropod populations, seasonal arthropod trends reflect the influence of a broad range of groundcover types. Additionally, the amount of coarse woody debris and hardwood midstory were not controlled for. Therefore, the results of this study reflect a broad range of conditions found in southeastern pine forests. In order to better understand seasonal arthropod trends, future research should focus on mechanisms that might be responsible for the observed trends.

Table 3.1. Results of seasonal abundance pairwise comparisons. Comparisons are between seasonal least squares means. Data from 3 month periods are combined to obtain seasonal data (winter - January, February, March; spring - April, May, June; summer - July, August, September; fall - October, November, December).

	Winter	Spring	Summer
Winter (O = 13.059)			
Spring (O = 23.409)	p < 0.0001		
Summer (O = 26.566)	p < 0.001	p = 0.53	
Fall (O = 16.453)	p = 0.65	p = 0.0002	p < 0.0001

Table 3.2. Results of seasonal biomass pairwise comparisons. Comparisons are between seasonal least squares means. Data from 3 month periods are combined to obtain seasonal data (winter - January, February, March; spring - April, May, June; summer - July, August, September; fall - October, November, December).

	Winter	Spring	Summer
Winter (O = 0.068g)			
Spring (O = 0.122g)	p < 0.0001		
Summer (O = 0.105g)	p < 0.0001	p = 0.25	
Fall (O = 0.068g)	p = 0.99	p < 0.0001	p = 0.0002

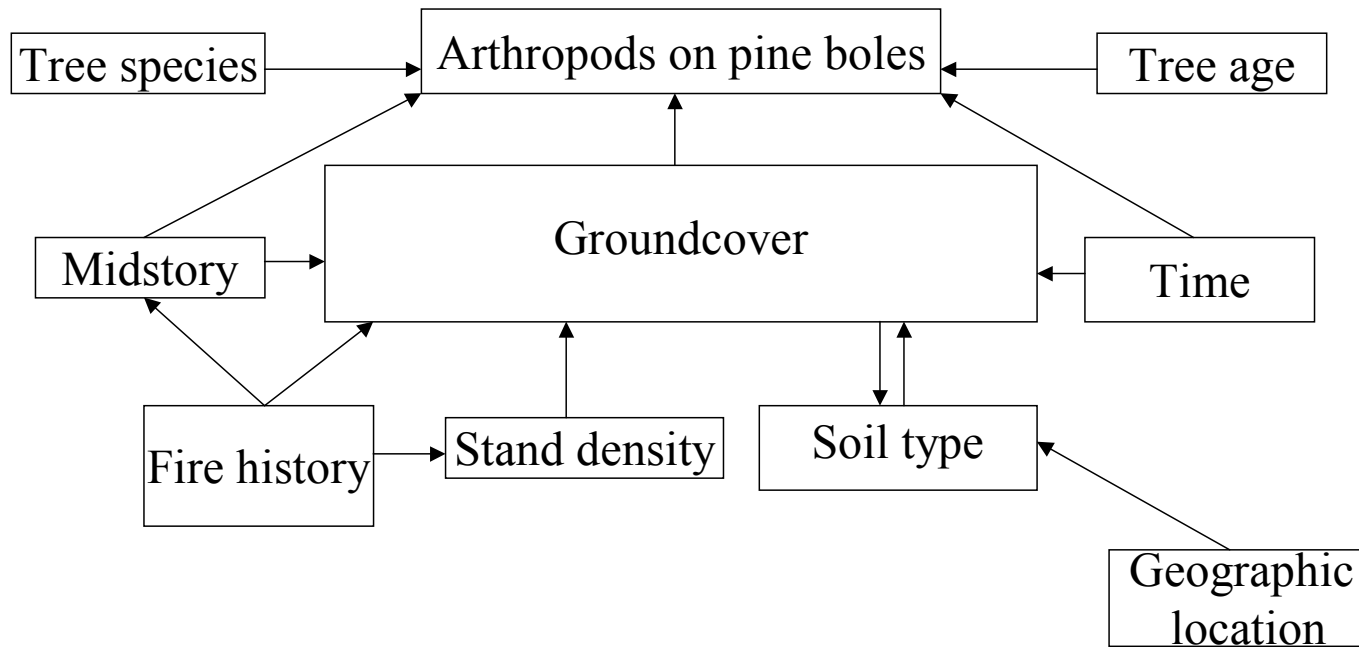


Figure 3.1. Inter-relationship of floral and faunal characteristics that influence the arboreal arthropod community of longleaf pine forests

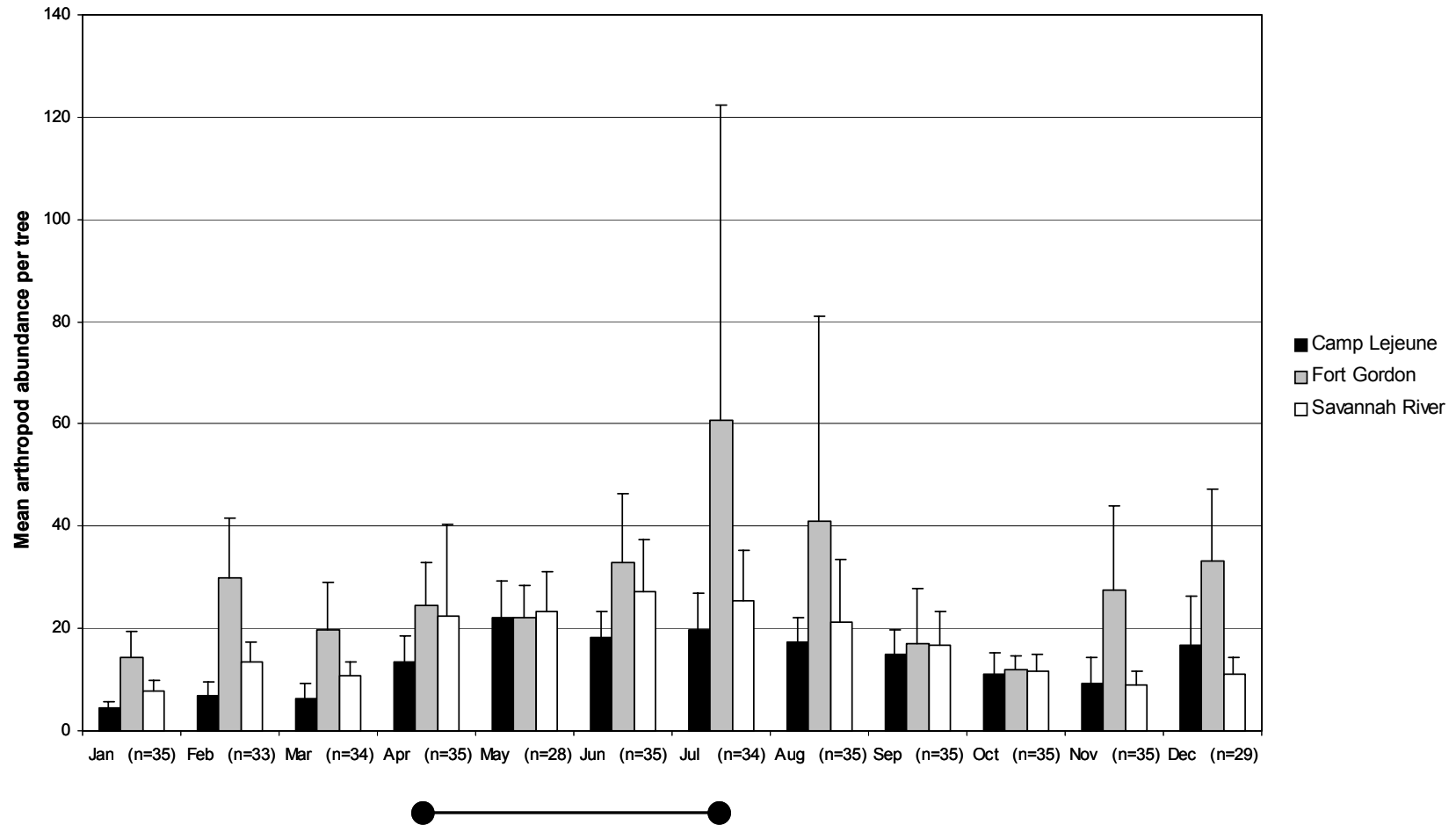


Figure 3.2. Mean number of arthropods per month in 2001. Values are an average of the timber stands at each field site. Values for each timber stand are the mean number of arthropods in the traps located in the stand. The duration of the red-cockaded woodpecker nesting season is indicated by the horizontal bar below the x-axis. Standard deviation error bars are shown.

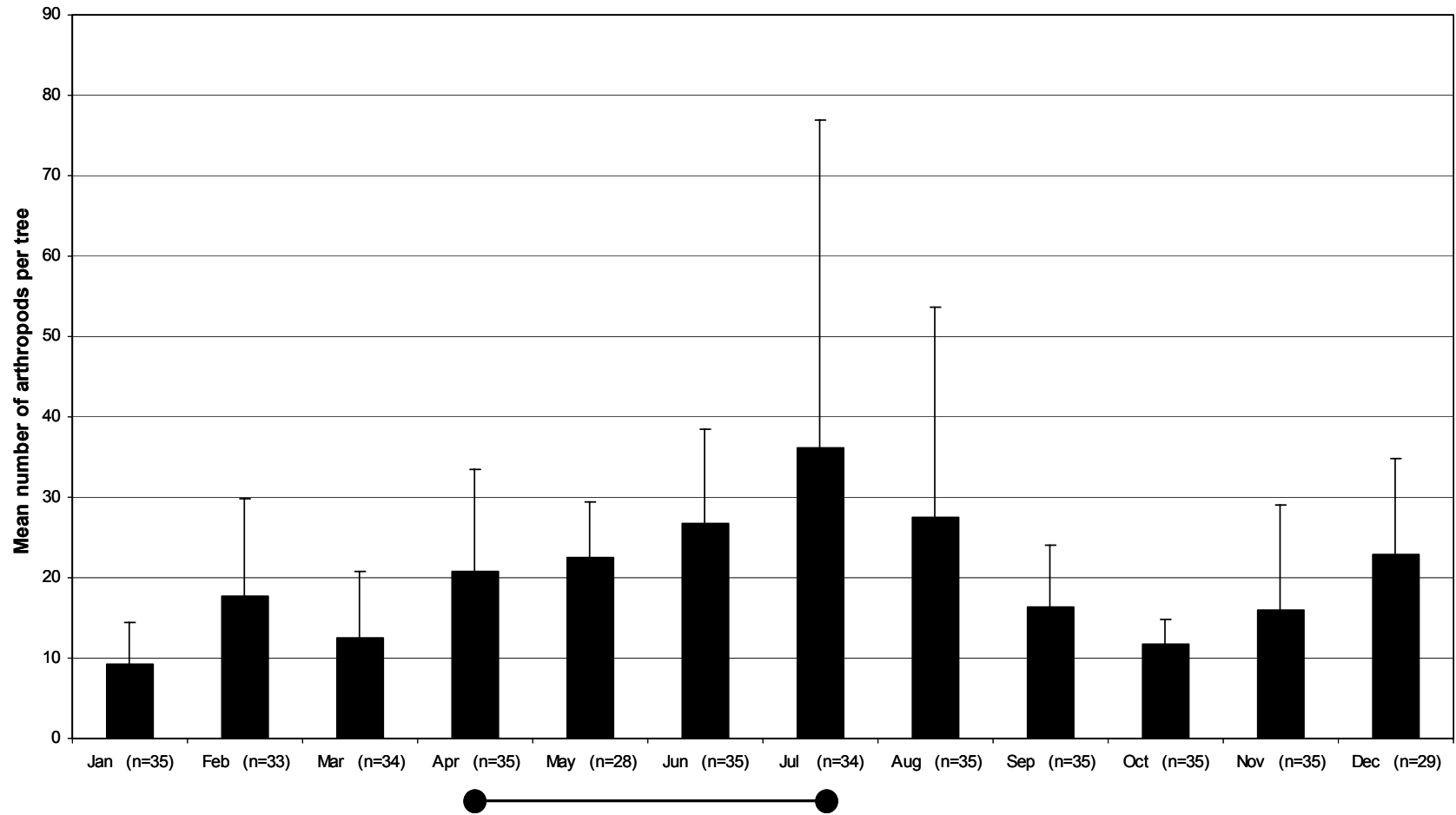


Figure 3.3. Mean number of arthropods per month in 2001 at all three study sites. Values are an average of the timber stands at all field sites. Values for each timber stand are the mean number of arthropods in the traps located in each timber stand. The duration of the red-cockaded woodpecker nesting season is indicated by the horizontal bar below the x-axis. Standard deviation error bars are shown.

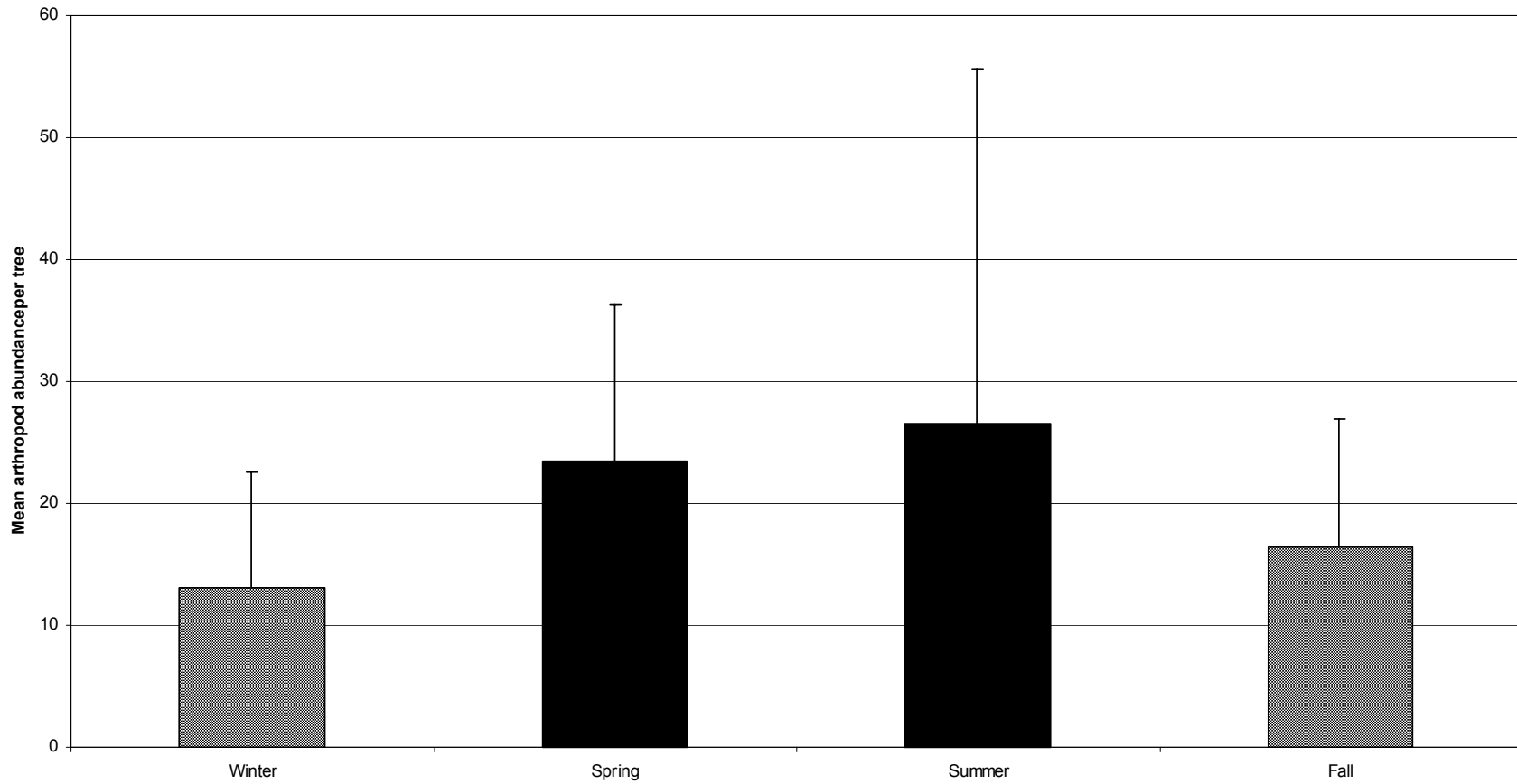


Figure 3.4. Comparison of arthropod seasonal abundance data from all three study sites in 2001. Bars of different color are significantly different ($\alpha = 0.05$). Data from 3 month periods are combined to obtain seasonal data (winter - January, February, March; spring - April, May, June; summer - July, August, September; fall - October, November, December). Standard deviation error bars are shown. Significance values of pairwise comparisons are presented in Table 3.1.

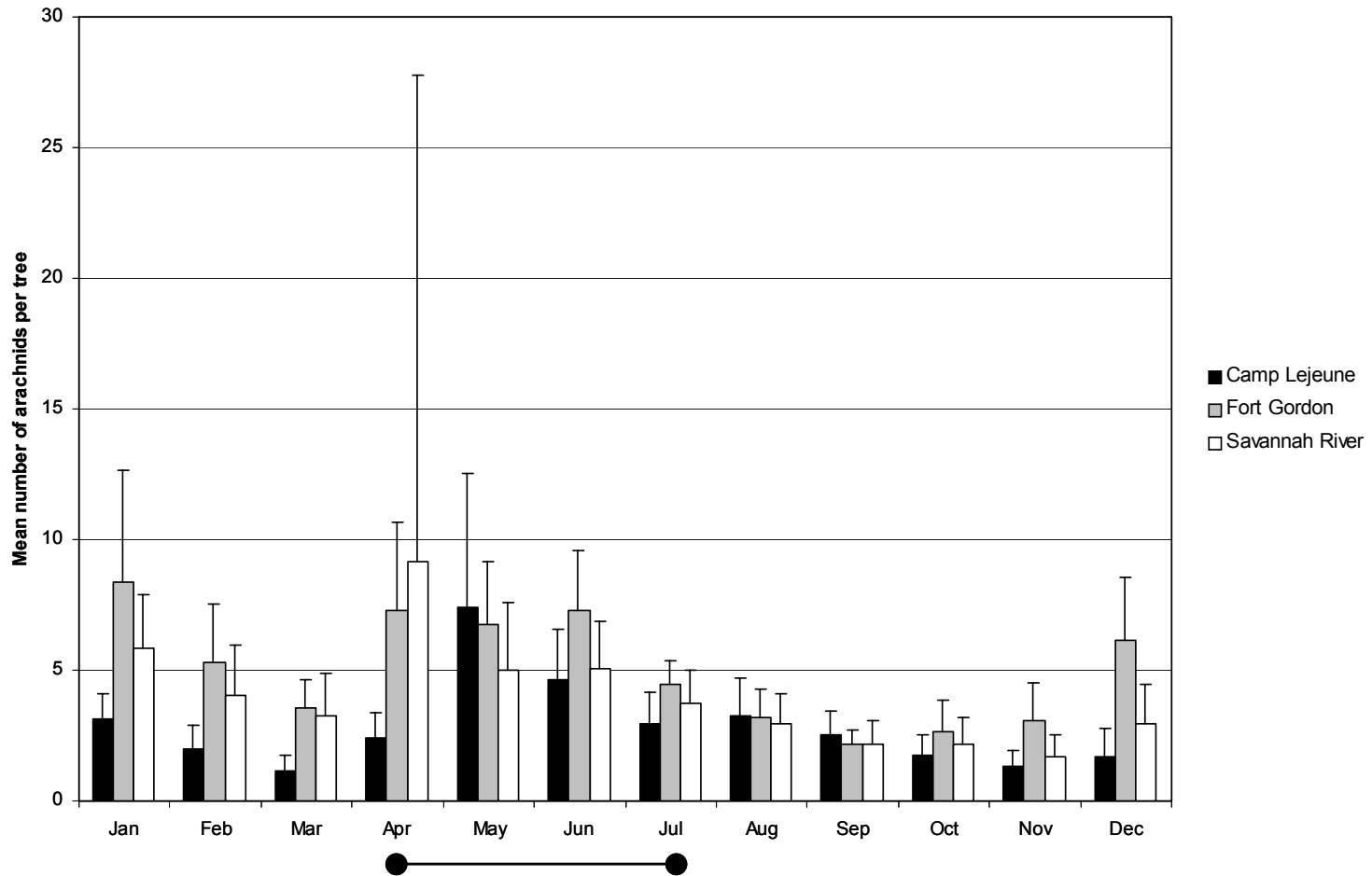


Figure 3.5. Mean number of Araneae per month in 2001. Values are an average of the timber stands at each field site. Values for each timber stand are the mean number of arthropods in the traps located in each timber stand. The duration of the red-cockaded woodpecker nesting season is indicated by the horizontal bar below the x-axis. Standard deviation error bars are shown.

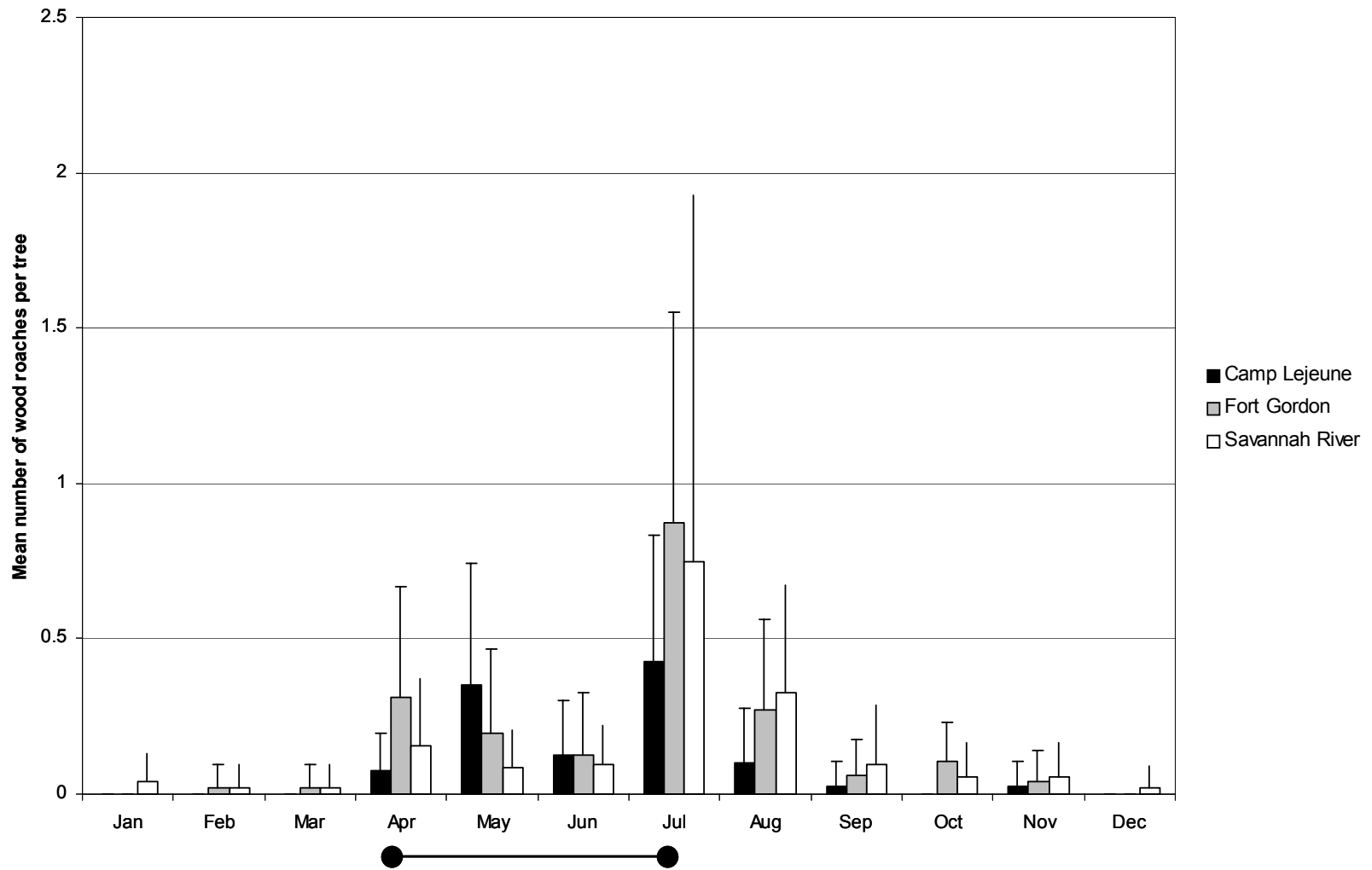


Figure 3.6. Mean number of Blattaria per month in 2001. Values are an average of the timber stands at each field site. Values for each timber stand are the mean number of arthropods in the traps located in each timber stand. The duration of the red-cockaded woodpecker nesting season is indicated by the horizontal bar below the x-axis. Standard deviation error bars are shown.

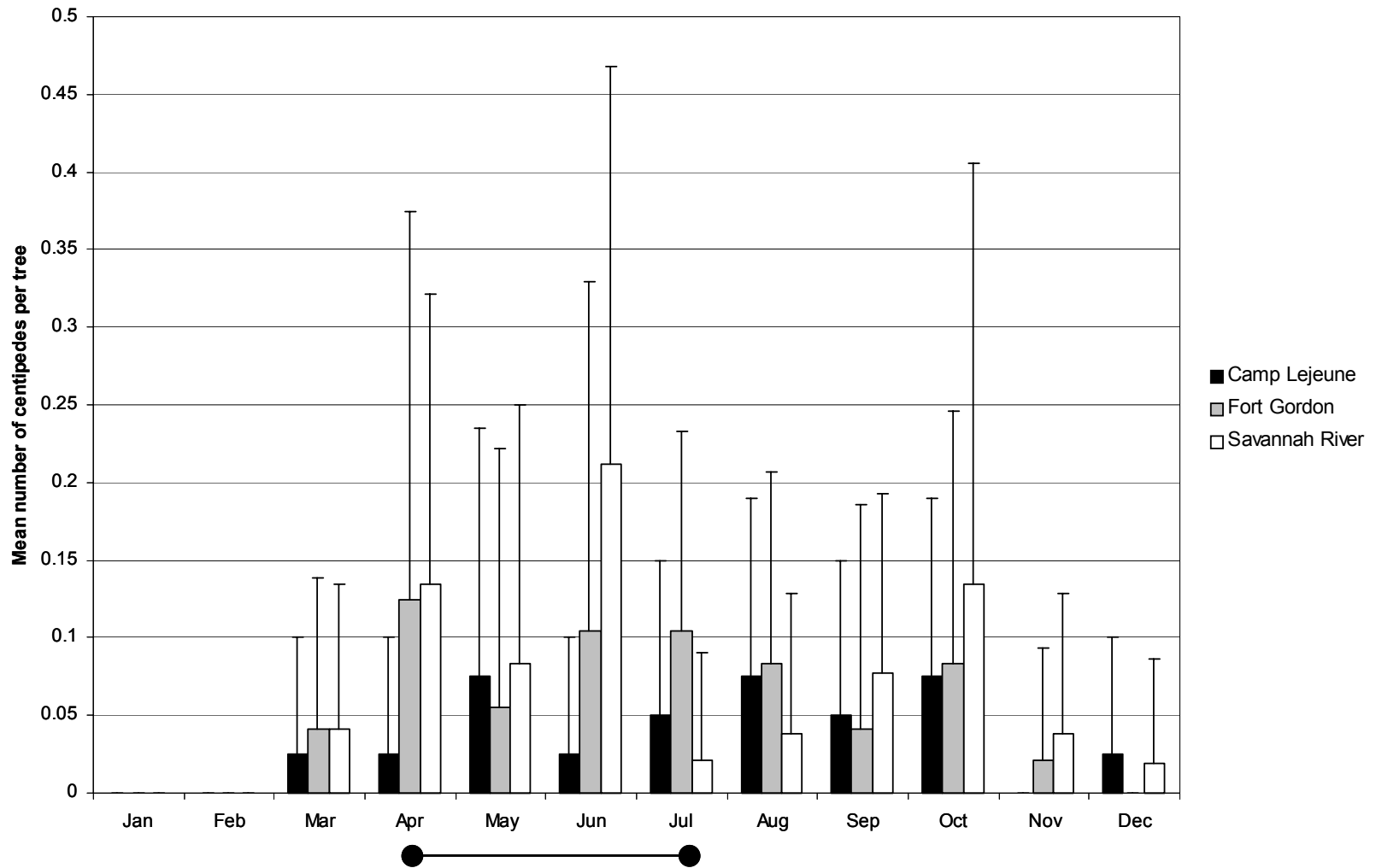


Figure 3.7. Mean number of Chilopoda per month in 2001. Values are an average of the timber stands at each field site. Values for each timber stand are the mean number of arthropods in the traps located in each timber stand. The duration of the red-cockaded woodpecker nesting season is indicated by the horizontal bar below the x-axis. Standard deviation error bars are shown.

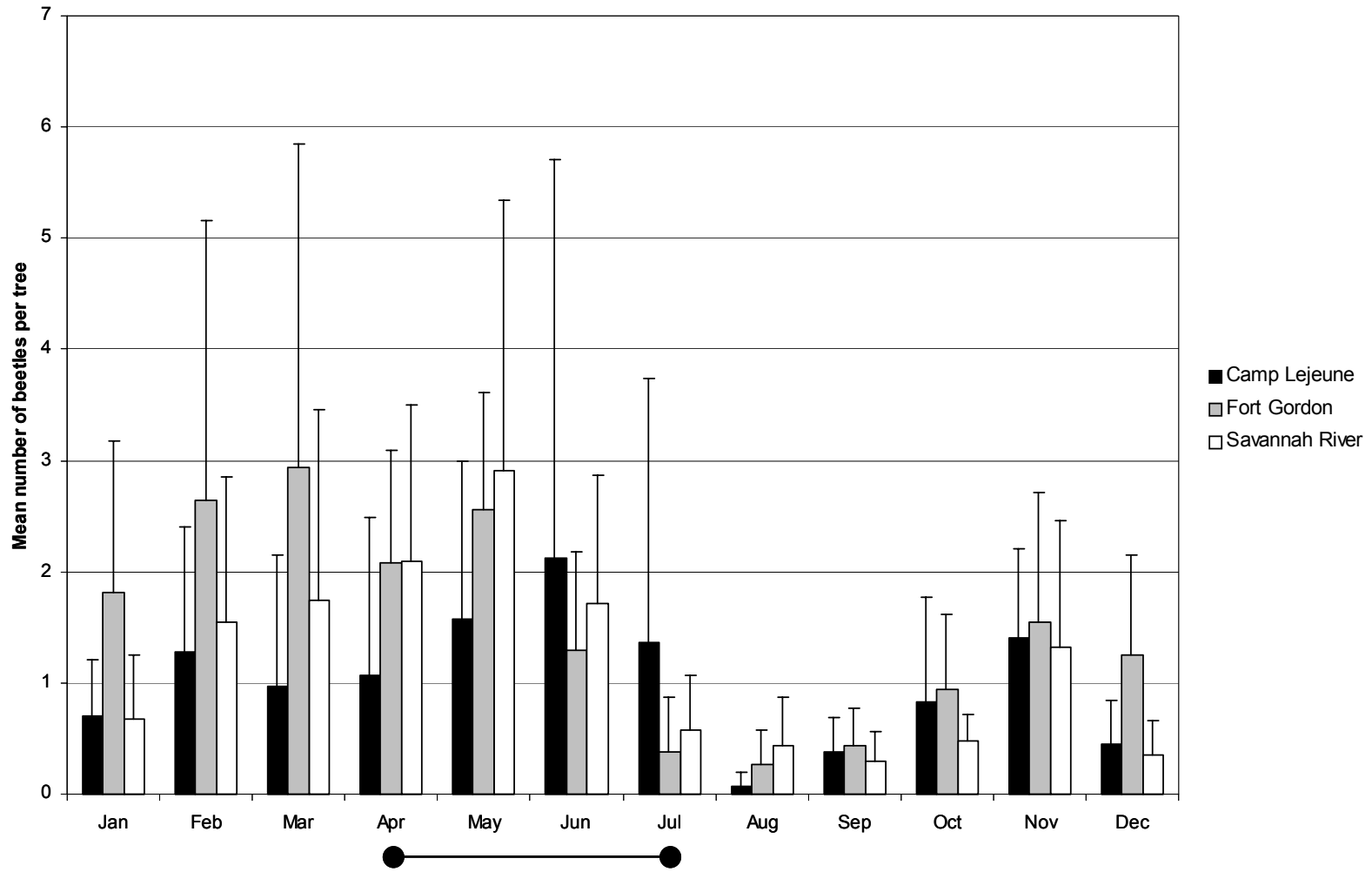


Figure 3.8. Mean number of Coleoptera per month in 2001. Values are an average of the timber stands at each field site. Values for each timber stand are the mean number of arthropods in the traps located in each timber stand. The duration of the red-cockaded woodpecker nesting season is indicated by the horizontal bar below the x-axis. Standard deviation error bars are shown.

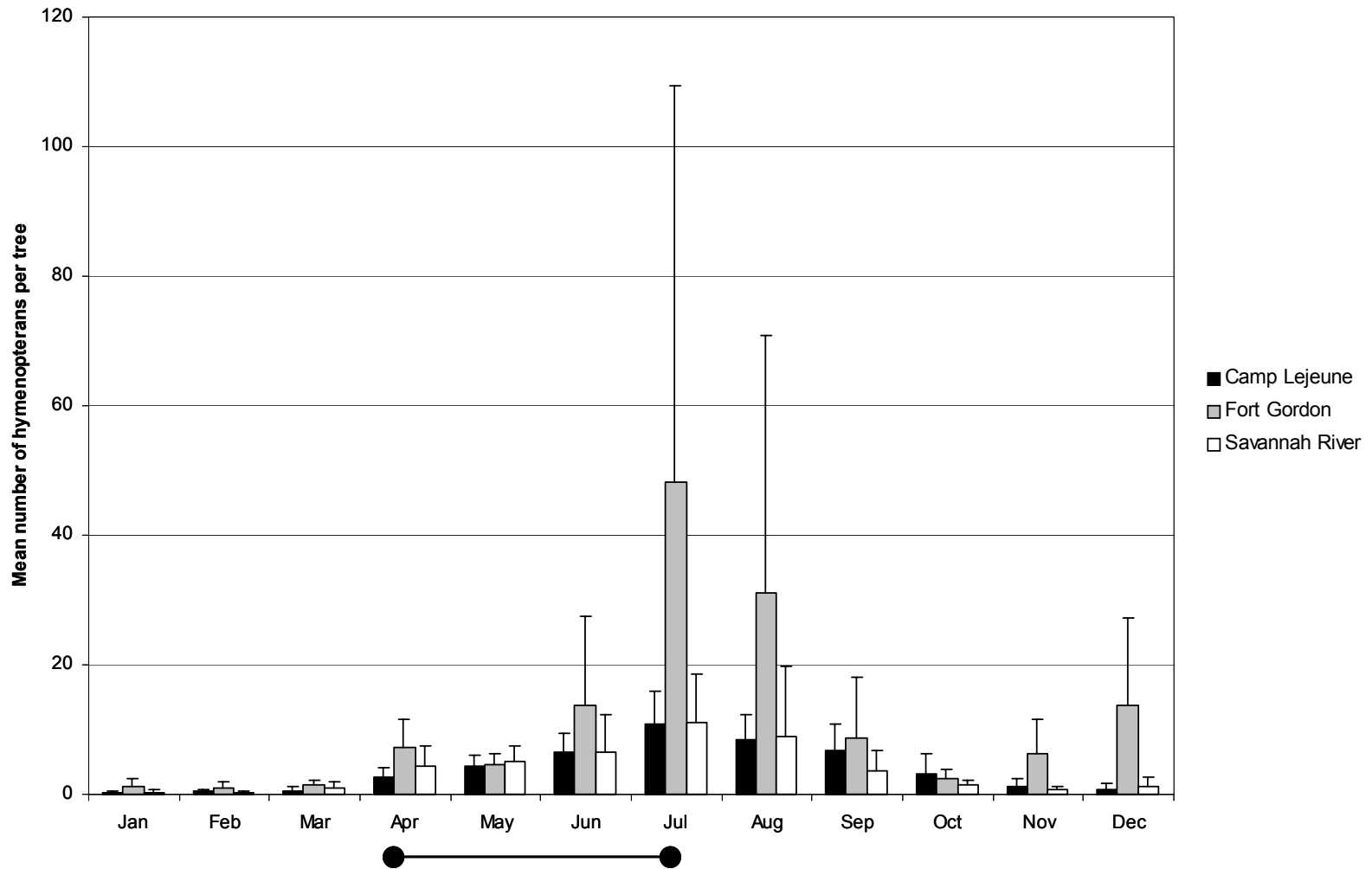


Figure 3.9. Mean number of Hymenoptera per month in 2001. Values are an average of the timber stands at each field site. Values for each timber stand are the mean number of arthropods in the traps located in each timber stand. The duration of the red-cockaded woodpecker nesting season is indicated by the horizontal bar below the x-axis. Standard deviation error bars are shown.

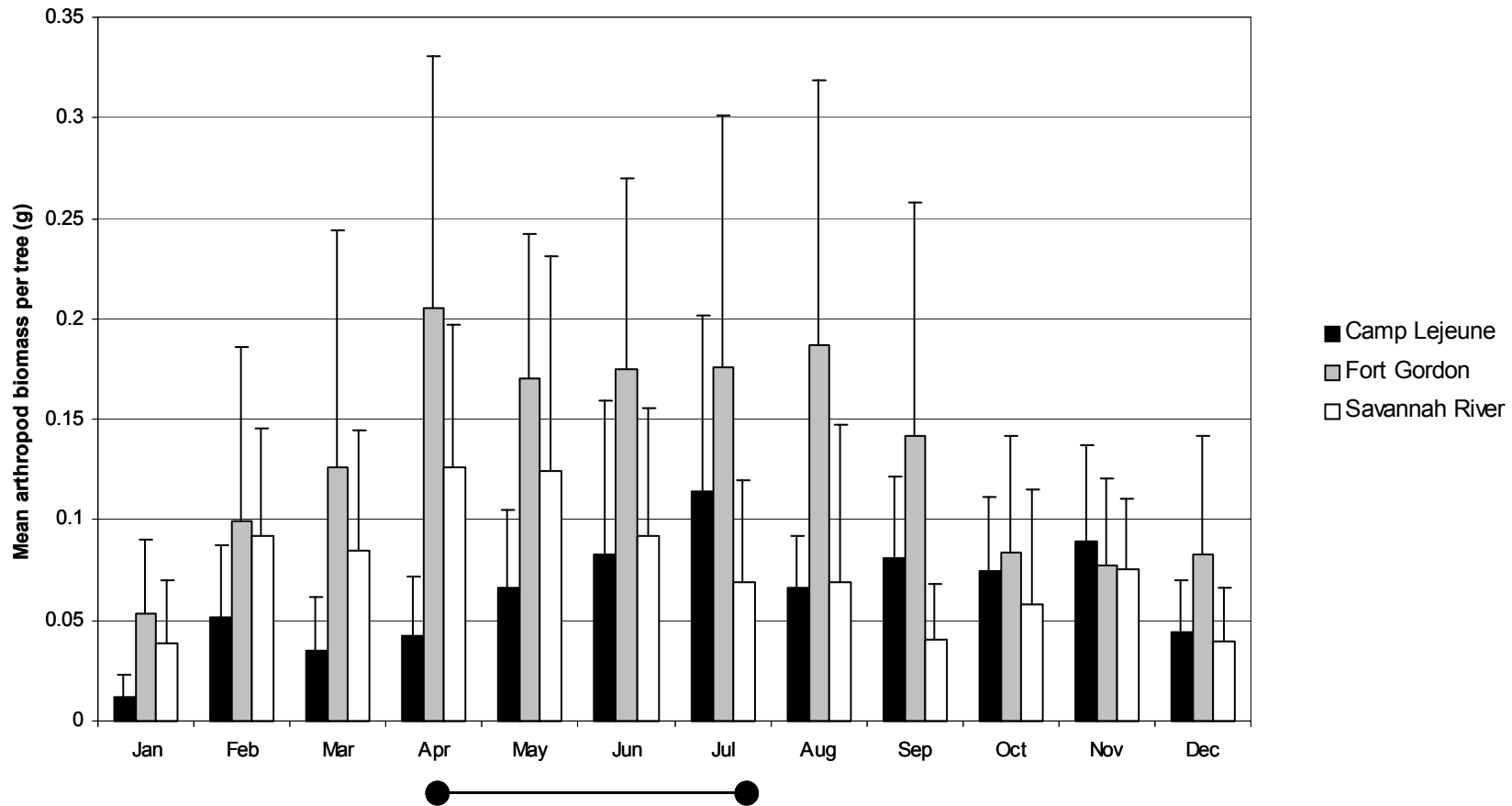


Figure 3.10. Mean arthropod biomass per month by site in 2001. Values are an average of the timber stands at each field site. Values for each timber stand are the mean number of arthropods in the traps located in each timber stand. The duration of the red-cockaded woodpecker nesting season is indicated by the horizontal bar below the x-axis. Standard deviation error bars are shown.

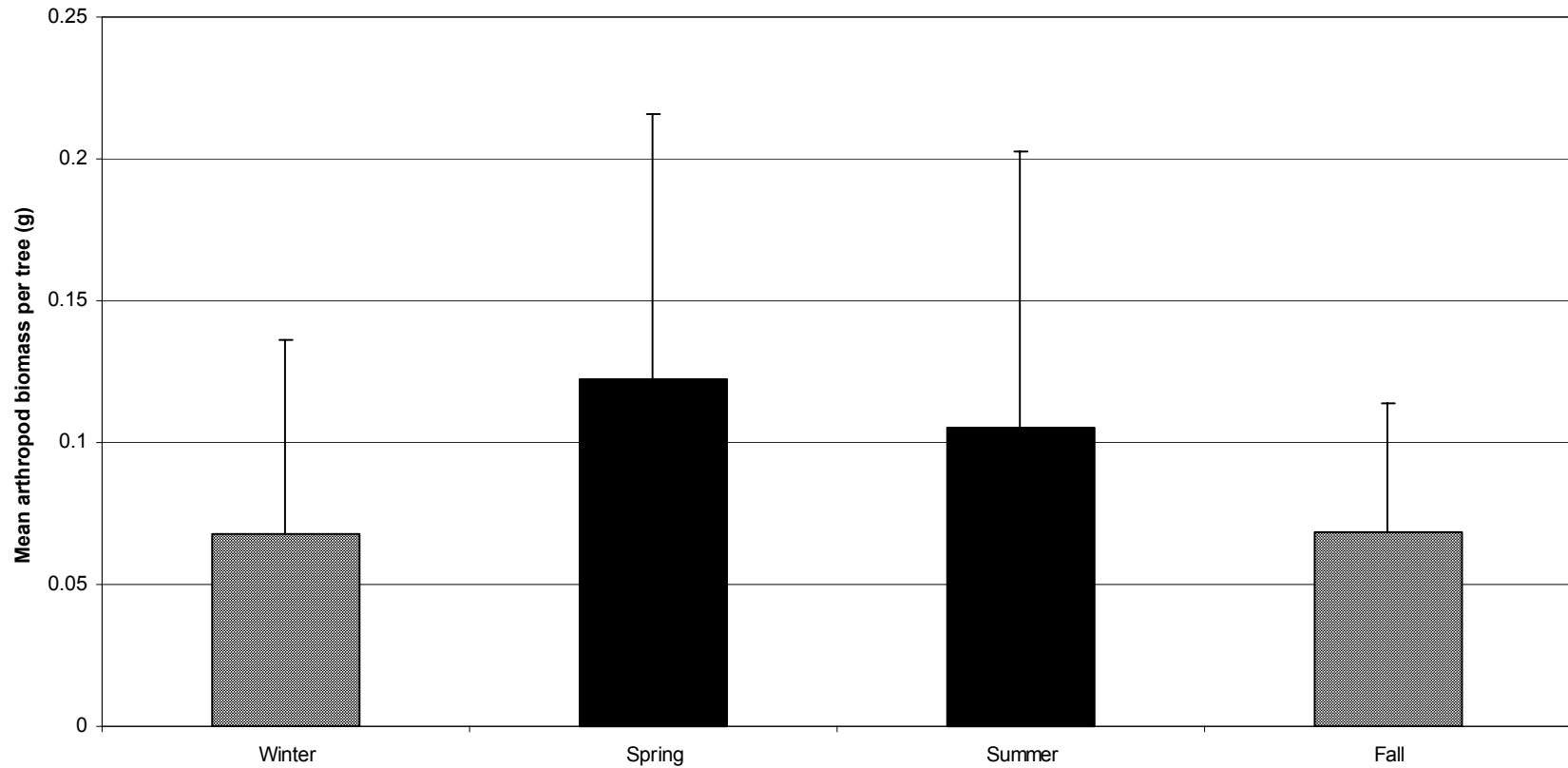


Figure 3.11. Comparison of arthropod seasonal biomass at all three study sites in 2001. Bars of different color are significantly different ($\alpha = 0.05$). Data from 3 month periods are combined to obtain seasonal data (winter - January, February, March; spring - April, May, June; summer - July, August, September; fall - October, November, December). Standard deviation error bars are shown. Significance values of pairwise comparisons are presented in Table 3.2.

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Chapter 4

Short Term Impacts of Prescribed Burning on Longleaf Pine Arthropods

INTRODUCTION

Although the importance of fire in the longleaf pine (*Pinus palustris* Miller) ecosystem has been recognized for many years, recent interest in restoring this ecosystem has led to an increase in the use of fire by land managers as a habitat management tool. The effects of frequent growing season fire on the vegetation of the longleaf pine ecosystem include the maintenance of a species rich groundcover (Lemon 1949, Christensen 1981, Langdon 1981, Walker and Peet 1983, Walker 1993, Provencher et al. 2001), the suppression of a hardwood midstory (Christensen 1981, Waldrop et al. 1992), and the maintenance of a low basal area overstory composed of fire resistant pines. Vegetation structure associated with frequent growing season fire is positively correlated with several fitness measures of the red-cockaded woodpecker (*Picoides borealis*) (Hardesty et al. 1997, James et al. 1997, James et al. 2001, Convery 2002), an endangered species that is the focus of much of the longleaf pine ecosystem recovery effort.

Although the vegetation structure favored by red-cockaded woodpeckers is well known, the mechanism for this preference is unclear. James et al. (1997), however, have suggested a possible pathway by which fire is thought to affect red-cockaded woodpeckers through their arthropod prey base (James et al. 1997, James et al. 2001). Red-cockaded woodpeckers feed primarily on arthropod prey that they glean from the rugose bark of southeastern pines, and in particular from the surface of longleaf pines (Ligon 1970, Hooper and Lennartz 1981, Engstrom and Sanders 1997, Hardesty et al. 1997). Hanula and Franzreb (1998) reported that a large portion of the arthropods found on pine boles originates from the groundcover. Because the passage of fire affects the species composition and percent coverage of groundcover, it should consequently impact the arboreal arthropod community that serves as the red-cockaded woodpecker prey base (James et al. 1997). Consistent with this theory, previous research indicates that groundcover indicative of frequent burning (*e.g.* herbaceous and graminoid species) is positively correlated with arthropod biomass (see Chapter 2).

Research on the impact of growing season fires on longleaf pine forests has primarily focused on vegetation structure, with little attention given to the arboreal arthropod community until recently. Two studies suggest that in the long-term, fires in the groundcover vegetation do not negatively impact the arboreal arthropod community (New and Hanula 1998, Provencher et al. 2002). Short-term (one to two months post-burn) impacts of growing season fire on the arboreal arthropod community have not been examined. However, considering that red-cockaded woodpeckers face additional energy requirements during the vegetation growing season due to the provisioning of nestlings and fledglings (Martin 1987), information on potential short-term impacts of growing season fire on red-cockaded woodpecker prey would be useful.

The purpose of this study is to examine the short-term (one to two month post-burn) impact of growing season prescribed fire on arboreal arthropod biomass. Because fire is a natural disturbance process in the longleaf pine ecosystem and has historically occurred during the growing season as a result of lightning strikes, I hypothesize that arthropod biomass will not be negatively impacted by growing season prescribed burns.

METHODS

This study is part of a larger, one year study examining correlations between the arboreal arthropod community on longleaf pines and the groundcover composition at Fort Gordon Army base near Augusta, GA and Savannah River Site near Aiken, SC. The close proximity of these sites allowed data to be combined for analysis purposes. Arthropods were sampled in twenty four longleaf pine timber stands on a continuous basis using passive traps, as described in Hanula and New (1996), mounted on similar sized longleaf pines (25.4-30.5cm dbh). Four pines were sampled in each timber stand for a total of ninety six arthropod traps. Samples were collected every thirty days for one year and were dried at 60 degrees Celsius for 24 hours to obtain sample biomass. Percent coverage of herbaceous and graminoid groundcover was measured over a two week period in late July and early August around each of the longleaf pines being sampled for arthropods. Groundcover sampling methodology is described in greater detail in Chapter 2. During the arthropod sampling period, seven longleaf pine timber stands (28 traps) experienced prescribed growing season burns in May, 2001.

To examine the effects of growing season fire, differences between pre-fire arthropod biomass and biomass one and two months post-fire in burned timber stands were compared to differences in arthropod biomass over the same time period in unburned timber stands. One and two month differences in arthropod biomass were calculated for each tree by subtracting June biomass measures from April biomass measures (one month) and by subtracting July biomass measures from April biomass measures (two month). Analyses of one and two month differences were performed separately using nested ANOVAs with burned timber stands as the treatment group and unburned timber stands as controls (SAS Institute 2001). The nesting procedure was necessary due to a perceived lack of independence among trees within a timber stand which required biomass measurements from individual trees to be nested within the timber stands.

The percent coverage of herbaceous and graminoid groundcover has been shown to be positively correlated to arthropod biomass (Chapter 2). Scatterplots of groundcover percent coverage versus differences in arthropod biomass indicate that percent coverage, measured in July-August, did not differ significantly in burned and unburned timber stands (Figures 4.1 and 4.2). Additionally, qualitatively comparing mean percent coverage of herbaceous and graminoid groundcover for burned (9.3%) and unburned (10.4%) timber stands indicated that groundcover did not differ between the two treatments. Therefore I did not include groundcover composition as a covariate in the nested ANOVA analyses.

RESULTS

Results of the analyses indicate that at a significance level of $\alpha=0.05$, prescribed burning did not affect arthropod biomass one and two months post-burn ($F=0.69$, $df=1,22$, $p=0.4$ and $F=0.28$, $df=1,22$, $p=0.3$ respectively). Furthermore, the percentage of stands with increasing and decreasing arthropod biomass for both treatments (burn and unburned) was very similar (Table 4.1).

DISCUSSION

These results support other studies that indicate growing season fire does not adversely affect longleaf pine arthropod communities (New and Hanula 1998, Provencher et al. 2002).

While initial declines may occur immediately following the passage of fires due to direct mortality and groundcover incineration, these declines are ephemeral and the arboreal arthropod community appears to recover quickly. Consistent with this lack of effect, New and Hanula (1998) concluded that “time elapsed after the prescribed burns were applied had little effect on the arthropod prey of red-cockaded woodpeckers”. Consistent with the lack of negative impacts, Provencher et al. (2002) observed that arthropod density and biomass had increased in previously hardwood encroached longleaf pine plots less than a year after growing season burns were applied. Studies of other fire adapted ecosystems, such as Australian savannas and North American oak savannas, indicate that native arthropod communities are adapted to the presence of fire and are not adversely affected by it (Nicolai 1991, Anderson and Muller 2000).

There are several hypotheses to explain the lack of short term effects of growing season fire on the arthropod community. One of these is related to the rapid regrowth of vegetation in recently burned areas. Not only is this young vegetation tender and more palatable, it also has been shown to initially contain high levels of nutrients (Christensen 1977). This flush of new growth attracts herbivorous arthropods which, in turn may attract predatory arthropods to the area (Warren et al. 1987). Although this increase in palatability and nutrient concentration is short-lived, Provencher et al. (2002) continued to observe positive arthropod community responses in plots burned two years earlier suggesting that once established, these increases in arthropod populations persist for several years. Although increases in arthropod populations were not observed in this study, the short time period between the burns and the resumption of arthropod sampling may not have allowed sufficient time for arthropod populations to respond.

Another mechanism that limits the impacts of growing season fire is the shelter provided by the convoluted bark of longleaf pines (Horn and Hanula 2002). When burning occurs in the growing season, many arthropods are in a mobile life stage that allows them a better chance to escape the heat and flames. Longleaf pines, due to the rugose nature of their bark, may provide a sheltered environment for arthropods seeking refuge from growing season fires. A study of fire-adapted oak savannas indicates that fissured and scaly bark creates sheltered areas of cooler

temperatures (Nicolai 1986). Because of this sheltered environment, the bark of longleaf pines may serve as a source of arthropods for recolonizing burned areas.

Patches of unburned vegetation created by the discontinuous coverage of many growing season fires may be another source of arthropods for colonizing burned areas. A comparative study of prairie arthropods in open versus enclosed burn plots (without adjacent unburned areas) suggests that unburned refuge areas are valuable sources of arthropods for burned areas as evidenced by the much higher species diversity in open plots which had adjacent unburned areas (Harper et al. 2000). These observations reinforce the practice of southeastern land managers of leaving unburned islands of vegetation as refuges during prescribed burns (Wade and Lunsford 1989).

While this study focused on the short-term impacts of growing season fire on arboreal arthropod communities, the long-term effects growing season fire has on vegetation structure in longleaf pine forests, e.g. increasing coverage of herbaceous and graminoid vegetation and suppression of a hardwood midstory, have been correlated with increased arthropod biomass and abundance (Chapter 2, Collins et al. 2002). These fire mediated changes in vegetation structure are consistent with high quality foraging habitat for red-cockaded woodpeckers (Hardesty et al. 1997, James et al. 1997, James et al. 2001, Convery 2002, Walters et al. 2002) suggesting that some of the preference shown by red-cockaded woodpeckers for this vegetation structure may be related to increased prey availability.

The lack of adverse effects seen in this study and other studies examining the impact of growing season fire on longleaf pine arthropod communities suggests that forest land managers can improve foraging habitat conditions for red-cockaded woodpeckers without causing short term adverse impacts on the arthropod community upon which the species feeds. Results of Provencher et al. (2002) and Collins et al. (2002) suggest the use of growing season prescribed burns may help to increase arthropod abundance in the long term. Therefore, growing season fire does not appear to negatively impact red-cockaded woodpecker prey in the short term and in the long run may lead to increases in the availability of food. Thus, concerns regarding short and

long term negative impacts of growing season fire on the red-cockaded woodpecker prey base appear to be unfounded.

Table 4.1. Summary of one and two month differences in arthropod biomass by treatment (burned and unburned) for each tree

		Burn Treatment	Unburned Treatment
1 month difference (April biomass minus June biomass)	Percent with decreasing biomass	57% (n=16)	53% (n=36)
	Percent with increasing biomass	43% (n=12)	47% (n=32)
2 months difference (April biomass minus July biomass)	Percent with decreasing biomass	68% (n=19)	60% (n=41)
	Percent with increasing biomass	32% (n=9)	40% (n=27)

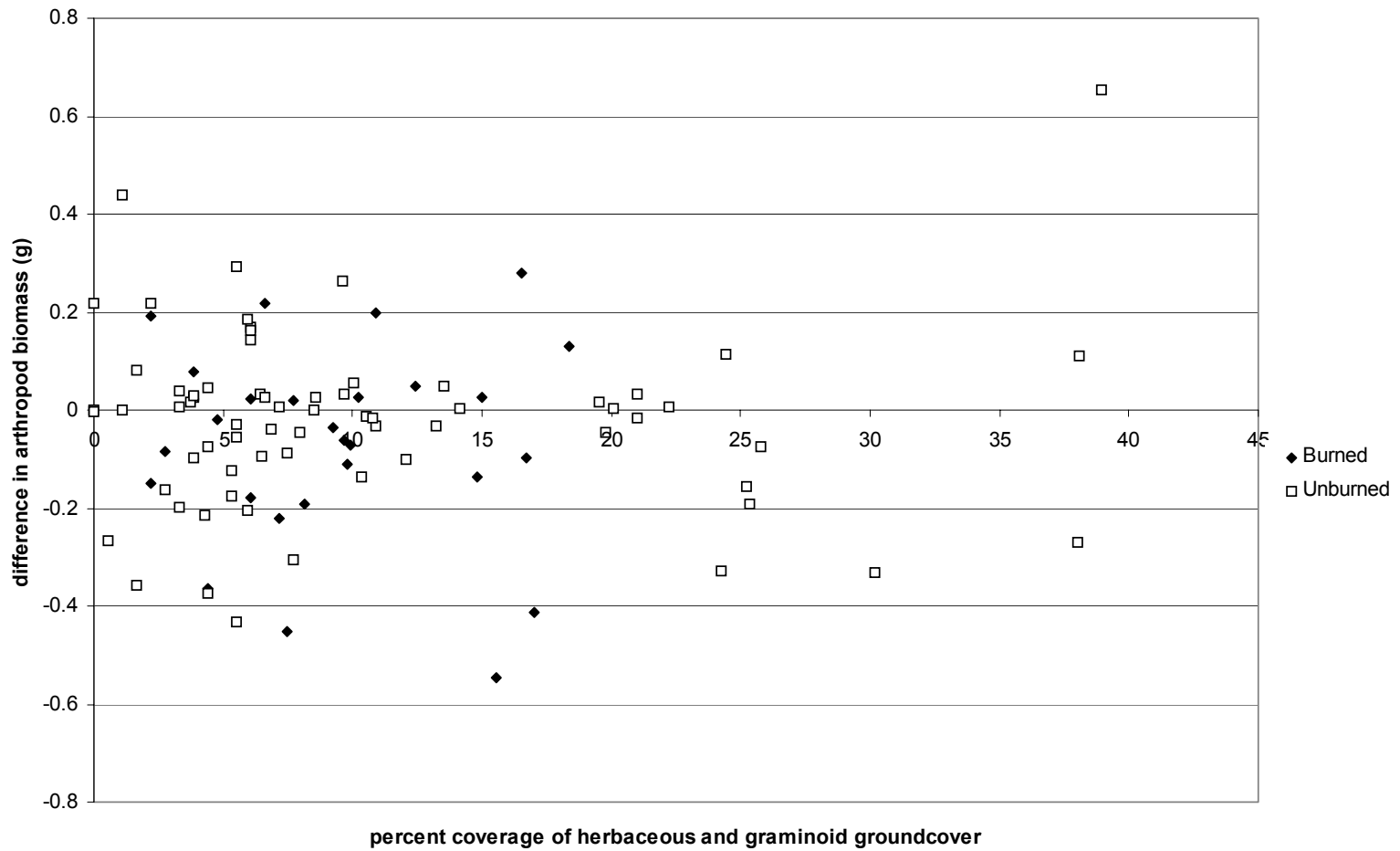


Figure 4.1. Relationship between percent coverage of herbaceous/graminoid groundcover and differences in arthropod biomass from April to June, 2001 for burned and unburned timber stands. Groundcover sampling took place over a 2 week period in late July-early August, 2001.

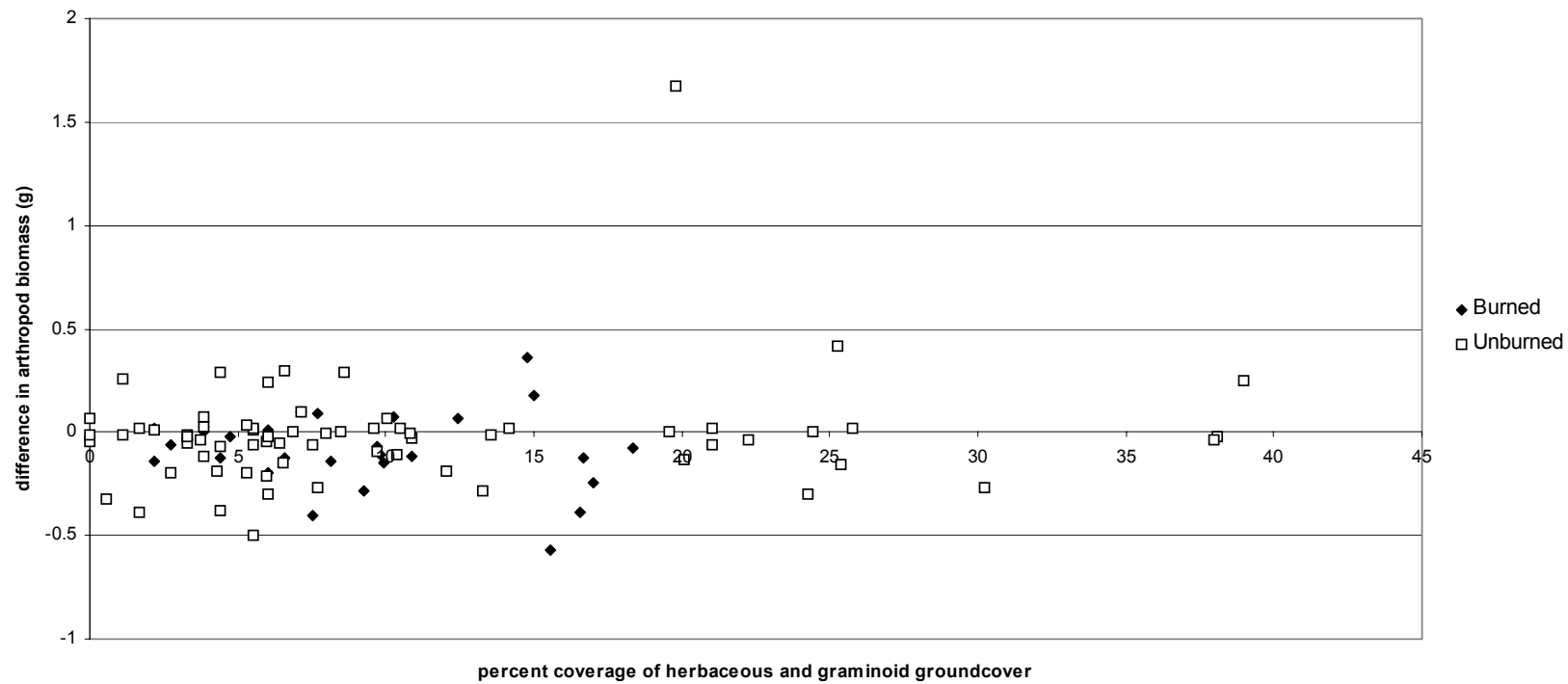


Figure 4.2. Relationship between percent coverage of herbaceous/graminoid groundcover and differences in arthropod biomass from April to July, 2001 for burned and unburned timber stands. Groundcover sampling took place over a 2 week period in late July-early August, 2001.

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- 1/99-5/03 Graduate Research Assistant, Department of Biology, Virginia Tech, Blacksburg, VA. Database management for long term monitoring study of red-cockaded woodpecker populations in the Sandhills region of N.C. Master's Degree research examined correlations between the arthropod prey of the red-cockaded woodpecker and the groundcover of the surrounding area. Research also documented the seasonal abundance and biomass patterns of red-cockaded woodpecker prey.
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