COARSE WOODY DEBRIS MANIPULATIONS AND THE RESPONSE OF SORICID AND HERPETOFAUNAL COMMUNITIES IN MATURE LOBLOLLY PINE (*PINUS TAEDA*) STANDS

by

AUDREY K. OWENS

(Under the Direction of Steven B. Castleberry)

ABSTRACT

Coarse woody debris (CWD) may increase abundance of forest-floor dwelling fauna. Understanding the role of CWD in ecosystem function is necessary to manage species that rely on it, however, the extent to which soricids and herpetofauna use CWD is not understood. This research took a large- and small-scale approach to investigate the response of soricids and herpetofauna to CWD manipulations in the southeastern Coastal Plain. The results suggest that the addition of CWD can increase abundance and activity of the southeastern shrew. However, herpetofauna exhibited little response to CWD manipulations. Many Coastal Plain species may be adapted to burrowing in soil or under leaf litter because of naturally low levels of CWD, although these species may use and benefit from CWD. Overall the results suggest that CWD, at least of early to moderate decay, is not a critical habitat component for most soricids and herpetofauna in the southeastern Coastal Plain.

INDEX WORDS: Amphibians, coarse woody debris, forest management, loblolly pine, reptiles, southeastern Coastal Plain, shrews

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CHAPTER 1

INTRODUCTION

Coarse woody debris (CWD), in the form of standing and downed dead trees, large boles, and downed branches, is being increasingly regarded as an ecosystem component that controls diversity and abundance of organisms (Hansen et al. 1991, Loeb 1996, Hanula 1996, Whiles and Grubaugh 1996). Natural inputs of CWD in forests include any agents of tree mortality, such as insect outbreaks, disease, competition, wind, fire, and natural tree death (Harmon et al. 1986). Little is known about historical volume and function of CWD in southern forests (Sharitz et al. 1992, Bragg 2002). Historical accounts often report that dead wood was not found in great quantities in southern pine forests prior to settlement, a result of rapid decomposition of wood due to high humidity and temperature, and historically frequent fire (Ligon 1971, Harmon et al. 1986). Current mean CWD volume in unmanaged forests of Georgia is 17.5 m^3 per ha (McMinn and Hardt 1996). In comparison, mean volume of CWD is about 500 m^3 per ha in old-growth forests of the Pacific Northwest (Spies and Cline 1988). Low volume of CWD in southern forests is probably also due to low input rate, because of the relatively young age of forests found in the region. For example, rate of CWD biomass input in Georgia longleaf pine forests is 0.79 Mg per ha per year, compared with 1.55-4.25 Mg per ha per year in Douglas fir forests in Oregon and Washington (Harmon et al. 1986).

Although southern pine forests have naturally low volume of CWD, managing stands for wood production can further reduce CWD volume (Hunter 1990, McMinn and Hardt 1996). Forests that are managed primarily or economic benefit, referred to as plantations, represent 15%

of commercial timberland in the South (Conner and Hartsell 2002). When forests are managed as plantations with little regard to natural forest dynamics, they become structurally simplified, which can negatively affect biodiversity (Harmon et al. 1986, deMaynadier and Hunter 1995). Plantations tend to have lower levels of CWD than unmanaged forests primarily because the short stand rotations do not allow maturation and senescence of trees that eventually fall to become CWD (Hansen et al. 1991). Additionally, harvesting and subsequent site preparations remove CWD and much of the slash that is created, providing little baseline CWD volume at stand initiation (Aubry et al. 1988, Hunter 1990).

Maintaining snags and downed wood while still producing timber in managed forests has been cited as a major challenge (Sharitz et al. 1992). The concept of ecosystem management allows for multiple uses of forest resources, including timber harvesting, while maintaining the stability of natural systems (Kaufmann et al. 1994). Although CWD is found in relatively low volumes in unmanaged southern pine forests, it represents one of the few sources of stand structure in this ecosystem. Managing for stand structural complexity, by allowing natural replacement of CWD, can contribute to ecosystem stability (Sharitz et al. 1992).

Understanding the use of CWD by vertebrates in southern pine forests is necessary if public and private landowners are to manage for biodiversity while also managing for multiple use strategies. The role of CWD as an important habitat component for vertebrates in many ecosystems has been demonstrated (Maser et al. 1979, Davis et al. 1983, Harmon et al. 1986, deMaynadier and Hunter 1995, Loeb 1996, McMinn and Crossley 1996, Whiles and Grubaugh 1996, Lohr et al. 2002). For example, a study of birds in the Coastal Plain found that breeding bird abundance, richness, and diversity were lower in forest plots in which all downed wood and

snags had been removed than in plots in which downed wood and snags were not manipulated (Lohr et al. 2002).

Objectives

The purpose of this research was to determine if CWD affects the diversity, abundance, and activity of soricids and herpetofauna. The first two studies were part of a long-term investigation that were designed to test the response of soricid and herpetofaunal populations to manipulation of CWD volume in mature loblolly pine stands in the southeastern Coastal Plain. The objective of our second study was to determine how activity of southern toads (*Bufo terrestris*) is affected by the presence or absence of CWD, and to determine if use of CWD by southern toads is affected by its decay state.

LITERATURE REVIEW

Coarse woody debris and soricids

Coarse woody debris often is cited as an important microhabitat component for soricids (Maser et al. 1979, Goodwin and Hungerford 1979, Harmon et al. 1986). Studies have found that shrews live in close association with downed wood (Morris 1955, McComb and Rumsey 1982, Maidens et al. 1998). Association of soricids with downed wood has been attributed to the moist microclimate and abundant invertebrate prey provided by decaying logs, which have both been cited as major factors influencing abundance (Healey and Brooks 1988, Kirkland 1991, Ford et al. 1997).

Despite reports suggesting shrews use CWD, quantitative results from research on population responses to CWD vary. The best evidence supporting for the hypothesis that CWD influences

shrew abundance comes from several studies in the Pacific Northwest, where shrew abundance has been correlated with amount of CWD (Corn et al. 1988, Carey and Johnson 1995, Lee 1995). Coarse woody debris also has been found to influence shrew reproduction in this region (Lee 1995). In the Central and Southern Appalachians, the evidence supporting the importance of CWD for shrews is less definitive. Some studies from this region have found that CWD positively influences shrew abundance (McComb and Rumsey 1982, Seagle 1985, Brannon 2000). For example, in a niche investigation of two shrews of the genus *Sorex* in the Appalachians of North Carolina, the presence of CWD was one of several microhabitat parameters that influenced abundances of smoky shrews (*S. fumeus*) and masked shrews (*S. cinereus*) (Brannon 2000). However, other studies have reported no effect of CWD abundance on shrew populations (Ford et al. 1997, Ford and Rodrigue 2001, Osbourne 2002, Greenberg and Miller 2004).

Few studies have examined the importance of CWD for small mammals, such as shrews, in the southeasteastern Coastal Plain (Loeb 1996). However, the few available data suggest that downed wood may be an important habitat component for soricids in the southeastern Coastal Plain. Loeb (1999) studied small mammal populations in plots in which trees damaged by a tornado were salvaged and in plots that were not salvaged in the Coastal Plain of South Carolina. The southeastern short-tailed shrew (*Blarina carolinensis*) was more abundant in unsalvaged plots than in salvaged plots, but sample size was too low for statistical testing. McCay and Komoroski (2004) performed a manipulative study on the effects of CWD removal on shrew communities in a managed loblolly pine stand and found that relative abundance of least shrews (*Cryptotis parva*) was lower in CWD removal plots than controls. In a continuation of the same study that also included snag and CWD addition plots, Moseley (2004) observed trends

indicating that least shrews, southeastern short-tailed shrews, and southeastern shrews (*Sorex longirostris*) might benefit from the addition of downed wood. All of these data suggest that CWD may be an important factor in the life history of shrews in the southeastern Coastal Plain.

The majority of the evidence supporting the hypothesis that shrews use and rely on CWD comes from correlative studies. Manipulative studies, such as those conducted in other regions (Pacific Northwest, Lee 1995; Central Appalachians, Osbourne 2002; Southern Appalachians, Greenberg 2004), are needed in the southeastern Coastal Plain because they are more likely to provide a causative link between CWD amount and the response variables of shrew populations.

Coarse woody debris and herpetofauna

The southeast contains the richest diversity of herpetofauna in the U.S. (Gibbons and Buhlmann 2001). Coarse woody debris is one of the habitat characteristics thought to influence herpetofaunal communities (Harmon et al. 1986, Maser et al. 1988), most likely because it provides structural diversity on the ground (Hansen et al. 1991). All taxonomic groups of herpetofauna use CWD for various reasons, including thermoregulation, moisture balance, nesting, feeding, and predator avoidance (Whiles and Grubaugh 1996).

Coarse woody debris is used by amphibians because of the moisture regime within fallen, decaying logs (Harmon et al. 1986, Aubry et al. 1988, Whiles and Grubaugh 1996). Amphibians have permeable skin and must regulate water balance. Logs represent a moisture-rich source of cover that can prevent water loss (Harmon et al. 1986). Anurans and salamanders also use CWD for foraging, because of the abundance and diversity of associated invertebrate fauna (Whiles and Grubaugh 1996). Fallen logs also play a role in amphibian reproduction. The eggs of terrestrial salamanders (e.g., Plethodontidae) require a stable, moist microhabitat to prevent

desiccation (Boddy 1983) which is provided by decaying logs (Thomas 1979). Several studies have documented the association between salamanders and CWD volume (Aubry et al. 1988, Corn and Bury 1991, Dupuis et al. 1995, Butts and McComb 2000), supporting the hypothesis that the cover provided by CWD is important for the survival and reproductive success of terrestrial salamanders.

In addition to CWD abundance, decay state and size of wood also may influence use by amphibians. For example, plethodontid salamanders in the Southern Appalachians are associated with large and well-decayed logs more than with small, non-decayed logs (Maidens et al. 1998). Amphibians may preferentially use well-decayed wood because it has the ability to absorb more moisture than non-decayed wood (Harmon et al. 1986),

The relationship between CWD and reptile communities is not well studied. Greenberg (2001) investigated the response of herpetofauna to forest gaps created after a hurricane, and found that CWD did not strongly influence habitat quality for reptiles. However, lizards and snakes use snags and downed wood are for basking, and they can move into and under CWD for cooling down (Goin and Goin 1971). They also forage on invertebrates, small mammals, and other herpetofauna in and around CWD (Ernst and Barbour 1989). Foraging on logs and snags allows them to concurrently bask, which can aid digestion (Goin and Goin 1971). Snakes and lizards also lay their eggs in sunlit logs because they provide the warm temperatures necessary for reptile egg development (Goin and Goin 1971).

Despite the documented uses of CWD by amphibians and reptiles for many critical functions, many of these cases are anecdotal. Furthermore, most of the data suggesting the importance of CWD to herpetofauna come from research on the effect of forest age on herpetofaunal abundances (Bury and Corn 1988, Aubry et al. 1988, Grant et al. 1994, Petranka et al. 1994,

Dupuis et al. 1995). Indirect methods that examine the relationship between characteristics of older forests and herpetofauna (deMaynadier and Hunter 1995) assume that microhabitats vary in parallel with forest age (Welsh 1990). This assumption may be inaccurate because some structures, such as CWD, are often found in low amounts in intermediate-aged stands (Spies et al. 1988, Petranka et al. 1994). Therefore, studies that quantitatively or experimentally investigate the relationship between herpetofauna and structural forest attributes, including CWD, are needed (deMaynadier and Hunter 1995).

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CHAPTER 2

COARSE WOODY DEBRIS MANIPULATIONS AND THE RESPONSE OF SORICID COMMUNITIES IN MATURE LOBLOLLY PINE (*PINUS TAEDA*) STANDS[1]

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ABSTRACT

Coarse woody debris (CWD) may increase abundance and diversity of certain forest-floor dwelling fauna. Understanding the role of coarse woody debris in ecosystem function is necessary for proper management of species dependent upon it. However, the extent to which CWD influences soricid communities is not understood. The purpose of this study was to manipulate CWD volume to test the response of shrew populations in the southeastern Coastal Plain. Drift-fences were used to sample shrews for 14-days each season from 2003 through 2005 in forest stands subjected to three treatments: downed, where downed CWD volume was increased; removal, where all downed CWD was removed; and control, where CWD volume was not manipulated. I hypothesized that shrew activity and abundance would be greatest in the downed plots and lowest in the removal plots. I also predicted that there would be greater correlation in daily activity and precipitation in the removal plots than downed plots. I hypothesized that there would be fewer younger individuals in the removal plots due to lower reproductive rates in the absence of logs. A total of 360 shrews was captured over 126 sample nights. *Sorex longirostris* (southeastern shrew) mean abundance ($F_{2,2} = 10.63$, $P < 0.0001$) and mean number of days captured ($F_{2,2} = 8.42$, $P = 0.002$) were greater in downed than removal treatment plots. The correlative relationship between precipitation and captures was stronger in the removal than in the downed treatment plots for this species, supporting the hypothesis that shrew activity is more limited by a lack of precipitation in the absence of logs. There were no differences in age class distributions among treatments for *Blarina carolinensis* (southeastern short-tailed shrew) ($G^2 = 10.51$, d.f. = 6, $P = 0.10$). However, there was a difference in age class distribution of *S. longirostris* among treatments ($G^2 = 8.34$, d.f. = 6, $P < 0.0001$), with a lower percentage of age class 4 (54 weeks or older) individuals in the removal plots, possibly because

individuals in removal plots are less healthy than those in control and downed plots. These results indicate that CWD may be an important component at least for the southeastern shrew. This species might be more affected by changes in surficial microhabitat because they are more epigeal than *B. carolinensis.* *Blarina carolinensis* and *Cryptotis parva* (least shrew) may use other sources of cover in the absence of CWD. Further research is needed on the importance of decay state and distribution of CWD, since these characteristics may influence the usefulness of CWD for these shrew species.

INTRODUCTION

Coarse woody debris (CWD) may be an important component in determining species assemblages in forest ecosystems (Hansen et al. 1991, Loeb 1996, Hanula 1996, Whiles and Grubaugh 1993). Forests managed for timber are often more homogenous in their ground and stand structure than unmanaged forests, because of a reduction in CWD and other microhabitat features (Harmon et al. 1986, deMaynadier and Hunter 1996). In accordance with the concept of ecosystem management (Kaufmann et al. 1994), forest managers allow for multiple uses of forest resources, including timber harvesting, while maintaining the integrity of natural systems. Because CWD is a microhabitat feature that can be manipulated, it is important that its role in the ecosystem is well-understood for proper management of species that may depend on it as an important habitat component.

Previous studies have suggested that soricids use CWD to varying degrees to fulfill several life history functions. Several studies have shown that abundance of well-decayed CWD is a good predictor of the abundance of shrews (Goodwin and Hungerford 1979, Brannon 2000). Harmon et al. (1986) reported that several soricid species use CWD to fulfill the primary functions of reproduction, feeding, and protection. Shrews, which are almost exclusively insectivorous, may feed on insects that reside in or along fallen logs (Loeb 1996). In fact, CWD has been found to increase arthropod prey abundance for shrews (Kirkland 1991). Fallen logs also serve to create continuity of habitat for small mammals, including soricids, allowing them to move along the forest floor at lower risk of predation (Harmon et al. 1986). Additionally, CWD might be an important source of refuge for shrews, which are susceptible to desiccation, because of its ability to retain moisture during dry periods (Loeb 1996).

Several studies, particularly from the Pacific Northwest, have suggested CWD to be an important habitat component for shrews. For example, Trowbridge's shrew abundance was accurately predicted by CWD volume in Washington (Carey and Johnson 1995). Similarly, Butts and McComb (2000) found that the probability of catching Trowbridge's shrew increased as CWD volume increased. Abundance and reproduction of *S. monticolus*, and reproduction of *S. trowbridgii* were greater on sites that had high CWD levels compared with sites that had low levels of CWD in Washington (Lee 1995). Lower reproductive rates may be a result of fewer reproductive opportunities, because some species of shrews use logs for nesting sites (Webster et al. 1985).

In the eastern U.S., most of the studies on the relationship between shrews and CWD are from Appalachian hardwood forests. Some studies suggest that shrew abundance is not related to CWD abundance in eastern hardwood forests (Ford et al. 1997, Ford and Rodrigue 2001, Osbourne 2002, Greenberg and Miller 2004), however, there is also evidence that shrews might benefit from CWD in Appalachian hardwood forests. In the southern Appalachians, capture rates of masked, smoky, and pygmy shrews were three times greater in traps placed beside CWD than those away from CWD (Maidens et al. 1998). Another study on the effects of forest clearings on small mammals in the central Appalachians found correlations between abundances of *S. fumeus* and *B. brevicauda* and number of logs (McComb and Rumsey 1982). Brannon (2000) found that *S. fumeus* and *S. cinereus* abundances in the southern Appalachians were both predicted by volume of CWD (R^2 = 92.8 and 57.7 %, respectively), among several other microhabitat features.

Few studies have investigated the response of shrews to CWD through controlled experiments (but see Osbourne 2002, Loeb 1999, Greenberg and Miller 2004). Controlled experimental

studies are necessary to differentiate between the response of fauna to CWD and to those of other microhabitat features commonly associated with older forests. Coarse woody debris studies are lacking in the southeastern Coastal Plain. Results from CWD studies performed in the Pacific Northwest and the Appalachians may not be relevant to the southeastern Coastal Plain, where CWD volumes are naturally low (McMinn and Hardt 1996) and shrew species richness is low (Mengak and Guynn 2003).

Objectives

This study was a continuation of a long-term investigation into the role of CWD as an ecosystem component in southeastern Coastal Plain pine forests, representing years 8 and 9 since treatment initiation. The study was designed to determine if CWD is a critical habitat component for shrews by testing their response to the addition and removal of downed logs against controls in three planted loblolly pine stands. If CWD was a critical habitat component, there were several predicted differences among populations from sites in which CWD was added, removed, and not manipulated. Shrew species abundance was predicted to show a positive response to the addition of CWD and a negative response to the removal of CWD, because CWD provides a moisture-rich source of cover for foraging and resting. I predicted that number of days of surface activity for shrews would be greatest where CWD was added and lowest where it was removed, because of their use of logs for foraging and movement during dry periods. Similarly, in sites where CWD was removed, I predicted that activity would be strongly correlated with precipitation, because shrews would not have logs to use as covered movement corridors in the absence of rain, thereby limiting the window of activity to periods of rain. In sites where CWD was not removed, shrew activity was predicted to be less strongly correlated with rainfall.

Finally, I predicted fewer younger individuals in sites where CWD was removed because of lower reproductive rates in the absence of logs, which are used as nesting sites, creating a population sink (Pulliam 1988, Van Horne 1983).

METHODS

Study site

The study plots were located on the Savannah River Site (SRS), a National Environmental Research Park administered by the U.S. Department of Energy (DOE). Located in the Upper Coastal Plain and Sandhills physiographic region, this area is characterized by periodic fire, sandy soils, and gently sloping hills dominated by pines with scattered hardwoods (Kilgo and Blake 2005). The region has been described as humid subtropical; mean annual temperature in the region is 18º C, and mean annual precipitation is 122.5 cm (Blake et al. 2005).

Old-field habitat dominated SRS when the DOE acquired the land in the early 1950's. The area is now composed mostly of pine, including loblolly (*Pinus taeda*), slash (*P. elliottii*) and longleaf (*P. palustris*) pines, mostly planted by the U. S. Forest Service, which manages the land. Although much of the land is managed for timber, the majority of the 78,000 hectares that make up the SRS are pine forests that are 30 years old or more (White 2005).

The study site on the SRS consisted of three loblolly pine stands that were planted between 1950-1953. The overstory in each of the stands was dominated by *P. taeda*, although *P. elliottii* and *P. palustrus* were interspersed among the canopy. Lespedeza (*Lespedeza* sp.), poison oak (*Toxicodendron pubescens*), blackberry (*Rubus* sp.), black cherry (*Prunus serotina*), and sassafras (*Sassafras albidum*) composed the majority of the understory vegetation.

Study design

The study was a randomized complete block design, with each of four treatments randomly assigned within each of the three forest stands (blocks). The treatments were 1) control (n = 3), where downed CWD was not manipulated; 2) snag (n = 3), where standing CWD volume was increased 10-fold (implemented in 2001); 3) removal (n = 3), where all downed CWD >10 cm diameter and 60 cm long was removed; and 4) downed (n =3), where volume of downed CWD was increased five-fold. Because I did not think the presence of snags would affect shrew populations, and because downed wood volume was not manipulated in snag plots, I treated the snag treatment plots as control plots. Therefore, there were 6 control plots recognized in the analyses. All 12 plots were thinned in 2001 so that each had a basal area of 13.8 - 20.8 m^2/ha of live pine. Each treatment plot consisted of a 6-ha core area where trapping occurred, surrounded by a 3.3-ha buffer zone that received the same treatment. Control and removal treatment plots were initiated in 1996. Annual removal of CWD was performed in the removal treatment plots to keep downed woody debris volume negligible. Downed treatments were implemented in 2001. All plots were burned by the U. S. Forest Service in summer 2004. No other large-scale disturbances were allowed at the study site during the period of this study.

Data collection

Downed woody debris inventories were conducted at the end of each year in eight randomly selected subplots (50 m x 50 m) within the inner 4-ha of each plot. Within each subplot, logs greater than 10-cm diameter and 60-cm length with at least 50% of their measurable length within the subplot were counted. Logs were classified as decay stage 1-5 based on Maser et al. (1979), where stage 1 logs were sound, with intact bark; stage 2 logs had mostly sound wood

with some bark starting to flake; stage 3 logs had broken branches and were missing bark; stage 4 logs were soft and blocky in texture; and stage 5 logs were powdery in texture and partly buried. In removal plots, all downed wood was measured and removed at the end of each year.

Sampling for shrews was conducted using drift-fence arrays located in the center of each treatment plot. The fences consisted of aluminum flashing buried 15-cm below ground with 19-liter plastic buckets buried flush to the ground against each fence. Each plot contained one cross-shaped drift fence array with four 30-m arms extending in each of the cardinal directions from the center of the plot, and four Y-shaped arrays with three 15-m arms located in each corner of the 6-ha core area (Figure 2-1). Bucket traps were maintained with a small amount of soil or water during sampling periods.

Shrews were sampled in all plots for 14-days each season from fall 2003-fall 2005, for a total of nine sampling periods. Live captures were identified to species, weighed for mass (g), and measured for snout-vent length (mm). Shrews that died during trapping were collected for identification, measurement, and aging in the lab. All resulting skull specimens were donated to the Georgia Museum of Natural History zoology collections. Weather data were collected from Central Climatology at the SRS, approximately 24 kilometers from my study site.

Statistical analysis

Two-way analysis of variance (ANOVA) was used to examine differences in relative abundance of shrew species among treatments and season from winter 2004-fall 2005. Surface activity, defined as the number of days each species was captured per 14-day sampling period, was analyzed using a two-way ANOVA for differences among treatments and seasons from spring 2004-fall 2005. For surface activity analysis, winter sampling periods were not used

because traps were checked every other day due to low capture rates. Significant results found using ANOVA were further analyzed using Tukey's Honestly Significant Difference (HSD) test and the estimation procedure to make pair-wise mean comparisons using a 95% confidence interval. Forest stand was used as a block factor for all ANOVA analyses. All statistical analyses were performed using SAS 9.1 (SAS Institute 2005).

Pearson's product moment correlation was used to examine relationships between daily precipitation amount and daily shrew captures within downed and removal treatments from spring 2004-fall 2005. Total number captured per sample night in downed and removal treatments for *B. carolinensis* and for *S. longirostris* was compared with precipitation amount in the 24-hour sampling period previous to capture. Winter sampling periods were not included in this analysis because traps were not checked daily.

Collected shrews were designated as age class 1, 2, 3, or 4 based on relative tooth attrition using methods based on Pearson (1945) for *Blarina carolinensis* and Rudd (1955) for *Sorex longirostris*. Rudd's 7-class system was modified, resulting in four age classes: age class 1 (combination of Rudd's age classes 1 and 2), class 2 (combination of classes 3 and 4), class 3 (combination of classes 5 and 6), and class 4 (corresponding with class 7). For *B. carolinensis*, age class 1 individuals were 0-24 weeks old, 2 were 24-40 weeks old, 3 were 40-64 weeks old, and 4 were older than 64 weeks. For *S. longirostris*, age class 1 included individuals 0-18 weeks old, 2 included individuals 18-36 weeks old, 3 included individuals 36-54 weeks old, and 4 included individuals 54 weeks or older. Age class frequencies were analyzed using log-likelihood ratio G-tests to determine whether the ratio of age classes differed among treatments. A significant difference in age class ratios among treatments was interpreted as a skew in age

class distribution. Because only individuals that died were used in this analysis, mortality was assumed to occur independent of treatment, age, sex, and weight.

RESULTS

In 2003, mean volume (± SE) of CWD was 56.2 m^3/ha ± 6.6 in downed plots, 7.2 m^3/ha (± 2.6) in control plots, 5.9 m^3/ha (± 1.1) in snag plots, and 1.9 m^3/ha (± 1.3) in removal plots. Mean decay state of logs in downed, control, and snag plots in 2003 was 2.5, and logs in decay states 1 and 2 represented 53% of all logs. Mean volume of CWD in 2004 was 57.9 m^3 (± 7.6) in downed plots, 11.1 m^3 (± 2.6) in control plots, 14.7 ± 5.4 in snag plots, and 0.1 m^3 (± 0.0) in removal plots. Mean decay state of logs in downed, control, and snag plots in 2004 was 2.3, and logs in decay states 1 and 2 represented 65% of all logs. Mean decay state of downed wood was greater at the end of 2003 than at the end of 2004 because an ice storm in January 2004 knocked down limbs and trees which increased downed wood volume and decreased mean decay state in all plots. Volume estimations were made assuming that logs were round in circumference, which may overestimate true downed wood volume.

A total of 360 shrews was captured from winter 2004 through fall 2005 in 126 sample nights. All three species documented at SRS were captured during the two years of trapping. *Blarina carolinensis* (southern short-tailed shrew) accounted for 50.3 % of captures, followed by *Sorex longirostris* (southeastern shrew) (45.5 %), and *Cryptotis parva* (least shrew) (4.2 %).

There were no significant interactions between treatment and season for abundance of any of the species ($P > 0.05$). Abundance of *B. carolinensis* ($F = 0.94$, d.f. = 2,2, $P = 0.39$) and *C. parva* ($F = 1.51$, d.f. = 2,2, $P = 0.24$) did not differ among treatments (Table 2-1). Abundance of *S. longirostris* was different among treatments ($F = 10.63$, d.f. = 2,2, $P < 0.0001$). In the control

plots, an estimated 2.79 more *S. longirostris* per season were captured than in removal plots, and an estimated 5.08 more *S. longirostris* per season were captured in downed than removal plots ($q = 3.47$, d.f. = 34, $P = 0.05$). There was a significant block effect for *C. parva* abundance ($F = 3.44$, d.f. = 2,2, $P = 0.04$).

There were no significant interactions between treatment and season, or any significant block effects for number of days active for any of the species ($P > 0.05$). Mean number of days active was similar among treatments for *B. carolinensis* ($F = 0.19$, d.f. = 2,2, $P = 0.83$) and for *C. parva* ($F = 1.29$, d.f. = 2,2, $P = 0.29$) (Table 2-2). Mean number of days active was different for *S. longirostris* ($F = 8.42$, d.f. = 2,2, $P = 0.002$). The mean estimated difference in number of days *S. longirostris* was captured between downed and control plots per season was 1.89, and between downed and removal plots per season was 3.56 ($q = 3.52$, d.f. = 25, $P = 0.05$).

Daily captures were correlated with amount of precipitation in the 24-hours previous to capture for *B. carolinensis* in downed ($r = 0.60$, $P < 0.0001$) and removal plots ($r = 0.68$, $P < 0.0001$). Similarly, *S. longirostris* daily captures were correlated with daily precipitation in downed ($r = 0.26$, $P = 0.02$) and removal plots ($r = 0.41$. $P = 0.0001$).

A total of 258 *B. carolinensis* and *S. longirostris* was collected for age class analysis from fall 2003 through winter 2005, and from summer 2005 through fall 2005. Mortality rates for *B. carolinensis* were 86, 83, 80, and 68 % among control, downed, removal, and snag plots, respectively. For *S. longirostris*, mortality rates were 93, 87, 88, and 86 % among control, downed, removal, and snag plots, respectively. Age class frequencies of *B. carolinensis* were similar among treatments ($G^2 = 10.51$, d.f. = 6, $P = 0.10$) (Figure 2-2). However, age class frequencies of *S. longirostris* differed among treatments ($G^2 = 8.34$, d.f. = 6, $P < 0.0001$), with a lower percentage of age class 4 individuals in removal plots (Figure 2-3).

DISCUSSION

I predicted a positive response in shrew abundance to the large-scale addition of CWD volume and a negative response to its removal, because abundance of shrews has been correlated with CWD volume. Shrew abundance results from previous years of this study showed little or no treatment effects. Capture rates of *B. carolinensis*, *S. longirostris,* and *C. parva* did not differ among treatments during research on the site during 2002-2003, though *B. carolinensis* and *S. longirostris* were 38 and 50% higher in the downed than removal treatments, respectively (Moseley 2004). McCay and Komoroski (2003) captured significantly fewer *C. parva* in removal than control plots when they sampled at the site from 1997-2001; there were no differences in abundances of the other two species among treatments. I found that *C. parva* and *B. carolinensis* did not respond to the treatments in this study, however, *S. longirostris* was captured more frequently and on more days in the downed plots, which matched my initial hypotheses.

The number of days *S. longirostris* was captured was greater in the downed plots than control, suggesting that surface activity of this species was influenced by CWD volume. Shrews are sensitive to changes in moisture, and become less active when conditions are unsuitable (Getz 1961). However, because of high metabolic demands shrews must maintain high levels of activity. Whittaker and Feldman (2005) suggested that a change in activity might be related to behavioral changes that reduce energy costs. The increased surface activity observed in the downed plots in this species may have been a response to the mitigating effects of the downed wood, which allowed the shrews to stay active on the surface for longer periods of time and for more days, possibly during otherwise unsuitable conditions. Supporting this hypothesis, correlation of daily captures and precipitation was stronger (greater r-value) in the removal plots

than the downed plots for *B. carolinensis* and for *S. longirostris*, as predicted. In the absence of logs, shrews may be more limited to being active during periods of precipitation. Staying active on the surface may allow individuals in the downed plots to continue foraging and thereby meet metabolic demands better than those individuals that must reduce activity during dry conditions.

Number of days active was similar among treatments for *B. carolinensis* and *C. parva*. *Blarina carolinensis* is a more fossorial species than *S. longirostris* and *C. parva,* which mostly inhabit leaf-litter (Whitaker and Hamilton 1998). *Blarina carolinensis* may therefore be influenced less by changes in surficial microhabitat. *Cryptotis parva* was captured relatively infrequently during this study period (4% of captures), and the lack of a treatment response may have been a function of low sample size.

I predicted that shrew age class ratios would differ among treatments, specifically that removal plots would have a fewer younger individuals. I hypothesized that the removal plots would have lower reproductive rates because of fewer or lower quality nesting sites in the absence of logs, creating proportionately fewer individuals in the youngest age classes, consistent with a population sink (Pulliam 1988, Van Horne 1983). *Blarina carolinensis* populations on removal plots were skewed toward older individuals during trapping from 1997-2001 at these same plots (McCay and Komoroski 2003). More recently, Moseley (2004), who studied soricids at these plots from 2002-2003 found no difference in age distribution among treatments. I found a difference in age class distribution of *S. longirostiris* among treatments, with fewer age class 4 individuals in the removal treatment. Although this did not match my original hypothesis, the complete lack of the oldest age class individuals might indicate that in removal plots individuals are not as healthy as those in downed plots, and therefore do not live as long. This hypothesis needs further research, but seems to be supported by my finding that

southeastern shrews were more limited in their activity to periods of rainfall in the removal plots, which may be affecting their ability to meet metabolic energy demands.

In both years of this study, the majority of the logs were of decay state 1 or 2. Logs in a more advanced state of decay might be used preferentially by shrews, possibly related to its increased moisture, favorable shape, and diverse insect prey (Brannon 2000, Goodwin and Hungerford 1979, Maidens et al. 1998, Maser et al. 1988, Harmon et al. 1986). In the current state, these logs may provide little moisture, because more-decayed logs are better able to absorb and retain moisture than non-decayed logs (Maser et al. 1988, Jaeger 1980). It is therefore possible that as the CWD at this study site reaches more advanced stages of decay, treatment responses for *B. carolinensis* and *C. parva* abundance and activity will be detected. Its use for breeding by all three species may likewise increase as the downed wood decays further.

The use of downed wood by vertebrates is influenced by several factors, including volume, decay state, and its distribution in a forest (Harmon et al. 1986). The CWD in the downed plots of this study was scattered somewhat homogenously throughout the treatment plots. This may not accurately mimic the natural distribution of dead wood, because input of CWD is usually associated with mortality factors that occur in clumps, creating aggregations of wood piles (Harmon et al. 1986). Piles of downed wood, such as those created by natural disturbances like tornadoes, may be more beneficial to soricids than a homogenous distribution of logs because they provide concentrations of cover. Supporting this hypothesis, a study that examined the small mammal community in a forest damaged by a tornado in the Coastal Plain of South Carolina found that *B. carolinensis* were more abundant in plots in which CWD was not salvaged than in salvaged plots. However, total captures were low, precluding strong conclusions (Loeb 1999).

The strongest evidence supporting the positive relationship between soricids and CWD volume comes from the Pacific Northwest. The relationship is less clear in the Appalachian region, although some studies provide evidence that CWD does positively affect soricid communities there (McComb and Rumsey 1982, Seagle 1985, Brannon 2000). Both regions have greater mean volumes of CWD in their forests compared with pine forests of the Coastal Plain. Average volume of CWD in pine forests of public land in Georgia is < 20 m^3 per ha (McMinn and Hardt 1996). Old-growth forests of the Pacific Northwest have a mean CWD volume that is about 25 times that of Georgia pine forests (Spies and Cline 1988,McMinn and Hardt 1996). Naturally low volume of CWD in the Coastal Plain may be a result of several factors, including rapid decomposition, historically frequent fire intervals (Ligon 1971, Harmon et al. 1986), shorter rotations, and smaller trees than what are found in other regions (McMinn and Hardt 1996). Considering the relative sparseness of CWD in the southeastern Coastal Plain, shrews in this region may not have evolved to rely on it as a critical habitat component as in other areas with greater CWD volumes. However, it does appear that *S. longirostris* responds positively to the presence of downed wood. Even if it is not a critical habitat component for the other species at this site, they probably incur some benefit from logs.

Although it is possible that the high mortality rate of shrews I captured had a negative effect on the population on shrews on the study plots, I only captured 360 shrews during the two years of my study. This probably represents a small percentage of the population that inhabits the study plots. In fact, studies have suggested that shrew removal at this level either has little influence on the population as a whole (McCay and Komoroski 2003, Nicolas et al. 2003).

CONCLUSION

Sorex longirostris abundance was greater in downed and control plots than removal plots. Additionally, this species exhibited greater activity in downed treatment plots than in plots in which wood was not manipulated or removed. Based on the results of this study, forest managers interested in managing for biodiversity should consider at least maintaining natural levels of downed CWD in the Coastal Plain.

It is possible that the other two species, *C. parva* and *B. carolinensis* benefit from the presence of CWD and use it facultatively, but its absence is not a limiting factor for their populations in this region. This relationship could become more obligate in environments where other microhabitat structures are diminished (i.e., leaf litter or herbaceous ground cover), such as after a fire (Greenberg et al. 1994, Moseley et al. 2003). Therefore, studies investigating the use of CWD by Coastal Plain shrews in habitats where resources are limited may have implications for use of prescribed fire in this region.

This study took a large-scale approach to investigate the relationship between shrews and CWD. A study on the interaction between shrews and CWD at the microhabitat spatial-scale might be more appropriate because of the small home ranges used by shrews. Investigations into the uses of fallen logs by shrews are needed to further elucidate the relationship between soricids and CWD. Experimental studies are also needed to test the hypothesis that shrews preferentially use more decayed logs, as has been suggested in the literature.

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Table 2-1. Mean (SE) number of shrews captured in control, downed, and removal treatment plots in upland loblolly pine (*Pinus taeda*) stands in Barnwell Co., South Carolina. Shrews were captured using drift fences from winter 2004 through fall 2005 over 126 sampling days. Letters adjacent to means indicate significant differences among treatments.

	Treatment		
Species	Control (n = 6)	Downed (n = 3)	Removal (n = 3)
Blarina carolinensis	15.7 (3.1)	17.3 (2.4)	11.3 (0.3)
Cryptotis parva	1.8 (0.5)	1.0 (0.6)	0.3 (0.3)
Sorex longirostris	17.8 (3.5)a	22.7 (3.8)a	5.7 (2.0)b

Table 2-2. Mean (SE) number of days captured of shrew species among control, downed, and removal treatment plots in upland loblolly pine (*Pinus taeda*) stands in Barnwell Co., South Carolina. Shrews were captured using drift fences and bucket traps from spring 2004-fall 2005 over 98 sampling days. Letters adjacent to means indicate significant differences among treatments.

	Treatment		
	Control (n = 6)	Downed (n = 3)	Removal (n = 3)
Blarina carolinensis	9.2 (1.9)	9.7 (1.2)	11.0 (0.6)
Cryptotis parva	1.3 (0.4)	1.3 (0.9)	1.0 (0.6)
Sorex longirostris	7.3 (1.9)a	14.7 (2.2)b	4.0 (1.0)a

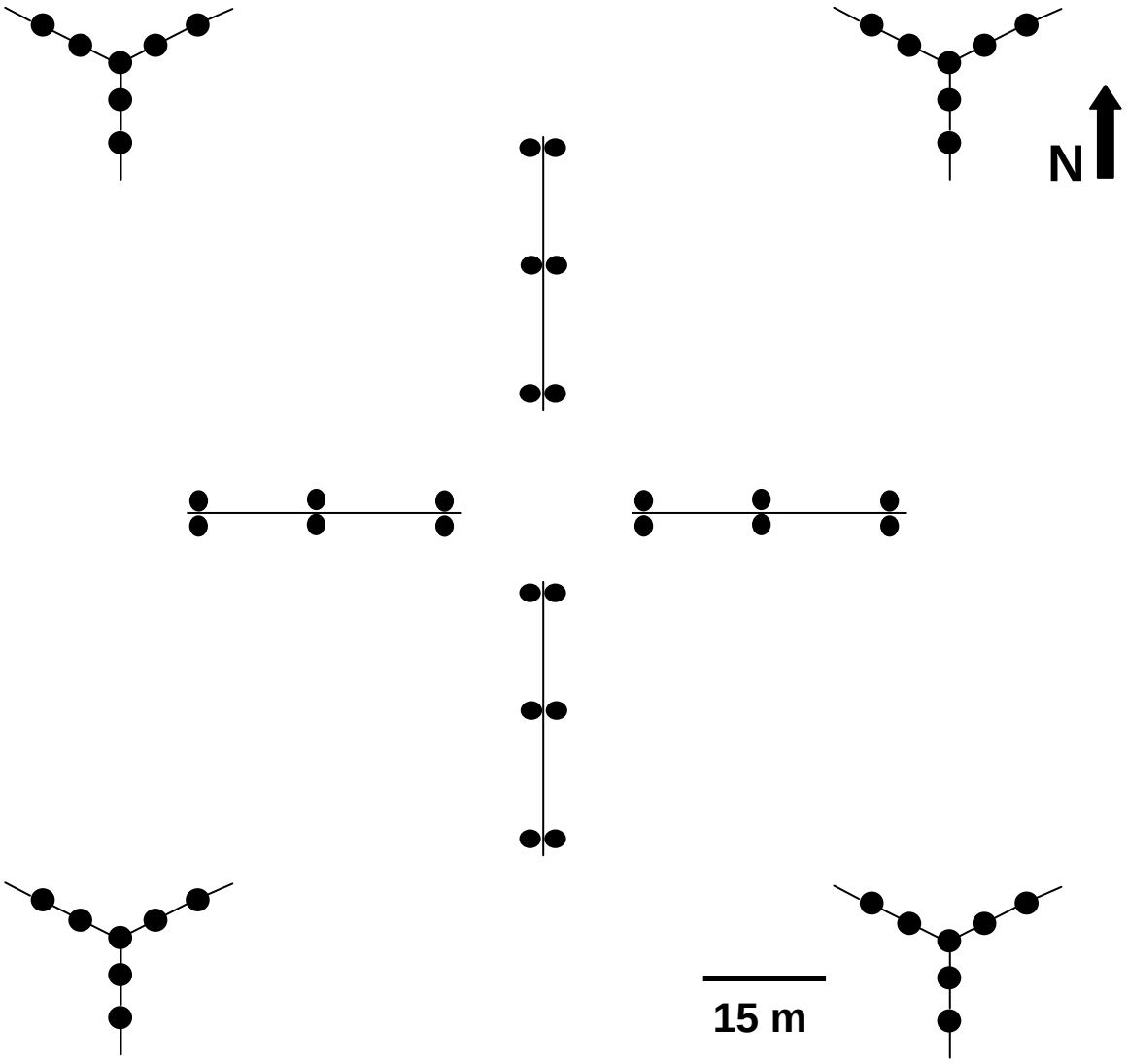

Figure 2-1. Arrangement of drift fence arrays and bucket traps used for sampling shrews on 6-ha core area of a 9.3-ha treatment plot in an upland loblolly pine stand at the Savannah River Site, Barnwell Co., South Carolina.

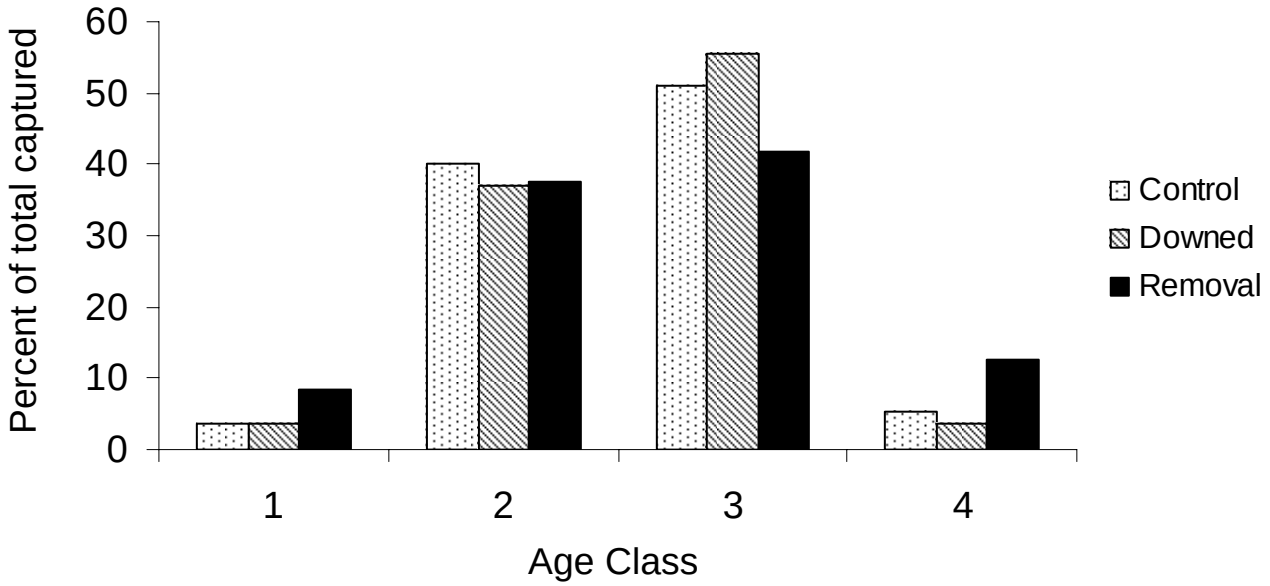

Figure 2-2. Age class distribution of *Blarina carolinensis* collected from control (n = 6), downed (n= 3), and removal (n = 3) treatment plots in three loblolly pine stands at the Savannah River Site in Barnwell Co., South Carolina. Shrews (n = 106) were captured during drift-fence sampling from fall 2003 through fall 2005.

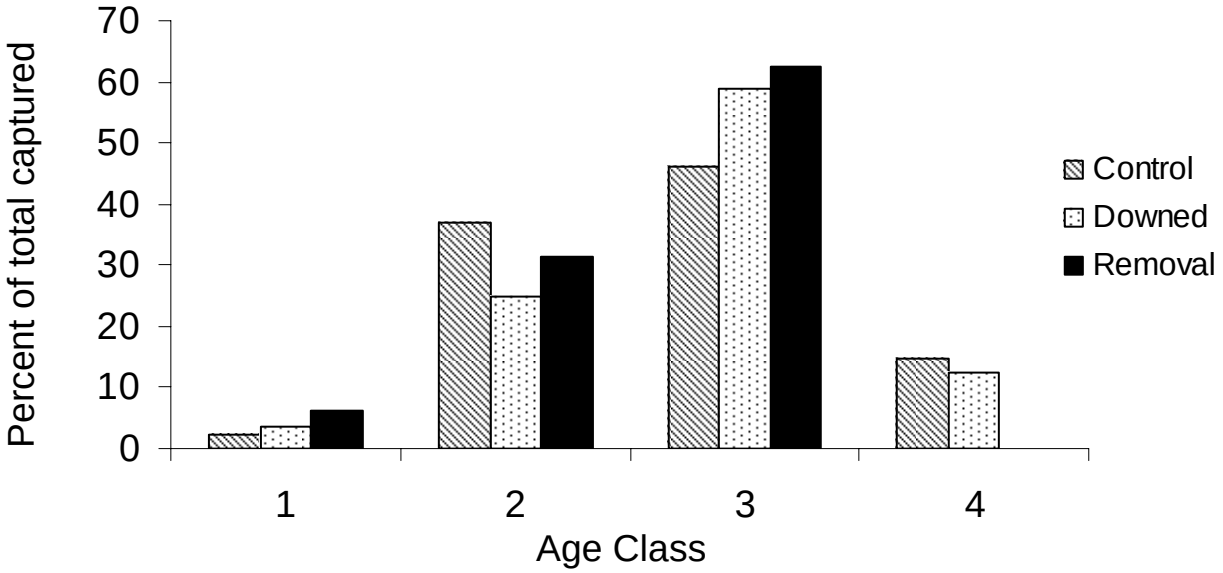

Figure 2-3. Age class distribution of *Sorex longirostris* collected from control (n = 6), downed (n = 3), and removal (n = 3) treatment plots in three loblolly pine stands at the Savannah River Site in Barnwell Co., South Carolina. Shrews (n = 151) were captured during drift-fence sampling from fall 2003 through fall 2005.

CHAPTER 3

HERPETOFAUNAL COMMUNITY RESPONSE TO COARSE WOODY DEBRIS MANIPULATIONS IN MATURE LOBLOLLY PINE (*PINUS TAEDA*) STANDS[1]

[1]Owens, A.K., S.B. Castleberry, and J.C. Kilgo. To be submitted to *Southeastern Naturalist*.

ABSTRACT

Coarse woody debris (CWD) often is cited as a habitat component that regulates diversity in terrestrial ecosystems, including diversity of herpetofauna. Rarely, however, have experimental manipulations of CWD been undertaken to quantitatively assess response in herpetofaunal communities. The purpose of this study was to test the response of herpetofauna to experimental manipulation of downed and standing CWD volume in a managed forest in the southeastern Coastal Plain. Sampling was performed using drift-fences for 14-days each season over two years. Randomized complete block two-way analysis of variance (ANOVA) was used to test the effect of treatment and season of capture on abundance, richness, and diversity of amphibians and reptiles. A total of 4,136 individual reptiles and amphibians was captured over 126 sampling days, representing 14 amphibian and 22 reptile species. The interaction between treatment and season was not significant for abundance, richness, or diversity of any of the taxonomic groups ($P > 0.05$). Abundance of the southern leopard frog was greater ($F_{2,3} = 5.23$, $P = 0.005$) in the removal plots than the downed, control, and snag plots ($q_{0.05, 30} = 3.85$), and the species was captured on more days in the removal plots than in the downed and snag treatments plots ($q_{0.05, 6} = 4.89$). Snake species richness was greater ($F_{2,3} = 3.45$, $P = 0.03$) in downed, removal, and control treatment plots than in snag treatment plots ($q_{0.05, 30} = 3.85$). All other response variables were similar among treatments. Most of the individuals captured are species adapted to burrowing in sandy soil or taking refuge under leaf litter instead of CWD, probably due to naturally low levels of CWD in southeastern Coastal Plain pine forests. As the CWD on this study site decays, its suitability as foraging, breeding, and cover habitat for herpetofauna may increase. However, an overall lack of convincing treatment responses suggests that CWD, at

least in early to moderate stages of decay, is not a critical habitat component for herpetofauna in the southeastern Coastal Plain.

INTRODUCTION

Forests of the southeastern Coastal Plain contain a rich assemblage of amphibians and reptiles, supporting almost half of the 450 species native to the United States (Russell et al. 2004). Herpetofauna are an important component of the forested communities in which they interact. Many species serve as mid-level predators, and some amphibians can attain high levels of biomass relative to other mid-level predators in their habitats (Burton and Likens 1975). Given their abundance and important ecological role, it is necessary that managers identify and understand critical habitat criteria for these vertebrates. However, appropriate management strategies for maintaining herpetofaunal diversity are still relatively unknown.

Habitat components that increase ground structural diversity in managed forests may be critical for maintaining southeastern herpetofaunal communities (Grant et al. 1994, Sharitz et al. 1992). One such component is coarse woody debris (CWD), defined as standing and downed dead trees, large boles, and downed branches greater than 10 cm in diameter and 60 cm in length (Harmon et al. 1986). CWD often is identified as an ecosystem component that controls diversity and abundance of organisms in forested ecosystems (Hansen et al. 1991, Loeb 1996, Hanula 1996, Whiles and Grubaugh 1996), where it serves many functions for invertebrates and vertebrates (Maser et al. 1979, Davis et al. 1983, Harmon et al. 1986, deMaynadier and Hunter 1995, Loeb 1996, McMinn and Crossley 1996).

Despite its potential importance to maintenance of biodiversity, managed forests tend to have lower levels of CWD than natural forests (McMinn and Hardt 1996). Typically, trees in managed forests are harvested before they reach natural mortality (Hunter 1990). The low level of CWD in managed forests is of concern in the Southeast, where commercial timberland represents 19 % of the forest coverage (Conner and Hartsell 2002). Sharitz et al. (1992)

suggested that in stands managed for timber, it is critical to maintain structural diversity, such as CWD, for ecosystem stability. Thus, land managers are being pushed to manage for multiple uses of forest resources, which allow for maintenance of ecosystem stability and sustainable timber harvest under the concept of ecosystem management (Kaufmann et al. 1994). Because CWD is a structural component of forests that can be manipulated, it is important to investigate its role in forest ecosystems to properly manage for species that use it, while also managing for multiple use strategies.

Although CWD is used by almost all forms of herpetofauna (Whiles and Grubaugh 1996), the extent to which many herpetofaunal species use CWD and the role of CWD in structuring herpetofaunal communities is unknown. Studies suggest that abundance, distribution, and condition of CWD are critical in determining diversity of herpetofauna (Harmon et al. 1986, Whiles and Grubaugh 1996), most of what is known about the use of CWD by herpetofauna is anecdotal (Whiles and Grubaugh 1996).

Herpetofauna in North American use CWD for thermoregulation, predator avoidance, foraging, and reproduction. The relatively stable temperature and moisture regime provided by CWD make it a favorable microhabitat for herpetofauna to avoid temperature extremes, and for amphibians in particular to avoid desiccation (Harmon et al. 1986, Aubry et al. 1988). Because amphibians and reptiles are ectothermic, they rely on components of their habitat to regulate their body temperature. Snags and logs can provide basking sites for lizards and snakes (Whiles and Grubaugh 1996). The permeable skin of amphibians makes them vulnerable to dehydration, requiring them to find microclimates, such as those provided by fallen logs, to keep cool and moist. Studies in the forests of the Pacific Northwest have shown a strong relationship between abundance of CWD and densities of salamanders (Corn and Bury 1991, Dupuis et al. 1995,

Aubry 2000, Butts and McComb 2000). Coarse woody debris also is an important habitat for invertebrate prey (Hanula 1996), and it allows herpetofauna to forage along the associated loose bark with little risk of predation (Whiles and Grubaugh 1996). Lizards, salamanders, and snakes have been documented using CWD for oviposition (Whiles and Grubaugh 1996), probably because downed logs provide such a wide range of thermal and moisture regimes that reptiles and amphibians can find optimal conditions for their eggs (Thomas 1979).

Despite the evidence supporting the hypothesis that CWD is important for herpetofauna, the only studies investigating CWD were observational and therefore do not separate the response of herpetofauna to CWD from other habitat components found in older forests. Russell et al. (2004) suggested manipulative studies are critical if managers are to acquire information that allows a successful blend of herpetofaunal conservation and economic objectives in southern forests. Additionally, the majority of the research on the relationship between CWD and herpetofauna comes from the Pacific Northwest and the Appalachian Mountains. The different climates, forest structures, and management practices among regions likely limit the applications from these studies to their respective regions. Average volume of CWD in Pacific Northwest old growth forests is about 25 times that of pine forests of the southeastern Coastal Plain (McMinn and Hardt 1996, Spies and Cline 1988). High humidity and warm climate create subtropical conditions in the Coastal Plain that increase decomposition rates of CWD (Ligon 1971, McMinn and Hardt 1996). Also, intensively managed southern pine forests are grown on 20 to 30 year rotations (Dickson 2001), which do not allow trees to grow as large as in other regions such as the Pacific Northwest and the Central and Southern Appalachians. As a result, CWD is on average smaller in southern pine forests. Because of natural volume differences among regions, its roles in these various ecosystems might likewise be different.

Objectives

This study was a continuation of a long-term investigation into the role of CWD as an ecosystem component in southeastern Coastal Plain pine forests. This study was conducted in years 8 and 9 of the long-term study. My objective was to determine how CWD, in the form of downed wood and snags, affects amphibian and reptile communities in managed pine forests of the southeastern Coastal Plain. I compared response variables among sites in which downed wood was added, downed wood was removed, snags were added, and in which CWD was not manipulated.

I predicted several responses of herpetofauna to these CWD manipulations. First, I hypothesized herpetofauna abundance and diversity would respond positively to the addition of downed wood because of increased resting and foraging habitat. I predicted many herpetofaunal species would respond positively to the presence of snags, because of their use of snags for foraging and basking. I also predicted surface activity would be greatest in sites where CWD was added and lowest where it was removed, because logs would allow moisture replenishment, preventing desiccation without having to burrow below the surface. Additionally, in the absence of logs, herpetofauna might be more limited by a lack of rain, and therefore their activity might be more strongly correlated with precipitation than activity of herpetofauna in sites where CWD was added. Finally, I predicted that herpetofauna exposed to downed wood would have a better body condition than those from sites without CWD, due to increased foraging opportunities.

METHODS

Study site

The study was conducted on the Savannah River Site (SRS), a National Environmental Research Park administered by the U.S. Department of Energy (DOE). Located in the Upper

Coastal Plain and Sandhills physiographic region (Kilgo and Blake 2005), this area is characterized by periodic fire, sandy soils, and gently sloping hills dominated by pines with scattered hardwoods. The region has been described as humid subtropical; mean annual temperature in the region is 18º C, and mean annual precipitation is 122.5 cm (Blake et al. 2005).

The SRS was composed mostly of old field habitat when the DOE acquired the land in the early 1950's. The DOE contracted the U.S. Forest Service to manage the land, which then began hand-planting the uplands with pine, including loblolly (*Pinus taeda*), slash (*P. elliottii*) and longleaf (*P. palustris*) pine. Pine forests continue to dominate the SRS landscape today; in 2001, the majority of the 78,000 hectares that make up the SRS was forested, and 72% of those forests were 30 years old or more (White 2005).

The research plots were located in loblolly pine stands planted between 1950-1953. Although *P. taeda* dominates the overstory in each of the stands, *P. elliottii* and *P. palustrus* were also interspersed among the canopy. Understory vegetation was mainly composed of lespedeza (*Lespedeza* sp.), poison oak (*Toxicodendron pubescens*), blackberry (*Rubus* sp.), black cherry (*Prunus serotina*), and sassafras (*Sassafras albidum*).

Study design

The study was designed as a randomized complete block, with each of four treatments randomly assigned to three adjacent blocks (forest stands), for a total of 12, 9.3-ha plots. Treatments were applied to the entire 9.3-ha plot, but trapping only occurred in the 6-ha core of each plot to avoid edge effects. The four treatments included *control*, where CWD was not manipulated; *removal*, where all CWD >10 cm diameter and 60 cm long was removed (implemented in 1996); *downed*, where volume of downed CWD was increased five-fold

(implemented in 2001); and *snag*, where standing CWD volume was increased 10-fold (implemented in 2001). Snags were created in snag treatment plots by girdling and later injecting herbicide into pines in 12 strips, resulting in a basal area of 15.9 m^3 of live trees. To increase downed wood volume in downed plots, 12 strips of pines were felled. All treatment plots were thinned in 2001 to standardize live-tree basal area across treatments to 13.8 - 20.8 m^2/ha.

Prescribed burns were conducted in the stands every 3-4 years by the U.S. Forest Service as part of their standard management practices for the site. All 12 plots were burned in the summer of 2004. Annual removal of CWD ensured that removal plots remained free of all limbs and downed trees greater than 10 cm diameter and 60 cm length. Besides prescribed burning, there were no other manipulations of the plots after the initiation of the downed and snag treatments in 2001.

Data collection

Downed woody debris inventories were conducted at the end of each year in randomly selected subplots (50 x 50 m) within the inner 4-ha of each plot. Coarse woody debris was measured in six subplots in downed treatment plots, eight subplots in snag plots, and 16 subplots in control plots. Within each subplot, logs greater than 10-cm diameter and 60-cm length with at least 50% of their measurable length within the subplot were counted. In downed, control, and snag plots, each piece of downed wood was tagged, measured, and given a decay classification. Logs were classified as decay stage 1-5 based on Maser et al. (1979), where stage 1 logs were sound, with intact bark; stage 2 logs had mostly sound wood with some bark starting to flake; stage 3 logs had broken branches and were missing bark; stage 4 logs were soft and blocky in

texture; and stage 5 logs were powdery in texture and partly buried. In removal plots, all downed wood was measured and removed at the end of each year. Volume (m^3/ha) of CWD in all plots was calculated from length and diameter measurements.

Amphibians and reptiles were sampled using drift fence arrays located on each plot, which are effectively used for sampling many ground-dwelling amphibian and reptile species (Gibbons and Bennett 1974, Gibbons and Semlitsch 1981). The fences consisted of aluminum flashing buried 15-cm below ground with 19-liter plastic buckets buried flush to the ground against each fence. Each plot contained one cross-shaped drift fence array with four 30-m arms extending in each of the cardinal directions from the center of the plot, and four Y-shaped arrays with three 15-m arms located in each corner of the 6-ha core area (Figure 3-1). Bucket traps were maintained with a small amount of soil or water during sampling periods.

Sample periods were 14-days each season from fall 2003 through fall 2005, for a total of nine periods. Buckets were checked daily during the sampling period except during winter, when capture rates were low and they were checked every other day. All captured amphibians and reptiles were identified to species, measured for mass and snout-vent length, marked with removal of a single toe, and released on the other side of the fence from which they were captured. Although toe-clipping can decrease survival and probability of recapture of frogs, the removal of a single toe appears to have a negligible effect (McCarthy and Parris 2004). The side of the fence each individual was caught on was recorded for analysis of movement direction. This was only possible on individuals captured in the cross-shaped drift fences, which were arranged according to cardinal directions. Weather data for each sample day were collected at the Central Climatology station, approximately 24 kilometers from the study site.

Statistical analysis

A randomized complete block two-way analysis of variance (ANOVA) was used to test the effects of treatment and season on all response variables. Significant results were further analyzed using Tukey's Honestly Significant Difference (HSD) test and the estimation procedure to make pair-wise mean comparisons using a 90% confidence interval. Response variables of interest were species abundance, richness, and diversity (Shannon-Weiner Index, H', Pielou 1977) of reptiles, amphibians, and of all taxonomic groups with at least 25 captures. Additionally, surface activity (total number of days captured) was examined to test the effect of treatment on activity of those species captured at least 25 times, including recaptures. Recaptures were not used in the other analyses.

A linear Pearson's correlation coefficient was used to examine the relationship between precipitation amount in the previous 24 hours within each treatment and total number of reptiles captured per day, reptile species richness per day, total number of amphibians captured per day, and amphibian species richness per day. Because these variables were a function of total activity, recaptures were included. Winter sampling periods were not included in these analyses because traps were checked only every other day.

For amphibians, we examined the effect of treatment on body condition. Length-weight regression was used as an indicator of condition, because healthier animals are likely to have higher body mass (Fellers and Drost 1994). The regression was calculated as length divided by the cube root of the mass for each individual. Regressions were calculated for all amphibian species captured and measured at least five times in each of the treatment/forest stand combinations (not including recaptures). These values were then compared among treatments using a randomized complete block ANOVA.

Movement direction of captured individuals was analyzed to determine what portion of the study population was migratory, as migration might affect treatment responses. Movement direction was assumed to be associated with side of capture. A Chi-square test was used to test for equal captures among the four sides, for amphibians and for reptiles, which would be interpreted as no specific movement direction. Because movement is likely seasonal, these analyses were performed for each of the four seasons by combining captures from eight sampling periods (capture side was not recorded during one sampling period, fall 2003). However, there were no reptile captures during winter, so reptile movement was not analyzed during winter.

Forest stand was used as a block factor for all ANOVA analyses. All statistical analyses were performed using SAS 9.1 (SAS Institute 2005).

RESULTS

Refer to Chapter 2 for downed wood volumes among treatment plots. A total of 4,136 individual reptiles and amphibians was captured over 1,512 plot-nights (Table 3-1), representing 14 amphibian and 22 reptile species. The most frequently captured species were *Ambystoma talpoideum* (mole salamander), *Bufo terrestris* (southern toad), and *Gastrophryne carolinensis* (eastern narrowmouth toad), which together represented 72% of all captures.

There was no interaction between treatment and season for abundances of any of the taxonomic groups ($P > 0.05$). Relative abundance was similar among treatments for herpetofauna, amphibians, reptiles, anurans, salamanders, lizards, and snakes ($P > 0.05$) (Table 3-2). Abundance of *Rana sphenocephala* (southern leopard frog) was greater ($F_{2,3} = 5.23$, $P = 0.005$) in the removal plots than the downed, control, and snag plots ($q_{0.05, 30} = 3.85$). Abundance of *Cnemidophorus sexlineatus* (six-lined racerunner) was different among treatments ($F_{2,3} = 2.91$,

$P = 0.05$), however, Tukeys' HSD test failed to detect a difference at the 0.05 alpha level. No other species abundances differed among treatments ($P > 0.05$). Season had a significant effect on relative abundance of several taxonomic groups ($P \leq 0.05$, $q_{0.05, 30} = 3.85$) (Table 3-3). There was a block effect for abundance of *Rana clamitans* (bronze frog) ($F_{2,3} = 9.87$, $P = 0.0005$), *R. sphenocephala* ($F_{2,3} = 3.75$, $P = 0.04$), *S. holbrookii* ($F_{2,3} = 7.21$, $P = 0.003$), *Tantilla coronata* ($F_{2,3} = 4.22$, $P = 0.02$), and snake ($F_{2,3} = 4.28$, $P = 0.02$).

Anuran richness exhibited a significant interaction between treatment and season ($F_{2,9} = 2.25$, $P = 0.05$) but the means separation tests failed to reveal any treatment differences during any of the seasons. The interaction between treatment and season was not significant for richness of any of the other taxonomic groups ($P > 0.05$). Species richness of amphibians, reptiles, salamanders, and lizards was similar among treatments ($P > 0.05$) (Table 3-2). However, snake species richness was greater ($F_{2,3} = 3.45$, $P = 0.03$) in downed, removal, and control treatment plots than in snag treatment plots ($q_{0.05, 30} = 3.85$). Species richness was different among seasons for all taxonomic groups analyzed ($P \leq 0.05$) (Table 3-3). There was a block effect for anuran richness ($F_{2,3} = 3.39$, $P = 0.05$).

No interaction between treatment and season was detected for diversity of any of the taxonomic groups ($P > 0.05$). Herpetofaunal, amphibian, reptile, anuran, salamander, lizard, and snake diversities were similar among treatments ($P > 0.05$) (Table 3-2). However, season was a significant factor on diversity of several taxonomic groups ($P \leq 0.05$) (Table 3-3).

The only species that exhibited a difference in surface activity among treatments was *R. sphenocephala* (Table 3-4). This species was captured in removal plots on average 11.0 days, control plots 7.3 days, downed plots 5.3 days, and snag plots 5.0 days. The Tukey's HSD test revealed that mean number of days *R. sphenocephala* was captured was greater in the removal

than both the downed and snag treatments ($q_{0.05, 6} = 4.89$). The results of the estimation procedure showed that the estimated mean difference in number of days captured between removal and control plots was 3.67 (SE = 1.48, t = 2.47, $P = 0.05$). The mean difference in number of days captured between removal and downed treatments was 5.33 (SE = 1.48, t = 3.59, $P = 0.01$). There was a block effect for activity of *B. terrestris* ($F_{2,3} = 6.77$, $P = 0.03$) and of *R. sphenocephala* ($F_{2,3} = 18.68$, $P = 0.003$).

Daily amphibian captures were correlated with daily precipitation in all treatments except downed (Table 3-5). Daily amphibian species richness was correlated with daily precipitation in all treatments. Daily reptile captures were correlated with daily precipitation in the downed treatment. Daily reptile species richness was not correlated with daily precipitation in any treatments. Mean daily precipitation during sampling days was 0.12 cm (SE = 0.03, n = 126 days).

The only amphibians captured at least five times in each of the treatment/forest combinations and examined for body differences among treatments were *B. terrestris, G. carolinensis,* and *S. holbrookii*. No treatment differences in body condition were observed ($P > 0.05$) for any species.

The results of the Chi-square analysis indicated that the number of reptile captures was not different ($P > 0.05$) among sides of the arrays suggesting there was no directional movement during any season (Table 3-6). However, the number of amphibian captures differed among sides during summer ($\chi^2_3 = 85.36$, $P = <0.0001$), with about 33 % of captures moving west, and 33 % moving north. During winter, amphibian captures also differed among sides ($\chi^2_3 = 32.11$, $P <0.0001$), with a largest percentage of captures (47 %) moving south. Amphibian captures did not differ among sides during spring or fall ($P > 0.05$) (Table 3-7).

DISCUSSION

Overall, my results do not support the hypothesis that herpetofauna respond positively to the addition of downed and standing dead wood, at least in early to moderate stages of decay. The only species that exhibited a response to the manipulations was *Rana sphenocephala,* and it appears to be negatively affected by the downed wood. However, because this is primarily a wetland species, it should be more susceptible to desiccation and therefore more sensitive to the absence of cover. This species is known to travel well away from water, especially in the summer (Conant and Collins 1998). *Rana sphenocephala* captured at this study site may have used the uplands for migration to other wetlands. The increased activity and capture rate observed in removal plots may have been an artifact of a behavioral change in the absence of logs, and not an actual increase in abundance. An assumption when using pitfall traps to measure relative abundance is that captures rates are similar across habitats (Corn 1994). However, there may be physiological reasons that amphibians adjust their activity levels in different habitats (deMaynadier and Hunter 1995), resulting in capture bias. In the removal plots, continuous movement of individuals may have been necessitated due to lack of suitable cover as they searched for refugia. In downed plots, *R. sphenocephala* may spend more time under CWD refugia, resulting in a lower number of captures compared with removal plots, where all the individuals in the plot are forced to be active on the surface. This behavior, termed "wandering" by Heatwole (1960) was observed in *Plethodon cinereus* (redback salamander) in a lab study that investigated their behavioral responses to desiccating conditions. Heatwole (1960) hypothesized that this behavior was a final effort to find moist conditions when suitable burrow sites were not available.

Reptiles did not respond positively to the creation of snags, as I expected would occur due to the increased foraging and basking opportunities provided by standing dead trees. Because of the trapping methodology employed, most of the snake species that were captured were juvenile snakes or small fossorial snake species that do not use snags for basking or foraging like larger, more arboreal species. I also expected to observe more lizards in the snag plots, especially *Sceloporus undulatus* (fence lizard) and *Anolis carolinensis* (green anole), which are both territorial and use snags for displaying to conspecifics and as sites for detecting predators (Whiles and Grubaugh 1996). These species may be incurring some benefit from the use of snags, such as greater basking opportunities. However, the increase in snags appears not to positively influence abundance of lizards and snakes. My trapping methods may not have allowed me to detect a treatment response, however, as these species are both arboreal and my traps were on the ground. A different methodology with traps placed closer to trees may have been more appropriate for these species.

I hypothesized that there would be stronger correlation between daily activity and daily rainfall in the removal treatment plots. I based this on the hypothesis that the use of CWD to replenish moisture would offer an advantage to herpetofauna that would allow them to remain active during dry periods. However, there was no pattern to the strength of correlation between activity and precipitation for amphibians or reptiles among treatments, suggesting that logs do not provide any advantage for the activity of herpetofauna. In the absence of standing water, terrestrial amphibians retreat to shelters to avoid desiccation when thermal and hydric conditions necessitate, because they cannot physiologically control their moisture loss (Tracy 1976, Wygoda 1988). Because CWD represents a shelter microhabitat that is moisture-rich (Harmon et al. 1986, Grover 1996), amphibians that use CWD for cover may concurrently replenish their

moisture. However, the sandy soil of the Coastal Plain may provide an alternative shelter source for herpetofauna, which may also offer moisture replenishment for amphibians. Soil moisture may not have been limiting during this study, but during extremely dry conditions the moisture content of CWD may be greater than that of soil, which may influence the ability of herpetofauna to remain active among treatments.

The movement data suggest that most amphibians captured in the summer and winter were non-resident individuals, either adults immigrating to the breeding area or recent metamorphs emigrating from ponds to the uplands. Even though these individuals may have been non-residents, migrating amphibians can be negatively affected by environmental variables that influence moisture loss in habitats through which they travel (Rothermel and Semlitsch 2002). However, the results of this study suggest that the removal of CWD, at least in the early to moderate stages of decay, does not influence the survival of migrating amphibians. The majority of the amphibians captured (91%) were *A. talpoideum*, *B. terrestris, G. carolinensis,* and *S. holbrookii*, which are species that can burrow to avoid desiccation. Surface litter is important in regulating temperature and moisture of amphibian microhabitats (Pough et al. 1997), and has been shown to adequately protect burrowed *A. talpoideum* from desiccation (Moseley et al. 2004). A sufficient pine litter layer may be more important than CWD in preventing desiccation of migrating amphibians in loblolly pine stands.

Further supporting the hypothesis that amphibians are not negatively affected by the absence of logs, body condition of the three anuran species analyzed was similar among treatments. Logs are used as habitat and food by many species of invertebrates (Hanula 1996), and invertebrate abundance can be negatively influenced by a decrease in CWD volume (McCay et al. 2002). I therefore hypothesized there would be more foraging opportunities for amphibians in the downed

treatment plots, resulting in better body condition of these individuals. Moseley et al. (2005) found that *B. terrestris* collected from these same treatment plots had similar body weights and mean number of prey items in their stomachs among treatments, suggesting that the removal of downed wood had no effect on foraging opportunities. The leaf and pine litter present on all plots may have contained sufficient arthropod abundance to allow equal foraging regardless of CWD volume. However, as the CWD reaches advanced stages of decay, it might provide a more abundant and diverse invertebrate prey base (Harmon et al. 1986), and may positively influence anuran body condition in the downed treatments.

The lack of positive responses to CWD observed was similar to results from previous research on this study site (Moseley 2004). The lack of response may have been a function of CWD decay state. As logs decay, they absorb and retain more moisture (Jaeger 1980, Maser et al. 1988), allowing amphibians to maintain water balance while under cover from predators. Branches that suspend logs break as they decay, allowing the logs to come into more contact with the ground (Maser and Trappe 1984), providing more effective cover for herpetofauna. Furthermore, a well-decayed log that has loosened bark and softened wood provides habitat for wood-feeding insects (Harmon et al. 1986), which increases foraging opportunities for herpetofauna. The majority of the logs (59%) at this study site were in decay stages 1 and 2 meaning that they had intact bark, were round in circumference, and were still elevated on supports (Maser et al. 1988). As the wood at the study site continues to decay, its use by herpetofauna may increase, resulting in a stronger treatment response.

In addition to decay state and volume of CWD, the distribution of downed wood can influence its use by vertebrates (Harmon et al. 1986). The CWD in the downed plots of this study was scattered randomly throughout the treatment plots. This may not accurately mimic the

natural distribution of dead wood, because input of CWD is usually associated with mortality factors that occur in clumps, creating aggregations of wood piles (Harmon et al. 1986). Woody debris piles, such as those created by mortality from insect infestations and tornadoes, may be more beneficial to herpetofauna than an abundance of logs scattered throughout a stand, because they provide more cover.

Most of the evidence suggesting that CWD influences herpetofaunal communities comes from studies in old-growth forests of the Pacific Northwest (Corn and Bury 1991, Aubry 2000, Butts and Comb 2000, Grialou et al. 2000), where mean volume of CWD is about 500 m^3 per ha compared with <20 m^3 per ha in pine forests of Georgia public land (Spies and Cline 1988, McMinn and Hardt 1996). Coastal Plain herpetofauna may not have evolved to rely critically on CWD because it is naturally found in relatively low volumes in the region. Additionally, most of the above studies involve plethodontid salamanders, which are thought to be more sensitive to changes in moisture after harvesting than other herpetofauna (DeMaynadier and Hunter 1995). The majority (79%) of the herpetofauna captured in the current study were *A. talpoideum*, *B. terrestris, G. carolinensis,* and *S. holbrookii*, which are all species adapted to avoid desiccation by burrowing in sandy soil. Additionally, anurans have the ability to store water in their bladders, making them less susceptible to water loss than salamanders (Duellman and Trueb 1986). These species may therefore be less reliant on sources of cover such as CWD than those species that cannot burrow.

Despite the lack of an observed treatment response of herpetofauna to CWD manipulations in this study, amphibians and reptiles may still use CWD, if only facultatively. One of the reasons that CWD is found in naturally low levels in the Coastal Plain may be due to frequent fires (Harmon et al. 1986). The use of CWD by herpetofauna may be more obligate in the absence of

other microhabitat features (i.e., leaf litter or pine straw), as occurs after an intense fire. In an enclosure study in a loblolly pine stand, *A. talpoideum* were found underneath CWD more frequently in enclosures with low pine litter and high CWD levels compared with *A. talpoideum* in enclosures with high pine litter and high CWD (Moseley et al. 2004). The authors suggested that in the absence of pine litter, CWD acted as a buffer against the negative effects of pine litter removal, supporting the hypothesis that CWD may not be a critical habitat component for these species, but one used when microhabitat conditions necessitate.

Coarse woody debris may not be a critical habitat component for herpetofauna in upland pine forests of the southeastern Coastal Plain, as the lack of responses to CWD manipulations in this study suggests. However, herpetofauna in this region probably use and benefit from CWD on a facultative basis. Further research is needed to determine the influence of other CWD attributes, such as decay state and spatial distribution within the stand, on herpetofaunal community structure. Nonetheless, because the importance of CWD in overall ecosystem function is poorly understood, management practices in pine forests of the southeastern Coastal Plain should maintain stand structural complexity by mimicking the effects of natural disturbance (Sharitz et al. 1992).

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Table 3-1. Total numbers of herpetofauna captured from drift fences in control (n = 3), downed (n = 3), removal (n = 3), and snag (n = 3) treatment plots in loblolly pine (*Pinus taeda*) stands at the Savannah River Site, Barnwell Co., South Carolina from fall 2003 through fall 2005. Recaptures are not included. Species with >25 total captures were analyzed individually for treatment effects.

	Treatment				
Species	Control	Downed	Removal	Snag	Total
Ambystoma talpoideum (mole salamander)	61	49	165	919	1194
Bufo terrestris (southern toad)	195	340	247	180	962
Gastrophryne carolinensis (eastern narrowmouth toad)	230	277	169	123	799
Scaphiopus holbrookii (eastern spadefoot toad)	77	57	91	58	283
Rana sphenocephala (southern leopard frog)	28	16	78	21	143
Tantilla coronata (southeastern crowned snake)	33	35	42	21	131
Sceloporus undulatus (eastern fence lizard)	24	54	29	22	129
Anolis carolinensis (green anole)	24	11	38	29	102
Pseudacris ornata (ornate chorus frog)	13	11	27	18	69
Rana clamitans (bronze frog)	10	3	14	8	35
Cnemidophorus sexlineatus (six-lined racerunner)	5	11	15	2	33
Scincella lateralis (ground skink)	3	6	14	9	32
Virginia valeriae (smooth earth snake)	9	7	8	4	28
Ambystoma tigrinum (tiger salamander)	5	8	5	6	24
Plethodon chlorobryonis (Atlantic Coast slimy salamander)	7	9	5	2	23
Eumeces inexpectatus (southeastern five-lined skink)	6	5	6	4	21
Eumeces laticeps (broadhead skink)	5	5	6	5	21
Rana catesbeiana (bullfrog)	6	6	8	1	21
Cemophora coccinea (scarlet snake)	1	7	4	2	14
Storeria occipitomaculata (redbelly snake)	2	7	0	2	11
Heterodon simus (southern hognose snake)	2	3	2	1	8
Thamnophis sirtalis (eastern garter snake)	3	1	1	0	5
Acris gryllus (southern cricket frog)	0	0	2	2	4
Coluber constrictor (black racer)	0	1	3	0	4
Eumeces fasciatus (five-lined skink)	1	0	1	2	4

Table 3-1 Cont.

	Treatment				
Species	Control	Downed	Removal	Snag	Total
Masticophis flagellum (eastern coachwhip)	0	0	4	0	4
Rana capito (gopher frog)	0	2	1	1	4
Heterodon platyrhinos (eastern hognose snake)	0	2	1	0	3
Diadophis punctatus (southern ringneck snake)	1	1	0	0	2
Ambystoma opacum (marbled salamander)	0	0	0	1	1
Elaphe obsoleta (eastern rat snake)	0	0	1	0	1
Pseudotriton ruber (southern red salamander)	0	0	1	0	1
Sistrurus miliaris (pigmy rattlesnake)	1	0	0	0	1
Storeria dekayi (northern brown snake)	1	0	0	0	1
Terrapene carolina (eastern box turtle)	0	0	0	1	1
Trachemys scripta (yellow-bellied slider)	0	0	0	1	1
Total	**753**	**934**	**988**	**1445**	**4120**

Table 3-2. Mean (SE) abundance, richness, and Shannon-Weiner diversity values of herpetofauna captured in drift fence from fall 2003 through fall 2005 in upland *Pinus taeda* stands on the Savannah River Site, Barnwell Co., South Carolina. Taxonomic groups analyzed are listed under each response variable. Letters adjacent to means indicate significant differences among treatment means using Tukey's Honestly Significant difference test ($\alpha = 0.05$).

	Mean (SE)			
Response	Control (n = 3)	Downed (n = 3)	Removal (n = 3)	Snag (n = 3)
Abundance				
Amphibian	211.0 (35.0)	260.0 (69.6)	271.0 (5.1)	449.3 (263.3)
Salamander	24.3 (17.9)	22.0 (10.0)	58.7 (45.0)	309.3 (294.8)
Ambystoma talpoideum	20.3 (16.9)	16.3 (6.4)	55.0 (44.2)	306.3 (294.8)
Anuran	186.7 (18.5)	238.0 (64.7)	212.3 (46.2)	140.0 (31.5)
Bufo terrestris	65.0 (10.1)	113.3 (55.9)	82.3 (31.0)	60.0 (21.8)
Gastrophryne carolinensis	76.7 (26.3)	92.3 (46.9)	56.3 (13.9)	41.0 (17.8)
Pseudacris ornata	4.3 (0.3)	3.7 (1.2)	9.0 (2.9)	6.0 (2.1)
Rana clamitans	3.3 (1.3)	1.0 (0.6)	4.7 (3.2)	2.7 (1.8)
Rana sphenocephala	9.3 (3.3)b	5.3 (1.7)b	26.0 (8.7)a	7.0 (3.2)b
Scaphiopus holbrookii	25.7 (7.1)	19.0 (3.6)	30.3 (5.2)	19.3 (8.4)
Reptile	40.7 (4.9)	52.3 (6.0)	58.3 (6.2)	36.0 (12.1)
Lizard	22.7 (1.3)	30.7 (9.3)	36.3 (9.4)	24.3 (5.6)
Sceloporus undulatus	8.0 (0.6)	18.0 (7.8)	9.7 (3.7)	7.3 (1.9)
Anolis carolinensis	8.0 (1.5)	3.7 (0.7)	12.7 (1.5)	9.7 (5.2)
Cnemidophorus sexlineatus	1.7 (1.7)	3.7 (2.0)	5.0 (2.1)	0.7 (0.3)
Scincella lateralis	1.0 (1.0)	2.0 (1.5)	4.67 (2.6)	3.9 (0.6)
Snake	18.0 (3.8)	21.7 (4.2)	22.0 (3.2)	11.0 (6.5)
Tantilla coronata	11.0 (8.2)	11.7 (2.7)	14.0 (2.3)	7.0 (5.5)
Virginia valeriae	3.0 (1.5)	2.3 (0.7)	2.7 (0.9)	1.3 (0.7)

Table 3-2 Cont.

	Mean (SE)			
Response	Control (n = 3)	Downed (n = 3)	Removal (n = 3)	Snag (n = 3)
Richness				
Herpetofaunal	2.5 (1.5)	1.0 (0.6)	4.7 (2.7)	5.7 (3.3)
Amphibian	9.7 (0.3)	9.3 (0.9)	9.3 (0.9)	9.7 (0.9)
Salamander	3.0 (0.0)	2.7 (0.3)	2.3 (0.3)	2.7 (0.7)
Anuran	5.7 (0.3)	5.7 (0.7)	6.0 (0.6)	6.0 (0.6)
Reptile	9.3 (0.3)	11.0 (1.2)	11.3 (0.7)	9.3 (1.3)
Lizard	4.7 (0.3)	5.3 (0.3)	5.3 (0.7)	5.7 (0.9)
Snake	4.3 (0.3)a	4.7 (0.3)a	5.0 (0.02)a	2.7 (0.3)b
Diversity				
Herpetofaunal	2.0 (0.1)	1.9 (0.3)	2.1 (0.1)	1.8 (0.7)
Amphibian	1.5 (0.0)	1.4 (0.2)	1.6 (0.1)	1.1 (0.4)
Salamander	0.8 (0.2)	0.6 (0.2)	0.5 (0.2)	0.4 (0.3)
Anuran	1.2 (0.1)	1.1 (0.2)	1.4 (0.1)	1.2 (0.1)
Reptile	1.9 (0.1)	1.9 (0.0)	2.0 (0.1)	1.8 (0.04)
Lizard	1.3 (0.1)	1.2 (0.1)	1.4 (0.1)	1.4 (0.0)
Snake	1.1 (0.0)	1.4 (0.1)	1.2 (0.0)	0.90 (0.2)

Table 3-3. Mean (SE) of response variables that differed among seasons in control, downed, removal, and snag treatment plots in upland *Pinus taeda* stands on the Savannah River Site, Barnwell Co., South Carolina, fall 2003 through fall 2005. Letters adjacent to means indicate significant differences among treatment means using Tukey's Honestly Significant difference test ($\alpha = 0.05$). Diversity was calculated using Shannon-Weiner Index (H').

	Mean			
Response	Spring	Summer	Fall	Winter
Abundance				
Herpetofauna	35.0 (2.2)ab	164.9 (21.0)a	128.6 (72.5)ab	16.2b
Amphibian	20.7 (2.7)ab	145.8 (20.6)a	115.2 (71.7)ab	16.2 (3.5)b
Anuran	15.8 (1.6)b	146.7 (20.6)a	25.0 (2.8)b	7.8 (2.6)b
Bufo terrestris	5.3 (0.7)b	68.5 (15.4)a	5.5 (1.3)b	0.9 (0.2)b
Gastrophryne carolinensis	7.8 (1.1)b	57.6 (13.4)a	0.4 (0.2)b	0.0 (0.0)b
Pseudacris ornata	0.2 (0.2)b	0.0 (0.0)b	3.2 (0.1)a	2.5 (0.8)a
Rana clamitans	0.4 (0.2)b	1.3 (0.5)a	0.7 (0.3)ab	0.5 (0.3)ab
Rana sphenocephala	0.1 (0.1)b	4.1 (1.0)ab	5.3 (1.5)a	2.5 (1.8)ab
Scaphiopus holbrookii	1.8 (0.4)c	12.2 (1.6)a	8.2 (1.7)b	1.3 (0.4)c
Reptile	14.3 (1.1)ab	19.1 (2.6)a	13.4 (1.8)b	0.0 (0.0)c
Lizard	12.8 (1.2)a	9.4 (2.0)ab	6.3 (1.2)b	0.0 (0.0)c
Anolis carolinensis	3.8 (0.8)a	2.0 (0.6)ab	2.8 (0.9)a	0.0 (0.0)b
Cnemidophorus sexlineatus	1.2 (0.4)a	1.3 (0.5)a	0.3 (0.2)ab	0.0 (0.0)b
Scincella lateralis	0.9 (0.4)ab	1.5 (0.7)a	0.3 (0.1)ab	0.0 (0.0)b
Sceloporus undulatus	5.2 (1.9)a	2.6 (0.4)ab	3.0 (1.1)a	0.0 (0.0)b
Snake	1.5 (0.3)b	9.6 (1.4)a	7.1 (1.2)a	0.0 (0.0)b
Tantilla coronata	0.7 (0.2)c	7.1 (1.2)a	3.2 (0.6)b	0.0 (0.0)c
Virginia valeriae	0.3 (0.1)bc	0.9 (0.2)ab	1.2 (0.4)a	0.0 (0.0)c
Richness				
Herpetofauna	10.8 (0.6)b	12.0 (0.6)ab	13.1 (0.5)a	3.8 (0.4)c
Amphibian	5.2 (0.4)b	5.0 (0.2)bc	7.7 (0.4)a	3.8 (0.4)c
Anuran	3.8 (0.4)a	4.8 (0.2)b	5.3 (0.3)b	3.1 (0.4)a

Table 3-3 Cont.

	Mean			
Response	Spring	Summer	Fall	Winter
Richness				
Salamander	1.4 (0.3)a	0.2 (0.1)b	2.3 (0.2)c	1.1 (0.3)a
Reptile	5.7 (0.3)a	7.3 (0.6)b	5.4 (0.3)a	0.0 (0.0)c
Lizard	4.3 (0.3)a	4.2 (0.5)a	2.3 (0.2)b	0.0 (0.0)c
Snake	1.3 (0.3)b	3.1 (0.3)a	3.2 (0.4)a	0.0 (0.0)c
Diversity				
Herpetofauna	2.1 (0.1)a	1.5 (0.1)b	2.0 (0.2)a	1.0 (0.1)c
Amphibian	1.4 (0.1)ab	1.0 (0.1)bc	1.5 (0.2)a	1.0 (0.1)c
Anuran	1.1 (0.2)b	1.0 (0.1)b	1.4 (0.1)a	0.9 (0.1)b
Salamander	0.3 (0.1)a	0.0 (0.0)c	0.5 (0.1)a	0.0 (0.0)c
Reptile	1.4 (0.1a	1.7(0.1a	1.5 (0.1)a	0.0 (0.0)b
Lizard	1.2 (0.1)a	1.3 (0.1)a	0.7 (0.1)b	0.0 (0.0)c
Snake	0.3 (0.1)b	0.8 (0.1)a	1.0 (0.1)a	0.0 (0.0)b

Table 3-4. Mean (SE) days active of each species captured at least 25 times from drift fences sampled from fall 2003 through fall 2005 in control, downed, removal, and snag treatment plots in upland *Pinus taeda* stands on the Savannah River Site, Barnwell Co., South Carolina. Letters adjacent to means indicate significant differences among treatment means using Tukey's Honestly Significant difference test ($\alpha = 0.05$).

	Mean (SE)			
Species	Control (n = 3)	Downed (n = 3)	Removal (n = 3)	Snag (n = 3)
Ambystoma talpoideum	5.0 (2.5)	6.3 (1.8)	5.7 (1.8)	6.0 (0.0)
Bufo terrestris	25.3 (2.0)	30.7 (3.3)	25.3 (3.7)	22.0 (3.2)
Gastrophryne carolinensis	18.0 (0.6)	18.3 (3.3)	17.3 (1.5)	16.3 (4.9)
Pseudacris ornata	2.3 (0.3)	2.7 (0.3)	4.7 (1.2)	2.0 (0.6)
Rana clamitans	3.3 (0.9)	1.7 (0.7)	5.3 (3.8)	2.0 (1.2)
Rana sphenocephala	7.3 (2.2)ab	5.7 (1.9)b	11.0 (3.2)a	5.0 (2.3)b
Scaphiopus holbrookii	14.3 (3.2)	13.7 (1.5)	18.0 (2.5)	11.3 (1.9)
Anolis carolinensis	7.0 (0.0)	3.7 (0.7)	10.0 (1.2)	7.3 (2.9)
Cnemidophorus sexlineatus	1.3 (1.3)	3.3 (1.8)	4.7 (1.7)	0.7 (0.3)
Sceloporus undulatus	8.0 (0.0)	16.0 (6.0)	8.3 (2.9)	6.7 (1.2)
Scincella lateralis	1.0 (1.0)	2.0 (1.5)	3.7 (2.0)	3.0 (0.6)
Tantilla coronata	9.3 (2.0)	10.7 (2.2)	10.0 (1.0)	6.33 (4.8)
Virginia valeriae	3.0 (1.5)	2.3 (0.7)	2.0 (0.6	1.0 (0.6)

Table 3-5. Correlation coefficients (r) and *P*-values from Pearson correlation tests between daily precipitation amount and these variables: daily number of amphibians captured, daily amphibian species richness, daily number of reptiles captured, and daily reptile species richness. Daily precipitation was defined as the amount of rain in the 24 hours prior to the morning that traps were checked. Amphibians were captured using drift fences and bucket traps from winter 2004-fall 2005 in loblolly pine (*Pinus taeda*) stands at the Savannah River Site in Barnwell Co., South Carolina.

	Control (n = 3)		Downed (n = 3)		Removal (n = 3)		Snag (n = 3)	
Variable	r	*P*-value	r	*P*-value	r	*P*-value	r	*P*-value
Daily amphibian captures	0.20	0.05	0.11	0.26	0.39	<0.0001	0.44	<0.0001
Daily amphibian richness	0.39	<0.0001	0.34	0.0006	0.30	0.003	0.32	0.002
Daily reptile captures	-0.15	0.13	-.18	0.08	-0.1	0.35	-0.15	0.14
Daily reptile richness	-0.16	0.11	-0.15	0.15	-0.15	0.14	-0.14	0.18

Table 3-6. Results of Chi-square tests showing observed (o_i) and expected (e_i) proportions of reptile captures among east, north, south, and west sides of drift fence arms during fall, spring, and summer during two years of sampling in loblolly pine stands at the Savannah River Site, Barnwell Co., South Carolina. Letters after values indicate where expected values differed from observed.

	Fall (n = 35)		Spring (n = 70)		Summer (n = 118)	
	o_i	e_i	o_i	e_i	o_i	e_i
East	34.29a	25a	21.43a	25a	25.42a	25a
North	14.29a	25a	24.29a	25a	19.49a	25a
South	20.00a	25a	30.00a	25a	31.36a	25a
West	31.43a	25a	24.29a	25a	23.73a	25a

Table 3-7. Results of Chi-square tests showing observed (o_i) and expected (e_i) proportions of amphibian captured moving in the east, north, south, and west directions based on drift-fence captures during fall, winter, spring, and summer during two years of sampling in loblolly pine (*Pinus taeda*) stands at the Savannah River Site, Barnwell Co., South Carolina. Letters after values indicate where observed values differed from expected.

	Fall (n = 30)		Winter (n = 99)		Spring (n = 102)		Summer (n = 755)	
	o_i	e_i	o_i	e_i	o_i	e_i	o_i	e_i
East	16.67a	25a	29.29a	25a	31.37a	25a	32.98a	25a
North	36.67a	25a	46.46b	25a	26.47a	25a	20.00a	25a
South	23.33a	25a	12.12b	25a	25.49a	25a	33.25a	25a
West	23.33a	25a	12.12b	25a	16.67a	25a	13.77b	25a

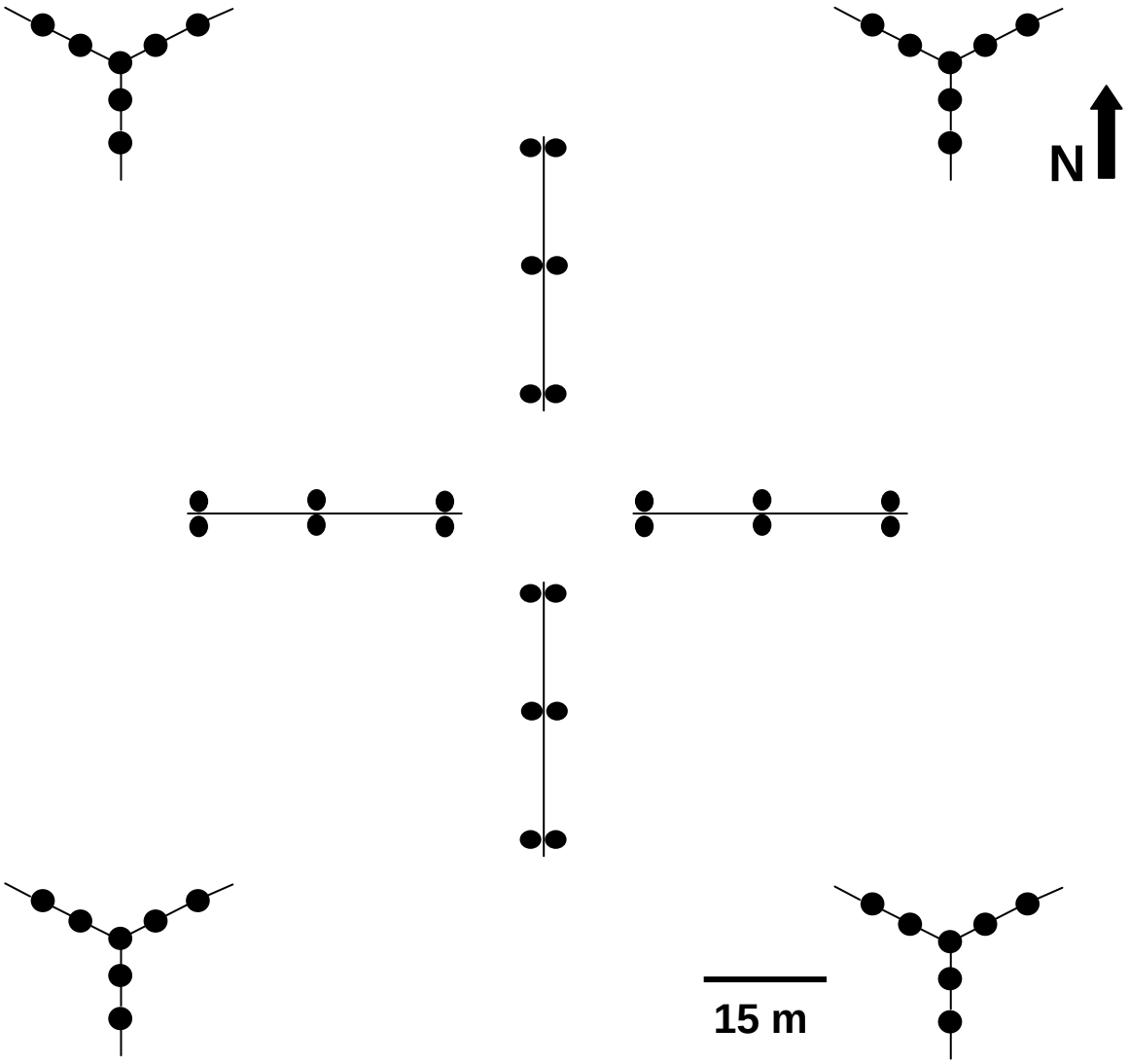

Figure 3-1. Arrangement of aluminum drift fence arrays and bucket traps used for sampling herpetofauna on the 6-ha core area of a 9.3-ha treatment plot at the Savannah River Site, Barnwell Co., South Carolina.

CHAPTER 4

THE EFFECT OF COARSE WOODY DEBRIS MANIPULATIONS ON MOVEMENT AND BURROW USE OF SOUTHERN TOADS (*BUFO TERRESTRIS)*

INTRODUCTION

Coarse woody debris (CWD), defined as downed and standing dead wood greater than 10 cm diameter and 60 cm long (Harmon et al 1986), is regarded as an ecosystem component that controls diversity and abundance (Hansen et al. 1991, Hanula 1996, Loeb 1996, Whiles and Grubaugh 1996). Although CWD is used by many invertebrates and vertebrates for the fulfillment of several life history functions (Harmon et al. 1986, Hanula 1996, Loeb 1996, Whiles and Grubaugh 1996) it is unknown if CWD is a critical habitat component for these species. Understanding how species interact with CWD is critical to determine proper management plans for species that use it.

Experimental studies on the importance of CWD for amphibians are lacking (but see Moseley et al. 2004, Rothermel and Luhring 2005) and the relationship between CWD and anurans is especially understudied (Whiles and Grubaugh 1996). Because of the potential role CWD plays in the natural history of anurans, CWD might impact not only their abundance, but also their behavior, and therefore, the health of individuals in a population. Bufonids, which live their adult lives in the uplands, may be especially reliant on CWD for cover and foraging. However, the use of CWD by bufonids has received little research attention, despite their relative abundance.

Toads have been documented using CWD for thermoregulation, protection from desiccation, and as refugia (Clarke 1974, Stebbins and Cohen 1995, Whiles and Grubaugh 1996) because CWD provides protection from dehydration and extreme daytime temperatures (Zug and Zug 1979, Seebacher and Alford 1999). Because they cannot control their rate of evaporate water loss (Tracy 1976, Wygoda 1988), the availability of suitable burrows is important for toads (Seebacher and Alford 2002). The selection of microhabitat during periods of inactivity by toads is therefore critical in minimization of water loss (Zug and Zug 1979, Schwartzkopf and Alford 1996). Because moisture is a limiting factor for amphibian activity (Spotila 1972, Fraser 1976), decaying wood represents a microhabitat that not only provides protection from predators, but also moisture replenishment. Fallen logs, rotting stumps, and root boles are preferred by amphibians over other types of shelter because of their ability to hold water and therefore prevent water loss (Grover 1996). Additionally, logs have the potential to provide more complete cover than soil or other microhabitats, because toads can enter or crawl underneath decaying logs.

Thermoregulation is an important process for ectotherms in accelerating digestion, leading to increased linear growth and weight increase (Lillywhite et al. 1973, Brattstrom 1979). However, under natural conditions, amphibians are poor thermoregulators because the behavior conflicts with their need to conserve body water (Brattstrom 1979). Bufonids can burrow into a sunlit log and effectively thermoregulate while minimizing water loss.

Decreases in CWD abundance can negatively influence amphibian abundance (Corn and Bury 1991, Dupuis et al. 1995, Aubry 2000, Butts and McComb 2000). However the mechanisms for the correlative relationship are not fully understood. Experimental studies that investigate the

behavior of herpetofauna in the absence of CWD might elucidate the causal mechanisms behind the reported negative responses of amphibians to decreases in CWD volume.

Objectives

Because of the documented and potential relationships between bufonids and CWD, presence of CWD has the potential to affect movement and choice of microhabitat. The purpose of this study was to determine the extent to which southern toads, *Bufo terrestris*, use CWD during periods of activity and rest by monitoring their movements in enclosures that contained CWD (wood enclosures) or did not contain CWD (non-wood enclosures). I tested the following hypotheses for this study. First, I hypothesized that movement of toads would be greater in the absence of CWD. Second, I predicted that in the presence of CWD, toads would use it for burrowing over other microhabitats. Finally, I predicted that in their use of CWD for moving and burrowing, toads would have a preference for extensively decayed CWD over non-decayed or moderately decayed CWD.

METHODS

Study site

The study area was at the Savannah River Site (SRS), a 78,000-ha National Environmental Research Park administered by the U.S. Department of Energy (DOE). Located in the Upper Coastal Plain and Sandhills physiographic region (Kilgo and Blake 2005), this area is characterized by periodic fire, sandy soils, and gently sloping hills dominated by pines with scattered hardwoods. The region has been described as humid subtropical; mean annual temperature in the region is 18º C, and mean annual precipitation is 122.5 cm (Blake et al. 2005).

The DOE contracted the U.S. Forest Service (USFS) to manage the land within the SRS in the 1950's. The USFS began hand-planting the uplands with pine, including loblolly (*Pinus taeda*), slash (*P. elliottii*) and longleaf (*P. palustris*) pine. Today, 72% of the upland pine forests are at least 30 years old (White 2005).

The study was conducted in a 50-year old loblolly pine stand managed with prescribed burning on a 2-4 year interval. The midstory of the stand was generally open but contained some black cherry (*Prunus serotina*). Common understory vegetation included sassafras (*Sassafras albidum*), poison oak (*Toxicodendron pubescens*), and blackberry (*Rubus* sp.).

Enclosure treatments

Twelve 4 x 4 m enclosures were constructed in summer 2004. Enclosure sides consisted of hardware cloth with approximately ½ cm mesh, which prevented toads from escaping while allowing invertebrates to move freely in and out of the enclosures. Six of the enclosures contained three pieces of CWD (wood enclosures), one each of three decay classes. Class 1 decay referred to wood that was sound and solid from bark to core; class 2 decay was defined as wood that has a hard inner core, but was slightly softened on the outside, with some bark; class 3 referred to wood that was decayed and easily crushed with little bark (Miley and Edwards 2002). Each piece of CWD was approximately 13 cm in diameter and cut to a length of 150 cm. The wood enclosures were constructed around an already existing piece of class 3 CWD so that the microhabitat beneath the wood remained intact. The class 2 CWD was put in each wood enclosure in 2004, approximately one year before experimental trials were conducted. The class 1 CWD was added in summer 2005 to simulate a newly fallen branch. Class 1 and 2 CWD was arranged in a triangle with the class 3 CWD, so that pieces were equidistant from each other.

The other six enclosures did not contain CWD (non-wood enclosures). Percent pine canopy cover was measured over each enclosure using a spherical convex densitometer and was similar among enclosure types using a two-sample t-test (mean canopy cover ± SE = 80.9 ± 0.88 over non-wood enclosures, 81.5 ± 1.9 over wood enclosures; t = -0.27, d.f. = 10, $P = 0.80$).

Trials

Trials were performed in September and October of 2005. For each trial, 12 toads were covered with DayGlo© fluorescent powder (Day-Glo Color Corporation, Cleveland, OH). DayGlo© pigments have been used safely for tracking reptiles and amphibians (Blankenship et al. 1990, Dodd 1992, Eggert 2002, Birchfield and Deters 2005). The entire ventral surface of each toad was covered with powder, including front and back feet. Toads were immediately placed in the center of the enclosure, one in each enclosure. All toads in the same trial were placed facing the same cardinal direction. Direction of placement was changed for each trial to prevent biasing movements. Each toad was used once in a wood enclosure and once in a non-wood enclosure. Because powders were persistent, colors used were switched at each new trial so that a color was not reused in the same week.

Each trial started at dusk (approximately 1900 h), which is just before when bufonids become active (Punzo 1992). Around 0500 h the next morning, I returned with an ultraviolet light to perform sampling. Toads usually become inactive near dawn to retreat to burrows (Creusere and Whitford 1976, Punzo 1992), so I assumed that if the toad was burrowed it had selected its diurnal burrow. Toads were located immediately within reaching the enclosure using the UV light to prevent influencing behavior. The time and individual's activity were recorded, and then the toad was removed from the enclosure. Initial activity was classified into one of three

categories: burrowed (partially or completely below the surface), active on surface (appeared alert), and inactive on surface (individual appeared inalert, but not burrowed). Each toad's trail and all burrows were flagged. Burrows were indicated by a large collection of powder in an indentation below the surface. The next day, total distance of each toad's trail was measured. The distance of each trail that was covered by any amount of vegetation (shrub canopy cover) was measured. I also recorded the microhabitat type (soil, pine straw, herbaceous ground cover, moss, deciduous leaves, CWD, or bare ground) of each individual's location at collection and the microhabitat of all burrows along trails. I measured soil moisture at all burrows in percent moisture content using a time domain reflectometry (TDR) probe with two 20 cm probes. In the wood enclosures, I measured the distance each toad traveled along CWD.

Statistical analysis

Mean distance moved per individual was compared between enclosure types using a two-sample t-test. Percent length of each individual's trail that was covered by shrub canopy vegetation was compared between enclosure types using a two-sample t-test. Percent of individuals found active on the surface per trial was compared between enclosure types using a Mann-Whitney U test. Percent of individuals found in non-wood burrows per trial was compared between enclosure types using a Mann-Whitney U test. Moisture between burrows associated with CWD and burrows not associated with CWD was compared with a one-way analysis of variance (ANOVA) blocked by trial.

I compared percent of all burrows associated with CWD (in or underneath) and percent of all burrows not associated with CWD (i.e., burrows in soil, vegetation, or other microhabitats) in wood enclosures using a Mann-Whitney U test. The percent of each individual's trail length

along CWD of each decay class was compared using a one-way analysis of variance (ANOVA). I also compared the percent of burrows in CWD among decay classes using a one-way ANOVA. Estimation was used for all post-hoc comparisons when significance was found using ANOVA. All non-normally distributed data used in parametric tests were log or log (+ 2) transformed.

RESULTS

Ten trials were performed for a total of 120 toad sampling nights. Means presented are followed by ± standard error.

Mean distance moved per individual was greater ($t = -2.28$, d.f. = 109, $P = 0.02$) in wood enclosures (mean ± SE = 631.1 cm ± 48.0) than non-wood enclosures (mean ± SE = 474.0 cm ± 40.0). Percent of trail length covered by shrub canopy was similar ($t = 0.43$, d.f. = 119, $P = 0.67$) between wood (mean ± SE = 15.2 ± 1.8) and non-wood enclosures (mean ± SE = 15.4 ± 1.4). Percent of individuals found active on the surface per trial was similar ($z = 0.31$, $P = 0.76$) between wood (mean ± SE = 41.5 ± 7.3) and non-wood enclosures (mean ± SE = 37.3 ± 6.7). Percent of individuals per trial found in burrows not associated with CWD was similar ($z = -0.74$, $P = 0.46$) between wood (42.3 ± 7.1) and non-wood (38.5 ± 7.7) enclosures. Percent moisture content differed ($F = 9.23$, d.f. = 1, 9, $P = 0.004$) between burrows associated with CWD (6.7 % ± 0.9) and burrows not associated with CWD (8.2 % ± 0.8). The estimated difference in mean percent moisture content was 2.8 (SE = 0.91, $t = -3.04$, $P = 0.004$).

There was no difference ($z = 0.76$, $P = 0.45$) in percent of burrows associated with (41.7 ± 10.0) and not associated with CWD (58.2 ± 10.0) in the wood enclosures. Percent of trail length moved along CWD was similar ($F = 1.92$, d.f. = 2, 177, $P = 0.15$) among decay classes (means for CWD 1, 2, and 3, respectively = 2.4 ± 0.8, 3.4 ± 0.8, and 1.6 ± 0.4). Percent of burrows

associated with CWD differed (F = 4.04, d.f. = 2, 9, P = 0.04) among decay classes (means for CWD 1, 2, and 3, respectively = 9.1 ± 6.8, 44.2 ± 13.0, and 16.4 ± 5.6). The estimation procedure revealed that the mean percent use of class 2 CWD for burrows was 35.1 percent higher than that of class 1 CWD (SE = 13.03, t = 2.69, P = 0.02). The percent use of class 2 CWD for burrows was 27.8 higher than that of class 3 CWD (SE = 13.03, t = 2.13, P = 0.05).

DISCUSSION

I expected that the presence of logs would offer an advantage to toads in finding suitable cover by allowing toads in the wood enclosures to find a suitable burrow after less movement and time. Concomitantly, the lack of cover in non-wood enclosures would necessitate more movement as the toads searched for suitable burrow sites. However, contrary to my predictions, southern toads moved greater distances in the wood enclosures. Furthermore, percent of individuals found active at dawn was not different between enclosure types. These findings suggest that CWD does not provide an advantage for toads in finding suitable burrow sites. Coarse woody debris may have been seen as an obstacle to the toads because of their preference for bare areas, which increased the distance moved. Toads may be opting for more open areas because they predominantly use sight to detect their prey (Stebbins and Cohen 1995), and cover may influence their foraging ability. Clarke (1974) reported that the major components of toad habitat were vegetative cover and open patches according to the literature. Toads did not seek out a more covered travel route in the absence of CWD, as shrub canopy cover of trails was not influenced by the presence of CWD. Thus, in the absence of CWD, toads did not require the additional cover from vegetation, further supporting the finding that CWD was not an important source of cover for toads.

Contrary to the hypothesis that CWD burrows offer more protection from water loss, I found that burrows used by toads that were not associated with CWD had greater moisture content than burrows associated with CWD. Most of the burrows (65%) that were not associated with CWD were burrows in pine litter. Toads were usually burrowed beneath the pine litter, with their dorsal surface exposed and their ventral surface in contact with the soil. Most of the burrows associated with CWD were under the log, meaning that the soil moisture measurement was of the moisture content under the log, not within the log. Similarly, Sanzone (1995) found that soil moisture was not different between cores taken close to or far away from logs. Logs may intercept and retain precipitation (Harmon et al. 1986, Roberts et al. 2005), making moisture below the surface of the log lower than that of more exposed surfaces. However, during periods of extremely high temperatures or drought, direct evaporation may be greater on more exposed soil, a hypothesis that remains to be tested. If this hypothesis is true, CWD may be more important as cover for amphibians seasonally, such as during the summer.

Toads may have used all microhabitats equally for burrows because of trade-offs between the complete cover offered by logs and the increased moisture offered by burrows not associated with CWD. Toads that were burrowed in soil or vegetation had at least their hindquarters burrowed into the soil, allowing their "seat patch" to come in contact with the soil. The seat patch is an absorbent patch of skin on the abdomen (Stebbins and Cohen 1995), so this behavior still allowed them to absorb moisture from the soil even if their dorsal surface was exposed. Moisture may not have been limiting enough in this environment to necessitate coverage of all exposed skin. Their use of CWD as a diurnal retreat site might increase during dry periods when the soil does not provide any moisture. A study of seasonal shelter microhabitat used by *B. marinus* (marine toads) in Australia found that the use of the coolest microhabitat (hollows under

live trees) increased in the driest time of year (Seebacher and Alford 2002). Another factor that may have influenced their microhabitat selection was air temperature. Decaying logs can provide toads with protection from high temperatures (Maser and Trappe 1984, Whiles and Grubaugh 1996). This study was performed in the fall, when temperatures were relatively cool, and so their use of CWD may not have been influenced by air temperature. However, in the summer when daytime temperatures in this region can be extremely high, toads may require greater protection from temperature extremes, as well as dehydration.

Percent of trail length moved along logs did not differ with decay class in wood enclosures. A class 1 log often still has branches, supporting it off the ground (Maser et al. 1979), which may create a microhabitat underneath that does not provide enough protection from predators. It was surprising that burrowing toads preferred class 2 CWD over class 3. Well-decayed CWD is soft and powdery and has established burrow systems within it, and is often used by amphibians and reptiles for burrowing (Maser 1979). Aubry et al. (1988) conducted searches for plethodontid salamanders in Douglas-fir forests and reported that almost all *Plethodon vehiculum* (western redback salamanders) were found under moderately-decayed logs, while only a few were found under intact or extensively decayed logs. In my study, many of the burrows associated with CWD 3 were inside the log, while burrows associated with CWD 2 logs were always under the log. Toads may not have been able to burrow beneath CWD 3 logs, and may have preferred the protection of being completely underneath the logs.

Many of the studies on the influence of CWD on herpetofauna are large-scale, and thus investigate the effects on the population level. This study was a small-scale study on the microhabitat use of CWD by toads, and therefore its implications are for the effect of CWD manipulations on the health of individuals. Small-scale studies are important because they have

the potential to determine the causal mechanisms for the population responses seen in large-scale manipulative studies. However, this study has several major drawbacks. First, data were only collected for 10 trials and during one season. More data are required to conduct more powerful statistical testing. Also, response variables may not be representative of true preferences because of stress and disorientation. Finally, the results of this study should therefore be considered preliminary because enclosures were too small for this species. Many of the individuals were found along the edge of the enclosure, which probably influenced the distance traveled and the microhabitats selected for their burrows. Using larger enclosures is necessary for studying the microhabitat use of such a mobile species, and this may provide more reliable conclusions.

Adult toads, which were used in this study, appear not to require CWD for diurnal retreats. However, recently metamorphosed bufonids are especially limited by moisture in their environment (Creusere and Whitford 1976). Further research is needed to investigate the hypothesis that juvenile toads, which are unable to excavate their own burrows (Creusere and Whitford 1976), are more reliant than adults on cover objects such as CWD for providing diurnal retreat sites. Further research is needed to determine if the use of CWD by southern toads varies with season, because of the potential use of decaying logs for protection from extreme daytime temperatures in the summer. More small-scale experimental studies on the microhabitat use of CWD by amphibians and reptiles are needed in order to explain the mechanisms involved with population responses to CWD manipulations.

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CHAPTER 5

CONCLUSION AND MANAGEMENT RECOMMENDATIONS

This objective of this research was to use both large- and small-scale, manipulative approaches to investigate the role of coarse woody debris (CWD) in determining community assemblages and activity of soricids and herpetofauna. The results from both scales suggest that the majority of shrew and herpetofaunal species found in southeastern Coastal Plain pine forests do not respond to manipulations of CWD volume.

At the large-scale, there were few conclusive responses to manipulation of CWD volume by soricids or herpetofauna. The southeastern shrew (*Sorex longirostris*) exhibited greater abundance and activity in the plots in which downed CWD volume was increased. Southern short-tailed shrews (*Blarina carolinensis*) and least shrews (*Cryptotis parva*) did not respond to the manipulations of CWD volume. The southern short-tailed shrew is a fossorial species that may be less sensitive to microhabitat changes on the surface. Similarly, most of the herpetofaunal species captured did not respond to the CWD manipulations. The only species with a demonstrated response was the southern leopard frog, which was most abundant and most active in the removal plots. Although seemingly contradictory, this result may support the hypothesis that herpetofauna respond negatively to the removal of CWD. Leopard frogs, which are wetland species, may be especially vulnerable to a lack of cover, and may increase their activity in search of cover objects when CWD is not available.

The lack of response to the CWD manipulations by the majority of the species at the large scale may be partly a function of decay state. Extensively decayed CWD may be more suitable

microhabitat for these species because of its increased ability to hold moisture (Harmon et al. 1986), provide cover (Maser and Trappe 1984), and to provide insect prey (Harmon et al. 1986). Most of the CWD in this study was in decay stage 1 or 2 (i.e., early to moderate stages of decay). The CWD manipulations may therefore result in stronger treatment effects on soricid and herpetofauna communities as the CWD continues to decay.

The enclosure study took a small-scale approach to investigate the use of CWD at the microhabitat-level. Studies at the microhabitat level can provide insight into the mechanisms for population-level responses to changes in CWD volume. Although preliminary, the results from this study suggest that southern toads do not prefer to use CWD over other microhabitats for travel routes or burrows. However, southern toads may prefer moderately decayed CWD over non-decayed or extensively decayed CWD, a preference that may be related to the ability of moderately decayed wood to provide the optimum amount of cover. Although there was no strong evidence that adult toads require CWD for diurnal shelters, juvenile toads may be more reliant on CWD because they are unable to dig their own burrows (Stebbins and Cohen 1995).

Although historical accounts of CWD loadings in southern pine forests are sparse, it is thought that CWD was not found in great amounts in pre-settlement pine forests of the Coastal Plain (Ligon 1971, Bragg 2002). It is thought that is a result of frequent fires and high decomposition rates (Ligon 1971, Harmon et al. 1986, McMinn and Hardt 1996). With low CWD volumes, Coastal Plain species may rely on burrowing into sandy soil or using other microhabitats, such as leaf and pine litter, for cover. In fact, many species of herpetofauna have evolved burrowing abilities to retreat below the surface to avoid desiccation.

Although based on this study CWD does not appear to be a critical habitat component for most Coastal Plain herpetofauna and shrews, their use of CWD may be facultative, and thus its

presence is still beneficial to them. In the absence of a litter layer CWD may be more important in providing cover. Further research is needed to determine if the use of CWD by Coastal Plain soricids and herpetofauna becomes more obligate in the absence of other cover. Therefore, studies investigating the use of CWD by Coastal Plain species in situations where resources are limited may have implications for use of prescribed fire in this region.

The results of manipulative studies are often more conclusive than those of observational studies, because manipulative studies can reveal causal relationships. Overall, these studies indicate that the removal of CWD can negatively influence some species, but it may not be a critical habitat component for soricids and herpetofauna, at least in early to moderate stages of decay. However, those species that do not rely on CWD probably use and benefit from its presence, and their use of CWD may increase as it decays. Because the importance of CWD in overall ecosystem function is not fully understood, management practices in pine forests of the southeastern Coastal Plain should maintain stand structural complexity by mimicking the effects of natural disturbance (Sharitz et al. 1992). Further research is needed on how other attributes of CWD, such as decay state and spatial distribution of logs in a forest stand, influence the importance of CWD for herpetofauna and soricids. Additionally, microhabitat-level research on how the use of CWD by these vertebrates changes in the absence of other microhabitat structures would provide more insight into their reliance on CWD as a microhabitat component.

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