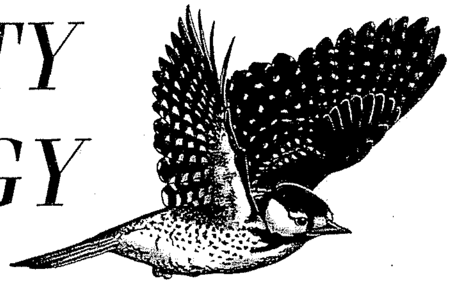
DE-AI09-00SR22188 PROCEEDINGS 2004 04-24-P

CHAPTER 11

PREY, FIRE, AND COMMUNITY ECOLOGY



AVAILABILITY AND ABUNDANCE OF PREY FOR THE RED-COCKADED WOODPECKER

JAMES L. HANULA, USDA Forest Service, Southern Research Station, 320 Green St., Athens, GA 30602-2044

SCOTT HORN, USDA Forest Service, Southern Research Station, 320 Green St., Athens, GA 30602-2044

Abstract: Over a 10-year period we investigated red-cockaded woodpecker (*Picoides borealis*) prey use, sources of prey, prey distribution within trees and stands, and how forest management decisions affect prey abundance in South Carolina, Alabama, Georgia, and Florida. Cameras were operated at 31 nest cavities to record nest visits with prey in 4 locations that ranged in foraging habitat from pine stands established in old fields to an old-growth stand in south Georgia. Examination of nearly 12,000 photographs recorded over 5 years revealed that, although red-cockaded woodpeckers used over 40 arthropods for food, the majority of the nestling diet is comprised of a relatively small number of common arthropods. Wood cockroaches (Blattaria: Blattellidae) were always the most common prey fed to nestlings, comprising 54.7% of their diet. Other common prey included caterpillars (Lepidoptera larvae), spiders (Araneae), woodborer larvae (Coleoptera: Cerambycidae), centipedes (Scolopendromorpha), and ants (Hymenoptera: Formicidae). Woodpeckers selected prey based on their abundance on tree boles and we saw no evidence that they preferentially selected cockroaches or other types of prey. Analysis of the woodpecker's diet and the community of arthropods on tree boles suggests that the food web supporting red-cockaded woodpeckers is detritus-based. However, the woodpeckers use a variety of arthropods and readily adapt to locally or temporally abundant food sources. Red-cockaded woodpeckers feed primarily on crawling arthropods that move onto the bole from the soil/litter layer. Therefore, most prey are not exclusively bark residents. Prey distribution within and between trees was regulated by bark thickness and, more importantly, bark flakiness. More prey were found near the base of the bole and in dead branches in the canopy where thick or loose, flaky bark provided better refuge. Arthropod abundance increased on trees up to 60-70 years of age after which it remained relatively constant on older trees. Prescribed burning had little effect on wood cockroaches but both winter and summer prescribed burns reduced ant and spider biomass. We found no evidence that herbaceous understory cover or diversity increased arthropod abundance on tree boles. Longleaf pine (*Pinus palustris*) trees harbored over twice as much arthropod biomass during the day as similar size loblolly pines (*P. taeda*) in the same area. The difference was due to the loose, flaky bark of longleaf pines. Longleaf pines 25-cm (10 in) diameter breast height (dbh) or larger harbored the most arthropod biomass. Our results suggest that management of foraging areas can be fairly flexible without harming the arthropods on which red-cockaded woodpeckers rely.

Key words: Blattellidae, cockroaches, *Parcoblatta* spp., prey, forest management, arthropods, foraging habitat, site quality, stand age.

As a high-profile endangered species the red-cockaded woodpecker, *Picoides borealis*, has received much attention and research. A good deal of that research has focused on the foraging behavior and territories of red-cockaded woodpecker groups, but prior to 1990 only 2 studies examined what the woodpeckers were actually eating. Beal (1911) studied the diet of adult birds through gut content analysis and Harlow and Lennartz (1977) studied nestling diets through observations of nest visits. In 1985 the Red-cockaded Woodpecker Recovery Plan (U.S. Fish and Wildlife Service 1985) focused attention on foraging habitat of this species, which brought to the forefront our lack of understanding about the arthropods that red-cockaded woodpeckers eat and whether forest management decisions affect prey abundance and availability.

To address this lack of knowledge we have been studying arthropods in pine stands over the past 10 years with the goal of answering 3 questions: (1) what arthropods do red-cockaded woodpeckers eat; (2) where do the prey come from and what forest habitats do they use in addition to live tree boles; and (3) how do stand conditions and forest management decisions affect abundance and availability of red-cockaded woodpecker prey? In this paper we summarize that work and provide additional analyses of data from published results.

PREY OF RED-COCKADED WOODPECKERS

Nestling Diet Studies

Red-cockaded woodpeckers forage for food on the boles of live pine trees so we were interested in what arthropods they find in that habitat. We used 35-mm cameras with 400-mm lenses capable of taking 250 exposures between film changes. The cameras were housed in watertight cases on top of 3-m tall tripod deer stands. Trailmaster 7 game monitors tripped the cameras to record red-cockaded woodpecker adults returning with food for nestlings (Hanula and Franzreb 1995). The resulting photographs (Figure 1) were examined with a stereomicroscope at 20-40X magnification to identify the prey. We classified prey as "insect" when insect legs or wings were observed in photographs but further identification was impossible. In most cases these appeared to be either cockroaches (Blattaria) or beetles (Coleoptera). In roughly 2% of the photographs adults were recorded with prey too small to identify or no prey were visible.

Figure 1. An example of the high quality photographs taken with automatic cameras to record nest visits with prey. Nearly 12,000 similar photographs were used to determine what red-cockaded woodpeckers feed on.

Using these cameras we recorded 11,941 nest visits with prey at 4 locations in the southeastern U.S. The sites were: the U.S. Dept. of Energy's Savannah River Site, a National Environmental Research Park on the Upper Atlantic Coastal Plain of South Carolina; Clemson University's Baruch Forest Science Institute in Georgetown Co., South Carolina on the Lower Atlantic Coastal Plain; the Piedmont National Wildlife Refuge in the Piedmont of Georgia; and the Wade Tract, an old-growth longleaf pine (*Pinus palustris*) remnant on the Gulf Coastal Plain near Thomasville, Georgia (Hanula and Franzreb 1995, Hanula et al. 2000*b*, Hanula and Engstrom 2000). In addition to being widely separated physically, the sites also represent 4 physiographic regions and a variety of forest types. Foraging areas on the Savannah River Site were primarily longleaf pine with some loblolly (*P. taeda*) and slash (*P. elliotti*) pines established on old farm fields. The Baruch Forest Science Institute is comprised of loblolly and longleaf pine stands with longleaf pine on the old beach ridges and loblolly pine in lower, wetter areas. The Piedmont National Wildlife Refuge is primarily loblolly and shortleaf pine (*P. echinata*) also established on old fields, and the Wade Tract is a remnant old growth longleaf pine habitat.

We monitored 31 groups over 5 years at the 4 sites. Collectively, red-cockaded woodpeckers used 41 different arthropods to feed nestlings (Table 1). Prey in Table 1 are listed as singular if adults brought 1 at a time and plural if they returned with more than 1 individual per visit. Wood cockroaches (Blattaria: Blattellidae, *Parcoblatta* spp.) were recorded in over 6,500 nest visits and represented 54.7% of the diet of all 31 red-cockaded woodpecker groups combined. The next most common prey were caterpillars (Lepidoptera larva), which were recorded in 8.2% of the visits. The large majority of caterpillars were coneworms (Lepidoptera: Pyralidae, *Dioryctria* spp.) that are most commonly found in pine cones during the nesting season. The long list in Table 1 demonstrates the variety of prey that red-cockaded woodpeckers utilize. However, many were only observed once or a few times suggesting that they were either not common on the foraging substrates, difficult to capture, or distasteful. In some cases the prey or food item were only recorded at 1 location. For instance, blueberries (*Vaccinium* spp.) were only recorded as a food source at the Lower Atlantic Coastal Plain site (Hanula et al. 2000*b*) and scorpions (Scorpiones: Buthidae) were only recorded at the Gulf Coastal Plain site (Hanula and Engstrom 2000). Of the 40+ prey groups recorded, 10 made up over 90% of the diet. Some of these groupings represent numerous species. For example, we observed adults with at least 5 different families and probably 10-20 species of spiders (Araneae). On the other hand, only a few species of centipedes (Scolopendromorpha) are found on the bark of trees (J. Hanula, USDA Forest Service, personal observation).

Red-cockaded woodpeckers consistently used the same types of prey despite differences in location, forest type, physiography or year of observation (Table 2). In every case wood cockroaches were the most commonly used prey item. They comprised nearly 50% or more of the diet at 3 of the 4 sample locations and 26% at the fourth. Spiders, caterpillars, and centipedes were consistently used in about equal proportions at all sites. Red-cockaded woodpeckers varied in their use of other prey such as woodborer larva (Coleoptera: Cerambycidae or Buprestidae) and ants (Hymenoptera: Formicidae) depending on location or year of observation.

Prey Selection

With just a few species of wood cockroaches comprising such a high proportion of the nestling diet the question arises—do red-cockaded woodpeckers preferentially forage for cockroaches? To answer that question we monitored prey abundance in the foraging territories of 4 red-cockaded woodpecker groups at the same time we were operating cameras at nest cavities of those groups in 1997 on the Savannah River Site.

Arthropods were monitored at a height of 1-1.5 m using burlap bands wrapped around the boles of trees (Figure 2). The burlap bands consisted of 1 x 1-m pieces of burlap fabric folded in half and sewn along the fold approximately 3-4 cm from the folded edge. A 1.4-m long piece of cotton rope was threaded through the fold and tied around the tree to hold the burlap in place. These bands provided refuges where the arthropods were easily observed. Sampling was limited to the base of the tree because previous studies showed arthropod community composition on mature longleaf pine trees was similar along the tree bole regardless of height above the ground (Hanula and Franzreb 1998).

Thirty burlap-banded trees were monitored in the foraging areas of each of the 4 red-cockaded woodpecker groups. The trees were distributed in 3 transects from the nest cavity tree radiating along three randomly chosen compass bearings. Ten trees were burlap-banded per line at 50-m intervals. The closest and largest living pine trees were used at each sample point and only trees >20-cm dbh received bands. Burlap bands were checked by slowly lifting 1 end of the burlap while walking around the tree to examine the burlap and bark beneath it for arthropods. Incidence of each taxa was noted, and arthropods were only collected if they were not represented in a reference collection used for field identifications. The study was conducted from 15 May through 7 July 1997. Burlap bands were checked weekly during the time nestlings were being fed from a given foraging area (roughly 3 weeks). Sampling stopped after the nestlings fledged. The proportion of a prey type selected by the woodpeckers was compared to the proportion found under the burlap bands using a *z*-statistic to make inferences about population proportions where sampling distributions are approximately normal (McClave and Dietrich 1982). The null

Table 1. Results of 3 diet studies[a] of red-cockaded woodpecker nestlings showing the total number of feeding visits observed with each prey type, the percentage of the total diet and the feeding habit of each prey type. Nest visits were recorded for 31 groups at 4 locations over a 5-year period.

Prey Item[b]	Feeding Habit	Number Observed	% of Diet
Wood Cockroach (Blattaria: Blattellidae)	Detritivore	6535	54.7
Caterpillar (Lepidoptera)	herbivore	982	8.2
Spider (Araneae)	predator	794	6.6
Wood Borer Larva (Coleoptera: Cerambycidae)	detritivore	669	5.6
Centipede (Scolopendromorpha)	predator	463	3.9
Insect (Insecta)	??	441	3.7
Insect Larva (Insecta)	??	372	3.1
Ants (Hymenoptera: Formicidae)	omnivore	358	3.0
Insect Larvae (Insecta)	??	285	2.4
Blueberry (Ericaceae)	—	226	1.9
Insect Adult (Insecta)	??	166	1.4
Moth Pupa (Lepidoptera)	herbivore	115	1.0
Bee Larva (Hymenoptera: Apidae)	herbivore	114	1.0
Beetle Larva/pupa (Coleoptera)	??	89	0.7
Beetle Adult (Coleoptera)	??	67	0.6
Longhorned Grasshopper (Orthoptera:Tettigoniidae)	herbivore	61	0.5
Sawfly Larvae (Hymenoptera: Diprionidae)	herbivore	52	0.4
Cicada Adult (Homoptera: Cicadidae)	herbivore	23	0.2
Moth (Lepidoptera)	herbivore	18	0.2
Ground Beetle Adult (Coleoptera: Carabidae)	predator	14	0.1
Wasp Adult (Hymenoptera: Vespidae)	predator	13	0.1
Cricket (Orthoptera: Gryllidae)	detritivore	10	0.1
Snail Shell	—	9	<0.1
Beetle Larvae (Coleoptera)	??	8	<0.1
Hemiptera Adult	??	7	<0.1
Scorpion (Scorpiones: Buthidae)	predator	6	<0.1
Shield-back Bug (Hemiptera: Pentatomidae)	herbivore	5	<0.1
Silverfish (Thysanura: Lepismatidae)	detritivore	5	<0.1
Shorthorned Grasshopper (Orthoptera: Acrididae)	herbivore	5	<0.1
Fly Adult (Diptera)	??	5	<0.1
Cockroach ootheca (Blattaria)	detritivore	4	<0.1
Harvestman (Phalangida)	detritivore	3	<0.1
Homoptera Nymphs	herbivore	3	<0.1
Woodborer Pupa	detritivore	3	<0.1
Insect Pupa	??	2	<0.1
Weevil Adult (Coleoptera: Curculionidae)	??	2	<0.1
Metallic Woodborer Adult (Coleoptera: Buprestidae)	detritivore	1	<0.1
Longhorned Woodborer Adult (Coleoptera: Cerambycidae)	detritivore	1	<0.1
Click Beetle Adult (Coleoptera: Elateridae)	detritivore	1	<0.1
Hawk Moth (Lepidoptera: Sphingidae)	herbivore	1	<0.1
Lacewing Adult (Neuroptera: Chrysopidae)	predator	1	<0.1
Preying Mantid (Mantoidea: Mantidae)	predator	1	<0.1

[a] Data for the table are from Hanula and Franzreb (1998), Hanula et al. (2000*b*) and Hanula and Engstrom (2000).

[b] Prey types listed as singular were delivered to nestlings individually and those listed as plural were delivered in groups of 2 or more.

hypothesis was that the 2 proportions were equal for a given arthropod group. Preference would be indicated by a higher proportion in the diet compared to what was on the tree. Statistical comparisons were only made when both the burlap bands and the nestling's diet contained the prey group.

Overall, cockroaches were the most common prey delivered to nestlings (Table 3). In addition, nestlings were fed spiders, centipedes, beetles, ants, and true bugs; all of which were also found under burlap bands. Prey such as woodborer larva, caterpillars, and cicadas (Homoptera: Cicadidae) were not found under burlap bands. Burlap bands were an effective method of sampling cockroaches on tree boles and they harbored them in proportions similar to the nestling's diet. The proportions of cockroaches, centipedes, and ants found under burlap bands were not significantly different from those of the diet. In contrast, burlap bands had significantly higher proportions of spiders, beetles, and true bugs than the diet of nestlings (Table 3). These results suggest that red-cockaded woodpeckers select food for nestlings based on availability and that they do not preferentially forage for specific prey. Had the woodpeckers preferred a particular prey we would have expected that prey to represent a higher proportion in the diet than found on the tree.

SOURCES OF RED-COCKADED WOODPECKER PREY

Tree Boles as Arthropod Habitat

Red-cockaded woodpeckers forage on live tree boles but an important consideration is whether the bole of a tree is a "closed" environment or habitat or an "open" one where arthropods move freely between tree boles and other forest habitats. If the latter is the case, then management should consider the whole forest to insure food availability for the woodpeckers. Therefore, we conducted a study to determine if arthropods on trees were restricted to that habitat (Hanula and Franzreb 1998). In that study we trapped arthropods on boles of live longleaf pine trees at 4 different heights: base (1 m aboveground), midbole (half the distance from the ground to the crown), base of the crown, and in the crown. Crawl traps (Figure 2) that captured arthropods crawling up the bole of the tree (Hanula and New 1996) were placed at each location. Each tree had traps at only 1 location so that lower traps would not interfere with captures of arthropods in traps higher up. We selected 2 trees in each stand for each trap height or a total of 8 trees. On half of the trees (1tree/trap height) we put a barrier to arthropod movement up the tree so we could compare captures of trees "open" (without barriers) to arthropods from other parts of the forest to those "closed" (with barriers) to the rest of the forest. The study was replicated in 8 longleaf pine stands within red-cockaded woodpecker foraging habitats on the Savannah River Site.

Trees without barriers to arthropod movement had twice as much arthropod biomass as trees with barriers (Figure 3). The effect of the barriers was greatest for traps at the base of the trees and diminished with increasing height of the traps (Hanula and Franzreb 1998). This study demonstrated that the tree bole was an "open" system and that a large proportion of the arthropod biomass available as forage for red-cockaded woodpeckers crawls onto the tree from the forest floor.

Table 2. Proportions of the most common prey groups fed to red-cockaded woodpecker nestlings at 4 locations in the Southeastern United States from 1993-1997.

	% Nest Visits			
Prey Item	Upper Atlantic Coastal Plain[a,b,c]	Lower Atlantic Coastal Plain[b]	Piedmont[b]	Gulf Coastal Plain[c]
Wood Cockroach	59.6	26.0	49.9	46.8
Wood Borer Larva	7.3	1.2	0.5	2.9
Caterpillar	7.7	9.1	9.3	8.9
Spider	6.4	7.2	5.2	8.3
Ants	2.5	7.2	0	1.1
Centipede	5.6	4.9	3.2	6.7
Insect Larva	2.4	1.3	4.1	7.4
Insect Larvae	1.9	6.0	1.0	2.5
Years Studied	1993-1997	1994	1995	1995-1997

[a] Data compiled from Hanula and Franzreb 1998

[b] Data compiled from Hanula et al. 2000

[c] Data compiled from Hanula and Engstrom 2000

Since barriers were not completely effective in stopping all arthropods that crawl and some insects flew to the trees, it was impossible to know exactly how much of the total biomass crawled on or flew to a given tree, but the study clearly demonstrated that the arthropods that represent the majority of the biomass on boles of southern pines are not full time bark residents.

Understory Plants as Prey Habitat

Since arthropods on tree boles do not live there exclusively we were interested in finding out what other habitats might be important for prey of red-cockaded woodpeckers. We examined published records of the behavior and feeding habits of arthropods that red-cockaded woodpeckers prey upon and assigned them to 1 of 4 groups (Table 1). We found that red-cockaded woodpecker prey were primarily detritivores and predators. Caterpillars were the largest herbivore group but most of our observations were of red-cockaded woodpeckers with coneworms that feed on pine cones. Woodborer larvae that feed on dead pine trees or dead limbs in live trees are another group of detritivores widely used by red-cockaded woodpeckers. Therefore, only a small proportion of the diet is composed of herbivores that might be dependent on live vegetation in the understory.

Examination of the diet at the different locations we studied also suggests that understory vegetation may not affect prey used by red-cockaded woodpeckers. Hanula and Engstrom (2000) found that woodpeckers foraging on or near the Wade Tract, an old-growth remnant with a lush and diverse understory plant community, had the same diet (Gulf Coastal Plain, Table 2) as woodpeckers foraging in longleaf pines stands growing on old field sites (Upper Atlantic Coastal Plain, Table 2) with much lower understory plant cover and diversity. Likewise, woodpeckers foraging in the Piedmont fed nestlings the same prey as those in the Lower or Upper Atlantic Coastal Plain (Table 2) despite very different understory plant communities among those sites (Hanula et al. 2000*b*). In addition, other studies also found insect herbivores comprised a small percentage of nestling and adult woodpecker diets (Beal 1911, Harlow and Lennartz 1977, Hess and James 1998).

Examination of what was captured on tree boles provides additional evidence that the community of arthropods on the foraging substrate is detritus-based. Hanula and Franzreb (1998) reported about equal

Table 3. Proportions of various arthropods in the diet of red-cockaded woodpecker nestlings and found under burlap bands on the boles of trees within foraging habitats. Numbers represent the total number of observations for all nests and burlaps combined.

	Nestling Diet[b]		Burlap Bands	
Arthropod group[a]	Number	%	Number	%
Cockroach[ns]	897	55.1	114	58
Spider *	131	8	36	18
Centipede[ns]	57	3.5	5	2.6
Beetle *	19	1.2	16	8.2
Ants[ns]	27	1.7	2	1
Woodborer Larva	279	17.1	0	0
True Bug *	1	0.06	11	5.6
Caterpillar	65	4	0	0
Cicada	5	0.3	0	0
Firebrat	0	0	12	6.1
Insect[c]	148	9.1	–	–

[a] A *z*-statistic was used to compared proportions in the diet and under burlap for a given group; ns = proportions did not differ significantly between nestling diet and burlap bands, * = proportions differed significantly at $\alpha = 0.05$.

[b] Diet data are the 1997 data from the Savannah River Site in Hanula and Engstrom (2000).

[c] "Insect" denotes prey that could no be identified further. All insects found beneath burlap bands were identified to a lower taxonomic level.

amounts of herbivore, detritivore and predator biomass captured in crawl traps on tree boles. However, a large portion of the herbivore biomass was in the form of 6 large grasshoppers (Orthoptera: Acrididae) and 2 leaf-footed bugs (Hemiptera: Coreidae) that have not been reported as prey. With those removed from the results herbivore biomass was reduced 50%, so most of the biomass widely distributed on tree boles in longleaf pine stands was in the form of detritivores and predators, the same groups eaten by red-cockaded woodpeckers.

The crawl traps used in that study were open 24 hours/day so some of the arthropods captured were nocturnal and not available during the day when red-cockaded woodpeckers forage. Recently, we sprayed tree boles with a quick knockdown insecticide (Pounce 5.2EC) and collected the arthropods that fell off to see what the arthropod community on tree boles was composed of during the daytime (Horn and Hanula 2002*a*). We sprayed 8 longleaf and 8 loblolly pine trees and collected arthropods falling off them for 2 hours after the insecticide was applied. The results (Figure 4) showed that the bulk of the arthropods inhabiting tree boles during the day and available for red-cockaded woodpeckers were primarily detritivores and predators. Omnivores, which were primarily ants, were an abundant group but detritivores, predators, and herbivores represented the greatest biomass, respectively.

Therefore, based on the diet of red-cockaded woodpeckers and the composition of the arthropod community on tree boles, our findings suggest that living understory vegetation may not be a critical part of the food web on which red-cockaded woodpeckers depend. We explored this further in a study conducted in 30 longleaf pine stands in southern Alabama and northern Florida varying from 20 to 90 years of age (Hanula et al. 2000*a*). In that study we fitted 10 trees in each stand (300 trees) with crawl traps and then trapped continuously for 1 year. At the end of the study we used standard survey techniques to determine herbaceous plant richness, the number of plant stems/m^2 and percent plant cover. Although all 3 variables were positively correlated with stand age, none of the plant community indicators we measured were correlated with arthropod abundance or biomass on tree boles.

Dead Wood as Prey Habitat

If arthropods on tree boles are using other habitats in pine stands in addition to live trees and the understory plant community is not directly affecting arthropod abundance on trees—what are the critical habitats for those arthropods? Our hypothesis is that detritus, in particular large (>10 cm [4 in]) diameter dead wood, provides important habitat and possibly food for the arthropods that red-cockaded woodpeckers prey on.

Figure 2. A burlap band (top) was wrapped around a pine tree to provide a hiding place for arthropods that use the bark during the daytime. Burlap bands harbored arthropods in about the same proportions as red-cockaded woodpeckers used them. Arthropods were counted by untying the rope and slowly lifting the burlap while going around the tree. A crawl trap (bottom) used for capturing arthropods crawling up trees. Arthropods moving up the tree encountered the aluminum band coated with Fluon (a slippery material) that acts as a drift fence forcing them into the funnel where they eventually crawl into the collection container.

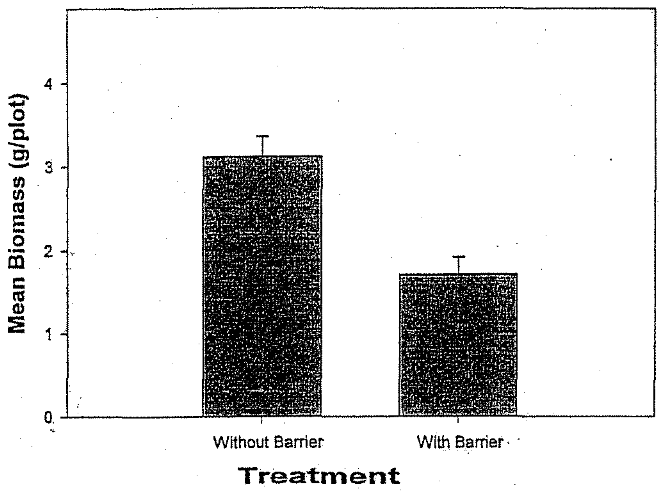


Figure 3. Mean arthropod biomass (g/plot; oven-dry weight) captured in crawl traps on longleaf pine trees *without a barrier at the base of the tree to prevent arthropods from crawling up from the ground compared* to those with a barrier. Means are significantly different ($P < 0.05$). Compiled from data in Hanula and Franzreb (1998).

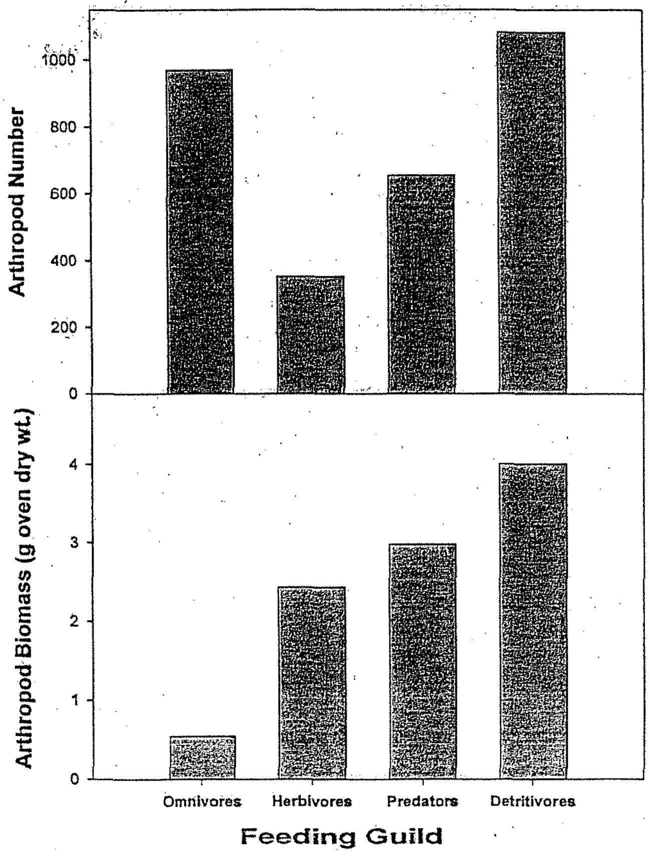


Figure 4. Total number and biomass (oven-dry weight) of arthropods in various feeding guilds collected from 16 pine trees (8 loblolly and 8 longleaf pine) following an application of a quick knockdown insecticide (Pounce 5.2 EC) to the tree boles. Compiled from data in Horn and Hanula (2002).

Support for this hypothesis comes from a number of studies. First, diet studies show that red-cockaded woodpeckers feed on wood cockroaches, centipedes, spiders, and ants (Beal 1911, Hanula and Franzreb 1998, Hanula et al. 2000*a*, Hanula and Engstrom 2000, Hess and James 1998), i.e., detritivores, predators, and omnivores. All of the major prey items can be found in and around dead wood. Second, dead branches in live trees contain as much or more arthropod biomass as any other part of the tree (Hooper 1996, Hanula and Franzreb 1998). Hooper (1996) found more arthropod biomass in dead branches than in bark at other positions on the tree bole. Likewise, Hanula and Franzreb (1998) found dead branches contained as much arthropod biomass as bark at the base of the tree and both locations contained more biomass than any other position along tree boles (Figure 5). Third, wood cockroaches are abundant in standing dead trees (snags) and downed dead wood (logs). Horn and Hanula (2002*b*) estimated that a hectare of mature loblolly pine forest contained approximately 725 wood cockroaches, *Parcoblatta* spp., in logs and snags. In contrast, we collected an average of 10.8 wood cockroaches/live tree when we sprayed entire tree boles with insecticide (Horn and Hanula 2002*a*) and our stands contained an average of 156 trees/ha (63trees/ac). Therefore, if each tree contained roughly 11 wood cockroaches, we estimated 1,716 wood cockroaches/ha (694.5 cockroaches/ac) on live trees or ca. twice as many as found in logs and snags (Figure 6). However, the stands contained an average volume of 8.6 m^3/ha (122 ft^3/ac) of dead wood over 10-cm (4 in) diameter compared to 188 m^3/ha (2,686 ft^3/ac) of live trees so dead trees contained almost 10 times more wood cockroaches per unit volume as live trees (Figure 6). The fact that wood cockroaches are more concentrated in dead wood suggests that it is important to their biology. In addition to cockroaches, larvae of wood boring beetles (Coleoptera: Cerambycidae or Buprestidae) are also common and important prey of red-cockaded woodpeckers found in dead trees or dead branches of live trees, and both carpenter ants (*Camponotus* spp.) and *Crematogaster* spp. ants are found nesting in dead branches of live trees (Hanula and Franzreb 1998) and in dead trees. In fact, carpenter ants were 6 times more abundant in dead branches than at any other sample position on live trees and *Crematogaster* spp. ants were equally abundant in dead branches and in the bark 1.5 m (5 ft) above the ground. Both sample positions contained 5 times the numbers of ants as the midbole or crown sample locations.

If logs and snags are important habitat for arthropods that serve as prey for red-cockaded woodpecker, what happens when they are removed from the system? We are currently investigating that question on large-scale (9 ha [22 ac]), long-term research plots on the Savannah River Site. In that study, all dead wood over 10 cm (4 in) in diameter is removed annually from 4 plots while the dead wood is left on 4 comparable control plots. The study was initiated in July 1996. We attached crawl traps to 15 trees widely distributed throughout the plots and monitored them monthly from October 1997 to September 1999. Burlap bands were placed on 30 trees per plot and monitored monthly from July 1998 to September 1999. The early results show that 2 to 3 years after removal began, overall arthropod abundance on tree boles as measured in crawl traps and under burlap bands was not affected by removal of large woody debris (Horn 2000). Whether long-term absence of woody debris will affect the community of arthropods that red-cockaded woodpeckers depend on is unclear, but it is a question that we are currently investigating.

FOREST MANAGEMENT EFFECTS ON ARTHROPOD AVAILABILITY

A critical concern of red-cockaded woodpecker management is what effect human activity has on them and the arthropods they eat. Some common management activities in red-cockaded woodpecker foraging habitats are prescribed burning to remove hardwoods and maintain the open pine habitat the woodpeckers prefer, management to shift age classes and tree sizes in foraging habitat to older trees greater than 25 cm dbh, and conversion to longleaf pine. Although all of these activities are based on sound biological observations of red-cockaded woodpecker behavior and habits, little was known about how they affect the arthropods red-cockaded woodpeckers eat. We have attempted to address some of those concerns.

Prescribed Burning

We were initially concerned prescribed burning would reduce prey abundance since our studies showed red-cockaded woodpeckers feed primarily on arthropods incapable of flight, or that fly infrequently, and

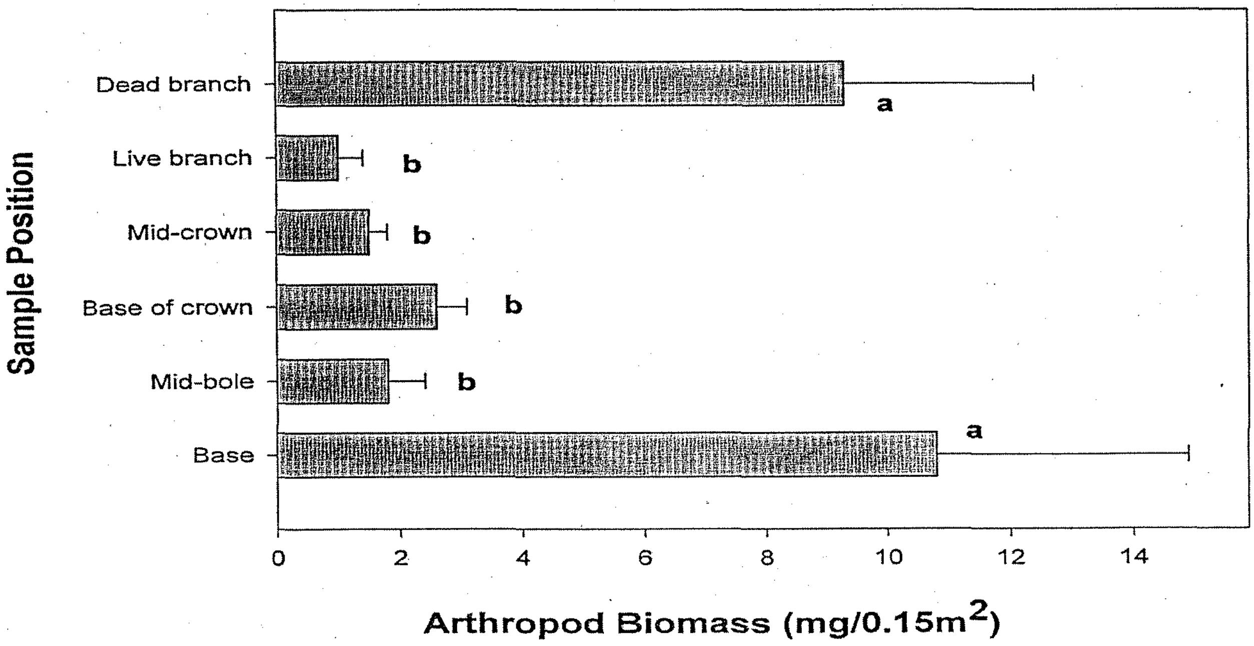


Figure 5. Mean (±SE) biomass (oven-dry weight) of arthropods collected by scraping 0.15m^2 areas of bark from various positions along the bole of 39 longleaf pine trees. Bars followed by the same letter are not significantly different ($P < 0.05$) by the Ryan-Einot-Gabriel-Welch multiple F test. Data are from Hanula and Franzreb (1998).

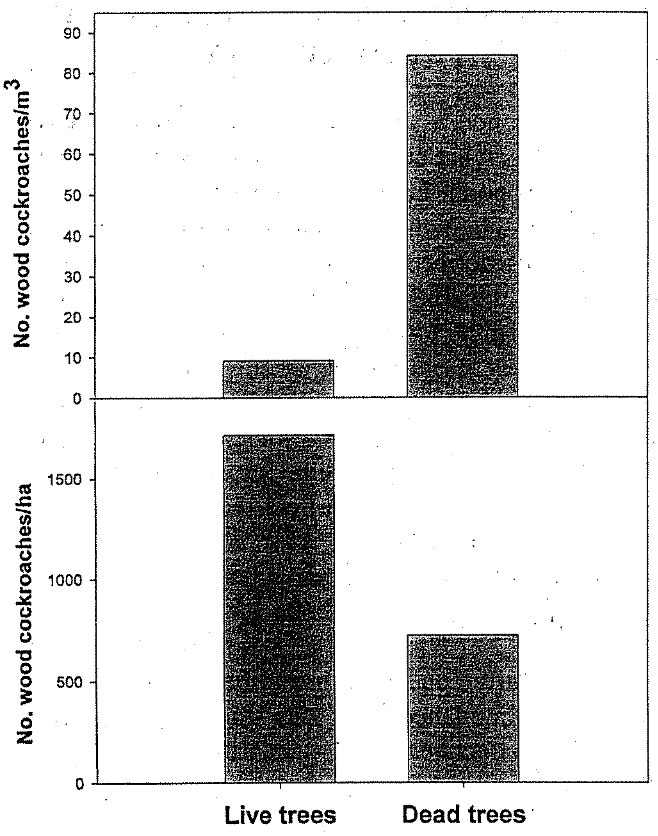


Figure 6. Estimated number of wood cockroaches on living and dead trees (logs and snags) on a hectare of loblolly pine forest at the Savannah River Site, South Carolina and the estimated number per cubic volume of live and dead trees.

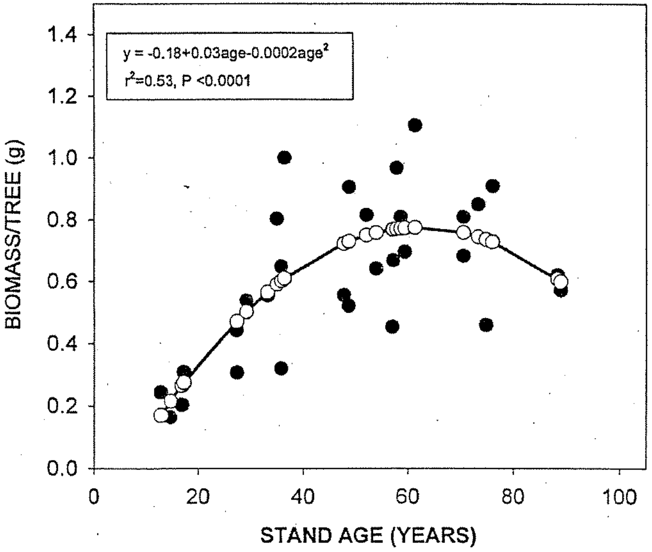


Figure 7. Relationship of the average age of longleaf pines in a stand to mean arthropod biomass/tree (oven-dry weight) captured in crawl traps on boles in the Escambia Experimental Forest, Alabama and the Blackwater State Forest, Florida (from Hanula et al. 2000 a). Open circles are predicted values.

arthropods on tree boles spend at least part of their life on the forest floor. We initiated a study in 1993 on the Savannah River Site to look at the effects of time after burning on arthropods in longleaf pine stands (New and Hanula 1998). We captured arthropods in pitfall traps on the ground, crawl traps on tree boles, and in flight traps on the ground and on tree boles in stands that had been burned in the winters of 1991, 1992, 1993, and 1994, and the summer of 1992. Winter burning had very little effect on prey abundance. The only prey group affected was spiders and spider biomass captured on tree boles was only reduced during the first year after the burn was applied. Summer prescribed burns had a greater effect on certain prey groups than winter burns conducted the same year. Spider and ant biomass were reduced on tree boles in stands burned during the summer when compared to those burned in the winter. Cockroaches and centipedes were not affected by the treatments. Therefore, burning did alter prey abundance but the effects appeared to be relatively minor. Summer burning reduced prey more than winter burning, possibly because of the increased intensity of summer burns, but the reductions were relatively small and we concluded that the effects of prescribed burning on the woodpecker's food were probably minimal.

Stand Age, Stand Density, Tree Size and Site Index

A second area of concern is how stand and tree characteristics affect prey abundance. Red-cockaded woodpeckers preferentially forage on trees 25 cm dbh or larger so the guidelines for managing foraging habitat focus on providing trees of that size (U.S. Fish and Wildlife Service 1985). We were interested in determining if stands of larger or older trees provided greater arthropod abundance so we conducted a study in longleaf pine stands on the Escambia Experimental Forest in Escambia County, Alabama and the Blackwater State Forest in Santa Rosa County, Florida (Hanula et al. 2000*a*). We selected 4 stands from each of the following age classes: 20-25, 30-35, 40-45, 50-55, 60-65, 70-75, 80-85, and 90-95 years old. Only 2 stands were available in the 70-75 year age class so we had a total of 30 stands. Within each stand we selected 10 dominant or codominant trees and placed a crawl trap on the bole of each. The traps were open continuously for 1 year but we only examined samples from every other month. At the end of the study in August 1995 we measured a variety of stand and tree characteristics including tree density, basal area, tree age, bark thickness, tree height, percent herbaceous groundcover, herb and shrub abundance, and herb and understory plant diversity. The site index of each stand was estimated from tree age and height data. Since arthropod biomass and numbers of individuals showed similar relationships with the various stand and tree characteristics, only biomass results are discussed below.

Stand age, tree size and bark thickness.—Arthropod biomass per tree increased with increasing age up to approximately age 60 years after which it remained constant on trees up to age 90 years (Figure 7). Arthropod biomass per tree was also correlated with diameter at breast height (dbh) and bark thickness (Figure 8). Biomass increased with increasing dbh up to 30-35 cm (11.8-13.8 in) after which arthropod biomass was similar on larger diameter trees. Arthropod biomass was correlated in a similar manner with bark thickness (Figure 8). Again, biomass increased with increased bark thickness up to ca. 1.75 cm (0.69 in) after which biomass remained relatively constant on trees with thicker bark.

Stand Density.—We estimated arthropod biomass per unit area using our data for the biomass per tree in each stand and tree density. We found that arthropod biomass per unit area declines with age until age 60-70 years when it begins to level off (Hanula et al. 2000*a*). Although younger, smaller trees had less arthropod biomass per tree, they occurred at higher densities resulting in more arthropods on trees per unit area.

Site Quality.—Site index was not correlated with arthropod biomass, abundance, or diversity, so higher quality sites for tree growth do not appear to provide better foraging habitat for red-cockaded woodpeckers. Likewise, arthropod abundance on tree boles was not correlated with understory plant diversity, density of herbaceous plants, or percent herbaceous plant cover.

Stand composition.—Another goal of management to support red-cockaded woodpecker populations is conversion of stands to longleaf pine wherever appropriate, so we conducted a study to see how this shift in forest composition might affect prey available to the red-cockaded woodpecker (Horn and Hanula 2002*a*). We selected 8 loblolly and 8 longleaf pine trees that were the same size dominant or codominant trees and growing on similar sites at the Savannah River Site. We used a hydraulic lift truck to access the entire bole, which we sprayed with a quick knockdown insecticide (Pounce 5.2 EC). Arthropods that fell from the trees were collected on 2 tarps on the ground beneath the trees for 2 hours after spraying. Trees were paired so that a loblolly and a longleaf tree were treated on successive days at the same time of day.

We collected twice as many arthropods/tree from longleaf pine compared to loblolly pine and more than twice as much arthropod biomass was recovered from longleaf pines (Figure 9). Ants were particularly abundant but contributed little to overall arthropod biomass. Numbers of cockroaches were not significantly different on the 2 tree species, but nearly 6 times as much cockroach biomass was recovered from longleaf pines indicating larger cockroaches were collected from longleaf trees. Greater biomasses of firebrats and silverfish (Thysanura) and true bugs (Hemiptera) were also recovered from longleaf pine trees. No arthropod group occurred in greater numbers or biomass on loblolly pine.

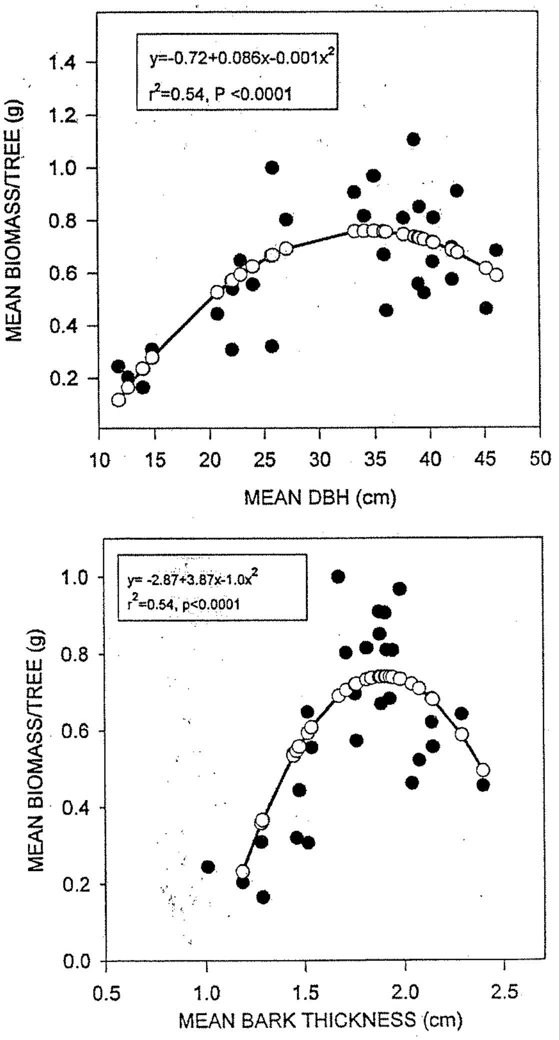


Figure 8. Relationship between average diameter at breast height (dbh) and bark thickness of longleaf pines and the arthropod biomass/tree (oven-dry weight) captured in crawl traps on boles (from Hanula et al. 2000 a). Open circles are predicted values.

We were interested in understanding why larger arthropods were more abundant on longleaf pine, so we scraped 3-m (10-ft) sections of 5 longleaf pines to remove the loose outer bark and compared them to 5 non-scraped trees to see if bark structure or chemical cues played a role. One month after scraping we sprayed the quick knockdown insecticide on the scraped area of each tree and the same size area on non-scraped trees, and collected all of the arthropods that fell from them. We collected significantly more ($P < 0.01$) arthropods from non-scraped trees ($\overline{x}$ = 30.2 arthropods/tree; SE = 5.4) compared to trees with the loose outer bark removed ($\overline{x}$ = 15.8 arthropods/tree; SE = 1.4). Although we only collected twice as many arthropods from non-scraped trees we collected 40 times as much arthropod biomass from those trees (scraped = 9.1 ± 3.6 mg/tree, non-scraped = 367.6 ± 164.5 mg/tree; $P < 0.01$), i.e., non-scraped trees harbored more arthropods and much larger ones. When we lightly scraped trees to determine how much bark flaked off easily we removed twice as much bark from longleaf pines. Moisture content of the bark and bark thickness were the same for both tree species so differences in arthropod abundance were due to more loose, flaky bark on longleaf pines providing more and better habitat for larger arthropods.

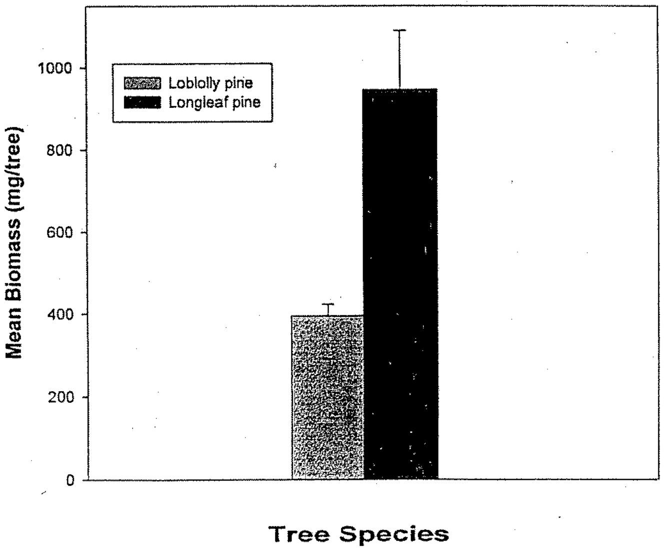


Figure 9. Mean biomass (oven-dry weight) per tree of arthropods collected from boles of loblolly and longleaf pine trees sprayed with a quick knockdown insecticide (Pounce 5.2 EC).

DISCUSSION

Wood cockroaches are a common and important prey of red-cockaded woodpeckers but we found no evidence that woodpeckers select cockroaches or any other type of prey in greater proportion than their availability. To date no studies have demonstrated red-cockaded woodpeckers prefer a given type of prey and our studies suggest that selection is based on availability, although we found some evidence that a few prey may be used less than their availability. The wide range of food used by red-cockaded woodpeckers, which includes atypical foods like sawflies (Hymenoptera: Diprionidae), scorpions (Scorpiones: Buthidae) and blueberries, shows the ability of these woodpeckers to take advantage of available food sources.

Clearly, the majority of red-cockaded woodpecker prey are arthropods readily found in most mature southern pine forests regardless of understory plant community characteristics. The woodpeckers eat high proportions of detritivores and predators, and the herbivores eaten by red-cockaded woodpeckers primarily feed on pine. Our studies show that the plant community can vary considerably without affecting the abundance of arthropods crawling on tree boles. Although we found no evidence that the understory plant community affects arthropod abundance on trees, it is an important part of forest diversity that should not be neglected.

Our results show that conversion of loblolly pine stands planted on longleaf sites to longleaf pines is desirable and should result in more arthropod biomass available for red-cockaded woodpeckers (Horn and Hanula 2002*a*). Although there are a number of other good reasons for such conversions, these data provide evidence that longleaf pine increases available food resources for this and possibly other bark-foraging birds.

Likewise, longleaf pines trees 60 or more years old or 25 cm (10 in) or more in diameter had more arthropod biomass captured on them than younger, smaller trees (Hanula et at. 2000*a*). Tree age was strongly correlated with tree dbh but the relationship is not fixed, i.e., trees can be grown to the desired diameter more quickly. Thus, techniques that increase growth so trees reach maximum arthropod yield (>25cm or 10 in) more quickly without jeopardizing other management goals, such as a diverse plant community, could result in maximum forage availability for bark foraging birds over a longer portion of the stand rotation.

These data along with those from other studies (Hooper 1996, Conner et al. 2004*a*) show that once trees reach the age of 60-80 years old they harbor just as much arthropod biomass as older trees. In addition, the data show that once trees reach the 25-30 cm (10-12 in) dbh preferred by red-cockaded woodpeckers for foraging they contain as many arthropods per tree as larger trees. Since there were fewer trees/ha in the older stands one might expect arthropod biomass/tree to increase on the remaining trees but that was not the case. Instead, trees in older stands contained a relatively constant biomass of arthropods per tree even though tree density declined. If that relationship is true for other areas then keeping stands well stocked throughout the rotation would likely result in more arthropods in a given area.

The results of our studies demonstrated that red-cockaded woodpeckers forage on detritivores and predators and those groups comprise the majority of the arthropod biomass on trees. In addition, the woodpeckers eat large numbers of wood cockroaches that were abundant in snags and logs suggesting these habitats are important (Horn and Hanula 2002*b*). However, after 3 years of annually removing logs and snags from mature pine stands we saw no evidence that the abundance of cockroaches or other prey were reduced (Horn 2000). Likewise, prescribed burning had no effect on cockroach abundance on tree boles and relatively small effects on other types of prey (New and Hanula 1998). To date, our data suggest that typical forest management activities such as thinning or burning in mature pine stands should have relatively minor effects on prey availability.

ACKNOWLEDGMENTS

Funding for this research was provided by the Department of Energy—Savannah River Operations Office through the USDA Forest Service Savannah River under Interagency Agreement DE-IA09-76SR00056. The Savannah River Site is a national environmental research park. We also thank the numerous technicians and student workers who collected, sorted, oven-dried, and weighed arthropod samples over the past 10 years. Finally, we thank John Blake (USDA Forest Service) for helpful discussions throughout the course of these studies and Mrs. Francis Brookshire who cheerfully worked at whatever task she was asked to do.