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Soricid response to coarse woody debris manipulations in Coastal Plain loblolly pine forests

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Abstract

We assessed shrew (soricids) response to coarse woody debris (CWD) manipulations in managed upland loblolly pine (*Pinus taeda*) stands in the upper Coastal Plain of South Carolina over multiple years and seasons. Using a completely randomized block design, we assigned one of the following treatments to 12, 9.3-ha plots: removal ($n = 3$; all CWD $\geq$ 10 cm in diameter and $\geq$60 cm long removed), downed ($n = 3$; 5-fold increase in volume of down CWD), snag ($n = 3$; 12-fold increase in standing dead CWD), and control ($n = 3$; unmanipulated). Therein, we sampled shrews during winter, spring, and summer seasons, 2003–2005, using drift-fence pitfall arrays. During 1680 drift-fence plot nights we captured 253 *Blarina carolinensis*, 154 *Sorex longirostris*, and 51 *Cryptotis parva*. *Blarina carolinensis* capture rate was greater in control than in snag treatments. *Sorex longirostris* capture rate was lower in removal than downed and control plots in 2005 whereas *C. parva* capture rate did not differ among treatments. Overall, the CWD input treatments failed to elicit the positive soricid response we had expected. Lack of a positive response by soricid populations to our downed treatments may be attributable to the early CWD decay stage within these plots or an indication that within fire-adapted pine-dominated systems of the Southeast, reliance on CWD is less than in other forest types.

Keywords: *Blarina*; Coarse woody debris; *Cryptotis*; Pine management; Short-rotation forestry; Shrews; *Sorex*; Soricids

1. Introduction

Intensively managed pine (*Pinus* spp.) plantations currently occupy approximately 15% of total forest area in the southeastern US (Conner and Hartsell, 2002), with area expected to stabilize over the next 20 years (National Commission on Science for Sustainable Forestry, 2005). These stands often are managed under short rotation, resulting in increased disturbance frequency as compared to unmanaged pine stands or those managed for sawtimber over longer rotation periods (Conner and Hartsell, 2002). Disturbance within plantations generally occurs in the form of even-aged harvesting and subsequent mechanized site preparation techniques including bedding, disking, root raking, and roller chopping (Siry, 2002). These techniques can compact soil, reduce litter depth and cover, displace mineral soil, and reduce coarse woody debris (CWD) volume (Harmon et al., 1986; Reisinger et al., 1988), thereby leading to a more homogenous and structurally simplified set of forest conditions (Hunter, 1990). Accordingly, these intensively managed pine plantations generally contain much lower CWD volumes than other pine or hardwood forests in the region (McMinn and Hardt, 1996). Reduction of this important microhabitat component may be particularly detrimental to shrews (soricids), as they are believed sensitive to alterations in environmental moisture (Getz, 1961).

Because of their high metabolic rate, shrews are subject to high rates of evaporative water loss and increased desiccation (Churchfield, 1990). Shrews often forage on the forest floor following precipitation (Ford et al., 2002) and during dry

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climatic periods they may be restricted to isolated areas of relatively higher moisture (Brannon, 2002). Because CWD retains moisture during dry climatic periods (Jaeger, 1980) and harbors diverse and abundant invertebrate assemblages (Harmon et al., 1986; Vanderwel et al., 2006), it undoubtedly serves as an important structural habitat and foraging substrate for shrew species in the region (Loeb, 1996). However, attempts to correlate shrew capture rates with CWD volume and density have been equivocal. Although shrew abundance has been positively correlated with CWD in southern Appalachian Mountain (Maidens et al., 1998; Brannon, 2000) and southeastern Coastal Plain (Cromer et al., 2007) hardwood forest communities, other research indicates shrew abundance is independent of CWD availability, suggesting that downed volumes characteristic of hardwood forests may be sufficiently high that CWD rarely becomes limiting (Ford et al., 1997; Ford and Rodrigue, 2001). However, CWD abundance in managed pine stands of the southeastern Coastal Plain is far lower and potentially more limiting for shrews than that of other forest types and physiographic regions of the Southeast (McMinn and Hardt, 1996).

Actual quantified shrew response to CWD volume manipulation in pine forests of the southeastern Coastal Plain is relatively unknown. McCay and Komoroski (2004) investigated CWD removal effects on shrews within upland loblolly pine (*P. taeda*) stands in the upper Coastal Plain of South Carolina. The authors observed reduced *Cryptotis parva* capture rates on CWD removal plots relative to unmanipulated control plots. Additionally, the authors attributed similar abundance of *Blarina carolinensis* and *Sorex longirostris* between treatments to low ambient CWD levels in control plots. Still, upper and lower thresholds of CWD volumes necessary to elicit a soricid response in southeastern pine forests remains unquantified.

Our study objective was to assess *S. longirostris*, *C. parva*, and *B. carolinensis* population response to CWD manipulations within managed loblolly pine stands in the upper Coastal Plain of South Carolina. We hypothesized that increased CWD volume would result in greater capture rates of *S. longirostris* and *B. carolinensis*, because of their association with more mesic forested habitats in the region (Loeb et al., 2005; Menzel et al., 2005), whereas *C. parva* would be impacted to a lesser extent due to its association with more open early successional habitats containing less CWD structure (Bryan, 1991; Blackburn and Andrews, 1992). Additionally, because adult shrews are often displaced from higher quality habitat by more vigorous juvenile and sub-adult shrews we hypothesized that CWD removal plots would support fewer young *S. longirostris* and *B. carolinensis* than control and downed treatment plots (Rychlik, 1998).

2. Study area

Our study was conducted at the US Department of Energy's Savannah River Site (SRS), a 78,000-ha National Environmental Research Park in Aiken, Barnwell, and Allendale counties, South Carolina (33°0–25′N, 81°25–50′W). The SRS is located on the upper Coastal Plain physiographic region in an area known as the Sandhills. Historically, a longleaf pine (*P. palustris*)–wiregrass (*Aristida* spp.) community dominated upland areas of the SRS before being cleared for agriculture in the early 1800s. Upon acquisition by the Atomic Energy Commission, the precursor to the Department of Energy, in 1951, the USDA Forest Service planted abandoned agricultural fields in loblolly, longleaf, and slash (*P. elliottii*) pine. Within the loblolly pine stands we studied, understory vegetation consisted of lespedeza (*Lespedeza* spp.), poison oak (*Toxicodendron pubescens*), and broomsedge (*Andropogon* spp.). The topography is gently rolling to flat with elevations ranging from 20 to 130 m. This study area has a warm temperate to subtropical climate, with a mean annual temperature of 18 °C and mean annual precipitation of 122.5 cm (Blake et al., 2005).

3. Methods

We used a randomized complete block design consisting of four 9.3-ha treatment plots replicated in three loblolly pine stands approximately 50 years in age. Plots within each block were randomly assigned one of four treatments: (1) removal: all CWD $\geq$ 10 cm in diameter and $\geq$60-cm long removed ($n = 3$); (2) downed: 5-fold increase in volume of down CWD ($n = 3$); (3) snag: 12-fold increase in standing dead CWD ($n = 3$); (4) unmanipulated control ($n = 3$). We implemented CWD removal treatments in summer 1996. Our annual CWD removal within removal treatment plots ensured that those plots remained free of all limbs and downed trees $\geq$10 cm diameter and 60 cm length. Downed treatments were implemented in August 2001 by randomly selecting 12, 3.7-m wide strips of trees at equal intervals and extending the entire plot length (Fig. 1). Prior to treatment application, all downed CWD was removed from downed treatment plots (McCay and Komoroski, 2004) with no further removals following treatment application (Fig. 1). Additionally, we implemented snag treatments in August 2001 by girdling and by later injecting herbicide into trees in 12 strips

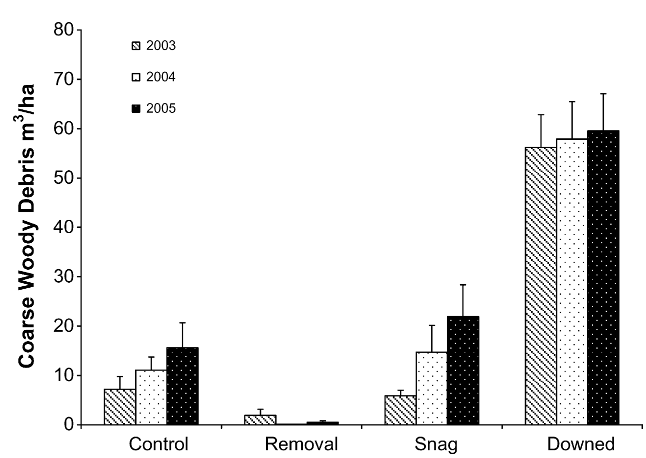

Fig. 1. Mean (±S.E.) coarse woody debris (CWD) volumes in 9.3-ha plots subject to unmanipulated control ($n = 3$), CWD removal ($n = 3$), 12-fold increase in standing CWD ($n = 3$), and 5-fold increase in downed CWD ($n = 3$) within upland loblolly pine (*Pinus taeda*) stands in the upper Coastal Plain physiographic region, South Carolina, 2003–2005.

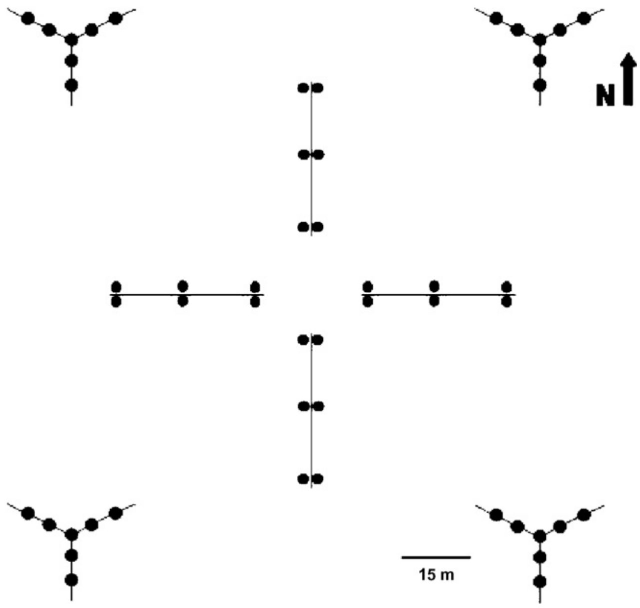

Fig. 2. Drift fence arrays within 6-ha core sampling area of 9.3-ha treatment plots in loblolly pine (*P. taeda*) stands in the upper Coastal Plain physiographic region, South Carolina, 2003–2005.

placed at equal intervals and extended the entire plot length (Fig. 1). We thinned all treatment plots in 2001 to standardize live-tree basal area across treatments to 13.8–20.8 m^2/ha. Because shrew sampling began shortly after trees were downed, all CWD additions within downed plots occupied the earliest stages of decay (Maser et al., 1979). All plots were prescribed burned during 2004 in accordance with normal land management practices for forests at the SRS.

We sampled shrews using a series of drift fence arrays constructed from aluminum flashing buried 15 cm in the ground (Fig. 2). On each plot, a centrally located cross-shaped array with 30-m arms was installed and within each corner of the center array, Y-shaped arrays with 15-m arms were installed (Laerm et al., 1999; Fig. 2). Nineteen-liter plastic buckets were buried against each fence. Each plot contained a 6-ha core area where shrew trapping occurred within a 3.3-ha buffer zone subject to the same treatment as the core area. We opened traps for 14 days during winter (January–February), spring (April–May), and summer (June–July) of 2003–2005. In April 2003, we opened traps for 28 days. We checked traps daily and collected all individuals under South Carolina Department of Natural Resources scientific research permit #G-02-09 and University of Georgia IACUC numbers A2002-10019-c2 and a2004-10204-0.

We retained all individuals found dead in traps (87%) and identified each to species based on external morphology and dental characteristics and recorded weight (g) and body length (cm). We assigned each shrew collected to one of three age classes based on tooth attrition characteristics described by Pearson (1945) for *S. longirostris* and Rudd (1955) for *B. carolinensis*.

To account for uneven trapping effort among years, we calculated capture rates by dividing plot captures by the number of plot nights. We tested data for normality using Shapiro–Wilks test for normality (Sokal and Rohlf, 1995). Because variables did not meet assumptions of normality ($P < 0.05$), we conducted analyses on rank-transformed data (Conover and Iman, 1981). We combined seasons within years and compared 2003–2005 capture rates of *B. carolinensis*, *S. longirostris*, and *C. parva* among treatments using a two-way analysis of variance (ANOVA; Proc Mixed), with block treated as a random effect and treatment, year, and the treatment × -year interaction term as main effects. If the interaction term was significant ($P < 0.05$), we then analyzed capture rates separately for each year using a one-way ANOVA, with block treated as a random effect and treatment as a main effect. To increase sample size, we combined body weight, body length, and age class proportions for all years and compared these variables among treatments using a one-way ANOVA with block treated as a random effect and treatment as a main effect. We used adjusted least-square means pair-wise comparisons when ANOVA models indicated significant effects ($P < 0.05$) to determine differences between individual treatments. We conducted all statistical analyses using SAS statistical software (SAS Institute, 1997).

4. Results

We trapped a total of 1680 drift-fence plot nights across downed, removal, snag, and control plots during 2003, 2004, and 2005. We captured 253 *B. carolinensis*, 154 *S. longirostris*, and 51 *C. parva*. As accidentals, we collected two talpids (moles): a single star-nosed mole (*Condylura cristata*) and a single eastern mole (*Scalopus aquaticus*). *Blarina carolinensis* capture rate was greater in control than snag treatments and greater in 2004 than 2003 (Table 1). *C. parva* capture rate did not differ among CWD treatments, but was greater in 2003 than 2004 and 2005 (Table 1). A significant interaction effect between treatment and year was found for *S. longirostris* capture rate (Table 1), but capture rate trends were functionally similar across our CWD treatments with low capture rates in 2003, followed by high capture rates in 2004, and low capture rates again in 2005 (Table 1). When we analyzed years separately, *S. longirostris* capture rates did not differ among treatments in 2003 ($F_{3,8} = 0.21$, $P = 0.888$) and 2004 ($F_{3,8} = 2.19$, $P = 0.67$). However, in 2005, *S. longirostris* capture rate was lower in removal than downed and control ($F_{3,8} = 5.25$, $P = 0.027$).

We examined 129 *B. carolinensis* and 127 *S. longirostris* for age class, body weight, and body length analysis. Variables analyzed did not differ among treatments (Table 2).

5. Discussion

Our results failed to support our initial hypothesis that *B. carolinensis*, *S. longirostris*, and *C. parva* abundance would increase with increased CWD inputs in managed loblolly pine stands. Our downed treatments represent a significant addition of structural diversity, an attribute important to many small mammal species, including shrews (Loeb, 1996). For example, capture rates of *B. brevicauda*, *S. cinereus*, *S. fumeus*, and *S.*

Table 1
Mean (±S.E.) capture rate of *Blarina carolinensis*, *Sorex longirostris*, and *Cryptotis parva* in upland loblolly pine (*Pinus taeda*) stands subject to unmanipulated control ($n = 3$), CWD removal ($n = 3$), 12-fold increase in standing CWD ($n = 3$), and 5-fold increase in downed CWD ($n = 3$) in the upper Coastal Plain physiographic region, South Carolina, 2003–2005

Species	Year[a]	Treatment				P_{trt}	P_{year}	$P_{trt\times year}$
		Control	Removal	Snag	Downed			
B. carolinensis[b]	2003A	0.14 ± 0.07A	0.10 ± 0.02AB	0.10 ± 0.03B	0.14 ± 0.01AB	0.022	0.006	0.551
	2004B	0.26 ± 0.06	0.15 ± 0.01	0.16 ± 0.06	0.18 ± 0.01	5.69	7.30	0.85
	2005AB	0.20 ± 0.03	0.11 ± 0.01	0.08 ± 0.01	0.25 ± 0.06			
S. longirostris	2003	0.01 ± 0.01	0.02 ± 0.00	0.01 ± 0.01	0.02 ± 0.01	0.029	<0.0001	0.044
	2004	0.22 ± 0.06	0.11 ± 0.06	0.24 ± 0.07	0.35 ± 0.06	5.10	51.22	2.85
	2005	0.08 ± 0.04	0.00 ± 0.00	0.04 ± 0.02	0.10 ± 0.06			
C. parva	2003A	0.06 ± 0.04	0.04 ± 0.03	0.02 ± 0.02	0.11 ± 0.02	0.584	0.008	0.274
	2004B	0.00 ± 0.00	0.01 ± 0.01	0.00 ± 0.01	0.01 ± 0.01	0.69	6.60	1.40
	2005B	0.03 ± 0.02	0.00 ± 0.00	0.02 ± 0.01	0.02 ± 0.01			

Capture rates compared among treatments with a two-way analysis of variance.
[a] In columns, variables means not followed by the same letter were significantly different ($P < 0.05$) using least-square means pair-wise comparison.
[b] In rows, variables means not followed by the same letter were significantly different ($P < 0.05$) using least-square means pair-wise comparison.

hoyi were greater near CWD occupying early decay stages in southern Appalachian hardwood forests of North Carolina (Maidens et al., 1998). The more rounded shape and branches were believed to have provided increased cover during foraging episodes (Maidens et al., 1998). However, increased CWD structure had negligible impacts on shrew populations within our downed treatment plots. Lower *S. longirostris* capture rate in removal relative to control treatments in 2005 suggests that shrews may exhibit somewhat stronger population response as downed CWD in our study reaches more advanced decay stages.

Microclimate variation associated with different forest stand structural characteristics can influence insect assemblages and, therefore, affect food resource availability for insectivorous species (Bellocq et al., 2000). McCay and Storm (1997) observed increased shrew and invertebrate prey abundance in irrigated mixed hardwood stands relative to non-irrigated forests in the Ridge and Valley physiographic region of Pennsylvania. They suggested increased onsite moisture resulted in greater invertebrate abundance, thereby providing a mechanism for increased shrew abundance. Conversely, Greenburg and Miller (2004) did not find a biologically significant difference in shrew capture rates between salvaged and unsalvaged areas in southern Appalachian upland hardwood forests despite greater arthropod abundance and biomass in unsalvaged plots. In our study plots, concurrent work showed that abundance of invertebrate taxa did not increase following CWD inputs (Moseley et al., 2005). Similarly, Sanzone (1995) found coleopteran (beetle) abundance in loblolly pine stands within the upper Coastal Plain of South Carolina was lower in pitfall traps associated with CWD than in traps independent of downed pine logs. Invertebrate prey in southeastern pine stands

Table 2
Mean (±S.E.) body weight, body length, and age class occurrence of *Blarina carolinensis* and *Sorex longirostris* in upland loblolly pine (*Pinus taeda*) stands subject to unmanipulated control ($n = 3$), CWD removal ($n = 3$), 12-fold increase in standing CWD ($n = 3$), and 5-fold increase in downed CWD ($n = 3$) in the upper Coastal Plain physiographic region, South Carolina, 2003–2005

	Treatment				$F_{3,8}$	P
	Control	Removal	Snag	Downed		
B. carolinensis						
Body length (cm)	6.33 ± 0.08	6.50 ± 0.20	6.76 ± 0.19	6.90 ± 0.12	2.83	0.106
Weight (g)	6.72 ± 0.14	7.01 ± 0.61	7.05 ± 0.37	8.33 ± 0.19	3.70	0.062
Age class (%)						
One	0.20 ± 0.10	0.29 ± 0.07	0.20 ± 0.10	0.17 ± 0.08	0.36	0.786
Two	0.45 ± 0.09	0.31 ± 0.16	0.44 ± 0.17	0.37 ± 0.05	0.28	0.837
Three	0.33 ± 0.05	0.33 ± 0.14	0.36 ± 0.27	0.42 ± 0.06	0.08	0.971
S. longirostris						
Body length (cm)	4.90 ± 0.15	4.88 ± 0.16	4.76 ± 0.16	5.14 ± 0.16	1.01	0.436
Weight (g)	2.73 ± 0.39	2.97 ± 0.04	3.18 ± 0.22	3.01 ± 0.21	0.55	0.663
Age class (%)						
One	0.21 ± 0.11	0.24 ± 0.12	0.02 ± 0.02	0.16 ± 0.03	1.37	0.320
Two	0.19 ± 0.08	0.38 ± 0.12	0.36 ± 0.07	0.21 ± 0.10	1.15	0.388
Three	0.47 ± 0.05	0.38 ± 0.23	0.51 ± 0.08	0.53 ± 0.10	0.25	0.857

Variables compared among treatments with a one-way analysis of variance.

can be abundant on the forest floor (Hanula and Franzreb, 1998; Hanula and Wade, 2003); therefore CWD may not function as an important substrate for increased prey in this system.

Pitfall trapping methodologies often result in high shrew capture mortality, that in turn results in declining shrew capture rates (McCay and Komoroski, 2004). However, *B. carolinensis* capture rates increased during our second trapping year. Shrew populations exhibit dramatic yearly fluctuations due, in part, to climatic conditions (Getz, 1989; Whittaker and Feldhamer, 2005). We observed changes in capture rates among years for all species. Coarse woody debris use may be temporally variable, becoming more important during dry climatic periods (Brannon, 2002). Conversely, *B. brevicauda*, *S. fumeus*, and *S. cinereus* capture rates in pitfall traps associated with CWD did not differ from traps unassociated with ground cover during a drought year in central Appalachian northern hardwood stands in West Virginia (Ford et al., 2002). Similarly, shrew capture rates, including *S. longirostris*, did not differ between stands with high and low CWD in xeric upland hardwood forests in the Southern Appalachians despite sampling occurring during a prolonged drought (Greenburg and Miller, 2004).

In addition to capture rates, our results failed to support the contention that increased CWD volume impacts shrew population demography (Lee, 1995; McCay and Komoroski, 2004). Overwintered adult shrews are often displaced from preferred habitat by more vigorous juvenile and sub-adult shrews born earlier in the year (Rychlik, 1998). *Blarina carolinenis* and *S. longirostris* age class distributions did not differ among treatments in our study. Prior to initiation of our study, *B. carolinensis* populations in removal plots were skewed toward older individuals (McCay and Komoroski, 2004). The increased number of older individuals was attributed to reduced reproduction in removal plots. Similarly, *S. monticolus* and *S. trowbridgii* reproduction decreased following CWD removal in Pacific Northwest hemlock (*Tsuga heterophylla*) stands (Lee, 1995). Conversely, occurrence of juvenile and adult *B. brevicauda*, *S. cinereus*, and *S. fumeus* did not differ among timber harvest treatments in central Appalachian northern hardwood forests despite CWD reductions following harvest treatment (Ford and Rodrigue, 2001). Because our study did not address female reproductive rate or dispersal patterns, our age class analysis may be insufficient to determine CWD manipulation influence on shrew demographics.

6. Conclusion

Our downed treatment represented a significant increase in CWD volume over naturally occurring levels in both natural and planted pine forests in the southern Coastal Plain (McMinn and Hardt, 1996). Within the region, large CWD volume inputs are often produced through major episodic disturbance, such as insect outbreak and wind blowdowns (Van Lear, 1996). However, these occurrences are isolated and likely do not represent significant additions of CWD to southern pine forests at the landscape scale. Additionally, southeastern pine stands typically contain low CWD volumes relative to hardwood forest assemblages (McMinn and Hardt, 1996; Moorman et al., 1999) due, in part, to natural environmental processes typical of the region such as short fire return intervals (Van Lear, 1996). Therefore, CWD importance to shrews in upland loblolly pine stands may be negligible. Shrews use a variety of structures, including underground and leaf litter burrows, for protection from dry conditions and nesting (Ford et al., 1999). Shrew species captured in our study occupy a variety of habitat types locally and throughout their distribution (French, 1980; Bryan, 1991; Blackburn and Andrews, 1992). Because pine stands are more xeric relative to hardwood stands they may not be capable of supporting high shrew densities (Wrigley et al., 1979). Shrew capture rates in pine forests are lower than those in hardwood assemblages in both the Piedmont and Coastal Plain physiographic regions (Blackburn and Andrews, 1992; Ford et al., 2006; Cromer et al., 2007). For example, at the SRS moist bottomland areas supported greater shrew densities than we encountered in our study plots (Menzel et al., 2005). However, clearly demonstrated mechanisms and consistent findings of shrew response to CWD abundance throughout southeastern pine forest types and elsewhere remain elusive and merit further study before conclusive management recommendations can be developed.

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References

Bellocq, M.I., Kloosterman, K., Smith, S.M., 2000. The diet of coexisting species of amphibians in Canadian jack pine forests. Herpetol. J. 10, 63–68.

Blackburn, L.D., Andrews, R.D., 1992. Higher efficiency of pitfall traps in capturing three shrew species for analysis of diet and habitat. Trans. Ill. Acad. Sci. 85, 173–181.

Blake, J.I., Hunter Jr., C.H., Bayle, B.A., 2005. Climate and air quality. In: Kilgo, J.C., Blake, J.I. (Eds.), Ecology and Management of a Forested Landscape: Fifty Years on the Savannah River Site. Island Press, Washington, D.C., pp. 20–30.

Brannon, M.P., 2000. Niche relationships of two syntopic species of shrews, *Sorex fumeus* and *S. cinereus*, in the southern Appalachian Mountains. J. Mammal. 81, 1053–1061.

Brannon, M.P., 2002. Epigeal movement of the smoky shrew *Sorex fumeus* following precipitation in ridgetop and streamside habitats. Acta Theriol. 47, 363–368.

Bryan, H.D., 1991. The distribution, habitat, and ecology of shrews (Soricidae: Blarina, Sorex, and Cryptotis) in Kentucky. J. Tennessee Acad. Sci. 66, 187–189.

Churchfield, S., 1990. The Natural History of Shrews. Cornell University Press, Ithaca.

Conner, R.C., Hartsell, A.J., 2002. Forest area and conditions. In: Wear, D.N., Greis, J.G. (Eds.), Southern Forest Resource Assessment. US For. Serv., Gen. Tech. Rep. SRS-53, pp. 357–402.

Conover, W.J., Iman, R.L., 1981. Rank transformations as a bridge between parametric and nonparametric statistics. Am. Stat. 35, 124–129.

Cromer, R.B., Gresham, C.A., Goddard, M., Lanham, J.D., Hanlin, H.G., 2007. Association between two bottomland hardwood forest shrew species and hurricane-generated woody debris. Southeast. Nat. 6, 235–246.

Ford, W.M., Rodrigue, J.L., 2001. Soricid abundance in partial overstory removal harvests and riparian areas in an industrial forest landscape of the central Appalachians. For. Ecol. Manage. 152, 159–168.

Ford, W.M., Laerm, J., Barker, K.G., 1997. Soricid response to stand-age in cove hardwood communities in the southern Appalachians. For. Ecol. Manage. 91, 175–181.

Ford, W.M., Menzel, A.M., McGill, D.W., Laerm, J., McCay, T.S., 1999. Effects of a community restoration fire on small mammals and herpetofauna in the southern Appalachians. For. Ecol. Manage. 114, 233–243.

Ford, W.M., Dobony, C.A., Edwards, J.W., 2002. Soricids in managed northern hardwood stands in the Allegheny Mountains of West Virginia. Proc. Ann. Conf. Southeast Assoc. Fish Wildl. Agen. 56, 374–384.

Ford, W.M., McCay, T.S., Menzel, M.A., Webster, W.D., Greenberg, C.H., Pagels, J.F., Merritt, J.F., 2006. Influence of elevation and forest type on community assemblage and species distribution of shrews in the central and southern Appalachian Mountains. In: Merritt, J.F., Churchfield, S., Hutterner, R., Sheftel, B.I. (Eds.), Advances in the Biology of Shrews. International Society of Shrew Biologists. Carnegie Mus. Nat. Hist., Pittsburgh, PA, pp. 303–315.

French, T.W., 1980. Natural history of the southeastern shrew, *Sorex longirostris* Bachman. Am. Midl. Nat. 104, 13–31.

Getz, L.L., 1961. Factors influencing the local distribution of shrews. Am. Midl. Nat. 65, 67–88.

Getz, L.L., 1989. A 14-year study of *Blarina brevicauda* populations in east-central Illinois. J. Mammal. 70, 58–66.

Greenburg, C.H., Miller, S., 2004. Soricid response to canopy gaps created by wind disturbance in the southern Appalachians. Southeast. Nat. 3, 715–732.

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

Hanula, J.L., Wade, D.D., 2003. Influence of long-term dormant-season burning and fire exclusion on ground-dwelling arthropod populations in longleaf pine flatwoods ecosystems. For. Ecol. Mange. 175, 163–184.

Harmon, M.E., Franklin, J.F., Swanson, F.J., Sollins, S., Gregory, S.V., Lattin, J.D., Anderson, N.H., Cline, S.P., Aumen, N.G., Sedell, J.R., Lienkaemper, G.W., Cromack Jr., K., Cummins, K.W., 1986. Ecology of coarse woody debris in temperate ecosystems. In: MacFadyen, A., Ford, E.D. (Eds.), Advances in Ecological Research, vol. 15. Academic Press, New York, pp. 133–302.

Hunter Jr., M.L., 1990. Wildlife, Forests and Forestry. Prentice Hall, Englewood Cliffs, New Jersey.

Jaeger, R.G., 1980. Microhabitats of a terrestrial forest salamander. Copeia 1980, 265–268.

Laerm, J., Carter, T.C., Menzel, M.A., McCay, T.S., Boone, J.L., Ford, W.M., Lepardo, L.T., Krishon, D.M., Balkcom, G., Van Der Maath, N.L., Harris, M.J., 1999. Amphibians, reptiles and mammals of Sapelo Island, Georgia. J. Elisha Mitchell Sci. Soc. 115, 104–126.

Lee, S.D., 1995. Comparison of population characteristics of three species of shrews and the shrew-mole in habitats with different amounts of coarse woody debris. Acta Theriol. 40, 415–424.

Loeb, S.C., 1996. The role of coarse woody debris in the ecology of southeastern Mammals. In: McMinn, J.W., Crossley Jr., D.A. (Eds.), Biodiversity of Coarse Woody Debris in Southern Forests. Proc. Work. Coarse Woody Debris in S. For.: Effects on Biodiversity. US For. Serv., Gen. Tech. Rep. SE-94, pp. 108–118.

Loeb, S.C., Wike, L.D., Mayer, J.J., Danielson, B.J., 2005. Nongame mammals. In: Kilgo, J.C., Blake, J.I. (Eds.), Ecology and Management of a Forested Landscape: Fifty Years on the Savannah River Site. Island Press, Washington, D.C., pp. 352–371.

Maidens, D.A., Menzel, M.A., Laerm, J., 1998. Notes on the effect of size and level of decay of coarse woody debris on relative abundance of shrews and salamanders in the southern Appalachian Mountains. Georgia J. Sci. 56, 226–233.

Maser, C., Anderson, R.G., Cromack Jr., K., Williams, J.T., Martin, R.E., 1979. Dead and down woody material. In: Thomas, J.W. (Ed.), Wildlife Habitat in Managed Forests—The Blue Mountains of Oregon and Washington. U.S. For. Serv., Agric. Handbook, 553. pp. 78–90.

McCay, T.S., Komoroski, M.J., 2004. Demographic responses of shrews to removal of coarse woody debris in a managed pine plantation. For. Ecol. Manage. 189, 387–395.

McCay, T.S., Storm, G.L., 1997. Masked shrew (*Sorex cinereus*) abundance, diet and prey selection in an irrigated forest. Am. Midl. Nat. 138, 268–275.

McMinn, J.W., Hardt, R.A., 1996. Accumulation of coarse woody debris in southern forests. In: McMinn, J.W., Crossley Jr., D.A. (Eds.), Biodiversity of Coarse Woody Debris in Southern Forests. Proc. Work. Coarse Woody Debris in S. For.: Effects on Biodiversity. US For. Serv., Gen. Tech. Rep. SE-94, pp. 1–9.

Menzel, M.A., Castleberry, S.B., Ford, W.M., McCay, T.S., 2005. Effects of a group selection timber harvest on the small mammal community in a southern bottomland hardwood forest. In: Fredrickson, L. (Ed.), Proceedings of the Symposium on Ecology and Management of Bottomland Hardwood Systems: the State of Our Understanding. University of Missouri Press, Columbia, pp. 389–396.

Moorman, C.E., Russell, K.R., Sabin, G.R., Guynn Jr., D.C., 1999. Snag dynamics and cavity occurrence in the South Carolina Piedmont. For. Ecol. Manage. 118, 37–48.

Moseley, K.R., Castleberry, S.B., Hanula, J.L., Ford, W.M., 2005. Diet of southern toads (*Bufo terrestris*) in loblolly pine (*Pinus taeda*) stands subject to coarse woody debris manipulations. Am. Midl. Nat. 153, 327–337.

National Commission on Science for Sustainable Forestry, 2005. Summary Report of the National Commission on Science for Sustainable Forestry (NCSSF). NCSSF Project 9C, Washington, DC.

Pearson, O.P., 1945. Longevity of the short-tailed shrew. Am. Midl. Nat. 49, 531–546.

Reisinger, T.W., Simmons, G.L., Pope, P.E., 1988. The impact of timber harvesting on soil properties and seedling growth in the south. S. J. Appl. For. 12, 58–67.

Rudd, R.L., 1955. Age, sex, and weight comparisons in three species of shrews. J. Mammal. 36, 323–339.

Rychlik, L., 1998. Evolution of social systems of shrews. In: Wojcik, J.M., Wolsan, M. (Eds.), Evolution of Shrews. Mammal Research Institute, Polish Academy of Science, Bialowieza, pp. 347–406.

Sanzone, D.M. 1995. Macroarthropods associated with coarse woody debris: factors influencing abundance and diversity patterns. MSc Thesis. University of Georgia, Athens, 112 p.

SAS Institute, 1997. SAS/STAT Software: Changes and Enhancements Through Release. SAS Institute, Cary, North Carolina.

Siry, J.P., 2002. Intensive timber management practices. In: Wear, D.N., Greis, J.G. (Eds.), Southern Forest Resource Assessment. US For. Serv., Gen. Tech. Rep. SRS-53, pp. 327–340.

Sokal, R.R., Rohlf, F.J., 1995. Biometry: The Principles and Practice of Statistics in Biological Research, 3rd ed. Freeman, New York.

Vanderwel, M.C., Malcolm, J.R., Smith, S.M., Islam, N., 2006. Insect community composition and trophic guild structure in decaying logs from eastern Canadian pine-dominated forests. For. Ecol. Manage. 225, 190–199.

Van Lear, D.H., 1996. Accumulation of coarse woody debris in southern forests. In: McMinn, J.W., Crossley Jr., D.A. (Eds.), Biodiversity of Coarse Woody Debris in Southern Forests. Proc. Work. Coarse Woody Debris in S. For.: Effects on Biodiversity. US For. Serv., Gen. Tech. Rep. SE-94, pp. 10–17.

Whittaker, J.C., Feldhamer, G.A., 2005. Population dynamics and activity of southern short-tailed shrews (*Blarina carolinensis*) in southern Illinois. J. Mammal. 86, 294–301.

Wrigley, R.E., Dubois, J.E., Copland, H.W.R., 1979. Habitat, abundance, and distribution of six species of shrews in Manitoba. J. Mammal. 60, 505–520.