Relationship of Coarse Woody Debris to Arthropod Availability for Red-Cockaded Woodpeckers and Other Bark-Foraging Birds on Loblolly Pine Boles[1]

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J. Entomol. Sci. 43(2): 153-168 (April 2008)

Abstract This study determined if short-term removal of coarse woody debris would reduce prey available to red-cockaded woodpeckers (*Picoides borealis* Vieillot) and other bark-foraging birds at the Savannah River Site in Aiken and Barnwell counties, SC. All coarse woody debris was removed from four 9-ha plots of mature loblolly pine (*Pinus taeda* L.) in 1997 and again in 1998. We sampled arthropods in coarse woody debris removal and control stands using crawl traps that captured arthropods crawling up tree boles, burlap bands wrapped around trees, and cardboard panels placed on the ground. We captured 27 orders and 172 families of arthropods in crawl traps whereas 20 arthropod orders were observed under burlap bands and cardboard panels. The most abundant insects collected from crawl traps were aphids (Homoptera: Aphididae) and ants (Hymenoptera: Formicidae). The greatest biomass was in the wood cockroaches (Blattaria: Blattellidae), caterpillars (Lepidoptera) in the Family Noctuidae, and adult weevils (Coleoptera: Curculionidae). The most common group observed underneath cardboard panels was Isoptera (termites), and the most common taxon under burlap bands was wood cockroaches. Overall, arthropod abundance and biomass captured in crawl traps was similar in control and removal plots. In contrast, we observed more arthropods under burlap bands (mean ± SE; 3,021.5 ± 348.6, $P = 0.03$) and cardboard panels (3,537.25 ± 432.4, $P = 0.04$) in plots with coarse woody debris compared with burlap bands (2325 ± 171.3) and cardboard panels (2439.75 ± 288.9) in plots where coarse woody debris was removed. Regression analyses showed that abundance beneath cardboard panels was positively correlated with abundance beneath burlap bands demonstrating the link between abundance on the ground with that on trees. Our results demonstrate that short-term removal of coarse woody debris from pine forests reduced overall arthropod availability to bark-foraging birds.

Key Words arthropods, bark-foraging birds, bark-gleaning guild, corticulous arthropods, saproxylic

In the southeastern U.S., efforts to increase red-cockaded woodpecker (*Picoides borealis* Vieillot) populations and improve their habitat have had a major impact on management of public forest lands. These efforts over several decades have resulted in a range-wide population increase from 1991-2003 (Costa 2004). Although its status as an endangered species has focused attention on the red-cockaded woodpecker, a wide variety of other birds also forage in the same types of habitats. Therefore, it is

[1]Received 17 September 2007; accepted for publication 04 December 2007.

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important to understand what factors or forest conditions contribute to sustained prey availability for these woodpeckers and other birds.

Red-cockaded woodpeckers and a variety of other bark-foraging birds use live pine tree trunks as a foraging substrate, but arthropods on tree boles are not restricted to this habitat (Moeed and Mead 1983, Hanula and Franzreb 1998, Hanula and Horn 2004). One component of forest ecosystems that may be important to bark-foraging, as well as a variety of other birds, is large dead wood or coarse woody debris (Hanula and Horn 2004) which includes snags, fallen trees, stumps and decomposing root systems (Harmon et al. 1986). Numerous studies have noted the importance of dead wood to bird diversity and abundance (Davis 1983, Raphael and White 1984, Zarnowitz and Manuwal 1985, Schreiber and deCalesta 1992, Bull and Holthausen 1993, Lanham and Guynn 1993, Lohr et al. 2002), but all dealt with the direct use of dead wood for activities such as feeding, nesting, or roosting. To date, no studies have addressed direct linkages between dead wood and arthropod abundance on live tree boles.

The importance of dead wood to terrestrial insects that spend most of their lives in it is well documented (Speight 1989, Hanula 1996, Grove 2002, Grove and Hanula 2006). However, little information is available on terrestrial arthropods that move readily within forests and only use dead wood as part of their habitat (Irmler et al. 1996, Marra and Edmonds 1998, Andrew et al. 2000, Buddle 2001). Dead wood may be an important part of the habitat for these arthropods, but if they also use live tree trunks they become available to bark-foraging birds. Studies have shown that tree trunks serve as important habitat corridors between the canopy and soil litter layer (Moeed and Mead 1983, Hanula and Franzreb 1998, Majer et al. 2003, Hanula and Horn 2004). Factors that affect this "biological highway" may have profound effects on bark-foraging birds as well as birds foraging in the canopy. As Mariani and Manuwal (1990) suggest, it is important to examine how habitat alterations affect food resource availability.

We studied the interrelationship of coarse woody debris and arthropods found on loblolly pine (*Pinus taeda* L.) trees. Loblolly pine is the most widely distributed and planted pine species in the southern U.S., occupying over 13.4 million ha (Schultz 1997). Because of its widespread occurrence and importance as a timber species, loblolly pine now serves as the predominant tree available to many bark-foraging birds in the Southeast. The objective of our study was to determine how the absence of coarse woody debris affects the diversity and abundance of arthropods on the boles of live pine trees.

Materials and Methods

Study area. This study was conducted on the Savannah River Site (SRS) near Aiken, SC, which is operated by the U.S. Department of Energy (DOE). The SRS occupies 80,269 ha located in the upper Atlantic Coastal Plain Physiographic Province. The forested land within the site is managed as a national environmental research park. 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).

The stands chosen for the study consisted of 40- to 45-yr-old upland loblolly pine plantations. Each plot was 9.3 ha of even-aged loblolly pine, with occasional longleaf or slash pine interspersed. The midstory consisted mostly of hardwood species including mockernut hickory (*Carya tomentosa* Nutt.), sweetgum (*Liquidambar styraciflua* L.), blackjack oak (*Quercus marilandica* Muenchh.), wax myrtle (*Myrica cerifera* L.), and sassafras (*Sassafras albidum* Nees). Understory species composition varied somewhat between plots; however, the most commonly encountered species were poison oak (*Toxicodendron pubescens* P. Mill), trumpet-vine (*Campsis radicans* L.), Carolina jessamine (*Gelsemium sempervirens* St.-Hil.), fox grape (*Vitis aestivalis* Michx.), and beggarticks (*Desmodium spp*). Less common but notable understory species included southern gooseberry (*Vaccinium stamineum* L.), sparkleberry (*V. arboretum* Marsh.), goldenrod (*Solidago spp.*), and the invasive, nonnative bicolor lezpedeza (*Lezpedeza bicolor* Turcz.).

Climate in the region is temperate and mild. Average daily temperatures range from 27°C in summer to 9°C in the winter with a frost-free period of 240 d (Sanzone 1995). Average rainfall is 120 cm per year. From January through December 1998 the site received approx. 174 cm. The largest amount received in one month during this study was in August 1998 (47.2 cm) and the lowest rainfall was recorded during October 1998 (1.78 cm).

Our study was part of a larger experiment examining coarse woody debris recruitment, rates of decomposition, and the effects of large dead wood removal on various animal groups (McCay et al. 2002). The study was a randomized complete block design consisting of 2 treatments: (1) an undisturbed control, and (2) a total annual removal of all large dead wood greater than 10 cm diam, including logs and snags. All large dead wood was removed from the plots in January and February 1997, February to March 1998 and March 1999. At the time of our study, control plots contained an average of 6.45-m^3/ha of downed logs and 2.04-m^3/ha of standing snags and removal plots averaged 0.35-m^3/ha and 0.22-m^3/ha of logs and snags, respectively (McCay et al. 2002). Plots were square and 9.3 ha in size, but all arthropod sampling was restricted to the central 6 ha of the plots to reduce edge effects.

Arthropod sampling. Arthropods were sampled with crawl traps, burlap bands and cardboard panels. Crawl traps captured arthropods climbing up the tree and were used to determine if coarse woody debris removal affected species richness and abundance. 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 (Hanula and New 1996). Arthropods crawled up the tree bole, through the funnel spout and into a container attached to the top of the funnel spout. From the container they fell into a specimen cup containing saturated NaCl solution with 1% formaldehyde and a drop of soap to reduce surface tension. A 10-cm wide aluminum drift fence, placed around and sealed to the tree with 100% silicone caulk, prevented most arthropods from bypassing the trap. Crawl traps were placed 2 m above the ground to facilitate sample collection because trap captures at that position are representative of other locations 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 (~50 m apart) so they were evenly distributed throughout the study area. Samples were collected monthly from October 1997 to September 1999 and 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, placed into 70% alcohol and identified to morphospecies using a reference collection. Morphospecies have been used successfully to contrast different forest arthropod communities (Oliver and Beattie 1996). The biomass of each morphospecies was estimated by oven-drying

(40°C for 48 h) and weighing all individuals of infrequently collected groups or a representative sample of 30-40 individuals for more common groups.

A second sampling method used burlap bands and cardboard panels (Hanula and Horn 2004) to determine whether coarse woody debris removal affected known prey of the red-cockaded woodpecker. Burlap bands are a nondestructive method of monitoring arthropods on tree boles that harbor arthropods in proportions similar to the red-cockaded woodpecker's diet (Hanula and Horn 2004). Burlap bands consisted of 1 × 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. They were checked monthly by slowly untying the rope and lifting the band from the tree to observe arthropods beneath.

Cardboard panels consisted of 4 layers of 0.5 × 0.75-m corrugated cardboard held together with gray duct tape. Panels were placed 1-3 m away from each tree with a corresponding burlap band and were used to monitor arthropods on the ground. Sampling consisted of identifying and counting arthropods beneath the cardboard panels. A carry-along reference collection was used to assist field identification. However, if an arthropod could not be identified in the field it was collected, identified later, and incorporated into the collection. Burlap bands and cardboard panels were monitored monthly from July 1998 to September 1999.

Statistical analyses. A paired *t*-test (SAS Institute 1985) was used to test differences between control and removal treatments in abundance and biomass in crawl traps, and abundance beneath burlap bands and cardboard panels. In some cases, we used $\log_{10}(x + 1)$ or $\sqrt{x + 0.5}$ transformations to reduce heteroscedasticity (Sokal and Rohlf 1981). We used simple linear regression analyses to examine relationships between arthropods found under burlap bands and cardboard panels.

Results

We captured >49,000 arthropods from 405 genera in 172 families and 27 orders in crawl traps. Table 1 lists some of the most common families that are known or suspected prey of red-cockaded woodpeckers and the number of genera captured. The most abundant orders collected were Homoptera (23,688) consisting primarily of large numbers of aphids, and Hymenoptera (8,047) which were mostly 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. Morphospecies richness was similar in control plots (167 ± 8 species/plot, $\bar{X}$ ± SE) and plots where dead wood was removed (165 ± 8 species/plot). In addition, the number of rare morphospecies (i.e., <5 individuals collected per yr) was also similar in control (62 morphospecies) and removal (56 morphospecies) plots.

Crawl traps on control (6,361 ± 893 arthropods/plot) and removal plots (6,060 ± 1131 arthropods/plot) caught equal numbers of arthropods and similar amounts of arthropod biomass (control = 14.66 ± 1.67 g/plot versus dead wood removal = 12.58 ± 0.49 g/plot; $P = 0.25$). No arthropod order was captured in significantly greater numbers or biomass. However, the mean biomass of the spider family Salticidae (jumping spiders) was higher in control plots (0.39 ± 0.07 g/plot) than in removal plots (0.25 ± 0.04 g/plot) ($P = 0.03$). In addition, the mean biomass of Araneidae (orb-weaving spiders) was also higher in control plots (0.27 ± 0.07 g/plot) compared with removal plots (0.12 ± 0.06 g/plot) ($P = 0.05$). Two spiders, *Neoscona* sp. (Araneidae) (0.23 ± 0.04 g/control plot and 0.10 ± 0.05 g/removal plot; $P = 0.03$) and *Phidippus* sp. (Salticidae) (0.35 ± 0.06 g/control plot and 0.22 ± 0.04 g/removal plot; $P = 0.03$) had significantly higher biomass on control plots and accounted for most of the biomass in those families.

We observed more than 45,000 arthropods beneath burlap bands and cardboard panels representing 20 orders and 82 families (Table 2). The most abundant order was Isoptera (17,425) beneath cardboard panels, followed by Blattaria (12,367) beneath cardboard and burlap. The latter were primarily wood cockroaches in the genus *Parcoblatta*. The most diverse orders were Coleoptera and Araneae. Regression analyses revealed positive correlations between abundance under burlap bands and abundance under adjacent cardboard panels for a wide variety of arthropod groups (Table 3).

Overall, we observed more arthropods beneath cardboard panels and burlap bands in control plots ($P = 0.02$) where dead wood was left undisturbed (Fig. 1). We removed termites from the analysis because they were attracted to and fed on the cardboard panels. Even with termites removed, control plots had greater numbers of arthropods (Fig. 1, $P = 0.04$). A number of arthropod taxa were found in slightly higher numbers under burlap bands and cardboard panels on control plots, but only the Hemiptera were significantly higher (Fig. 2). However, this general trend of higher numbers in control plots resulted in the overall arthropod abundance being significantly different as mentioned above. Analyses of the various genera showed only *Crematogaster* spp. ants occurred in significantly greater numbers in control plots (567 ± 82 ants/plot) compared with dead wood removal plots (217 ± 56 ants/plot) ($P = 0.04$). Conversely, harvestmen (Order Opiliones) were the only group observed in greater numbers in dead wood removal plots (7 ± 2.1 individuals/plot) versus control plots (3 ± 1.9 individuals/plot) ($P = 0.01$), although the number collected was small.

Burlap bands and cardboard panels analyzed separately had more arthropods in control plots (burlap bands, $P = 0.03$; cardboard panels, $P = 0.04$). Hemiptera were more abundant beneath burlap bands (441 ± 91 individuals/plot; $P = 0.03$) and cardboard panels (14 ± 4.2 individuals/plot; $P = 0.02$) in control plots compared with burlap bands (286 ± 42 individuals/plot) and cardboard panels (5 ± 1.8 individuals/plot) in dead wood removal plots. Members of the Family Formicidae were more abundant in control plots (391 ± 95 individuals/plot) compared with removal plots (181 ± 27 individuals/plot) beneath burlap bands only ($P = 0.05$).

Overall abundance of arthropods beneath burlap bands was relatively high throughout the year whereas numbers observed beneath cardboard panels declined in the winter months from November through March. Conversely, arthropod abundance was greatest beneath burlap bands on tree boles during the same period (Fig. 3). We found wood cockroaches were relatively abundant throughout the year beneath burlap bands, whereas ants were least abundant in the fall and winter but their number gradually increased from March through September.

Discussion

Our findings provide baseline information regarding arthropods occurring on live loblolly pine tree boles, the linkage between tree boles and the soil/litter layer, and their relative abundance in the absence of coarse woody debris. This information is relevant to ornithologists and wildlife biologists interested in the feeding habitats and

Table 1. Total number, biomass, and number of genera of arthropod groups known or suspected to be prey of the red-cockaded woodpecker that were captured in crawl traps. Traps were open during the period October 1997 to September 1999 on loblolly pine tree boles at the Savannah River Site, SC

Order (common name)	Family	No. of Genera	Number caught	Biomass (g)
Araneae (spiders)	Anyphaenidae	4	39	0.0657
	Araneidae	9	53	1.5314
	Clubionidae	7	399	0.5947
	Corinnidae	2	114	0.0383
	Ctenizidae	1	1	0.0003
	Dictynidae	2	409	0.4014
	Gnaphosidae	9	774	0.9384
	Hahniidae	1	33	0.0095
	Linyphiidae	15	2259	0.6136
	Lycosidae	4	586	1.8908
	Lyssomanidae	1	31	0.0194
	Mimetidae	1	79	0.0429
	Oxyopidae	2	11	0.0258
	Philodromidae	2	53	0.1494
	Pholcidae	1	1	0.0001
	Pisauridae	2	21	0.5893
	Salticidae	11	522	2.5681
	Segestriidae	1	17	0.0755
	Tetragnathidae	1	10	0.01
	Theridiidae	13	1077	1.3087
	Uloboridae	1	2	0.0003
	Zoridae	1	2	0.002
Blattaria (cockroaches)	Blatellidae	3	2845	12.2952
Coleoptera (beetles)	Unknown	—	9	0.0008
	Alleculidae	2	55	0.3297
	Anobiidae	2	3	0.0171
	Anthicidae	1	1	0.0001
	Anthribidae	1	2	0.0042
	Cantharidae	1	9	0.006

Table 1. Continued.

Coleoptera (beetles)	Carabidae	4	27	0.2886
	Cebrionidae	1	1	0.005
	Cerambycidae	2	3	0.1184
	Chrysomelidae	5	14	0.1377
	Cleridae	1	14	0.1173
	Coccinellidae	7	32	0.0304
	Colydiidae	3	3	0.0012
	Corylophidae	3	28	0.0044
	Crytophagidae	2	13	0.0038
	Cucujidae	2	3	0.0075
	Curculionidae	11	266	9.9125
	Dytiscidae	1	1	0.0023
	Elateridae	13	139	2.6073
	Endomycidae	1	5	0.0152
	Hydrophilidae	1	7	0.0012
	Lampyridae	1	2	0.0064
	Leptodiridae	1	1	0.0002
	Lycidae	1	1	0.0009
	Melandryidae	3	4	0.0044
	Meloidae	1	1	0.1367
	Melyridae	2	7	0.0016
	Micromathidae	1	1	0.0001
	Rhizophagidae	1	1	0.003
	Mordellidae	2	4	0.0041
	Mycetophagidae	3	23	0.0082
	Nitidulidae	4	19	0.0159
	Oedemeridae	1	1	0.0017
	Ptinidae	1	1	0.0001
	Scarabaeidae	4	45	3.7561
	Scolytidae	4	56	0.0162
	Scydmaenidae	1	3	0.0001
	Staphylinidae	1	123	0.0197
	Tenebrionidae	2	89	1.555
	Throscidae	1	26	0.0103
	Trogossitidae	1	1	0.0013

Table 1. Continued.

Order (common name)	Family	No. of Genera	Number caught	Biomass (g)
Hymenoptera (ants only)	Formicidae	19	6706	5.4701
Lepidoptera (moths)	Arctiidae	1	8	0.2063
	Gelechidae	1	62	0.0219
	Geometridae	1	625	0.842
	Lasiocampidae	1	3	0.0399
	Lycaenidae	1	1	0.0115
	Noctuidae	2	341	13.3235
	Notodontidae	1	12	0.0302
	Oecophoridae	1	3	0.014
	Psychidae	1	6	0.0262
	Pyralidae	1	18	0.0477
	Sphingidae	2	24	1.1997
Microcoryphia (bristletails)	Machilidae	1	568	0.5114
Orthoptera (grasshoppers	Unknown	1	2	0.0011
and crickets)	Acrididae	2	14	0.3191
	Gryllidae	4	214	0.5481
	Tettigoniidae	5	63	0.9492
Scolopendromorpha	Cryptopididae	1	5	0.1667
(centipedes)	Scolopendridae	1	20	1.512
Thysanura (silverfish)	Lepismatidae	1	11	0.0041

forage availability of bark-foraging birds commonly found in loblolly pine forests. Red-cockaded woodpeckers readily forage on loblolly pine trees but were not present in our study areas. The most frequently observed birds foraging in our research areas were: red-headed woodpeckers (*Melanerpes erythrocephalus* L.), red-bellied woodpeckers (*Melanerpes carolinus* L.), northern flickers (*Colaptes auratus* L.), pileated woodpeckers (*Dryocopus pileatus* L.), and brown-headed nuthatches (*Sitta pusilla* Latham). Other species that glean on loblolly pine bark but take advantage of a variety of other substrates were chickadees (*Poecile carolinensis* Audubon), titmice (*Baeolophus bicolor* L.), and pine warblers (*Dendroica pinus* Wilson) (J. Kilgo, pers. comm.).

We collected many of the same common species described by Hanula and Franzreb (1998) and Horn and Hanula (2002a) on longleaf pine, showing that the arthropod community on pines is similar regardless of tree species. Removal of coarse woody debris did not reduce overall arthropod diversity, abundance or biomass captured in crawl traps. The only differences noted were for the 2 spider families Saltici-

Table 2. Total genera and number of individuals observed for each arthropod order found beneath burlap bands and cardboard panels from July 1998 until September 1999 in loblolly pine stands on the Savannah River Site near Aiken, SC

Order	Number of Genera	Number Observed
Araneae	27	2753
Blattaria	3	12367
Callipodida	1	101
Coleoptera	53	3867
Diptera	1	1
Geophilomorpha	1	34
Hemiptera	18	2938
Hymenoptera	10	3861
Isoptera	1	17425
Lepidoptera	6	30
Lithobiomorpha	1	84
Mantodea	1	2
Microcoryphia	1	7
Neuroptera	3	46
Opiliones	1	38
Orthoptera	6	189
Polydesmida	1	18
Scolopendromorpha	2	266
Thysanura	1	1677

dae and Araneidae, primarily because of the genera *Phidippus* and *Neoscona*, respectively. Because so few families or genera were significant, it is difficult to know if these differences are simple artifacts of the large number of analyses that we conducted. Our study was conducted over a 2-yr period, and coarse woody debris removal started 1 yr prior to sampling. Therefore, the effect of dead wood removal on overall arthropod diversity and abundance, as indicated by crawl traps, may become more evident over a longer period of time. For example, many arthropods have one generation per year so their populations may decrease gradually over time in the absence of dead wood.

Crawl traps provide a passive method of collecting many arthropod groups crawling on tree boles and have been used successfully to study the overall arthropod community associated with tree boles (Moeed and Mead 1983, Hanula and Franzreb 1998, Hanula and New 1996, Hanula et al. 2000a). However, previous studies have shown that red-cockaded woodpeckers select relatively few, common arthropods

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

			P		SE	
Regression Model	R^2	F-value	b_0	b_1	b_1	b_0
yAraneae = 0.37 + 0.02burlap	0.63	390.19	0.0001	0.0001	0.05	0.0011
yCallipoda = 1.21 + 1.03burlap	0.76	98.53	0.0003	0.0001	0.3	0.1
yColeoptera = 0.15 + 0.02burlap	0.62	296.41	0.03	0.0001	0.07	0.0008
yHemiptera = 0.11 + 0.02burlap	0.31	93.87	0.31	0.0001	0.10	0.002
yOrthoptera = 0.8 + 0.78burlap	0.58	109.05	0.0001	0.0001	0.2	0.07
yScolopendromorpha = 0.93 + 0.26burlap	0.34	51.70	0.0001	0.0001	0.12	0.04
yAcrididae = −0.14 + 0.10burlap	0.68	40.97	0.0028	0.0001	0.04	0.02
yCasiopetalidae = 1.21 + 1.03burlap	0.76	98.53	0.0003	0.0001	0.3	0.1
yLycosidae = 0.41 + 0.06burlap	0.32	56.47	0.0001	0.0001	0.08	0.008
yPentatomidae = −0.17 + 0.09burlap	0.32	45.82	0.39	0.0001	0.20	0.01
yThomisidae = −0.04 + 0.02burlap	0.37	23.21	0.24	0.0001	0.03	0.005

* Includes arthropod groups with $R^2 > 0.30$.

(Beal 1911, Harlow and Lennartz 1977, Hanula and Franzreb 1995, Hess and James 1998, Hanula and Engstrom 2000, Hanula et al. 2000a,b) and that prey selection is related to prey availability (Hanula and Horn 2004). Pechacek and Kristin (2004) found that three-toed woodpeckers (*Picoides tridactylus*) also consistently selected a narrow range of prey (spiders and beetle larvae) even though other groups were available. Likewise, brown creepers (*Certhia americana*) (Mariani and Manuwal 1990) and Eurasian treecreepers (*Certhia familiaris*) (Jantti et al. 2001) seemed to preferentially select common groups such as spiders.

In contrast to crawl traps that capture arthropods continuously, burlap bands provide a nondestructive method of assessing prey available for use by bark-foraging birds when birds are actively foraging. Burlap bands also sample arthropods in approximately the same proportions as they were selected as prey by red-cockaded woodpeckers (Hanula and Horn 2004). Likewise three-toed woodpeckers in Germany selected spiders in comparable numbers to their availability on trees (Pechacek and Kristin 2004). It is highly likely that other bark-foraging birds choose prey based on availability.

We found significant positive correlations of the arthropod numbers observed beneath cardboard panels on the ground and beneath burlap on nearby trees for a large number of arthropod groups. These results support previous studies (Hanula and Franzreb 1998) showing that the bark of pine trees is an "open system" with ready

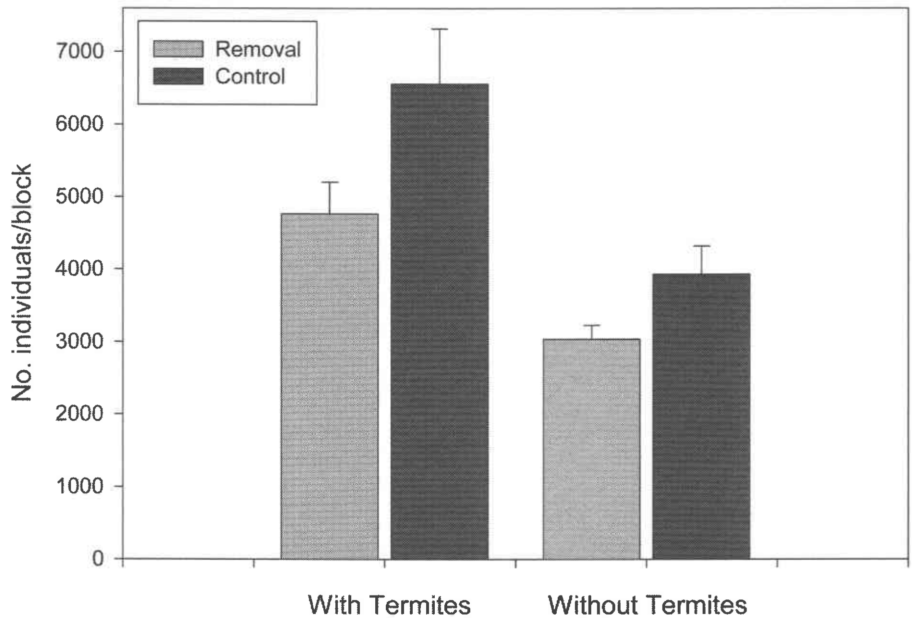

Fig. 1. Mean (± SE) arthropods/block observed underneath burlap bands and cardboard panels in control and removal plots. Traps were monitored from July 1998 to September 1999. Means are significantly different for overall arthropods ($P = 0.02$) according to a paired *t*-test. Even with termites removed the difference was significant ($P = 0.04$).

exchange of arthropods from the soil/litter layer to the bark surface, but they also show that arthropod abundance on tree boles is directly related to the abundance of those arthropods occurring on the ground in close proximity to the tree.

Cardboard panels on the ground had large numbers of termites. Because termites were attracted to and fed upon the cardboard and were not found on tree boles in any trap, we removed them from the analyses which did not affect the results. Even with termites excluded from the analyses removal of dead wood resulted in a reduction in the overall numbers of arthropods found beneath cardboard panels and burlap bands.

Wood cockroaches in the genus *Parcoblatta* were the next most abundant group. We were especially interested in monitoring changes in wood cockroach abundance because they constitute a high proportion of the woodpecker's diet on the Savannah River Site and elsewhere (Hanula and Franzreb 1995, Hanula and Engstrom 2000, Hanula et al. 2000b). The short-term removal of dead wood in this study had no effect on the abundance of wood cockroaches despite the clear association of these insects with both standing dead trees and logs lying on the ground (Horn and Hanula 2002). It is unclear whether dead wood is an essential habitat for cockroaches, but removal of coarse woody debris over 2 yrs did not affect their populations.

In general, most arthropod orders were lower in number on coarse woody debris removal plots, but only Hemiptera were significantly reduced. These data suggest that

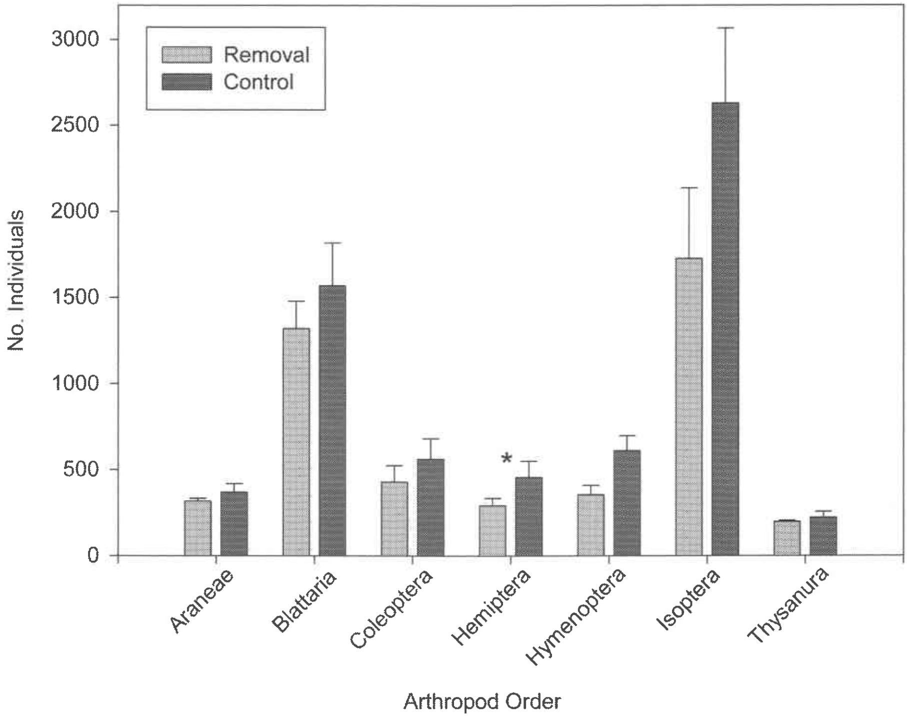

Fig. 2. Comparison of arthropod abundance in control and removal plots of the most commonly collected orders beneath burlap bands and cardboard panels. (*) Denotes that the relationship was significant ($P = 0.05$) according to a paired *t*-test.

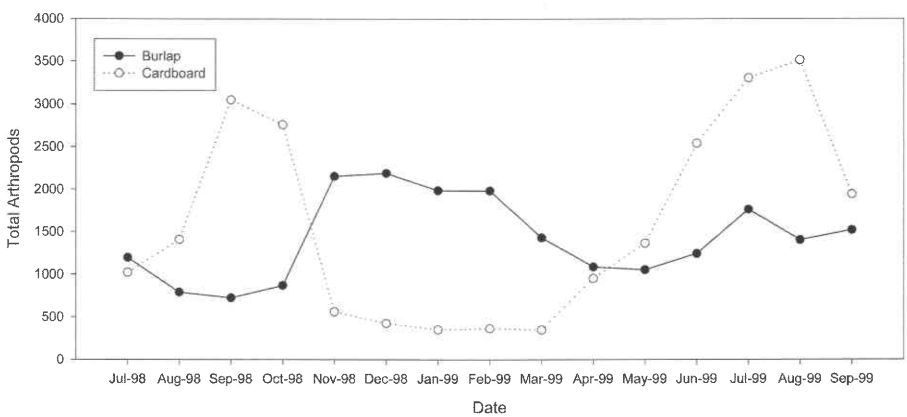

Fig. 3. Seasonal abundance of total arthropods underneath burlap bands and cardboard panels combined for coarse woody debris control and removal plots from July 1998 to September 1999.

the removal of dead wood from pine forests affects a lot of groups in small amounts resulting in a cumulative reduction of available prey. Whether this was due to removal of the arthropods with the dead wood or to a loss of habitat and subsequent population declines is unknown.

Crematogaster ants were significantly more abundant in control plots. Hess and James (1998) found that prescribed burning reduced the number of *Crematogaster* ants in longleaf pine stands, and New and Hanula (1998) found that summer burning reduced ant and spider biomass on pine tree boles when compared with winter burns conducted the same year. These results may be due in part to removal of woody debris through burning. The role coarse woody debris might play in the biology of *Crematogaster* spp. ants is not clear (Hahn and Tschinkel 1997, Tschinkel and Hess 1999, Tschinkel 2002). Hahn and Tschinkel (1997) found that queens preferentially established colonies in beetle galleries in dead branches of the longleaf pine saplings they studied. Colonies also have been found in dead branches of mature longleaf pines (Hanula and Franzreb 1998) and pine cones killed by coneworms, *Dioryctria* spp. (Hanula, unpubl. data). Their association with dead wood in live trees is clear but whether they also use insect galleries in dead trees is not known. Likewise, it is unclear how removal of coarse woody debris would affect abundance of *Crematogaster* spp. on live trees.

Seasonal trends in arthropod availability on bark are important for identifying times when food might be limited (Hanula et al. 2000a). Beyer et al. (1996) hypothesized that in years of good arthropod production red-cockaded woodpecker reproduce successfully, and in years of low arthropod production red-cockaded woodpeckers with poorer foraging habitat may be negatively affected. For example, Schaefer et al. (2004) found that red-cockaded woodpecker foraging in an area with large numbers of dying pines benefited from the increase in prey biomass they obtained by foraging on the dead trees.

Skorupa and McFarlane (1976) predicted that winter would be a time of limited arthropod availability and 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. (2000a) found that arthropod abundance on pine tree boles was lowest during the summer and greatest in the winter. Likewise, we found overall arthropod abundance increased during winter under burlap bands on trees, and it was somewhat lower in spring and summer. In contrast, arthropod abundance beneath cardboard panels placed on the ground was greatest in summer. It is not clear whether seasonal declines in prey availability affect red-cockaded woodpecker survival.

Burlap bands are a simple and effective way to monitor arthropods readily available to bark-foraging birds. Previous studies showed that wood cockroaches comprise 50% or more of the red-cockaded woodpecker nestling diet in a variety of locations and pine habitats (Hanula and Franzreb 1995, Hanula and Engstrom 2000, Hanula et al. 2000b). Crawl traps collected more than 2800 wood cockroaches over the course of 24 months. Observations beneath burlap bands and cardboard panels yielded >12,000 wood cockroaches in 15 months demonstrating the utility of these techniques at collecting and observing this and other common arthropod groups.

Southern forests are typically managed without considering the role of dead and dying trees to the overall food web. Our data suggest that allowing natural inputs of coarse woody debris and maintaining diverse decay stages will ensure sufficient habitat for arthropod communities occurring on loblolly pine. Future studies should evaluate how the arthropod community changes in coarse woody debris over time, and how that change contributes to the overall food web.

Acknowledgments

The authors thank Todd Kuntz for technical assistance throughout the project and also thank Kelly Horn, Mike Slice, Nicole Rankine, Mary Williams, Arthur Phalo, and Mark Rubenstein for work in the lab. We also thank Lee Reynolds and James Pitts for identification of many lesser-known arthropod taxa and John Kilgo for information on bird species. This study was funded by the Department of Energy, Savannah River Site, and the USDA Forest Service, Savannah River Site Natural Resources Management and Research Institute.

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