The Role of Coarse Woody Debris in Southeastern Pine Forests: Preliminary Results from a Large-scale Experiment[1]

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Abstract

We initiated a long-term experiment involving manipulation of coarse woody debris (CWD) at the Savannah River National Environmental Research Park in the upper Coastal Plain of South Carolina. Each of four 9.3-ha plots in each of four blocks was subject to one of the following treatments: removal of all snags and fallen logs, removal of fallen logs only, felling and girdling to simulate a catastrophic pulse of CWD, and control. Removal treatments were applied in 1996, and the felling or snag-creation treatment will be applied in 2000-2001. Monitoring of invertebrate, herptile, avian, and mammalian assemblages and CWD dynamics began immediately after CWD removal and continues through the present. Removal treatments resulted in a fivefold to tenfold reduction in CWD abundance. To date, significant differences among treatments have only been detected for a few animal taxa. However, preliminary results underscore the benefits of large-scale experiments. This experiment allowed unambiguous tests of hypotheses regarding the effect of CWD abundance on fauna. Coupled with studies of habitat use and trophic interactions, the experimental approach may result in stronger inferences regarding the function of CWD than results obtained through natural history observation or uncontrolled correlative studies.

Introduction

Coarse woody debris (CWD) includes standing or fallen dead wood and decomposing root systems. Several studies have generally supported the conclusion that CWD provides an important resource for many animals and plants. However, these studies have often been based on data collected under uncontrolled conditions (Harmon and others 1986). Uncontrolled studies of the effects of CWD on animals

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are susceptible to confounding factors because the same conditions leading to CWD abundance (e.g., wind storms) often lead to increased vegetative growth. Changes in vegetation may positively affect populations of animals through increased cover and food availability. Controlled experiments are, therefore, necessary to produce unambiguous conclusions regarding the effects of woody debris within an ecosystem.

The amount and role of CWD markedly vary among forested ecosystems. The amount and role of CWD in old-growth conifer forests of the Pacific Northwest have been intensively studied, but few studies of CWD in southeastern pine forests exist (McMinn and Crossley 1996a). In general, southeastern pine forests are younger than western conifer forests, with tree species that exhibit smaller maximum sizes and shorter life spans than western species. With shorter rotations, often for pulpwood production, managed southeastern forests have low amounts and small pieces of CWD. Typical volumes of CWD in managed forests of the Southeast are poorly known, but mean volume of CWD in natural pine forests on public land in Georgia is estimated at < 20 m^3 ha^{-1} (McMinn and Hardt 1996). By contrast, some of the highest recorded mean CWD volumes are in old-growth Douglas-fir forests of western Oregon (502 m^3 ha^{-1}; Spies and Cline 1988).

Dead wood also decomposes more quickly in southeastern than northwestern forests because of the humid, warm climate of the Southeast (Barber and Van Lear 1984, Harmon and others 1986). Rapid decay, shorter rotations, and smaller trees combine to produce very different CWD characteristics in the Southeast compared to the Pacific Northwest. Consequently, we expect that the role of CWD as a resource for fauna also differs between the two regions. Because managed southern pine forests typically have low structural and vegetative diversity, coarse woody debris may be particularly important as a refuge and food substrate for animals in this environment.

Woody debris is an ecosystem component amenable to management (McMinn and Crossley 1996a). Indeed, forest management practices lead to changes in the abundance of CWD—planned or not. A workshop entitled "Biodiversity and Coarse Woody Debris in Southern Forests," held in Athens, Georgia, in 1994 underscored the potential negative consequences of failure to understand the role of CWD in southeastern forests. Understanding the role of CWD in managed loblolly pine *(Pinus taeda)* forests in the Southeast is particularly important because of the predominance of this forest type in the landscape (Schultz 1997). Currently, there are insufficient data to allow specific management recommendations for CWD in managed southeastern pine forests (McMinn and Crossley 1996b).

The purpose of this paper is to present the preliminary results of a manipulative experiment into the role of CWD in southeastern forests. This study is a unique interdisciplinary examination of the importance of dead wood to the biotic community in a largely unstudied environment.

Methods

We initiated an experiment to better understand the importance of CWD to fauna in loblolly-pine plantations of the southeastern Coastal Plain. This experiment has been underway since summer 1996, with annual re-treatment of plots. Re-treatment of plots and monitoring of woody debris and fauna are planned through 2007.

Study Area

This research was conducted at the Savannah River National Environmental Research Park (SRNERP), a 78,000-ha nuclear production facility managed by the United States Department of Energy. The SRNERP is located in Aiken, Barnwell, and Allendale Counties, South Carolina (33°0-25'N, 81°25-50'W). The study area lies in the upper portion of the Coastal Plain Physiographic Province (Fenneman 1938) and is bounded on the west by the Savannah River. Vegetation communities of the SRNERP range along topographic and moisture gradients from freshwater wetlands to xeric sandhills (Workman and McLeod 1990). Pine plantations dominate a majority of the SRNERP; loblolly pine is the most abundant species.

Experimental Design

The study was designed as a randomized complete block with four treatments replicated in four blocks. Blocks were four forest stands chosen subject to the following criteria: forested with approximately 45-year-old loblolly pine plantations; ≥ 76 m from nearest wetland, road, and power line; and able to accommodate four square 9.3-ha plots. Finally, accessibility was considered to allow installation and frequent checking of various traps. Within each stand, we established four square 9.3-ha plots. Each plot consisted of a 6-ha core area used for CWD and faunal surveys, surrounded by a 3.3-ha buffer area subject to the same treatment as the core area. Buffer areas were largely unused for surveys to avoid the influence of edge effects. Timber harvesting was prohibited within 61 m of plots.

Within each stand, each of the four plots was randomly assigned to one of the following treatments: removal of all snags and fallen logs, removal of fallen logs only, felling and girdling to simulate a catastrophic pulse of debris, and control. We defined CWD as dead woody material ≥ 10 cm in diameter and ≥ 60 cm in length. Removals were conducted by a private crew under USDA Forest Service supervision in July/August 1996, February 1997, February/March 1998, and February/March 1999. Annual removals are planned during the winter of each year of the study. The catastrophic treatment, which will result in the addition of fallen logs and snags, is planned for the winter of 2000-2001. We are currently planning the specific management action involved in the catastrophic treatment. Choices include cutting trees to mimic wind breakage, pulling trees down to create tip-up mounds, and girdling trees to create snags. Activities would mimic natural blow-down events or beetle attacks. Preliminary proposals call for the felling of 60-90 m^3 ha^{-1} (340-360 stems ha^{-1}), which is roughly 10 times the current CWD load.

All plots had been thinned between 1991 and 1996. Plots were thinned as necessary in 1996 to achieve a standing basal area of 13.8–20.8 m^2 ha^{-1}. All plots will be thinned at about 10-year intervals throughout the study. Most of the experimental areas had been intentionally burned between 1990 and 1996, although some areas had not been burned since 1972. In the winter of 1999-2000 all plots will be burned to normalize plots with respect to this important factor. Thereafter, plots will be burned at about 5-year intervals.

Two grids of equally spaced markers have been used to orient investigators within the plots. A large-scale 7-by-7 grid, with 50-m spacing, has been used for the monitoring of birds. A small-scale 8-by-8 grid, with 20-m spacing, has aided in studies of small mammals, invertebrates, reptiles, and amphibians. Monitoring of woody debris has also been referenced to the 7-by-7 grid.

Monitoring of Woody Debris

Inventories of fallen logs and snags were completed during the late spring and early summer of 1997-1999 on all plots. All fallen logs and snags were tagged with a unique number. Species or genus, length, sound class (range 1-3 based on wood integrity), and bark presence (percent) were measured for all CWD. When possible, cause of mortality (e.g., lightning) was noted. Number of cavities, diameter at breast height (DBH), and standing integrity (degree to which branches and trunk remain intact) were recorded for snags. Mid-point diameter, degree of ground contact, and shape (round, elliptical, or flat) were recorded for fallen logs. Surveys have been conducted annually to measure recruitment of CWD and note changes in the decomposition of previously marked debris.

Population Responses

Arthropods are being monitored with crawl traps (Hanula and New 1996) and burlap bands on tree boles. Pitfalls are used to capture arthropods on the ground. Crawl traps and burlap bands aid in determining whether CWD is important in maintaining arthropod resources on trees, which are a common foraging habitat for a variety of birds. Fifteen crawl traps per plot are open continuously and samples are collected monthly. Fifteen burlap bands per plot are monitored monthly. Arthropods crawling on the ground are sampled with 15 pitfalls placed throughout each plot and operated for 1 week every other month.

Sampling of amphibians, reptiles, and insectivorous small mammals is being conducted at 3 of the 4 experimental stands, for a total of 12 plots. These animals are monitored using a series of pitfall-drift-fence arrays and snake traps. We are using four Y-shaped arrays (Kirkland and Sheppard 1994) and one X-shaped array (Campbell and Christman 1982) at each plot. Aluminum flashing is used as drift fencing. Interspersed along drift-fence spans are pitfall traps (19-l buckets) and snake traps. All traps are opened and checked daily during a 14-day period in each of winter, summer, and autumn, and a 28-day period in spring. Because frogs and salamanders have been observed to breed within temporary pools within or near certain plots, we have restricted our analyses to adults.

Small rodents and some larger mammals are being sampled with box-style traps at three of the four experimental stands. At each station in the 8 × 8 grid, one Sherman live trap (7.5 × 9.0 × 25.5 cm) is placed on the ground and one Sherman live trap is placed on the nearest (≤ 5 m) tree trunk. Traps on trees are placed in wooden sleeves attached to the tree approximately 1.5 m above the ground. Mosby-type wooden box traps (19 × 19 × 61 cm) are placed on the ground at selected stations. Trapping sessions are conducted every other month and include nine consecutive nights of trapping during the new- to quarter-moon phases.

Birds have been sampled using spot-mapping and nest searches during the breeding season (May to July; Bibby and others 1992) and transect surveys during winter (December to February; Kolb 1965). Both morning and afternoon surveys were conducted during the breeding seasons of 1997 and 1998. Transect surveys were conducted during the winters of 1997-1998 and 1998-1999 (Lohr 1999). In addition to determining population responses, Shannon's measure of diversity (*H'*; Ludwig and Reynolds 1988) also was calculated for bird assemblages at each study plot.

Study of Habitat Use

Use of woody debris by cotton mice *(Peromyscus gossypinus)* was examined in 1997 and 1998 using radio-telemetry and fluorescent-powder tracking (McCay 2000). Locations of mice were noted at night when mice were active, and during the day when mice were inactive. Observations were made in areas where CWD was not manipulated.

Preliminary Results

Sampling and analyses are ongoing. Nevertheless, preliminary results underscore many benefits of large-scale experiments in the study of CWD. Our results also illustrate some problems common in ecological field studies.

Woody Debris Loading

Treatments involving removal of fallen CWD resulted in a greater than tenfold decrease in the density and volume of fallen logs *(table 1)*. The treatment involving removal of snags also was successful, reducing snag density by 75 percent and snag volume by 90 percent. There were few differences in the size distribution, decay class, or species composition of CWD among treatments. However, CWD at removal plots was more decayed than at non-removal plots because of the difficulty of removing very decayed logs. Starting with the 1999 removal, very decayed logs located in removal plots will be raked apart if they cannot be removed.

Table 1—*Mean density (No./ha) and estimated volume (m^3/ha) of coarse woody debris at plots in one of four treatments: removal of all woody debris (ALL); removal of fallen logs, but not snags (DOW); catastrophic felling (CAT); and control (CON) in 1998. The catastrophic treatment will be implemented in 2000; thus, neither control nor catastrophic plots had been manipulated in 1998.*[1]

		Down woody debris		Standing woody debris	
Treatment	**N**	**Density**	**Volume**	**Density**	**Volume**
ALL	4	6.3 A	0.35 A	2.1	0.22
DOW	4	8.4 A	0.39 A	8.4	2.18
CAT	4	98.9 B	7.87 B	8.1	2.19
CON	4	94.4 B	6.45 B	8.2	2.04

[1] Means not followed by the same letter were different at $\alpha = 0.05$ (Fisher's least-significant-difference test).

Population Response

We have presently identified arthropods collected in pitfalls for 1 year after initial CWD removal. We captured an average (± SE) of 703 (± 175.6) beetles per plot in control plots and 350 (± 149.4) beetles per plot in removal plots. Flies (control, 165.0 ± 40.1; removal, 91.3 ± 46.8) and spiders (control, 532.5 ± 130.9; removal, 296.0 ± 86.6) showed similar trends. Despite these relatively large differences in higher taxonomic categories, only a few families of arthropods were significantly affected by CWD removal. Pitfall captures of ground beetles (Carabidae; control, 134.0 ± 21.3; removal, 58.5 ± 13.3; $p < 0.03$), silken fungus beetles (Cryptophagidae; control, 192.0 ± 62.1; removal, 30.0 ± 26.5; $p < 0.07$), and bark-gnawing beetles (Trogositidae; control, 19.0 ± 6.2; removal, 1.5 ± 0.5; $p < 0.06$) were lower in the CWD removal than in the non-removal plots.

Studies of amphibians, reptiles, and insectivorous mammals have presently demonstrated no treatment effects *(table 2)*. However, mean capture rates of most groups were greater at plots without log removal than plots from which logs were removed. There was relatively strong spatial and temporal variation in these data, which reduced our ability to detect treatment differences (i.e., statistical power, Sokal and Rohlf 1981). Additional sampling should increase our ability to detect an effect of log removal on these forest-floor vertebrates.

Among rodents, only southern flying squirrels *(Glaucomys volans)* varied significantly in abundance among treatments ($F = 6.18$, $df = 3{,}8$, $P = 0.02$; *table 3)*. Relative abundance of flying squirrels was highest in plots from which dead trees had been removed. Because this species commonly nests in tree cavities, we were surprised by this result. Presently, it is unclear whether differences in flying squirrel captures reflect treatment effects, pre-existing plot differences, or differences in sampling ability related to snag removal.

A previous study on the SRNERP demonstrated that increased abundance of CWD was associated with increased abundance of cotton mice and that cotton rat *(Sigmodon hispidus)* populations may also be positively affected by large amounts of CWD (Loeb 1999). Although there were no significant differences in captures of cotton mice or cotton rats *(table 3),* both species appeared to be slightly more abundant in plots where no CWD removal had occurred. Again, spatial and temporal variation may have reduced statistical power to detect differences.

The number of breeding territories of woodpeckers and of all birds combined was lower on plots from which snags were removed than control plots *(table 4)*. In particular, removal of snags affected red-headed woodpeckers *(Melanerpes erythrocephalus),* red-bellied woodpeckers *(Melanerpes carolinus),* and Carolina wrens *(Thryothorus ludovicianus)*. Breeding bird diversity also was highest on control ($H' = 2.72$) and lowest on all removal ($H' = 2.01$) plots ($P < 0.05$). Abundance of weak excavators and secondary cavity-nesters, as well as birds that nest in vegetation, was not markedly affected by treatments. Likewise, CWD removal apparently had no effect on the bird community during winter (Lohr 1999).

Table 2—*Mean number of captures per 14-day sampling period of taxa of forest-floor vertebrates at 3 replicates receiving 1 of 4 treatments: removal of all woody debris (ALL), removal of fallen logs (DOW), catastrophic felling (CAT), and control (CON).*[1]

	Removal plots		Non-removal plots		
Taxon	**ALL**	**DOW**	**CAT**	**CON**	**F-value**
Shrews	2.93	2.60	3.33	3.87	0.41
Frogs and toads	60.87	53.00	74.87	77.67	0.33
Salamanders	7.13	5.33	8.73	6.93	0.21
All amphibians	68.00	58.37	83.60	84.60	0.32
Lizards	7.53	6.27	5.20	5.93	0.34
Snakes	1.53	1.40	1.00	2.53	1.44
All reptiles	9.07	7.73	6.20	8.53	0.42

[1] *F*-value for tests of the hypothesis in which means did not differ (df = 3,6) is also included. The hypothesis was not rejected for any group at $\alpha = 0.05$.

Table 3—*Mean number of captures per 1000 trap nights (± 1 SE) of common species of rodents at 3 replicates receiving 1 of 4 treatments: removal of all woody debris (ALL), removal of fallen logs (DOW), catastrophic felling (not implemented to date; CAT), and control (CON).*[1]

Species	**ALL**	**DOW**	**CAT**	**CON**
Southern flying squirrel *(Glaucomys volans)*	29.10 ± 1.92 A	17.87 ± 0.89 B	21.97 ± 2.88 AB	24.28 ± 1.22 AB
Cotton mouse *(Peromyscus gossypinus)*	15.92 ± 3.50 A	13.49 ± 3.82 A	17.83 ± 4.19 A	16.82 ± 6.16 A
Golden mouse *(Ochrotomys nuttali)*	0.77 ± 0.35 A	1.30 ± 0.89 A	0.61 ± 0.31 A	1.71 ± 1.59 A
Old-field mouse *(Peromyscus polionotus)*	1.17 ± 0.96 A	0.05 ± 0.05 A	0.25 ± 0.18 A	0.54 ± 0.30 A
Fox squirrel *(Sciurus niger)*	1.14 ± 0.44 A	0.93 ± 0.53 A	1.28 ± 0.81 A	0.34 ± 0.81 A
Cotton rat *(Sigmodon hispidus)*	0.03 ± 0.03 A	0.17 ± 0.17 A	0.66 ± 0.39 A	1.14 ± 0.62 A
All	25.33 ± 3.87 A	19.17 ± 4.25 A	24.35 ± 3.74 A	26.41 ± 5.27 A

[1] Means not followed by the same letter were significantly different ($\alpha = 0.05$; Fisher's Least Significant Difference Test).

Table 4—*Mean number of breeding territories for breeding-bird guilds at plots receiving one of three treatments: removal of all woody debris (ALL), removal of fallen logs (DOW), and control (CON) during 1997 and 1998.*[1]

Breeding-bird Guild	ALL	DOW	CON
Woodpeckers	1.4 A	3.5 A	4.5 B
Secondary cavity-nesters	1.8 A	2.2 A	4.8 A
Understory nesters	5.1 A	5.5 A	7.1 A
Midstory and canopy nesters	9.9 A	11.7 A	12.4 A
All breeding birds	20.1 A	23.5 AB	27.5 B

[1]Means not followed by the same letter were significantly different ($\alpha = 0.05$; Fisher's Least Significant Difference Test).

Study of Habitat Use

Cotton mice selectively used decomposing root systems during the day and fallen logs at night (McCay 2000). One hundred out of 108 unique daytime den sites of cotton mice were associated with some form of CWD, usually decomposing root systems. Because other den sites used by cotton mice elsewhere (e.g., burrows of large vertebrates; Frank and Layne 1992) are not abundant in managed loblolly stands, there were probably few alternatives to decomposing root systems. Analysis of powder trails demonstrated the selective inclusion of fallen logs in the pathways of mice, perhaps because logs are useful in navigation (McCay 2000).

Discussion and Conclusion

Animals responding to CWD manipulation during the first few years of this study were those for which CWD is probably a critical resource (e.g., cavity-nesting birds). Reduction in the volume of CWD in forest stands, especially stands with low ambient amounts of CWD, probably changes the quality of the environment for most animals in subtle ways. Thus, detecting the effects of CWD manipulation in southeastern pine forests may require several years of observation. Because population responses reflect differences present in the first few years after manipulation of CWD, they provide conservative depictions of the long-term importance of CWD in pine ecosystems of the Southeast.

The size of plots used in this study was many times larger than the size of home ranges of most insects, many birds (Gill 1994), and most small mammals (e.g., cotton mouse; Wolfe and Linzey 1977). Thus, this experiment permits inferences concerning demographic responses of these species. In contrast, most studies of the effects of CWD on animals have only permitted inferences regarding microhabitat use (e.g., Planz and Kirkland 1992). Nevertheless, even the large plot size used in this study was too small to test population-level responses of highly mobile species, such as the fox squirrel.

The large size of plots in this study precluded the establishment of more than four replicates within each treatment. Furthermore, the effort that was required to sample animals within these large areas precluded the use of all four replicates for the study of some groups (e.g., small mammals). Low replication, coupled with expected temporal and spatial variability, reduced our ability to detect all but the most drastic changes in animal populations during the first few years of study. Over time, however, we expect our ability to detect treatment effects to increase as differences become larger.

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