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RELATIONSHIP OF COARSE WOODY DEBRIS TO RED-COCKADED WOODPECKER PREY DIVERSITY AND ABUNDANCE

by

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INTRODUCTION

The Red-cockaded Woodpecker (*Picoides* borealis) (RCW) is an endangered species endemic to the pine forests of the southern United States. The decline of this species can be attributed to the loss of open, mature longleaf pine (*Pinus palustris*) stands that once dominated forests of the Southern Coastal Plain. The RCW prefers to nest in mature pine stands with little midstory or understory vegetation (Crosby 1971, Hopkins and Lynn 1971, Thompson and Baker 1971, Grimes 1977).

Historically, longleaf forests were cleared for urban development, agriculture, and timber harvesting (Jackson 1971). More recently, forest management practices such as shorter rotations, substitution of faster growing species, and fire exclusion (Jackson 1986, Ligon et al. 1986, Walters 1990) have rendered many southern pine forests unsuitable as RCW habitat. As stands become more structurally complex as a result of hardwood encroachment due to fire exclusion, their ability to accommodate the RCW on a sustained basis declines (Wood and Kleinhofs 1992). To correct this problem prescribed burning is often recommended as a method for creating and maintaining desirable RCW habitat (Costa and Escano 1989). Despite efforts to produce mature pine stands suitable for the RCW, populations on federal lands continue to decrease (Ortego and Lay 1988, Conner and Rudolph 1989, Costa and Escano 1989, James 1991).

Federal law requires that all current guidelines of the RCW recovery plan be followed to afford protection to this endangered species (USFWS 1985). Recovery plans call for the retention of old-growth longleaf 95 years old or older, and other pine species at least 75 years old to provide adequate nesting habitat and the management of this ecosystem by removal of competing hardwood species. The plan states that because longleaf pine seems to be preferred, efforts should encourage longleaf regeneration on all suitable sites. Foraging guidelines stipulate that a minimum of 789 m^2 basal area of pine at least 30 years old should be provided. Foraging areas should encompass 5 1 ha with a minimum of 6,350 pine stems greater than 25.4 cm DBH, with 40 % of the 5 1 ha consisting of stands 60 years old and older (USFWS 1985). All provided foraging areas must be within 800 m of the cavity tree cluster.

Providing adequate nesting and foraging habitat has caused numerous conflicts between protection of this endangered species and forestry operations. The most difficult job of land managers is to develop strategies that implement recovery programs and integrate timber management. Striking a balance between economical benefits and sound, ecological management continues to be a major challenge for foresters and biologists. Efforts to increase RCW populations and improve their habitats have had a major impact on forest management practices on public lands within its range, including national and state forests and military reservations. Presently, the management of over 1 ,OOO,OOO ha of public lands in the southern United States is directly affected by RCW recovery efforts (Hooper 1996). Guidelines for National Forests call for up to 1.6 million ha to be managed to support recovery efforts (U.S Forest Service 1985).

Despite being listed as an endangered species, the RCW is locally common where suitable habitat exists, and its range is widespread. Due to its endangered status and high profile, much is known about the biology of this bird (Thompson 1971, Wood 1983, USFWS 1985, Walters 1990, 1991, Jackson 1994, Kulhavy et al. 1995). Because mature pines are necessary for the establishment of RCW nests, and most population dynamics are attributed to nesting success, a large body of knowledge on nesting habitat requirements already exists.

The Red-cockaded Woodpecker is the only species of woodpecker that nests exclusively in living pines. 'They have been reported to use most species of pine, however the largest remaining populations of RCW's are found where longleaf pine predominates, mainly the Southern Coastal Plain physiographic provinces (Lennartz et al. 1983a,b). The presence of cavities has been viewed as the most important factor of RCW territories (Ligon 1970). The RCW prefers to construct its nests in trees infected with red-heart fungus (*Fomes pini*), which softens the heartwood of the tree making cavity excavation easier (Ligon 1971). Red-heart infection generally occurs in longleaf pine trees greater than 100 years old and loblolly pine (*Pinus taeda)* trees greater than 70 years old (Wahlenberg 1946, 1960). Therefore, older stands typically have more infected trees resulting in better conditions for cavity excavation. Management that favors retention of some larger trees should promote conditions favorable to RCW recovery.

Availability of suitable trees for nest cavity construction is considered the major reason for RCW population declines, however little is known about how stand conditions affect forage availability. An understanding of how forest management activities affect foraging habitat may allow timber harvests and RCW recovery efforts to coexist, but little information exists about the ecology of RCW forage species (Jackson 1995).

The RCW forages almost exclusively on live pine trees (Ligon 1968, Morse 1972, Wood 1977, Miller 1978, Nesbitt et al. 1978, Skorupa 1979, Ramey 1980, Hooper and Lennartz 198 1, Patterson and Robertson 198 1, DeLotelle et al. 1983, Repasky 1984, Porter and Labisky 1986, Walters 1990, Jackson 1994). They have been observed foraging on pines as small as 5 cm diameter at breast height (DBH), but they prefer trees greater than 25 cm DBH (Skorupa 1979, Hooper and Lennartz 198 1, DeLotelle et al 1983, Repasky 1984, Porter and Labisky 1986, Engstrom and Sanders 1997). Zwicker and Walters (1999) found that woodpeckers spend more time foraging on older longleaf pine in a north Carolina habitat. In contrast, Engstrom and Sanders (1997) found that woodpecker groups had higher productivity in old-growth forests and that birds selectively foraged on larger trees but not necessarily older ones. They suggest forest management should favor the retention of large trees throughout foraging territories.

It has been estimated that more than 50,000 ha may be required to support a healthy RCW population (Reed et al. 1988, Zwicker and Walters 1999). Much of this land will be managed to provide foraging habitat. Recent studies have focused on the amount of foraging habitat available to RCW groups. Rudolph and Conner (1991) evaluated the effects of thinning and sudden midstory removal on RCW groups during the nonbreeding season. They concluded that sudden or drastic changes had no negative effects on RCW clusters.

Studies examining the effect of clearcutting found no evidence that this practice affected short-term forage availability, even when as much as 43 % of the foraging habitat was removed (Wood et al. 1985a,b, Hooper and Lennartz 1995). Beyer et al. (1996) tested the idea that reproductive success was directly related to habitat quality and availability. They concluded that short-term management that drops foraging habitat below the guidelines should be considered, if it is beneficial to the long-term success of the RCW.

RCW choose relatively few common arthropods from tree boles (Beal 1911, Hanula and Franzreb 1995, Hess and James 1998, Hanula et al. 2000b, Hanula and Engstrom in press). Hanula and Franzreb (1995) examined arthropod prey captured and fed to nestling woodpeckers in South Carolina and found that woodroaches (Blatellidae) were the most common prey making up 50-70% of the diet. Although they recorded 28 prey items, the majority of the diet was composed of a few common arthropods during the breeding season. Studies of nestling diets show that woodroaches are consistently the most important prey regardless of geographic location, dominant overstory pine species, relative abundance of forage trees or availability of old-growth longleaf pine (Hanula et al. 2000b, Hanula and Engstrom in press).

In contrast, Hess and James (1998) used stomach flushing of nestlings and adults to determine prey consumption by the RCW. Their results showed that ants (Formicidae) were the dominant prey item selected. Beal (19 11) used gut analysis and also found ants to be the most common prey. However studies by Rosenburg and Cooper (1990) and Koersvald (195 1) state that these techniques may be limited due to differential digestion rates of prey among birds. Regardless, recent studies suggest that prey are selected based on availability not preference (Hanula pers. comm.).

Several studies have looked at arthropod abundance on RCW forage trees. Hooper (1996) sampled arthropod biomass in winter and its relation to the age of individual longleaf pine trees of differing ages. He found arthropod biomass increased with tree age up to 86 years. Hanula and Franzreb (1998) examined the diversity and abundance of macroarthropods on mature longleaf pines, and determined that a majority of arthropods available to the RCW were not full time bark-inhabiting residents. Rather, a significant amount of the biomass was composed of arthropods that crawl up from the soil/litter layer and move freely within stands.

Hanula et al. (2000a) evaluated arthropod abundance and biomass on the boles of longleaf pine and how it varied with factors such as stand age, tree density, site quality, and understory vegetation. They found that numbers and biomass of arthropods per tree was correlated to stand age, diameter, bark thickness, and basal area. Trees 60 years old or older were equal in terms of arthropod biomass on tree boles. They conclude that bark thickness is probably the most important characteristic determining arthropod availability on tree boles, and that management practices that favored more rapid tree growth could result in high quality forage trees at an earlier age.

Other studies have evaluated arthropods on the bark of living trees other than pine (Moeed and Mead 1983, Nicholai 1986, Mariani and Manuwal 1990), but no consideration has been given to other habitats that might support part-time bark-inhabiting arthropods. Knowledge of how forest conditions and forest management practices affect the crawling fauna that RCW rely on for food is important for its recovery (Hanula and Franzreb 1995, Hanula et al. 2000a,b).

Coarse woody debris (CWD) is an important component of forested ecosystems that Elton (1966) considered one of the three greatest resources for animal species in a natural forest. Franklin et al. (1987) considered CWD an important habitat for terrestrial invertebrates. Harmon et al. (1986) reviewed work on CWD, and considered it an important but neglected component of many ecosystems. In Oregon, Maser et al. (1979) found 179 vertebrates that used woody debris on the forest floor. McMinn and Crossley (1996) examined the effect of woody debris on biodiversity of southern forests.

Coarse woody debris is integral to functioning and productive forest ecosystems (McCarthy and Bailey 1994). The presence of woody debris enhances the diversity of soil organisms by increasing the physical, structural, and chemical heterogeneity of the forest floor (Warren and Key 1991). It also contributes to soil organic matter, maintenance of soil stability, and moisture retention (Amaranthus et al. 1989, Harvey et al. 1989, Edmonds 1991, Marra and Edmonds 1998). Fallen tree boles contribute significantly to nutrient cycling and energy flow in forested systems, and provide structure for regulating sediment displacement (Harmon et al. 1986).

Woody debris is the key to the unique compositional and functional attributes of a forest community (Franklin 1988). Dead and down woody material may play several roles in forest ecology, such as providing a base for growth of new trees, harboring fungi, and providing habitat for wildlife (Bolen and Robinson 1995). Species diversity appears to be strongly correlated with CWD microhabitat in many forest types (Franklin et al. 1986, 1989, Westman 1990, McCarthy and Bailey 1994). Studies have also shown the importance of standing woody debris to birds. Hunter (1990) estimates that as much as 40% of the birds in a forest community can be dependent on cavities in dead trees. Other studies removed snags and found decreases of 77% (Raphael and White 1984) and 44% of cavity nesters (Haapanen 1965). Any management practice that increases the spatial heterogeneity by providing a range of temporal successional patterns will increase the diversity of both microflora and fauna (McMinn and Crossley 1996). This is supported by Hansen et al. (1991) who conclude that biodiversity increases within a stand as structural complexity increases. It is evident from these reviews that CWD is an important component to forested systems.

Inputs of woody debris can occur from breakage and mortality of living trees due to fire, wind, lightning, insects, disease, ice storms, competition, and forest management (Van Lear 1996). Coarse woody debris typically includes, but is not limited to standing dead trees (snags), fallen trees, large limbs, broken tree tops, and decomposing root systems. Coarse woody debris size is often influenced by site quality, because the size of logs on the forest floor is a function of standing tree size (Sturtevant et al. 1997). Accumulations of logs in southern forests vary, depending on factors such as forest type, stand age, and disturbance history (McMinn and Hardt 1996). CWD is dynamic and undergoes constant change due to inputs from tree breakage and mortality and removals through decomposition and fire (Harmon et al. 1986, Maser et al. 1988, Van Lear 1996).

The decomposition of woody debris is initiated by invasions of white, brown, and soft rot fungi, causing a loss of density (Kaarik 1974, Van Lear 1996). These fungi break down CWD into forms usable by some insects while others feed directly on the fungi (Hanula 1996). Decay is more rapid in the South due to warmer climates and high amounts of moisture compared to other regions. Other microhabitat conditions affect decomposition rates such as the size of woody debris, tree species, and the relative position of the woody debris in relation to the ground. Larger snags tend to stand longer than smaller snags (Bull 1983, Raphael and Morrison 1987), and hardwood forests usually contain larger concentrations of snags than pine forests (Harlow and Guynn 1983, McComb et. al 1986b, Sabin 1991). Woody debris on the ground generally decays much faster than snags because of its high moisture content (Van Lear 1996).

A considerable amount of effort has been devoted to documenting the importance of CWD on obligate insect communities that spend most, if not all, of their lives in dead wood (Hanula 1996). Coarse woody debris is also recognized as an important feature in southeastern stream ecosystems (Wallace et al. 1996). However, little information is available on terrestrial arthropods that only use woody debris as a part-time habitat.

A study in South Carolina found that pitfall traps in close proximity to logs caught a larger array of spiders than did pitfalls without logs (Sanzone 1995). Elton (1966) stated that once a log reaches the point where the bark is loose it supports a diverse assemblage of arthropods that are not specifically associated with a given tree species. Woody debris may serve as a key element in maintaining overall forest biodiversity by providing refuge from predation or severe environmental conditions, or it may provide a place for aggregation, mating or oviposition. Few studies have evaluated the importance of CWD to the diversity of southern forests. Therefore, it is unknown whether this resource is important for maintaining arthropod populations or whether other habitats such as the bark of live trees can substitute in the absence of CWD. If CWD is an integral part in the life cycle of many arthropods, its removal may have an impact on predator species that rely on these arthropods as prey such as the RCW.

Recently many southern forests have been managed with shorter rotations, resulting in few stands that reach maturity. The objective of modem forestry is to reduce fiber loss resulting from tree mortality that occurs before final harvest. Timber harvests generally leave stands with few snags (Carmichael and Guynn 1983). Commercial thinning presumably limits the contribution of large CWD to the forest floor (McCarthy and Bailey 1994). Substantial increases in production may be achieved by salvaging material that might otherwise be lost, but the result of this may be a reduction in CWD input into the southern pine ecosystem. A need exists to understand the role of CWD in the life cycles of arthropods, and the effects of its removal on the food web.

Prescribed burning is a technique used to modify pine forests so that they are more suitable to the needs of the RCW, however it has been suggested that this management tool may temporarily reduce arthropod availability. Hanula and New (1998) tested this hypothesis by evaluating arthropod abundance in stands burned l-3 years before sampling. Their results showed that burning, regardless of time of year or time. elapsed since burning, had little effect on availability of the primary prey of the RCW. Previous studies have shown that arthropods that serve as prey of the RCW (Hanula and Franzreb 1995, Hanula et al. 2000a,b) are common in CWD (Hanula personal communication). Therefore, one side effect of prescribed burning or thinning could be a reduction in CWD and prey of RCW.

Compared to other regions of the United States, the Southeast has received little attention in respect to CWD studies. A majority of the work on CWD is from forests of the northwestern United States (Maser et al. 1979, Cline et al. 1980, Graham and Cromack 1982, Sollins et al. 1987, Carpenter et al. 1988, Arthur and Fahey 1990, Harmon and Franklin 1989), however this may have little relevance to the temperate forests of the south. It is essential to understand CWD dynamics, rates of input, distribution, and ecological influences on forested environments so that managers can take appropriate measures to protect this important resource.

If CWD is critical to maintaining populations of part-time bark inhabiting arthropods, then efforts need to be taken to assure that southern forests provide suitable habitat. Understanding the relationship between woody debris and the bark surface could have implications for RCW management. Field experiments are needed to identify the best practices for managing CWD and associated biota (Hendrix 1996).

Because woodroaches are common and important prey of the RCW, it is important to understand their habitat needs. Many species of roaches are well studied because they conflict directly with man, but little is known about the life history of many common woodland species. No systematic effort has been made to carefully examine the distribution, relative abundances, population dynamics, and general natural history of the several commonly sympatric species of wood cockroaches comprising a typical temperate cockroach community (Gorton 1980). Woodroaches have been observed in all types of woody debris, however it is necessary to develop an understanding of preferred substrates so that management can reflect this need.

Despite the studies examining RCW foraging and the few attempts to inventory arthropods available on the bark of live pine, no efforts have been made to determine the standing crop of arthropods on pine at a given time. A study by Hooper (1996) stipulated that older pines had more arthropods possibly due to the bark structure being thicker, having more epiphytes, and more large live and dead limbs. Hooper and Lennartz (1981), DeLotelle et al. (1983), Porter and Labisky (1986), and Engstrom and Sanders (1997) all concluded that RCW preferentially selected larger trees on which to forage.

Hanula et al. (2000a) speculated bark thickness was the most likely reason for increased arthropod abundance as tree age increased. A study by Nicholai (1986) in Europe found that trees with smooth bark had far less arthropods than trees with fissured bark. Another study by Mariani and Manuwal (1990) found that more spiders were captured on trees with deeper bark crevices. Studies are needed to determine what tree characteristics favor retention of crawling arthropods, since arthropod availability is likely to be a major reason for RCW tree selection.

Studies examining pine selection by foraging RCW have had conflicting results. Nesbitt et al. (1978) discovered that RCW used pond *(P. serotina)*- slash pine flatwoods more than their relative acreage, but used longleaf less than its availability. However, Porter and Labisky (1986) reported that woodpeckers used longleaf more than slash pine, relative to availability. Because RCW are associated with longleaf habitat, the best management practices will be based on an understanding of what attracts the birds to this species (Zwicker and Walters 1999). Zwicker and Walters (1999) concluded that RCW do not prefer longleaf necessarily, but possibly their fire-forged structure or some other characteristic. There is a need to understand if longleaf pine does harbor more arthropods at a given time. If so, it is probably the relative abundance of arthropods available that make longleaf more appealing to foraging birds, not the tree itself.

An understanding of habitat requirements of common RCW prey seems appropriate when developing management strategies. Longleaf pine appears to have more flaky, loose bark compared to similar-aged loblolly pines. No studies have examined the standing crop of arthropods on the two most common pines available to the RCW. It is important to understand which species harbors the greatest number of arthropods so management can favor trees that harbor more arthropods, and thus provide better foraging habitat for the RCW.

Since the RCW appears to select prey based on availability (Hanula unpublished data), it is likely that the diet of the RCW is similar to that of other generalists that forage on the bark. Common generalists of southern pine forests that have adaptations to foraging on the bark are other woodpeckers, nuthatches *(Sittu sp)*, brown creepers *(Certhia familiaris),* and black-and-white warblers *(Mniotilta varia)* (Grinnell 1924, Burt 1930, Richardson 1942, Spring 1965, Feduccia 1972). A variety of other species take advantage of the arthropod prey on the bark of trees such as chickadees, titmice, other warblers, flycatchers, and hummingbirds. Forest management that attempts to increase arthropod availability to the RCW should benefit other bark-foraging birds as well.

This study is part of a large, long-term study at the Savannah River Site, National Environmental Research Park, designed to investigate the effects of CWD removal on many taxonomic groups common in the southern pine ecosystem. In particular, this examination will contribute to our understanding of how or if CWD is an integral part of the food web that supports the RCW and other bark foraging species. The objectives of this study were to: (1) determine the effects of CWD removal on the abundance and diversity of arthropods on the bole of live trees, (2) determine the effects of CWD removal on known prey of the RCW (eg. woodroaches, centipedes, and spiders), and (3) determine which microhabitats are frequently used by woodroaches, and other part-time bark inhabitants.

LITERATURE CITED

AMARANTHUS, M.P., AND D.A. PERRY. 1989. Rapid root tip and mycorrhiza formation and increased survival of Douglas-fir seedlings after soil transfer. New Forests. 3:77-82.

ARTHUR, M.A. AND T.J. FAHEY. 1990. Mass and nutrient content of decaying boles in an Englemann spruce-subalpine fir forest, Rocky Mountain National Park, Colorado. Can. J. For. Res. 20:730-737.

BEAL, F.E.L. 1911. Food of the woodpeckers of the United States. U.S. Dept. Agr. Biol. Surv. Bull. No. 37.

BEYER, D.E., JR., R. COSTA, R.G. HOOPER, AND C.A. HESS. 1996. Habitat quality and reproduction of red-cockaded woodpecker groups in Florida. J. Wildl. Manage. 60:826-835.

BOLEN, E.G. AND W.L. ROBINSON. 1995. Wildlife Ecology and Management. Prentice Hall. 620 p.

BOYER, W.D. 1990. Growing-season burns for control of hardwoods in longleaf pine Stands. USDA For. Serv. Res. Pap. SO-256. Pp. 7.

BULL, E.L. 1983. Longevity of snags and their use by woodpeckers. In Davis, J.W., G.A. Goodwin, and R.A. Ockenfels (eds.). Snag Habitat Management. Dept. of Agriculture. U.S. For. Serv. Gen. Tech. Rep. RM-99. Fort Collins, CO.

BURT, W. 1930. Adaptive modifications in the woodpeckers. Univ. Calf. Publ. Zool. 32:455.

CARMICHAEL, D.B., JR. AND D.C. GUYNN, JR. 1983. Snag density and utilization by wildlife in the upper piedmont of South Carolina. In Davis, J.W., G.A. Goodwin, R.A. Ockenfels (tech. coords.). Proceedings, symposium on snag habitat management. Dept. of Agr. U.S. For. Serv. Flagstaff, AZ.

CARPENTER, S.E., M.E. HARMON, E.R. INGHAM, R.G. KELSEY, J.D. LATTIN, AND T.D. SCHOWALTER. 1988. Early patterns of heterotroph activity in conifer logs. Proceedings of the Royal Society of Edinburgh 94B:33-43.

CLINE, S.P., A.B. BERG, AND H.M. WIGHT. 1980. Snag characteristics and dynamics in Douglas-fir forests, western Oregon. J. Wildl. Manage. 44: 773-786.

CONNER, R.N., AND D.C. RUDOLPH. 1989. Red-cockaded woodpecker colony status and trends on the Angelina, Davy Crocket, and Sabine National Forests. U.S. Dept. Agr., For. Serv., Res. Paper SO-250. New Orleans, LA.

COSTA, R., AND R.E.F. ESCANO. 1989. Red-cockaded woodpecker status and management in the southern region. USDA For. Serv. Tech. Publ. R8-TP-12. pp. 71.

CROSBY, G. T. 1971. Home range characteristics of the red-cockaded woodpecker In North-Central Florida. In R.L. Thompson, (ed.). The Ecology and Management of the Red-cockaded Woodpecker. Tallahassee, Florida, Bur. Sport Fish. Wildl., U.S. Dept. Interior, and Tall Timbers Research Station. Pp 60-73.

DAARIK, A.A. 1974. Decomposition of wood. In C.H. Dickson, C.J.E. Pugh (eds.). Biology of plant litter decomposition. London, Academic Press. Pp. 129-l 74.

DELOTELLE, R.S., J.R. NEWMAN, AND A.E. JERAULD. 1983. Habitat use by red-cockaded woodpeckers in central Florida. In: D.A. Wood (ed.), Red-cockaded Woodpecker Symposium II Proceedings, 27-29 January 1983, at Panama City, FL, Florida Game and Freshwater Fish Commission, Tallahassee, FL, pp. 59-67.

EDMONDS, R.I., T.B. THOMAS, AND J.J. RHODES. 1991. Canopy and soil modifications of precipitation in a temperate rain forest. Soil Sci. Soc. Am. J . 55:1685-1693.

ELTON, C.S. 1966. The pattern of animal communities. Methuen, London.

ENGSTROM, R.T. AND F.J. SANDERS. 1997. Red-cockaded woodpeckers in the upper coastal plain of South Carolina. Wilson Bull. 109:203-217.

FEDUCCIA, A. 1972. Variation in the posterior border of the sternum in some tree-trunk foraging birds. Wilson Bulletin. 84:3 15-328.

FRANKLIN, J.F., T. SPIES, D. PERRY, M. HARMON, AND A. MCKEE. 1986. Modifying Douglas-fir management regimes for non-timber objectives. ***In*** Modifying Douglas-fir management regimes for non-timber objectives. C.D. Oliver, D.P. Hanley, and J.A. Johnson (eds.). USDA Forest Service, Seattle, Washington. Pp 373-379.

FRANKLIN, J.F ., H.H. SHUGART, AND M.E. HARMON. 1987. Tree death as an ecological process: the causes, consequences, and variability of tree mortality. Bioscience. 37:550-556.

FRANKLIN, J.F. 1988. Structural and Functional Diversity in Temperate Forests. In E.O. Wilson and F.M. Peters. Biodiversity. National Academy Press, Washington. Pp. 166- 175.

FRANKLIN, J.F., D.A. PERRY, T.D. SCHOWALTER, M.E. HARMON, A. MCKEE, AND T.A. SPIES. 1989. Importance of ecological diversity in maintaining long-term site productivity of Pacific Northwest forest ecosystems. D.A. Perry, R. Meurisse, B. Thomas, R. Miller, J. Boyle, J. Means, C.R. Perry, and R.F. Powers. Timber Press. Portland, Oregon. Pp. 82-97.

GORTON, R.E. 1980. A comparative ecological study of the wood cockroaches in northeastern Kansas. Univ. Kansas Sci. Bull. 52:2130.

GRAHAM, R.L., AND K. CROMACK, JR. 1982. Mass, Nutrient content, and decay rate of dead boles in rain forests of Olympic National Park. Can. J. For. Res. 12:511-512.

GRIMES, T.L. 1977. Relationship of red-cockaded woodpecker *(Picoides borealis)* productivity to colony area characteristics. MS thesis, Clemson Univ., Clemson, S.C.

GRINNELL, J. 1924. A possible function of the whiteness of the breast in crevice-Searching birds. Condor. 67:32-33.

HAAPANEN, A. 1965. Bird fauna of the Finnish forests in relation to forest succession J. Ann. Zool. Fenn. 2: 153-196.

HANSEN, A.J., T.A. SPIES, F.J. SWANSON, AND J.L. OHMANN. 1991. Conserving biodiversity in managed forests: lessons from natural forests. Bioscience. 41: 382-392.

HANULA, J.L. 1996. Relationship of Wood-Feeding Insects and Coarse Woody Debris. Pp. 55-81 In J.W. McMinn and D.A. Crossley Jr. (eds.). Biodiversity and Coarse Woody Debris in Southern Forests. USDA Forest Service, General Technical Report SE-94.

HANULA, J.L. AND K.E. FRANZREB. 1995. Diet of nestling red-cockaded woodpeckers in the Upper Coastal Plain of South Carolina. Wilson Bulletin. 107:485-495.

HANULA, J.L., AND K.E. FRANZREB. 1998. Source, distribution, and abundance of macroarthropods on the bark of longleaf pine: potential prey of the red-cockaded woodpecker. For. Ecol. Manage. 102:89-102.

HANULA, J.L., AND K.C. NEW. 1998. Effect of time elapsed after prescribed burning in longleaf pine stands on potential prey of the red-cockaded woodpecker. Southern Journal of Applied Forestry. 22: 175-183.

HANULA, J.L., K.E. FRANZREB, AND W.D. PEPPER. 2000a. Longleaf pine characteristics associated with arthropods available for red-cockaded woodpeckers. J. Wildl. Manage. 64:60-70.

HANULA, J.L., D. LIPSCOMB, K.E. FRANZREB, AND S.C. LOEB. 2000b. Diet of nestling Red-cockaded Woodpeckers at three locations. J. Field Ornithol. 71: 126-134.

HANULA, J.L., AND F.T. ENGSTROM. IN PRESS. Comparison of Red-cockaded Woodpecker *(Picoides borealis)* nestling diet in old-growth and old-field longleaf pine *(Pinuspalustris)* habitats. Am. Midl. Nat.

HARLOW, R.F. AND D.C. GUYNN, JR. 1983. Snag densities in managed stands of the South Carolina coastal plain. S. Jour. Appl. For. 7:224-229.

HARMON, M.E. AND J.F. FRANKLIN. 1989. Tree seedlings on *logs* in *Picea-tsuga* forests of Oregon and Washington. Ecol. 70:224-229.

HARMON, M.E., J.F. FRANKLIN, F.J. SWANSON, P. SOLLINS, S.V. GREGORY, J.D. LATTIN, N.H. ANDERSON, S.P. CLINE, N.G. AUMEN, J.R. SEDELL, G. W. LIENKAEMPER, J.R. CROMACK, AND K. W. CUMMINS. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research. 15: 133-302.

HARVEY, A.E., R.T. MEURISSE, J.M. GEIST, M.F. JURGENSEN, G.I. MCDONALD, R.T. GRAHAM AND N. STARK. 1989. Managing productivity processes in the inland Northwest- mixed conifers and pines. In D.A Perry, R. Meurisse, B. Thomas, R. Miller, J. Boyle, J. Means, C.R. Perry, and R.F. Powers (eds.). Maintaining the long-term productivity of Pacific Northwest forest ecosystems. Timber. Portland, Oregon. Pp 164- 184.

HENDRIX, P. 1996. Earthworms, Biodiversity, and Coarse Woody Debris in Forest Ecosystems of the Southeastern U.S.A. In J.W. McMinn and D.A. Crossley Jr. (eds.). Biodiversity and Coarse Woody Debris in Southern Forests. USDA Forest Service, General Technical Report SE-94. Pp. 43-54.

HESS, C.A., AND F.C. JAMES. 1998. Diet of the red-cockaded woodpecker in the Apalachicola National Forest. J. Wildl. Manage. 62:509-5 17.

HOOPER, R.G. 1996. Arthropod biomass in winter and the age of longleaf pines. For. Ecol. Manage. 82:115-131.

HOOPER, R.G., AND M.R. LENNARTZ. 1981. Foraging behavior of the red-cockaded woodpecker in South Carolina. Auk. 98:321-334.

HOOPER, R.G., AND M.R. LENNARTZ. 1995. Short-term response of a high density red-cockaded woodpecker population to removal of foraging habitat. In Kulhavy, D.L, R.G. Hooper, and R. Costa (eds.). Red-cockaded Woodpecker: Ecology, Recovery, and Management. Nacogdoches, Texas. Pp 283-302.

HOPKINS, M.L. AND T.E. LYNN JR. 1971. Some characteristics of red-cockaded Woodpecker trees and management implications in South Carolina. In R.L. Thompson (ed.). The Ecology and Management of the Red-cockaded woodpecker. Tallahassee, Florida, Bur. Sport Fish. Wildl., U.S. Dept. Interior, and Tall Timbers Research Station. Pp 140-169.

HUNTER, M.L. 1990. Wildlife, forests and forestry: principles of managing forests for biological diversity. Prentice Hall. New Jersey, NJ. 370 p.

JACKSON, J.A. 1971. The evolution, taxonomy, distribution, past populations, and current status of the red-cockaded woodpecker. In R.L. Thompson (ed.). The Ecology and Management of the Red-cockaded Woodpecker. Tallahassee, Florida, Bur. Sport Fish. Wildl., U.S. Dept. Interior, and Tall Timbers Research Station. Pp 4-29.

JACKSON, J.A. 1986. Biopolitics, management, of federal lands, and the conservation of the red-cockaded woodpecker. American Birds. 40: 1162- 1168.

JACKSON, J.A. 1994. Red-cockaded woodpecker (*Picoides* borealis). The birds of North America, number 85. The American Ornithologists' Union, Washington, D.C., USA. The Academy of Natural Sciences, Philadelphia, PA, USA.

JACKSON, J.A. 1995. The Red-cockaded Woodpecker: Two Hundred Years of Knowledge, Twenty Years Under the Endangered Species Act. In Kulhavy, D.L., R.G. Hooper, and R. Costa (eds.). Red-cockaded Woodpecker: Recovery, Ecology, and Management Nacogdoches, Texas. Pp 42-57.

JAMES, F.C. 1991. Signs of trouble in the largest remaining population of red-cockaded woodpeckers. Auk. 108:419-423.

KAARIK, A.A. 1974. Decomposition of wood. In Dickson, C.H. and G.J.E. Pugh, (eds.). Biology of plant litter decomposition. Academic Press. London. Pp 129-174.

KOERSVALD, E.V. 195 1. difficulties in stomach analysis. Pp. 592-594 in Proceedings 1 0th International Ornithological Congress. Uppsala, Sweden.

LENNARTZ, M.R., P.H. GEISSLER, R.F. HARLOW, R.C. LONG, K.M. CHITWOOD AND J.A. JACKSON. 1983a. Status of the red-cockaded woodpecker populations on federal lands in the south. Proceedings of the Red-cockaded Woodpecker Symposium. 2:7-12.

LENNARTZ, M.R., H.A. KNIGHT, J.P. MCCLURE, AND V.A. RUDIS. 1983b. Status of red-cockaded woodpecker nesting habitat in the South. Proceedings of the Red-cockaded Woodpecker Symposium. 2: 13-l 9.

LIGON, J.D. 1968. Sexual differences in foraging behavior in two species of *Dendrocopus* woodpeckers. Auk. 85:203-2 15.

LIGON, J.D. 1971. Some factors influencing numbers of the red-cockaded woodpecker. In R.L. Thompson (ed.). The Ecology and Management of the Red-cockaded Woodpecker. Tallahassee, Florida, Bur. Sport Fish. Wildl., U.S. Dept. Interior, and Tall Timbers Research Station. Pp 30-43.

LIGON, J.D., P.B. STACEY, R.N. CONNER, C.E. BOCK, AND C.S. ADKISSON. 1986. Report of the American Ornithologists' Union Committee for the Conservation of the Red-cockaded Woodpecker. Auk. 103:848-855.

KULHAVY, D.L., R.G. HOOPER, AND R. COSTA, EDITORS. 1995. Red-cockaded woodpecker: recovery, ecology, and management. Center for Applied Studies, College of Forestry, Stephen F. Austin State University, Nacogdoches, Texas, USA.

MARIANI, J.M., AND D.A. MANUWAL. 1990. Factors influencing brown creeper (*Certhia* Americana) abundance patterns in the southern Washington Cascade range. Studies Avian Biol. 13:53-57.

MARRA, J.L., AND R.L. EDMONDS. 1998. Coarse woody debris and soil respiration in an old-growth coniferous forest on the Olympic Peninsula. Washington, USA. Can. J. For. Res. 24:1811-1817.

MASER, C., G. ANDERSON, K. CROMACK, J.T. WILLIAMS, AND R.E. MARTIN. 1979. Dead and down woody material. In Ward, T.J. (ed.). Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. Agriculture Handbook No. 553. Washington D.C. USDA Forest Service. Pp. 78-95.

MASER, C., R.F. TARRANT, J.M. TRAPPE, AND J.F. FRANKLIN. 1988. From the forest to the sea: a story of fallen trees. General Technical Report. PNW-229. Portland, Oregon. USDA Forest Service, Pacific Northwest Research Station. 153 pages.

MCCARTHY, B.C., AND R.R. BAILEY. 1994. Distribution and abundance of coarse woody debris in a managed forest landscape of the central Appalachians. Can. J. For. Res. 24:1317-1329.

MCCOMB, W.C., S.A. BONNEY, R.M. SHEFFIELD, AND N.D. COST. 1986b. Den tree characteristics and abundance in Florida and South Carolina. J. Wildl. Manage. 50:584-591.

MCMINN, J.W., AND D.A.J. CROSSLEY. 1995. Biodiversity and Coarse Woody Debris in Southern Forests. USDA Forest Service, Southern Experiment Station, Asheville.

MCMINN, J.M., AND R.A. HARDT. 1996. Accumulations of coarse woody debris in Southern forests. In McMinn, J.W. and D.A. Crossley Jr. (eds.). Biodiversity and Coarse Woody Debris in Southern Forests. USDA Forest Service, General Technical Report SE-94. Pp. l-9.

MILLER, W.E. 1978. Use of prescribed burning in seed production areas to control red Pine cone beetle. Environ. Intimal. 7:698-702.

MOEED, A., AND M.J. MEAD. 1983. Invertebrate fauna of four tree species in Orongorongo Valley New Zealand, as revealed by trunk traps. NZ J. Ecol. 6: 39-53.

MORSE, D.H. 1972. Habitat utilization of the red-cockaded woodpecker during the Winter. Auk. 89:429-435.

NESBITT, S.A., D.T. GILBERT, AND D.B. BARBOUR. 1978. Red-cockaded woodpecker fall movements in Florida flatwoods community. Auk. 95: 145-151.

NICHOLAI, V. 1986. The bark: thermal properties, microclimate and fauna. Oecologia. 69: 148-l 60.

ORTEGO, B. AND D. LAY. 1988. Status of red-cockaded woodpecker colonies on private lands in east Texas. Wildl. Soc. Bull. 16:403-405.

PATTERSON, G.A. AND W.B. ROBERTSON. 1981. Distribution and habitat of the red-cockaded woodpecker in Big Cypress National Preserve. National Park Service, South Florida Research Center. Report T-6 13. Homestead.

PORTER, M.L. AND R.F. LABISKY. 1986. Home range and foraging habitat of red-cockaded woodpeckers in Northern Florida. J. Wildl. Manage., 50:239-247.

RAMEY, P. 1980. Seasonal, sexual, and geographical variation in the foraging ecology of red-cockaded woodpeckers (*Picoides borealis).* M.S. Thesis, Mississippi State Univ., Starkville, Mississippi.

RAPHAEL, M.G. AND M.L. MORRISON. 1987. Decay and dynamics of snags in the Sierra Nevada, California. For. Sci. 3:774-783.

RAPHAEL, M.G. AND M. WHITE. 1984. Use of snags by cavity-nesting birds in the Sierra Nevada. Wildl. Monogr. 66 p.

REED, J.M., P.D. DOERR, AND J.R. WALTERS. 1988. Minimum viable population size of the red-cockaded woodpecker. J. Wildl. Manage. 52:385-391.

REPASKY, R.R., 1984. Home range and habitat utilization of the red-cockaded woodpecker. M.S. Thesis, North Carolina State Univ. Raleigh, NC. 136pp.

RICHARDSON, F. 1942. Adaptive modifications for tree-trunk foraging in birds. Univ. Calf. Publ. Zool. 46:3 17-368.

ROSENBURG, K.V. AND R.J. COOPER. 1990. Approaches to avian diet analysis. in Avian foraging : theory, methodology and applications. Studies in Avian Biology No. 13 (Morrrison, M.L., C.J. Ralph, J. Verner, and J.P. Jehl, Jr. (eds.). Cooper Ornithol. Society. San Diego, California. Pp 80-90.

RUDOLPH, D.C., AND R.N. CONNER. 1991. Cavity tree selection by red-cockaded woodpeckers in relation to tree age. Wilson Bull. 103:458-467.

SABIN, G.R. 1991. Snag dynamics and utilization by wildlife in the upper Piedmont of South Carolina. M.S. Thesis. Clemson, SC.

SANZONE, D.M. 1995. Macroarthropods associated with coarse woody debris: factors Influencing abundance and diversity patterns. M.S. Thesis, Univ. of Georgia, Athens, Georgia. 113 pages,

SKORUPA, J.P. 1979. Foraging ecology of the red-cockaded woodpecker in South Carolina. M.S. Thesis, Univ. of California, Davis.

SOLLINS, P., S.P. CLINE, T. VERHOEVEN, D. SACHS, AND G. SPYCHIR. 1987. Patterns of log decay in old-growth Douglas-fir forests. Can. J. For. Res. 17: 1585-1595.

SPRING, L. W. 1965. Climbing and pecking adaptations in some North American Woodpeckers. Condor. 67:457-488.

STURTEVANT, B.R., J.A. BISSONETTE, J.N. LONG, AND D.W. ROBERTS. 1997. Coarse woody debris as a function of age, stand, structure, and disturbance in Boreal Newfoundland. Ecological Applications. 7:702-712.

THOMPSON, R.L. 197 1. The ecology and management of the red-cockaded Woodpecker. Tallahassee, Florida. Bur. of Sport Fish. and Wildl., U.S. Dept. of Interior and Tall Timbers Research Station.

THOMPSON R.L. AND W.W. BAKER. 1971. A survey of red-cockaded woodpecker nesting habitat requirements. In R.L. Thompson (ed.). The Ecology and Management of the Red-cockaded woodpecker Tallahassee, Florida, Bur. Sport Fish. Wildl., U.S. Dept. Interior, and Tall Timbers Research Station. Pp 170-186.

U.S. DEPARTMENT OF THE INTERIOR. 1973. Threatened Wildlife of the United States. Compiled by the Office of Endangered Species and International Activities. Bureau of Sport Fisheries and Wildlife Resource Publication. pp. 114.

U.S. FISH AND WILDLIFE SERVICE. 1985. Red-cockaded Woodpecker Recovery Plan. U.S. FISH AND WILDLIFE SERVICE, Atlanta, Georgia. 88pp.

U.S. FOREST SERVICE. 1985. Wildlife habitat management handbook, chapter 420, red- cockaded woodpecker. US. Dept. Agr., For. Serv., Handbook 2609.23R. Southern Region, Atlanta, Georgia.

VAN LEAR, D.H. 1996. Dynamics of coarse woody debris in southern forest ecosystems. In McMinn, J.W. and D.A. Crossley Jr. (eds.). Biodiversity and Coarse Woody Debris in Southern Forests. USDA Forest Service, General Technical Report SE-94. Pp. 10-17.

WAHLENBERG, W.G. 1946. Longleaf pine-its use, ecology, regeneration, protection, growth, and management. C. Lathrop Pack Forestry Foundation. Washington, D.C.

WAHLENBERG, W.G. 1960. Loblolly pine: its use, ecology, regeneration, protection, growth and management. Duke Univ., School of Forestry, Durham, N.C.

WALLACE, J.B., J.W. GRUBAUGH, AND M.R. WHILES. 1996. Influences of coarse woody debris on stream habitats and invertebrate biodiversity. In McMinn, J.W. and D.A. Crossley Jr. (eds). Biodiversity and Coarse Woody Debris in Southern Forests. USDA Forest Service, General Techinical Report SE-94. Pp. 119-129.

WALTERS, J.R. 1990. Red-cockaded woodpeckers: a “primitive” cooperative breeder. In Stacey, P.B. and W.D. Koenig, editors. Cooperative breeding in Birds: long-term studies of ecology and behavior. Cambridge University Press. Cambridge, United Kingdom. Pp 67-102.

WALTERS, J.R. 199 1. Application of ecological principles to the management of endangered species: the case of the red-cockaded woodpecker. Annual Review of Ecology and Systematics. 22:505-523.

WARREN, M.S., AND R.S. KEY. 1991. Woodlands: past, present, and potential for Insects. In Warren, M.S. and R.S. Key (eds.), The conservation of insects and their habitats. Academic, London. Pp. 155-211.

WESTMAN, W.E. 1990. Managing for biodiversity. Bioscience. 40:26-33

WOOD, D.A. 1977. Status, habitat, home range, and notes on the behavior of the red-cockaded woodpecker in Oklahoma. M.S. Thesis, Oklahoma State Univ., Stillwater, Oklahoma.

WOOD, D.A. 1983. Foraging and colony habitat characteristics of the red-cockaded Woodpecker in Oklahoma. . Proceedings of the Red-cockaded Woodpecker Symposium II. Florida Game and Freshwater Fish Commission and USFWS. Pp. 51-58

WOOD, G.W., AND J. KLEINHOFS. 1992. Integration of timber management and red-cockaded woodpecker conservation goals on Georgia-Pacific Corporation timberlands in the southern United States. Georgia Pacific Corporation. Pp. 29.

WOOD, G.W., L.J. NILES, R.M. HENDICK, J.R. DAVIS AND T.L. GRIMES. 1985a. Compatibility of even-aged management and red-cockaded woodpecker conservation. Wildl. Soc. Bull. 13:5-17.

WOOD, G.W., L.J. NILES, R.M. HENDRICKS AND T.L. GRIMES. 1985b. Influences of clearcutting on red-cockaded woodpecker reproduction and nestling tending. For. Bull. Dept. Forestry, Clemson Univ., Clemson, S.C.

ZWICKER, S.M., AND J.R. WALTERS. 1999. Selection of pines for foraging by red-cockaded woodpeckers. J. Wildl. Manage. 63:843-852.

RELATIONSHIP OF COARSE WOODY DEBRIS TO RED-COCKADED WOODPECKER PREY DIVERISITY AND ABUNDANCE[1]

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ABSTRACT

Red-cockaded woodpeckers (*Picoides* ***borealis)*** forage almost exclusively on the bole of live pine trees, however their arthropod prey are not confined to this habitat but are often found in or near coarse woody debris (CWD). We used crawl traps to capture arthropods crawling up loblolly pine (*Pinus taeda*) ***tree*** boles to determine if removal of woody debris affected prey availability for this endangered woodpecker and other bark-foraging species. In addition, we utilized burlap bands wrapped around trees and cardboard panels placed on the ground that harbor arthropods so that they could be easily observed. Woody debris was removed annually from four 9 ha plots beginning in 1997 and arthropod diversity, abundance, and biomass were compared to undisturbed controls. Crawl traps captured 27 orders of arthropods while 20 arthropod orders were observed under burlap bands and cardboard panels. The most abundant orders collected from crawl traps were Homoptera (primarily aphids) and Hymenoptera (mostly ants). The most common group observed underneath cardboard panels was Isoptera (termites), and the most common taxon under burlap bands was Blattaria (woodroaches). Overall, arthropod abundance and biomass captured in crawl traps was similar in control and CWD removal plots. However, we observed a significantly higher abundance of arthropods under burlap bands and cardboard panels in control plots. Our results suggest that removal of coarse woody debris from pine forests reduces overall arthropod abundance available to the Red-cockaded woodpecker, and it is likely that in the long-term certain groups will be reduced as well.

INTRODUCTION

The red-cockaded woodpecker (*Picoides borealis*) (RCW) is an endangered species endemic to the pine forests of the southern United States. The decline of this species can be attributed to the loss of open, mature longleaf pine (*Pinus palustris*) stands that once dominated forests of the Southern Coastal Plain. The RCW prefers to nest in mature pine stands with little midstory or understory vegetation (Crosby 1971, Hopkins and Lynn 1971, Thompson and Baker 1971, Grimes 1977). Forest management practices such as shorter rotations, substitution of faster growing species, and fire exclusion (Jackson 1986, Ligon et al. 1986, Walters 1990) have rendered many southern pine forests unsuitable as RCW habitat. Efforts to increase RCW populations and improve their habitats have had a major impact on forest management practices on public lands in the South, but despite extensive efforts to improve RCW habitat, many populations continue to decline (Conner and Rudolph 1989, Costa and Escano 1989, James 1991).

Live pine tree trunks are the primary foraging substrate of RCW, but their arthropod prey do not live exclusively in this habitat (Hanula and Franzreb 1998). Present guidelines for recovery of this endangered species only consider the amount of bark surface, neglecting other factors that may be important to RCW foraging habitats. If habitats other than the bark surface are important for prey species, then current guidelines may be inadequate.

One component of forest ecosystems that may be important to RCW prey is coarse woody debris (CWD), which includes snags, fallen trees, and decomposing root systems. The common prey of RCW include woodroaches (Blattaria), spiders (Araneae), ants (Hymenoptera), centipedes (Chilopoda), woodborer larvae (Coleoptera), and caterpillars (Lepidoptera) (Beal 1911, Hanula and Franzreb 1995, Hanula et al. 2000b, Hanula and Engstrom in press, Hess and James 1998), of these only caterpillars are not commonly found in or near CWD.

Elton (1966) considered CWD one of the three greatest resources for animal species in a natural forest. The presence of woody debris enhances the diversity of soil organisms by increasing the physical, structural, and chemical heterogeneity of the forest floor (Warren and Key 1991) and overall species diversity appears to be strongly correlated with CWD microhabitats in many forest types (Franklin et al. 1986, 1989, Westman 1990, McCarthy and Bailey 1994).

A large body of knowledge exists documenting the importance of CWD to terrestrial insects that spend most of their life in dead wood (Hanula 1996). However, little information is available on terrestrial arthropods that only use woody debris as part of their habitat and move readily within the forest. The objective of our study was to determine how the absence of CWD affects the diversity and abundance of arthropods available to RCW.

METHODS

Site Description

This study was conducted at the Savannah River Site (SRS) near Aiken, South Carolina (Fig. 1), which is owned and operated by the United States Department of Energy (DOE). The Savannah River Site is an 80,269 ha facility located in the upper Atlantic Coastal Plain Physiographic Province, covering parts of Aiken, Barnwell, and Allendale counties. The site was purchased in 1952 when approximately 67 % of the land was covered by natural forest communities and the remaining land consisted of agriculture and pasture land (Workman and McLeod 1990). In 1972, the forested portion of the site was designated as a National Environmental Research Park.

Upland forests on the site are dominated by artificially regenerated even-aged stands of loblolly (*Pinus taeda*), longleaf (*P. palustris*), and slash pine (*P. elliottii*) (Fig. 2). These species cover approximately 25,677 ha, 14,924 ha, and 12,011 ha respectively (Knox and Sharitz 1990). Prescribed burns and herbicide applications are used to limit hardwood intrusion within managed pine stands. A large portion of the SRS consists of dry uplands and sandhills where many communities are dominated by longleaf pine. Mesic and riparian areas consist of loblolly and bottomland hardwood species (Knox and Sharitz 1990). Most of the former agricultural fields have been converted to longleaf and loblolly pine plantations.

Climate in the region is temperate and mild (Soil Survey Staff 1977). Temperatures are lowest in January and highest in July. Average temperatures range from 27” C in summer to 9” C in the winter with a frost-free period of 240 days (Sanzone 1995). Average rainfall is usually 120 cm per year. From January 1998 through December 1998 the site received approximately 174 cm. The largest amount received during this study came during August 1998 (47.2 cm) and the lowest rainfall was recorded during October 1998 (1.78 cm).

Research Design

This study was part of a larger study to determine CWD recruitment, rates of decomposition, and the effects of CWD removal on various animal groups. The overall study design was a randomized complete block consisting of four treatments replicated in four blocks. Only treatments 1 and 2 were used to determine the effects CWD removal on arthropods in managed pine forests. The two treatments used were:

1. An undisturbed control.
2. A total annual removal of all CWD greater than 10 cm in diameter including standing snags. Removal began in July-August 1996.

All forest management activities such as prescribed burning and thinning were applied to the plots per management guidelines. However, plots were undisturbed except for CWD removals during the course of this study.

The stands chosen for the study consisted of 40-45 year old upland loblolly pine plantations. Each plot was 9 ha of even-aged monoculture, with occasional longleaf or slash pine interspersed. The midstory consisted mostly of hardwood species including mockernut hickory (*Carya tomentosa*), sweetgum *(Liquidumbar styraciflua*), blackjack *oak (Quercus murilundicu), wax* myrtle (*Myrica ceriferu),* and sassafras (*Sassafras albidum*). Understory species composition varied somewhat between blocks, however the most commonly encountered species were poison oak (*Rhus toxicodendron),* trumpet-vine *(Cumpsis radicans),* Carolina jessamine (*Gelsemium sempervirens),* fox grape (*Vitis uestivulis),* beggarticks *(Desmodium spp.),* and dog fennel *(Euputorium spp.).* Less common but notable understory species included southern gooseberry *(Vuccinium stamineum),* sparkleberry *(Vuccinium urboreum),* goldenrod (*Solidago spp.),* and the invasive, non-native bicolor lezpedeza *(Lezpedezu bicolor).*

Sampling Methods

Two sampling techniques were used during this study. Crawl traps with a drift fence (Hanula and New 1996) were used to determine if CWD removal affected species richness (i.e., number of species in a given area) and abundance of arthropods on tree boles. Each crawl trap consisted of an inverted metal funnel cut on the side so the funnel would fit against the tree with the spout pointed upward. Arthropods would crawl into the funnel and fall into a container that was placed on top of the funnel spout. From the container they fell into a cup that contained a saturated NaCl solution containing 1% formaldehyde and a drop of soap to reduce surface tension. A 10 cm wide aluminum drift fence placed around the tree prevented arthropods from crawling up the tree and forced them into the trap. Crawl traps were placed 2 m above the ground to facilitate sample collection since trap captures are similar regardless of location on the tree bole (Hanula and Franzreb 1998). Fifteen trees within the center 6 ha of each plot were fitted with a crawl trap. The traps were placed in 3 rows of 5 traps so that traps were evenly distributed throughout the study area. Crawl traps were collected monthly from October 1997 to September 1999. Samples from individual traps within a plot were combined into a collective sample for that plot and date.

Samples were sorted into morphologically similar types and placed into 70% alcohol. Morphospecies identifications were made using a reference collection. Morphospecies have been used successfully to contrast different forest arthropod communities (Oliver and Beattie 1996). Biomass estimates were made for all specimens by oven-drying them at 40” C for 48 hr and weighing.

We used burlap bands and cardboard panels to determine whether CWD removal affects known prey of the RCW. These techniques are non-destructive ways of monitoring specific groups of arthropods important in the RCW diet (Hanula unpublished data). Of main concern were woodroaches, which constitute a considerable bulk of the woodpecker's diet. Burlap bands consisted of 1 x 1 m pieces of burlap folded and sewn at the top along the fold, allowing a piece of cotton rope to be threaded through to hold the burlap in place around the tree. Bands were placed around 30 trees within the center 6 ha of each plot at a height of 1- 1.5 m. Ten bands were placed in each of 3 rows so that they were equally distributed throughout the plot. Burlap bands were checked by slowly untying the rope and lifting the band from the tree to observe arthropods beneath.

The cardboard panels consisted of four layers of 0.5 x 0.75 m corrugated cardboard held together with duct tape. They were placed 1-3 meters away from each tree that had a corresponding burlap band and were used to monitor arthropods on the ground. Sampling consisted of identifying and counting arthropods beneath the burlap and cardboard panels. A carry-along reference collection was used to help with field identification, however if an arthropod could not be identified in the field, it was collected and identified later.

Studies have documented the importance of woodroaches (Blatellidae) and ants (Formicidae) in the diet of RCW (Hanula and Franzreb 1995, Hanula et al. 2000, Hanula and Engstrom in press, Hess and James 1998) so we examined the relative seasonal abundance of these two arthropod groups using burlap and cardboard observations. The burlap bands and cardboard panels were monitored monthly from July 1998 to September 1999.

Statistical Analysis

A paired t-test (SAS 1985) was used to test for differences in mean abundance and biomass in crawl trap and abundance beneath burlap bands and cardboard panels between control and removal treatments. In some cases, we used $\log_{10}(x + 1)$ or $\sqrt{x + .5}$ transformations to stabilize the variance.

RESULTS

We captured > 49,000 arthropods from 405 genera in 172 families and 27 orders in crawl traps (Table 1). The most abundant orders were Homoptera (23,688) with large numbers of aphids, and Hymenoptera (8,047) consisting mostly of ants. The most diverse orders were Araneae (spiders), Hymenoptera (ants, bees, wasps), and Coleoptera (beetles), respectively. The highest biomasses were found in Coleoptera and Araneae. There was no difference in morphospecies richness between CWD control (167 ± 8 species/plot; x ± SE) and removal (165 ± 8 species/plot) plots. In addition, there was no difference in rare genera collected per year (ie. < 5 individuals) in control (62 genera) and removal (56 genera) plots.

We found little difference in mean arthropod abundance captured in crawl traps on CWD control (6,361 ± 893 arthropods/plot) and removal plots (6,060 ± 1131 arthropods/plot) ($P = 0.80$). Likewise, we found no significant difference in mean arthropod biomass captured on control (14.66 ± 1.67 g/plot) and removal (12.58 ± 0.49 g/plot) plots ($P = 0.25$). No arthropod order was captured in significantly higher numbers or biomass. However, the mean biomass of Salticidae (jumping spiders) was higher in control plots (0.39 ± 0.07 g/plot) than in removal plots (0.25 ± 0.04 g/plot) ($P = 0.03$). The mean biomass of Araneidae (orb-weaving spiders) was also higher in control plots (0.27 ± 0.07 g/plot) compared to removal plots (0.12 ± 0.06 g/plot) ($P = 0.05$). Two spiders, *Neoscona* sp. (Araneidae) *(0.23* ± *0.04* g/plot) (P = *0.03)* and *Phidippus* sp. (Salticidae) (0.35±0.06 g/plot) (P = 0.03) had significantly higher biomass on control plots as did a *fly* in the genus *Sciara* (Sciaridae) (0.0008 ± 0.0001 g/plot) (P = 0.03). The weights for *Neoscona* sp. (0.10 ± 0.05 g/plot), *Phidippus* sp. (0.22 ± 0.04 g/plot), and *Sciara* sp. (0.0005 ± 0.0001 g/plot) were lower on removal plots.

Burlap bands and cardboard panels resulted in > 47,000 arthropod observations, from 20 orders and 82 families (Table 2). The most abundant order was Isoptera (termites) (17,425) in cardboard panels, followed by Blattaria (11,560) beneath cardboard and burlap. The latter were primarily woodroaches in the genus *Parcoblatta.* The most diverse orders were Coleoptera and Araneae. Regression analyses revealed positive correlations between a number of arthropod groups found underneath burlap bands and adjacent cardboard panels (Table 3).

Overall, we collected a significantly greater number of arthropods from CWD control plots (P = 0.02) (Fig. 3). We removed termites from the analysis since they were attracted to and fed on the cardboard panels. When termites were removed, control plots still had significantly higher numbers of arthropods overall (P = 0.04). However, the Hemiptera (true bugs) were the only arthropod order found in significantly higher numbers in control plots (Fig. 4) (P = 0.05). Ants in the genus *Crematogaster* were also found in higher numbers in control plots (567 ± 82 ants/plot) than removal plots (217 ± 56 ants/plot) (P = 0.04). The order Opiliones (harvestmen) was the only group that was significantly higher in removal plots (7 ± 2.1 individuals/plot) than in control plots (3 ± 1.9 individuals/plot) (P = 0.01), however the'number collected was relatively small.

Several arthropod taxa observed under burlap bands and cardboard panels were found in higher numbers in control plots, however these relationships were not significant ($P < 0.05$) (Fig. 4).

When we analyzed non-destructive traps separately we still observed significantly higher overall arthropod abundance in control plots underneath burlap bands ($P = 0.03$) and cardboard panels ($P = 0.04$) (Fig. 5). Hemiptera was the only arthropod order found in significantly greater abundance underneath burlap bands (441 ± 91 individuals/plot) ($P = 0.03$) and cardboard panels (14 ± 4.2 individuals/plot) ($P = 0.02$) in control plots, compared to burlap bands (286 ± 42 individuals/plot) and cardboard panels (5 ± 1.8 individuals/plot) in removal plots. However, the family Formicidae was found in significantly higher numbers in control plots (391 ± 95 individuals/plot) compared to removal plots (181 ± 27 individuals/plot) beneath burlap bands only ($P = 0.05$).

We found overall abundance of arthropods beneath burlap bands and cardboard panels relatively high throughout the year, with the lowest numbers occurring in March (Fig. 6). Seasonally, we observed the highest number of arthropods in summer (11,044), while the lowest number occurred during spring (6,238). We found woodroaches to be most abundant during winter, while ants were most abundant during summer (Fig 7).

DISCUSSION

The results of our study, using crawl traps to sample arthropod diversity and abundance on pine boles suggests that CWD removal has little effect. We collected many of the same common species described by Hanula and Franzreb (1998) on longleaf pine, showing that the arthropod community is similar regardless of tree species.

We found that CWD removal did not reduce overall arthropod diversity, abundance and biomass captured in crawl traps. The only differences noted were for the two spider families Salticidae and Araneidae, primarily because of the genera *Phidippus* and *Neoscona*, respectively. It is unclear why these two spiders were affected. Coarse woody debris may be an important habitat for macroarthropods serving as prey to these spiders, however macroarthropod groups sampled showed similar numbers regardless of treatment. The biomass of *Sciara* sp. flies was also higher in control plots. Many small flies rely on moist logs and other debris for egg and larval development (Borrer et al. 1989) and this may explain why these flies were affected.

Our study was conducted over a two-year period, and CWD removal had only begun one year prior to our sampling. Therefore, it is possible that the effect of CWD removal will become more evident or pronounced over a longer period of time. Many arthropods have one generation a year so with time some arthropod populations may decrease gradually in the absence of CWD. Crawl traps provided a passive method of collecting many arthropod groups crawling on tree boles and provide insights into overall arthropod diversity and abundance on tree boles (Hanula and Franzreb 1998, Hanula and New 1999, Hanula et al. 2000a). However, previous studies have shown that RCW select relatively few, common arthropods (Beal 1911, Harlow and Lennartz 1977, Hanula and Franzreb 1995, Hanula et al. 2000a,b, Hanula and Engstrom in press, Hess and James 1998) so it is important to understand how forest management affects groups comprising the RCW diet.

We used a non-destructive sampling technique to monitor the relative abundance of common part-time bark-inhabiting arthropods over the course of one year. This method may be the best way of monitoring RCW prey over time. It allows observation of known arthropod prey without the problems associated with traps. In addition, studies suggest RCW select prey in approximately the same proportions as they are found underneath burlap bands (Hanula unpublished data).

Because we used cardboard panels placed on the ground, we observed large numbers of termites that were feeding on the panels. Although important to the food web and in decomposition processes, we do not consider termites in our discussion because they have not been documented as RCW prey. Removal of termites from our analyses did not affect the results. Woodroaches were the next most abundant group, predominantly individuals in the genus *Parcoblatta.*

Overall, we observed significantly higher numbers of arthropods in control plots beneath cardboard panels and burlap bands. Several arthropod orders were found in higher numbers in control plots, although Hemiptera was the only one that was significant. *Crematogaster* ants were also significantly more abundant in control plots. A study by Hess and James (1998) found that prescribed burning reduced the number of *Crematogaster* ants in longleaf pine stands. Their results may be due in part to removal of woody debris through burning. Hanula and Franzreb (1998) found large numbers of *Crematogaster* ants in both dead limbs and in the bark at the base of live trees. It is likely that dead wood is an important habitat component in the ecology of these ants.

Seasonal trends in arthropod availability on the bark are important for identifying times when food is limited (Hanula et al. 2000a). Red-cockaded woodpeckers are non-migratory so it is important to understand how its prey varies with season. Beyer et al. (1996) hypothesized that in years of good arthropod production RCW reproduce successfully, and in years of low arthropod production RCW with poorer foraging habitat may be negatively affected. By monitoring arthropods monthly for one year we were able to determine relative seasonal abundance of common bark-inhabiting arthropods.

Skorupa and McFarlane (1976) predicted that winter would be a time of limited arthropod availability, while summer would be a time of abundance. Likewise, Hooper (1996) stated that winter would be a time of arthropod scarcity. In contrast, Hanula and Franzreb (1998) and Hanula et al. (2000) found that arthropod abundance on tree boles was lowest during the summer and highest in the winter. Likewise, we found overall arthropod abundance was higher in winter under burlap bands on trees and somewhat lower in spring and summer. In contrast, arthropod abundance beneath cardboard on the ground was highest in summer. At no time did we observe a significant decline in numbers, however populations of certain groups fluctuated throughout the year.

We observed > 11,000 woodroaches over the course of one year. Studies (Hanula and Franzreb 1995 and Hanula et al. 2000b) have shown that woodroaches constitute a considerable amount of the RCW nestling diet. Our findings show that woodroaches were abundant on live pine trees throughout the year so it is likely that they are important to foraging adults as well.

The result of our collection of arthropods using crawl traps suggests that CWD removal has little affect on the overall bark community. However, burlap bands and cardboard panels show that CWD removal affects the overall abundance of arthropods that are the most likely prey of RCW. Burlap bands and cardboard panels are a simple and effective way to monitor RCW prey. For example, woodroaches comprise as much as 75% of the RCW nestling diet at SRS (Hanula and Franzreb 1995). Crawl traps collected slightly more than 2,800 woodroaches over the course of 24 months. Monitoring burlap bands and cardboard panels for 15 months yielded more than 11,000 woodroach observations.

Studies have shown that RCW may not be affected by removal of live trees, their primary foraging habitat (Wood et al. 1985b, Conner and Rudolph 1991a,b, Hooper and Lennartz 1995, Beyer et al. 1996). Wood et al. (1985) removed 37% and Hooper and Lennartz (1995) removed 43% of RCW foraging habitats without affecting populations. Many arthropods used dead wood as a part of their habitat. Forest management that reduces this component of the forest may be reducing prey availability for RCW. Monitoring trees for one year showed that removal of CWD significantly reduced overall arthropod abundance. Since this study was conducted shortly after CWD removals began, it is possible that effects on individual groups will become more evident as the study continues. An understanding of forest practices that reduce habitats used by arthropods will be helpful in developing RCW foraging guidelines. More research is needed, but management that retains woody debris is likely to help RCW recovery efforts.

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REFERENCES CITED

BEAL, F.E.L. 1911. Food of the woodpeckers of the United States. Dept. Agric. Biol. Surv. Bull. 37, 1-6.

BEYER, D.E., JR., R. COSTA, R.G. HOOPER, AND C.A. HESS. 1996. Habitat quality and reproduction of red-cockaded woodpecker groups in Florida. J. Wildl. Manage. 60:826-835.

BORRER, D.J., C.A. TRIPLEHORN, AND N.F. JOHNSON. 1989. An introduction to the study of insects. Saunders College Publishing. Fort Worth. 875 pp.

CONNER, R.N. AND D.C. RUDOLPH. 1989. Red-cockaded woodpecker colony status and trends on the Angelina, Davy Crockett, and Sabine National Forests. U.S. For. Serv. Res. Pap. SO-250. 15pp.

CONNER, R.N. AND D.C. RUDOLPH. 1991a. Effects of midstory reduction and thinning in red-cockaded woodpecker cavity tree clusters. Wildl. Soc. Bull. 19:63-66.

CONNER, R.N. AND D.C. RUDOLPH. 1991b. Forest habitat loss, fragementation, and red-cockaded woodpecker populations. Wilson Bull. 103:446-457.

COSTA, R. AND R.E.F. ESCANO. 1989. Red-cockaded woodpecker status and management in the southern region. U.S. For. Serv. Tech. Publ. R8-TP-12. 71pp.

CROSBY, G. T. 1971. Home range characteristics of the red-cockaded woodpeckerIn North-Central Florida. In: Thompson, R.L. (Ed.), The Ecology and Management of the Red-cockaded Woodpecker. Bur. Sport Fisheries, Wildl., U.S. Dept. of Interior, and Tall Timbers Res. Station, Tallahassee, FL, pp. 60-73.

DELOTELLE, R.S., J.R. NEWMAN, AND A.E. JERAULD. 1983. Habitat use by red-cockaded woodpeckers in central Florida. In: D.A. Wood (Ed.), Red-cockaded Woodpecker Symposium II Proceedings, 27-29 January 1983, at Panama City, FL, Florida Game and Freshwater Fish Commission, Tallahassee, FL, pp. 59-67.

ELTON, C.S. 1966. The pattern of animal communities. Methuen, London.

ENGSTROM, R.T. AND F.J. SANDERS. 1997. Red-cockaded woodpecker foraging ecology in an old-growth longleaf pine forest. Wilson Bull. 109, 203-217.

FRANKLIN, J.F., T. SPIES, D. PERRY, M. HARMON, AND A. MCKEE. 1986. Modifying Douglas-fir management regimes for non-timber objectives. In: CD. Oliver, D.P. Hanley, and J.A. Johnson (Eds.), Modifying Douglas-fir management regimes for non-timber objectives. USDA For. Serv., Seattle, pp. 373-379.

FRANKLIN, J.F., D.A. PERRY, T.D. SCHOWALTER, M.E. HARMON, A. MCKEE, AND T.A. SPIES. 1989. Importance of ecological diversity in maintaining long-term site productivity of Pacific Northwest forest ecosystems. In: D.A. Perry, R. Meurisse, B. Thomas, R. Miller, J. Boyle, J. Means, C.R. Perry, and R.F. Powers (Eds). Timber Press, Portland, pp. 82-97.

GRIMES, T.L. 1977. Relationship of red-cockaded woodpecker (*Picoides* borealis) productivity to colony area characteristics. M.S. thesis, Clemson University, Clemson, S.C.

HANULA, J.L. AND K.E. FRANZREB. 1995. Diet of nestling red-cockaded woodpeckers in the Upper Coastal Plain of South Carolina. Wilson Bull. 107, 485-495.

HANULA, J.L. 1996. Relationship of wood-feeding insects and coarse woody debris. Pp. 55-81. In: J. W. McMinn and D.A. Crossley Jr. (Eds.), Biodiversity and coarse woody debris in southern forests. USDA For. Serv., Gen. Tech. Report. SE-94.

HANULA, J.L., AND K.C. NEW. 1996. A trap for capturing arthropods crawling up tree boles. Res. Note SRS-3, USDA For. Serv., Southern Research Station, Asheville, NC, 7 pp.

HANULA, J.L., AND K.E. FRANZREB. 1998. Source, distribution, and abundance of macroarthropods on the bark of longleaf pine: potential prey of the red-cockaded woodpecker. For. Ecol. Manage. 102, 89-102.

HANULA, J.L., K.E. FRANZREB AND W.D. PEPPER. 2000a. Longleaf pine characteristics associated with arthropods available for red-cockaded woodpeckers. J. Wildl. Manage. 64, 60-70.

HANULA, J.L., D. LIPSCOMB, K.E. FRANZREB, AND S.C. LOEB. 2000b. Diet of nestling Red-cockaded Woodpeckers at three locations. J. Field Ornithol. 71: 126-134.

HANULA, J.L., AND F.T. ENGSTROM. IN PRESS. Comparison of Red-cockaded Woodpecker (*Picoides* borealis) nestling diet in old-growth and old-field longleaf pine (*Pinus palustris*) habitats. Am. Midl. Nat.

HESS, C.A., AND F.C. JAMES. 1998. Diet of the red-cockaded woodpecker in the Apalachicola National Forest. J. Wildl. Manage. 62, 509-517.

HOOPER, R.G. AND M.R. LENNARTZ. 1981. Foraging behavior of the red-cockaded woodpecker in South Carolina. Auk. 98, 321-334.

HOOPER, R.G., AND M.R. LENNARTZ. 1995. Short-term response of a high density red-cockaded woodpecker population to removal of foraging habitat. Pages 283-302 in Red-cockaded Woodpecker: Ecology, Recovery, and Management. Nacogdoches, Texas.

HOOPER, R.G. 1996. Arthropod biomass in winter and the age of longleaf pines. For. Ecol. Manage. 82, 115-131.

HOPKINS, M.L. AND T.E. LYNN JR. 1971. Some characteristics of red-cockaded woodpecker trees and management implications in South Carolina. In: R.L. Thompson (Ed.), The Ecology and Management of the Red-cockaded woodpecker . Tallahassee, Bur. Sport Fish. Wildl., U.S. Dept. Interior and Tall Timbers Res. Station, pp. 140-l 69.

JACKSON, J.A. 1986. Biopolitics, management, of federal lands, and the conservation of the red-cockaded woodpecker. American Birds. 40, 1162-l 168.

JACKSON, J.A. 1994. Red-cockaded woodpecker (***Picoides borealis*).** The birds of North America, No. 85. The American Ornithologists' Union, Washington, D.C. The Academy of Natural Sciences, Philadelphia.

JAMES, F.C. 1991. Signs of trouble in the largest remaining population of red-cockaded woodpeckers. Auk. 108:4 19-423.

KNOX, J.N., AND R.R. SHARITZ. 1990. Endangered, threatened, and rare vascular Flora of the Savannah River Site. Savannah River Site National Environmental Research Park Program, Savannah River Ecology Lab, Aiken, SC.

LIGON, J.D. 1968. Sexual differences in foraging behavior in two species of *Dendrocopus* woodpeckers. Auk. 85, 203-2 15.

LIGON, J.D. 1970. Behavior and breeding biology of the red-cockaded woodpecker. Auk. 87, 255-278.

LIGON, J.D., P.B. STACEY, R.N. CONNER, C.E. BOCK, AND C.S. ADKISSON. 1986. Report of the American Ornithologists' Union Committee for the Conservation of the Red-cockaded Woodpecker. Auk. 103, 848-855.

MCCARTHY, B.C., AND R.R. BAILEY. 1994. Distribution and abundance of coarse woody debris in a managed forest landscape of the central Appalachians. Can. J. For. Res. 24, 1317-1329.

MILLER, W.E. 1978. Use of prescribed burning in'seed production areas to control red pine cone beetle. Environ. Intimal. 7, 698-702.

MORSE, D.H. 1972. Habitat utilization of the red-cockaded woodpecker during the Winter. Auk. 89, 429-435.

NESBITT, S.A., D.T. GILBERT, AND D.B. BARBOUR. 1978. Red-cockaded woodpecker fall movements in a Florida flatwoods community. Auk. 95, 145-151.

OLIVER, I. AND A.J. BEATTIE. 1996. Designing cost-effective invertebrate sampling methods for rapid assessment of biodiversity. Ecol. Soc. Am. Washington D.C.

PATTERSON, G.A. AND W.B. ROBERTSON. 1981. Distribution and habitat of the red-cockaded woodpecker in Big Cypress National Preserve. National Park Service, South Florida Research Center. Report T-6 13. Homestead.

PORTER, M.L. AND R.F. LABISKY. 1986. Home range and foraging habitat of red-cockaded woodpeckers in Northern Florida. J. Wildl. Manage. 50, 239-247.

RAMEY, P. 1980. Seasonal, sexual, and geographical variation in the foraging ecology of red-cockaded woodpeckers (*Picoides borealis).* M.S. Thesis, Mississippi State University, Starkville, MS.

REPASKY, R.R., 1984. Home range and habitat utilization of the red-cockaded woodpecker. M.S. Thesis, North Carolina State University, Raleigh, NC.

SANZONE, D.M. 1995. Macroarthropods associated with coarse woody debris: factors influencing abundance and diversity patterns. M.S. Thesis, University of Georgia, Athens, Georgia.

SAS INSTITUE . 1985. SAS guide for personal computers. Version 6 ed., SAS Institute, Cary, NC. 378 pp.

SKORUPA, J.P. 1979. Foraging ecology of the red-cockaded woodpecker in South Carolina. M.S. Thesis, University of California, Davis.

SKORUPA, J.P., AND R.W. MCFARLANE. 1976. Seasonal variation in foraging territory of red-cockaded woodpeckers. Wilson Bull. 88:281-289.

SOIL SURVEY STAFF. 1977. Soil survey of Barnwell County, South Carolina, eastern part. U.S. Soil Conservation Service, Washington D.C.

THOMPSON R.L. AND W.W. BAKER. 1971. A survey of red-cockaded woodpecker nesting habitat requirements. In: R.L. Thompson (Ed.), The Ecology and Management of the Red-cockaded woodpecker, Tallahassee, Florida, Bur. Sport Fish. Wildl., U.S. Dept. Interior and Tall Timbers Res. Station, pp. 170-186.

U.S. FISH AND WILDLIFE SERVICE. 1985. Red-cockaded Woodpecker Recovery Plan. U.S. Fish and Wildlife Service, Atlanta, GA., 88pp.

WALLACE, J.B., J.W. GRUBAUGH, AND M.R. WHILES. 1996. Influences of coarse woody debris on stream habitats and invertebrate biodiversity. In: J.W. McMinn and D.A. Crossley Jr. (Eds.), Biodiversity and Coarse Woody Debris in Southern Forests. USDA For. Serv., Gen. Tech. Report SE-94, pp. 119-129.

WALTERS, J.R. 1990. Red-cockaded woodpeckers: a “primitive” cooperative breeder. In: P.B. Stacey and W.D. Koenig (Eds.), Cooperative breeding in Birds: long-term studies of ecology and behavior. Cambridge University Press, Cambridge, United Kingdom, pp. 67-102.

WARREN, M.S., AND R.S. KEY. 1991. Woodlands: past, present, and potential for insects. In: M.S. Warren and R.S. Key (Eds.), The conservation of insects and their habitats. Academic, London, pp. 155-211.

WESTMAN, W.E. 1990. Managing for biodiversity. Bioscience. 40, 26-33.

WOOD, D.A. 1977. Status, habitat, home range, and notes on the behavior of the red-cockaded woodpecker in Oklahoma. M.S. Thesis, Oklahoma State University, Stillwater, OK.

WOOD, G.W., L.J. NILES, R.M. HENDRICKS AND T.L. GRIMES. 1985b. Influences of clearcutting on red-cockaded woodpecker reproduction and nestling tending. For. Bull. Dept. Forestry, Clemson Univ., Clemson, S.C.

WORKMAN, S.W., AND K.W. MCLEOD. 1990. Vegetation of the Savannah River Site: Major community types., Savannah River Ecology Laboratory, National Environmental Research Park Program.

Table1. Total number and biomass of arthropods captured in crawl traps during the period October 1997 to September 1999 on loblolly pine tree boles at the Savannah River Site, South Carolina.

ORDER	FAMILY	GENUS	TOTAL NO.	TOTAL WT.
Araneae				
	Agelenidae	*Agelenopsis*	262	3.6620
		Coras	56	0.5018
	Anyphaenidae	*Anyphaena*	25	0.0423
		Aysha	7	0.0108
		Teudis	5	0.0083
		Wulfila	2	0.0043
	Araneidae	*Acanthepeira*	5	0.1571
		Araneus	9	0.0101
		Eustala	4	0.0099
		Mangora	1	0.0005
		Melynogea	3	0.0099
		Metepeira	5	0.0206
		Neoscona	20	1.3109
		Neosconella	3	0.0103
		Wixia	3	0.0021
	Clubionidae	*Agroeca*	27	0.0314
		Castianeira	23	0.1028
		Chiracanthium	9	0.0127
		Clubiona	6	0.0205
		Clubionoides	214	0.3777
		Strotarchias	3	0.0153
		Trachelas	117	0.0343
	Corinnidae	*Phrurotimpus*	109	0.0365
		Scotinella	5	0.0018
	Ctenizidae	*Myrmekiaphilia*	1	0.0003
	Dictynidae	*Dictyna*	3	0.0006
		Lathys	406	0.4008
	Gnaphosidae	*Callilepsis*	25	0.0159
		Cesonia	4	0.0032
		Drassodes	4	0.0202

ORDER	FAMILY	GENUS	TOTAL NO.	TOTAL WT.
		Drassyllus	17	0.0146
		Gnaphosa	30	0.0144
		Haplodrassus	141	0.1936
		Herpyllus	119	0.3162
		Micaria	1	0.0007
		Zelotes	433	0.3596
	Hahniidae	*Hahnia*	33	0.0095
	Linyphiidae	*unknown*	56	0.1849
		Allomengea	2	0.0002
		Ceraticelus	261	0.0310
		Eridantes	22	0.0046
		Erigone	1	0.0001
		Grammonota	723	0.2643
		Lepthyphantes	42	0.0012
		Pocadicnemis	1	0.0001
		Sciastes	1	0.0002
		Scylaceus	2	0.0011
		Sisicottus	73	0.0193
		Spirembolus	3	0.0009
		Stemonyphantes	1	0.0001
		Tennesseellum	5	0.0002
		Walckenaeria	1066	0.1054
	Lycosidae	*unknown*	1	0.0007
		Hogna	101	0.6925
		Pardosa	476	1.1811
		Schizocosa	8	0.0165
	Lyssomanidae	*Lyssomanes*	31	0.0194
	Mimetidae	*Mimetus*	79	0.0429
	Oxyopidae	*Hamataliwa*	5	0.0042
		Oxyopes	6	0.0216
	Philodromidae	*Philodromus*	40	0.1000
		Thanatus	13	0.0494
	Pholcidae	*Pholcus*	1	0.0001

ORDER	FAMILY	GENUS	TOTAL NO.	TOTAL WT.
	Pisauridae			
		Dolomedes	16	0.5633
		Pisaurina	5	0.0260
	Salticidae	unknown	177	0.0280
		Eris	6	0.0128
		Habrocestrum	29	0.0505
		Hentzia	18	0.0215
		Metacyrba	9	0.0176
		Metaphidippus	3	0.0061
		Peckhamia	3	0.0010
		Phiddipus	198	2.2574
		Synemosyna	1	0.0003
		Thiodina	39	0.1584
		Zygoballus	39	0.0145
	Segestriidae	*Ariadna*	17	0.0755
	Tetragnathidae	*Tetragnatha*	10	0.0100
	Theridiidae	unknown	1	0.0001
		Achaearanea	8	0.0058
		Anelosimus	1	0.0015
		Chrysso	1	0.0001
		Dipoena	99	0.0330
		Enoplognatha	18	0.0028
		Episinus	1	0.0011
		Euryopsis	114	0.1084
		Latrodectus	11	0.7239
		Rhomphaea	2	0.0014
		Steatoda	3	0.0041
		Theridion	750	0.2413
		Tidarren	68	0.1852
	Thomisidae	*Coriarachne*	213	**0.9078**
		Misumenops	4	0.0373
		Tmarus	3	0.0059
		Xysticus	14	0.0452
	Uloboridae	*Hyptiotes*	2	0.0003
	Zoridae	*Zora*	2	0.0020

ORDER	FAMILY	GENUS	TOTAL NO.	TOTAL WT.
Blattaria				
	Blatellidae	***Aglaopteryx***	2397	6.4108
		Cariblatta	127	0.4454
		Parcoblatta	321	5.4390
Callipodida				
	Casiopetalidae	***Abacion***	4	0.0139
Chordeumatida				
	Cleidogonidae	***Cleidogona***	1	0.0016
Coleoptera				
	Unknown Families		9	0.0008
	Alleculidae	***Hymenorus***	18	0.1058
		Lobopoda	37	0.2221
	Anobiidae	***Lasioderma***	1	0.0005
		Petalium	2	0.0166
	Anthicidae	***unknown***	1	0.0001
	Anthribidae	***Goniocloeus***	2	0.0042
	Cantharidae	***Cantharis***	9	0.0060
	Carabidae	***Dromius***	1	0.0060
		Mioptachys	6	0.0027
		Pinacodera	23	0.2378
		Pterostichus	2	0.0421
	Cebrionidae	***unknown***	1	0.0050
	Cerambycidae	***Enaphalodes***	1	0.0018
		Xylotrechus	2	0.1166
	Chrysomelidae	***Anomoea***	4	0.0252
		Calomicrus	2	0.0022
		Glyptoscelis	5	0.1062
		Hornaltica	1	0.0001
		Paria	2	0.0040

ORDER	FAMILY	GENUS	TOTAL NO.	TOTAL WT.
	Cleridae	***Cymatoderma***	14	0.1173
	Coccinellidae	***unknown***	3	0.0024
		Brachyacantha	1	0.0012
		Coccinella	3	0.0159
		Coleomegilla	1	0.0006
		Diomus	12	0.0047
		Hyperaspis	1	0.0008
		Nephus	11	0.0048
	Colydiidae	***Bitoma***	**1**	0.0003
		Namunaria	**1**	0.0005
		Pycnomerus	**1**	0.0004
	Corylophidae	Unknown	23	0.0037
		Arthrolips	4	0.0003
		Orthoperus	1	0.0004
	Cryptophagidae	***Cryptophagus***	12	0.0037
		Diplocoelus	1	0.0001
	Cucujidae	***unknown***	2	0.0011
		Catogenus	1	0.0064
	Curculionidae	***unknown***	5	0.0069
		Cercopeus	4	0.0049
		Cimberis	2	0.0027
		Contrachelus	1	0.0026
		Cryptorhynchus	1	0.0123
		Curculio	3	0.0263
		Dryophthorus	1	0.0004
		Hylobius	233	9.1693
		Pachylobius	14	0.6793
		Pandeleteius	1	0.0066
		Pantomorus	1	0.0012
	Dytiscidae	***unknown***	1	0.0023
	Elateridae	***unknown***	21	0.2881
		Alaus	1	0.0943
		Ampedus	2	0.0020
		Anchastus	2	0.0161
		Blauta	1	0.0128

ORDER	FAMILY	GENUS	TOTAL NO.	TOTAL WT.
		Conoderus	4	0.0734
		Diopropus	2	0.0102
		Glyphonyx	13	0.2911
		Lacon	9	0.0461
		Megapenthes	11	0.0290
		Melanotus	70	1.4807
		Neotrichophorus	2	0.0424
		Orthostethus	1	0.2211
	Endomychidae	*Stenotarsus*	5	0.0152
	Hydrophilidae	*Dactylosternum*	7	0.0012
	Lampyridae	*Photinus*	2	0.0064
	Lathridiidae	*Corticaria*	1	0.0006
	Leptodiridae	*Ptomaphagus*	1	0.0002
	Lycidae	*Calopteron*	1	***0.0009***
	Melandryidae	*unknown*	1	0.0020
		Allopoda	1	0.0001
		Canifa	2	0.0023
	Meloidae	*Lytta*	1	0.1367
	Melyridae	*Ablecrus*	3	0.0006
		Attalus	4	0.0010
	Micromathidae	*Micromalthus*	1	0.0001
	Rhizophagidae	*Rhizohagus*	1	0.0030
	Mordellidae	*Glipodes*	3	0.0033
		Mordellistena	1	0.0008
	Mycetophagidae	*unknown*	16	***0.0069***
		Litargus	6	0.0012
		Mycetophagus	1	0.0001
	Nitidulidae	*Brachypeplus*	6	0.0048
		Cychramus	2	0.0024
		Carpophilus	10	0.0078

ORDER	FAMILY	GENUS	TOTAL NO.	TOTAL WT.
		Stelidota	1	0.0009
	Oedemeridae	*Heliocis*	1	0.0017
	Ptinidae	*Ptinus*	1	0.0001
	Scarabaeidae	*Anomala*	3	0.0651
		Diplotaxis	14	0.6216
		Phyllophaga	18	2.6675
		Serica	10	0.4019
	Scolytidae	*unknown*	8	0.0009
		Hypothenemus	19	0.0059
		Xyleborus	28	0.0093
		Xylosandrus	1	0.0001
	Scydmaenidae	*Scydmaenus*	3	0.0001
	Staphylinidae	*unknown*	123	0.0197
	Tenebrionidae	*Alobates*	1	0.0397
		Helops	88	1.5153
	Throscidae	*Aulonothroscus*	26	0.0103
	Trogossitidae	*Tenebroides*	1	0.0013
Diptera				
	Unknown Families		20	0.0113
	Anthomyiidae	*Anthomyia*	1	0.0015
		Pegomya	1	0.0024
	Aulacigastridae	*Aulacigaster*	1	0.0001
	Bibionidae	*unknown*	1	0.0005
	Cecidomyiidae	*unknown*	76	0.0028
		Cecidomyia	2	0.0003
		Planetella	1	0.0001
	Ceratopogonidae	*unknown*	1	0.0002

ORDER	FAMILY	GENUS	TOTAL NO.	TOTAL WT.
		Forcipomyia	4	0.0005
	Chaoboridae	*Corethrella*	1	0.0001
	Chironomidae	*unknown*	37	0.0028
		Ablabesmyia	1	0.0001
		Chironomus	2	0.0019
		Procladius	1	0.0001
	Chloropidae	Unknown		
		Thaumatomyia	2	0.0003
	Dolichopodidae	*Chrysoma*	1	0.0009
		Chrysotus	3	0.0015
		Condylostylus	2	0.0009
		Gymnopterus	2	0.0005
		Medetera	9	0.0034
		Sciapus	7	0.0053
	Drosophilidae	*Chymomyza*	1	0.0005
		Drosophila	1	0.0002
	Empididae	*Drapetis*	7	0.0007
		Euhybus	2	0.0004
		Hilaria	1	0.0001
	Micropezidae	*Composobata*	2	0.0016
	Milichidae	*Leptometopa*	8	0.0009
	Muscidae	*unknown*	1	0.0036
		Coenosia	2	0.0020
		Muscina	7	0.0189
	Mycetophilidae	Unknown	18	0.0037
		Anatella	1	0.0008
		Cordyla	3	0.0006
		Exechia	12	0.0031
		Exechiopsis	2	0.0002
		Mycetophila	48	0.0235
		Novakia	1	0.0001
		Orfelia	4	0.0022
		Pseudobrachypeza	1	0.0004

ORDER	FAMILY	GENUS	TOTAL NO.	TOTAL WT.
		Sciophila	1	0.0006
	Otitidae	*Euxesta*	1	0.0007
	Phoridae	*Beckerina*	1	0.0003
		Dohrniphora	3	0.0020
		Puliciphora	8	0.0005
		Megaselia	453	0.0468
		Metopinini	2	0.0001
		Rhyncophoromyia	3	0.0002
	Piophilidae	*unknown*	1	0.0001
	Psychodidae	*unknown*	3	0.0003
	Pyrogotidae	*Sphecomyiella*	1	0.0107
	Sarcophagidae	*unknown*	1	0.0176
		Sarcofahrtiopsis	1	0.0018
		Sarcophagula	1	0.0022
	Scatopsidae	*Colobostema*	1	0.0002
		Rhegmoclemina	12	2.9273
	Sciaridae	*Bradysia*	13	0.0020
		Corynoptera	43	0.0065
		Scaptosciara	3	0.0002
		Sciara	133	0.0049
	Syrphidae	*unknown*	3	0.0047
	Tipulidae	*unknown*	1	0.0015
		Elliptera	1	0.0004
		Limonia	1	0.0006
		Tipula	1	0.0016
Geophilomorpha				
	Geophilidae	*unknown*	3	0.023 1
Hemiptera				
	Anthocoridae	*unknown*	1	0.0001

ORDER	FAMILY	GENUS	TOTAL NO.	TOTAL WT.
	Aradidae	***Aradus***	3	0.0021
		Neuroctonus	1	0.0002
	Coreidae	***Acanthocephala***	2	0.0002
		Leptoglossus	4	0.0032
	Largidae	***unknown***	37	0.1242
		Largus	131	3.9873
	Lygaeidae	***unknown***	28	0.0013
	Miridae	***unknown***	82	0.2208
		Phytocoris	129	0.0406
		Pilophorus	1	0.0003
	Nabidae	***Metatropiphorus***	1	0.0003
	Pentatomidae	***Brochymena***	23	0.3887
	Reduviidae	***Arilus***	5	0.8924
		Empicoris	2	0.0002
		Melanolestes	4	0.1178
		Ploiaria	1	0.0003
		Pselliopus	10	0.0168
		Sinea	1	0.0040
		Stenolemus	1	0.0016
	Scutelleridae	***unknown***	1	0.0011
		Tetyra	4	0.5616
	Tingidae	***unknown***	1	0.0003
		Corythucha	2	0.0003
Homoptera				
	Achilidae	***Epiptera***	2	0.0079
	Aphididae	***unknown***	23109	1.8546
	Cicadellidae	***unknown***	504	0.1053
		Erythroneura	8	0.0009
		Typhlocybinax	1	0.0045

ORDER	FAMILY	GENUS	TOTAL NO.	TOTAL WT.
	Cicadidae	***Cicada***	7	0.5233
		Tibicen	16	10.8117
	Cixidae	***unknown***	9	0.0025
		Myndus	1	0.0005
		Oliarus	14	0.0330
	Derbidae	***Cedusa***	3	0.0007
	Dictyopharidae	*Phylloscelis*	5	0.0004
	Flatidae	***unknown***	4	0.0025
		Cyarda	1	0.0009
	Issidae	***Thionia***	1	0.0003
	Tropiduchidae	***unknown***	3	0.0020
Hymenoptera				
	Unknown Families		10	0.0066
	Ampulicidae	***Rhiopsis***	2	0.0036
	Bethylidae	***Epyris***	9	0.0075
		Goniozus	1	0.000 1
		Holepyris	1	0.000 1
		Pseudobrachium	2	0.0003
		Rhabdepyris	4	0.0009
	Braconidae	***unknown***	12	0.0013
		Aleiodes	2	0.0005
		Apanteles	2	0.0004
		Blacus	1	0.0005
		Eubazus	1	0.0003
		Meteorus	1	0.0001
		Parahormis	1	0.0001
		Rhoptrocentrus	1	0.0029
		Rogas	1	0.0003
		Zele	1	0.0013
	Ceraphronidae	***Ceraphron***	1	0.0001

ORDER	FAMILY	GENUS	TOTAL NO.	TOTAL WT.
	Chalcidae	***Brachymeria***	1	0.0027
		Phasgonophora	1	0.0002
	Cynipidae	***unknown***	1	***0.0001***
		Aylax	1	0.0009
	Diapriidae	***unknown***	3	0.0015
	Diprionidae	***unknown***	1	0.0257
	Encyrtidae	***Arrhenophagoidea***	2	0.0003
		Isodromus	14	0.0022
		Microterys	2	0.0005
	Eucoilidae	***Dicerataspis***	2	0.0002
	Eulophidae	***Cucarastichus***	434	0.0239
		Eulophus	1	0.0001
		Pentastichus	2	0.0002
		Pnigalio	214	0.0043
	Eupelmidae	***Keidosiella***	2	0.0009
	Evaniidae	***Hyptia***	19	0.0560
	Formicidae	***Amblyopone***	1	0.0009
		Aphaenogaster	71	0.0202
		Camponotus	1765	4.4068
		Crematogaster	3966	0.7634
		Cyphomyrmex	1	0.0004
		Dorymyrmex	14	0.0008
		Forelius	26	0.0055
		Formica	110	0.1432
		Hypoponera	6	0.0019
		Lepthothorax	20	0.0049
		Monomorium	1	0.0001
		Myrmecina	2	0.0009
		Myrmica	1	0.0004
		Paratrechina	63	0.0064
		Pheidole	245	0.0279
		Prenolepis	160	0.0486

ORDER	FAMILY	GENUS	TOTAL NO.	TOTAL WT.
		Solenopsis	178	0.0300
		Tapinoma	75	0.0075
		Trachymyrmex	1	0.0003
	Halictidae	*Halictus*	2	0.0002
	Ichneumonidae	**unknown**	10	0.0253
		Gelis	56	0.0411
		Mesostenus	13	0.0568
		Trychosis	5	0.0126
	Megaspilidae	***Conostigmus***	1	0.0001
	Mutillidae	***Dasymutilla***	12	0.1027
		Lomachaeta	1	0.0017
		Photomorphus	10	0.0321
		Sphaeropthalma	4	0.0124
		Timulla	8	0.0729
	Pompilidae	***Anoplius***	8	0.1535
		Paracyphononyx	3	0.0499
		Phanagenia	12	0.2926
		Pompilus	11	0.0660
		Priocnemella	129	0.7907
	Pteromalidae	**unknown**	37	0.0057
		Andersena	2	0.0002
		Exixestes	4	0.0005
		Metastenus	2	0.0013
	Scelionidae	***Aradoctonus***	7	0.0011
		Duta	2	0.0002
		Eumicrosoma	3	0.0003
		Gryon	51	0.0047
		Idris	64	0.0045
		Macroteleia	1	0.0002
		Phlebiaporus	1	0.0001
		Trimorus	13	0.0019
	Sphecidae	***Argogorytes***	3	0.0028
		Liris	1	0.0002
		Mellinus	5	0.0229

ORDER	FAMILY	GENUS	TOTAL NO.	TOTAL WT.
		Podium	11	0.1755
		Tachysphex	1	0.0079
		Trypoxylon	2	0.0571
	Tiphiidae	*Tiphia*	2	0.0335
	Vespidae	***Euodynerus***	1	0.0342
		Polistes	78	2.2551
		Vespula	2	0.0446
	Xyelidae	***unknown***	8	0.0056
Isoptera				
	Rhinotermitidae	***Reticulitermes***	409	0.2611
Julida				
	Parajulidae	*Uroblaniulus*	4	0.0761
Lepidoptera				
	Arctiidae	***unknown***	8	0.2063
	Gelechidae	***unknown***	62	0.0219
	Geometridae	***unknown***	625	0.8420
	Lasiocampidae	*Malacosoma*	3	0.0399
	Lycaenidae	***unknown***	1	0.0115
	Lymantridae	***unknown***	5	0.5028
	Noctuidae	***unknown***	317	13.0636
		Autographa	24	0.2599
	Notodontidae	***unknown***	12	0.0302
	Oecophoridae	***unknown***	3	0.0140
	Psychidae	***unknown***	6	0.0262
	Pyralidae	***unknown***	18	0.0477

ORDER	FAMILY	GENUS	TOTAL NO.	TOTAL WT.
	Sphingidae	*unknown*	22	0.3463
		Lapara	2	0.8534
Litobiomorpha				
	Lithobiidae	Unknown	1	0.0001
Mantodea				
	Mantidae	*unknown*	1	0.0219
		Stagmomantis	1	0.0679
Mecoptera				
	Bittacidae	*Bittacus*	1	0.0003
Microcoryphia				
	Machilidae	*Machilis*	568	0.5114
Neuroptera				
	Ascalaphidae	*Ululodes*	13	0.8727
	Chrysopidae	*unknown*	1	0.0001
		Chrysopa	25	0.0283
	Hemerobiidae	*unknown*	88	0.0449
		Hemerobius	6	0.0071
	Mantispidae	*Mantispilla*	1	0.0016
Opiliones				
	Cosmetidae	*unknown*	28	0.0133
	Gagrellidae	*Leiobunum*	1	0.0047
	Phalangiidae	*unknown*	227	0.1795
Orthoptera				
	Unknown Families		2	0.0011
	Acrididae	*unknown*	4	0.0059
		Schistocerca	10	0.3132
	Gryllidae	*unknown*	31	0.0176
		Myogryllus	3	0.0018
		Oecanthus	1	0.0048
		Orocharis	179	0.5239

ORDER	FAMILY	GENUS	TOTAL NO.	TOTAL WT.
	Tettigoniidae	***unknown***	58	0.0789
		Atlanticus	2	0.0755
		Belocephalus	1	0.0692
		Hubellia	1	0.1951
		Pterophylla	1	0.5305
Polydesmida				
	Platyrhacidae	***Euryurus***	15	0.0767
Psocoptera				
	Lepidopsocidae	***unknown***	1884	0.3744
Scolopendromorpha				
	Cryptopididae	***unknown***	5	0.1667
	Scolopendridae	***unknown***	20	1.5120
Spirobolida				
	Spirobolidae	***Narceus***	14	2.1170
Thysanoptera				
	‘Unknown Family		3	0.0001
Thysanura				
	Lepismatidae	***Thermobia***	11	0.0041
Trichoptera				
	Unknown Family		1	0.0003

Table 2. Total number of arthropods observed beneath burlap bands and cardboard panels from July 1998 until September 1999. Arthropods were identified to the lowest classification possible using morphospecies identification.

ORDER	FAMILY	GENUS	TOTAL NO.
Araneae			
	Agelenidae	***Agelenopsis***	13
		Coras	174
	Araneidae	***Acanthepeira***	1
		Neoscona	3
		Nuctenea	3
	Clubionidae	***Castianeila***	2
		Clubionoides	113
	Ctenidae	***Ctenus***	5
	Gnaphosidae	***Herpyllus***	1
		Micaria	98
		Zelotes	1
	Lycosidae	***Hogna***	408
		Schizocosa	72
	Oxyopidae	***Oxyopes***	4
	Philodromidae	***Philodromus***	14
	Pisauridae	***Dolomedes***	27
	Salticidae	***Habrocestrum***	67
		Hentzia	16
		Phidippus	1525
		Thiodina	1
	Theridiidae	***Diopoena***	34
		Euryopsis	7
		Theridion	1
		Tidarren	1

ORDER	FAMILY	GENUS	TOTAL NO.
	Thomisidae	*Coriarachne*	156
		Misumenops	3
	Uloboridae	*Uloborus*	2
Blattaria			
	Blatellidae	*Aglaopteryx*	807
		Cariblatta	93
		Parcoblatta	11467
Callipodida			
	Casiopetalidae	*Abacion*	101
Coleoptera			
	Alleculidae	*Hymenorus*	1993
		Lobopoda	12
	Anthribidae	*Euparius*	2
	Buprestidae	*Buprestis*	3
		Chalcophora	1
	Cantharidae	*unknown*	1
	Carabidae	*Pinacodera*	76
		Pterostichus	6
	Cerambycidae	*Enaphalodes*	3
		Graphisurus	4
		Spondylis	3
		Xylotrechus	1
	Chelonariidae	*Chelonarium*	2
	Chrysomelidae	*unknown*	13
		Glyptoseclis	4
		Kushchelina	1
	Cleridae	*unknown*	2
		Cymatoderma	10
		Thanasimus	1

ORDER	FAMILY	GENUS	TOTAL NO.
	Coccinellidae	***Coccinella***	4
	Cucujidae	***Catogenus***	1
	Curculionidae	***Cimberis***	1
		Curculio	2
		Hylobius	282
		Pandeleteius	1
		Pissodis	5
	Elateridae	unknown	1
		Alaus	3
		Blauta	5
		Heteroderes	129
		Megapenthes	7
		Melanotus	2
		Orthostethus	1
		Pityobius	1
	Endomychidae	***Stenotarsus***	2
	Eucnemidae	*Fornax*	4
		Microrhagus	1
	Lagriidae	***Statira***	2
	Lycidae	***Plateros***	1
	Monommidae	***Hyporhagus***	10
	Nitidulidae	***Amphotis***	1
	Scarabaeidae	***Anomala***	4
		Copris	1
		Diplotaxis	1
		Orthophagus	1
		Serica	2

ORDER	FAMILY	GENUS	TOTAL NO.
	Staphylinidae	unknown	17
	Tenebrionidae	unknown	47
		Alobates	81
		Helops	1194
		Platyderma	3
		Polypleurus	4
	Trogossitidae	***Temnochila***	5
		Tenebroides	1
Diptera			
	Muscidae	***unknown***	1
Geophilomorpha			
	Geophilidae	***unknown***	34
Hemiptera			
	Anthocoridae	***unknown***	11’
	Aradidae	***Neuroctonus***	156
	Coreidae	*Leptoglossus*	35
	Largidae	***unknown***	25
		Largus	1234
	Lygaeidae	***unknown***	1
		Atrozonatus	4
	Miridae	***unknown***	1
	Nabidae	***Pagasa***	1
	Pentatomidae	***Brochymena***	552
	Reduviidae	***Apiomerus***	5
		Arilus	1
		Melanolestes	4
		Pselliopus	461

ORDER	FAMILY	GENUS	TOTAL NO.
		Rasahus	2
		Stenopoda	2
	Scutelleridae	*Diolcus*	429
		Tetyra	14
Homoptera			
	Achilidae	*Epiptera*	11
	Aphididae	unknown	13
	Cercopidae	Unknown	10
		Aphrophora	4
	Cicadidae	*Cicada*	4
		Tibicen	4
	Cixiidae	*Oliarus*	3
	Coccidae	*unknown*	198
Hymenoptera			
	Diprionidae	*unknown*	3
	Formicidae	*Camponotus*	202
		Crematogaster	3351
		Formica	274
	Ichneumonidae	*unknown*	2
	Mutillidae	*Dasymutilla*	2
		Sphaeropthalma	1
	Vespidae	*Euodynerus*	1
		Polistes	22
	Xyelidae	*unknown*	3
Isoptera			
	Rhinotermitidae	*Reticulotermes*	17425
Lepidoptera			

ORDER	FAMILY	GENUS	TOTAL NO.
	Unknown Family	*unknown*	6
	Arctiidae	*unknown*	14
	Lasiocampidae	***Malacosoma***	1
	Noctuidae	*Autographa*	3
	Sphingidae	*Laparis*	5
	Thyrididae	*unknown*	1
Lithobiomorpha			
	Lithobiidae	*unknown*	84
Mantodea			
	Mantidae	*Stagmomantis*	2
Microcoryphia			
	Machilidae	***Machilis***	7
Neuroptera			
	Ascalaphidae	***Ululodes***	26
	Hemerobiidae	*unknown*	4
		Hemerobius	16
Opiliones			
	Gagrellidae	*unknown*	38
Orthoptera			
	Acrididae	*unknown*	8
		Schistocerca	30
	Gryllacrididae	*Ceuthophilus*	1
	Gryllidae	*Orocharis*	135
	Tettigoniidae	*unknown*	3
		Atlanticus	12

ORDER	FAMILY	GENUS	TOTAL NO.
Polydesmida			
	Xystodesmidae	unknown	18
Scolopendromorpha			
	Cryptopidae	unknown	125
	Scolopendridae	unknown	141
Thysanura			
	Lepismatidae	*Thermobia*	1677

Table 3. Regression analyses of arthropod abundance underneath burlap bands (x) and cardboard panels

Regression Model	R^2	F-value	P	
			b_0	b_1
$y_{Araneae} = 0.37 + 0.02burlap$	0.63	390.19	0.0001	0.0001
$y_{Callipoda} = 1.21 + 1.03burlap$	0.76	98.53	0.0003	0.0001
$y_{Coleoptera} = 0.15 + 0.02burlap$	0.62	296.41	0.03	0.0001
$y_{Hemiptera} = 0.11 + 0.02burlap$	0.31	93.87	0.31	0.0001
$y_{Orthoptera} = 0.8 + 0.78burlap$	0.58	109.05	0.0001	0.0001
$y_{Scolopendromorpha} = 0.93 + 0.26burlap$	0.34	51.70	0.0001	0.0001
$y_{Acrididae} = -0.14 + 0.10burlap$	0.68	40.97	0.0028	0.0001
$y_{Casiopetalidae} = 1.21 + 1.03burlap$	0.76	98.53	0.0003	0.0001
$y_{Lycosidae} = 0.41 + 0.06burlap$	0.32	56.47	0.0001	0.0001
$y_{Pentatomidae} = -0.17 + 0.09burlap$	0.32	45.82	0.39	0.0001
$y_{Thomisidae} = -0.04 + 0.02burlap$	0.37	23.21	0.24	0.0001

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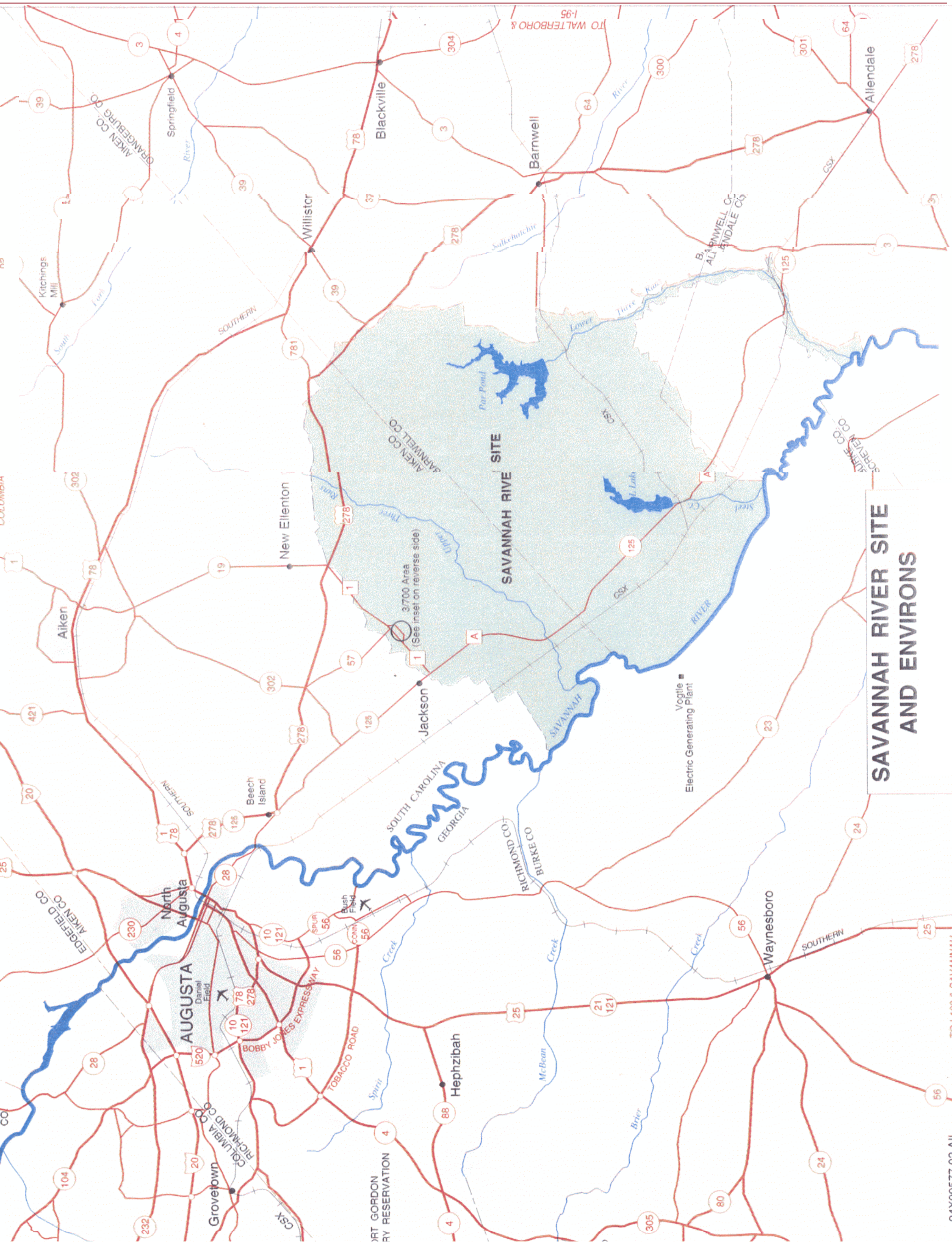
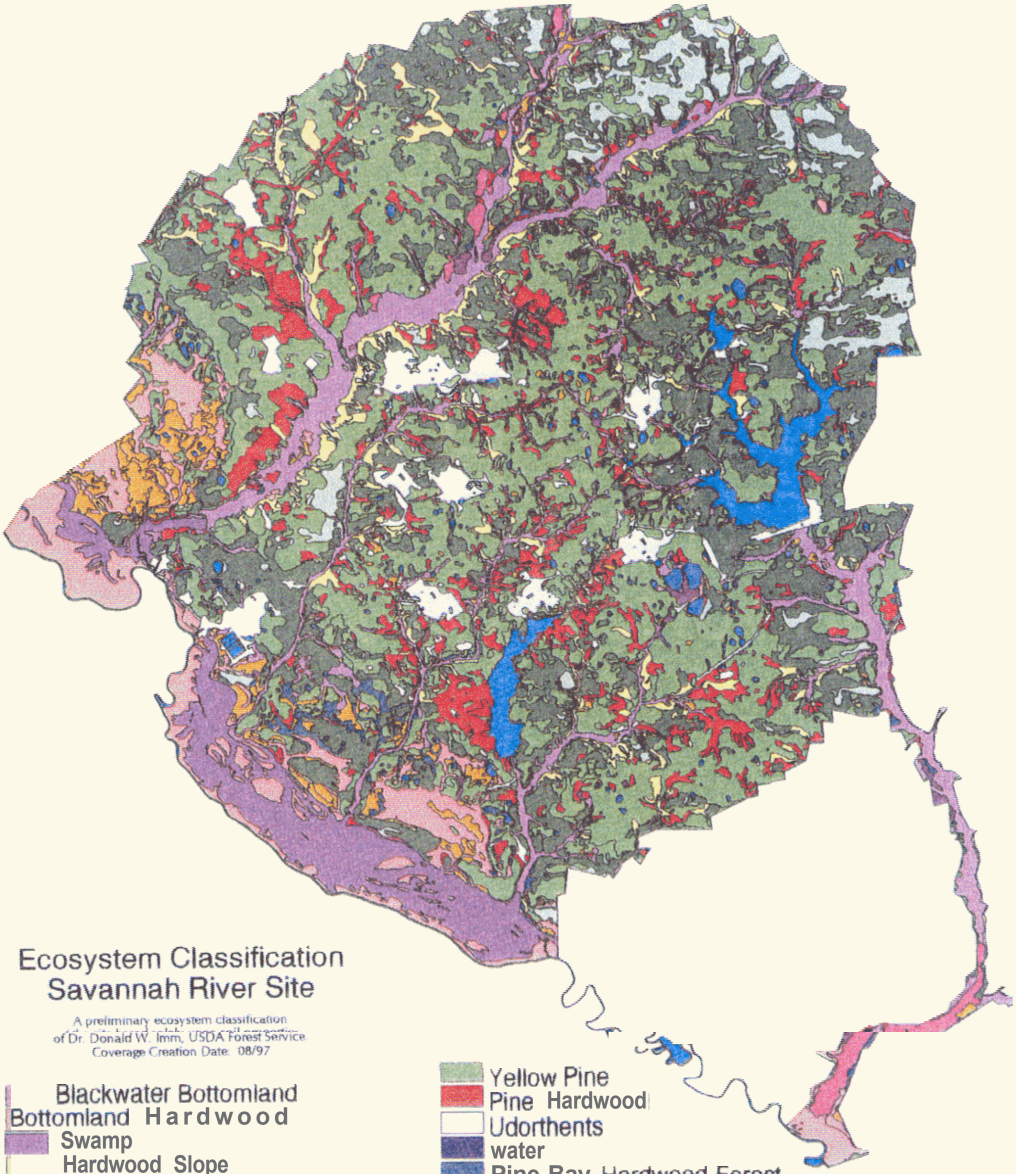
[1] Includes arthropod groups with $R^2 > 0.30$.

Figure 1. Map shows the Savannah River Site, South Carolina in relation to surrounding areas (Map courtesy of USFS-SRS).



SAVANNAH RIVER SITE AND ENVIRONS

Figure 2. Map shows ecosystem classifications and major forest types found on the Savannah River Site, South Carolina (Map courtesy USFS-SRS).



Ecosystem Classification
Savannah River Site

A preliminary ecosystem classification
of Dr. Donald W. Imm, USDA Forest Service
Coverage Creation Date: 08/97

Blackwater Bottomland
Bottomland Hardwood
Swamp
Hardwood Slope
Longleaf Pine
Longleaf Pine Scrub Oak
Muck Swamp

Yellow Pine
Pine Hardwood
Udorthents
water
Pine Bay Hardwood Forest
Pine Bay Hardwood Swamp
Carolina Bays, Upland Depressions
Southern Mixed Hardwood

N

Figure 3. Mean (H SE) arthropods/block observed underneath burlap bands and cardboard panels in control and removal plots in which coarse woody debris was removed annually. Traps were monitored from July 1998 to September 1999. Means are significantly different (P = 0.02) according to a paired t-test.

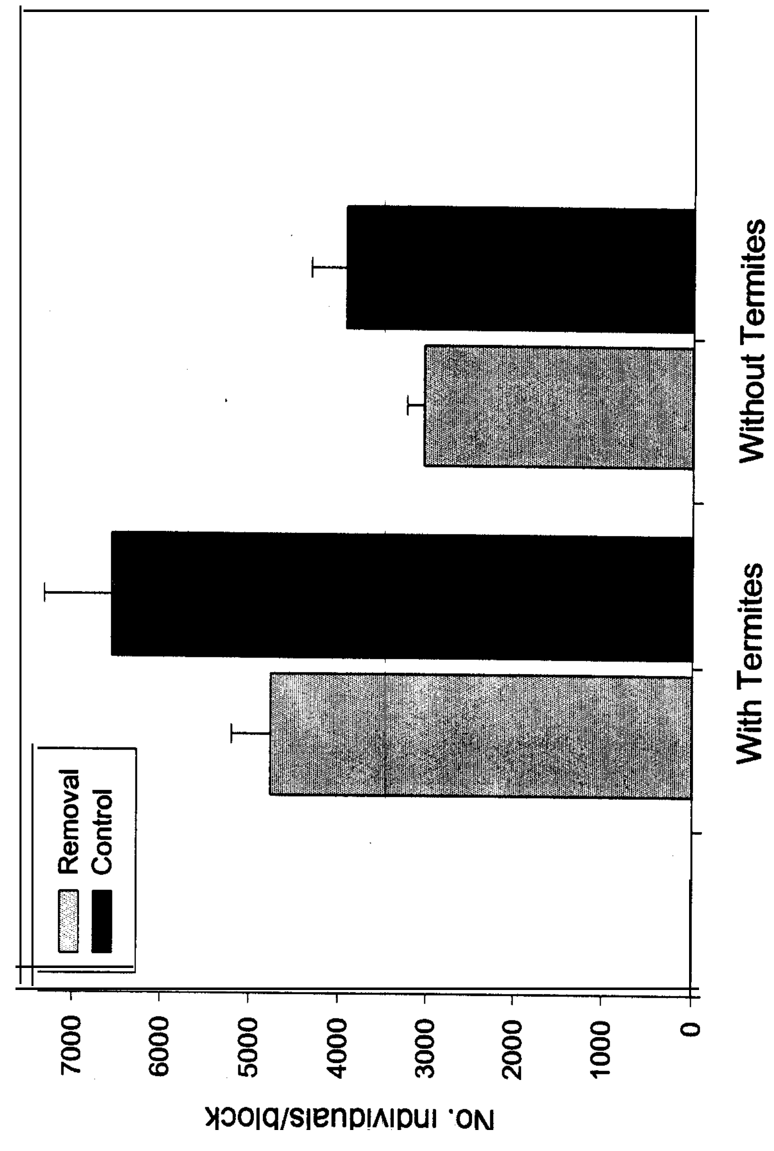

No. individuals/block
0
1000
2000
3000
4000
5000
6000
7000
Removal
Control
With Termites
Without Termites

Figure 4. Comparison of arthropod abundance in control and removal blocks of the most commonly collected orders underneath burlap bands and cardboard panels. (*) denotes that the relationship was significant ($P < 0.05$) according to a paired t-test.

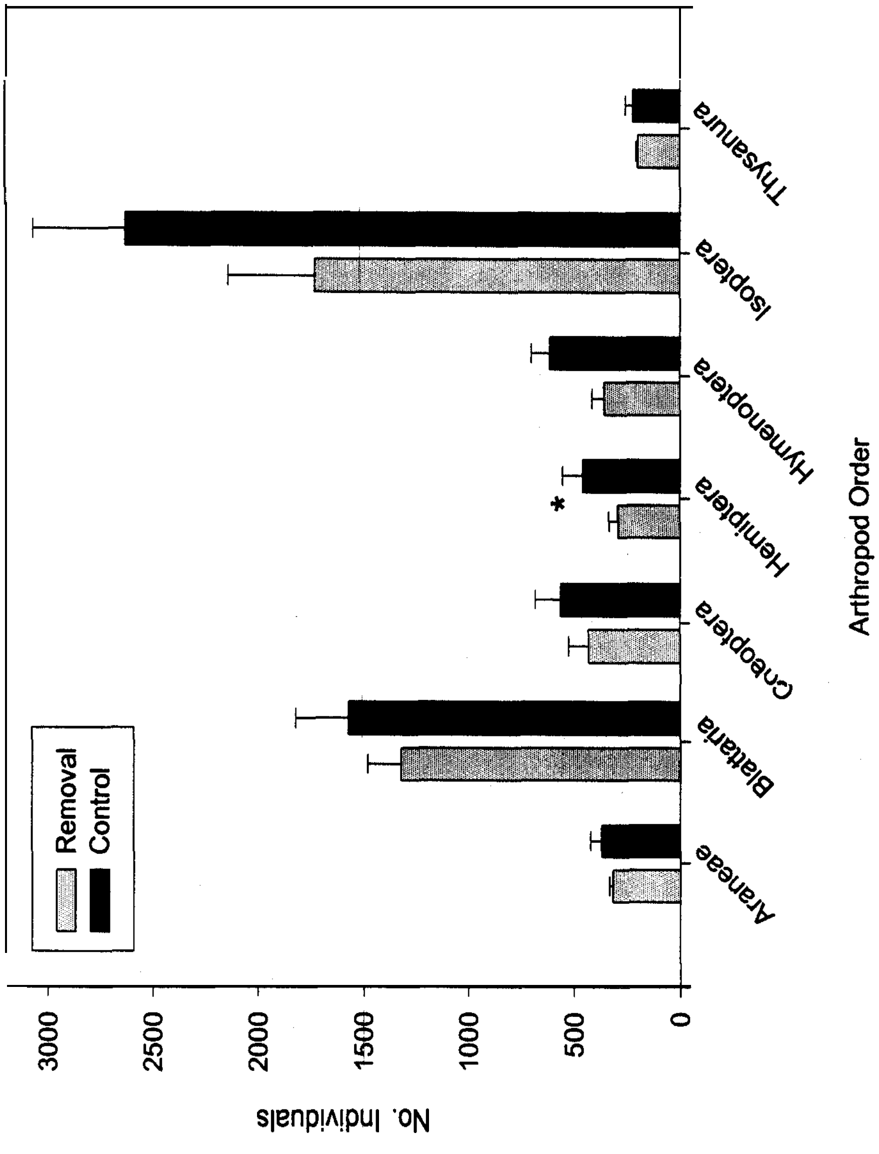

No. Individuals
0
500
1000
1500
2000
2500
3000
▨ Removal
■ Control
*
Araneae
Blattaria
Cneoptera
Hemiptera
Hymenoptera
Isoptera
Thysanura
Arthropod Order

Figure 5. Comparison of arthropod abundance found beneath burlap bands and cardboard panels from coarse woody debris control and removal plots from July 1998 to September 1999.

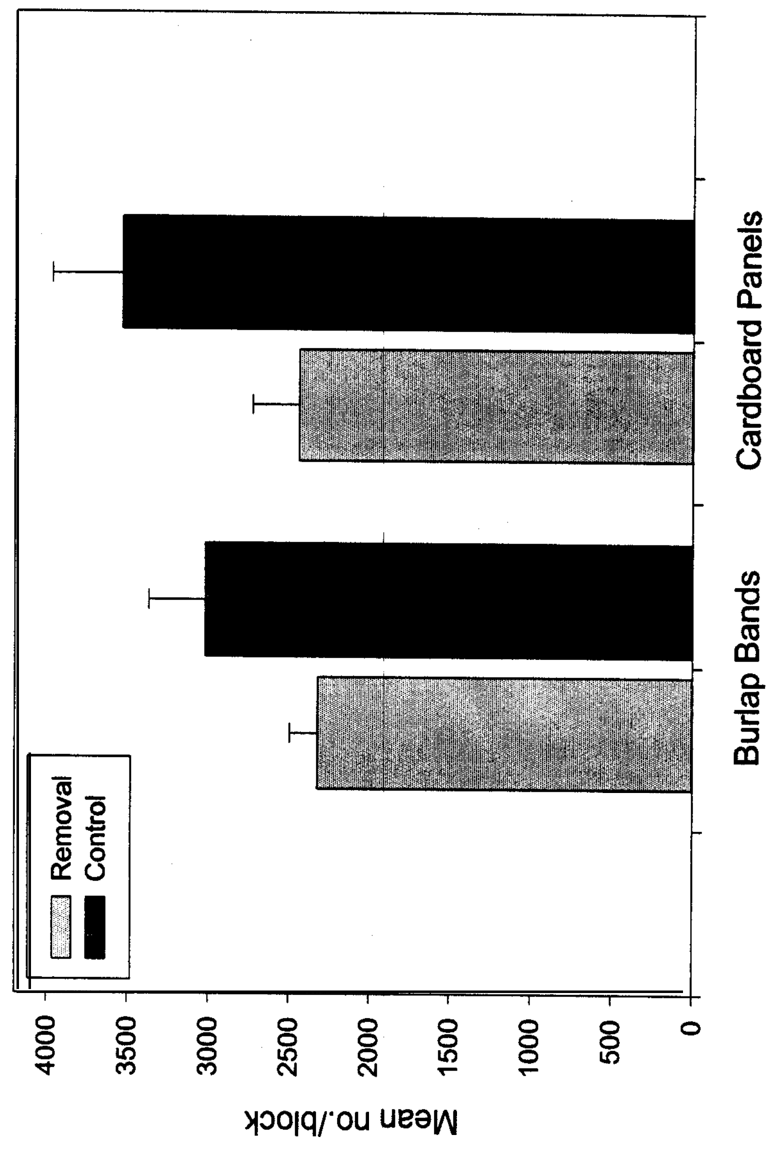

Mean no./block
0
500
1000
1500
2000
2500
3000
3500
4000
Removal
Control
Burlap Bands
Cardboard Panels

Figure 6. Seasonal abundance of total arthropods underneath burlap bands and cardboard panels combined for coarse woody debris control and removal plots from July 1998 to September 1999.

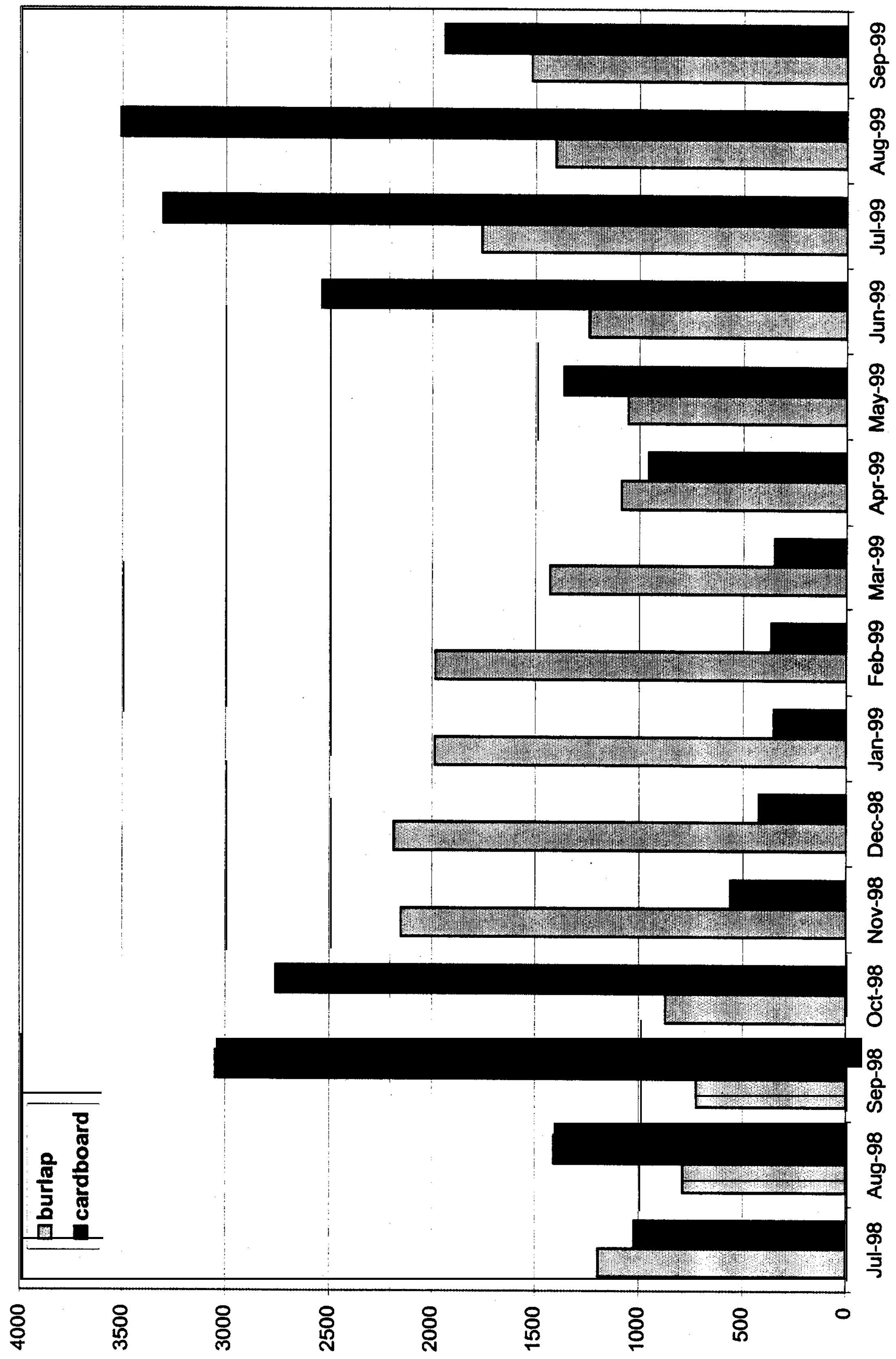
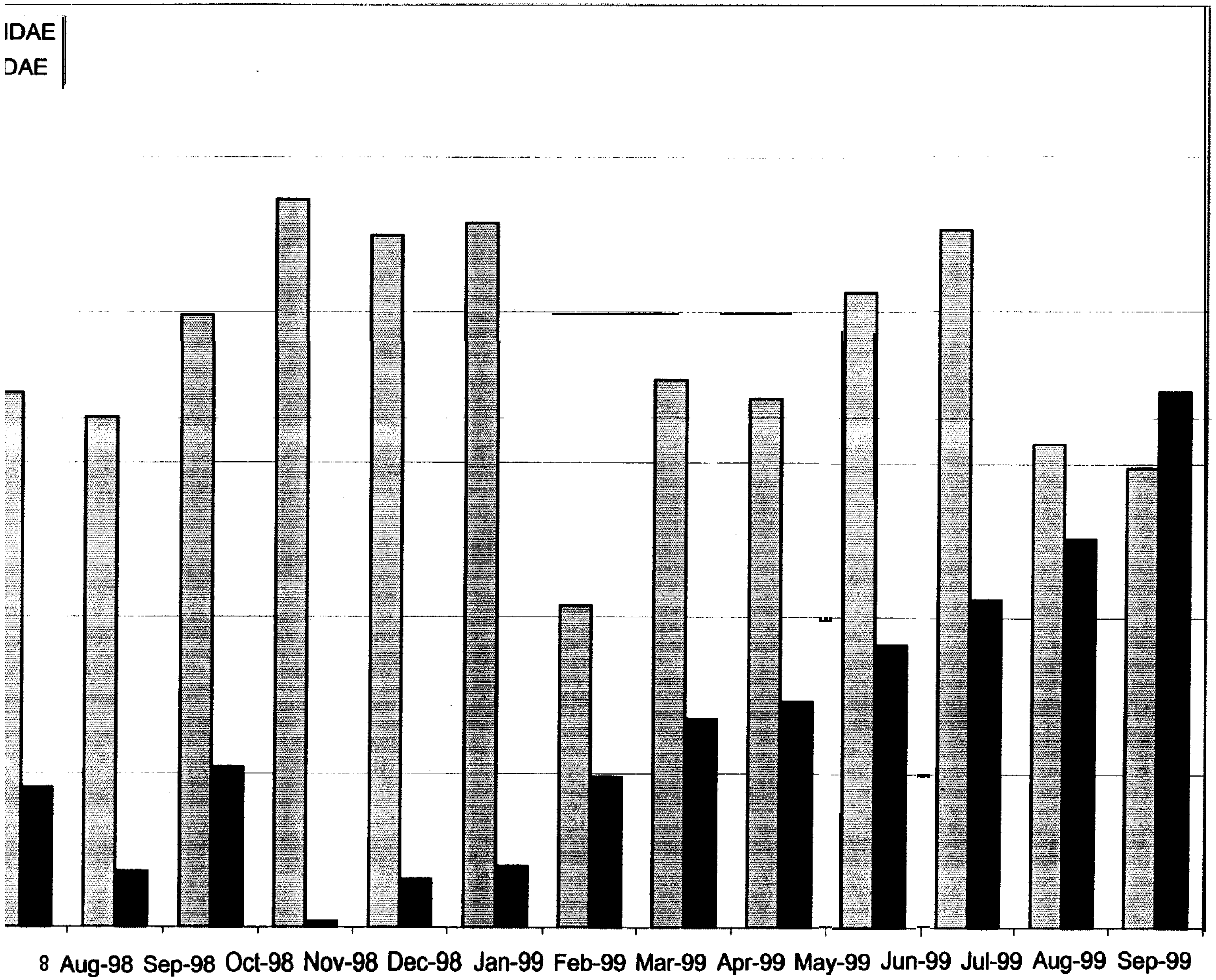

burlap
cardboard
4000
3500
3000
2500
2000
1500
1000
500
0
Jul-98
Aug-98
Sep-98
Oct-98
Nov-98
Dec-98
Jan-99
Feb-99
Mar-99
Apr-99
May-99
Jun-99
Jul-99
Aug-99
Sep-99

Figure 7. Seasonal abundance of woodroaches and ants underneath burlap bands and cardboard panels. Numbers represent a combination of individuals from coarse woody debris control and removal plots from July 1998 to September 1999.


IDAE
DAE
8
Aug-98
Sep-98
Oct-98
Nov-98
Dec-98
Jan-99
Feb-99
Mar-99
Apr-99
May-99
Jun-99
Jul-99
Aug-99
Sep-99

COMPARISON OF ARTHROPODS ON THE BOLES OF LOBLOLLY AND LONGLEAF PINES (PINACEAE)[1]

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[1] Horn, G.S. and J.L. Hanula. To be submitted to Environmental Entomology.

ABSTRACT

Red-cockaded woodpeckers *(Picoides borealis)* (RCW) forage on the bole of most southern pines. We used knockdown insecticides to sample the standing crop of arthropods on longleaf (*Pinus palustris* Mill) and loblolly pine *(P. taeda* L.), two common pines within foraging habitats of RCW to determine which harbored the greater abundance of potential prey. Longleaf pine had significantly higher arthropod abundance (278 ± 44.4/tree) compared to loblolly pine (132 ± 13.2/tree). Oven-dried biomass of arthropods was also significantly higher on longleaf pine (945 mg ± 145/tree) compared to loblolly pine (395 mg ± 28/tree). Certain groups were found in significantly higher numbers on longleaf pine, including Thysanura, Hemiptera, and Pseudoscorpiones. The biomass of Blattaria was also much higher on longleaf boles, suggesting that larger arthropods may prefer the bark structure of longleaf pine. We altered the bark surface of longleaf pine to determine if it was bark structure influencing greater numbers of arthropods residing on the tree bole. When the loose bark was removed by scraping we recovered fewer arthropods from scraped than from unscraped control trees. We also lightly scraped the outer bark of both tree species and found that longleaf pine had significantly more loose, flaking, bark scales than loblolly. These results suggest that it is the bark structure and not the chemical nature of the bark that results in more and larger arthropods on longleaf pine. Retaining or restoring longleaf pine in RCW habitats should increase arthropod availability for this endangered bird and other bark-foraging species.

Many birds forage on the boles of live trees where they find arthropods that constitute a large portion of their diet. In the southern United States, the red-cockaded woodpecker is an endangered species that forages for arthropods on live pines (Lignon 1968, Morse 1972, Wood 1977, Miller 1978, Nesbitt et al. 1978, Skorupa 1979, Ramey 1980, Hooper and Lennartz 198 1, Patterson and Robertson 198 1, DeLotelle et al. 1983, Repasky 1984, Porter and Labisky 1986, Walters 1990, Jackson 1994). They have been observed foraging on pines as small as 5 cm diameter at breast height (DBH), but they prefer trees greater than 25 cm DBH ($korupa 1979, Hooper and Lennartz 1981, DeLotelle et al. 1983, Repasky 1984, Porter and Labisky 1986, Engstrom and Sanders 1997). Because red-cockaded woodpeckers are non-migratory, their survival is directly influenced by the quality of foraging habitats surrounding roosting and nesting cavities. Most remaining RCW populations exist on federal lands, so survival of this endangered species will depend on management of these forests. Presently, over 1 ,000,000 ha of public lands in the southern United States are directly affected by RCW recovery efforts (Hooper 1996).

Despite efforts to increase RCW numbers, populations remain fragmented and continue to decline throughout its range. Early declines were attributed to the loss of mature longleaf pine (*Pinus palustris*) stands from timber harvesting, clearing for agriculture, and urban development. Longleaf pine once covered as much as 24 million ha in the southeastern U.S., but remaining forests contain less than 1.3 million ha (Outcalt and Sheffield 1996). Conversion of forests to faster growing species, such as loblolly pine (*P. taeda),* is another reason for the decline of the longleaf ecosystem. As many as 5000 arthropod species may be found in the xeric, longleaf pine communities of the southeastern United States, with perhaps 10 % of these being found in no other habitats (Folkerts et al. 1993). No information exists about what effects the transition to loblolly pine may have on bark arthropods available to the RCW.

Trees provide model habitats for a range of studies in community ecology (Moran and Southwood 1982, Crawley 1983), but little is known about the arthropods that inhabit the bark of trees (Pschorn-Walcher and Gunhold 1957, Wunderlich 1982). Moeed and Mead (1983) evaluated the arthropods found on the bark of four species of trees in New Zealand and noted the importance of the tree bole as a means to access the canopy. Likewise, Hanula and Franzreb (1998) found that a barrier to arthropod movement up longleaf pine boles reduced arthropod biomass throughout the length of the bole. Bark is an important habitat for many arthropods living in southern pine forests and bark structure may influence the diversity and abundance of these arthropods found on trees. Jackson (1979) stated that highly rugose bark has more surface area and may support more hiding places for arthropods. He also observed that older trees of the same species typically have more rugose bark than younger trees. Nicholai (1986) studied hardwood trees in Europe and found that trees with smooth bark had fewer arthropods than trees with fissured bark. He concluded that thermal properties of the bark, resulting from bark structure, provided a better microclimate for arthropods. Mariani and Manuwal (1990) found brown creeper (*Certhia americana*) abundance increased with spider abundance and that spiders were found in higher numbers on Douglas fir (*Pseudotsuga menziesii* Franco) trees with deeper crevices.

It is likely that RCW choose forage trees based on arthropod abundance to maximize foraging efficiency (Garton 1979). Studies have shown that RCW preferentially select larger trees on which to forage (Hooper and Lennartz 198 1, DeLotelle et al. 1983, Porter and Labisky 1986, Hooper 1996, Engstrom and Sanders 1997). Hooper (1996) pointed out that older trees had thicker bark, more epiphytes, and more dead limbs that might account for the greater numbers of arthropods. Hanula et al. (2000a) found that longleaf pines 60 years old and older were equal in terms of biomass and arthropod abundance, and that bark thickness was positively correlated with arthropod biomass. Since bark thickness was also correlated with tree age, they suggested bark thickness might be the best characteristic for determining arthropod availability on tree boles.

If structure or bark thickness is an important tree characteristic resulting in greater arthropod abundance on tree boles, them management that favors planting or retention of species with desirable bark characteristics may benefit RCW. We compared the abundance and biomass of arthropods on loblolly and longleaf pines, common species within foraging habitats of RCW, and examined how bark structure influences arthropod abundance.

Materials and Methods

Study Site. This study was conducted at the Savannah River Site (SRS), an 80,270 ha Department of Energy nuclear production facility located in the upper Atlantic Coastal Plain Physiographic Province. Both longleaf and loblolly pine forests are prevalent on the site, covering approximately 14,924 ha and 25,677 ha, respectively (Knox and Sharitz 1990). Historically, longleaf pine dominated the dry, sandhill habitats while loblolly pine existed mostly along riparian areas. Presently, the site consists of artificially regenerated even-aged stands of loblolly, longleaf, and slash pine, but managers are making it a priority to restore species to their original habitats. The stands selected for our study were similar in age (40-45 yrs old), appearance, and understory plant composition. Common understory species include wax myrtle (*Myrica cerifera* L.), American beautyberry (*Callicarpa americana* L.), black cherry (*Prunus serotina* Ehrhart), yellow jessamine (*Gelsimium sempervirens* L.), poison ivy (*Rhus radicans* L.), and sassafras (*Sassafras albidum* Nuttall).

Arthropod Sampling. To remove arthropods from the tree bole we sprayed POUNCE 5.2 (FMC), a synthetic pyrethroid that provides quick knockdown of most arthropods. Because we wanted to sample only the tree bole, we used a two-gallon hand held sprayer instead of fogging. This method allowed us to restrict insecticide to the tree bole so arthropods were only collected from this area.

Four stands were selected based on similarities in age, vegetation, and accessibility. We used a hydraulic lift truck to gain access to the tree bole up to the lower canopy. The insecticide was applied to the entire tree bole starting at the base of the crown. Insecticide applications were made throughout the day (0800-1930). During our study, weather conditions consisted of light to no wind and partly cloudy skies. Arthropods that fell from the tree bole were collected on two tarps (3 x 3.5 m) placed on the ground at the base of the, tree. Approximately 5 liters of insecticide solution (1% AI) were applied to each tree bole. Because insecticides affect arthropods at different rates, we collected from the tarps for 2 h. Arthropods were collected by hand and placed in 70 % alcohol as soon as they fell to the tarps.

Eight loblolly and 8 longleaf pine trees were sprayed in July and August 1999. Tree species were sprayed on successive days, i.e., one day we sprayed loblolly pine and the next day longleaf pine. However, we sprayed trees and collected during the same time intervals each day to reduce differences in arthropod diversity or abundance due to time of day. Total tree height, height to the base of the living crown, and diameter at breast height (dbh) were recorded for each tree sprayed.

Bark Structure. A second experiment was conducted to determine if bark structure plays a role in defining tree bole arthropod communities. We selected 10 longleaf pine trees in the same habitat as before. In August 1999, bark scraping tools were used to scrape 3 m sections of the boles of 5 trees until the outer bark was smooth. Care was taken so that trees were uninjured, reducing the possibility of attracting insects to the wounds. Five trees were left as controls having no bark removed. We waited one month and then applied insecticide to the 3 m scraped sections and a similar size area on unscraped controls for collection of arthropods as described previously.

Little quantitative evidence exists regarding differences in southern pine bark structure, weight, moisture content or exfoliation rates, which might be important indicators of arthropod abundance. Howard (197 1) stated that the manner and ease of scale exfoliation are related to structure and may have some species significance. To compare the outer bark of loblolly and longleaf pine, we marked off a .5 m^2 area on 10 previously unscraped trees of each species, and scraped off bark that was loose or would come of relatively easily. Care was taken to apply the same amount of force to the scraping tool on each tree. Bark was oven-dried at 40” C for 72 hr and weighed. In addition to bark weights, we calculated the percent moisture content of the bark to determine if bark moisture may be a factor influencing tree selection by arthropods. We also measured bark thickness using a bark gauge to determine if this characteristic influences the presence of arthropods.

Statistical Analysis. Morphospecies identification was made using a reference collection. Arthropod biomass was estimated by oven-drying the specimens at 40°C for 48 hr and weighing them. Differences in the mean biomass and abundance were compared using a t-test (SAS 1985). For some taxa, the data were transformed using $\log_{10}(x+1)$ or $\sqrt{x+.5}$ transformation to balance the variance.

Results

Pine Species Comparison. Both the loblolly and longleaf trees averaged 38.1 cm dbh, but we sampled slightly higher on loblolly (13.1 ± 0.1 lm) compared to longleaf (12.2 ± 0.10m) because the loblolly trees were taller. We collected 3279 arthropods from 15 orders (Table 1). Hymenoptera (mostly ants) were the most common, followed by Blattaria (roaches), Coleoptera (beetles), Hemiptera (true bugs), Araneae (spiders), and Thysanura (silverfish), respectively. Other groups collected included Diptera (flies), Psocoptera (bark lice), Orthoptera (crickets), Homoptera (aphids), and the Pseudoscorpiones (pseudoscorpions). Biomass was highest in the Blattaria and Hemiptera, a result of capturing large woodroaches in the genus *Parcoblatta*, and large bugs in the genus ***Largus.*** Tree species were paired by time of day, and at no time did a loblolly yield more arthropods than its paired longleaf.

Although there was no difference in species found on the two types of pine, the mean arthropod abundance per tree was significantly higher on longleaf tree boles

($P=0.01$) (Fig 1). The six most commonly collected orders were found in higher numbers on longleaf pine (Fig 2) but only Thysanura ($P=0.0004$), Hemiptera ($P=0.02$), and the Pseudoscorpiones ($P=0.03$) were significantly higher. Mean arthropod biomass per tree was also much higher on longleaf pine boles ($P=0.007$) (Fig 1). Although the mean biomass of five of the six most commonly collected orders was higher on longleaf pine (Fig 3), only Thysanura ($P=0.0002$) and Blattaria ($P=0.01$) were significantly higher.

Bark Structure. Our second experiment resulted in the collection of 230 arthropods, including 47 genera from 41 families and 11 orders. Unscraped trees accounted for 66 % of the total number of arthropods recovered (Table 2). The mean number of arthropods collected per tree was higher for unscraped trees than for scraped trees ($P=0.01$). Biomass per tree was also significantly higher on unscraped trees ($P=0.01$). Thysanura ($P=0.0008$), Araneae ($P=0.021$), and Blattaria ($P=0.047$) were found in higher numbers on trees that had no bark removed. Certain arthropod groups had higher biomasses per unscraped tree, such as Coleoptera ($P=0.011$) and Araneae ($P=0.05$).

We removed significantly more ($P=0.0012$) outer bark by lightly scraping longleaf pines (164g ± 16) than loblolly (89g ± 8) within the same size area. We also found that the moisture content was similar for longleaf (6.8% ± 0.24) and loblolly pine (6.0% ± 0.35). In addition, bark thickness was almost identical for longleaf (2.25cm ± 0.16) and loblolly (2.28cm ± 0.16) pine.

Discussion

The bark of southern pine is host to a large and diverse arthropod community, many of which serve as prey of RCW. This study shows that longleaf pine may be particularly important to the foraging ecology of the RCW. Overall, we found longleaf pines harbor greater numbers and more biomass of arthropods than loblolly pine. We saw no evidence of differences in the taxonomic composition of arthropod communities on the two species of trees. Likewise, Nicolai (1986) demonstrated that the dominant communities found on bark are similar in a given area regardless of tree species, and Hanula et al. (2000b) reported that prey fed to nestling RCW was similar regardless of foraging substrate (ie. longleaf pine or loblolly pine). Although they take similar prey, our findings show that longleaf pine harbors more arthropods than loblolly pine of comparable age and size, possibly because the structure of longleaf bark provides more hiding places or a more suitable microclimate. It is likely that similar arthropod communities exist on most southern pines, but bark structure may influence arthropod abundance available to bark-foraging birds.

Despite similar communities, the abundance and biomass of Thysanura and Hemiptera was higher on longleaf pine, as was the biomass of Blattaria and abundance of Pseudoscorpiones. We collected silverfish from both pine species, however 82% were collected from longleaf pine where they either prefer or survive better in the microhabitats associated with longleaf bark.

We recovered significantly more Hemiptera in the genus *Largus* from longleaf pine. Unlike many arthropods we collected, this species is active throughout the day (‘personal observation). Despite being active and common, *Largus sp.* have not been reported as prey (Beal 1911, Harlow and Lennartz 1977, Hanula and Franzreb 1995, Hess and James 1998, Hanula et al. 2000b, Hanula and Engstrom in Press), which could be a result of distastefulness. Although they are more abundant on longleaf pine trees, it is not clear what they do in that habitat.

Our sampling revealed that Hymenoptera was the most abundant group on both types of pine. This was primarily because of two genera of ants, ***Crematogaster*** sp. and ***Camponotus*** sp. We collected three times as many ants from longleaf pine as from loblolly pine, however biomass estimates were about the same. This was because we collected more ***Crematogaster*** sp. from longleafpine, which are much smaller in size. Although ants were abundant in our study, biomass may be a better predictor of RCW tree selection. Woodroaches were reported to be the most common prey item fed to nestling RCW on the Savannah River Site (Hanula and Franzreb 1995, Hanula et al. 2000b, Hanula and Engstrom in press). In our study, they were the most commonly collected group behind Hymenoptera and had the highest overall biomass. We found that biomass was significantly higher on longleaf pine, despite the fact that abundance of woodroaches was not. This suggests larger woodroaches prefer habitats associated with the bark of longleaf pine.

Pseudoscorpions were also collected more frequently from longleaf pine, however this relationship is somewhat unclear. Pseudoscorpions are common inhabitants of pine bark were they feed on Collembola (springtails) and small Acarina (mites) (Ruppert and Barnes 1991). Due to their general habits and very small size, pseudoscoripions probably play a minor role in the ecology of the RCW.

Our findings are similar to others who attributed increases in arthropod abundance to differences in bark structure. In Europe, Nicholai (1986) found that trees with smooth bark had far less arthropods than trees with fissured bark and suggested that bark microclimate was better on scaly barked trees. He suggested that many bark-inhabiting arthropods might be negatively affected by the conversion from one forest tree species to another. Mariani and Manuwal (1990) captured a greater number of spiders from trees with deeper bark crevices. They found that an increase in brown creepers was correlated with larger numbers of spiders, evidence suggesting that bark structure may influence numbers of bark-foraging birds. More research is needed, but it is likely that many of the arthropods serving as prey of the RCW exist on most southern pines, but may be more abundant on longleaf pine or pines with similar bark characteristics.

We hypothesized that the physical nature of the outer bark of longleaf is structurally different from loblolly, resulting in the retention of more arthropods. Our experiment showed unscraped trees had significantly more arthropods, suggesting that the loose, flaky outer bark of longleafpine is important to arthropods and not-other characteristics, such as host odors.

It is difficult to quantify bark differences. Externally, the bark of southern pine is highly variable within a species, while samples from trees of different species may be quite similar (Howard 1971). Only two species of pine are easily differentiated based on external appearance; spruce pine is oak-like in appearance, and shortleaf pine often has very conspicuous resin pockets on the rhythidome (outer bark). Often, visual differences between longleaf and loblolly pine are evident with longleaf generally having flaky, overlapping bark scales, while loblolly pine is characterized by having bark tightly bound to the tree with deeper grooves. We estimated bark flakiness or looseness by lightly scraping the same size area on both species. We removed significantly more bark from longleaf pine using this technique. Because bark densities are similar between these two pines (Martin and Crist 1968), we suggest that it's the structural differences of longleaf bark that accounted for the difference in the amount of bark removed. Hooper (1996) stated that differences in exfoliation among trees may cause differences in arthropod biomass, but he was unable to quantify this characteristic. He found that bark weight was not a significant factor affecting arthropod biomass, except on live limbs. However, Hooper's study was conducted exclusively in longleafpine so it is likely that all trees sampled had similar bark structure.

Hanula and Franzreb (1998) found that bark samples at the base of mature longleaf trees had the same numbers of roaches as samples in the canopy. However, samples at the base of the tree had significantly higher biomass. They suggested that the thicker bark lower on the bole allowed larger roaches to hide there. Our findings suggest that not just bark thickness but large, loose, flaky bark scales may be more important. Another study conducted in longleaf pine showed that trees with a bark thickness greater than 1.5 cm harbors a greater biomass of arthropods than trees with thinner bark (Hanula et al. 2000a). We measured bark thickness to determine if it could have influenced the presence of arthropods in our study. Bark thickness was very similar between the two species of pine, eliminating the possibility that arthropods were influenced by this characteristic.

We found no difference in bark moisture content of the two species so it is unlikely that moisture content influenced arthropod abundance. The outer bark contains an abundance of deposited materials such as tannins, phlobaphenes, and other phenolic substances (Koch 1972, Howard 1971). The effect these substances have on arthropods is unknown. Our study suggests that if chemicals in the bark are important to arthropods, they are not enough by themselves to attract and retain the arthropods. Trees with bark scraped lightly to remove loose bark scales had fewer and smaller arthropods than unscraped controls. It has been suggested that epiphytes, living on the outer bark of pine, may serve as a food source for many part-time bark inhabiting arthropods (Hooper 1996). Although this may be true, it is unlikely that arthropods would remain exposed on smooth barked species during daylight where they are easily seen by predators.

Hanula et al. (2000a) assessed the availability of arthropods on longleaf pine under varying stand conditions. They found numbers and biomass of arthropods per tree were positively correlated with stand age, diameter, bark thickness, and basal area. They concluded that bark thickness is probably the most important characteristic for determining arthropod abundance on tree boles, stating that thick bark probably provides nocturnal arthropods with better daytime refuges. Our study suggests that bark thickness may be less important than the presence of loose bark scales.

Forest management that provides good arthropod habitat on live tree boles should optimize RCW foraging habitat, increase prey abundance for other bark-foraging species, and possibly reduce the amount of land needed to sustain RCW groups, allowing higher densities of birds in the same area. Beyer et al. (1996) states that there is clearly a need for research that identifies which habitat component affect RCW reproductive success and how these components can be manipulated through management. If RCW select or prefer trees that support higher numbers of arthropods than our data show that retention and regeneration of longleaf pine in RCW foraging territories should benefit RCW. It seems bark thickness alone is not as important as bark structure, with the loose, flaky bark of longleaf pine providing better habitat for arthropods than the deep, exposed fissures of loblolly pine.

Acknowledgements

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References Cited

Beal, F.E.L. 1911. Food of the woodpeckers of the United States. USDA, Biological Survey Bulletin 37.

Beyer, D.E., JR., R. Costa, R.G. Hooper, and C. A. Hess. 1996. Habitat quality and reproduction of red-cockaded woodpecker groups in Florida. J. Wild. Manage. 60:826-835.

Crawley, M.J. 1983. Herbivory: Studies in Ecology, vol. 10. Blackwell Science Publications, Oxford.

Delotelle, R.S., J.R. Newman, and A.E. Jerauld. 1983. Habitat use by red-cockaded woodpeckers in central Florida, pp. 59-67. *In* D.A. Wood (ed.), Red-cockaded Woodpecker Symposium II Proceedings, 27-29 January 1983, Panama City, FL, Florida Game and Freshwater Fish Commission, Tallahassee, FL.

Engstrom, R.T., and F. J. Sanders. 1997. Red-cockaded woodpecker foraging ecology in an old-growth longleaf pine forest. Wilson Bull. 109:230-2 17.

Folkerts, G.W., M.A. Deyrup, and D.C. Sisson. 1993. Arthropods associated with Xeric longleafpine habitats in the southeastern united states: a brief overview. *In:* S.H. Hermann (ed.), Proceedings of the 18th Tall Timbers fire ecology conference. The longleaf pine ecosystem: ecology, restoration and management; May 30-June 2 1991; Tallahassee, FL, Tall Timbers Research Station 18: 159-192.

Garton, E.O. 1979. Tree surfaces as foraging substrates for insectivorous birds, pp. 69-74. *In* J.G. Dickson, R.N. Conner, R.R. Fleet, J.C. Kroll and J.A. Jackson (Eds.), The Role of Insectivorous Birds in Forest Ecosystems. Academic Press, New York.

Hanula, J.L. and K.E. Franzreb. 1995. Diet of nestling red-cockaded woodpeckers in the Upper Coastal Plain of South Carolina. Wilson Bull. 107:485-495.

Hanula, J.L. and K.E. Franzreb. 1998. Source, distribution, and abundance of macro-arthropods on the bark of longleaf pine: potential prey of the red-cockaded woodpecker. For. Ecol. Manage. 102:89-102.

Hanula, J.L., K.E. Frauzreb, and W.D. Pepper. 2000a. Longleaf pine characteristics associated with arthropods available for red-cockaded woodpeckers. J. Wildl. Manage. 64:60-70.

Hanula, J.L., D. Lipscomb, K.E. Franzreb, and S.C. **Loeb. 2000b.** Diet of nestling red-cockaded woodpeckers at three locations. J. Field Ornithol. 71: 126-134.

Hanula, J.L., and R.T. Engstrom. 2000. Comparison of red-cockaded woodpecker nestling diet in old-growth and old-field longleaf pine habitats. Am. Midl. Naturalist. (in press).

Hess, C.A., and F.C. James. 1998. Diet of the red-cockaded woodpecker in the Apalachicola National Forest. J. Wildl. Manage. 62:509-517.

Hooper, R.G. and M.R. Lennartz. 1981. Foraging behavior of the red-cockaded woodpecker in South Carolina. Auk. 98:321-334.

Hooper, R.G. and R.F. Harlow. 1986. Forest stands selected by foraging red-cockaded woodpeckers. U.S. For. Serv. Res. Pap. SE-259.

Hooper, R.G. 1996. Arthropod biomass in winter and the age of longleaf pines. For. Ecol. Manage. 82:115-131.

Howard, E.O. 1971. Bark structure of southern pines. Wood Sci. 3: 134-148.

Jackson, J.A. 1979. Tree surfaces as foraging substrates for insectivorous birds, pp. 69-74 ***In:*** J.G. Dickson, R.N. Conner, R.R. Fleet, J.C. Kroll and J.A. Jackson (Eds.), The Role of Insectivorous Birds in Forest Ecosystems. Academic Press, New York.

Jackson, J.A., and B.J.S. Jackson. 1986. Why do red-cockaded woodpeckers need old trees? Wild. Soc. Bull. 14:3 18-322.

Jackson, J.A. 1994. Red-cockaded woodpecker (*Picoides* ***borealis).*** The birds of North America, no. 85. The American Ornithologists' Union, Washington, D.C., USA. The Academy of Natural Sciences, Philadelphia, PA, USA.

Knox, J.N., and RR. Sharitz. 1990. Endangered, threatened, and rare vascular flora of the Savannah River Site. Savannah River Site, National Environmental Research Park Program, Svannah River Ecology Lab, Aiken, South Carolina.

Koch, P. 1972. Utilization of southern pines. USDA For. Serv. Agric. Handb. No. ***420.*** Vol 1. 734pp.

Ligon, J.D. 1968. Sexual differences in foraging behavior in two species of ***Dendrocopus*** woodpeckers. Auk. 85:203-215.

Mariana, J.M., and D.A. Manuwal. 1990. Factors influencing brown creeper (*Certhia* ***Americana)*** abundance patterns in the southern Washington Cascade range. Studies Avian Biol. 13:53-57.

Martin, R.E. and J.B. Crist. 1968. Selected physical-mechanical properties of eastern tree barks. Forest Prod. J. 18:54-60.

Miller, W.E. 1978. Use of prescribed burning in seed production areas to control red pine cone beetle. Environ. Intimal. 7:698-702.

Moeed, A., and M.J. Mead. 1983. Invertebrate fauna of four tree species in Orongorongo Valley New Zealand, as revealed by trunk traps. NZ J. Ecol. 6: **39-53.**

Moran, V.C. and T.R.E. Southwood. 1982. The richness, abundance and biomass of the arthropod communities on trees. J. of An. Ecol. 51:289-306.

Morse, D.H. 1972. Habitat utilization of the red-cockaded woodpecker during the winter. Auk. 89:429-435.

Nesbitt, S.A., D.T. Gilbert, and D.B. Barbour. 1978. Red-cockaded woodpecker fall movements in Florida flatwoods community. Auk. 95: 145-15 1.

Nicholai, V. 1986. The bark: thermal properties, microclimate and fauna. Oecologia. 69:148-160.

Outcalt, D.W., and R. M. Sheffield. 1996. The longleafpine forest: trends and current conditions, U.S. For. Serv. Res. Bulletin SRS-RB-9.

Patterson, G.A. and W.B. Robertson. 1981. Distribution and habitat of the red-cockaded woodpecker in Big Cypress National Preserve. National Park Service, South Florida Research Center. Report T-61 3. Homestead.

Porter, M.L. and R.F. Labisky. 1986. Home range and foraging habitat of red-cockaded woodpeckers in Northern Florida. J. Wildl. Manage. 50:239-247.

Pschorn-Walcher, H. and P. Gunhold. 1957. Zur Kenntnis der Tiergemeinschaft in Moos-und Flechtenrasen an Park-und Waldbaumen. Z Morph u Okol. 46:342-354.

Ramey, P. 1980. Seasonal , sexual, and geographical variation in the foraging ecology of red-cockaded woodpeckers (*Picoides* borealis). M.S. Thesis, Mississippi State University, Starkville, Mississippi.

Repasky, R.R., 1984. Home range and habitat utilization of the red-cockaded woodpecker. M.S. Thesis, North Carolina State University, Raleigh, NC.

Ruppert, E.E. and R.D. Barnes. 1991. Invertebrate Zoology. Saunders College Publishing, New York, NY.

SAS Institute. 1987. SAS/STAT guide for personal computes. Version 6 edition, SAS Institute, Cary, NC.

Skorupa, J.P. 1979. Foraging ecology of the red-cockaded woodpecker in South Carolina. M.S. Thesis, University of California, Davis.

Stacey, P.B. and W.D. Koenig. 1990. Cooperative breeding in birds: long-term studies of ecology and behavior. Cambridge University Press, New York, NY.

Stork, N.E., J. Adis, and R.K. Didham. 1995. Canopy Arthropods. Chapman and Hall, London.

Walters, J.R. 1990. Red-cockaded woodpeckers: a “primitive” cooperative breeder, pp. 67-102. *In* P.B. Stacey and W.D. Koenig (eds.), Cooperative breeding in birds: long-term studies of ecology and behavior. Cambridge University Press, Cambridge, United Kingdom.

Wood, D.A. 1977. Status, habitat, home range, and notes on the behavior of the red-cockaded woodpecker in Oklahoma. M.S. Thesis, Oklahoma State University, Stillwater, Oklahoma.

Wunderlich, J. 1982. Mitteleuropaische Spirmen (Araneae) der Baumrinde. Z ang Ent. 94:9-21.

Table 1. Total number and biomass of arthropods collected from the boles of 8 longleaf and 8 loblolly
treatment.

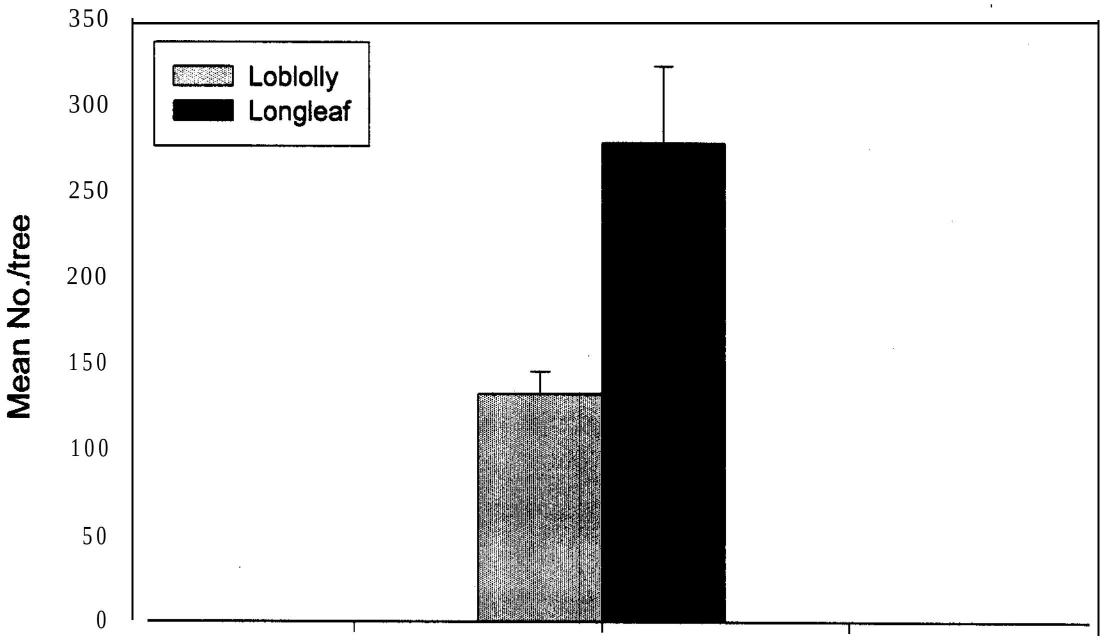
	Longleaf			Lo	
Arthropod Order	No. genera	Number	Biomass (g)	No. genera	Nu
Araneae	19	190	0.7671	19	
Blattaria	3	332	2.2455	2	
Coleoptera	31	226	1.0546	22	
Diptera	4	43	0.0065	7	
Geophilomorpha	1	9	0.0273	1	
Hemiptera	16	264	1.4735	3	
Homoptera	3	4	0.0095	5	
Hymenoptera	19	717	0.3162	14	
Isoptera	0	0	0.0000	1	
Lepidoptera	2	7	0.0042	4	
Opiliones	1	1	0.0235	1	
Orthoptera	3	94	0.1616	1	
Pseudoscorpiones	1	52	0.0242	1	
Thysanura	1	251	1.0492	1	

Table 2. Mean ± SE for arthropods collected from scraped (S) and unscraped (UN) longleaf pine boles.

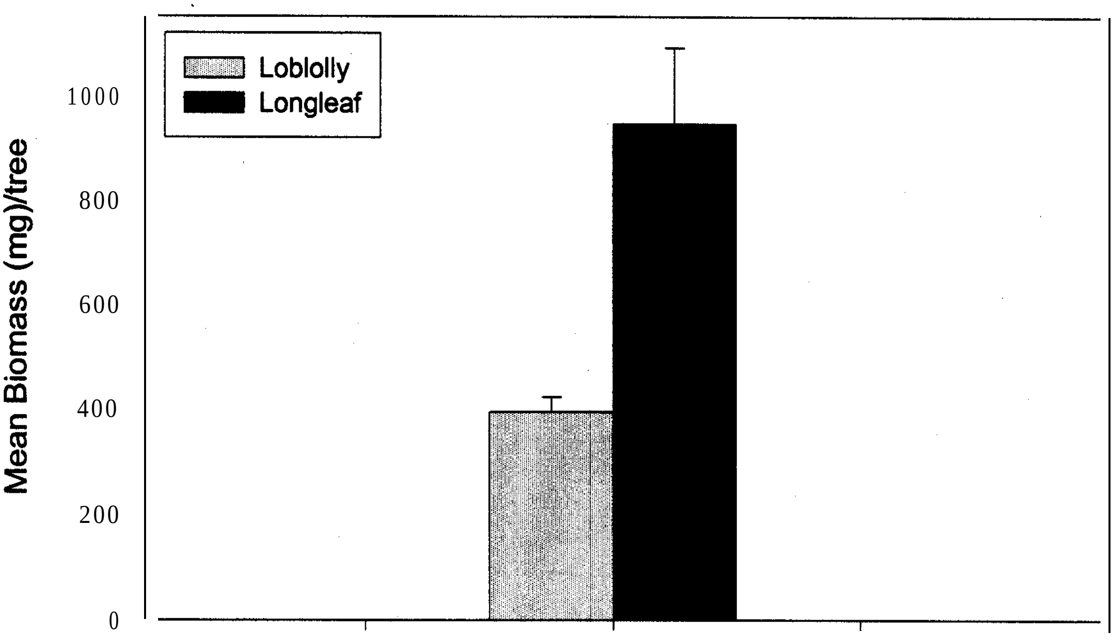
	Number (Mean ± SE)			Biomass (g) (Mean ± SE)		
Arthropod Order	S	UN	P value[1]	S	UN	P v
Araneae	4.2 ± 0.80	8.6 ± 1.53	0.0212	0.0013 ± 0.0007	0.0965 ± 0.0379	0.0
Blattaria	0.0 ± 0.00	0.8 ± 0.4	0.0470	0.0000 ± 0.0000	0.0046 ± 0.0023	.0
Coleoptera	2.8 ± 0.58	3.8 ± 0.80	0.2597	0.0051 ± 0.0035	0.0228 ± 0.0040	0.0
Diptera	3.8 ± 1.52	1.0 ± 0.31	0.1381	0.0007 ± 0.0003	0.0001 ± 0.0000	0.1
Hemiptera	0.2 ± 0.20	1.2 ± 0.58	0.1434	0.0000 ± 0.0000	0.1997 ± 0.1737	0.2
Hymenoptera	3.0 ± 0.77	5.2 ± 3.24	0.5427	0.0008 ± 0.0003	0.0076 ± 0.0056	0.2
Orthoptera	0.0 ± 0.00	4.0 ± 2.44	0.1411	0.0000 ± 0.0000	0.0019 ± 0.0012	0.1
Pseudoscorpiones	0.8 ± 0.37	0.6 ± 0.40	0.6533	0.0002 ● 0.0001	0.0002 ± 0.0001	0.8
Psocoptera	0.6 ± 0.40	1.8 ± 0.96	0.2856	0.0000 ± 0.0000	0.0004 ± 0.0002	0.1
Scolopendromorpha	0.2 ± 0.20	1.0 ± 0.63	0.2844	0.0002 ● 0.0002	0.0023 ± 0.0014	0.2
Thysanura	0.2 ± 0.20	5.8 ± 2.10	0.0008	0.0005 ± 0.0005	0.0313 ± 0.0132	0.0
Total/tree	15.8 ± 1.39	30.2 ± 5.41	0.0093	0.0091 ± 0.0036	0.3676 ± 0.1645	0.0

[1] t-test. We used $\log_{10(x+1)}$ and $\sqrt{x} + .5$ to stabalize the variance.

Figure 1. Mean number (A) and biomass (oven-dried weight) (B) of arthropods collected from longleaf and loblolly pine. (*) denotes that the relationship was significant using a t-test ($P < 0.05$).


Mean No./tree
350
300
250
200
150
100
50
0
Loblolly
Longleaf

(A)


Mean Biomass (mg)/tree
1000
800
600
400
200
0
Loblolly
Longleaf

(B)

Figure 2. Mean number of individuals collected per tree for the most commonly collected arthropod orders. (*) denotes that the relationship was significant using a t-test ($P < 0.05$).

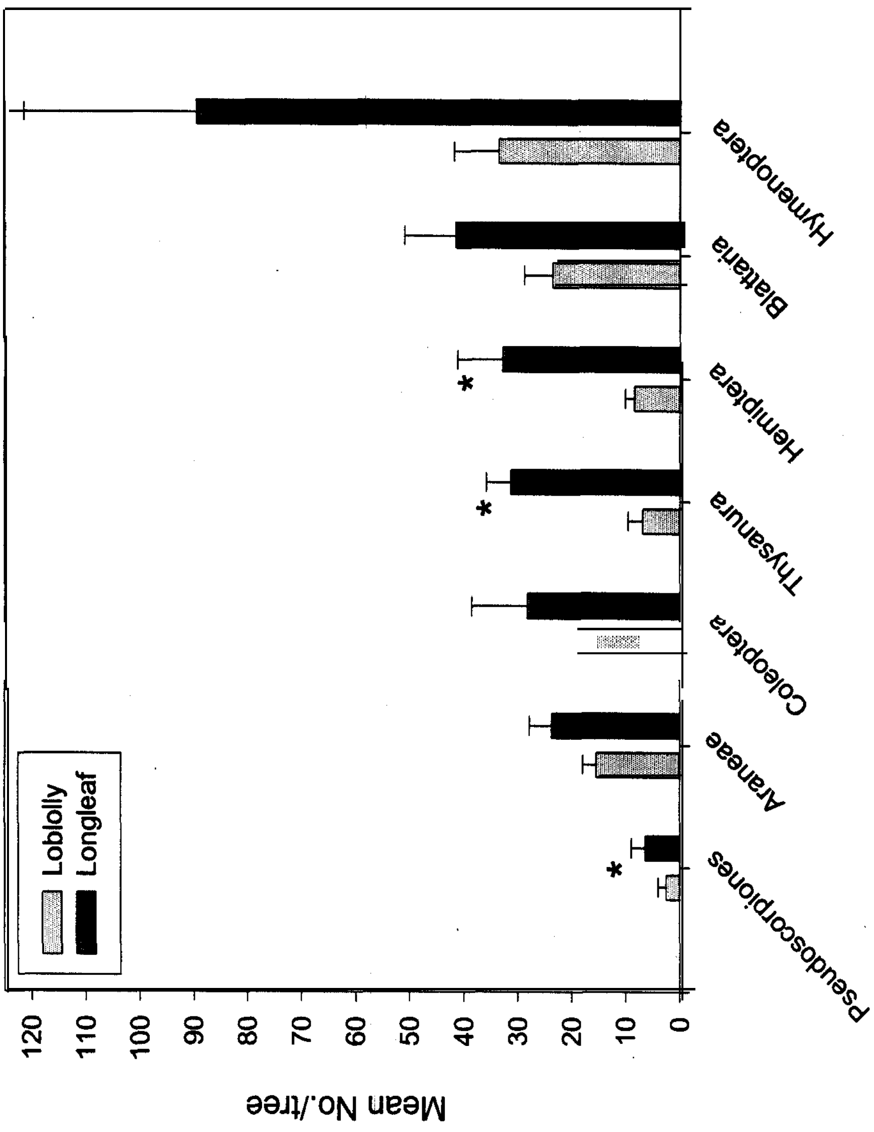
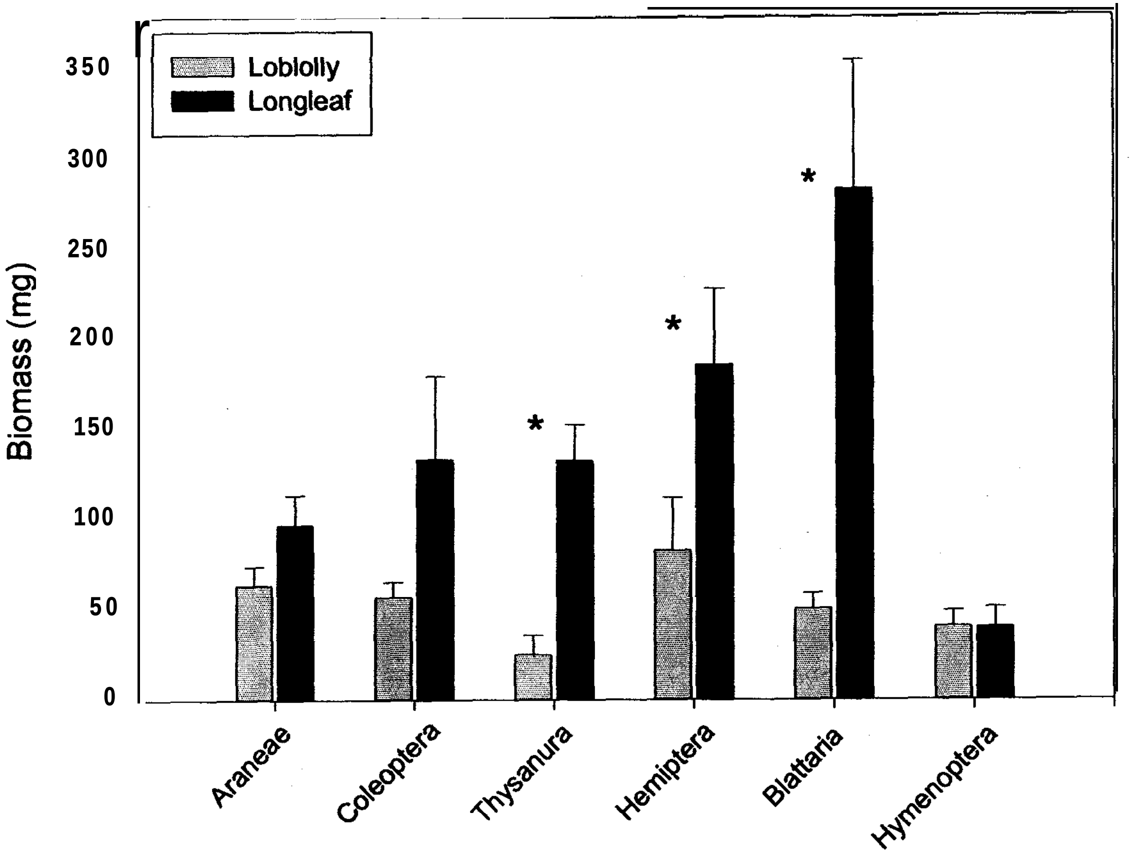

Loblolly
Longleaf
Mean No./tree
0
10
20
30
40
50
60
70
80
90
100
110
120
Pseudoscorpiones
Araneae
Coleoptera
Thysanura
Hemiptera
Blattaria
Hymenoptera
*
*
*

Figure 3. Mean biomass (oven-dried weight) per tree of the most commonly collected arthropods. (*) denotes that the relationship was significant using a t-test ($P < 0.05$).



Loblolly
Longleaf
Biomass (mg)
350
300
250
200
150
100
50
0
*
*
*
Araneae
Coleoptera
Thysanura
Hemiptera
Blattaria
Hymenoptera

LIFE HISTORY AND HABITAT ASSOCIATIONS OF WOODROACHES (BLATTARIA: BLATELLIDAE) IN THE UPPER COASTAL PLAIN OF SOUTH CAROLINA[1]

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[1] Horn, G.S. and J.L. Hanula. To be submitted to the Journal of Entomological Science

ABSTRACT

Downed logs and standing snags were sampled in a South Carolina pine forest to determine which habitat harbored the most woodroaches (Blattaria), and nocturnal observations of live pine tree boles were made to determine which species occur there. In addition, lab studies with the broad woodroach, *Parcoblatta lata*, were conducted to determine basic biological parameters such as longevity and fecundity. Nearly 80% of the 662 woodroaches we collected were found in snags. A total of five woodroach species were collected from woody debris and live pine boles. These include *P. lata*, *P. divisa*, *Aglaopteryx gemma*, *Cariblatta lutea lutea*, and *P. fulvescens*. *P. lata* was the most common on live pine boles, comprising 46% of the woodroaches observed. Lab studies showed that female *P. lata* live longer than males, and that they were capable of producing an average of 12.6 oothecae/female in their lifetime. Our results show that standing dead trees are an important habitat for woodroaches in pine forests.

INTRODUCTION

Approximately 69 species of roaches occur in the United States and Canada, of which 24 are considered exotics (Atkinson et al. 1991). Many have been studied extensively because they conflict directly with man, but little is known about the life history of common woodland species. General habitat descriptions were given by Blatchley (1920) and Lawson (1967), but neither of these provided much quantitative data. Rau (1940) noted longevity, molting, and natural enemies for ***P. pennsylvanica*** in Missouri and Gorton (1980) conducted lab and field studies on intraspecific and interspecific interactions of woodroaches in Kansas. Helfer (1966) and Dakin and Hays (1970) published taxonomic keys to distinguish woodroaches, but provided little information on natural history. The most extensive treatment of cockroach taxonomy was done by Hebard (1917), but few studies have addressed the basic natural history of most common woodroaches.

Recent studies have shown that woodroaches in the genus *Parcoblatta* **are** important prey of the endangered red-cockaded woodpecker ***(Picoides borealis)*** (RCW) (Hanula and Franzreb 1995, Hanula et al. 2000b, Hanula and Engstrom in press). The RCW is a generalist predator, taking advantage of relatively few common prey found on the boles of live pine trees. Because woodroaches are common bark inhabitants, it is likely that they are important to other bark-foraging birds as well. Even though woodroaches are found on tree boles (Hebard 1917, Gorton 1980, Hanula and Franzreb1995, 1998) they are not exclusive to this habitat. They are also commonly associated with decomposing logs, leaf litter, and other forest debris (Cantrall 1943, Gorton 1980, Brenner 1988, Hanula and Franzreb 1998).

Coarse woody debris (CWD), consisting of snags, downed logs, and decomposing root systems is an important part of productive forest ecosystems (McCarthy and Bailey 1994). Dead and down woody material may play several roles in forests, such as providing a base for new tree growth, harboring fungi, or providing habitat for wildlife (Bolen and Robinson 1995). Brenner (1988) tested the idea that peridomestic roaches in Florida were concentrated in principal habitats. He observed that specific microhabitats (i.e.woodpiles, mulch, tree holes) seemed to harbor greater numbers of roaches. CWD may be an important habitat component of southern pine forests, where woodroaches seek refuge from severe weather or predation, find food, or reproduce and oviposit.

As forests are managed with shorter rotations the end result may be a reduction in CWD. In addition, commercial thinning reduces the amount of large CWD on the forest floor (McCarthy and Bailey 1994), and many timber harvests leave stands with few snags (Carmichael and Guynn 1983). Because woodroaches in southern pine forests are commonly associated with CWD (Hanula and Horn personal observation) and they are important food for RCW, we wanted to determine which type of CWD harbored more roaches. If CWD is a preferred habitat, its removal may affect woodroach populations and the overall food web.

Eight species of ***Parcoblatta*** occur throughout South Carolina (Atkinson et al. 1991) where they are the most common roaches found on longleaf pine (Pinus palustris) tree boles (Hanula and Franzreb 1998). Despite this importance to RCW little is known about the basic biological parameters of these woodroaches. Rau (1940) investigated molting and longevity of adult ***P.*** *pennsylvanica* and found that females far outlive males. Another study examined how quickly newly emerged females mate and form oothecae and how often they produced new oothecae (Cochran 1986). We sampled standing and downed CWD for woodroaches and conducted nocturnal surveys of live tree boles to determine which species were present in these habitats. In addition, we reared ***P. lata*** in the laboratory to determine adult longevity and fecundity.

METHODS AND MATERIALS

Study Site

This study was conducted at the Savannah River Site (SRS), located near Aiken, South Carolina. The site is in the upper Atlantic Coastal Plain Physiographic Province and is dominated by longleaf and loblolly pine ***(P. taeda)*** stands. All stands used in this study were 40-45 year old even-aged pine monoculture. Common understory plants included wax myrtle (*Myrica cerifera*), yellow jessamine (*Gelsemium sempervirens*), and poison ivy (*Rhus radicans*).

Habitat Sampling

We sampled downed logs and standing snags to determine which type of CWD harbored more woodroaches. The tree bole below the crown was the section of tree sampled for downed logs, but snags were more difficult to find and most resulted from wind breakage, although some snags were whole trees. We sampled only the lower part of snags that could be reached from the ground (2-3 m height). For both logs and snags, we recorded the length or height and diameter at the mid-point of the sampled area and used Huber's Equation (Avery 1975) to estimate cubic volume (m^3) of the sample log or snag.

We sampled 25 pine snags and 27 pine logs from May 1999 to September 1999 and counted all woodroaches hiding in them. Each piece was carefully tom apart, and woodroaches were removed so that they were not counted twice. Burned trees or those with tight bark were not sampled since they rarely contained roaches. The numbers of woodroaches per cubic meter of snags and downed logs were multiplied times the cubic volume of CWD in 40-45 year old loblolly pine stands (Miley and McMinn unpublished data) to estimate the number of woodroaches that might be found per hectare in a typical pine stand.

Night-time transects were conducted to determine which woodroach species were most commonly found on the bark of live pines, the primary foraging substrate of RCW. We established 12 transects and sampled 900 trees from May to August 1999. We walked 6 transects each night of sampling and alternated to the other 6 transects the following sample night. We examined each tree up to a height of 3 m using a flashlight and recorded the number and species of woodroaches observed. We also made observations of woodroach predators, habitat associations, seasonal abundance, or other events during this and other studies (Horn 2000).

In order to monitor arthropod seasonal abundance, we used burlap bands wrapped around trees and cardboard panels placed on the ground (Chapter 1). These techniques are non-destructive ways of monitoring specific groups of arthropods important in the RCW diet (Hanula unpublished data). Burlap bands were 1 x 1 m pieces of burlap folded and sewn at the top along the fold, allowing a cotton rope to be threaded through to hold the burlap in place. Bands were placed around 30 trees within the center of a 6 ha plot at a height of l-l .5 m. Ten bands were placed in 3 rows so that they were equally distributed throughout the plot. Cardboard panels consisted of 4 layers of 0.5 x 0.75 m cardboard held together with gray duct tape. They were placed l-3 m away from each tree that had a burlap band. Sampling consisted of identifying and counting arthropods beneath burlap bands and cardboard panels. The burlap bands and cardboard panels were monitored monthly from July 1998 to September 1999.

Biological Parameters

In order to determine longevity and reproductive capacity we used *P. lata* woodroaches captured as immatures in October 1998 and held in relative darkness until the beginning of our study. On 8 February 1999, the immature woodroaches were placed in a room at 25-30° C on a 12: 12 (L:D) photoperiod. Woodroaches were checked daily for adults. New adults were paired (1 ♂ and 1 ♀) in glass containers (4 L) and given food (commercial dog food) and water. We observed a total of 50 pairs. Pairs were checked daily for: (1) formation of oothecae, (2) deposition of oothecae, and (3) death of either sex. From this information we calculated the average longevity for each sex, number of oothecae a female produces in her life, how long each oothecae is carried, and how many days between oothecal production. We also recorded the number of eggs present in the oothecae of *P. lata* by counting them in 117 oothecae. This information was used to estimate the reproductive potential of female woodroaches in the wild. Woodroaches that escaped or died early in our study were eliminated from our analysis. Pairs were checked beginning with the first adult male emergence on 28 March 1999 until the last female died on 13 December 1999.

We used wild-caught specimens to obtain estimates of length and pronotal width. We measured specimens of all species caught during this study to develop averages to aid in future field identification. Measurements were made using a digital caliper from specimens preserved in 70% alcohol.

RESULTS

Habitat Sampling

Downed logs (n = 27) had a mean length of 2.8 1 m (± 0.33 SE) and diameter of 0.20 m (± 0.01). The sampled portion of the 25 snags averaged 2.46 m (± 0.1) in length and 0.28 m (± 0.02) in diameter. Plots similar to those we sampled contained an average volume of 2.14 m^3/ha of snags and 6.45 m^3/ha of logs. Snags contained significantly more roaches/m^3 than logs, however estimates show that logs harbor more woodroaches/ha than snags (Fig 2). The most common woodroach species encountered during sampling of CWD *was **P. lata***, with ***P. fulvescens*** encountered occasionally. No other woodroach species was found in CWD during our sampling.

Nocturnal counts resulted in the observation of 237 woodroaches on live pine. The most commonly encountered was ***P. lata,*** accounting for 46% of all observations. A. *gemma* made up 29% of our observations, while ***P. divisa, P. fulvescens*** and C. *lutea lutea* made up 19%, 3%, and 3%, respectively.

Using data from another study (Horn 2000), we determined the relative seasonal abundance of the two most common woodroach genera encountered. ***Parcoblatta*** spp. were most abundant under burlap bands and cardboard panels on tree boles during the winter, however the smaller A. gemma was most abundant during the summer (Fig 3).

Biological Parameters

We monitored ***P. lata*** woodroaches in the lab for over 8 months (Table 1). Adult males typically appeared before females in the lab, as was the case in the field (personal observation). Females far outlived males held in captivity. One adult female survived in the lab for 237 days, while the maximum longevity for an adult male was 152 days. Because they produce a new oothecae every week females were able to produce an average of 12.6 oothecae over their lifetime. We had five females that produced 20 or more oothecae. ***P. lata*** oothecae averaged 42 egg chambers.

We also collected and measured adult male and female woodroaches to develop size estimates for future field studies (Table 2). Both ***sexes*** of ***P. lata*** were larger than the other ***two Parcoblatta*** spp. we collected. ***P. divisa*** males were larger than ***P. fulvescens*** males, however the reverse was true for females.

Predators and Associates

The most common associates in CWD and on live pine boles, along with witnessed and suspected predators can be seen in Table 3. Associated arthropods residing in woody debris varied little between logs and snags (personal observation). In addition, common groups were found associated with woodroaches throughout the year on live pine boles. We also observed several acts of predation of ***Parcoblatta*** spp. on live pine boles during day and night sampling.

OBSERVATIONS AND DISCUSSION

Habitat Sampling

Our study revealed that significantly more roaches are found in standing snags than in downed CWD. Brenner (1988) suggested that cockroaches are located in predictable, identifiable habitats, and his study was the first to document the significance of tree holes to cockroaches. It has been suggested that physiological requirements influence habitat suitability and selection (Cornwell 1968). Therefore, it is possible that stable microhabitats within snags serve as preferred daytime refuges. Our findings show the importance of standing dead trees as a habitat of woodroaches in southern pine forests. However, our other studies suggest that roaches are able to adapt to removal of snags and logs from their habitats and maintain their populations at the same levels as undisturbed areas (Horn 2000). It is unknown whether they could maintain population levels long-term without logs or snags.

Environmental conditions such as relative humidity, air circulation, and food availability probably influence woodroach habitat selection. Compared to snags, downed logs have a higher moisture content probably as a result of contact with the soil allowing greater fungal invasion. This characteristic may be important for oothecal deposition since we observed as many as 20 oothecae in one meter of moist log. However, during our study downed logs that harbored woodroaches usually had them in the driest part of the log (personal observation). Therefore, moist woody debris is probably important for woodroach oviposition, but standing snags may be important refuges for woodroaches during the day when they are less active.

We found that snags harbor larger numbers of roaches compared to logs, but our data suggest that logs may be equally important due to the large amount of downed woody debris found in pine stands on the SRS. These estimates represent only large CWD and not smaller debris, forest litter, or portions of snags out of reach. Our estimates are conservative since we only sampled snags up to 2-3 m in height. Forestry practices that reduce snags and downed woody material may be negatively affecting woodroach populations, but our results suggest that woodroaches are unaffected by removal of snags and logs in the short-term (Horn 2000).

We found that ***P. lata*** is the most common cockroach associated with CWD in pine forests at SRS. This species is also found on the boles of live pine, demonstrating the possible importance of CWD for maintaining woodroach populations on the bark of live trees. We conducted night surveys to determine species composition on the boles of live trees when the woodroaches were most active. We found that ***P. lata*** was the most common woodroach active on pine boles at night, followed by ***A. gemma***, ***P. divisa, P. fulvescens***, and, C. *lutea lutea* respectively.

Both Lawson (1967) and Blatchley (1920) describe ***P. lata*** as a forest species, while Gorton (1980) found this species in several different habitats where he observed it feeding on tree sap and the cambium layer of a wood chip. Hebard (1943) collected ***P. lata*** from underneath pine bark in Alabama and considered it to be abundant in pinelands of the southeastern coastal plain. Likewise, Dakin and Hays (1970) stated that this species was the most common and widespread in Alabama. Helfer (1963) found ***P. lata*** under signs on pine trees and under loose bark. We found ***P. lata*** to be abundant in CWD and on pine boles in upland pine forests, and on one occasion collected it from underneath pine bark in a bottomland hardwood forest.

P. fulvescens was also collected from CWD and live pine boles. According to studies by Hubbard and Goff (1939) and Peck and Beninger (1989), ***P. fulvescens*** is a common inhabitant of pinelands of the southeast. Even though we collected this species from both habitats it was less abundant than ***P. lata. P. divisa*** was another common woodroach collected during our study that was found only on the bark of living pines. Rarely did we observe individuals of this species under bark of logs or snags or similar habitats. Hebard (1943) also collected this species from dry pinelands and considered it to be abundant in Georgia. The most closely related species, *P. pennsylvanica*, was considered by Gorton (1980) to be a patch specialist, occurring anywhere trees are present. Gorton (1980) further states that *P. pennsylvanica* is found high in trees, and may exclude other species through agonism.

A. *gemma* was the second most common woodroach encountered during nocturnal observations of pine trees, and the second most common genus collected from pine boles in another study (see chapter 2). In that study, we used burlap bands to monitor pine boles monthly for *15* months and observed over *800 A. gemma*. Most observations of this species were on the boles of live pine, similarly Hebard (1943) commented that most specimens he collected were from arboreal habitats as well. Although little information exists on the natural history of this species, our data and others suggest that *A. gemma* may be entirely arboreal in their habits.

C. lutea lutea is another common species associated with live tree habitats, but we also observed them occasionally under bark of logs and snags. Accounts have listed this species as occurring in a variety of habitats (Blatchley 1920, Friauf 1953, Dakin and Hays 1970), including disturbed areas (Lawson 1967, Hagenbuch et al. 1988, Wright et al. 1990).

Biological Parameters

After initial subjection to a 12:12 (L:D) photoperiod, male *P. lata* were the first to molt into adults. This was consistent with field observations where males appeared in

April and females appeared in May. Although we observed adult male ***P. lata*** in April, ***P. divisa*** males were not present until May, when females of both species begin to molt into adults.

Female ***P. lata*** outlived males held in captivity, findings similar to Rau (1940) who studied ***P. pennsylvanica.*** Gorton (1980) also found that males died long before females. In our study, adult females lived over two months longer than males in the lab. Findings were similar in the field, with males persisting only a couple months, while adult females were found for 6 months after they first appeared.

Cochran (1986) stated that egg production in woodroaches consists of two distinct periods: an oothecal-carrying period and a period between egg cases. He found that ***P. fulvescens*** and ***P. pennsylvanica*** produce new oothecae every 7-8 days. We examined oothecal production in ***P. lata*** and found similar results, with females producing a new eggcase every 7 days. One female produced 21 eggcases during her life, however the average per female was 13. Oothecae of ***P. lata*** had an average of 42 eggs. Therefore, it is possible under optimal circumstances that females produce an average of 546 offspring throughout their lifetime.

Conclusions

Five species of woodroaches are found in pine forests of the Savannah River Site. Of these, ***P. lata*** seems was most prevalent, occurring in a wide range of habitats. The only other woodroach in the genus collected frequently was ***P. divisa.*** These two species are known prey of the endangered red-cockaded woodpecker and likely serve as prey to other bark-foraging birds. Although early evidence suggests otherwise, long-term absence of CWD may negatively affect ***P. lata*** populations on trees, resulting in reduced numbers available as prey. However, because *P. lata* is able to occupy habitats associated with live pine boles they may be able to substitute this habitat in place of CWD. *P. divisa* appears to live almost entirely on live trees so increased densities of *P. lata* on pine trees may affect *P. divisa* through increased competition. It is unclear what effect reduction of CWD has on the woodroach community in pine forests, but the large number of woodroaches associated with CWD suggests that it is an important habitat. An understanding of woodroach habitat requirements and how forest management affects woodroach abundance will help in establishing management guidelines for bark-foraging birds.

ACKNOWLEDGEMENTS

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REFERENCES CITED

Atkinson, T.H., P.G. Koehler, and R.S. Patterson. 1991. Catalog and atlas of the cockroaches (Dictyoptera) of North America North of Mexico. Misc. Pub. of the Ent. Soc. of Am. 78:1-86.

Avery, T.E. 1975. Natural Resources Measurements. McGraw-Hill. 339p.

Blatchley, W.S. 1920. Orthoptera of Northeastern America. Indianapolis.

Bolen, E.G. and W.L. Robinson. 1995. Wildlife Ecology and Management. Prentice Hall. New Jersey.

Brenner, R.J. 1988. Focality and mobility of some peridomestic cockroaches in Florida (Dictyoptera: Blattaria). Ann. Entomol. Soc. Am. 81:581-592.

Cantrall, I.J. 1943. The ecology of the Orthoptera and Dermaptera of The George Reserve, Michigan. Misc. Pub. 54:71-182.

Carmichael, D. B., Jr. and D.C. Guynn, Jr. 1983. Snag density and utilization by wildlife in the upper piedmont of South Carolina. In: Davis, J.W., G.A. Goodwin, A. Gregory, R.A. Ockenfels, tech coords. Proceedings, symposium on snag habitat management. 1983. June 7-9. Flagstaff, AZ. Gen Tech Rep. RM-99. Fort Collins, Colorado: USDA, Forest Service. Pp 107-l 10.

Cochran, D.G. 1986. Biological parameters of reproduction in Parcoblatta Cockroaches (Dictyoptera: Blattellidae). Ann. Entomol. Soc. Am. 79:861-864.

Cornwell, P.B. 1968. The cockroach. Vol. 1. Hutchinson. London.

Gorton, R.E. 1980. A comparative ecological study of the wood cockroaches in northeastern Kansas. Univ. Kansas Sci. Bull. 52:2130.

Gorton, **R.E. 1980.** Behavioral and ecological correlations within a cockroach community. J. Kansas Entomol. Soc. 54:278-284.

Dakin, M.E. and K.L. Hays. 1970. A synopsis of Orthoptera (sensu lato) of Alabama. Alabama Agric. Exp. Sta. Bul. 118p.

Friauf, J.J. 1953. An ecological study of the Dermaptera and Orthoptera of the Welaka area in northern Florida. Ecol. Mon. 23:79- 126.

Hagenbuch, B.E., P.G. Koehler, R.S. Patterson, and R.J. Brenner 1988. Peridomestic cockroaches (Orthoptera: Blattidae) of Florida: their species Composition and suppression. J. Med. Entomol. 25:277-380.

Hanula, J.L. and K.E. Franzreb. 1995. Diet of nestling red-cockaded woodpeckers in the Upper Coastal Plain of South Carolina. Wilson Bulletin. 107:485-495.

Hanula, J.L., and K.E. Franzreb. 1998. Source, distribution, and abundance of macroarthropods on the bark of longleaf pine: potential prey of the red-cockaded woodpecker. For. Ecol. Manage. 102:89-102.

Hanula, J.L., D. Lipscomb, K.E. Franzreb, and S.C. Loeb. 2000b. Diet of nestling Red-cockaded Woodpeckers at three locations. J. Field Omithol. 7 1: 126-134.

Hanula, J.L., and F.T. Engstrom. IN PRESS. Comparison of Red-cockaded Woodpecker (*Picoides* borealis) nestling diet in old-growth and old-field longleaf pine *(Pinuspalustris)* habitats. Am. Midl. Nat. ,

Hebard, M. 1917. The Blattidae of North America north of the Mexican boundary. Mem. Amer. Entomol. Soc. 2: l-284.

Hebard, M. 1943. The Dermaptera and Orthopterous families Blattidae, Mantidae, and Phasmidae of Texas. Trans. Amer. Entomol. Soc. 63:239-3 11.

Helfer, J.R. 1963. How to know the grasshoppers, cockroaches, and their allies. Wm. C. Brown Co. Dubuque, Iowa.

Hubbard, T.H. and C.C. **Goff. 1939.** Florida pocket gopher burrows and their arthropod inhabitants. Proc. Florida Acad. Sci. 4:127-166.

Lawson, F.A. 1967. Ecological and collecting notes on eight species of ***Parcoblatta*** (Orthoptera: Blattidae) and other cockroaches. J. Kansas Entomol. Soc. 40:267-269.

McCarthy, B.C., and R.R. Bailey. 1994. Distribution and abundance of coarse woody debris in a managed forest landscape of the central Appalachians. Can. J. For. Res. 24:1317-1329.

Peck, S.B. and C. Beninger. 1989. Insects of the Florida Keys cockroaches (Blattodea, mantids (Mantodea), and walkingsticks (Phasmatodea). Florida Entomol. 72:612-617.

Rau, P. 1940. The life history of the woodroach *Parcoblatta pennsylvanica* DeGeer (Orthoptera: Blattidae). Entomol. News. 5 1:4-9, 33-35.

Wright, C.G., T.P. Nuhn, and H.E. Dupree, Jr. 1990. Ants and cockroaches trapped outside suburban houses in the area of Raleigh, Wake County, North Carolina. N.C. Ag. Res. Serv. Raleigh, N.C. Pp. 9-16.

Table 1. Mean and range of selected biological parameters of P. *lata* maintained in the lab from March to December 1999.

Variable (sample size)	Mean	Range
Male Longevity (n = 34)	91.3 d	20-152 d
Female Longevity (n = 34)	158.2 d	48-237 d
Oothecae/female (n = 34)	12.6	6-21
Days Holding Oothecae (n = 34)	4.7 d	3.38-6.63 d
Days Between Deposition (n = 34)	7.3 d	5.13-12.8 d
No. Egg Chambers (n = 117)	42	26-46
Oothecal Length/Height (n = 117)	1013.9 mm	6-12/3-4 mm
Oothecal Biomass (n = 23)	0.0556 g	0.041 l-0.747 g

Table 2. Mean body length and pronotal width (mm) (± SE) of five species of woodroaches collected from

Savannah River Site, near New Ellenton, SC.’

	Male			Fe	
Species	No.	Total Length	Pronotal Width	No.	Total Length
P. lata	21	22.16 (0.40)	6.31 (0.09)	16	20.86 (0.42)
P. divisa	27	17.33 (0.35)	4.89 (0.10)	13	14.26 (0.40)
P. fulvescens	14	15.70 (0.28)	4.47 (0.11)	2	16.08 (0.44)
A. gemma	13	9.55 (0.20)	2.99 (0.05)	10	9.76 (0.27)
C. lutea lutea	2	7.86 (0.14)	2.75 (0.05)	2	7.94 (0.12)

‘All measurements were made on individuals preserved in 70% alcohol.

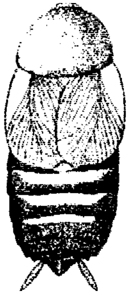
Table 3. Taxonomic list of common arthropods associated with *Parcoblatta* sp. by habitat and predators witnessed upon woodroaches.

Coarse Woody Debris		Live Pine Boles
Taxonomic Name	Common Name	Taxonomic Name
Araneae: Lycosidae: *Hogna*[1]	wolf spider	Araneae: Salticidae: *Phidippus*[1]
Coleoptera: Tenebrionidae: *Alobates*	darkling beetle	Araneae: Lycosidae: *Hogna*[1]
Coleoptera: Tenebrionidae: *Helops*	darkling beetle	Araneae: Agelenidae: *Agenlenopsis*[1]
Coleoptera: Curculionidae: *Hylobius*	pales weevil	Coleoptera: Curculionidae: *Hylobius*
Coleoptera: Tenebrionidae: *Uloma*	darkling beetle	Coleoptera: Tenebrionidae: *Helops*
Hemiptera: Pentatomidae: *Brochymena*	stinkbug	Hemiptera: Reduviidae: *Pselliopus*[1]
Hemiptera: Reduviidae: *Micortomus*[1]	assassin bug	Hemiptera: Pentatomidae: *Brochymena*
Hymenoptera: Formicidae: *Camponotus*	carpenter ant	Hemiptera: Scutelleridae: *Diolcus*
Hymenoptera: Formicidae: *Crematogaster*	ant	Hymenoptera: Evaniidae: *Hyptia*[2]
Hymenoptera: Formicidae: *Pheidole*	ant	Hymenoptera: Formicidae: *Cumponotus*
Isoptera: Rhinotermitidae: *Reticulitermes*	termite	Hymenoptera: Formicidae: *Crematogaster*
Scolopendromorpha: Cryptopidae’	centipede	Hymenoptera: Formicidae: *Formica*
Scolopendromorpha: Scolopendridae’	centipede	Hymenoptera: Formicidae: *Pheidole*
Scorpiones: Buthidae: *Centruroides*[2]	scorpion	Passeriformes[2]
Squamata: Iguanidae: *Sceloporus undulatus*[2]	fence lizard	Piciformes: Picidae: *Picoides*[1]
Squamata: Scincidae: *Eumeces fasciatus*[2]	Five-lined skink	Rodentia: Sciuridae: *Glaucomys volans*[2]
Squamata: Scincidae: *Eumeces laticeps*[2]	SE five lined skink	Scolopendromorpha: Scolopendridae’
		Squamata: Iguanidae: *Anolis carolinensis*[2]
		Squamata: Iguanidae: *Sceloporus undulatus*
		Squamata: Scincidae: *Eumeces fasciatus*[2]
		Squamata: Scincidae: *Eumeces laticeps*[2]
		Thysanura: Lepismatidae: *Thermobia*

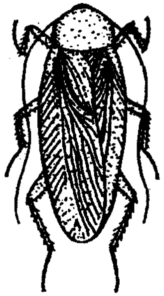
[1] Act of predation witnessed.
[2] Suspected predator.

Figure 1. Woodroaches collected in pine forests of the Upper Coastal Plain of South Carolina during 1998-2000 (figures from Hebard 1917 and Helfer 1966).

Parcoblatta lata

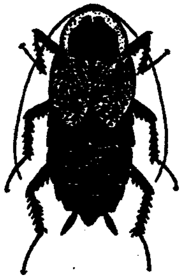


Female



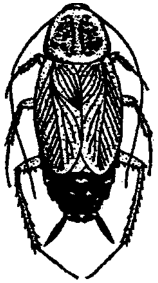
Male

Parcoblatt



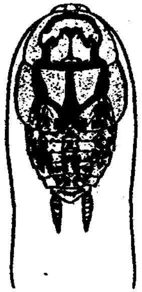
Female

Cariblatta **lutea lutea**



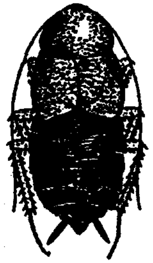
Female

Aglaopteryx **gemma**



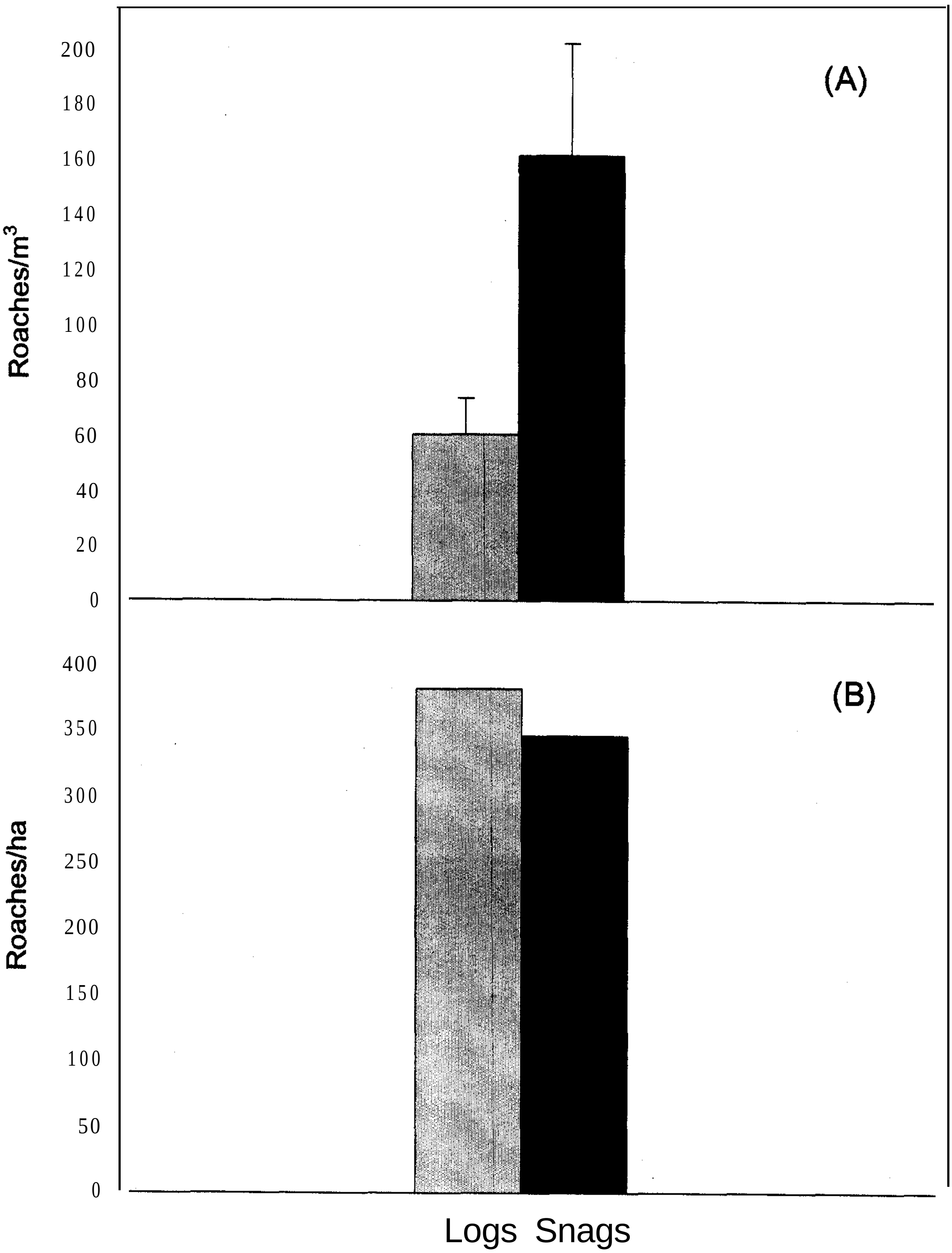
Male

Parcoblatta



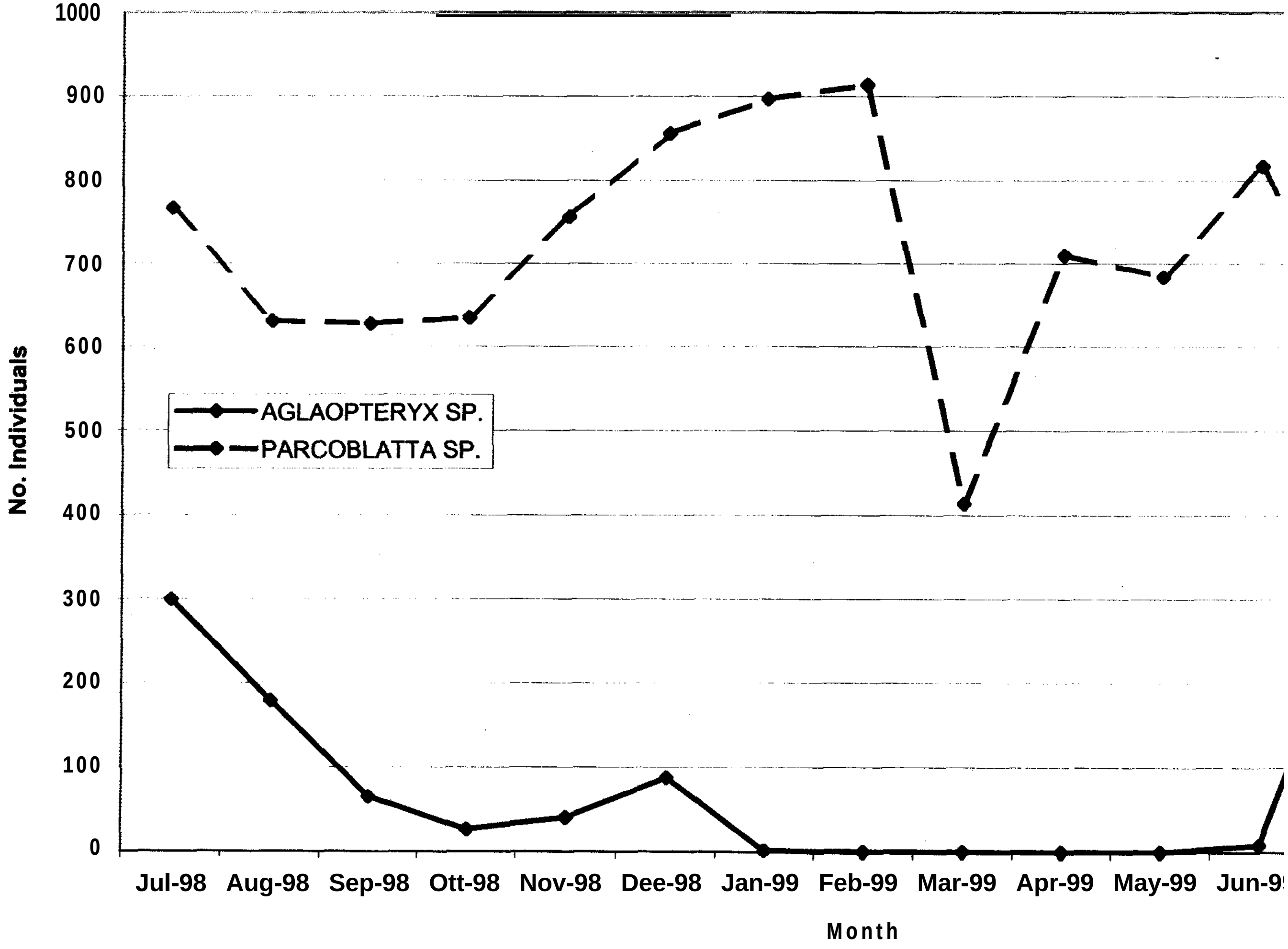
Female

Figure 2. (A) Comparison of the number of woodroaches found per cubic meter of pine logs and snags on the Savannah River Site, South Carolina. Means are significantly different (P = 0.03, t = -2.36). (B) Estimate of woodroaches/ha in CWD similar to that sampled.



Types of Coarse Woody Debris

Figure 3. Seasonal abundance of the two most common woodroach genera at the Savannah River Site based on observations made of woodroaches beneath burlap bands and cardboard panels from July 1998 to September 1999.


1000
900
800
700
600
500
400
300
200
100
0
No. Individuals
AGLAOPTERYX SP.
PARCOBLATTA SP.
Jul-98
Aug-98
Sep-98
Ott-98
Nov-98
Dee-98
Jan-99
Feb-99
Mar-99
Apr-99
May-99
Jun-9
Month

CONCLUSION

The use of burlap bands and cardboard panels revealed that common arthropods selected as prey by the red-cockaded woodpecker are reduced when coarse woody debris is removed from the landscape. Overall abundance of these part-time, bark-inhabiting arthropods was significantly greater in plots retaining coarse woody debris, regardless of trap type. Termites fed on cardboard panels resulting in high numbers of observations so we eliminated them from our analysis. Overall arthropod abundance was still significantly greater in plots that retained coarse woody debris. Even though overall arthropod abundance was significantly higher in control plots, Hemiptera were the only arthropod group found in significantly higher numbers.

Crawl traps indicated no difference in overall arthropod diversity, abundance, or biomass between coarse woody debris control and removal plots. However, the biomasses of Salticidae, Araneidae, and ***Sciara*** were all higher in coarse woody debris control plots.

Longleaf pine harbored significantly greater numbers of arthropods and greater arthropod biomass than loblolly pine. Arthropod groups found in significantly higher numbers on longleaf pine were Thysanura, Hemiptera, and Pseudoscorpiones. In addition, the biomass of Blattaria was much higher on longleaf pine, suggesting that larger arthropods may prefer the bark structure of longleaf pine. By altering the bark surface of longleaf pine, we found that it was outer bark structure that influences the presence of arthropods on longleaf pine boles.

Destructive sampling of downed and standing coarse woody debris revealed that twice as many woodroaches were found in standing coarse woody debris. Even though standing coarse woody debris seems to be a preferred habitat of woodroaches, logs may be just as important due to the large amount of downed woody material found on the forest floor. The most common woodroach in pine forests at Savannah River Site is *Parcoblatta lata.* It was the most commonly observed woodroach on pine trees, therefore it may be the most important forage species to red-cockaded woodpeckers.