

RESPONSE OF HERPETOFAUNA AND SORICIDS TO COARSE WOODY DEBRIS
MANIPULATIONS IN UPLAND LOBLOLLY PINE STANDS

by

KURTIS ROOKS MOSELEY

(Under the Direction of Steven B. Castleberry)

ABSTRACT

Although use of coarse woody debris (CWD) by herpetofauna and shrew species has been well documented in the Pacific Northwest and southern Appalachian Mountain regions of the United States, little information exists regarding the importance of CWD to herpetofaunal and shrew assemblages in pine forests of the southeastern Coastal Plain. Furthermore, few manipulative studies have assessed response to increased CWD volume. The primary objective of my study was to assess the response of herpetofauna and shrews to CWD manipulations in upland loblolly pine (*Pinus taeda*) stands of the South Carolina Coastal Plain physiographic region as part of an interdisciplinary study undertaken to better understand the ecological role of CWD in southeastern pine forests.

INDEX WORDS: Ambystomatidae, Amphibians, *Bufo terrestris*, Coarse woody debris, Herpetofauna, Loblolly Pine, Shrews, Soricidae

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KURTIS ROOKS MOSELEY

B.S.F.R., The University of Georgia, 2001

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial
Fulfillment Of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2004

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KURTIS ROOKS MOSELEY

Major Professor: Steven B. Castleberry

Committee: Karl V. Miller
John C. Kilgo

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
May 2004

ACKNOWLEDGEMENTS

Firstly, I would like to thank my major professor, Dr. S.B. Castleberry, for his generosity and support over the past few years. I would also like to thank Dr. W.M. Ford for reviewing my thesis and providing extremely helpful comments and ideas. I would also like to thank my committee members, Dr. J.C. Kilgo and Dr. K.V. Miller, for providing helpful comments on my thesis and helping me get things moving at the Savannah River Site. Last, and most certainly not least, I thank my Mom and Dad and Heather M. Kling for their support throughout this little adventure.

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	iv
LIST OF TABLES	vii
LIST OF FIGURES	ix
INTRODUCTION	1
CHAPTER	
1 INTERNAL HARMONIC RADAR TAGS FOR RELOCATING <i>AMBYSTOMA TALPOIDEUM</i>	8
2 COARSE WOODY DEBRIS AND PINE LITTER MANIPULATION EFFECTS ON MOVEMENT AND MICROHABITAT USE OF <i>AMBYSTOMA TALPOIDEUM</i> IN A <i>PINUS TAEDA</i> STAND	23
3 SEASONAL AND SEXUAL VARIATION IN DIET COMPOSITION OF SOUTHERN TOADS IN UPLAND LOBLOLLY PINE STANDS	52
4 DIET OF <i>BUFO TERRESTRIS</i> IN <i>PINUS TAEDA</i> STANDS SUBJECT TO COARSE WOODY DEBRIS MANIPULATIONS	74

5	DEMOGRAPHIC RESPONSE OF SORICIDS TO COARSE WOODY DEBRIS MANIPULATIONS IN UPLAND LOBLOLLY PINE (<i>PINUS TAEDA</i>) STANDS.....	99
6	AMPHIBIAN AND REPTILE RESPONSE TO COARSE WOODY DEBRIS MANIPULATIONS IN UPLAND LOBLOLLY PINE (<i>PINUS TAEDA</i>) STANDS.....	117
	CONCLUSION.....	140
	REFERENCES.....	142

LIST OF TABLES

Table 1-1: Change in weight of <i>Ambystoma talpoideum</i> 60-days post implantation.....	20
Table 2-1: Number of activity areas and nights moved per day during daily locations and night surveys by <i>Ambystoma talpoideum</i> in enclosure study one.....	47
Table 2-2: Percentage of days pine litter and coarse woody debris were used by <i>Ambystoma talpoideum</i> during daily locations.....	48
Table 2-3: Number of activity areas and nights moved per day during daily locations and night surveys by <i>Ambystoma talpoideum</i> in enclosure study two.....	49
Table 3-1: Relative abundance and frequency of occurrence of invertebrate groups identified in stomach contents of southern toads.....	68
Table 3-2: Relative abundance and frequency of occurrence of invertebrate groups identified in stomach contents of male and female southern toads.....	70
Table 3-3: Relative abundance and frequency of occurrence of invertebrate groups identified in stomach contents of gravid and nongravid female southern toads.....	72
Table 4-1: Relative abundance of prey items identified in stomach contents of southern toads.....	93
Table 4-2: Frequency of occurrence of prey items identified in stomach contents of southern toads.....	94
Table 4-3: Abundance of arthropod groups captured.....	95
Table 4-4: Relative abundance of arthropod groups captured.....	96

Table 5-1: Capture rate of southern short-tailed shrews, southeastern shrews, and least shrews.....	114
Table 6-1: Total amphibians and reptiles captured by species.....	137
Table 6-2: Capture rate, Shannon-Weiner Index and, species richness for amphibians.....	138
Table 6-3: Capture rate, Shannon-Weiner Index, and species richness for reptiles.....	139

LIST OF FIGURES

Figure 1-1: Diagram of internal harmonic radar reflector tag.....	21
Figure 1-2: Detection depth of internal harmonic radar tags.....	22
Figure 2-1: Percent of nights <i>Ambystoma talpoideum</i> in pine litter in removal and control treatment enclosures were active.....	50
Figure 2-2: Percent of days <i>Ambystoma talpoideum</i> were located under coarse woody debris.....	51
Figure 4-1: Relative abundance of invertebrates consumed by southern toads versus relative abundance of invertebrates captured.....	98
Figure 5-1: Age distribution of southern short-tailed shrews and southeastern shrews.....	116

INTRODUCTION

Coarse woody debris (CWD) is an important ecological component of forest stand structure (Harmon et al. 1986, Hunter 1990, McComb and Lindenmayer 1999), serving a variety of functions including seed germination sites, sites of nutrient exchange and plant uptake, reservoirs of moisture during drought, and habitat for forest organisms (Maser et al. 1979, Harmon et al. 1986). In unmanaged forest stands, CWD is generated through a variety of processes including natural catastrophic disturbances such as fire, disease, windfall, and ice damage, suppression mortality in maturing stands, and small-scale gap dynamics. Fluctuation of CWD volume from stand initiation until maturation generally resembles a U-shaped pattern (Lambert et al. 1980, Romme 1982, Lang 1985, Agee and Huff 1987, Spies et al. 1988, Sturtevant et al. 1997), with sources of CWD inputs changing as forest stands age. Contribution from previous stands comprises a large proportion of initial inputs, whereas contributions from the current stand comprise the majority of inputs during latter stand development (Spies et al. 1988, Hansen et al. 1991). Initial CWD inputs are often high following a catastrophic disturbance. As a stand matures, suppression mortality adds new inputs, peaking with development of an uneven age structure (Harmon et al. 1986, Siitonen et al. 2000). However, in forest stands managed for timber production the role of these processes are altered by anthropogenic disturbances.

Disturbance in managed stands often occurs as even-aged harvesting followed by intensive site preparation such as stump removal, roller-chopping, and mechanical

bedding (Hunter 1990, Smith et al. 1997). Coarse woody debris input following timber harvesting often is high, but is dependant upon site preparation techniques employed. Percent coarse woody debris cover in managed pine stands subject to clearcutting in the Coastal Plain of South Carolina was 35.7% higher than in unmanipulated reference stands and 21.9% higher than in clearcut stands subject to clearcutting and subsequent disking and bedding (Russell et al. 2002). However, much of the CWD input from timber harvesting is composed of small diameter woody debris in early stages of decay. Although initial CWD inputs may be high, most is eliminated through decomposition (Barbour and Van Lear 1984), prescribed fire, and a lack of new inputs by mid-rotation (Van Lear and Waldrop 1994). During midrotation natural mortality of suppressed trees generally supplements declining volume of initial CWD inputs. However, in managed stands this contribution is reduced by stand thinning, which aims to harvest trees exhibiting a high potential for mortality (Smith et al. 1997).

In the southeastern United States, managed pine stands generally are younger than unmanaged pine stands, with 81% less than 23 years old (Conner and Hartsell 2002). Because these stands often are managed on short rotation lengths, tree growth is truncated before significant mortality of mature trees can occur (Hansen et al. 1991). Timber harvesting and subsequent site preparation act to reduce the structural legacy passed on to subsequent stands, contributing to overall reduction of structural diversity within managed pine stands.

Forest managers in the southeastern United States are increasingly challenged to balance timber production with conservation of biodiversity and maintenance of wildlife habitat (Sharitz et al. 1992). Concomitantly, use of intensively managed pine (*Pinus*

spp.) plantations in the region is increasing to meet burgeoning demand for wood fiber products. Pine plantations currently occupy 15% of timberland area in the southeastern United States (Conner and Hartsell 2002), and are expected to increase from 13 to 22 million ha by the year 2040 (Prestemon and Abt 2002). Increased use of pine plantations will reduce regional levels of CWD in forested stands. In South Carolina, CWD volume in intensively managed pine plantations is 7.3 m³/ha compared to 17.5 m³/ha in unmanaged pine forests (McMinn and Hardt 1996). Low levels of CWD may negatively impact terrestrial vertebrates, such as herpetofauna and soricids, within managed stands (Loeb 1996, Whiles and Grubaugh 1996).

Coarse woody debris use by herpetofaunal species

The southeastern United States harbors a rich diversity of amphibian and reptile species. In the Coastal Plain region of South Carolina, 101 species of amphibians and reptiles have been reported (Buhlman et al. In Review). Coarse woody debris is an important habitat component for many of these species (Wilson 1995, Conant and Collins 1998). Reptiles and amphibians use CWD for a variety of purposes including shelter, reproduction, thermoregulation, and foraging (Whiles and Grubaugh 1996). However, response of amphibians and reptiles to CWD volume probably varies by taxonomic group, forest type, and region (Russell et al. In Press).

Amphibians may be particularly sensitive to changes in CWD availability and decay class distribution. The epidermis of amphibians must remain moist to respire, making them highly susceptible to desiccation during dry climatic conditions (Duellman and Trueb 1994, Stebbins and Coen 1997). Coarse woody debris has a relatively constant

moisture regime, remaining moist during dry periods, thereby buffering against temperature and moisture extremes (Harmon et al. 1986). Coarse woody debris in advanced stages of decay is especially beneficial due to its greater water holding capability (Jaeger 1980, Boddy 1983). Abundance of plethodontid salamanders has been positively correlated with CWD in various hardwood forest types in the southern Appalachian Mountains (Maidens et al. 1998, Moore et al. 2001) and coniferous forests of the Pacific Northwest and Canada (Aubry et al. 1988, Bury and Corn 1988, Dupuis et al. 1995, Butts and McComb 2000). In the southern Appalachian Mountains of Virginia, body mass of redbacked salamanders (*Plethodon cinereus*) was greater in plots where logs and rocks had been artificially increased (Grover 1998). Conversely, ambystomatid salamanders prefer underground burrows that generally are independent of CWD (Williams 1970, Douglas 1981, Semlitsch 1981a, Semlitsch 1983, Loredó et al. 1996, Madison 1997, Madison and Farrand 1998, Trenham 2001). However, when underground burrows and other microhabitats are limiting, ambystomatid salamanders may become more dependent on CWD to escape adverse surface conditions. Chazal and Niewiarowski (1998) compared juvenile mole salamanders (*Ambystoma talpoideum*) within enclosures in a 4-month-old clearcut to individuals maintained in an adjacent 40-year old loblolly pine (*Pinus taeda*) stand at the Savannah River Site, South Carolina. Juveniles did not differ in abundance, body mass, snout-vent-length, clutch size, percent whole-body nonpolar storage lipid, or percent storage lipid of eggs after 5-6 months of exposure to enclosure conditions. Lack of difference between the two treatments was partially attributed to the large amounts of CWD in clearcut enclosures, which may have

ameliorated unsuitable surface conditions, including reduced litter cover, by retaining on-site moisture.

Ability of CWD to buffer against extreme temperature and moisture fluctuations (Harmon et al. 1986) is important for reptile reproduction. Temperature of eggs during incubation has a major effect on fitness of emerging young (Goin and Goin 1971, Ernst and Barbour 1989) and is presumably why many reptiles deposit their eggs within well decayed CWD (Hecnar 1994). Additionally, CWD is used by many small semi-fossorial snakes as cover and foraging substrate (Minton 1949, Hardy 1952, Brode and Allison 1958, Semlitsch 1981b). Semlitsch (1981b) found xeric microhabitat with sufficient logs and rotting stumps was more important for southeastern crowned snakes (*Tantilla coronata*) than vegetation type or macrohabitat in Coastal Plain forests of South Carolina. Additionally, CWD harbors high densities of invertebrates (Graham 1925, Savely 1939, Hanula 1996, Hutcheson and Jones 1999, Koenigs et al. 2002, Lockaby et al. 2002) that act as food for many amphibian and reptile species (Toft 1985).

Coarse woody debris use by Soricids

The southeastern United States harbors diverse shrew assemblages. However, most of this diversity is concentrated in the cool, moist hardwood forests of the southern Appalachian Mountains. Because shrews generally make up a smaller proportion of small mammal species at southern latitudes than northern latitudes (Churchfield 1990), abundance and diversity of shrew species in the southeastern Coastal Plain is lower than in other physiographic regions of the Southeast. Only three shrew species occur in the Coastal Plain of South Carolina: the southern short-tailed shrew (*Blarina carolinensis*),

southeastern shrew (*Sorex longirostris*) and least shrew (*Cryptotis parva*) (Loeb et al. In Review). Coarse woody debris is an important habitat component for these species (Burt and Grossenheider 1980). Most species use CWD, primarily for shelter and as a foraging substrate (Loeb 1996). Moisture is an important factor influencing local distribution and abundance of shrew assemblages (Getz 1961). Because of their high metabolic rate, shrews are subject to high rates of evaporative water loss (Chew 1951, Churchfield 1990), subjecting them to increased desiccation risk. Shrews often forage on the forest floor following precipitation (Ford et al. 2002). However, during dry climatic periods shrews may be restricted to isolated areas of moisture (Brannon 2002). Coarse woody debris retains moisture during dry periods and may serve as important refugia (Loeb 1996). In a manipulative study conducted in managed western hemlock (*Tsuga heterophylla*) forests of Washington, stands subject to CWD removal harbored lower abundance of Trowbridge's shrews (*S. trowbridgii*) and a greater abundance of vagrant shrews (*S. vagrans*) than unmanipulated control stands. Furthermore, dusky shrews (*S. monticolus*) experienced lower reproductive rates in CWD removal stands (Lee 1995). Although studies in the Pacific Northwest (Corn et al. 1988, Butts and McComb 2000) and southern Appalachians (Maidens et al. 1998, McCay et al. 1998, Brannon 2000) found positive relationships between CWD and shrew abundance, CWD volumes within these regions may surpass threshold amounts needed to support shrew populations. However, CWD within managed pine stands of the southeastern Coastal Plain physiographic region typically are low (McMinn and Hardt 1996) and may therefore be limiting. In a study of the effects of CWD removal in upland loblolly pine stands in the Coastal Plain of South Carolina, capture rates of least shrews were lower on CWD

removal plots than in control stands (McCay and Komoroski 2003). They speculated that low ambient levels of CWD in control plots may be responsible for the similar abundance of southern short-tailed shrews and southeastern shrews observed between treatments. Ford et al. (1994) hypothesized that there was an upper threshold of CWD input required to solicit a response by shrew populations.

Objectives

Although use of CWD by herpetofauna and shrews has been well documented in the Pacific Northwest and southern Appalachian Mountains, little information exists regarding the importance of CWD to herpetofaunal and shrew assemblages in pine forests of the southeastern Coastal Plain. Furthermore, few manipulative studies have assessed response to increased CWD volume. The primary objective of my study was to assess the response of herpetofauna and shrews to CWD manipulations in upland loblolly pine stands of the South Carolina Coastal Plain physiographic region as part of an interdisciplinary study undertaken to better understand the ecological role of CWD in southeastern pine forests.

CHAPTER 1

INTERNAL HARMONIC RADAR TAGS FOR RELOCATING *AMBYSTOMA*

*TALPOIDEUM*¹

¹ Moseley, K.R., and S.B. Castleberry. To be submitted to *Georgia Journal of Science*.

ABSTRACT—The highly fossorial life history of mole salamanders (*Ambystoma talpoideum*) has made them difficult to study. We assessed the usefulness of an internal harmonic radar tag for relocating mole salamanders in the terrestrial environment. We determined maximum detection depth of reflector tags with varying antenna lengths. In addition, we subcutaneously implanted reflector tags into mole salamanders to assess retention and effects of tags on body condition during a 60-day period. We were able to detect reflector tags of all antenna lengths as deep as 30 cm below the soil. Only 20% of mole salamanders implanted with reflector tags retained them for the entire 60-days. Although retention of tags was low, we believe that internal harmonic radar tags can provide useful information regarding terrestrial habitat use of mole salamanders.

Key words: *Ambystoma talpoideum*, Ambystomatidae, harmonic radar detection, mole salamanders, reflector tag, tracking

INTRODUCTION

Mole salamanders are a highly fossorial species, spending most of their life in burrows 3-4 cm below the soil surface (1). This aspect of their life history has made them notoriously difficult to study. Most ecological investigations of mole salamanders have been conducted during the breeding season when individuals migrate from terrestrial environments to ponds to mate (2,3,4,5). Once breeding is completed, individuals return to terrestrial environments where they may remain for as long as 362-days (1). Little surface activity occurs during the nonbreeding season, rendering traditional monitoring techniques such as drift fences and pitfall traps inadequate for

assessing land management impacts on this species. Because of their small size, mole salamanders cannot be radio-tracked, like larger ambystomatid species such as tiger salamanders (*A. tigrinum*; 6,7) and spotted salamanders (*A. maculatum*; 8). Radioisotope tags have been used to track a variety of ambystomatid species (1,9,10,11), but are expensive and difficult to acquire (12). Harmonic radar detection (HRD) may provide an effective method to track mole salamanders as well as other small terrestrial vertebrates.

Harmonic radar detection was first developed to locate avalanche victims. The technique consists of a hand held transceiver that emits a 1.7 W continuous microwave frequency of 917 MHz. When the microwaves strike a diode they are reflected at double the frequency (1,834 MHz), which is then detected by the transceiver. Harmonic radar detection has been used to track movements of carabid beetles (13) and a variety of other insect species (14,15,16). Application has been extended to herpetofaunal species, including broad-headed snakes (*Hoplocephalus bungaroides*; 17), sharp-tailed snakes (*Contia tenuis*; 18), juvenile spotted salamanders (19), juvenile box turtles (*Terrapene Carolina*; Brisbin pers. comm.), and Lesueur's frog (*Litoria lesueuri*; 20). There are several limitations to HRD including inability to read tags in water, reduced detection range for animals underground (19), interference from metal objects, and distorted or blocked signals due to excessive soil moisture. Results vary depending upon antennae length and type of diode used. Nonetheless, Webb and Shine (17) reported detecting individuals inside coarse woody debris (CWD), under leaf litter, and as deep as 30 cm underground. However, individuals that make large dispersal movements (i.e. migrations associated with reproduction) may be difficult to locate. Langkilde and Alford (20) reported a detection distance of 40 m for an external tag developed for use with Lesueur's

frog. Eaton (19) had limited success with juvenile spotted salamanders due to failure of external tags to stay attached to animals. Subcutaneous implantation has been successfully accomplished using radio-transmitters on large adult ambystomatid species (6,7,8) and with HRD on broad-headed (17) and sharp-tailed snakes (18). The objective of our study was to assess the use of internal harmonic radar tags as a method for tracking mole salamanders.

MATERIALS AND METHODS

We used reflector tags constructed from Vishay-Telefunken BAT85S schottky barrier diodes (Newark In One, Chicago, IL) at \$0.11 (US) each. We constructed antennae of 37-gauge copper wire. We soldered a wire to each lead as close as possible to the diode and then removed leads with wire cutters (Figure 1-1). We cut antennae to desired length and used a Dremel® rotary tool (Bosch Tool Corporation, Stuttgart, Germany) to remove excess solder material. We coated tags with Plasti-Dip® (Plasti-Dip International, Blaine, MN) to provide further protection from rough edges.

We tested detection range of tags with antenna lengths of 13, 11, 9, and 7 mm. We inserted tags into 5.2 by 1.8-cm canned sausages to simulate effects of a salamander body cavity and to provide a standard for measuring detection distance of different tag antenna lengths. We placed sausages into small, clear plastic bags to prevent damage when buried underground. We then measured detectability at depths of 5, 10, 20, and 30 cm. We also determined detection distance on the soil surface, and beneath large (29 cm diameter) and small (13 cm diameter) CWD. We recorded the maximum vertical distance that tags could be read with the transceiver.

To test effects of internal implantation and retention rate of tags on mole salamanders, we performed a 60-day retention experiment during April through June 2003. We collected animals near wetlands at the U.S. Department of Energy's Savannah River Site (SRS), a 78,000-ha National Environmental Research Park located on the upper Coastal Plain physiographic region in Aiken, Barnwell, and Allendale Counties, South Carolina (33°0-25'N, 81°25-50'W). All individuals were collected under South Carolina Department of Natural Resources scientific research permit #G-02-09 and University of Georgia IACUC number A2002-10019-c2.

We randomly assigned individuals to one of two treatments: 1) subcutaneous implantation of reflector tag and 2) a sham operation as a control in which individuals underwent the same procedure as treatment animals except no tag was implanted. Ten individuals were assigned to the treatment group and nine to the control. We anesthetized animals in 30% ethanol (21) and recorded weight (g), snout-vent length (cm), total length (cm), and sex for each individual. We sterilized all instruments and reflector tags in 100% ethanol for at least half an hour prior to surgery. We inserted an 18-gauge catheter needle under the skin on the dorsal side of the animal, making insertions at the anterior end of the animal, posterior to the neck. We inserted the catheter along the back, lateral to the spine, stopping before the pelvic bone. We removed the catheter from the animal and inserted a 0.1-g reflector tag with two 11-mm antennae (total length 25.9 mm) into the hole created by the needle. We covered the reflector tag with a thin layer of KY liquid lubricant to reduce friction and facilitate a smooth entry into the cavity and then used tweezers to guide the reflector tag until completely under the skin. We allowed animals to soak in water for an hour to aid in

recovery from the effects of the ethanol solution and then placed individuals into 20 cm by 15 cm by 5-cm plastic containers with a damp paper towel. We fed each individual 20-30 termites every 7-14 days. We kept animals at 21°C and natural light:dark period. At the end of 60 days, we weighed individuals to determine if tags had any effects on individual body weight and tested treatment effect on weight using a two-sample Wilcoxon rank sum test. We performed analysis with SAS software (22).

RESULTS

Detection distances for reflector tags within canned sausages generally decreased with decreasing antenna length and depth of tag from the soil surface (Figure 1-2). Greatest detection distance was obtained from surface readings of tags having 9-mm antenna (144 cm). Tags with a 7-mm antenna, however, could still be detected 30 cm below the soil. Tags located under small and large CWD were only detected when the transceiver was placed within 2.5 cm from the ground near the CWD.

Individuals generally recovered quickly following surgery with healing evident 2-5 days post-surgery. During the first 6 days following implantation, 3 individuals (2 treatment, 1 sham) died and another treatment individual died 12 days after implantation. Mole salamanders implanted with reflector tags retained tags from 14 – 60 days, with an average retention time of 42.5 days (± 6.5). Of the 10 individuals implanted with tags, only 2 retained their tags for the duration of the study. The 7 individuals who lost their tags survived, healing rapidly following expulsion of tag. Weight of individuals was not different between treatments ($Z = -0.18$, $P = 0.861$; Table 1-1).

DISCUSSION

Mole salamanders burrow an average of 3-4 cm below the soil surface (1). Therefore the smallest reflector tags in our study should be adequate for detecting individuals within the soil. Additionally, detection distance may increase for a given reflector tag depending upon the size of the individual. The body cavity increases detection distance of tags. Once tags are removed or fall out, they can no longer be detected, and therefore will not provide false signals that will mislead investigators.

Mortality may have been a result of infection at the site of implantation. Before death we observed that the tag was protruding half way out of the posterior end of the animals. Sixty-three percent of individuals that expelled tags survived. Two marbled salamanders (*A. opacum*) died within the first two weeks following anesthetization with 2-phenoxy ethanol and passive integrated transponder (PIT) implantation (23). In our study, the first signs of tag expulsion often occurred within 8 days of implantation. Bending of the body pushes the tag toward the posterior end, eventually applying pressure on the skin near the tail region. Other animals in which the tag is not pushed towards the tail region through normal body movement lose their tags when an ulcer forms in the area of the skin where the tag is applying pressure, and is eventually expelled through the ulcerated region. A similar response was observed for radioactive ^{182}Ta wire tags implanted into mole salamanders (24). All tags expelled in the 60-day period were pushed through the skin near the tail. Using smaller tags or using large individuals may have improved the 20% tag retention rate of individuals in our study. Semlitsch (24) reported 83% of radioactive ^{182}Ta wire tags were expelled 100-days after implantation. Our reflector tags implanted in mole salamanders for another study were retained for as long as 8 months (25).

Harmonic radar detection can be a valuable technique in studying the terrestrial ecology of mole salamanders. Because of the small size of their activity areas (Semlitsch 1981a), mole salamanders may be tracked within large field enclosures. Field enclosures have been used to study the terrestrial ecology of a variety of small vertebrates including mole salamanders (26), cotton mice (*Peromyscus gossypinus*) (27), and northern short-tailed shrews (*Blarina brevicauda*) (28). Conditions within enclosures can easily be manipulated and controlled to test effects of habitat changes. Although external tags may alter behavior of animals (20), the effect of internal tags on behavior is unknown. However, in manipulative enclosure studies where all individuals are tagged, relative differences in movement patterns among treatments can be attributed to treatment effects even if behavioral alterations occur. We believe internal HRD reflector tags can be used to provide valuable data on the terrestrial ecology of mole salamanders, and also may be applicable to all salamander species large enough to be implanted.

ACKNOWLEDGEMENTS

We are grateful to the U.S. Department of Energy for access to the Savannah River Site. Funding for this project was provided by the U. S. Department of Energy--Savannah River Operations Office through the U. S. Forest Service--Savannah River and the USFS Northeast Research Station under Interagency Agreement DE-AI09-00SR22188.

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Table 1-1. Mean body weight ($\pm$ SE) before and after 60-day period (April 18, 2003 – June 16, 2003) in which mole salamanders (*Ambystoma talpoideum*) were given sham procedures or implanted with harmonic radar reflector tags.

	Treatment (n)	Sham (n)	<i>Z</i>	<i>P</i>
Weight (g) at 0 Days	7.3 $\pm$ 0.4 (7)	6.9 $\pm$ 0.4 (8)	0.52	0.601
Weight (g) at 60 Days	7.0 $\pm$ 0.5 (7)	6.7 $\pm$ 0.4 (8)	0.29	0.771
Change in Weight (g)	0.3 $\pm$ 0.1 (7)	0.2 $\pm$ 0.1 (8)	-0.18	0.861

Figure 1-1. Diagram of internal harmonic radar reflector tag constructed from Vishay-Telefunken BAT85S schottky barrier diodes and 37-gauge copper wire implanted in mole salamanders (*Ambystoma talpoideum*).

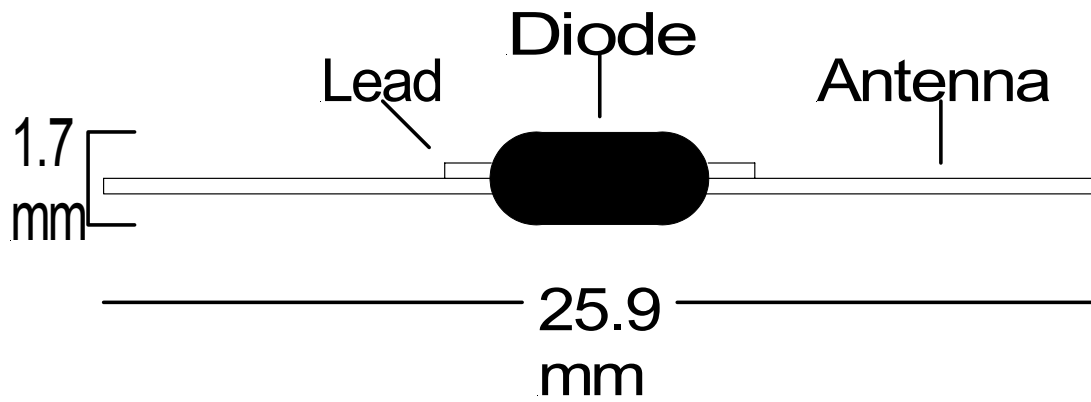
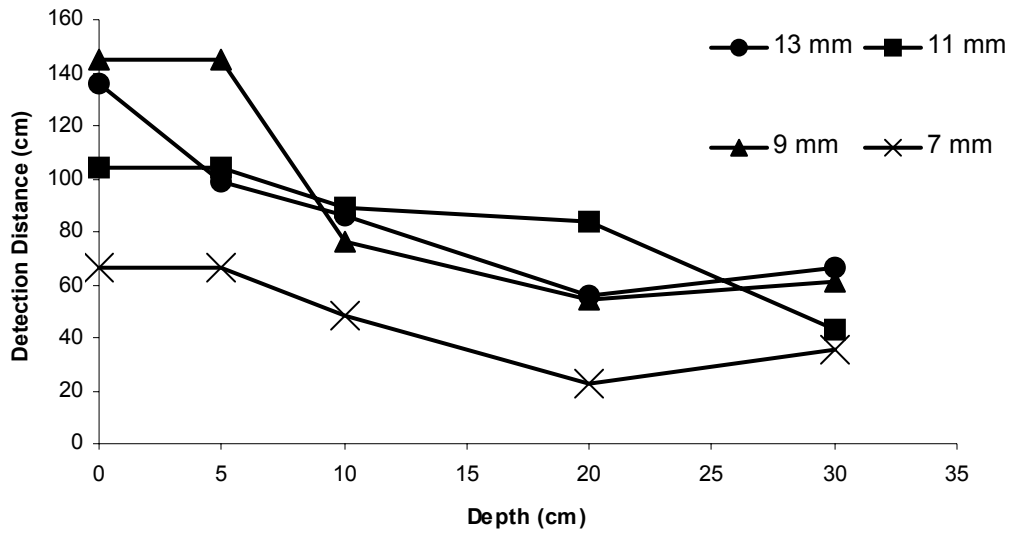


Figure 1-2. Detection range of harmonic radar reflector tags with varying antennae lengths ($n = 1$) inserted into canned sausages and buried at 4 depths below the soil surface.



CHAPTER 2

COARSE WOODY DEBRIS AND PINE LITTER MANIPULATION EFFECTS ON MOVEMENT AND MICROHABITAT USE OF *AMBYSTOMA TALPOIDEUM* IN A *PINUS TAEDA* STAND¹

Abstract

¹ Moseley, K.R., S.B. Castleberry, and W.M. Ford. 2004. *Forest Ecology and Management*. 191:387-396. Reprinted here with permission of publisher.

We examined effects of coarse woody debris (CWD) and pine litter (PL) manipulations on movement and microhabitat use by mole salamanders (*Ambystoma talpoideum*) in the upper Coastal Plain of South Carolina. Individuals were tracked within field enclosures using harmonic radar detection from 3 December 2002 to 1 August 2003. Enclosure study one (ES1) consisted of three treatments: 1) high CWD/high PL, 2) low CWD/low PL, and 3) high CWD/low PL. Enclosure study two (ES2) consisted of two treatment types: complete PL removal and unmanipulated control. Activity of *A. talpoideum* within ES1 high CWD/low PL, low CWD/high PL, and high CWD/high PL treatments did not differ. Individuals subject to ES2 PL removal treatments moved during more nights than individuals in control treatments. During night surveys ES2 PL removal treatments moved on a greater percentage of nights, and were active for longer periods of time, than individuals in control treatments. *Ambystoma talpoideum* exposed to low PL treatments may have utilized CWD as a means of compensating for inadequate microclimate conditions provided by reduced pine litter depth. Our results suggest that reduction of CWD and pine litter has little effect on *A. talpoideum* activity levels. Conversely, complete pine litter removal prompts individual salamanders to move more frequently and for longer periods, thereby potentially being subjected to increased desiccation and predation risk. Within managed pine forests in the southeastern United States, forest management practices that minimize pine litter and CWD removal can help maintain suitable habitat for amphibian groups such as ambystomatid salamanders.

Key words: Ambystomatidae; *Ambystoma talpoideum*; coarse woody debris; pine litter; plantation silviculture

1. Introduction

Alteration and destruction of forest habitat has been cited as a major factor in the decline of many amphibian populations (Blaustein and Wake, 1990; Wyman, 1990; Blaustein and Wake, 1995). Conversion of natural forests to intensively managed plantations is increasing to meet burgeoning demand for wood fiber products. In the southeastern United States, these intensively managed plantations typically contain a less diverse and abundant amphibian assemblage as those in less disturbed unmanaged pine or hardwood stands (Bennett et al., 1980; Grant et al., 1994; Hanlin et al., 2000). Reduction of microhabitat features through use of intensive harvesting and subsequent plantation reestablishment methods are believed to be a major factor leading to the decrease of amphibian populations within these stands (Enge and Marion, 1986).

Pine plantations account for 15% of timberland in the southeastern United States, occurring predominately in the Coastal Plain and Piedmont physiographic regions. These stands are generally much younger than natural pine stands, with 81% less than 23 years old (Conner and Hartsell, 2002). Because plantations are managed on short rotation lengths, disturbance occurs more frequently than in unmanaged pine stands. Plantations generally are subject to clearcut harvesting followed by intensive site preparation such as stump removal, roller chopping, and mechanical bedding (Hunter, 1990; Smith et al., 1997). Even-aged harvest methods and subsequent site preparation compact soil, reduce litter depth and cover, displace mineral soil, and reduce volume of CWD (Harmon et al., 1986; Reisinger et al., 1988; deMaynadier and Hunter, 1995), leading to the development of more homogenous and structurally simplified forest stands. Reduction of these

microhabitat features diminishes onsite moisture, a critical component for amphibians which require moist skin to respire (Duellman and Trueb, 1994), and reduces favorable cover sites used to escape extreme temperature and dry surface conditions (Russell et al., 2002). While response of amphibian species to forest management in the Southeastern Coastal Plain region has been documented, little information exists on the underlying causal mechanisms, especially for members of the family Ambystomidae.

Existing information indicates that establishment of pine plantations has an adverse affect on *Ambystoma* populations. Means et al. (1996) found that a breeding population of flatwoods salamanders (*Ambystoma cingulatum*) drastically declined after their terrestrial habitat, a natural longleaf pine (*Pinus palustris*)-wiregrass (*Aristida* spp.) forest in Florida, had been converted into an intensively managed slash pine (*Pinus elliottii*) plantation. Raymond and Hardy (1991) documented a reduction in survival of adult mole salamanders (*Ambystoma talpoideum*) at a Louisiana pond that migrated from an adjacent portion of forest that had been clearcut. Management practices that produce sites with increased climatic variation and inadequate microhabitat may result in reduced survival of individuals within altered forest stands. However, effects of microhabitat alterations on *Ambystoma* species are not well understood because of their highly fossorial behavior.

Although ambystomid salamanders primarily utilize underground retreat sites, surface cover conditions can have a significant influence on microclimate within burrows by buffering against temperature and moisture extremes in the soil (Williams and Gray, 1974; Geiger et al., 1995). The objectives of our study were to determine how alterations in pine litter depth and CWD volume effect movement, activity levels, and microhabitat use of *A. talpoideum*. Because individuals of this species are too small for

radiotransmitters and because of difficulty in obtaining permits to use radioisotope tagging, a new tracking technique called harmonic radar detection (HRD) was employed to track movement of individuals within an enclosed area.

2. Study Site and methods

2.1. Site Description

Our study was conducted in a 50-year-old loblolly pine (*Pinus taeda*) stand on the U.S. Department of Energy's Savannah River Site (SRS), a 78,000-ha national environmental research park in Aiken, Barnwell and Allendale Counties, South Carolina (33°0-25'N, 81°25-50'W). The SRS is located on the upper Coastal Plain physiographic region in an area known as the Sandhills. Historically, the longleaf pine-wiregrass community dominated upland areas of the SRS before being cleared for agriculture in the early 1800's. Upon acquisition of the land comprising the SRS by the Atomic Energy Commission in 1951, the U.S. Forest Service planted abandoned agricultural fields in loblolly and slash pine. Stands were established on these sites primarily by hand planting. Our study stand was located on a well-drained sandhill at an elevation of 100 m. Soils were of the Blanton-Lakeland association. Understory vegetation was sparse, consisting mostly of poison oak (*Toxicodendron pubescens*), black cherry (*Prunus serotina*), muscadine (*Vitis rotundifolia*), and broomsedge (*Andropogon virginicus*). Our study stand was last prescribed burned in 1993 (D. Shea, USFS Savannah River Site,

Pers. Comm.). Mean annual temperature is 18°C and mean annual precipitation is 122.5 cm.

2.2. Treatments and experimental design

Our first enclosure study (ES1) consisted of three replicate sets of three enclosure treatments of high CWD/high pine litter (PL), low CWD/low PL, and high CWD/low PL. We added three pieces of similarly sized, slightly decayed CWD with mostly shed bark to the center of each enclosure. High CWD treatments had a volume of $91,730 \pm 6736 \text{ cm}^3$, whereas those with low CWD treatments had a volume $25,061 \pm 3190 \text{ cm}^3$. We removed the L, F1, and F2 layers of the A-horizon (Millar, 1974) within each treatment enclosure and replaced it with pine litter collected from the pine stand. Pine litter in high and low PL enclosures had a mean depth of 2.98 ± 1.02 and 0.78 ± 0.43 cm, respectively. Because of soil disturbance caused by removal of pine litter, we created 16 burrows at 64 cm intervals with a 0.64 cm diameter lead pipe. We randomly assigned treatments for one set of enclosures; we then assigned treatment types in remaining enclosures depending upon which treatment had been assigned to enclosures in the first set. This was to ensure that center enclosures, which share walls with adjoining enclosures, received each of the three treatment types in order to eliminate any possible bias associated with having two common walls with adjoining enclosures as opposed to one shared by outside enclosures.

We constructed enclosures for ES1 of 0.635 cm plastic hardware cloth to prevent salamanders from escaping while permitting prey items, primarily insects, to move freely through enclosures. We buried hardware cloth to a depth of 30 cm with an above ground

height of 30 cm. We attached polyvinyl chloride (PVC) pipe to the top of fences as well as 12.7 cm above the ground to create a barrier to salamanders attempting to climb out. We then attached a 12.7 cm piece of hardware cloth to the bottom of each side of enclosures to reduce hole size. Each enclosure was 4.57 by 4.57 m, with a total area of 20.88 m². We oriented all enclosures with each side facing one of the cardinal directions. We completed enclosures and treatments for ES1 on 25 July 2002.

Our second enclosure study (ES2) consisted of 9 pairs of two enclosure treatments, total pine litter removal and unmanipulated controls. We constructed enclosures from aluminum flashing buried 15 cm below ground with 15 cm above ground. We bent tops of enclosure walls to create a lip to prevent climbing salamanders from escaping. Each enclosure measured 3 by 3 m. We randomly assigned treatments to each enclosure pair. For PL removal treatments, we removed all pine litter to expose mineral soil while control enclosures were left undisturbed. Pine litter in control enclosures had a mean depth of 4.04 (± 1.23) cm. We completed enclosures and treatments on 15 February 2003.

We collected individual *A. talpoideum* during breeding migrations at nearby Carolina Bay wetlands (Sharitz and Gibbons, 1982) from November 2002 until cessation of emigration from wetlands in April 2003. We used only females for ES1 because they stay at breeding sites for shorter periods than males and therefore spend more time in terrestrial environments (Semlitsch, 1981). In ES2, we used both male and female *A. talpoideum* captured emigrating from wetlands. We kept captured individuals in 20 cm by 15 cm by 5 cm containers with moist paper towels at 21°C and natural L:D periods. We did not keep individuals in captivity longer than 21 days. We constructed harmonic radar tags from Zener-telefunken BAT85S schottky-barrier diodes with two 11 mm

antennae (total length 25.9 mm) and a total weight 0.1 grams. We subcutaneously implanted one into each salamander. HRD consists of a hand held transceiver and a diode tag. The transceiver emits a 1.7 W continuous microwave frequency of 917 MHz. When the microwaves strike a diode attached to an animal they are reflected at double the frequency (1,834 MHz), which is detected by the receiver. We recorded snout-vent-length (SVL) (cm), total length (cm), sex, and weight (g) of individuals. We allowed individuals to recover for 7 to 10 days post-surgery and following a random assignment to treatment, we released animals at night into 10.2 cm deep artificially constructed burrows (initial burrow). If a tagged salamander in an enclosure died, escaped, or lost its tag, and was not subsequently recovered, we replaced that individual. If individuals expelled tags and were recovered, we implanted new tags and released them back into enclosures. Because adult *A. talpoideum* are not easily found once breeding migrations have ended, we collected a group of individuals from a breeding wetland on 9 April, 2003 (n=12) and placed them in a 2 by 2 m enclosure in the study area for use in replacing lost, dead, or escaped individuals.

2.3. Sampling

We located individuals in ES1 using harmonic radar once during daylight (0800-1800) and once during night (2100-0200) hours, 2-7 days a week from 3 December 2002 to 1 August 2003 (n=241 days). We located individuals in ES2 during the same time periods from 15 February 2003 to 1 August 2003 (n=166 days). We conducted intensive night surveys when heavy precipitation occurred and movement seemed likely. During

night surveys we located individuals once every 60 to 90 minutes from sunset until sunrise. We collected daily temperature and rainfall at the study site during daily readings from a thermometer (°C) and rain gauge (cm) located 30 cm above ground level. We conducted night surveys on 26 February (ES1 only), 15 March (ES1 only), 8 April, 6 May (ES1 only), 18 May, 22 May, and 1 July 2003. We marked location of each individual and time was recorded for each reading. We measured nearest point of locations (cm) using an XY coordinate with the southwest corner of enclosures serving as the origin. We then plotted coordinates and total distance moved (cm) was measured for each individual in QuickCAD 8.0.

2.4. Statistical Analysis

We converted measured variables during each 24-hr sampling period and analyzed them on a per day basis because some enclosures were occupied longer than others. We did not count individuals occupying enclosures for less than 14 days in final analysis. We compared number of activity areas and number of nights moved during 24-hr sampling periods among treatments in ES1 using one-way analysis of variance (ANOVA) with individuals nested within treatments. We also compared movement rate, defined as distance moved (cm) per minute, and total minutes of activity during night surveys among treatments in ES1 using one-way ANOVA with individuals nested within treatments. We considered an activity area to be any point occupied by an individual for ≥ 1 day. We compared percent of nights an individual was active within enclosures during night surveys among treatments in ES1 using a one-way ANOVA. We compared

percent of days in which individuals occupied pine litter and CWD among treatments using a one-way ANOVA. We used linear contrasts to compare high PL with low PL treatments and high CWD with low CWD treatments for all variables in ES1. For ES2, we compared number of activity areas and number of nights moved during 24-hr sampling periods and movement rate and total minutes of activity during night surveys between treatments using one-way ANOVA with individuals nested within treatments. We compared percent of nights an individual was active within enclosures during night surveys between treatments in ES2 with a two-sample t-test. Effect of sex on number of activity areas and nights moved were compared using a two-sample t-test. All variables were tested for normality with Shapiro-wilk's test for normal distribution. Percentage data were arcsine transformed. Data that were not normally distributed and that could not be successfully transformed were ranked and analysis was performed on the ranks. All analyses were performed in SAS statistical analysis software (SAS, 1997).

3. Results

There was a total of 618, 628, and 640 salamander nights in high CWD/low PL, low CWD/low PL, and high CWD/high PL, respectively. Number of activity areas and number of nights moved during daily locations for ES1 did not differ among treatments (Table 2-1). Percent use of pine litter and CWD were not different among treatments (Table 2-2). However, linear contrasts revealed that individuals in low CWD treatments utilized CWD to a greater extent than individuals in high CWD treatments ($F=6.94$,

$p=0.0388$). Time active (min), movement rate, and percent of nights active in ES1 during night surveys were not different among treatments (Table 2-1).

In ES2 there was a total of 835 and 987 salamander nights for PL removal and control treatments, respectively. Number of activity areas for ES2 did not differ between treatments (Table 2-3). However, individuals in PL removal treatments moved more frequently than control individuals during night surveys (Fig. 2-1). Individuals in PL removal enclosures also were active for longer periods and moved during a larger percentage of night surveys than control individuals (Table 2-3). Males and females did not differ in any other variables measured.

4. Discussion

Pine litter removal had a significant effect on movement and activity levels of *A. talpoideum*. Individuals within ES2 PL removal enclosures were active an average 91.7% of nights surveyed, 32% more than those within control enclosures, and moved 61.6% more than controls during the 241-day sampling period. Increased activity is likely due to absence of adequate microclimate conditions within removal enclosures. Litter acts as an insulating layer for soil, buffering against extreme surface temperatures, and retaining moisture during dry periods (Williams and Gray, 1974; Geiger et al., 1995). Elimination of ground cover reduces availability of suitable temperature and moisture conditions for salamanders (Pough et al., 1987). Reduction of forest floor litter depth also has been found to reduce abundance of arthropod prey (Seastedt and Crossley, 1981; Shure and Phillips, 1991; Siira-Pietikainen et al., 2003). Initial burrows within PL

removal treatments were not insulated from fluctuations in ambient climatic conditions, prompting individuals to attempt relocation more frequently during rainy nights. Exposure of the soil surface to rain further decreased available microhabitats by eroding burrow entrances, forcing individuals to maintain occupancy in suboptimal initial burrows. Reductions in microhabitat and arthropod density may have been responsible for the increased surface activity of individuals in PL removal enclosures. In contrast, *A. talpoideum* within control treatments were exposed to more suitable microenvironments, enabling them to spend less time on the surface where they were at risk of being consumed by predators.

During our study, snakes consumed two individuals. The first was depredated on 12 May 2003 by a Southern hognose snake (*Heterodon simus*) and another on 1 August 2003 by an Eastern garter snake (*Thamnophis sirtalis*). While neither depredation occurred in ES2 removal enclosures (both depredations occurred within plots of ES1), they illustrate the predation risk encountered during surface activity and while occupying burrows with an exposed entrance. Increased surface activity time also may subject individuals to desiccation (Semlitsch, 1983a). One individual in an ES2 removal plot was found exposed on the surface alive during daylight hours, and two were found dead more than 30 days after being put into enclosures from what appeared to be desiccation. Although PL removal treatments were mostly devoid of suitable habitat, *A. talpoideum* were able to exploit several microhabitats including plant root systems and shallow patches of pine litter that collected in small depressions.

Unlike conditions in ES2 PL removal treatments, ES1 enclosures containing pine litter and CWD appeared to have provided more suitable microhabitats for *A. talpoideum*

to exploit. No differences were found among movement variables measured. Use of CWD compared to availability was greater for individuals in low PL treatments (Fig. 2-2). Individuals in low PL treatments were found under CWD 22.73% of days located, whereas those in high CWD treatments occupied CWD only 2.15% of days located (Table 2-2). Increased pine litter depth in high PL treatments probably provided adequate moisture for individuals, reducing their need to utilize CWD as an alternative microhabitat. Inability of individuals in low PL treatments to find adequate moisture and temperature conditions under pine litter was probably mitigated through use of CWD.

Like pine litter, CWD buffers against extreme temperature fluctuations, retains moisture during dry periods (Boddy, 1983; Harmon et al., 1986), and contains abundant insect prey (Hanula, 1995). Coarse woody debris has been found to play an important role in the terrestrial ecology of plethodontid salamanders (Kleeberger and Werner, 1982; Aubrey et al., 1988; Bury and Corn, 1988; Dupuis et al., 1995; Maidens et al., 1998). However, CWD may be of less significance in the terrestrial ecology of ambystomatid salamanders, which prefer underground burrow systems (Williams, 1970; Semlitsch, 1983b; Douglas, 1981; Loreda et al., 1996; Madison, 1997; Madison and Farrand, 1998; Trenham, 2001) that are generally independent of CWD (Semlitsch, 1981). Locally, subterranean burrows created by small mammals such as moles (Talpidae) and *Peromyscus* spp., as well as preexisting cracks and crevices in the soil, can be exploited by *A. talpoideum* (Semlitsch, 1983a). However, if pine litter depth becomes inadequate in regulating burrow conditions from extreme climatic variation, individuals may seek refuge under CWD. At the Savannah River Site, Chazal and Niewiarski (1998) compared juvenile *A. talpoideum* within enclosures in a 4-month-old clearcut to

individuals maintained in an adjacent 40-year old loblolly pine stand. Juveniles did not differ in abundance, body mass, snout-vent-length, clutch size, percent whole-body nonpolar storage lipid, or percent storage lipid of eggs after 5-6 months of exposure to enclosure conditions. Lack of difference between the two treatments was attributed partially to the large amounts of CWD in clearcut enclosures, which were believed to have ameliorated clearcut surface conditions by retaining on-site moisture.

In most natural situations where pine litter is sufficient, use of CWD by *A. talpoideum* probably is low. Following clearcutting and subsequent site preparation pine litter depth and cover is significantly reduced (Russell et al., 2002). During this stage, amount of residual CWD on site may play a significant role in providing necessary microhabitat for *A. talpoideum*.

5. Conclusion

Availability of microhabitat is greatly influenced by silvicultural techniques used during harvesting and site preparation. Intensive mechanical treatments such as disking, harrowing and rollerchopping are frequently used in the southeastern Coastal Plain. The primary goal of these techniques is to reduce logging slash and competing vegetation, and expose mineral soil. Mechanical site preparation treatments likely produce the most harm by increasing bare ground cover, reducing forest floor depth, disturbing and compacting mineral soil, and eliminating much of the CWD left on site following tree harvesting (Harmon et al., 1986; deMaynadier and Hunter, 1995; Russell et al., 2003). Mechanical operations also mix organic material with mineral soil, accelerating

decomposition (Salonius, 1983), and destroy underground burrows preferred by ambystomid salamanders. Alteration of terrestrial habitat through intensive site preparation of a slash pine stand is believed to have been responsible for a twenty-two year decline in a breeding population of *A. cingulatum* within the disturbed stand (Means et al., 1996). Because *A. talpoideum* in our study were subject to pine litter and CWD manipulation within an intact 50-year old slash pine stand, our results should be interpreted cautiously when applied to stand conditions produced by harvesting and site preparation. However, retaining some woody debris as refugia following site preparation (American Forest and Paper Association, 2002) may mitigate effects of inadequate pine litter depth and destruction of underground burrows.

Most CWD remaining after harvest and site preparation is generally lost through decay (Barber and Van Lear, 1984), prescribed fire and deficiency of new inputs by mid-rotation (Van Lear and Waldrop, 1994). However, loss of CWD at this period of stand development is probably not detrimental to ambystomid salamanders, which favor use of underground burrows. Pine litter increases rapidly during the first 15-years following establishment of pine plantations due to the low decomposition rate of pine litter (Gholz et al., 1985). Once sufficient pine litter is available, *A. talpoideum* will become less dependent upon CWD for refugia. Increased pine litter facilitates recovery of soil structure (Switzer et al., 1979) and stabilizes microclimate in underground burrows. Therefore rapid recovery of pine litter depth ensures rapid restoration of preferred ambystomid habitat.

Throughout the duration of stand development in much of the Southeast, land managers often employ practices that reduce forest floor material. Prescribed fire is

frequently used to create wildlife habitat, reduce heavy fuel accumulation, expose mineral soil, and control competing vegetation, insects and diseases (Hunter, 1990). Although prescribed burns reduce litter depth, they are generally not intense enough to remove all organic material on the forest floor. Organic matter in uneven-aged loblolly and shortleaf (*Pinus echinata*) pine stands in southeastern Arkansas was only 15% lower one year after a prescribed fire than in similar stands which had not been burned for 6-years or in unburned control stands (Cain et al., 1998). In the Atlantic Coastal Plain of Maryland, a 50-year old stand dominated by loblolly pine and subject to 8 prescribed burns in 13 years had a litter depth of 1.7 ± 0.8 cm, 46% deeper than litter depth in low PL enclosures of our study, whereas a similar unburned pine stand contained a depth of 4.9 ± 0.4 cm (McLeod and Gates, 1998). While prescribed fire reduces pine litter depth, remaining organic material should provide adequate buffering of the soil from climatic extremes and maintain integrity of underground burrows. However, reduction of pine litter through other removal practices, such as pine straw harvesting for horticultural and landscaping markets may have a negative impact on ambystomid salamanders due to increased disturbance to the organic soil layer.

Demand for pine straw in natural landscaping is increasing (Morris et al, 1992). Harvesting of pine litter reduces litter depth and may increase soil bulk density (McLeod et al., 1979; Haywood et al., 1994); however, if removals are performed at 2 to 3 year intervals these effects should be negligible, leaving partially decomposed and fragmented needle litter intact. Although soil compaction may be a problem depending on techniques and equipment used, it is regarded as unlikely (Morris et al., 1992). Nonetheless, if removals are conducted too regularly, exposure of mineral soil may result (Morris et al.,

1992), compelling resident *A. talpoideum*, or other ambystomids, to move more frequently. Sustainable pine straw harvests should limit removal to 20% of pine litter (Duryea and Edwards, 2002), thereby leaving adequate litter depth and minimizing disturbance to underground burrows of *A. talpoideum*.

Ambystoma talpoideum are capable of exploiting a variety of refugia, responding to depletion of one microhabitat by utilizing another. Our study supports sustainable forestry initiative guidelines, which suggest leaving logging slash on site following harvesting in order to provide refugia for salamander species (American Forest and Paper Association, 2002). Although our study demonstrated the ability of *A. talpoideum* to survive adverse conditions, immediate and longterm effects of frequent, mechanized habitat disturbance may have profound impacts on breeding populations of ambystomid species. Quality of terrestrial habitat is important for maintaining viable amphibian populations (Semlitsch, 2000). Plantation forest management practices that minimize mechanical disturbance and retain adequate microhabitat throughout stand development will provide necessary habitat for resident fossorial salamander species.

6. Acknowledgements

We thank J.C. Kilgo for help in locating study sites and D. Croshaw for aiding in collection of salamanders. We also thank R.J. Cooper for statistical advice. We are grateful to the U.S. Department of Energy for access to the Savannah River Site. Funding for this project was provided by the U. S. Department of Energy--Savannah River Operations Office through the U. S. Forest Service--Savannah River and the USFS Northeast Research Station under Interagency Agreement DE-AI09-00SR22188

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Table 2-1. Mean ($\pm$ SE) number of activity areas and nights moved per day during daily locations, and mean ($\pm$ SE) time active, movement rate, and nights active during night surveys for *A. talpoideum* in high CWD/low pine litter (PL) (N=618 Salamander days), low CWD/low PL (n=628 salamander days), and high CWD/high PL (n=640 salamander days) enclosures at the Savannah River Site, Aiken County, South Carolina, from 3 December, 2002 to 1 August, 2003.

Variable	High CWD/Low PL Mean $\pm$ SE (N)	Low CWD/Low PL Mean $\pm$ SE (N)	High CWD/High PL Mean $\pm$ SE (N)	F (df)	<i>p</i>
Daily Locations					
Activity Areas ¹	0.06 $\pm$ 0.03 (3)	0.04 $\pm$ 0.01 (3)	0.04 $\pm$ 0.01 (3)	0.29 (2,6)	0.7586
Nights Moved ¹	0.06 $\pm$ 0.03 (3)	0.04 $\pm$ 0.01 (3)	0.02 $\pm$ 0.01 (3)	0.66 (2,6)	0.5491
Night Surveys					
Time Active (min)	445 $\pm$ 96.1 (3)	423 $\pm$ 82.3 (3)	261 $\pm$ 32.2 (2)	1.86 (2,5)	0.2485
Movement Rate (cm/min)	2.65 $\pm$ 0.6 (3)	2.85 $\pm$ 0.6 (3)	2.07 $\pm$ 0.7 (2)	0.19 (2,5)	0.8345
Nights Active (%)	42.86 $\pm$ 20.53 (3)	29.21 $\pm$ 7.7 (3)	18.89 $\pm$ 14.2 (2)	0.74 (2,5)	0.5146

¹ – ANOVA performed on ranked data

Table 2-2. Mean ($\pm$ SE) percentage of days pine litter and coarse woody debris (CWD) were used by *A. talpoideum* during daily locations in high CWD/low pine litter (PL) (N=618 Salamander days), low CWD/low PL (n=628 salamander days), and high CWD/high PL (n=640 salamander days) enclosures at the Savannah River Site, Aiken County, South Carolina, from 3 December, 2002 to 1 August, 2003.

Variable	High CWD/Low PL Mean $\pm$ SE (N)	Low CWD/Low PL Mean $\pm$ SE (N)	High CWD/High PL Mean $\pm$ SE (N)	F (df)	<i>p</i>
Pine litter use (%)	49.72 $\pm$ 16.96 (3)	45.46 $\pm$ 11.91 (3)	35.64 $\pm$ 21.03 (3)	0.18 (2,6)	0.8410
CWD use (%)	16.81 $\pm$ 12.75 (3)	37.62 $\pm$ 7.40 (3)	2.15 $\pm$ 2.15 (3)	4.17 (2,6)	0.0732

Table 2-3. Mean ($\pm$ SE) number of activity areas and nights moved per day during daily locations, and mean ($\pm$ SE) time active, movement rate, and nights active during night surveys for *A. talpoideum* in pine litter removal (n=835 salamander days) and control (n=987 salamander days) enclosures at the Savannah River Site, Aiken County, South Carolina, from 15 February, 2003 to 1 August, 2003.

Variable	Pine litter Removal Mean $\pm$ SE (N)	Control Mean $\pm$ SE (N)	F (df)	<i>p</i>
Daily Locations				
Activity Areas	0.06 $\pm$ 0.01 (9)	0.05 $\pm$ 0.01 (9)	0.01 (1,16)	0.9171
Nights Moved ¹	0.06 $\pm$ 0.01 (9)	0.03 $\pm$ 0.01 (9)	5.21 (1,16)	0.0365
Night Surveys				
Time Active (min)	463 $\pm$ 32.83 (7)	272 $\pm$ 56.05 (6)	13.21 (1,11)	0.0039
Movement Rate (cm/min)	2.45 $\pm$ 0.14 (7)	2.54 $\pm$ 0.25 (6)	0.14 (1,11)	0.7110

¹ – ANOVA performed on ranked data

Fig. 2-1. Percent of nights in which *A. talpoideum* in pine litter removal (n=835 salamander days) and control (n=987 salamander days) treatment enclosures were active on the forest floor during night surveys conducted on 8 April, 18 May, 22 May, and 1 July, 2003. Treatments were compared by ranks with a two-sample t-test (t-value= -2.42, $p=0.0341$).

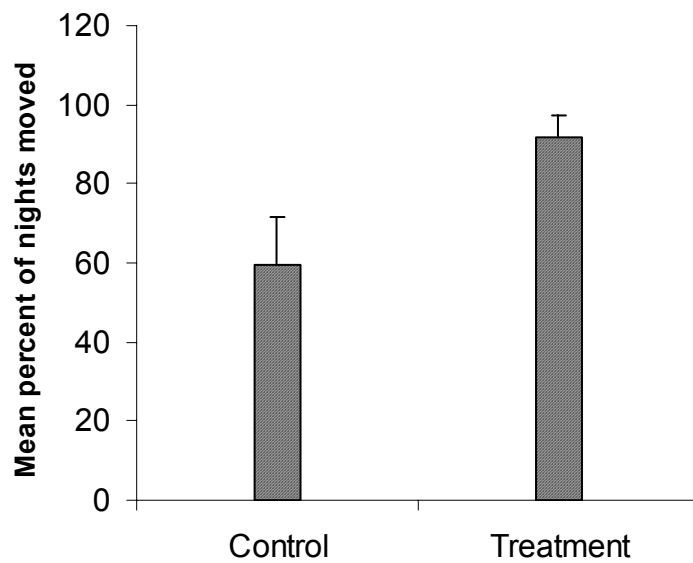
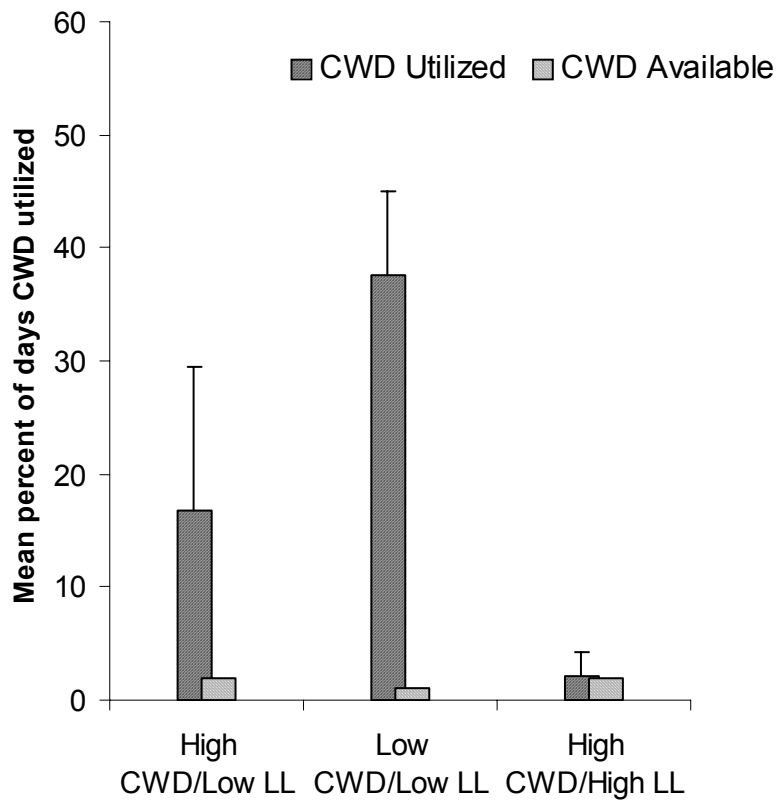


Fig. 2-2. Mean percent of days, with standard error, in which *A. talpoideum* were located under coarse woody debris (CWD) within high CWD/low pine litter (PL) (N=618 Salamander days), low CWD/low PL (n=628 salamander days), and high CWD/high PL (n=640 salamander days) enclosures containing from 3 December 2003 to 1 August 2003.



CHAPTER 3

SEASONAL AND SEXUAL VARIATION IN DIET COMPOSITION OF SOUTHERN
TOADS IN UPLAND LOBLOLLY PINE STANDS¹

¹ Moseley, K.R., S.B. Castleberry, and W.M. Ford. To be submitted to *Southeastern Naturalist*.

ABSTRACT —We collected southern toads (*Bufo terrestris* B.) in upland loblolly pine (*Pinus taeda* L.) stands in the Coastal Plain of South Carolina for stomach content analysis. We compared relative abundance of invertebrate groups consumed, body weight (g), and stomach content weight (g wet) among seasons (summer 2002, fall, spring, and summer 2003), between males and females, and between gravid and nongravid females. Consumption of ants, beetles, and insect larvae (immatures) varied by season. Additionally, stomach content weight of southern toads collected during spring was less than for other sampling periods ($F_{2,66} = 5.12$, $P = 0.009$). Relative abundance of prey items found in male and female southern toads did not differ. Nongravid females consumed a greater proportion of ants ($Z = 2.69$, $P = 0.009$) and gastropods ($Z = 3.50$, $P = 0.001$), whereas gravid females consumed a greater proportion of immatures ($Z = -2.25$, $P = 0.027$). Our results suggest that fluctuations in consumption of major prey groups may be due to reduced movement of southern toads during dry periods. Energy demands of vitellogenesis may be responsible for increased consumption of prey by females.

INTRODUCTION

In the southeastern Coastal Plain physiographic region, pine (*Pinus* spp.) stands harbor diverse amphibian assemblages depending on overstory species composition, age and stand structure (Bennett et al. 1980, Grant et al. 1994, Hanlin et al. 2000). Although pine forests are dominant in the region with the loblolly-shortleaf (*P. echinata* Mill.) type comprising nearly 25 % of timberland area (Conner and Hartsell 2002), seasonal, and sexual variation in the diet of terrestrial anurans within these stands has been inadequately documented. Dietary composition of anurans can be influenced by seasonal

availability of prey items (Anderson et al. 1999, Bush and Menhinick 1962, Jenssen and Klimstra 1966, Toft 1980, Whitaker et al. 1977) and sexual differences in nutritive requirements associated with reproduction (Donnelly 1991, Lamb 1984). Because land management activities in southeastern pine forests are intensive and are expected to increase in intensity and scope (Prestemon and Abt 2002), knowledge of species dietary requirements is important for implementing effective land management strategies (Litvaitis et al. 1996).

The southern toad is an abundant species throughout the Coastal Plain of the Southeast (Conant and Collins 1998), where it primarily consumes ants and beetles (Krakauer 1968, Punzo 1992). In a review of dietary studies, Clarke (1974a) concluded that stomach contents of *Bufo* spp. reflect availability of prey items of appropriate size within a given habitat. Although dietary composition of southern toads has been investigated in Florida, there is little information documenting seasonal and sexual variation of prey items consumed in upland pine forest habitats. The objective of our study was to examine seasonal and sexual variation in diet composition of southern toads captured within upland loblolly pine stands.

FIELD SITE DESCRIPTION

Our study was conducted at the Savannah River Site (SRS), a 78,000-ha National Environmental Research Park located in Aiken, Barnwell, and Allendale Counties, South Carolina (33°0-25'N, 81°25-50'W) on the Upper Coastal Plain region in an area known as the Sandhills. Southern toads and arthropods were collected in thinly stocked loblolly pine stands approximately 50 years in age. Midstory was sparse and consisted primarily of black cherry (*Prunus serotina* Ehrh.) and water oak (*Quercus nigra* L.). Elevation of

stands ranged from 20-130 m with sandy, well-drained soils. Dominant understory vegetation consisted of lespedeza (*Lespedeza* spp.), poison oak (*Toxicodendron pubescens* P.), beggarweed (*Desmodium* spp.), and broomsedge (*Andropogon* spp.). The region is characterized as warm temperate to subtropical with mean annual precipitation of 122.5 cm and a mean annual temperature of 18°C.

METHODS

We sampled southern toads using drift fences in 12 loblolly pine stands. In each stand we installed a cross-shaped array with 30-m arms and X-shaped arrays with 15-m arms in each corner of the center array (Corn 1994). Drift fence arrays were constructed from aluminum flashing buried 15-cm in the ground and 19-l plastic buckets buried against each fence. We opened traps for 14-days during June (summer 2002) and October (fall) 2002, and June (summer 2003) 2003. Additionally, we opened traps for 28-days during April (spring) 2003. We checked traps daily and only collected southern toads ≥ 4 cm snout-vent length (SVL). Within 6-hrs of collection, we euthanised individuals via double pithing (McDiarmid 1994, AVMA Panel on Euthanasia 2001) and froze them for later dissection. All individuals were collected under South Carolina Department of Natural Resources scientific research permit # G-02-09 and University of Georgia IACUC number A2002-10019-c2.

We weighed (g) individual southern toads, recorded SVL (cm), and removed the stomach. Stomach contents were weighed (g wet) and examined for prey. We preserved invertebrates collected from stomachs in 70 % ethanol. We did not record body weight or stomach content weight in summer 2002. Invertebrates were identified to order or class, and in the case of ants, to family. We identified invertebrates primarily through

presence of head capsules to prevent counting a single individual twice. We calculated relative abundance of each invertebrate group consumed by dividing abundance of each group by total capture abundance. We calculated frequency of occurrence for each prey group as percent of stomachs containing at least one item of a given prey group.

We compared differences in relative abundance of invertebrate groups consumed and number of prey items identified in stomach contents among seasons with a Kruskal-Wallis rank sum test. When significant differences were detected among treatments, we used a two-tailed Wilcoxon rank sum test to determine which means were different (Saville 1990). A Shapiro-Wilks test indicated that seasonal body weight and stomach content weight were not normally distributed and efforts to transform them were unsuccessful. Thus, we compared body weight and stomach content weight among seasons using a two-way analysis of variance (ANOVA) blocked by sex and SVL on ranked data. We compared relative abundance of invertebrate groups consumed between males and females and nongravid and gravid females using a two-tailed Wilcoxon rank sum test. We tested for differences in body weight and stomach content weight between male and females and gravid and nongravid females using a two-way ANOVA blocked by SVL on ranked data. All statistical tests were conducted using SAS statistical software (SAS Institute 1997).

We compared dietary overlap between seasons, sex, and gravid versus nongravid females using Morisita's index (Litvaitis et al. 1996), which produces values between 0 and 1, where 0 indicates no overlap in diet and 1 indicates total dietary overlap. This index (C) is considered the least biased diet overlap estimator (Smith and Zaret 1982). However, because we only identified most prey items to order our results should be

interpreted cautiously as similarity between treatments may be overestimated (Green and Jaksic 1983).

RESULTS

During summer and fall 2002, and spring and summer 2003, we collected a total of 49, 29, 29, and 37 southern toads, respectively. Ants were consumed less in fall than in either summer 2002 or spring ($X^2 = 9.77$, $P = 0.021$; Table 3-1). Beetles were consumed less in spring ($X^2 = 8.60$, $P = 0.035$; Table 3-1) and fewer insect larva (immatures) were consumed in summer 2002 ($X^2 = 12.87$, $P = 0.005$; Table 3-1). Ants were the most frequently consumed prey item in all seasons except summer 2003, when beetles were most frequently consumed (Table 3-1). We found 4.1, 6.9, 3.5, and 5.4 % of stomachs empty from summer 2002, fall, spring, and summer 2003, respectively. Mean ($\pm$ SE) number of prey items identified in southern toads captured in summer 2002, fall, spring, and summer 2003 were 15.8 ± 2.4 , 6.4 ± 0.8 , 8.4 ± 1.6 , and 11.0 ± 2.4 , respectively. Mean number of prey items identified in stomach contents differed among seasons ($X^2 = 9.98$, $P = 0.019$) with southern toads captured in summer 2002 containing more prey items than individuals in spring or fall. Mean body weight ($\pm$ SE) of southern toads in fall, spring, and summer 2003 were 18.5 ± 1.3 , 23.6 ± 1.6 , and 18.6 ± 1.1 , respectively. Body weight was greater for individuals captured in spring than in either summer 2003 or fall 2002 ($F_{2,67} = 10.46$, $P = 0.0001$). Mean stomach content weight ($\pm$ SE) of individuals captured in fall, spring, and summer 2003 were 0.8 ± 0.1 , 0.5 ± 0.1 , and 0.9 ± 0.1 , respectively. Stomach content weight of individuals collected during spring was less than for other sampling periods ($F_{2,66} = 5.12$, $P = 0.009$). Dietary overlap was similar among all seasons with fall and summer 2003 being most similar ($C = 0.92$) followed by

summer 2002 and spring ($C = 0.92$), summer 2003 and spring ($C = 0.89$), summer 2002 and fall ($C = 0.88$), fall and spring ($C = 0.87$), and summer 2002 and summer 2003 ($C = 0.87$).

Our collections included 88 females and 56 male southern toads. Over all seasons combined, relative abundance of invertebrate groups consumed did not differ between sexes ($P > 0.05$; Table 3-2). Ants were the most frequently consumed prey item in both male and female southern toads (Table 3-2). Mean number of prey items identified in male and female stomach contents were 10.3 ± 1.5 and 11.8 ± 1.6 , and did not differ between sexes ($Z = -1.27$, $P = 0.203$). Of southern toads examined, 8.9 and 2.3 % of males and females, respectively, contained empty stomachs. Mean body weight ($\pm$ SE) of males and females was 15.2 ± 0.8 and 22.7 ± 1.0 , respectively. Females were heavier than males ($F_{1,69} = 65.39$, $P < 0.0001$). Mean stomach content weight ($\pm$ SE) of male and female southern toads was 0.5 ± 0.1 and 0.9 ± 0.1 , respectively. Stomach content weight of females was greater than that of males ($F_{1,68} = 7.81$, $P = 0.007$). Males and females exhibited a high degree of dietary overlap ($C = 0.88$).

Of the 88 females collected, 58 were gravid and 30 were nongravid. Nongravid females contained a greater relative abundance of ants ($Z = 2.69$, $P = 0.007$; Table 3-3) and gastropods ($Z = 3.50$, $P = 0.0005$; Table 3-3) whereas gravid females consumed more immature prey items ($Z = -2.25$, $P = 0.024$; Table 3-3). Ants were the most frequently found prey item in both gravid and nongravid females (Table 3-3). Mean number of prey items identified in gravid and nongravid females was 9.7 ± 3.1 and 15.5 ± 3.1 , respectively. Gravid females consumed a greater number of prey items than nongravid females ($Z = 2.31$, $P = 0.021$). Mean stomach content weight ($\pm$ SE) of gravid and

nongravid females was 0.9 ± 0.1 and 0.9 ± 0.0 , respectively. Stomach content weight was similar between gravid and nongravid females ($F_{1,39} = 0.30$, $P = 0.589$). Gravid and nongravid females exhibited a high degree of dietary overlap ($C = 0.87$).

DISCUSSION

Seasonal Variation in Diet Composition

Our results suggest that consumption of certain invertebrate groups by southern toads in upland loblolly pine stands may be influenced by seasonal availability of prey items, although there was a high degree of overlap in content across seasons. Ant consumption was greatest in summer 2002, during which we found ants in 93.9 % of southern toad stomachs examined. Frequent consumption of ants during this period probably accounts for the increased number of stomach items observed in summer 2002. Because of their small size, the total number of prey consumed by an individual is dependent on quantity of ants found in stomach contents (Bush and Menhinick 1962). Fewer ants were consumed by southern toads in fall. Conversely, ants comprised the majority of prey items consumed in spring (61.1 %). Increased consumption of ants during spring corresponds with a decline in consumption of beetles, which, because of their size relative to ants, probably accounts for the observed decrease in stomach content weight during this period (Clarke 1974a).

Fluctuations in ant consumption during fall and spring in our study may be due to reduced movement of southern toads during dry periods. At the SRS, mean rainfall during the October trapping period was 0.20 cm (± 0.03 SE), whereas 0.81 cm (± 0.10 SE) fell during the April sampling period. *Bufo* spp. are generally less active during periods of low moisture (Clarke 1974b, Gibbons and Bennett 1974). Less movement

may reduce encounters with ants, whose distribution often exhibits patchiness and high levels of crowding (Levings 1983, Lynch 1981, Lynch et al. 1988). Prey items consumed during dry periods probably reflect opportunistic encounters during restricted foraging periods as opposed to active searching of preferred prey. The increased rainfall during spring may have permitted southern toads to move greater distances when foraging, enabling them to exploit patchy ant distribution.

Ants and beetles comprised the overwhelming majority of prey items in our study, supporting the observations of other researchers investigating dietary composition of southern toads and *Bufo* spp. (Clarke 1974a). Ants and beetles possess defensive characteristics, such as the ability to secrete formic acid and thick exoskeleton that would make them less palatable to many predators and in part very abundant in forested environments. The ability of southern toads to consume these noxious prey items ensures an adequate food supply (Clarke 1974a). In our study, ants comprised more than 64 % of prey items during all seasons combined. However, because of their small size ants may contribute fewer overall calories than beetles. Anurans breeding in playa wetlands in the southern High Plains of the southwestern United States concentrated their feeding efforts on beetles (Anderson et al. 1999), presumably because they possess higher protein content compared to other invertebrate groups (Anderson and Smith 1998). However, invertebrates that possess a greater proportion of chitin in their exoskeletons, such as ants and beetles, contribute proportionately fewer calories than softer bodied prey items (Dimmitt and Ruibal 1980). Therefore, nutritional contribution of few soft bodied prey items by southern toads should not be discounted.

Spiders made up only 5.1 % of prey items consumed, but were found in > 25 % of all stomachs examined. Spiders were common prey of adult southern toads in Florida, comprising 8-11 % of prey items and represented in 42.5 and 85.1 % of stomachs examined in spring and summer, respectively (Punzo 1992). Across seasons, spiders accounted for > 18 % of terrestrial arthropods within our stands (J.L. Hanula, Unpub. Data). The discrepancy in relative abundance of spiders consumed may be due to their movement patterns. Southern toads are active foragers, generally consuming small, slow-moving, chitinous prey that live in aggregations and often possess chemical defenses (Clarke 1974a, Lima and Moreira 1993, Toft 1980). Therefore, unlike ants and beetles, the sessile movement behavior of spiders may not solicit an attack response from toads.

Sexual Variation in Diet Composition

Diet composition of male and female southern toads was similar, which supports earlier observations on lack of sexual differences in diet composition of this species (Punzo 1992, Smith and Bragg 1949). No differences were found for prey items consumed by male and female southern toads collected from temporary pools and roadsides in Florida (Punzo 1992). Additionally, Smith and Bragg (1949) found little difference in prey items consumed between sexes of Great Plains toads (*B. cognatus* Say) and Woodhouse's toads (*B. woodhouseii woodhouseii* Girard) captured in Oklahoma. However, stomach content weight of females in our study was greater than that of males.

Difference in stomach content mass is likely a consequence of differential breeding behavior between male and female southern toads. During the breeding season male anurans generally reduce foraging time, allotting more effort to calling (Klimstra and Myers 1962, Lamb 1984). The majority of males we collected exhibited dark throat

coloration, indicating that they had been engaged in chorusing. Stomach content volume of male pig frogs (*Rana grylio* Stejneger) collected in Georgia was less than that of females (Lamb 1984). During the breeding season, females may increase foraging effort to meet increased energy requirements for vitellogenesis (Donnelly 1991). Female boreal toads (*Bufo boreas* B. and Girard) in Rocky Mountain National Park, Colorado, were found to occupy larger home ranges than males, presumably to meet energy demands associated with reproduction (Muths 2003). Southern toads have a prolonged breeding season, acting opportunistically during moist conditions to migrate to nearby water pools (Krakauer 1968). Of female southern toads collected during summer 2002, fall, spring, and summer 2003, 25.9, 100, 100, and 53.9%, respectively, were gravid. Additionally, 57% of all southern toads collected in spring were gravid, which probably accounts for the increased body weight observed during this period. Because of the lengthy breeding season, females must be able to continually acquire adequate nutrients for vitellogenesis and may do this by consuming greater amounts of food and increasing concentration on prey items of high caloric value.

Gravid females consumed a greater relative abundance of immatures than nongravid females. We found immatures in 15.5 % of gravid female stomachs examined. Additionally, fewer immatures were consumed during summer 2002, which also contained the lowest percentage of gravid females captured. Also, fewer ants were consumed by gravid females, perhaps indicating increased efforts by female southern toads to locate prey items of higher caloric value. Although gravid females in our study contained fewer ants than nongravid females, they consumed a greater number of prey

items, indicating that they may consume anything they identify as prey to acquire sufficient nutrients for egg vitellogenesis.

ACKNOWLEDGEMENTS

We are grateful to the U.S. Department of Energy for access to the Savannah River Site. Funding for this project was provided by the U. S. Department of Energy--Savannah River Operations Office through the U. S. Forest Service--Savannah River and the USFS Northeast Research Station under Interagency Agreement DE-AI09-00SR22188

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Table 3-1. Mean relative abundance ($\pm$ SE) and frequency of occurrence of invertebrate groups identified in stomach contents of southern toads (*Bufo terrestris* B.) collected in upland loblolly pine (*Pinus taeda* L.) stands in the Coastal Plain of South Carolina during June and October 2002 and April and June 2003.

	Summer 2002 (n=49)	Fall 2002 (n=29)	Spring 2003 (n=29)	Summer 2003 (n=37)	H	P
Formicidae						
Relative abundance	0.580 $\pm$ 0.039 ^a	0.391 $\pm$ 0.056 ^b	0.611 $\pm$ 0.056 ^a	0.460 $\pm$ 0.058 ^{a,b}	9.77	0.021
Frequency	93.88	82.76	93.10	70.27		
Coleoptera						
Relative abundance	0.292 $\pm$ 0.036 ^a	0.356 $\pm$ 0.053 ^a	0.182 $\pm$ 0.049 ^b	0.318 $\pm$ 0.052 ^a	8.60	0.035
Frequency	85.71	79.31	55.17	81.08		
Araneae						
Relative abundance	0.033 $\pm$ 0.010	0.080 $\pm$ 0.028	0.112 $\pm$ 0.037	0.057 $\pm$ 0.028	3.48	0.323
Frequency	26.53	34.48	37.93	24.32		
Orthoptera						
Relative abundance	0.034 $\pm$ 0.008	0.072 $\pm$ 0.023	0.028 $\pm$ 0.016	0.048 $\pm$ 0.018	3.49	0.322
Frequency	34.69	31.03	13.79	24.32		
Hymenoptera ¹						
Relative abundance	0.016 $\pm$ 0.005	0.014 $\pm$ 0.010	0.044 $\pm$ 0.021	0.074 $\pm$ 0.030	3.16	0.367
Frequency	22.45	6.90	20.69	21.62		
Immatures						
Relative abundance	0 $\pm$ 0 ^a	0.038 $\pm$ 0.015 ^b	0.015 $\pm$ 0.009 ^b	0.023 $\pm$ 0.018 ^b	12.87	0.005
Frequency	0.00	24.14	10.34	8.11		
Chilopoda						
Relative abundance	0.010 $\pm$ 0.004	0.022 $\pm$ 0.016	0 $\pm$ 0	0.001 $\pm$ 0.001	4.40	0.221
Frequency	10.20	6.90	0	2.70		
Blattaria						
Relative abundance	0.012 $\pm$ 0.007	0.024 $\pm$ 0.013	0 $\pm$ 0	0.007 $\pm$ 0.004	2.93	0.403

Frequency	8.16	10.34	0.00	8.11		
Gastropoda						
Relative abundance	0.011 ± 0.005	0 ± 0	0.002 ± 0.002	0.003 ± 0.002	6.225	0.101
Frequency	14.29	0.00	3.45	8.11		
Homoptera						
Relative abundance	0.004 ± 0.002	0 ± 0	0 ± 0	0.005 ± 0.005	3.610	0.307
Frequency	6.12	0.00	0.00	2.70		
Diplopoda						
Relative abundance	0.005 ± 0.004	0 ± 0	0.004 ± 0.004	0 ± 0	2.610	0.456
Frequency	4.08	0.00	3.45	0.00		
Diptera						
Relative abundance	0.002 ± 0.001	0 ± 0	0.001 ± 0.001	0.003 ± 0.003	2.065	0.5591
Frequency	6.12	0.00	3.45	2.70		
Isoptera						
Relative abundance	0.002 ± 0.002	0.003 ± 0.003	0 ± 0	0 ± 0	1.952	0.5825
Frequency	2.04	3.45	0.00	0.00		

[†] – Excluding Formicidae

Table 3-2. Mean ($\pm$ SE) relative abundance and frequency of occurrence of prey items in male and female southern toads (*Bufo terrestris* B.) collected in upland loblolly pine (*Pinus taeda* L.) stands in the Coastal Plain of South Carolina.

	Female (n=88)	Male (n=56)	Z	P
Formicidae				
Relative abundance	0.483 $\pm$ 0.032	0.572 $\pm$ 0.044	1.703	0.089
Frequency	84.09	87.50		
Coleoptera				
Relative abundance	0.306 $\pm$ 0.030	0.263 $\pm$ 0.039	-1.281	0.200
Frequency	80.68	71.43		
Araneae				
Relative abundance	0.067 $\pm$ 0.015	0.060 $\pm$ 0.023	-1.261	0.207
Frequency	34.09	23.21		
Orthoptera				
Relative abundance	0.051 $\pm$ 0.010	0.033 $\pm$ 0.011	-1.273	0.203
Frequency	30.68	21.43		
Hymenoptera ¹				
Relative abundance	0.031 $\pm$ 0.009	0.043 $\pm$ 0.020	-0.623	0.533
Frequency	20.45	16.07		
Immatures				
Relative abundance	0.022 $\pm$ 0.009	0.008 $\pm$ 0.004	-0.688	0.491
Frequency	10.23	7.14		
Blattaria				
Relative abundance	0.015 $\pm$ 0.006	0.004 $\pm$ 0.002	-0.660	0.509
Frequency	7.95	5.36		
Chilopoda				
Relative abundance	0.011 $\pm$ 0.006	0.003 $\pm$ 0.003	-0.831	0.406
Frequency	6.82	3.57		
Gastropoda				
Relative abundance	0.005 $\pm$ 0.002	0.006 $\pm$ 0.003	0.467	0.640
Frequency	6.82	8.93		
Diptera				
Relative abundance	0.003 $\pm$ 0.002	0.001 $\pm$ 0.001	-0.885	0.376
Frequency	4.55	1.79		
Diplopoda				
Relative abundance	0.004 $\pm$ 0.003	0 $\pm$ 0	-1.383	0.167
Frequency	3.41	0.00		
Isoptera				
Relative abundance	0.001 $\pm$ 0.001	0.002 $\pm$ 0.002	0.324	0.746
Frequency	1.14	1.79		
Homoptera				
Relative abundance	0.001 $\pm$ 0.001	0.006 $\pm$ 0.004	1.483	0.138

Frequency	1.14	5.36
¹ – Excluding Formicidae		

Table 3-3. Mean ($\pm$ SE) relative abundance and frequency of occurrence of invertebrate groups in stomach contents of gravid and nongravid female southern toads (*Bufo terrestris* B.) collected in upland loblolly pine (*Pinus taeda* L.) stands in the Coastal Plain of South Carolina.

	Gravid (n=58)	Nongravid (n=30)	Z	P
Formicidae				
Relative abundance	0.422 $\pm$ 0.040	0.601 $\pm$ 0.046	2.6929	0.007
Frequency	79.31	93.33		
Coleoptera				
Relative abundance	0.333 $\pm$ 0.039	0.254 $\pm$ 0.042	-0.9685	0.333
Frequency	77.59	86.67		
Araneae				
Relative abundance	0.079 $\pm$ 0.021	0.044 $\pm$ 0.016	-0.495	0.621
Frequency	34.48	33.33		
Orthoptera				
Relative abundance	0.055 $\pm$ 0.014	0.044 $\pm$ 0.015	0.1132	0.910
Frequency	29.31	33.33		
Hymenoptera ¹				
Relative abundance	0.038 $\pm$ 0.012	0.019 $\pm$ 0.007	0.1187	0.906
Frequency	18.97	23.33		
Immatures				
Relative abundance	0.034 $\pm$ 0.014	0 $\pm$ 0	-2.2515	0.024
Frequency	15.52	0		
Blattaria				
Relative abundance	0.017 $\pm$ 0.008	0.011 $\pm$ 0.009	-0.3283	0.743
Frequency	8.62	6.67		
Chilopoda				
Relative abundance	0.015 $\pm$ 0.008	0.004 $\pm$ 0.003	-0.1108	0.912
Frequency	6.90	6.67		
Diplopoda				
Relative abundance	0.005 $\pm$ 0.004	0.001 $\pm$ 0.001	-0.042	0.9665
Frequency	3.45	3.33		
Diptera				
Relative abundance	0.001 $\pm$ 0.001	0.007 $\pm$ 0.005	1.756	0.079
Frequency	1.72	10.00		
Gastropoda				
Relative abundance	0 $\pm$ 0	0.013 $\pm$ 0.007	3.4953	0.001
Frequency	0	20.00		
Isoptera				
Relative abundance	0.001 $\pm$ 0.001	0 $\pm$ 0	-0.6952	0.487
Frequency	1.72	0		

Homoptera				
Relative abundance	0 ± 0	0.002 ± 0.002	1.3665	0.172
Frequency	0	3.33		
[†] – Excluding Formicidae				

CHAPTER 4

DIET OF *BUFO TERRESTRIS* IN *PINUS TAEDA* STANDS SUBJECT TO COARSE WOODY DEBRIS MANIPULATIONS¹

¹ Moseley, K.R., S.B. Castleberry, J.L. Hanula, and W.M. Ford. To be submitted to *American Midland Naturalist*

ABSTRACT.—In the southeastern United States coarse woody debris (CWD) typically harbors high densities of invertebrates. However, its importance as a foraging substrate for amphibians is relatively unknown. We examined effects of CWD manipulations on diet composition of southern toads (*Bufo terrestris*) in upland loblolly pine (*Pinus taeda*) stands in the southeastern Coastal Plain physiographic region of South Carolina. Twelve 9.3-ha plots were assigned one of the following treatments using a randomized complete block design: removal- all CWD ≥ 10 cm in diameter and ≥ 60 cm long removed, downed- five-fold increase in volume of down CWD, and unmanipulated control stands. Southern toads ≥ 4 cm were collected during 14 d sampling periods in June and October 2002, June 2003, and during a 28 d sampling period in April 2003. We collected 80, 36, and 35 southern toads in control, downed, and removal treatments, respectively. We found no difference in relative abundance or frequency of invertebrate groups consumed among treatments ($P > 0.05$). Average body weight (g), snout-vent length (cm), and stomach content weight (g wet) of individuals also were similar among treatments ($P > 0.05$). The role CWD as a foraging substrate for southern toads in loblolly pine stands of the southeastern Coastal Plain probably is negligible, at least in the early stages of decay.

INTRODUCTION

Coarse woody debris (CWD) often harbors high densities of invertebrates in terrestrial habitats (Graham, 1925; Savely, 1939; Harmon *et al.*, 1986; Hanula, 1996; Lockaby *et al.*, 2002). Coarse woody debris also offers added protection from predation and dry ambient conditions during foraging periods by terrestrial insectivorous vertebrate species (Loeb, 1996; Whiles and Grubaugh, 1996). These characteristics are believed to make CWD ideal foraging sites for forest dwelling amphibians (Maser *et al.*, 1979).

Although use of CWD as a foraging substrate by amphibians has been documented (Whiles and Grubaugh, 1996), its importance as a foraging substrate remains unknown.

The southern toad is an abundant species throughout the Coastal Plain of the southeastern United States. *Bufo* species, such as the southern toad, feed predominately on ants (Formicidae) and beetles (Coleoptera; Bush and Menhinick, 1962; Brown, 1974; Clarke, 1974a; Punzo, 1992; Bellocq *et al.*, 2000). For example, stomach contents of southern toads collected in Florida were composed primarily of beetles (19-31%) and ants (12-18%), with spiders (Araneae; 8-11%) and unidentified insects (22-35%) comprising the remainder (Punzo, 1992). Stomach contents of Fowler's toads (*B. woodhousei fowleri*) collected in agricultural fields and nearby hardwood forests in the Coastal Plain of Arkansas were limited almost entirely to ground-dwelling insects such as ants and beetles (Brown, 1974). Diet of American toads (*B. americanus*), Great Plains toads (*B. cognatus*), plateau toads (*B. compactilis*), and Woodhouse's toads (*B. woodhousei woodhousii*) in Oklahoma consisted primarily of different types of beetles and ants (Smith and Bragg, 1949). In a southern boreal forest habitat in Ontario, Canada, American toad diets were primarily composed of ants (Bellocq *et al.*, 2000). Furthermore, Bellocq *et al.* (2000) speculated that microclimate variation associated with different forest stand structural characteristics influence insect assemblages and therefore affect food resource availability for insectivorous vertebrate species.

In a broad ecological sense, CWD is an important component of forest stand structure (Hunter, 1990; McComb and Lindenmayer, 1999). Many invertebrate groups associated with decomposing woody material are affected negatively by CWD volume reductions (Harmon *et al.*, 1986; Lattin, 1993; Freedman *et al.*, 1996; McCay *et al.*, 2002).

Abundance of ground beetles (Carabidae) and silken fungus beetles (Cryptophagidae) declined one year after removal of downed CWD in upland loblolly pine stands in the Coastal Plain of South Carolina (McCay *et al.*, 2002). As predators dependent on invertebrates in forested ecosystems, *Bufo* species may be heavily affected by fluctuations in invertebrate abundance caused by reductions in CWD volume.

We investigated effects of CWD manipulations in upland loblolly pine stands on diet composition of the southern toad. We hypothesized that southern toads captured in plots subject to CWD removal would consume a lower diversity and abundance of prey items. Furthermore, we hypothesized that fewer foraging opportunities, due to reductions in cover from predators and inadequate availability of moist refugia, would result in lower stomach content and body weight.

STUDY AREA AND METHODS

Our study was conducted at the Savannah River Site (SRS), a 78,000-ha National Environmental Research Park located in the Upper Coastal Plain physiographic region in an area known as the Sandhills in Aiken, Barnwell, and Allendale counties, South Carolina (33°0-25''N, 81°25-50''W). Upland areas were dominated by the longleaf pine (*P. palustris*)-wiregrass (*Aristida* spp.) community before being cleared for agriculture in the early 1800s. The Atomic Energy Commission acquired the land comprising the SRS in 1951 and the USDA Forest Service was contracted to plant abandoned agricultural fields in loblolly, longleaf, and slash pine (*P. elliotii*). Currently, pine plantations dominate most of the SRS landscape. Warm temperate to subtropical, mean annual temperature is 18 C and mean annual precipitation is 122.5 cm.

Experimental stands were selected based on the following criteria: forested with approximately 45-50-year-old loblolly pine forests, capable of accommodating four square 9.3-ha plots and were located ≥ 76 m from nearest wetland, road or power line. Four square 9.3-ha plots were established within stands, each containing a 6-ha core area to be used for southern toad and invertebrate sampling surrounded by a 3.3-ha buffer area subject to the same treatment. Dominant understory vegetation consisted of lespedeza (*Lespedeza* spp.), poison oak (*Toxicodendron pubescens*), beggarweed (*Desmodium* spp.), and broomsedge (*Andropogon* spp.).

Plots within each stand were randomly assigned to one of three treatments: removal- all downed woody debris ≥ 10 cm in diameter and ≥ 60 cm long removed ($n = 3$), downed- 5-fold increase in volume of down CWD ($n = 3$), and control ($n = 6$). Coarse woody debris removal treatments were implemented in summer 1996 and were maintained annually. Downed treatments were implemented in August 2001 by randomly selecting 12 rows of trees to be felled within plots using a feller-buncher. Because sampling began shortly after trees were downed, all CWD additions occupied the earliest stages of decay. Additionally, effects of below ground CWD, such as decomposing tree stumps, was beyond the scope of our study. Control and removal plots were subsequently thinned to standardize basal area among treatments. Estimates of mean ($\pm$ SE) coarse woody debris loadings were 56.2 ± 6.6 , 4.5 ± 1.0 , and 2.4 ± 1.0 m³/ha in downed, control, and removal plots, respectively. Most plots were prescribed burned between 1990 and 1996 in accordance with normal land management practices for forests at the SRS.

We sampled southern toads using a series of drift fence arrays. Drift fences were made from aluminum flashing buried 15-cm in the ground. Nineteen-l plastic buckets were buried against each fence, flush to the ground. On each plot, a centrally located cross-shaped array with 30-m arms was installed. In each corner of the center array, X-shaped arrays with 15-m arms were installed (Corn, 1994). We opened traps for 14-d periods during June and October 2002, and June 2003. Additionally, we opened traps for a 28-d period during April 2003. We checked traps daily and only collected southern toads ≥ 4 cm snout-vent length. We euthanised individuals via double pithing (McDiarmid, 1994; AVMA Panel on Euthanasia, 2001) within 6 hrs of collection and then froze them for later dissection. We collected all individuals under South Carolina Department of Natural Resources scientific research permit # G-02-09 and University of Georgia IACUC number A2002-10019-c2.

We sampled terrestrial arthropods using 15 pitfall traps placed throughout each plot. We opened traps for 7-d periods in May, July, September and November 2002, and January and March 2003. At the end of each collection period, we stored arthropods in 70% ethanol for later analysis. We identified arthropods to order or class and in the case of ants, to family (Formicidae). We calculated relative abundance of arthropods groups for each plot by dividing total number of individuals within each group by the total number of invertebrates captured within that plot.

We weighed (g) individual southern toads, recorded SVL (cm), and then removed the stomach, the contents of which we weighed (g wet) and then examined for prey. We did not record body weight or stomach content weight of individuals captured during the June 2002 sampling period. Invertebrates found within stomach contents were identified

to order or class and in the case of ants, to family. We identified invertebrates primarily through presence of head capsules to prevent counting a single individual twice. We calculated relative abundance as described above for invertebrate groups consumed. We defined frequency of occurrence as percent of stomachs from each treatment plot containing at least one individual of a given prey group.

We treated individual toads as subsamples within replicates to test for CWD treatment effects. Diet composition did not differ between sexes ($P > 0.05$), so we pooled them for analysis. We tested data for normality using Shapiro-Wilks test for normality, ranked variables that did not meet assumptions of normality, even after transformation, and performed analysis on the ranks. We used a two-way analysis of variance (ANOVA) to test for differences in relative abundance of invertebrate groups consumed, frequency of occurrence of each invertebrate group consumed, and mean number of prey items identified in stomach contents among control, removal, and downed treatments. We standardized body weight and stomach content weight by individual SVL and tested for differences in body weight, stomach content weight, SVL among treatments using a two-way ANOVA. We analyzed differences among invertebrate abundance and relative abundance of invertebrates captured within plots among treatments with a two-way ANOVA. We considered treatment effects significant at $P \leq 0.05$. All statistical analyses were conducted using SAS statistical software (SAS Institute, 1997).

Diet similarity among treatments was compared using Morisita's index of dietary overlap (Litvaitis *et al.*, 1996), which produces values between 0 and 1, where 0 indicates no overlap in diet and 1 indicates total dietary overlap. This index (C) is considered the least biased diet overlap estimator (Smith and Zaret, 1982). However,

because we only identified most prey items to order our results should be interpreted cautiously as similarity between treatments may be overestimated (Greene and Jaksic, 1983).

RESULTS

We collected 80, 36, and 35 southern toads in control, downed, and removal treatments, respectively. Southern toad stomach contents examined consisted of 13 invertebrate groups with ants being the most abundant (Table 4-1) and most frequently (Table 4-2) consumed prey item among all three treatments, followed by beetles and spiders (Araneae). We found no differences in relative abundance (Table 4-1) or frequency (Table 4-2) of the 13 invertebrate groups consumed among treatments. Mean ($\pm$ SE) number of prey items found in stomachs was 9.97 ± 1.64 , 11.07 ± 1.14 , and 11.92 ± 1.61 in control, downed, and removal plots, respectively. Number of prey items in stomach contents did not differ among treatments ($F_{2,7} = 0.52$, $P = 0.618$).

We captured representatives of 18 terrestrial arthropod groups across all treatments. Arthropod groups captured in plots were similar in both numbers captured (Table 4-3) and relative capture rate (Table 4-4) among treatments. Combined abundance of captured arthropods in the 13 groups identified in stomach contents did not differ among treatments ($F_{2,7} = 0.69$, $P = 0.535$).

Mean weight of individual southern toads (g/cm) was 3.41 ± 0.09 , 3.57 ± 0.06 , and 3.32 ± 0.16 in control, downed, and removal plots, respectively. Weight did not differ among treatments ($F_{2,7} = 1.35$, $P = 0.320$). Mean stomach content weight (g/cm) of individuals was 0.12 ± 0.02 , 0.13 ± 0.02 , and 0.12 ± 0.02 in control, downed, and removal plots, respectively, and did not differ among treatments ($F_{2,7} = 0.11$, $P = 0.900$).

Mean SVL (cm) of individuals in control, downed, and removal plots was 5.50 ± 0.06 , 5.44 ± 0.06 , and 5.39 ± 0.02 , respectively, and SVL did not differ among treatments ($F_{2,7} = 0.80$, $P = 0.487$).

We found a high degree of dietary overlap among treatments, with downed and removal treatments being the most similar ($C = 0.99$) followed by downed and control ($C = 0.98$) and removal and control ($C = 0.97$). Individuals captured in removal plots contained the highest number of prey groups ($n=13$) followed by control ($n=12$) and downed ($n=11$) plots.

Because relative abundance of invertebrates consumed and relative capture rate of invertebrates captured within plots did not differ among treatments for all southern toads, we combined treatments to compare consumption of invertebrate groups with their occurrence in plots using a one-way ANOVA (Figure 4-1). Variables did not meet assumptions of normality. We rank transformed all variables except spiders and ants and performed analysis on the ranks. Ants ($F_{1,20} = 60.85$, $P < 0.0001$), beetles ($F_{1,20} = 14.74$, $P = 0.001$), and true bugs (Homoptera) ($F_{1,20} = 5.73$, $P = 0.027$) were consumed in greater proportion to their relative capture rate, whereas spiders ($F_{1,20} = 73.14$, $P < 0.0001$), flies (Diptera) ($F_{1,20} = 100.32$, $P < 0.0001$), and millipedes (Diplopoda) ($F_{1,20} = 60.42$, $P < 0.0001$) were consumed proportionately less than their relative capture rate in plots (Figure 4-1).

DISCUSSION

Although CWD has been identified as an important foraging substrate for amphibians (Whiles and Grubaugh, 1996), our results indicate that southern toads are not necessarily dependent on CWD for invertebrate prey in upland pine stands of the southeastern

Coastal Plain. The only obligatory CWD invertebrate group identified in stomach contents was termites. Termites were consumed infrequently by southern toads in our study, being identified in less than 4% of all stomachs and consumed in proportion to their relative capture rate on plots. Termites represented 7-11% of prey items consumed by southern toads captured in the Coastal Plain of Florida during Spring, but decreased (3-5%) for individuals captured during Summer (Punzo, 1992). Conversely, stomach contents of southern toads collected along roadsides within Everglades National Park did not contain any termites (Krakauer, 1968). Because they are more digestible than invertebrates with more chitinous exoskeletons, such as ants and beetles (Dimmitt and Rubal, 1980), termites may be underrepresented in stomach contents examined. Termites found in fecal matter collected from common Malayan toads (*Bufo melanostictus*) were almost completely digested, identifiable only by presence of head capsules. Conversely, ant exoskeletons were frequently found intact, having undergone little digestion (Berry and Bullock, 1962).

Consumption of roaches, a common inhabitant of standing and downed coarse woody material (Horn and Hanula, 2002), in our study was 8.5 times greater in downed than in control treatments. However, because they were consumed proportional to their relative capture rate and constituted a minor component of all prey items identified, increased consumption may only reflect opportunistic use of CWD. Ants and beetles comprised the majority of prey items in our study, which combined, accounted for 79.2, 88.9, and 82.7 % of stomach contents in downed, removal, and control treatments, respectively.

We found no difference in relative abundance or frequency of invertebrate groups consumed among treatments. Similar diet composition observed among treatments is

likely attributable to lack of response by preferred invertebrate groups, such as ants and beetles, to CWD manipulations. Abundance of certain invertebrate groups can be negatively affected by CWD removal (Harmon *et al.*, 1986; Lattin, 1993; Freedman *et al.*, 1996; McCay *et al.*, 2002; Bouget and Duelli, 2003); however, abundance of ants and beetles remained similar among treatment types despite a 56.2 m³/ha increase or complete removal of downed woody material. Ants and beetles are abundant in southeastern pine forests (Hanula and Franzreb, 1998; Hanula and Wade, 2003). Sanzone (1995) found abundance of Coleopterans and Hymenopterans captured in a loblolly pine stand on the Coastal Plain of South Carolina were lower in pitfall traps associated with CWD than in traps independent of downed pine logs. Additionally, ant abundance adjacent to partially decomposed CWD was greater than near recently felled CWD.

The lack of treatment responses by arthropods in our study may be due in part to the early decay stage of the recently downed CWD. As wood decays composition of the invertebrate community in the logs will change (Graham, 1925; Savely, 1939; Elton 1966), but whether CWD in more advanced stages of decay will affect composition of ground dwelling invertebrate assemblages, and thus diet composition of southern toads, is unclear.

We found no difference in body weight and stomach content weight of southern toads or mean number of prey items consumed among our treatments, indicating that individuals were able to effectively forage following removal of CWD. Despite greater CWD inputs in recently harvested stands, body weight of southern toads in 19-y old intensively managed loblolly pine stands was similar to individuals in recently clearcut

loblolly pine stands in the Coastal Plain of South Carolina (Baughman, 2000). Studies investigating effects of forest management practices, such as timber harvesting and subsequent site preparation, in the Coastal Plain region of the United States have found these practices to have relatively little effect on abundance and diversity of many terrestrial invertebrates in the near-term, at least at higher taxonomic levels (Greenberg and Thomas, 1995; Greenberg and McGrane, 1996; Bird *et al.*, 2000). Abundance and biomass of ground-dwelling arthropods in sand pine (*P. clausa*) scrub stands in Ocala National Forest, Florida did not differ in stands subjected to intense burning and salvage logging, clearcutting followed by roller-chopping, clearcutting followed by bracke seeding, and naturally regenerated mature stands despite lower woody debris in roller-chopped and mature stands in terms of density, diversity, and evenness of beetles (Greenberg and Thomas, 1995; Greenberg and McGrane, 1996). Clarke (1974a) suggested that food is rarely a limiting factor during the terrestrial stage of *Bufo* species and that availability of moisture in the terrestrial environment may be more limiting.

Historically, upland areas of the southeastern Coastal Plain were dominated by the longleaf pine-wiregrass community, which was maintained by frequent, low intensity, ground fires that occurred during the growing season (Landers *et al.*, 1995; Frost, 1998; Van Lear and Harlow, 2002). Frequent fires, combined with greater decomposition rates, probably prevented buildup of CWD within upland pine stands (Van Lear, 1996). Indeed, pine forests of the Southeast generally have a lower abundance of CWD than forests of the Pacific Northwest or Appalachian regions (McMinn and Hardt, 1996). Properties of CWD that would benefit *Bufo* species as a moist microhabitat are probably only achieved after advanced stages of decomposition and greater water holding ability

develops (Boddy 1983). However, because of high decomposition rates and frequent fires in upland pine systems, CWD occupying advanced decay classes is probably sparse and short-lived. As a foraging substrate, CWD may be less important than leaf litter and exposed forest floor, where *Bufo* species often forage on nights with acceptable levels of ambient moisture and temperature (Klimstra and Myers, 1964; Clarke, 1974b; Gibbons and Bennett, 1974).

Acknowledgements.—We thank J. Kilgo and P. Champlin for assistance. We are grateful to the U.S. Department of Energy for access to the Savannah River Site. Funding for this project was provided by the U. S. Department of Energy--Savannah River Operations Office through the U. S. Forest Service--Savannah River and the USFS Northeast Research Station under Interagency Agreement DE-AI09-00SR22188

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Table 4-1. Mean ($\pm$ SE) relative abundance of prey items in stomach contents of southern toads (*Bufo terrestris*) captured in June and October 2002 and April and June 2003 at the Savannah River Site, Barnwell County, South Carolina in loblolly pine (*Pinus taeda*) stands subject to addition of downed coarse woody debris (CWD), removal of CWD, and controls. Relative abundance of each group was compared among treatments with a 2-way Analysis of Variance

	Downed (n=3)	Removal (n=3)	Control (n=6)	F _{2,7}	P
Formicidae	0.622 $\pm$ 0.004	0.731 $\pm$ 0.034	0.611 $\pm$ 0.058	1.84	0.228
Coleoptera	0.170 $\pm$ 0.030	0.158 $\pm$ 0.023	0.216 $\pm$ 0.028	1.30	0.330
Araneae	0.064 $\pm$ 0.013	0.022 $\pm$ 0.007	0.060 $\pm$ 0.017	1.79	0.236
Hymenoptera ^{1,2}	0.038 $\pm$ 0.011	0.012 $\pm$ 0.004	0.041 $\pm$ 0.020	1.21	0.353
Orthoptera	0.026 $\pm$ 0.010	0.045 $\pm$ 0.012	0.037 $\pm$ 0.015	0.63	0.562
Immatures ¹	0.024 $\pm$ 0.018	0.008 $\pm$ 0.005	0.008 $\pm$ 0.004	0.17	0.844
Blattaria ¹	0.017 $\pm$ 0.004	0.002 $\pm$ 0.002	0.005 $\pm$ 0.003	3.63	0.083
Chilopoda ¹	0.013 $\pm$ 0.009	0.003 $\pm$ 0.003	0.007 $\pm$ 0.005	0.66	0.548
Gastropoda ¹	0.013 $\pm$ 0.006	0.007 $\pm$ 0.004	0.003 $\pm$ 0.002	1.39	0.310
Isoptera ¹	0.003 $\pm$ 0.003	0.002 $\pm$ 0.002	0 $\pm$ 0	1.01	0.412
Diptera ¹	0.002 $\pm$ 0.002	0.002 $\pm$ 0.002	0.002 $\pm$ 0.001	0.02	0.979
Diplopoda ¹	0 $\pm$ 0	0.002 $\pm$ 0.002	0.006 $\pm$ 0.004	0.57	0.588
Homoptera ¹	0 $\pm$ 0	0.005 $\pm$ 0.005	0.006 $\pm$ 0.005	0.60	0.575

¹ - ANOVA performed on ranks

² - Excluding Formicidae

Table 4-2. Mean ($\pm$ SE) frequency of occurrence of prey items identified in stomach contents of southern toads (*Bufo terrestris*) captured in June and October 2002 and April and June 2003 at the Savannah River Site, Barnwell County, South Carolina in loblolly pine (*Pinus taeda*) stands subject to addition of downed coarse woody debris (CWD), removal of CWD, and controls. Relative abundance of each group was compared among treatments with a 2-way Analysis of Variance

	Downed (n=3)	Removal (n=3)	Control (n=6)	F _{2,7}	P
Formicidae	87.08 $\pm$ 2.39	74.44 $\pm$ 2.94	80.60 $\pm$ 3.00	2.5	0.152
Coleoptera	78.08 $\pm$ 1.03	65.56 $\pm$ 9.88	74.95 $\pm$ 6.64	1.03	0.404
Araneae	34.84 $\pm$ 3.31	23.33 $\pm$ 8.82	25.95 $\pm$ 4.68	0.84	0.472
Hymenoptera ^{1,2}	18.58 $\pm$ 4.31	15.56 $\pm$ 7.29	17.45 $\pm$ 8.24	0.42	0.670
Orthoptera	26.41 $\pm$ 10.44	33.33 $\pm$ 3.33	23.47 $\pm$ 5.22	0.58	0.585
Immatures ¹	7.63 $\pm$ 3.82	5.56 $\pm$ 2.94	7.93 $\pm$ 3.76	0.16	0.857
Blattaria	12.70 $\pm$ 4.91	3.33 $\pm$ 3.33	5.37 $\pm$ 2.17	1.52	0.282
Chilopoda ¹	10.37 $\pm$ 5.79	2.22 $\pm$ 2.22	5.52 $\pm$ 2.86	0.64	0.556
Gastropoda ¹	12.55 $\pm$ 6.31	7.78 $\pm$ 4.01	3.27 $\pm$ 2.18	1.39	0.310
Isoptera ¹	3.70 $\pm$ 3.70	3.33 $\pm$ 3.33	0 $\pm$ 0	1.01	0.412
Diptera ¹	1.96 $\pm$ 1.96	3.33 $\pm$ 3.33	2.99 $\pm$ 1.38	0.29	0.757
Diplopoda ¹	0 $\pm$ 0	3.33 $\pm$ 3.33	3.57 $\pm$ 2.44	0.54	0.606
Homoptera ¹	0 $\pm$ 0	4.44 $\pm$ 4.44	3.42 $\pm$ 2.40	0.60	0.575

¹ – ANOVA performed on ranks

² – Excluding Formicidae

Table 4-3. Mean ($\pm$ SE) captures of arthropod groups in plots subject to downed coarse woody debris (CWD) additions, CWD removal, and controls in upland loblolly pine (*Pinus taeda*) stands at the Savannah River Site, Barnwell County, South Carolina during May, July, September and November 2002 and January and March 2003. Relative abundance of each group was compared among treatments with a two-way analysis of variance

	Downed (n=3)	Removal (n=3)	Control (n=6)	F _{2,7}	P
Formicidae	1683 $\pm$ 168	1427 $\pm$ 183	1483 $\pm$ 182	0.33	0.729
Araneae	714 $\pm$ 78	649 $\pm$ 90	805 $\pm$ 53	1.95	0.212
Diptera	570 $\pm$ 154	497 $\pm$ 160	564 $\pm$ 117	0.10	0.905
Coleoptera	429 $\pm$ 86	464 $\pm$ 33	531 $\pm$ 54	1.89	0.221
Orthoptera	223 $\pm$ 24	161 $\pm$ 53	183 $\pm$ 24	0.78	0.496
Hymenoptera ²	208 $\pm$ 63	134 $\pm$ 26	176 $\pm$ 27	0.99	0.419
Diplopoda	130 $\pm$ 25	192 $\pm$ 29	154 $\pm$ 42	0.54	0.604
Immatures	73 $\pm$ 25	49 $\pm$ 10	61 $\pm$ 8	0.69	0.534
Hemiptera	32 $\pm$ 3	26 $\pm$ 7	39 $\pm$ 4	3.81	0.076
Phalangida	31 $\pm$ 12	25 $\pm$ 10	34 $\pm$ 6	0.19	0.832
Blattaria	27 $\pm$ 1	26 $\pm$ 8	39 $\pm$ 4	2.41	0.160
Chilopoda	31 $\pm$ 10	30 $\pm$ 2	34 $\pm$ 4	0.33	0.729
Homoptera	15 $\pm$ 2	11 $\pm$ 0	16 $\pm$ 2	1.86	0.225
Lepidoptera	10 $\pm$ 2	7 $\pm$ 3	14 $\pm$ 1	3.85	0.075
Thysanura ¹	14 $\pm$ 12	8 $\pm$ 7	12 $\pm$ 7	0.46	0.648
Chelonethida	7 $\pm$ 2	5 $\pm$ 2	6 $\pm$ 3	0.15	0.863
Psocoptera ¹	7 $\pm$ 5	4 $\pm$ 1	19 $\pm$ 8	1.11	0.381
Isoptera ¹	6 $\pm$ 6	13 $\pm$ 7	5 $\pm$ 4	1.55	0.277

¹ – ANOVA performed on ranks

² – Excluding Formicidae

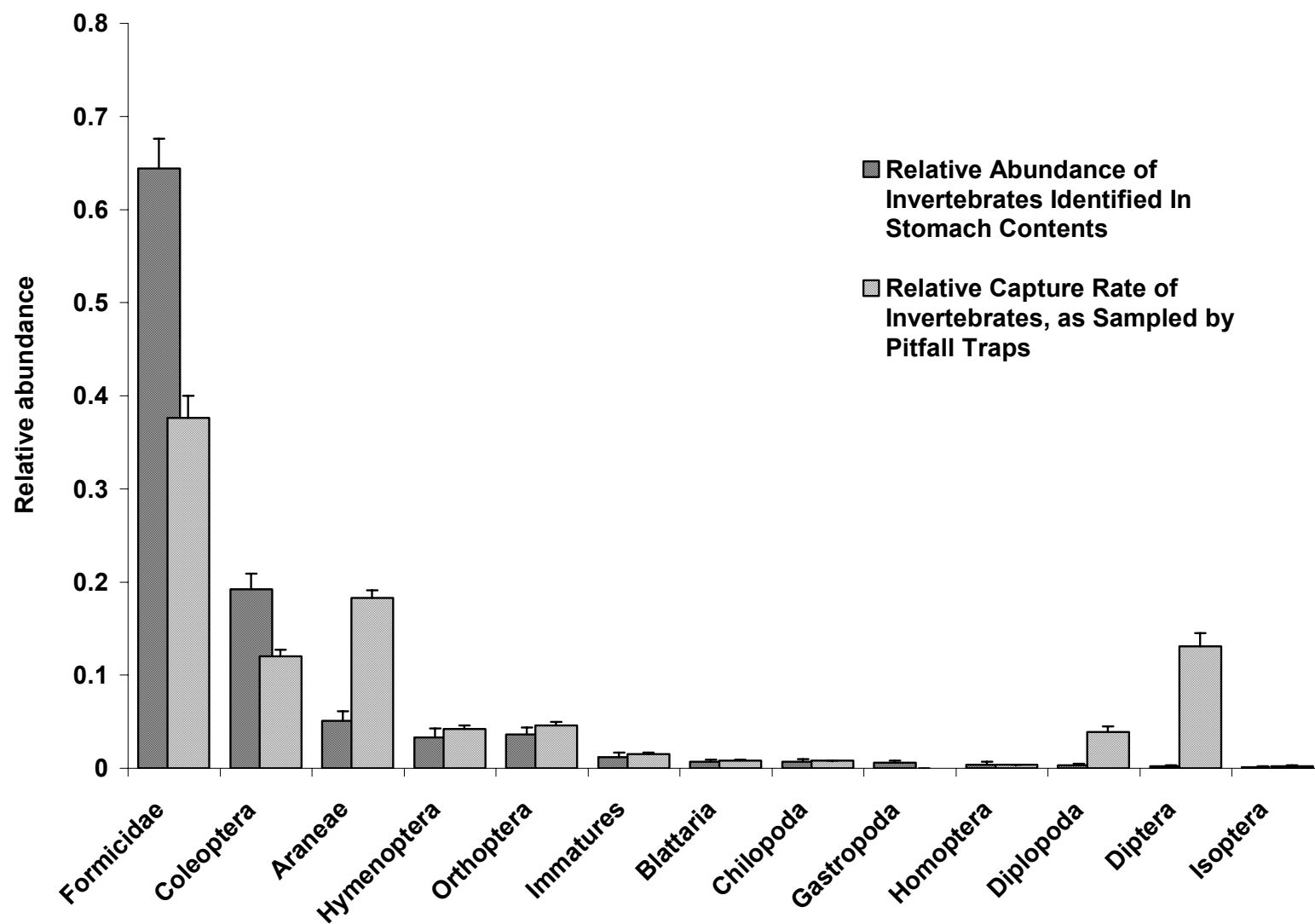
Table 4-4. Mean ($\pm$ SE) relative capture rate of arthropod groups captured in plots subject to downed coarse woody debris (CWD) additions, CWD removal, and controls in upland loblolly pine (*Pinus taeda*) at the Savannah River Site, Barnwell County, South Carolina during May, July, September and November 2002 and January and March 2003. Relative abundance of each group was compared among treatments with a two-way analysis of variance

	Downed (n=3)	Removal (n=3)	Control (n=6)	F _{2,7}	P
Formicidae	0.404 $\pm$ 0.030	0.385 $\pm$ 0.048	0.357 $\pm$ 0.042	0.36	0.710
Araneae	0.170 $\pm$ 0.008	0.173 $\pm$ 0.013	0.194 $\pm$ 0.013	1.10	0.383
Diptera	0.131 $\pm$ 0.020	0.129 $\pm$ 0.030	0.133 $\pm$ 0.025	0.01	0.992
Coleoptera	0.102 $\pm$ 0.016	0.128 $\pm$ 0.018	0.013 $\pm$ 0.006	2.21	0.180
Orthoptera	0.054 $\pm$ 0.005	0.042 $\pm$ 0.010	0.044 $\pm$ 0.005	0.61	0.569
Hymenoptera ²	0.047 $\pm$ 0.009	0.037 $\pm$ 0.010	0.043 $\pm$ 0.007	0.32	0.735
Diplopoda	0.031 $\pm$ 0.006	0.051 $\pm$ 0.003	0.037 $\pm$ 0.010	0.98	0.421
Immatures	0.018 $\pm$ 0.007	0.013 $\pm$ 0.002	0.015 $\pm$ 0.002	0.65	0.551
Hemiptera	0.008 $\pm$ 0	0.007 $\pm$ 0.001	0.009 $\pm$ 0.001	3.35	0.095
Phalangida	0.008 $\pm$ 0.004	0.007 $\pm$ 0.003	0.008 $\pm$ 0.002	0.02	0.979
Blattaria	0.007 $\pm$ 0.001	0.007 $\pm$ 0.002	0.009 $\pm$ 0.001	1.17	0.365
Chilopoda	0.007 $\pm$ 0.001	0.008 $\pm$ 0	0.008 $\pm$ 0.001	0.99	0.419
Homoptera	0.004 $\pm$ 0	0.003 $\pm$ 0	0.004 $\pm$ 0	0.94	0.435
Lepidoptera	0.003 $\pm$ 0.001	0.002 $\pm$ 0.001	0.004 $\pm$ 0	2.82	0.127
Thysanura ¹	0.003 $\pm$ 0.002	0.002 $\pm$ 0.002	0.003 $\pm$ 0.001	0.24	0.794
Chelonethida	0.002 $\pm$ 0	0.001 $\pm$ 0.001	0.001 $\pm$ 0.001	0.11	0.894
Psocoptera ¹	0.002 $\pm$ 0.001	0.001 $\pm$ 0	0.004 $\pm$ 0.002	1.19	0.360
Isoptera ¹	0.002 $\pm$ 0.001	0.004 $\pm$ 0.002	0.001 $\pm$ 0.001	1.55	0.277

¹ – ANOVA performed on ranks

² – Excluding Formicidae

Figure 4-1. Mean ($\pm$ SE) relative abundance of invertebrates consumed by southern toads (*Bufo terrestris*) versus mean relative capture rate of invertebrates captured in plots subject to downed coarse woody debris (CWD) additions, CWD removal, and controls in upland loblolly pine (*Pinus taeda*) at the Savannah River Site, Barnwell County, South Carolina during May, July, September, and November 2002 and January and March 2003.



CHAPTER 5

DEMOGRAPHIC RESPONSE OF SORICIDS TO COARSE WOODY DEBRIS MANIPULATIONS IN UPLAND LOBLOLLY PINE (*PINUS TAEDA*) STANDS¹

¹ Moseley, K.R., S.B. Castleberry, and W.M. Ford. To be submitted to *Forest Ecology and Management*.

Abstract

We assessed the response of Soricids (shrews) to coarse woody debris (CWD) manipulations in upland loblolly pine (*Pinus taeda*) stands in the Coastal Plain physiographic region of South Carolina. Twelve 9.3-ha plots were assigned one of the following treatments using a completely randomized block design: removal- all CWD $\geq$ 10 cm in diameter and $\geq$ 60 cm long removed, downed- 5-fold increase in volume of down CWD, and control. Shrews were sampled using a series of drift-fence-pitfall arrays opened during June and October 2002 and January, April, and June 2003. Over 924 drift-fence plot-nights we captured 193 individuals, representing 3 shrew species. Trends in total shrew capture rate and capture rates of southern short-tailed shrews (*Blarina carolinensis*), southeastern shrews (*Sorex longirostris*), and least shrews (*Cryptotis parva*) suggest that shrews benefit from increased CWD volume. Response of shrews to CWD manipulations may become more pronounced as CWD reaches more advanced stages of decay.

Key Words: *Blarina*, coarse woody debris, *Cryptotis*, pine management, shrews, *Sorex*

1. Introduction

Acreage of intensively managed pine plantations in the southeastern United States is expected to increase to meet burgeoning demand for wood fiber products (Prestemon and Abt, 2002). These stands often are managed under short rotation, resulting in increased

disturbance frequency as compared to unmanaged pine stands (Conner and Hartsell, 2002). Disturbance within plantations generally occurs in the form of even-aged harvesting and subsequent mechanized site preparation techniques such as bedding, discing, root raking, and rollerchopping (Hunter, 1990; Smith et al., 1997). These techniques compact soil, reduce litter depth and cover, displace mineral soil, and reduce volume of CWD (Harmon et al., 1986; Reisinger et al., 1988; deMaynadier and Hunter, 1995), leading to the development of more homogenous and structurally simplified forest conditions (Hunter, 1990). Pine plantations in the southeastern US contain lower CWD volumes than unmanaged pine and hardwood forests (McMinn and Hardt, 1996). Reduction of this important microhabitat component within these stands may be particularly detrimental to shrews which are highly sensitive to alterations in environmental moisture (Getz, 1961).

Because of their high metabolic rate, shrews are subject to high rates of evaporative water loss (Chew, 1951; Churchfield, 1990) and increased desiccation risk. Shrews often forage on the forest floor following precipitation (Ford et al., 2002). However, during dry periods shrews may be restricted to isolated areas of moisture (Brannon, 2002). Coarse woody debris is capable of retaining moisture during these dry climatic periods and may therefore serve as important refugia for shrew species (Loeb, 1996). Although shrew abundance has been positively correlated with CWD in the southern Appalachian Mountains (Maidens et al., 1998; Brannon, 2000), other studies within the region have shown shrew abundance to be independent of CWD availability, suggesting that CWD volumes characteristic of hardwood forests in the region may be sufficiently high that CWD rarely becomes a limiting (Ford et al., 1997; Ford and Rodrigue, 2001). However,

CWD availability in managed pine stands of the southeastern Coastal Plain is low compared to other forest types and physiographic regions of the Southeast (McMinn and Hardt, 1996) and may become a limiting resource during dry conditions.

Response of shrew assemblages in pine forests of the southeastern Coastal Plain to manipulations of CWD volume is relatively unknown. In a manipulative study conducted in managed western hemlock (*Tsuga heterophylla*) forests of Washington, stands subject to CWD removal had lower abundance of Trowbridge's shrews (*S. trowbridgii*) and a greater abundance of vagrant shrews (*S. vagrans*) than unmanipulated control stands. Dusky shrews (*S. monticolus*) had lower reproductive rates in CWD removal stands (Lee, 1995). McCay and Komoroski (2003) investigated effects of CWD removal in upland loblolly pine stands in the Coastal Plain of South Carolina. They reported lower capture rates of least shrews on CWD removal plots than in control stands. They speculated that low ambient levels of CWD in control plots may be responsible for the similar abundance of southern short-tailed shrews and southeastern shrews found between treatments. Ford et al. (1994) suggested that there may be an upper threshold of CWD input required to solicit a response by shrew populations.

We assessed the response of shrews to coarse woody debris (CWD) manipulations in loblolly pine stands of the South Carolina Coastal Plain physiographic. We hypothesized that increased volume of CWD would result in greater capture rates of southeastern shrews and southern short-tailed shrews, because of the association of these species with more mesic forested habitats in the region (Loeb et al., In Review). Conversely, effects of CWD manipulations on least shrews would be negligible due to their association with habitats, such as old-fields, that generally contain low levels of CWD.

2. Study Area

Our study was conducted at the US Department of Energy's Savannah River Site (SRS), a 78,000-ha National Environmental Research Park in Aiken, Barnwell, and Allendale Counties, South Carolina (33°0-25'N, 81°25-50'W). The SRS is located on the Upper Coastal Plain in an area known as the Sandhills. Historically, the longleaf pine (*P. palustris*)-wiregrass (*Aristida* spp.) community dominated upland areas of the SRS before being cleared for agriculture in the early 1800's. Upon acquisition of the land comprising the SRS by the Atomic Energy Commission in 1951, the US Forest Service planted abandoned agricultural fields in loblolly, longleaf, and slash (*P. elliotii*) pine. Stands were established on these sites primarily by hand planting. Understory vegetation consisted of lespedeza (*Lespedeza* spp.), poison oak (*Toxicodendron pubescens*), and broomsedge (*Andropogon* spp.). The topography is gently rolling to flat with elevations ranging from 20 – 130 m. This region is characterized by a warm temperate to subtropical climate, with a mean annual temperature of 18°C and mean annual precipitation of 122.5 cm.

3. Methods

We used a randomized complete block design consisting of four 9.3-ha treatment plots replicated in three stands. Experimental stands were selected based on the following criteria: forested with approximately 45-50-year-old loblolly pine plantations, sizes that were capable of accommodating four square 9.3-ha plots, and proximity ≥ 76 m

from nearest wetland or edge habitat such as a road or power line. Plots within each block were randomly assigned one of three treatments: 1) removal- all CWD ≥ 10 -cm in diameter and ≥ 60 -cm long removed ($n = 3$); 2) downed- 5-fold increase in volume of down CWD ($n = 3$); and 3) control ($n = 6$). Each plot contained a 6-ha core area, on which trapping occurred, within a 3.3-ha buffer zone subject to the same treatment as the core area. Coarse woody debris removal treatments were implemented in summer 1996. Downed treatments were implemented in August 2001 by randomly selecting 12 rows of trees to be felled within plots using a feller-buncher. Because shrew sampling began shortly after trees were downed, all CWD additions occupied the earliest stages of decay. Additionally, effects of below ground CWD, such as decomposing tree stumps, was beyond the scope of our study. Control and removal plots were subsequently thinned to standardize basal area among treatments. Estimates of mean ($\pm$ SE) coarse woody debris loadings were 56.2 ± 6.6 , 4.5 ± 1.0 , and 2.4 ± 1.0 m³/ha in downed, control, and removal plots, respectively. Most plots were prescribed burned between 1990 and 1996 in accordance with normal land management practices for forests at the SRS.

We sampled shrews using a series of drift fence arrays constructed from aluminum flashing buried 15-cm in the ground. Pitfall trapping is an effective method for sampling shrew abundance (Ford et al., 1997; McCay et al., 1998). Nineteen-liter plastic buckets were buried against each fence. On each plot, a centrally located cross-shaped array with 30-m arms was installed and within each corner of the center array, X-shaped arrays with 15-m arms were installed (Laerm et al., 1999). We opened traps for 14-days during June and October 2002 and January and June 2003. Additionally, we opened traps for 28-days during April 2003. We checked traps daily and collected all individuals under South

Carolina Department of Natural Resources scientific research permit #G-02-09 and University of Georgia IACUC number A2002-10019-c2.

We collected individuals found dead in traps (87%) and froze them for later necropsy. We identified collected individuals based on external morphology and dental characteristics and recorded weight (g), snout-vent length (cm), and sex. We assigned each shrew collected to one of four age classes based on tooth attrition characteristics described by Pearson (1945) for southeastern shrews and Rudd (1955) for southern short-tailed shrews.

We eliminated one control plot from final analysis due to excessive flooding which rendered most drift fences ineffective. We tested data for normality using Shapiro-Wilks test for normality. Data not meeting assumptions of normality were natural-log transformed. We calculated capture rates by dividing plot captures by the number of plot nights. We compared total shrew capture rate and capture rates of southern short-tailed shrews, southeastern shrews, and least shrews among treatments using a 2-way analysis of variance (ANOVA) blocked for stand. We compared age distribution of southern short-tailed shrews and southeastern shrews using log-likelihood ratio tests (Sokal and Rohlf, 1985). We compared body weight of collected southern short-tailed shrews and southeastern shrews among treatments using a 2-way ANOVA blocked for age class and sex. We conducted all statistical analyses using SAS statistical software (SAS Institute, 1997).

4. Results

We trapped a total of 924 plot nights across downed, removal, and control plots during our 5 sampling periods, capturing a total of 193 shrews. Additional insectivores captured included one starnosed mole (*Condylura cristata*) and one eastern mole (*Scalopus aquaticus*). Total capture rate did not differ among treatments (Table 5-1). We captured a total of 123 southern short-tailed shrews, 52 southeastern shrews, and 18 least shrews. Capture rates of southern short-tailed shrews, southeastern shrews, and least shrews did not differ among treatments (Table 5-1).

We collected 83 southern short-tailed shrews and 51 southeastern shrews for age class analysis (Figure 5-1). Age class distribution did not vary among treatments for southern short-tailed shrews ($G^2 = 8.70$, $df = 6$, $P = 0.191$) or southeastern shrews ($G^2 = 0.75$, $df = 4$, $P = 0.945$). Mean ($\pm$ SE) body weight of southern short-tailed shrews was 8.9 ± 0.7 , 7.4 ± 0.5 , and 7.3 ± 0.4 in downed, removal, and control treatments, respectively. Body weight of southern short-tailed shrews did not differ among treatments ($F_{2,72} = 2.70$, $P = 0.074$). Mean body weight of southeastern shrews in downed, removal, and control treatments was 3.0 ± 0.2 , 2.6 ± 0.2 , and 3.0 ± 0.2 , respectively, and did not differ among treatments ($F_{2,38} = 0.73$, $P = 0.486$).

5. Discussion

Although our sampling effort was temporally limited, shrews are prolific reproducers and short lived (French, 1980; Churchfield, 1990), therefore populations within our study

plots should have reflected current habitat conditions (Ford et al., 2000; Ford and Rodrigue, 2001). Trends in shrew capture rates suggest a positive response to increases in downed CWD. Least shrew capture rates were weakly significant, with the highest capture rate occurring in downed stands. However, small sample size precludes us from drawing conclusions regarding treatment effects on this species. Although least shrews are associated with old-field habitats that generally contain low levels of CWD, limited evidence does suggest that they benefit from increases in CWD volume. For example, least shrew capture rate in open canopy pine plantations in the Coastal Plain of North Carolina was positively correlated with CWD (Mitchell et al., 1995).

Capture rates of southern short-tailed shrews and southeastern shrews in downed treatments were 38 and 50% higher, respectively, than in removal treatments. Additionally, body weight of southern short-tailed shrews in our study was weakly significant, with individuals in downed treatments having the highest mean body weight. Short-tailed shrews in longleaf pine stands that received a pulse of downed woody debris due to tornado damage were more abundant than in salvaged stands, although the author cautions that small sample size precludes conclusions regarding treatment effects (Loeb, 1999). Increased CWD volume may provide greater cover from predators, enabling shrews to increase foraging activity. Capture rates of northern short-tailed shrews (*B. brevicauda*), masked shrews (*S. cinereus*), smoky shrews, and pygmy shrews (*S. hoyi*) were greater near CWD occupying early decay stages in southern Appalachian hardwood forests of North Carolina (Maidens et al., 1998). The more rounded shape and branches were speculated to have provided better cover during foraging episodes because CWD in early stages of decay possesses more abundant hiding areas. Although our data suggest

that shrews benefited from increased cover, treatment effects may become more pronounced as CWD reaches advanced stages of decay.

The function of CWD in the ecology of shrews in upland loblolly pine stands may be predominately determined by decay stage. Ability of CWD to retain moisture during dry periods is dependent upon decay stage, with CWD in more advanced stages of decay capable of retaining more moisture than CWD in early decay stages (Jaeger, 1980; Boddy, 1983). Abundance of some shrew species has been positively correlated with CWD in advanced stages of decay (Corn et al., 1988; Brannon, 2000). Additionally, environmental moisture levels within these stands may influence dependence of shrew species on CWD. Because upland pine stands tend to be more xeric relative to other forest types, CWD may be an important source of moisture within these stands.

Acknowledgements

We gratefully acknowledge the initiation of this project by J. Blake, S. Loeb, M. Dorcas, and the late J. Laerm. Thanks to A. Menzel, N. Castleberry, J. Hill, H. Hoyle, and P. Champlin for help in the field. We thank J. Kilgo for logistic assistance. We are grateful to the U.S. Department of Energy for access to the Savannah River Site. Funding for this project was provided by the U. S. Department of Energy--Savannah River Operations Office through the U. S. Forest Service--Savannah River and the USFS Northeast Research Station under Interagency Agreement DE-AI09-00SR22188

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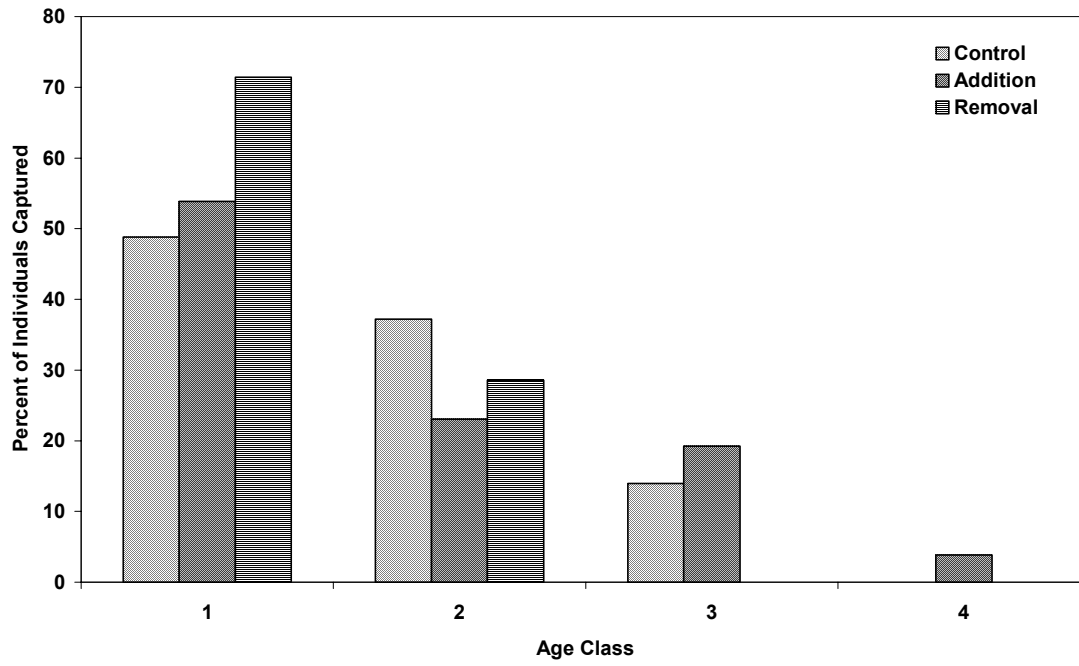
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Table 5-1. Mean ($\pm$ SE) capture rate of southern short-tailed shrews (*Blarina carolinensis*), southeastern shrews (*Sorex longirostris*), and least shrews (*Cryptotis parva*) captured in June and October 2002 and January, April, and June 2003 at the Savannah River Site, Barnwell County, South Carolina in upland loblolly pine (*Pinus taeda*) stands subject to addition of downed coarse woody debris (CWD), removal of CWD, and controls.

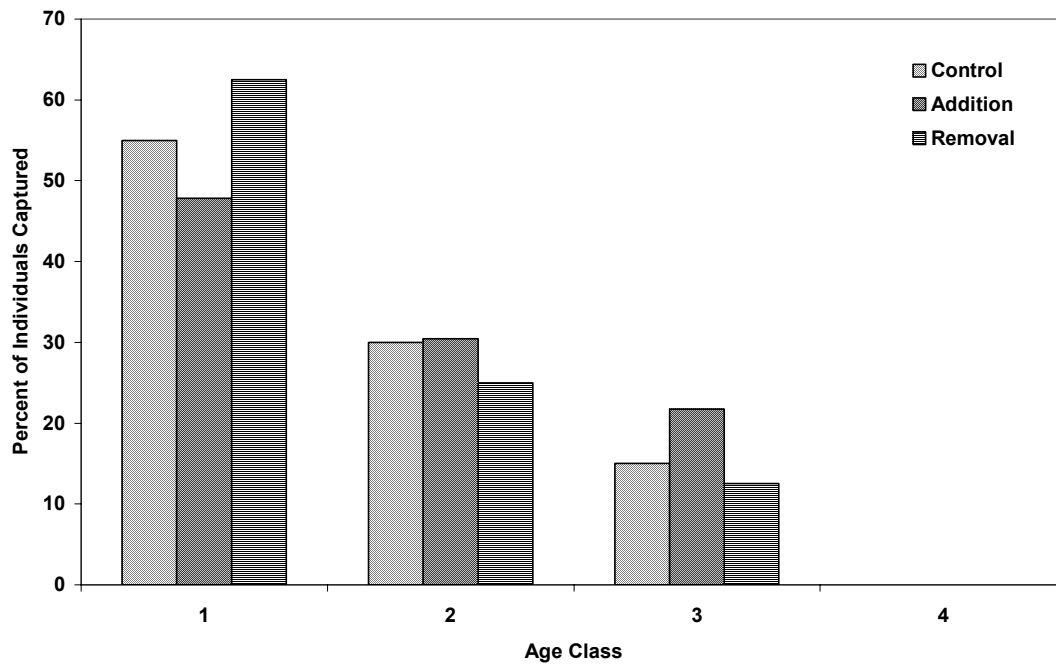
	Downed (n = 3)	Control (n = 3)	Removal (n = 5)	F _{2,6}	P
southern short-tailed shrew	0.16 $\pm$ 0.05	0.13 $\pm$ 0.04	0.10 $\pm$ 0.01	0.53	0.614
southeastern shrew	0.09 $\pm$ 0.03	0.04 $\pm$ 0.01	0.04 $\pm$ 0.01	2.72	0.144
least shrew	0.04 $\pm$ 0.01	0.01 $\pm$ 0.01	0.02 $\pm$ 0.01	4.41	0.066
Total shrew capture rate	0.30 $\pm$ 0.06	0.18 $\pm$ 0.05	0.15 $\pm$ 0.01	2.05	0.210

Fig. 5-1. Age distribution of southern short-tailed shrews (A; *Blarina carolinensis*) and southeastern shrews (B; *Sorex longirostris*) captured in June and October 2002 and January, April, and June 2003 at the Savannah River Site, Barnwell County, South Carolina in upland loblolly pine stands (*Pinus taeda*) stands subject to addition of downed coarse woody debris (CWD), removal of CWD, and controls.

A



B



CHAPTER 6

AMPHIBIAN AND REPTILE RESPONSE TO COARSE WOODY DEBRIS MANIPULATIONS IN UPLAND LOBLOLLY PINE (*PINUS TAEDA*) STANDS¹

¹ Moseley, K.R., S.B. Castleberry, and W.M. Ford. To be submitted to *Biological Diversity*.

Abstract

We studied the response of amphibians and reptiles to coarse woody debris (CWD) manipulations in upland loblolly pine (*Pinus taeda*) stands in the southeastern Coastal Plain physiographic region of South Carolina. Four 9.3-ha plots within 3 stands were assigned one of the following treatments using a randomized complete block design: removal- all CWD ≥ 10 cm in diameter and ≥ 60 cm long removed, downed- 5-fold increase in volume of down CWD, snag- 17-fold increase in standing CWD, and control. Amphibians and reptiles were sampled using a series of drift-fence-pitfall arrays and sticky traps opened for 14-day trapping periods during June and October 2002 and January and June 2003, with an additional 28-day sampling period during April 2003. We captured 1420 amphibians and 473 reptiles, representing 11 and 19 species, respectively, during 1008 plot nights. Amphibian and reptile capture rate, diversity, and species richness did not differ among treatments. Anurans and salamanders also exhibited no differences in capture rate among treatments. Additionally, no difference in lizard or snake capture rate was found among treatments. Amphibian assemblages occupying upland sites in the southeastern Coastal Plain are probably more dependent on burrowing and increased water retention as a means of escaping adverse surface conditions. Lack of treatment response by slimy salamanders and small semi-fossorial snakes may be attributable to the early decay stage of CWD in our study.

Key words: amphibians, coarse woody debris, herpetofauna, pine plantations, reptiles

1. Introduction

Use of intensively managed pine plantations in the southeastern United States is increasing to meet burgeoning demand for wood fiber products (Prestemon and Abt, 2002). Pine plantations comprise approximately 15 % of timberland in the Piedmont and Coastal Plain of the Southeast (Conner and Hartsell, 2002). They generally consist of a single conifer (*Pinus* spp.) and are managed by a number of silvicultural practices including clearcutting and mechanical site preparation techniques such as stump removal, roller chopping, and mechanical bedding (Hunter, 1990; Smith et al., 1997; Siry, 2002). Because pine plantations are managed under shorter rotation lengths as compared to unmanaged pine stands, disturbance occurs more frequently. Even-aged harvesting and subsequent site preparation compact soil, reduce litter depth and cover, displace mineral soil, and reduce volume and alter decay class distribution of coarse woody debris (CWD) (Harmon et al., 1986; Reisinger et al., 1988; deMaynadier and Hunter, 1995), leading to the development of more homogenous forest stands (Hunter, 1990). Intensively managed plantations typically contain a less diverse and abundant amphibian assemblage than those in less disturbed unmanaged pine or hardwood stands (Bennett et al., 1980; Grant et al., 1994; Hanlin et al., 2000). Reduction of microhabitat features, such as CWD, within intensively managed plantations in the Coastal Plain is believed to be a major factor in observed reductions of some amphibian and reptile populations within these stands (Enge and Marion, 1986).

Response of amphibians and reptiles to forest management practices that alter CWD volume varies by taxonomic group, physiographic region, and silvicultural techniques

employed (Russell et al., In Press). Reduction of CWD was a major factor in lower reptile abundance and diversity in a Florida flatwood stand that had been clearcut and subject to intensive site preparation including stump removal, burning, windrowing, harrowing, bedding, and planting (Enge and Marion, 1986). Caudate abundance was positively correlated with CWD volume in 19-year old managed pine stands in the Coastal Plain of South Carolina (Baughman, 2000). However, anuran abundance was negatively correlated with CWD abundance following clearcutting of these stands. Near absence of logs in pine stands subject to prescribed fire in the Coastal Plain of Maryland was cited as a major factor in reduced abundance of amphibians and fossorial snakes (McLeod and Gates, 1998). Although these studies indicate a varied response by amphibian and reptiles assemblages to alterations in CWD abundance, influence of CWD additions on herpetofaunal populations has not been examined independently from effects of timber harvesting, site preparation, and prescribed fire.

Coarse woody debris is used by herpetofauna as a source of moist refugia, basking substrate, site of egg deposition, and cover from predators (Whiles and Grubbaugh, 1996). However, the degree to which herpetofauna are dependent upon CWD is not well known, especially within southeastern pine forests. Therefore, we assessed the response of amphibian and reptile assemblages in upland loblolly pine stands to increases CWD volume.

2. Study Site and Methods

2.1. Site description

Our study was conducted at the U.S. Department of Energy's Savannah River Site (SRS), a 78,000-ha National Environmental Research Park in Aiken, Barnwell, and Allendale Counties, South Carolina. The SRS is located on the upper Coastal Plain in an area known as the Sandhills. Historically, upland areas of the SRS were dominated by the longleaf pine (*P. palustris*) -wiregrass (*Aristida* spp.) community before being cleared for agriculture in the early 1800's. Upon acquisition of the land comprising the SRS by the Atomic Energy Commission in 1951, the US Forest Service planted abandoned agricultural fields in loblolly, longleaf, and slash (*P. elliotii*) pine. Stands were established on our sites by hand planting between 1951 and 1954. Understory vegetation consisted of lespedeza (*Lespedeza* spp.), poison oak (*Toxicodendron pubescens*) and broomsedge (*Andropogon* spp.). The topography is gently rolling to flat with elevations ranging from 20 – 130 m. Mean annual temperature is 18°C and mean annual precipitation is 122.5 cm.

2.2. Methods

Our study was designed as a randomized complete block design consisting of four 9.3-ha treatment plots replicated in three stands. Experimental stands were selected based on the following criteria: forested with approximately 45-50-year-old loblolly pine

plantations, sizes that were capable of accommodating four square 9.3-ha plots, and proximity ≥ 76 m from nearest wetland, road, and power line. Four square 9.3-ha plots were established within individual study stands. Plots within each stand were randomly assigned one of four treatments: 1) Removal- all CWD ≥ 10 cm in diameter and ≥ 60 cm long; 2) Downed- 5-fold increase in volume of down CWD; 3) Snag- 17-fold increase in standing volume of CWD; and 4) control. Each plot contained a 6-ha core area, in which herpetofaunal sampling occurred, within a 3.3-ha buffer zone subject to the same treatment as the core area. Coarse woody debris removal treatments were implemented in summer 1996 and were maintained annually. Downed treatments were implemented in August 2001 by randomly selecting 12 rows of trees to be felled within plots using a feller-buncher. Because herpetofaunal sampling began shortly after trees were downed, all CWD additions occupied the earliest stages of decay. Additionally, effects of below ground CWD, such as decomposing tree stumps, was beyond the scope of our study. Control and removal plots were subsequently thinned to standardize basal area among treatments. Trees in 12 randomly selected rows were girdled for creation of snag treatment plots in spring 2001 and were retreated in fall 2001 with herbicide injection. Snag creation resulting in a residual basal area of $15.96 \text{ m}^3/\text{live trees ha}$. Trees were felled during August 2001 for down woody debris treatments. Estimates of mean ($\pm$ SE) coarse woody debris loadings were 56.2 ± 6.6 , 5.9 ± 1.1 , 3.1 ± 1.4 , and $2.4 \pm 1.0 \text{ m}^3/\text{ha}$ in downed, snag, control, and removal plots, respectively. Most plots were prescribed burned between 1990 and 1996 in accordance with normal land management practices for forests at the SRS.

We sampled amphibians and reptiles using a series of drift fence arrays (Gibbons and Semlitsch, 1981) and sticky traps (Downes and Borges, 1998). Drift fences were made from aluminum flashing buried 15-cm in the ground. Nineteen-liter plastic buckets were buried against each fence. On each plot, a centrally located cross-shaped array with 30-m arms was installed (Corn, 1994). In each corner of the center array, X-shaped arrays with 15-m arms were installed. We attached a sticky trap to two trees on the outside of each 30 m straight fence. Because our sampling techniques are not effective at capturing large snakes, we did not consider them when assessing treatment effects. We opened traps during June and October 2002 and January, April, and June 2003. We checked traps daily identified individuals captured, recorded snout-vent-length (SVL; cm), and recorded sex when possible. We marked individuals by toe clipping and released them.

Captured species were pooled into the following taxonomic categories for analysis: amphibians, reptiles, anurans, salamanders, lizards, and snakes. Capture rates of individual species with ≥ 25 captures also were compared among treatments. We calculated capture rates by dividing plot captures by the number of plot nights. Variables not normally distributed were $\log_{10}$ transformed. We calculated diversity of amphibians and reptiles for each plot using the Shannon-Weiner index (Pielou, 1977). Amphibian and reptile species richness was calculated as the total number of species occurring in a plot. All variables were analyzed using a two-way analysis of variance (ANOVA) blocked for stand. All statistical analyses were conducted using SAS statistical software (SAS Institute, 1997).

3. Results

We captured 1429 amphibians and 473 reptiles in 1008 plot nights (Table 6-1). Seventy-seven percent of all captures combined consisted of four species: southern toad (*Bufo terrestris*; 30%), eastern narrowmouth toad (*Gastrophryne carolinensis*; 24%), eastern spadefoot toad (*Scaphiopus holbrookii*; 13%), and green anole (*Anolis carolinensis*; 10%). Amphibian capture rate, diversity, and richness did not differ among treatments (Table 6-2). Anurans and salamanders also exhibited no differences in capture rate among treatment types (Table 6-2). Additionally, no differences were found among treatments for eastern spadefoot toads ($F_{3,6} = 0.14$, $P = 0.935$), southern toads ($F_{3,6} = 0.28$, $P = 0.837$), and eastern narrowmouth toads ($F_{3,6} = 0.29$, $P = 0.830$). Individual salamander species, mole salamanders ($F_{3,6} = 0.86$, $P = 0.511$) and slimy salamanders ($F_{3,6} = 0.77$, $P = 0.551$), also did not differ among treatments.

Reptile capture rate, diversity, and species richness did not differ among treatments (Table 6-3). No difference in lizard or snake capture rate was found among treatments (Table 6-3). Capture rate of the two most common reptile species, the green anole ($F_{3,6} = 0.16$, $P = 0.286$), and eastern fence lizard ($F_{3,6} = 0.14$, $P = 0.931$) did not differ among treatments. Capture rate of the most common snake species, southeastern crowned snake (*Tantilla coronata*), also did not differ among treatments ($F_{3,6} = 2.21$, $P = 0.188$).

4. Discussion

4.1. *Amphibian response to treatments*

Despite an 89.5, 94.5, and 95.7% increase in downed CWD over snag, control, and removal stands, respectively, we found no response by amphibians to our treatments. Most captures consisted of three anuran species, with southern toads, eastern narrowmouthed toads, and eastern spadefoot toads comprising 89.7% of all amphibian captures. Dependence of these species on CWD in the Coastal Plain is probably negligible due to their ability to escape dry climatic conditions by burrowing (Pearson, 1955; Conant and Collins, 1998), generally only emerging following rainfall or periods of high humidity (Gibbons and Bennett, 1974). Anurans are capable of tolerating high temperatures compared to other amphibian groups, such as salamanders, and can store and reabsorb large quantities of water (Stebbins and Coen, 1997), which may further reduce their dependence on CWD as a source of moist refugia. Similarly, dependence on CWD by other amphibians adept at burrowing, such as ambystomatid salamanders, may be minimal.

Ambystomatid salamanders generally occupy underground burrow systems (Williams, 1970; Semlitsch, 1983a) independent of CWD (Semlitsch, 1981a). Locally, subterranean burrows created by small mammals such as moles (Talpidae) and *Peromyscus* spp., as well as preexisting cracks and crevices in the soil, can be exploited during periods of unsuitable surface conditions (Semlitsch, 1983b). However, dependence on CWD may increase following reductions in litter depth and cover. Mole

salamanders (*A. talpoideum*) within enclosures containing low pine litter depth used CWD more than individuals within high pine litter treatments, presumably because reduced pine litter depth failed to adequately buffer underground burrows from ambient climatic fluctuations (Moseley et al., 2004). Chazal and Niewiarowski (1998) compared juvenile *A. talpoideum* within enclosures in a 4-month-old clearcut to individuals maintained in an adjacent 40-year old loblolly pine stand at the Savannah River Site, South Carolina. Juveniles did not differ in abundance, body mass, snout-vent-length, clutch size, percent whole-body nonpolar storage lipid, or percent storage lipid of eggs after 5-6 months of exposure to enclosure conditions. Lack of difference between the two treatments was partially attributed to the large amounts of CWD in clearcut enclosures, which may have ameliorated clearcut surface conditions by retaining on-site moisture.

Unlike ambystomatid salamanders, members of the family Plethodontidae rely entirely upon dermal respiration. This requires that their skin remain moist to facilitate efficient oxygen exchange with the atmosphere (Stebbins and Coen, 1997). Abundance of many plethodontid salamanders has been positively correlated with CWD volume in various hardwood forest types in the Appalachians (Maidens et al., 1998; Moore et al., 2001) and coniferous forests of the Pacific Northwest and Canada (Aubry et al., 1988; Bury and Corn, 1988; Dupuis et al., 1995; Butts and McComb, 2000). The lack of response by slimy salamanders to our manipulations may be due to the early decay stage of CWD in downed treatments. Coarse woody debris in advanced stages of decay has greater water holding ability (Jaeger, 1980; Boddy, 1983) and therefore may serve as better cover from adverse climatic conditions. Highly decayed logs are also important

sites for egg deposition by slimy salamanders in the Coastal Plain (Highton, 1956). As CWD reaches more advanced stages of decay it may facilitate higher densities of slimy salamanders within downed CWD plots.

4.2. Reptile response to treatments

Response of reptiles to CWD manipulations was similar to that of amphibians. Green anoles, eastern fence lizards, and southeastern crowned snakes were the most abundant species, representing 82.9% of all reptile captures. Although many lizard species captured in our study use CWD as a site for egg deposition and basking substrate (Whiles and Grubaugh, 1996), we did not detect any differences in abundance among treatments. Increased reptile abundance following clearcut harvesting of a bottomland hardwood forest in the Coastal Plain of South Carolina was attributed to increased logging slash (Phelps and Lancia, 1995). Green anoles are primarily arboreal, so their dependence on CWD may be negligible. Abundance of green anoles in Florida scrub pine stands subject to various silvicultural prescriptions, including clearcutting, prescribed fire, salvage logging, and roller-chopping did not differ from control stands despite increased woody debris cover (Greenberg et al., 1994). Green anole and southeastern crown snake capture rates were most influenced by bare ground and shrub cover. Southeastern crowned snakes, smooth earth snakes (*Virginia valeriae*), and scarlet snakes (*Cemophora coccinea*) represented 84.5% of all snakes captured in our study. Snakes did not differ among treatments despite evidence suggesting that species representing the majority of our snake captures rely to some extent on CWD as a source of refugia and insect prey

(Minton, 1949; Hardy, 1952; Brode and Allison, 1958; Semlitsch, 1981b). Increased abundance of southern ringnecked snakes (*Diodophus punctatus*), scarlet kingsnakes (*Lampropeltis triangulum*), and rough earth snakes (*Virginia striatula*) in central Florida Flatwoods stands subject to clearcut harvesting and minimum site preparation techniques was presumably a result of greater CWD abundance. Semlitsch (1981b) found xeric microhabitat with sufficient logs and rotting stumps was more important for use of an area by southeastern crowned snakes than either vegetation type or macrohabitat. Like plethodontid salamanders, small cryptozoic snakes may become more abundant as CWD reaches advanced stages of decay.

5. Conclusion

Our study suggests that dependence of amphibians and reptiles on CWD in upland pine stands of the southeastern Coastal Plain is probably minimal, at least for CWD in early stages of decay. Historically, upland areas of the region were characterized by the longleaf pine-wiregrass community (Landers et al., 1995; Frost, 1998; Van Lear and Harlow, 2002). The frequent, low intensity ground fires that maintained this community combined with high decomposition rates, as compared with those of other regions, probably prevented large accumulations of CWD in upland areas (Van Lear and Waldrop, 1994; Van Lear, 1996). Additionally, CWD in advanced stages of decay probably did not persist for long periods. Amphibian and reptile assemblages within upland pine stands may be more dependent upon underground burrows and leaf litter for refuge from adverse climatic conditions. Pine litter contains abundant invertebrate prey

(Sanzone, 1995; Hanula and Wade, 2003) and buffers soil burrows from extreme temperature and moisture fluctuations (Geiger et al., 1995). A number of forest floor microhabitat features including litter, CWD, and underground burrows probably act synergistically to sustain amphibian and reptile abundance and diversity within upland pine stands of the southeastern Coastal Plain.

Acknowledgements

We gratefully acknowledge the initiation of this project by J. Blake, M. Dorcas, S. Loeb, and the late J. Laerm. Thanks to A. Menzel, N. Castleberry, J. Hill, H. Hoyle and P. Champlin for help in the field. We thank J. Kilgo logistic assistance. We are grateful to the U.S. Department of Energy for access to the Savannah River Site. Funding for this project was provided by the U. S. Department of Energy--Savannah River Operations Office through the U.S. Forest Service--Savannah River and the USFS Northeast Research Station under Interagency Agreement DE-AI09-00SR22188

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Table 6-1. Numbers of amphibian and reptile species captured in June and October 2002 and January, April, and June 2003 at the Savannah River Site, Barnwell County, South Carolina in loblolly pine (*Pinus taeda*) stands subject to addition of downed coarse woody debris (CWD), addition of standing CWD, removal of CWD, and controls.

Species	Common Name	Downed	Removal	Control	Snag
<i>Bufo terrestris</i>	Southern Toad	146	158	151	118
<i>Gastrophryne carolinensis</i>	E. Narrowmouth Toad	118	90	167	82
<i>Anolis carolinensis</i>	Green Anole	56	54	52	36
<i>Scaphiopus holbrookii</i>	E. Spadefoot toad	53	44	83	64
<i>Sceloperus undulatus</i>	E. Fence Lizard	41	27	26	32
<i>Plethodon chlorobryonis</i>	Atlantic Coast Slimy Salamander	18	14	20	9
<i>Tantilla coronata</i>	Southeastern Crowned Snake	15	28	14	11
<i>Pseudacris ornata</i>	Ornate Chorus Frog	7	3	5	6
<i>Ambystoma talpoideum</i>	Mole Salamander	6	9	21	14
<i>Cnemidophorus sexlineatus</i>	Six-Lined Racerunner	4	4	0	1
<i>Scincella lateralis</i>	Ground Skink	4	6	7	2
<i>Virginia valeriae</i>	Smooth Earth Snake	4	1	3	3
<i>Cemophora coccinea</i>	Scarlet Snake	2	4	1	1
<i>Eumeces laticeps</i>	BroadHead Skink	2	0	1	0
<i>Ambystoma tigrinum</i>	Tiger Salamander	1	1	2	2
<i>Eumeces fasciatus</i>	Five-Lined Skink	1	1	3	1
<i>Eumeces inexpectatus</i>	Southeastern Five-Lined Skink	1	0	2	3
<i>Storeria occipitomaculata</i>	Redbelly Snake	1	0	0	0
<i>Acris gryllus</i>	S. Cricket Frog	0	0	0	1
<i>Diadophis punctatus</i>	S. RingNeck Snake	0	1	3	0
<i>Elaphe guttata</i>	Corn Snake	0	1	0	0
<i>Elaphe obsoleta</i>	Black Rat Snake	0	1	1	0
<i>Heterodon platirhinos</i>	E. Hognose Snake	0	1	0	1
<i>Heterodon simus</i>	S. Hognose Snake	0	1	0	1
<i>Lampropeltis triangulum</i>	Scarlet Kingsnake	0	1	2	0
<i>Pseudotriton ruber</i>	S. Red Salamander	0	2	0	0
<i>Rana catesbeiana</i>	Bullfrog	0	0	1	0
<i>Rana clamitans</i>	Bronze Frog	0	0	2	2
<i>Terrapene carolina</i>	E. Box Turtle	0	1	1	1
<i>Thamnophis sirtalis</i>	E. Garter Snake	0	0	1	0

Table 6-2. Mean ($\pm$ SE) capture rates, Shannon-Weiner Index, and species richness of amphibians and capture rates of anurans and salamanders captured in plots subject to addition of downed coarse woody debris (CWD), addition of standing CWD, removal of CWD, and controls in upland loblolly pine stands (*Pinus taeda*) at the Savannah River Site, Barnwell County, South Carolina, June 2002-June 2003.

	Downed (n = 3)	Control (n = 3)	Snag (n = 3)	Removal (n = 3)	F _{3,6}	P
Amphibians						
Capture rate ¹	1.39 $\pm$ 0.32	1.79 $\pm$ 0.89	1.18 $\pm$ 0.25	1.27 $\pm$ 0.07	0.19	0.900
Shannon-Weiner Index	1.24 $\pm$ 0.08	1.22 $\pm$ 0.11	1.38 $\pm$ 0.04	1.39 $\pm$ 0.13	0.8	0.537
Richness	6.00 $\pm$ 0.00	6.33 $\pm$ 0.88	6.67 $\pm$ 0.33	7.00 $\pm$ 0.58	0.49	0.703
Anurans						
Capture rate ¹	1.44 $\pm$ 0.75	1.44 $\pm$ 0.75	0.95 $\pm$ 0.26	0.92 $\pm$ 0.12	0.18	0.906
Salamanders						
Capture rate	0.10 $\pm$ 0.02	0.17 $\pm$ 0.03	0.10 $\pm$ 0.02	0.10 $\pm$ 0.04	1.29	0.361

¹ – Log₁₀ transformed

Table 6-3. Mean ($\pm$ SE) capture rates, Shannon-Weiner Index, and species richness of reptiles and capture rates of lizards and snakes captured in plots subject to addition of downed coarse woody debris (CWD), addition of standing CWD, removal of CWD, and controls in upland loblolly pine stands (*Pinus taeda*) at the Savannah River Site, Barnwell County, South Carolina, June 2002-June 2003.

	Downed (n = 3)	Control (n = 3)	Snag (n = 3)	Removal (n = 3)	F _{3,6}	P
Reptiles						
Capture rate	0.52 $\pm$ 0.06	0.52 $\pm$ 0.03	0.46 $\pm$ 0.12	0.37 $\pm$ 0.13	0.95	0.475
Shannon-Weiner Index	1.38 $\pm$ 0.17	1.64 $\pm$ 0.18	1.53 $\pm$ 0.13	1.39 $\pm$ 0.21	1.14	0.405
Richness	7.33 $\pm$ 1.20	8.33 $\pm$ 0.67	8.33 $\pm$ 0.88	6.67 $\pm$ 0.88	0.69	0.593
Lizards						
Capture rate	0.43 $\pm$ 0.07	0.37 $\pm$ 0.03	0.36 $\pm$ 0.11	0.30 $\pm$ 0.11	0.85	0.515
Snakes						
Capture rate	0.10 $\pm$ 0.01	0.16 $\pm$ 0.03	0.10 $\pm$ 0.02	0.07 $\pm$ 0.03	2.71	0.138

CONCLUSION

Historically, much of the upland areas of the southeastern Coastal Plain were covered by the longleaf pine (*Pinus palustris*)-wiregrass (*Aristida* spp.) community, which was maintained by frequent, low intensity, ground fires that occurred during the growing season (Landers et al. 1995, Frost 1998, Van Lear and Harlow 2002). Frequent fires, combined with greater decomposition rates in the region, probably prevented buildup of CWD within upland pine stands (Van Lear 1996). Indeed, pine forests of the Southeast generally have a lower abundance of CWD than in other forest types of the Pacific Northwest or Appalachian regions (McMinn and Hardt 1996). Properties of CWD that benefit many herpetofauna and shrew species as a moist microhabitat are probably only achieved after advanced stages of decomposition are reached and greater water holding ability develops (Jaeger 1980, Boddy 1983). However, because of high decomposition rates and natural growing season ground fires that frequently occurred in upland pine systems, CWD occupying advanced decay classes was probably sparse and short-lived, and perhaps prompted many terrestrial species inhabiting these xeric upland stands to rely instead on underground burrows to escape adverse surface conditions.

Trends in shrew capture rates among treatments suggest that CWD provides an important source of cover in the well drained, sandy soils of xeric pine stands in the Coastal Plain. However, effects of CWD additions in my study were limited to above ground CWD in early stages of decay. Response of shrew populations to increased CWD volume may become more pronounced as CWD reaches advanced stages of decay.

Conversely, my study suggests that dependence of amphibians and reptiles on CWD occupying early stages of decay in upland pine stands of the southeastern Coastal Plain is probably negligible. Additionally, use of CWD in early stages of decay as foraging substrate by southern toads is negligible. Ambystomatid salamanders may become more dependent on CWD when other microhabitats such as leaf litter and underground burrows are reduced. Forest management practices that reduce microhabitat features, such as leaf litter, may increase dependence of ambystomatids on CWD. Our study supports sustainable forestry initiative guidelines, which suggest leaving logging slash on site following harvesting in order to provide refugia for ambystomatid salamanders (American Forest and Paper Association 2002).

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