RESPONSE OF SMALL MAMMALS TO VARIABLE RETENTION OF WOODY DEBRIS FOLLOWING BIOMASS HARVESTS IN THE SOUTHEAST

by

CHRISTOPHER BRIAN FARRELL

(Under the Direction of Steven B. Castleberry)

ABSTRACT

Woody biomass harvesting is defined as the removal of debris normally left after timber harvests (i.e., limbs, tops) to be used in sustainable energy production. Increased use of woody debris left after harvest may negatively affect wildlife species that depend on coarse woody debris (CWD) to meet various life history requirements. Studies that have been conducted on the importance of CWD to small mammals were mainly in standing forests of the Pacific Northwest and southern Appalachian Mountains. I examined the response of small mammals to varying levels of CWD retention after biomass harvests in the southeastern Coastal Plain using models incorporating CWD volume and vegetation characteristics. I captured 10 species in 81,177 trap nights. Vegetation characteristics had more influence on total captures and captures of most species than CWD volume. Based on my results, biomass harvests appear to have limited effect on small mammal abundance.

INDEX WORDS: small mammals, coarse woody debris, biomass harvest, southeastern Coastal Plain, *Peromyscus*

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INTRODUCTION AND LITERATURE REVIEW

Introduction

The need for renewable energy sources in the U.S. is becoming more important given concerns about fossil fuel prices, limited supplies of fossil fuels and climate change. New state and federal policies provide incentives, such as tax breaks, for using renewable transportation fuels, or require renewable power generation (Database of State Incentives for Renewable Energy 2013). The Renewable Fuel Standard (RFS) program was created under the Energy Policy Act of 2005 and modified under the Energy Independence and Security Act of 2007 to require renewable power generation on a national level. In addition to federal legislation, some states have implemented renewable energy source regulations independently. One example of adopted state legislative policy is Renewable Portfolio Standards (RPS). Currently, 29 states and two U.S. territories have RPS and 8 more have Renewable Portfolio Goals, with these numbers growing each year. RPS require utilities to use renewable energy sources to account for a percentage of retail electricity sales (Database of State Incentives for Renewable Energy 2013). The renewable energy required under RPS can come from woody biomass, wind energy, solar energy or hydropower. These new policies are expected to create demand to produce more energy using woody biomass from forests, especially in the Southeast which has a large timber industry. This wood-based energy likely will come from logging slash or small diameter trees, tops, and limbs that are typically left on the harvest site and not used for higher value products (Titus et al. 2010).

Forests are unique ecosystems that provide many important functions, including carbon sequestration, clean water, wildlife habitat, a renewable source of energy, and wood products. Woody biomass is an important part of forest ecosystems that provides a myriad of essential processes such as nutrient cycling, hydrological functioning, soil organic matter, and coarse and fine woody debris for wildlife use (Janowiak and Webster 2010). Forestry Best Management Practices (BMPs) are designed to minimize sediments in streams and to protect against erosion, but they do not specify protocols for the removal of slash or other woody biomass residues.

Removal of woody material typically left on site after traditional timber harvests could alter wildlife habitat (Abbas et al. 2011). This woody material, present in the form of snags, downed boles, downed limbs, and finer debris left from previous harvest is a key feature of wildlife habitat because the harvested area is still in its earliest successional stage with little above ground structure (McMinn and Crossley 1996, Sullivan et al. 2011). Woody debris removal at time of harvest leaves only the naturally produced CWD for wildlife use in a stand, which takes several years to accumulate.

My study was part of a broader study designed to provide scientific research to aid in the creation of Biomass Harvesting Guidelines (BHGs) to protect or enhance managed forest ecosystems. My study was designed specifically to examine the effect of varying amounts of CWD remaining after harvest on small mammal abundance in Georgia and North Carolina. My research will be integrated with the results of the larger study and used as the basis for development of BHGs for the Southeast.

Literature Review

Woody Debris

Coarse woody debris is defined as dead tree and shrub boles, snags, large downed limbs, roots, and other woody pieces that are separated from their original source of growth (Harmon et al. 1986, United States Department of Agriculture 2007). Coarse woody debris is an important feature of forest ecosystems, serving as an important component for nutrient retention and water dynamics in forested ecosystems (Harmon et al. 1986). Because CWD also could be a long-term reservoir of carbon in some forests, it has implications for climate change and carbon sequestration (Currie and Nadelhoffer 2002). Volume of CWD typically found in southern forests is considerably lower than volumes found in other regions of the U.S. due to intensive site preparation, short rotation lengths, and a high rate of decay (McMinn and Hardt 1996). In the South, CWD functions as reservoirs of moisture during drought, seed germination sites, and as sites of nutrient exchange for use by plants (Van Lear 1996). CWD volume is dynamic in southern forests due to inputs by tree mortality and losses by fire and decomposition which occurs at a rapid rate. The climate and weather patterns of the Southeast, including hurricanes and tornadoes, are primary contributing factors in the dynamics of CWD in the region.

The amount of woody debris present in a managed forest typically follows a “U-shaped timeline" (Harmon et al. 1986). Woody debris is generated naturally as the forest ages, trees and limbs die, and the accumulation rate exceeds the decay rate. Residual woody debris from the previous harvest declines over time as it decomposes, while the naturally generated woody debris takes over as critical habitat (Harmon et al. 1986). Biomass harvests alter the “U-shaped timeline” of woody debris abundance and reduce the amount of woody debris available during the development of a timber stand until the naturally generated woody debris is generated.

Small Mammal Use of Woody Debris

Many organisms, including invertebrates, vertebrates, fungi and plants, rely on woody debris for a variety of functions (Hunter 1999). Most of the studies examining CWD and its importance to wildlife have been conducted in the Pacific Northwest where more debris is generated and old-growth forests are more common than in the Southeast. The volume of CWD in the Pacific Northwest can reach 500 m^3/ha in old-growth forests compared to 17.5 m^3/ha in natural pine stands of South Carolina (Spies and Cline 1988, McMinn and Hardt 1996).

Many studies in the Pacific Northwest have demonstrated relationships between small mammal species and CWD (Bowman et al. 2000, Etcheverry et al. 2005, Manning and Edge 2008). Small mammals use CWD for protection, travel and escape routes, and as a substrate for feeding (Barry and Francq 1980, Barnum et al. 1992, Tallmon and Mills 1994, Loeb 1996, Whiles and Grubaugh 1996). More than 32 small mammal species across the U.S. use CWD and abundance of several species is directly correlated with CWD volume (Loeb 1999, Butts and McComb 2000, McCay 2000, Cromer et al. 2007, Davis et al. 2010). Of the approximately 81 mammal species that occur in the Southeast, at least 55 use downed woody debris in some way (Loeb 1996).

Abundance of some small mammal species in the Southeast is related to the amount of CWD present on a site (Loeb 1999). Coarse woody debris has been shown to be an important habitat component for golden mice (*Ochrotomys nuttali*), deer mice (*Peromyscus* spp.), and hispid cotton rats (*Sigmodon hispidus*) in the southeastern Coastal Plain. Cotton mice (*Peromyscus gossypinus*), have been observed using CWD to evade predators while feeding at night and as daytime refugia (Hinkelman and Loeb 2007, Hinkelman et al. 2012). Proximity to CWD also plays a role in selection of cotton mouse daytime refuges (Derrick et al. 2010).

White-footed mice (*Peromyscus leucopus*) use CWD for navigational landmarks and travel routes (Barry and Francq 1980, Barnum et al. 1992). In the few studies that examined cotton rats and CWD, proximity to stumps and diameter of logs were important in predicting presence (Mengak and Guynn 2003).

The majority of studies evaluating the relationship between soricids (shrews) and CWD in the Pacific Northwest or central Appalachians showed a positive relationship between shrew abundance and CWD volume (McComb and Rumsey 1982, Carey and Johnson 1995, Ford et al. 1997, Loeb 1999). Studies conducted in the southeastern Coastal Plain have had mixed conclusions with regards to the importance of CWD to shrews. Some soricid species in the Southeast have been shown to be affected by the presence of CWD (Cromer et al. 2007, Davis et al. 2010), while no relationship has been demonstrated for others (McCay et al. 1998, McCay and Komoroski 2004).

Biomass Harvesting Guidelines

The Forest Stewardship Council and Sustainable Forestry Initiative certification systems were created in the early 1990s as a result of societal concerns about forestry and its impacts on the environment. These programs promote sustainable forest management by guiding economic, environmental and social components of forestry (Forestry Stewardship Council U.S. 2013, Sustainable Forestry Initiative 2013). The forest certification system standards were revised in 2010, and placed more emphasis on environmental components. However, the revisions did not address biomass harvesting.

Many stakeholder groups nationwide are lobbying for the development of BHGs to be added to existing Forestry Best Management Practices. Some states have already enacted BHGs. Michigan, for example, has BHGs that call for the retention of 1/6 to 1/3 of the harvestable biomass scattered throughout the harvested area (Michigan Department of Natural Resources and Environment 2010). In Wisconsin, BHGs set standards for 10% of fine woody debris retention but do not specify any retention strategies for CWD (Wisconsin Council on Forestry 2008). Missouri's BHGs do not specify any size or amount requirement for the retention of CWD, only stating that varying sizes of CWD should be left behind when conducting a biomass harvest (Evans et al. 2010, Missouri Department of Conservation 2010). None of the BHGs cite specific research to back guidelines.

The proposed creation of BHGs elucidated the problem that data needed to develop appropriate guidelines are lacking, including data on how biomass harvesting affects wildlife habitat (Titus et al. 2010). If BHGs are to be effective, additional information on biomass harvesting effects are necessary. Data on how increased woody debris removal affects invertebrate species, some of which use CWD as a source of moisture, refugia, and food, are currently lacking. Information regarding how society views biomass harvests is also a necessary component to developing and implementing BHGs. When these data are available, truly effective BHGs can be developed to protect, enhance, and improve the environment.

Literature Cited

Abbas, D., D. Current, M. Phillips, R. Rossman, H. Hoganson, and K. N. Brooks. 2011. Guidelines for harvesting forest biomass for energy: A synthesis of environmental considerations. Biomass and Bioenergy 35:4538-4546.

Barnum, S. A., C. J. Manville, J. R. Tester, and W. J. Carmen. 1992. Path selection by Peromyscus leucopus in the presence and absence of vegetative cover. Journal of Mammalogy 73:797-801.

Barry, R. E., Jr., and E. N. Francq. 1980. Orientation to landmarks within the preferred habitat by *Peromyscus leucopus*. Journal of Mammalogy 61:292-303.

Bowman, J. C., D. Sleep, G. J. Forbes, and M. Edwards. 2000. The association of small mammals with coarse woody debris at log and stand scales. Forest Ecology and Management 129:119-124.

Butts, S. R., and W. C. McComb. 2000. Associations of forest-floor vertebrates with coarse woody debris in managed forests of western Oregon. Journal of Wildlife Management 64:95-104.

Carey, A. B., and M. L. Johnson. 1995. Small mammals in managed, naturally young, and old-growth forests. Ecological Applications 5:336-352.

Cromer, R. B., C. A. Gresham, M. Goddard, J. D. Landham, and H. G. Hanlin. 2007. Associations between two bottomland hardwood forest shrew species and hurricane-generated woody debris. Southeastern Naturalist 6:235-246.

Currie, W. S., and K. J. Nadelhoffer. 2002. The imprint of land-use history: Patterns of carbon and nitrogen in downed woody debris at the harvard forest. Ecosystems 5:446-460.

Database of State Incentives for Renewable Energy [DSIRE]. 2013. Database of state incentives for renewables and efficiency homepage. <http://www. dsireusa.org>. Accessed 12 January 2013.

Davis, J. C., S. B. Castleberry, and J. C. Kilgo. 2010. Influence of coarse woody debris on the soricid community in southeastern Coastal Plain pine stands. Journal of Mammalogy 91:993-999.

Derrick, A. M., L. M. Conner, and S. B. Castleberry. 2010. Effects of prescribed fire and predator exclusion on refuge selection by *Peromyscus gossypinus* Le Conte (cotton mouse). Southeastern Naturalist 9:773-780.

Etcheverry, P., J. P. Ouellet, and M. Crete. 2005. Response of small mammals to clear-cutting and precommercial thinning in mixed forests of southeastern Quebec. Canadian Journal of Forest Research 35:2813-2822.

Evans, A. M., R. T. Perschel, and B. A. Kittler. 2010. Revised assessment of biomass harvesting and retention guidelines. Forest Guild, Santa Fe, NM.

Ford, W. M., J. Laerm, and K. G. Barker. 1997. Soricid response to forest stand age in southern Appalachian cove hardwood communities. Forest Ecology and Management 91:175-181.

Forest Stewardship Council. 2013. Our history. <https://us.fsc.org/our-history.180.htm.> Accessed 5 July 2013.

Harmon, M. E., J. F. Franklin, F. J. Swanson, P. Sollins, S. V. Gregory, J. D. Lattin, N. H. Anderson, S. P. Cline, N. G. Aumen, J. R. Sedell, G. W. Lienkaemper, K. Cromack, and K. W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research 15:133-302.

Hinkelman, T. M., and S. C. Loeb. 2007. Effect of woody debris abundance on daytime refuge use by cotton mice. Southeastern Naturalist 6:393-406.

Hinkelman, T. M., J. L. Orrock, and S. C. Loeb. 2012. Effect of downed woody debris on small mammal anti-predator behavior. Ethology 118:17-23.

Hunter, M. L. 1999. Maintaining biodiversity in forest ecosystems. Cambridge University Press, Cambridge, UK.

Janowiak, M. K. and C. R. Webster. 2010. Promoting ecological sustainability in woody biomass harvesting. Journal of Forestry 108:16-22

Lanham, J. D., D. C. Guynn, Jr. 1996. Influences of coarse woody debris on birds in southern forests. Pages 101-107 *in* J. W. McMinn, and D. A. Crossley, editors. Biodiversity and coarse woody debris in southern forests: proceedings of the workshop on coarse woody debris in southern forests. U.S. Forest Service General Technical Report SE-94, Washington, D.C., USA.

Loeb, S. C. 1996. The role of coarse woody debris in the ecology of southeastern mammals. Pages 108-118 *in* J. W. McMinn, and D. A. Crossley, editors. Biodiversity and coarse woody debris in southern forests: proceedings of the workshop on coarse woody debris in southern forests. U.S. Forest Service General Technical Report SE-94, Washington, D.C., USA.

Loeb, S. C. 1999. Responses of small mammals to coarse woody debris in a southeastern pine forest. Journal of Mammalogy 80:460-471.

Manning, J. A., and W. D. Edge. 2008. Small mammal responses to fine woody debris and forest fuel reduction in southwest Oregon. Journal of Wildlife Management 72:625-632.

McCay, T. S. 2000. Use of woody debris by cotton mice (*Peromyscus gossypinus*) in a southeastern pine forest. Journal of Mammalogy 81:527-535.

McCay, T. S., and M. J. Komoroski. 2004. Demographic responses of shrews to removal of coarse woody debris in a managed pine forest. Forest Ecology and Management 189:387-395.

McCay, T. S., J. Laerm, M. A. Menzel, and W. M. Ford. 1998. Methods used to survey shrews (Insectivora: Soricidae) and the importance of forest-floor structure. Brimleyana:110-119.

McComb, W. C., and R. L. Rumsey. 1982. Response of small mammals to forest clearings created by herbicides in the central Appalachians. Brimleyana 8:121-134.

McMinn, J. W., and D. A. Crossley. 1996. Preface. Page iii *in* J. W. McMinn, and D. A. Crossley, editors. Biodiversity and coarse woody debris in southern forests: proceedings of the workshop on coarse woody debris in southern forests. U.S. Forest Service General Technical Report SE-94, Washington, D.C., USA.

McMinn, J. W., and R. A. Hardt. 1996. Accumulation of coarse woody debris in southern forests. Pages 1-9 *in* J. W. McMinn, and D. A. Crossley, editors. Biodiversity and coarse woody debris in southern forests: proceedings of the workshop on coarse woody debris in southern forests. U.S. Forest Service General Technical Report SE-94, Washington, D.C., USA.

Mengak, M. T., and D. C. Guynn. 2003. Small mammal microhabitat use on young loblolly pine regeneration areas. Forest Ecology and Management 173:309-317.

Michigan Department of Natural Resources and Environment. 2010. Michigan woody biomass harvesting guidance. Technical document IC4069. Lansing, Michigan.

Missouri Department of Conservation. 2010. Missouri woody biomass harvesting. Best management practices manual. Jefferson City, Missouri.

Spies, T. A., and S. P. Cline. 1988. Coarse woody debris in forests and plantations of coastal Oregon. Pp. 5-24 *in* C. Maser, S. P. Cline, K. Cromack, Jr., J. M. Trappe, and E. Hansen, eds. From the forest to the sea: a story of fallen trees. United States Department of Agriculture Forest Service General Technical Report PNW-229:1-53.

Sullivan, T. P., D. S. Sullivan, P. M. F. Lindgren, D. B. Ransome, J. G. Bull, and C. Ristea. 2011. Bioenergy or biodiversity? Woody debris structures and maintenance of red-backed voles on clearcuts. Biomass and Bioenergy 35:4390-4398.

Sustainable Forestry Initiative. 2013. Basics of SFI. Accessed 5 July 2013.

Tallmon, D., and L. S. Mills. 1994. Use of logs within home ranges of California red-backed voles on a remnant of forest. Journal of Mammalogy 75:97-101.

Titus, B., T. Smith, D. Puddister and J. Richardson. 2010. The scientific foundation for sustainable forest biomass harvesting guidelines and policies. Forestry Chronicles. 86: 18–19.

U.S. Department of Agriculture [USDA] Forest Service. 2007. Phase 3 Field Guide – down woody material, Version 4.0. 40 Pp. <http://www.srs.fs.usda.gov/fia/manual/sections/Section%2014.0_1.61.pdf>. Accessed 12 January 2013.

Whiles, M. R., and J. W. Grubaugh. 1996. Importance of coarse woody debris to southern forest herpetofauna. Pages 94-100 *in* J. W. McMinn, and D. A. Crossley, editors. Biodiversity and coarse woody debris in southern forests: proceedings of the workshop on coarse woody debris in southern forests. U.S. Forest Service General Technical Report SE-94, Washington, D.C., USA.

Wisconsin Council on Forestry. 2008. Wisconsin's forestland woody biomass harvesting guidelines. <http://council.wisconsinforestry.org/biomass/pdf/BHG-FinalizedGuidelines12-16-08.pdf.> Accessed 1 April 2013.

Van Lear, D.H. 1996. Dynamics of coarse woody debris in southern forest ecosystems. Pages 10-17 *in* J. W. McMinn, and D. A. Crossley, editors. Biodiversity and coarse woody debris in southern forests proceedings of the workshop on coarse woody debris in southern forests. U.S. Forest Service General Technical Report SE-94, Washington, D.C., USA.

CHAPTER 2

RESPONSE OF SMALL MAMMALS TO VARIABLE RETENTION OF WOODY DEBRIS FOLLOWING BIOMASS HARVESTS IN THE SOUTHEAST[1]

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Abstract

Small mammal abundance has been linked to coarse woody debris (CWD) in many regions of the U.S. Woody biomass harvesting, where non-merchantable woody debris is harvested and used for energy production, may negatively affect small mammal abundance by reducing the amount of CWD. I examined the response of small mammals to variable CWD retention in loblolly pine (*Pinus taeda*) stands after biomass harvesting on 8 study sites in the Coastal Plain of Georgia (n=4) and North Carolina (n=4). Sites were divided into 6 treatment plots which were randomly assigned treatments representing varying levels of CWD retention and arrangement. Small mammals were captured from April-August, 2011 and 2012 using drift fence pitfall arrays and Sherman live traps. CWD volume and vegetation characteristics were measured in each treatment plot in 2012. I captured a total of 1,828 individuals of 10 species across both years and all study sites combined. There were no consistent relationships between small mammal captures and CWD volume. However, many species captures were related to vegetation metrics. My results suggest that biomass harvesting with current levels of debris retention has limited effect on small mammal abundance in the southeastern Coastal Plain in the first 2 years following harvest. In early successional stages following biomass harvest, vegetation composition and structure may be more important in determining small mammal abundance than CWD.

Key words: Coarse woody debris; small mammals; biomass harvest; vegetation; timber harvest

<u>Introduction</u>

Societal concerns about fossil fuel prices, finite supply and climate change related to the burning of fossil fuels are driving demand for sustainable energy production in the U.S. Recent legislation either provided incentives for using renewable transportation fuels, such as biodiesel, or required renewable power generation (Database of State Incentives for Renewable Energy 2013). Currently, 29 states have Renewable Portfolio Standards which require a portion of the retail electricity to come from renewable sources (Database of State Incentives for Renewable Energy 2013).

The demand for renewable energy sources in the U.S. has led to the utilization of woody residues, primarily coarse woody debris (CWD), left after timber harvest. Coarse woody debris is defined as dead trees and shrub boles, snags, large downed limbs, roots and other woody pieces that are separated from their original source of growth (Harmon et al. 1986, United States Department of Agriculture 2007). After harvest, woody residues are collected and co-fired with coal to create energy (United States Department of Agriculture 2008). The U.S. Forest Service outlined several benefits to woody biomass utilization, including its use for green energy production (United States Department of Agriculture 2008). However in this document, potential negative ecological affects are not addressed, largely due to a lack of research (Titus et al. 2010).

Woody biomass harvest could alter the typical "U-shaped timeline" demonstrated by woody debris abundance throughout the life of a managed stand (Harmon et al. 1986). Abundant downed CWD generated by harvesting activities is present in the stand immediately following traditional clearcut harvests. Early in the next stand rotation, existing debris decays and there is little debris naturally generated by growing trees. However, as the stand ages and trees senesce, debris is generated faster than it can decay which increases downed CWD abundance. Biomass harvesting removes the CWD generated during harvests which leaves only naturally generated debris that takes several years or decades to accumulate. This reduction in CWD may negatively impact wildlife populations (Harmon et al. 1986, Bunnell and Houde 2012).

Downed woody material is an important component of forest systems (Harmon et al. 1986). More than 32 small mammal species in the Southeast use CWD, and studies have shown that abundance of many small mammal species is directly correlated with CWD volume (Loeb 1999, Butts and McComb 2000, McCay 2000, Cromer et al. 2007, Davis et al. 2010). Small mammals use CWD as feeding sites, sources of moisture in times of drought, protection from predators and travel corridors (Barry and Francq 1980, Barnum et al. 1992, Tallmon and Mills 1994, Loeb 1996, Whiles and Grubaugh 1996). With the removal of CWD from harvested plantations, remaining CWD may become a limiting factor, negatively affecting small mammal abundance or survival. The limiting effect on small mammals may affect other aspects of the ecosystem because small mammals play an important role in seed dissemination, plant herbivory, and serve as prey items for many larger, charismatic species, such as coyotes, foxes, and raptors (Weltzin et al. 1997, Wilson and Ruff 1999).

Concerns about the impact of forestry on the environment have led to several policies and guidelines to ensure the sustainability of silvicultural practices. Forestry Best Management Practices (BMPs) were developed in response to the Federal Water Pollution Control Act of 1972 to prevent erosion and protect stream quality while harvesting timber and preparing sites for the next rotation (Aust and Blinn 2004). In addition to BMPs, the Forest Stewardship Council and the Sustainable Forestry Initiative certification systems were developed in the 1990s to address societal concerns about the forestry industry and its impact on other aspects of the environment. Many stakeholders concerned about the possible negative effects of biomass harvesting are now requesting the development of Biomass Harvesting Guidelines (BHGs) to be integrated into BMPs or the forestry certification systems. BHGs are meant to protect ecosystem services, including wildlife habitat, during and after woody biomass harvests.

Given the need for sustainable energy production and the potential for biomass harvesting to meet a portion of this need, I examined the effect of varying levels of CWD retention and arrangement (clustered versus dispersed) following timber harvest on small mammal abundance. I hypothesized that CWD retention levels beyond what is left in a traditional biomass harvest will result in greater small mammal abundance regardless of the arrangement. I also hypothesized that areas with dispersed CWD will yield a higher abundance of small mammal species that have been shown to use CWD as travel corridors (*Peromyscus* sp.) than in areas that received clustered CWD treatments (Barry and Francq 1980, Mengak and Guynn 2003). My results will provide a critical component of the information necessary for development and implementation of scientifically-based BHGs.

Methods

Study Areas

Eight study sites were selected in the Coastal Plain regions of Georgia and North Carolina, 4 in each state. All sites were loblolly pine (*Pinus taeda*) plantations in a matrix of managed stands in various successional stages. In North Carolina, stands were managed for sawtimber production and were between 32 and 39 years old at the time of harvest. Stands had received 2 thinnings during the rotation along with mid-rotation mechanical vegetation control. Georgia sites were managed for pulpwood and chip’n’saw and were between 25 and 33 years old at the time of harvest. Three of the 4 sites had been thinned.

Each study site was approximately 48 ha and each was divided into 6 treatment plots of approximately 8 ha. Under a randomized complete block design, 1 of 6 treatments was randomly assigned to each plot. Treatments were designed to vary in the amount and distribution of CWD retained following a clearcut timber harvest. Treatments included:

- Traditional clearcut harvest (NOBIOHARV) – Trees were delimbed and the remaining CWD was scattered throughout the plot.
- Biomass harvest with 30% retention clustered (30CLUS) – Approximately 30% of the harvestable biomass from the harvesting operations was piled at random locations on the plot.
- Biomass harvest with 30% retention dispersed (30DISP) – Approximately 30% of the harvestable biomass from the harvesting operations was scattered throughout the plot.
- Biomass harvest with 15% retention clustered (15CLUS) – Approximately 15% of the harvestable biomass from the harvesting operations was piled at random locations on the plot.
- Biomass harvest with 15% retention dispersed (15DISP) – Approximately 15% of the harvestable biomass from the harvesting operations was scattered throughout the plot.
- Biomass harvest with no BHGs (NOBHG) – As much of the remaining wood from the harvesting operations was removed as was economically and mechanically feasible.

Treatments were implemented in winter 2010-11 on the North Carolina replicates. All plots were sheared immediately following harvest. North Carolina replicates received a broadcast herbicide treatment in summer 2011 and a banded herbicide application in summer 2012 to control herbaceous and woody competition with planted seedlings. Mechanical site preparation in North Carolina consisted of shearing and leaving the debris in place, which created small rows of debris and altered the scattered debris treatments. All replicates were planted at 1.5 x 6.1 m spacing (1,077 trees/ha) in winter 2011 after bedding.

Treatments were implemented on 2 of the Georgia sites in winter 2010-11, which were available for sampling in summer 2011. Treatments were implemented on the remaining 2 sites in summer and fall of 2011. One of these was available for partial sampling during the 2011 field season. Three of the Georgia replicates received a banded herbicide treatment and one Georgia replicate received a broadcast herbicide treatment in spring 2012. Three Georgia sites were planted at 1.8 x 3.7 m spacing (1,495 trees/ha) and 1 site was planted at 1.5 x 3.7 m spacing (1,794 trees/ha). Mechanical site preparation activities in Georgia included shearing and piling of debris into windrows and spot piles creating large rows of debris and eliminating the scattered debris treatments. Instead of obtaining the 6 discrete treatments in the initial study design, treatment units within study sites represented a range of percent CWD retention.

Vertebrate Sampling

I captured small mammals using drift fence pitfall arrays and Sherman live traps. I sampled shrews using 3 drift fence pitfall arrays placed in each of the treatment plots. Arrays had 3 7.6-m arms spaced approximately 120 degrees apart (Figure 2.1). Array arms were constructed of 91-cm high silt fence buried 10-cm into the soil. I buried a 19-l bucket with the top flush to the ground at the outer ends of the arms. In the buckets, I drilled small holes in the bottom to prevent flooding and, put approximately 5 cm of soil in the bottom, a wet sponge, and shade board to prevent animals from desiccating. A modified snake trap design (Burgdorf et al. 2005) to accommodate a 3-armed array was installed in the center of one randomly selected drift fence array. The remaining two drift fence arrays had a 19-l pitfall trap in the center.

I opened drift fence arrays for three primary 10-day sampling periods from April to August 2011 at the North Carolina replicates. I also opened some arrays for shorter secondary sampling periods throughout this time period to accommodate a concurrent study on the sites. In Georgia, I opened drift fence arrays for three 10-day sampling periods with no additional sampling periods on the two replicates sampled in 2011.

Additionally, I sampled small mammals using Sherman live traps on 3 Georgia replicates and all North Carolina replicates in 2011 and all replicates in Georgia and North Carolina in 2012. I sampled each treatment plot within a replicate simultaneously using 50 Sherman traps spaced 15-m apart in a 5 x 10 grid arrangement. Grids were located as centrally as possible in treatment plots and, if plot shape permitted, 50-m away from the treatment edge. I baited each trap with oatmeal daily. I opened traps for 5 consecutive nights, 3 times/replicate between April and August of 2011 and 2012. Each morning, I checked traps before 1000 hrs to limit trap mortality from heat. I identified (to genus for *Peromyscus*), weighed, sexed, and aged each captured individual. I also determined reproductive status when possible and placed a uniquely numbered ear in the right ear of all captures.

CWD Quantification

I estimated volume of CWD pre-harvest and each year post-harvest in North Carolina and second year post-harvest in Georgia using a line intersect technique (United States Department of Agriculture 2007). I identified 9 sampling points distributed throughout each treatment area using a systematic sampling grid and painted a 7.32-m transect line at 0^0, 120^0 and 240^0 azimuths at each sample point. Along the azimuths, I measured (length and diameter at each end) all CWD ($\geq$ 7.62 cm diameter) that intersected the 7.32 m transects. I also measured fine woody debris (FWD; 2.54 - 7.61 cm at the point of intersection) along the last 3.04 m of the

7.32-m transects. In addition, I measured any woody debris measuring 0.91 m or longer that intersected any of the three transects. I assigned each piece of woody debris a decay class using the Forest Inventory and Analysis (FIA) Protocol (United States Department of Agriculture 2007).

I also measured CWD piles created during treatment implementation and site preparation. Because of the differences in treatment implementation and site preparation between the Georgia and North Carolina sites, I quantified the woody debris piles differently in the 2 states. In North Carolina, woody debris piles were created from site preparation activities resulting in numerous small rows. I included piles with centers within 7.32 m of the sampling point and containing CWD. I recorded height, width, and length of piles with respect to each shape code in the FIA protocol (United States Department of Agriculture 2007). To better estimate the amount of CWD on sites, I measured the length, width, height, and packing ratio (i.e., woody debris versus soil and air) of every large pile or cluster. For the large windrows and spot piles created from site preparation activities in Georgia, I measured height of each windrow and pile at 50-m intervals along the row. I measured length and width in ArcMap 10 (Esri, Redlands, CA) using the spatial analyst tool and aerial imagery. I assumed all windrows and piles were shape code 2 from the FIA protocol (United States Department of Agriculture 2007). I also estimated packing ratio of woody debris in windrows at each 50-m interval. These data were combined with the line intersect data to estimate volume of woody debris in the treatment units.

Vegetation Sampling

I conducted vegetation sampling in Georgia and North Carolina in 2012 at the same 9 sampling points used for CWD sampling in each treatment unit. I established 10-m transects placed 120 degrees apart starting at the sampling point. At 1-m intervals along the transects, I estimated percent cover (ground cover) of woody stems, woody vines, herbaceous vines, forbs, fern, switchcane (*Arundinaria gigantea*), grass, bare ground, woody debris (twigs, sticks), and litter (leaves, pine needles). From these data, I calculated mean percent of each ground cover category for each treatment unit at each study site.

Statistical Analysis

I standardized small mammal captures as captures/100 trap nights for each treatment unit across all sampling periods in each year. I analyzed captures separately by capture method (Sherman or pitfall) and year. Also, I omitted drift fence data from Georgia due to low captures, and analyzed captures separately for each state because of differences in treatment implementation and CWD volumes. Although the original study design was a randomized complete block design with discrete treatments, treatment implementation resulted in a range of CWD retention values across treatment plots. Therefore, regression analyses were more appropriate than analysis of variance. Because vegetation data were not collected in 2011, I used simple linear regression to examine the relationship between the standardized total captures (not including recaptures) and CWD volume across treatment plots for both states. I also used simple linear regression to examine the relationships between CWD volume and individual species with >30 captures/year.

For 2012 data, I created a priori models to examine the effect of CWD volume and vegetation characteristics on small mammal captures (total captures and species with >30 captures/year) using multiple regression. Models were ranked using Akaike's Information Criterion adjusted for small sample size (AIC_c) and model weights (w_i; Burnham and Anderson 2002). I developed a set of models separately for each of 3 data sets (Georgia Sherman trap captures, North Carolina Sherman trap captures, North Carolina drift fence captures). For North

Carolina, I developed models for total captures in Sherman traps and drift fence arrays, deer mouse captures in Sherman traps and drift fence arrays, and southeastern shrew, least shrew and eastern harvest mouse captures in drift fence arrays. For Georgia, I developed models only for deer mouse captures because deer mice accounted for 86% of total captures. Models for total small mammal captures consisted of all possible combinations of CWD volume and habitat variables because of the wide range of habitat preferences of the captured species. I created separate models for species with >30 captures using select combinations of variables, along with a global and null model. Models were based on known habitat associations of individual species. I defined the confidence set as models within $\Delta AIC \leq 2$ of the top model. To incorporate model selection uncertainty into models with similar AIC values, I calculated model-averaged parameter estimates for the models accounting for 90% of the total weight of captures (Arnold 2010).

Results

I recorded a total of 25,728 Sherman trap nights on all replicates in 2011 and 33,986 in 2012. I opened drift fence arrays in North Carolina a total of 11,997 trap nights in 2011 and 9,466 trap nights in 2012. In North Carolina, I captured 11 species, including deer mouse (*Peromyscus* spp.; n =705), house mouse (*Mus musculus*; n =228), eastern harvest mouse (*Reithrodontomys humilis*; n =116), golden mouse (*Ochrotomys nuttalli*; n =1), hispid cotton rat (*Sigmodon hispidus*; n =16), marsh rice rat (*Oryzomys palustris*; n =5), southern short-tailed shrew (*Blarina carolinensis*; n =28), southeastern shrew (*Sorex longirostris*; n =269), least shrew (*Cryptotis parva*; n =64), woodland vole (*Microtus pinetorum*; n =15), and eastern cottontail (*Sylvilagus floridanus*; n =7). In Georgia, I only captured deer mice (n =338), hispid cotton rats (n =32) and eastern harvest mice (n =4). Sherman trap captures showed a decreasing trend during the second year of sampling in both states (Table 2.1). Drift fence arrays in North Carolina captured more species and had higher capture rates in 2012 than 2011 (Table 2.2).

In 2011, analyses only included standardized small mammal captures and CWD volume. North Carolina had considerably less CWD volume than Georgia across all treatment units (Table 2.3; Appendix 1). In North Carolina, total Sherman trap captures (R^2 = 0.08, *d.f.* = 1, 22, P = 0.178), Sherman trap captures of deer mice (R^2 = 0.05, *d.f.* = 1, 22, P =0.296), and Sherman trap captures of house mice (R^2 = 0.04, *d.f.* = 1, 22, P = 0.373) were not related to CWD volume. Total drift fence captures (R^2 = 0.02, *d.f.* = 1, 22, P = 0.517), and drift fence captures of deer mice (R^2 = 0.07, *d.f.* = 1, 22, P = 0.228), southeastern shrews (R^2 = 0.10, *d.f.* = 1, 22, P = 0.127), eastern harvest mice (R^2 = 0.001, *d.f.* = 1, 22, P=0.86), and house mice (R^2 = 0.08, *d.f.* = 1, 22, P = 0.187) also were not related to CWD volume Similarly, in Georgia, deer mouse captures (R^2 = 0.01, *d.f.* =1, 16, P = 0.699) were not related to CWD volume.

Mean percent of most ground cover categories included in 2012 models was greater in Georgia for most treatment units than in North Carolina (Table 2.4; Appendix 2). The confidence set for total North Carolina Sherman trap captures ($\Delta AIC_c < 2$, Table 2.5) included 3 models, Woody Vines (R^2 = 0.18, *d.f.* = 1, 22, P = 0.039), CWD Volume (R^2 = 0.14, *d.f.* = 1, 22, P = 0.074), and Woody Vines + CWD Volume (R^2 = 0.22, *d.f.* = 2, 21, P = 0.069). Model-averaged parameter estimates indicated that percent woody vines was an informative parameter by the exclusion of zero in the 90% confidence interval (Table 2.6). The confidence set for Sherman trap deer mouse captures included Woody Vines (R^2 = 0.15, *d.f.* = 1, 22, P = 0.063), the null model and Woody Vines + Woody Stems (R^2 = 0.20, *d.f.* = 2, 21, P = 0.095). Only the parameter estimate for percent woody vines had 90% confidence intervals that did not include zero. Grass + Woody Vines (R^2 = 0.56, *d.f.* = 2, 21, P < 0.001) and Woody Vines (R^2 = 0.49, *d.f.*

= 1, 22, $P < 0.001$) were in the confidence set for total drift fence captures with percent grass and woody vines cover were informative parameters by the exclusion of zero in the 90% confidence interval. Deer mouse drift fence captures included the null model, Woody Vines ($R^2 = 0.09$, *d.f.* = 1, 22, $P = 0.149$), and Woody Stems ($R^2 = 0.04$, *d.f.* = 1, 22, $P = 0.373$) in the confidence set, with no confidence intervals of parameter estimates excluding zero. Southeastern shrew capture data only had the Forbs model ($R^2 = 0.37$, *d.f.* = 1, 22, $P < 0.001$) in the confidence set. The model-averaged parameter estimate for percent forbs did not include zero in the 90% confidence interval. Grass was the lone model in the confidence set for least shrew captures and the parameter estimate for percent grass cover did not include zero in the 90% confidence interval. Least shrew captures and Grass were significantly related ($R^2 = 0.31$, *d.f.* = 1, 22, $P = 0.005$). The null model was the only model in the confidence set for eastern harvest mouse captures indicating that no model containing parameters was informative in predicting captures.

In Georgia, the confidence set for deer mouse Sherman trap captures included the null model and the woody stem model ($R^2 = 0.09$, *d.f.* = 1, 22, $P = 0.161$; Table 2.7). The model-averaged parameter estimate for percent cover of woody stems had 90% confidence intervals that included zero.

Discussion

My results suggest that CWD volume did not influence captures of most small mammal species on my sites, which was contrary to my hypothesis and many studies in the Southeast, but supported findings of other studies, particularly those conducted in standing forests (Osbourne and Anderson 2002, Moseley et al. 2008). For example, Loeb (1999) found abundance of small mammals in a pine forest to be greater in plots with abundant tornado-generated CWD than in similar plots where CWD was removed. I believe my contradictory findings are due to the harvest on my sites as opposed to the standing forests in which these other studies were conducted.

The lack of relationship between CWD volume and southeastern shrew captures may be explained by the early stage of decay of the CWD on my sites. The decay state of CWD is thought to be important to shrew captures due to abundant invertebrate prey supported by the decaying wood which may account for the increase in captures during my second year of trapping (Davis et al. 2010). Moseley et al. (2008) similarly found little correlation between CWD and southeastern shrews when CWD was in early stages of decay, while Davis et al. (2010) found abundance of southeastern shrews to be greater in plots where CWD was added several years prior than in control plots and plots with CWD removed. As CWD decays further on my sites, shrew captures can be expected to increase.

Small mammal abundance typically increases following timber harvest, because of the abundant herbaceous and low woody vegetation that establishes after the disturbance (Atkeson and Johnson 1979, Kirkland 1990, Constantine et al. 2004). CWD may not be a critical habitat component for the species captured if early successional vegetation is present to fulfill shelter and food requirements. Small mammal species richness and abundance has been shown to correspond with succession (Foster and Gaines 1991). Small mammals colonize areas after a disturbance to take advantage of the abundant resources offered by early successional vegetation (Atkeson and Johnson 1979, Foster and Gaines 1991).

Site preparation on the Georgia study areas consisted of windrowing harvest residues whereas North Carolina sites had small rows of sheared debris, which may affect small mammal abundance differently. To date, studies examining the effect of windrows on small mammals in the Southeast are lacking. In British Columbia, Sullivan et al. (2012) found that more small mammals were captured in areas with windrows than in areas with dispersed debris or in standing forests. Therefore, if small mammals responded to windrow presence in Georgia, I was not able to detect the change in abundance given my study design. More research is warranted to determine effects of windrows in the Southeast on small mammal populations.

Although the study design dictated the same treatment implementation at both sites, Georgia sites contained much greater CWD volume on all treatments than North Carolina sites. The apparent variation of CWD volume of treatments between the states was likely due to the windrowing of material in Georgia. In a study examining the composition of windrows in North Florida, Morris et al. (1983) determined that there was 10-times more soil in windrows than woody debris. The volume of CWD could have been inflated because I measured the outside dimensions and assumed the packing ratio was uniform throughout the windrows, which may not have been accurate. It is possible that the correct amount of debris remained on the Georgia sites after harvest but it is impossible to quantify without dissecting the windrows to determine the proportions of CWD and soil present in the windrows.

Although I found no significant relationships between small mammal abundance and CWD volume, abundance of some species was related to vegetation metrics. Deer mouse captures were positively related with woody vine coverage. Woody vines may be an important structural component of deer mouse habitat because it creates higher structural complexity in areas that presumably offer greater protection from predators (Manson and Stiles 1995). Contradictory to findings of some previous studies, I found deer mouse captures to be negatively related to woody stems, Mengak and Guynn (2003) found captures of deer mice to be positively correlated with areas of greater woody structure in pine regeneration areas. Similarly, Dueser and Shugart (1978) found deer mice captures to be greater in areas with high woody stem density than in other types of vegetation in forests of Tennessee. Captures of eastern harvest mice were the lowest among the species for which models were developed and it is possible that there were not enough captures to establish relationships with the measured variables or no relationship existed.

Captures of two shrew species were affected more by herbaceous cover than by CWD volume. Percent cover of forbs was the best indicator of southeastern shrew captures. Positive relationships between forbs and other *Sorex* species have been documented in recent clearcuts in the Pacific Northwest, presumably due to the invertebrates supported by forbs (Morrison and Anthony 1989). Least shrews exhibited a positive relationship with percent grass cover. The morphological characteristics of least shrews are similar to other fossorial mammals but least shrews spend more time above ground than most other shrews and often are associated with grassy and old-field habitats (Bellows et al. 2001). The lack of relationship between CWD volume and least shrews has been documented previously and has been attributed to their possible historical exclusion from forested habitats by other competing shrews. Therefore, least shrews may have evolved without CWD as a critical habitat component (Moseley et al. 2008, Davis et al. 2010).

Sherman trap captures decreased in North Carolina and Georgia from 2011 to 2012, possibly because of the reduction in vegetation following site preparation herbicide applications. Herbicide application has been shown to reduce small mammal populations during the year of initial treatment, but abundance typically recovers 1 year post-treatment (O'Connell and Miller

1994, Miller and Miller 2004). Method of herbicide application has also been shown to have varying effects on small mammals (Lane 2010).

Conclusions and Management Recommendations

Biomass harvesting appeared to have little effect on small mammal abundance on my study areas. CWD volumes similar to or well above (>100 m^3/ha) other manipulative studies remained on all treatment plots, which may have been enough to support small mammal communities. It is also possible that early successional vegetation provided the resources necessary to support small mammal communities, making retained CWD a less critical habitat component for small mammals. Additionally, my results suggest that either clustered or dispersed arrangements of CWD after a biomass harvest can be used without negatively affecting small mammal communities. Further research is needed to examine differences in the plant communities in response to biomass harvesting, which may have an effect on granivorous and herbivorous small mammals. In addition, research in other physiographic regions and additional taxa are needed to fully elucidate the effects of biomass harvesting.

Literature Cited

Adler, G. H. 1985. Habitat selection and species interactions: an experimental analysis with small mammal populations. Oikos 45:380-390.

Anderson, P. K. 1986. Foraging range in mice and voles: the role of risk. American Journal of Zoology 64: 2645-2653

Arnold, T. W. 2010. Uninformative parameters and model selection using Akaike's Information Criterion. The Journal of Wildlife Management 74:1175-1178.

Atkeson, T. D. and A. S. Johnson. 1979. Succession of small mammals on pine plantations in the Georgia USA Piedmont. American Midland Naturalist 101:385-392.

Aust, W. M., and C. R. Blinn. 2004. Forestry best management practices for timber harvesting and site preparation in the eastern United States: an overview of water quality and productivity research during the past 20 years (1982-2002). Water, Air, and Soil Pollution: Focus 4:5-36.

Barry, R. E., Jr., and E. N. Francq. 1980. Orientation to landmarks within the preferred habitat by Peromyscus leucopus. Journal of Mammalogy 61:292-303.

Bellows, A. S., J. F. Pagels, and J. C. Mitchell. 2001. Macrohabitat and microhabitat affinities of small mammals in a fragmented landscape on the upper Coastal Plain of Virginia. American Midland Naturalist 146:345–360.

Bellows, A. S., J.F. Pagels, and J. C. Mitchell. 2001. Plant community composition and small mammal communities in old fields on Virginia's Coastal Plain. Journal of the Elisha Mitchell Scientific Society 117:101-112.

Brown, J. P. and B. P. Kotler. 2004. Hazardous duty pay and the foraging cost of predation. Ecology Letters 7:999-1014.

Bunnell, F. L. and I. Houde. 2012. Down wood and biodiversity- implications to forest practices. Environmental Reviews 18:397-421.

Burgdorf, S. J., D. C. Rudolph, R. N. Conner, D. Saenz, and R. R. Schaefer. 2005. A successful trap design for capturing large terrestrial snakes. Herpetological Review 36:421-424.

Burnham, K.P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretical approach. Second edition. Springer-Verlag. New York, New York, USA.

Butts, S. R., and W. C. McComb. 2000. Associations of forest-floor vertebrates with coarse woody debris in managed forests of western Oregon. Journal of Wildlife Management 64:95-104.

Constantine, N. L., T. A. Campbell, W. M. Baughman, T. B. Harrington, K. V. Miller. 2004. Effects of clearcutting with corridor retention on abundance, richness, and diversity of small mammals in the Coastal Plain of South Carolina, USA. Forest Ecology and Management 202:293-300.

Cromer, R. B., C. A. Gresham, M. Goddard, J. D. Landham, and H. G. Hanlin. 2007. Associations between two bottomland hardwood forest shrew species and hurricane-generated woody debris. Southeastern Naturalist 6:235-246.

Davis, J. C., S. B. Castleberry, and J. C. Kilgo. 2010. Influence of coarse woody debris on the soricid community in southeastern Coastal Plain pine stands. Journal of Mammalogy 91:993-999.

Database of State Incentives for Renewable Energy [DSIRE]. 2013. Database of state incentives for renewables and efficiency homepage. <http://www. dsireusa.org>. Accessed 12 January 2013.

Dolan, J. D., and R. K. Rose. 2007. Depauperate small mammal communities in managed pine plantations in eastern Virginia. Virginia Journal of Science 58:147-163.

Dueser, R. D., and H. H. Shugart. 1978. Microhabitats in a forest-floor small mammal fauna. Ecology 59:89-98.

Feldhamer, G. A., D. B. Lesmeister, J. C. Devine, and D. I. Stetson. 2012. Golden mice (*Ochrotoys nuttalli*) co-occurrence with *Peromyscus* and the abundant-center hypothesis. Journal of Mammology 93:1042-1050

Harmon, M. E., J. F. Franklin, F. J. Swanson, P. Sollins, S. V. Gregory, J. D. Lattin, N. H. Anderson, S. P. Cline, N. G. Aumen, J. R. Sedell, G. W. Lienkaemper, K. Cromack, and K. W. Cummins. 1986. Ecology of Coarse Woody Debris in Temperate Ecosystems. Advances in Ecological Research 15:133-302.

Healy, W. M., and R. T. Brooks. 1988. Small mammal abundance in northern hardwood stands in West Virginia. Journal of Wildlife Management 52:491-496.

Hunter, M. L. 1999. Maintaining biodiversity in forest ecosystems. Cambridge University Press, Cambridge, UK.

Kirkland Jr., G. L. 1990. Patterns of initial small mammal community change after clearcutting of temperate North American forests. Oikos 59:313-320.

Lane, V. R. 2012. Plant, small mammal, and bird community responses to a gradient of site preparation intensities in pine plantations in the coastal plain of North Carolina. Dissertation. University of Georgia. Athens, Georgia, USA.

Layne, J. N. 1970. Climbing behavior of *Peromyscus floridanus* and *Peromyscus gossypinus*. Journal of Mammalogy 51:580-591

Lanham, J. D., D. C. Guynn, Jr. 1996. Influences of coarse woody debris on birds in southern forests. Pages 101-107 *in* J. W. McMinn, and D. A. Crossley, editors. Biodiversity and coarse woody debris in southern forests: proceedings of the workshop on coarse woody debris in southern forests. U.S. Forest Service General Technical Report SE-94, Washington, D.C., USA.

Loeb, S. C. 1996. The role of coarse woody debris in the ecology of southeastern mammals. Pages 108-118 *in* J. W. McMinn, and D. A. Crossley, editors. Biodiversity and coarse woody debris in southern forests: proceedings of the workshop on coarse woody debris in southern forests. U.S. Forest Service General Technical Report SE-94, Washington, D.C., USA.

Loeb, S. C. 1999. Responses of small mammals to coarse woody debris in a southeastern pine forest. Journal of Mammalogy 80:460-471.

Manson, R. H. and E. W. Stiles. 1998. Links between microhabitat preferences and seed predation by small mammals in old fields. Oikos 82:37-50.

Manson, R. H., R. S. Ostfeld, and C. D. Canham. 1999. Responses of a small mammal community to heterogeneity along forest-old-field edges. Landscape Ecology 14:355-367.

McCay, T. S. 2000. Use of woody debris by cotton mice (*Peromyscus gossypinus*) in a southeastern pine forest. Journal of Mammalogy 81:527-535.

McMinn, J. W., and R. A. Hardt. 1996. Accumulation of coarse woody debris in southern forests. Pages 1-9 in J. W. McMinn, and D. A. Crossley, editors. Biodiversity and coarse woody debris in southern forests: proceedings of the workshop on coarse woody debris in southern forests. U.S. Forest Service General Technical Report SE-94, Washington, D.C., USA.

Mengak, M. T. and D. C. Guynn. 2003. Small mammal microhabitat use on young loblolly pine regeneration areas. Forest Ecology and Management 173:309-317.

Miller, K. V., and J. H. Miller. 2004. Forestry herbicide influences on biodiversity and wildlife habitat in southern forests. Wildlife Society Bulletin 32:1049-1060.

Morris, L. A., W. L. Pritchett, and B. F. Swindel. 1983. Displacement of nutrients into windrows during site preparation of a flatwood forest. Soil Science Society of America Journal 47:591-594.

Morrison, M. L., and R. G. Anthony. 1989. Habitat use on early-growth clear-cuttings in western Oregon. Canadian Journal of Zoology 67:805-811.

Moseley, K. R., A. K. Owens, S. B. Castleberry, W. M. Ford, J. C.Kilgo, and T. S. McCay. 2008. Soricid response to coarse woody debris manipulations in Coastal Plain loblolly pine forests. Forest Ecology and Management 255:2306–2311.

O'Connell, W. E., and K. V. Miller. 1994. Site preparation influences on vegetative composition and avian and small mammal communities in the South Carolina upper Coastal Plain. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 48:321-330.

Osbourne J. D., and J. T. Anderson. 2002. Small mammal response to coarse woody debris in the central Appalachians. Proceedings of the Annual Conference of Fish and Wildlife Agencies 56:198-209.

Sullivan, T. P., D. S. Sullivan, P. M. F. Lindgren, and D. B. Ransome. 2012. If we build habitat, will they come? Woody debris structures and conservation of forest mammals. Journal of Mammalogy 93:1456-1468.

Sullivan, T. P., D. S. Sullivan, P. M. F. Lindgren, D. B. Ransome, J. G. Bull, and C. Ristea. 2011. Bioenergy or biodiversity? Woody debris structures and maintenance of red-backed voles on clearcuts. Biomass and Bioenergy. 10:4390-4398

Titus, B., T. Smith, D. Puddister and J. Richardson. 2010. The scientific foundation for sustainable forest biomass harvesting guidelines and policies. Forestry Chronicles. 86: 18–19.

U.S. Department of Agriculture [USDA] Forest Service. 2007. Phase 3 Field Guide –

down woody material, Version 4.0. 40 Pp. <http://www.srs.fs.usda.gov/fia/manual/sections/Section%2014.0_1.61.pdf>. Accessed 12 January 2013.

U.S. Department of Agriculture [USDA] Forest Service. 2008. Woody biomass utilization: benefits. <http://www.fs.fed.us/woodybiomass/benefits.shtml>. Accessed 12 January 2013

U.S. Department of Agriculture [USDA] Forest Service. 2008. Woody biomass utilization: what is woody biomass utilization. <http://www.fs.fed.us/woodybiomass/whatis.shtml>. Accessed 12 January 2013

Verdolin, J. L. 2006. Meta-analysis of foraging and predation risk trade-offs in terrestrial ecosystems. Behavioral Ecology and Sociobiology 60:457-464.

Wagner, D. M., G. A. Feldhamer, and J. A. Newman. 2000. Microhabitat selection by golden mice (*Ochrotomys nuttalli*) at arboreal nest sites. American Midland Naturalist 144:220-225.

Weltzin, J. F., S. Archer, and R. K. Heitschmidt. 1997. Small-mammal regulation of vegetation structure in a temperate savanna. Ecology 78:751-763.

Whiles, M. R., and J. W. Grubaugh, 1996. Importance of coarse woody debris to southern forest herpetofauna. Pages 94-100 *in* J. W. McMinn, and D. A. Crossley, editors. Biodiversity and coarse woody debris in southern forests: proceedings of the workshop on coarse woody debris in southern forests. U.S. Forest Service General Technical Report SE-94, Washington, D.C., USA.

Wilson, D. E., and S. Ruff, editors. 1999. The Smithsonian Book of North American Mammals. Smithsonian Institution Press, Washington D.C., USA.

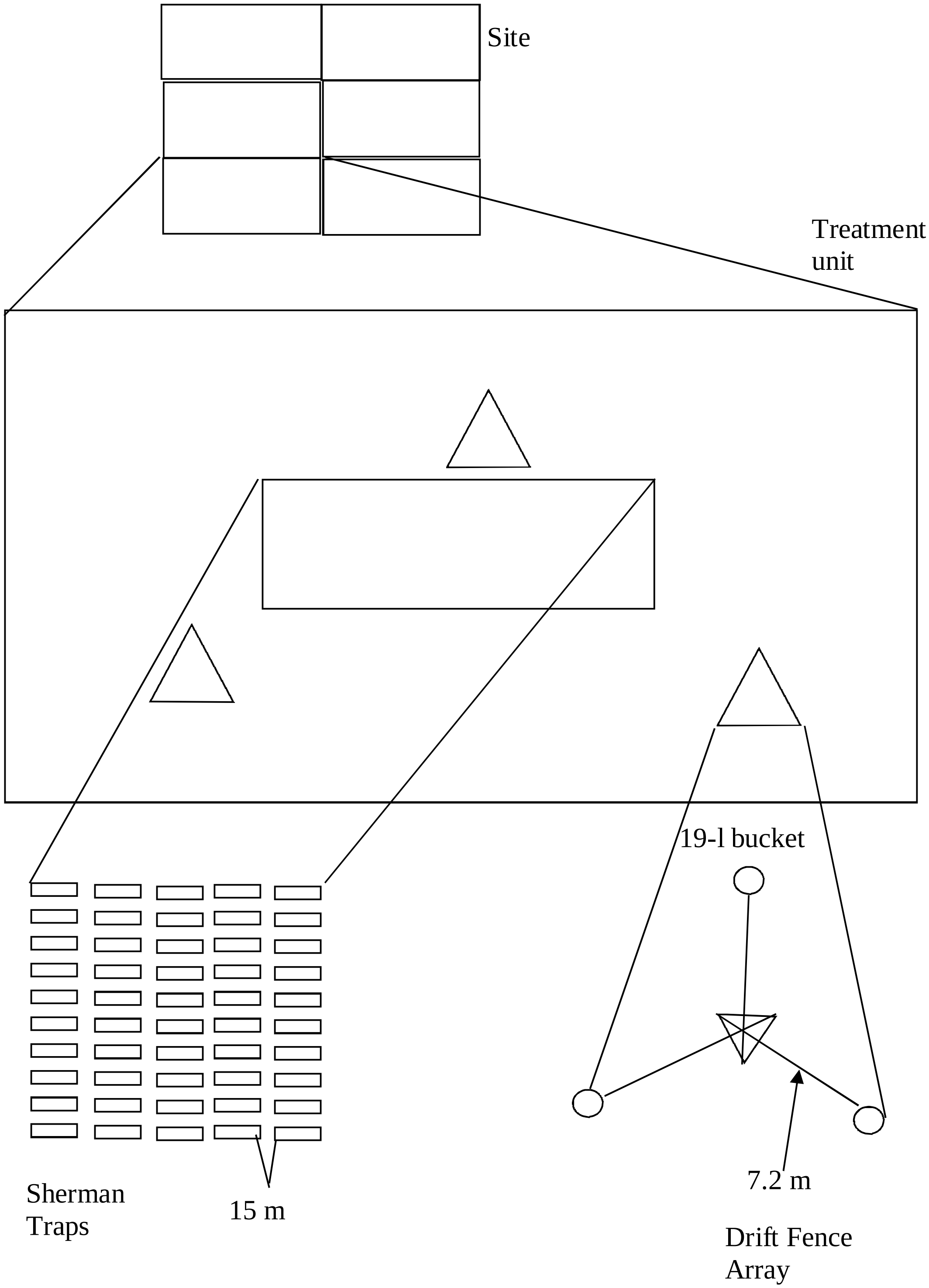

Figure 2.1: Sherman live trap and drift fence array layout used to sample small mammals in harvested loblolly pine (*Pinus taeda*) stands in the Coastal Plain of North Carolina and Georgia, 2011-2012.

Table 2.1: Sherman live trap captures/100 trap nights by year and species on harvested loblolly pine (*Pinus taeda*) stands in the Coastal Plain of Georgia and North Carolina, 2011-2012.

	Georgia		North Carolina	
Species	2011	2012	2011	2012
Mus musculus	-	-	1.12	0.16
Oryzomys palustris	-	-	-	0.03
Peromyscus spp.	1.73	0.70	1.79	2.08
Reithrodontomys humilis	0.01	0.01	0.09	0.04
Sigmodon hispidus	0.09	0.11	0.04	0.04
Sylvilagus floridanus	-	-	0.01	0.01
Total	1.83	0.82	3.05	2.36

Table 2.2: Drift fence array captures/100 trap nights by year and species on harvested loblolly pine (*Pinus taeda*) stands in the Coastal Plain of North Carolina, 2011-2012.

Species	2011	2012
Blarina carolinensis	0.09	0.18
Cryptotis parva	0.05	0.61
Microtus pinetorum	0.10	0.03
Mus musculus	0.32	0.11
Ochrotomys nuttalli	-	0.01
Peromyscus spp.	0.45	0.77
Reithrodontomys humilis	0.48	0.40
Sigmodon hispidus	0.01	0.02
Sorex longirostris	0.28	2.49
Sylvilagus floridanus	0.01	0.03
Total	1.79	4.65

Table 2.3: Mean woody debris volume (m^3/ha) (± SE) among coarse woody debris retention treatments following harvest of loblolly pine (*Pinus taeda*) stands in the Coastal Plain of North Carolina and Georgia, 2011-2012.

State	NOBIOHARV[1]	30CLUS	30DISP	15CLUS	15DISP	NOBHG
North Carolina	108.2 (17.4)	55.2 (8.6)	55.7 (10.8)	37.8 (8.2)	40.8 (11.4)	20.6 (1.5)
Georgia	497.2 (49.4)	463.8 (101.7)	409.6 (69.9)	375.2 (86.5)	468.3 (88.0)	432.2 (74.3)

[1]NOHARV = traditional clearcut harvest, 30CLUS = biomass harvest with 30% clustered CWD retention, 30DISP = biomass harvest with 30% dispersed CWD retention, 15CLUS = biomass harvest with 15% clustered CWD retention, 15DISP = biomass harvest with 15% dispersed CWD retention, NOBHGS = biomass harvest with no BHGs

Table 2.4: Mean percent (±SE) cover of vegetation type categories among coarse woody debris retention treatments following harvest on loblolly pine (*Pinus taeda*) stands in the Coastal Plains of North Carolina and Georgia, 2012.

State	NOBIOHARV	30CLUS	30DISP	15CLUS	15DISP	NOBHG
North Carolina						
Woody stem	1.7 (0.3)	1.2 (0.2)	2.2 (0.3)	1.1 (0.2)	1.1 (0.3)	0.9 (0.3)
Woody vine	4.5 (1)	3.2 (1.2)	4.4 (1.6)	2.7 (0.8)	1.7 (0.7)	4.4 (1.1)
Herbaceous vine	-	-	-	-	-	-
Forbs	5.1 (1.5)	5.7 (1.7)	5.3 (1.1)	3.3 (1.4)	4.4 (1.4)	5.7 (1.5)
Grass	6.1 (1.5)	7.6 (2.0)	11.6 (3.0)	6.9 (1.1)	7.5 (2.8)	9.1 (4.0)
Cane	0.5 (0.4)	2.3 (1.3)	2.6 (1.8)	3.2 (2.0)	4.3 (3.3)	0.6 (0.4)
Bare	47.7 (4.5)	49.8 (1.4)	48.0 (3.7)	52.5 (1.6)	50.0 (4.1)	53.0 (3.2)
Woody debris	12.6 (1.1)	10.6 (0.6)	12.1 (0.9)	8.8 (0.4)	9.1 (1.5)	8.7 (1.2)
Litter	27.5 (2.2)	22.1 (3.9)	19.2 (1.6)	21.9 (2.3)	23.2 (3.6)	21.4 (3.3)
Georgia						
Woody stem	5.7 (1.7)	9.3 (2.4)	11.9 (4.6)	9.6 (3.1)	9.1 (2.7)	6.9 (1.8)
Woody vine	5.5 (1.1)	4.5 (0.9)	5 (1.5)	8.8 (2.5)	4.3 (0.5)	11.3 (4)
Herbaceous vine	0	0.3 (0.2)	0.9 (0.4)	0.3 (0.2)	1 (0.7)	0.6 (0.5)
Forbs	14.6 (3.1)	17.1 (2.3)	15.4 (3.3)	11.2 (1)	12 (2.8)	10.9 (1.9)
Grass	27.7 (4.5)	35.5 (4.1)	29.6 (2.7)	30.4 (5.1)	29.5 (4.4)	29.8 (4.3)
Cane	-	-	-	-	-	-
Bare	41.3 (9.3)	28.7 (7.7)	31.8 (10)	32.5 (5.4)	37.1 (9.8)	32.8 (5.3)
Woody debris	1.9 (0.5)	1.6 (0.9)	1.0 (0.5)	1.5 (0.6)	2.5 (0.9)	1.8 (0.5)
Litter	2.7 (0.9)	2.4 (0.4)	3.9 (0.7)	3.9 (0.7)	3.5 (1.1)	5.4 (1.6)

Table 2.5: Models in the confidence set ($2 > \Delta AIC_c$), number of parameters in the model (*K*), Akaike's information criterion adjusted for small sample size (AIC_c), AIC_c difference between a model and the model with the lowest AIC_c (ΔAIC_c), and weights (w_i) of models used to examine relationships between small mammal captures and habitat variables in the Coastal Plain of North Carolina, 2012.

Model	*K*	AICc	ΔAICc	w_i
Sherman total captures				
Woody Vines	1	56.2809	0	0.2193
CWD Volume	1	57.4672	1.1863	0.1212
Woody Vines + CWD Volume	2	57.9654	1.6845	0.0945
Sherman *Peromyscus* spp. captures				
Woody Vines	1	52.4832	0	0.3162
Null	0	53.6413	1.15808	0.1772
Woody Vines + Woody Stems	2	53.9729	1.48967	0.1501
Drift fence total captures				
Grass + Woody Vines	2	87.6550	0	0.3427
Woody Vines	1	88.1700	0.5148	0.2650
Drift fence *Peromyscus* spp.				
Null	0	46.5709	0	0.2976
Woody Vines	1	46.9387	0.36781	0.2476
Woody Stems	1	48.3821	1.8112	0.1203
Drift fence *Sorex longirostris*				
Forbs	1	76.8521	0	0.6387
Drift fence *Cryptotis parva*				
Grass	1	53.0880	0	0.6256
Drift fence *Reithrodontomys humilis*				
Null	0	22.8059	0	0.4748

Table 2.6: Model-averaged parameter estimates, standard errors (SE), and 90% confidence intervals (CI) for variables in the confidence set of models (2 > ΔAIC_c) used to examine relationships between small mammal captures and habitat variables in the Coastal Plain of North Carolina, 2012.

Variable	Estimate	SE	Lower 90% CI	Upper 90% CI
Sherman total captures				
Woody Vines	12.945	6.937	1.567	24.323
CWD Volume	0.007	0.005	-0.001	0.015
Sherman *Peromyscus* spp.				
Woody Vines	10.547	5.611	1.345	19.749
Woody Stems	-23.881	20.357	-57.266	9.505
Drift fence total captures				
Grass	8.862	4.912	0.807	16.919
Woody Vines	53.974	12.137	34.069	73.878
Drift fence *Peromyscus* spp.				
Woody Vines	7.946	5.061	-0.355	16.248
Woody Stems	-17.069	17.715	-46.121	11.983
Drift Fence *Sorex longirostris*				
Forbs	26.592	7.416	14.430	38.754
Drift Fence *Cryptotis parva*				
Grass	7.668	2.472	3.614	11.722

Table 2.7: Models in the confidence set (2 > ΔAIC_c) number of parameters in the model (*K*), Akaike's information criterion adjusted for small sample size (AIC_c), AIC_c difference between a model and the model with the lowest AIC_c (ΔAIC_c), and weights (w_i) of models used to examine relationships between small mammal captures and habitat variables in the Coastal Plain of Georgia, 2012.

Model	*K*	AICc	ΔAICc	*wi*
Peromyscus spp. captures				
Null	0	33.9370	0	0.3562
Woody Stems	1	34.4368	0.4998	0.2774

CHAPTER 3

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

The need for renewable energy sources in the U.S. is becoming more important given concerns about fossil fuel prices, limited supplies of fossil fuels and climate change. New state and federal policies provide incentives, such as tax breaks, for using renewable transportation fuels, or require renewable power generation (Database of State Incentives for Renewable Energy 2013). One option for a renewable power source is the coarse woody debris (CWD) normally left on site after timber harvests. The CWD is harvested, chipped and co-fired with coal to produce energy (United States Department of Agriculture 2008). However, the increased removal of CWD after harvest may negatively influence small mammal populations. The objective of my study was to examine the response of small mammals to varying amounts and arrangements of CWD in the Coastal Plain physiographic region of Georgia and North Carolina following varying intensities of biomass harvests.

Despite having been demonstrated as an important ecosystem component (Harmon et al. 1986, Van Lear 1996) and important to small mammals in the Southeast (Loeb 1996, Loeb 1999, Cromer et al. 2007, Davis et al. 2010), CWD volume remaining after biomass harvests generally did not influence small mammal captures in my study. Similarly, Osbourne and Anderson (2002) and Moseley et al. (2005) found no relationship between small mammal abundance and CWD volume. Moseley et al. (2008) concluded that the CWD in early stages of decay did not elicit a response from shrews. I sampled in the first 2 years following harvest and as CWD decays, shrews abundance may increase in response to CWD volume.

Using current harvesting technology, it is operationally impossible or inefficient to remove all woody debris during biomass harvests. Thus, a volume of CWD 5 m^3/ha or more above natural levels found in standing forests of the Southeast remained on my sites even after a complete biomass harvest was conducted (Van Lear 1996). The remaining CWD on all treatment plots may be enough to support small mammal communities. Alternatively, small mammals may be able to obtain resources from vegetation present in early successional habitats, making CWD a less crucial habitat component. Until efficiency of biomass harvesting increases removal of CWD, effects of increased CWD removal from biomass harvesting on small mammals in the Coastal Plain appear to be minimal.

Type of ground cover was the most important factor related to small mammal abundance in my study. The importance of groundcover has been documented in the Southeast with regards to timber harvest and the transition into the next stand (Atkeson and Johnson 1979, Kirkland 1990, Constantine et al. 2004). I found positive relationships between small mammal abundance and woody vines and grasses, and negative relationships with forbs and woody stems. My results are consistent with Healey and Brooks (1988) who found that small mammal captures were highest in areas of forests with an abundance of vines. Bellows et al. (2001) documented increased *Peromyscus* sp. use of areas consisting of grasses over other vegetation types in the Coastal Plain of Virginia. The negative relationship I found between woody stems and small mammals is contrary to most previous studies. Many other studies have shown positive relationships between small mammal abundance and woody stems thought to be related to predator avoidance (Manson et al. 1999, Mengak and Guynn 2003, Brown and Kotler 2004, Verdolin 2006). More research is needed to examine the effects biomass harvesting may have on plant communities and in turn the small mammal response.

Removal of CWD during biomass harvests may not directly affect small mammals in the Coastal Plain, but the value of CWD as an ecosystem component should be understood before effective BHGs are developed. Small mammals are one of many groups of organisms that may be affected by biomass harvesting, and research is needed on other components of the ecosystem. Information on a variety of ecosystem components should be integrated into BHGs to ensure that biomass harvesting is a sustainable practice.

Literature Cited

Atkeson, T. D. and A. S. Johnson. 1979. Succession of small mammals on pine plantations in the Georgia USA Piedmont. American Midland Naturalist 101:385-392.

Barnum, S. A., C. J. Manville, J. R. Tester, and W. J. Carmen. 1992. Path selection by Peromyscus leucopus in the presence and absence of vegetative cover. Journal of Mammalogy 73:797-801.

Barry, R. E., Jr., and E. N. Francq. 1980. Orientation to landmarks within the preferred habitat by Peromyscus leucopus. Journal of Mammalogy 61:292-303.

Bellows, A. S., J. F. Pagels, and J. C. Mitchell. 2001. Plant community composition and small mammal communities in old fields on Virginia's Coastal Plain. Journal of the Elisha Mitchell Scientific Society 117:101-112.

Brown, J. P. and B. P. Kotler. 2004. Hazardous duty pay and the foraging cost of predation. Ecology Letters 7:999-1014.

Constantine, N. L., T. A. Campbell, W. M. Baughman, T. B. Harrington, K. V. Miller. 2004. Effects of clearcutting with corridor retention on abundance, richness, and diversity of small mammals in the Coastal Plain of South Carolina, USA. Forest Ecology and Management 202:293-300.

Database of State Incentives for Renewable Energy [DSIRE]. 2013. Database of state incentives for renewables and efficiency homepage. <http://www. dsireusa.org>. Accessed 12 January 2013.

Davis, J. C., S. B. Castleberry, and J. C. Kilgo. 2010. Influence of coarse woody debris on the soricid community in southeastern Coastal Plain pine stands. Journal of Mammalogy 91:993-999.

Healy, W. M., and R. T. Brooks. 1988. Small mammal abundance in northern hardwood stands in West Virginia. Journal of Wildlife Management 52:491-496.

Kirkland Jr., G. L. 1990. Patterns of initial small mammal community change after clearcutting of temperate North American forests. Oikos 59:313-320.

Lanham, J. D., D. C. Guynn, Jr. 1996. Influences of coarse woody debris on birds in southern forests. Pages 101-107 *in* J. W. McMinn, and D. A. Crossley, editors. Biodiversity and coarse woody debris in southern forests: proceedings of the workshop on coarse woody debris in southern forests. U.S. Forest Service General Technical Report SE-94, Washington, D.C., USA.

Loeb, S. C. 1999. Responses of small mammals to coarse woody debris in a southeastern pine forest. Journal of Mammalogy 80:460-471.

Loeb, S. C. 1996. The role of coarse woody debris in the ecology of southeastern mammals. Pages 108-118 *in* J. W. McMinn, and D. A. Crossley, editors. Biodiversity and coarse woody debris in southern forests: proceedings of the workshop on coarse woody debris in southern forests. U.S. Forest Service General Technical Report SE-94, Washington, D.C., USA.

Manson, R. H. and E. W. Stiles. 1998. Links between microhabitat preferences and seed predation by small mammals in old fields. Oikos 82:37-50.

Mengak, M. T. and D. C. Guynn. 2003. Small mammal microhabitat use on young loblolly pine regeneration areas. Forest Ecology and Management 173:309-317.

Whiles, M. R., and J. W. Grubaugh, 1996. Importance of coarse woody debris to southern forest herpetofauna. Pages 94-100 *in* J. W. McMinn, and D. A. Crossley, editors. Biodiversity and coarse woody debris in southern forests: proceedings of the workshop on coarse

Tallmon, D., and L. S. Mills. 1994. Use of logs within home ranges of California red-backed voles on a remnant of forest. Journal of Mammalogy 75:97-101.

U.S. Department of Agriculture [USDA] Forest Service. 2008. Woody biomass utilization: benefits. <http://www.fs.fed.us/woodybiomass/benefits.shtml>. Accessed 12 January 2013

Van Lear, D.H. 1996. Dynamics of coarse woody debris in southern forest ecosystems. Pages 10-17 *in* J. W. McMinn, and D. A. Crossley, editors. Biodiversity and coarse woody debris in southern forests proceedings of the workshop on coarse woody debris in southern forests. U.S. Forest Service General Technical Report SE-94, Washington, D.C., USA.

Verdolin, J. L. 2006. Meta-analysis of foraging and predation risk trade-offs in terrestrial ecosystems. Behavioral Ecology and Sociobiology 60:457-464.

Appendix 1: Volume (m^3/ha) of woody debris by site and treatment on harvested loblolly pine (*Pinus taeda*) stands in the Coastal Plain of North Carolina and Georgia, 2011-2012.

SITE	TREATMENT	VOLUME
NC1	NOBIOHARV	155.6885
	30CLUS	81.6476
	30DISP	52.1709
	15CLUS	30.7710
	15DISP	44.1093
	NOBHG	24.4720
NC2	NOBIOHARV	58.1428
	30CLUS	34.1516
	30DISP	32.3729
	15CLUS	29.0086
	15DISP	16.2800
	NOBHG	21.3420
NC3	NOBIOHARV	114.8554
	30CLUS	55.1711
	30DISP	91.0152
	15CLUS	65.8284
	15DISP	76.1513
	NOBHG	18.5211
NC4	NOBIOHARV	104.1048
	30CLUS	49.6962
	30DISP	47.4305
	15CLUS	25.4499
	15DISP	26.6727
	NOBHG	18.2547
GA5	NOBIOHARV	437.2260
	30CLUS	446.7254
	30DISP	534.5657
	15CLUS	447.5794
	15DISP	506.1882
	NOBHG	513.7229

Appendix 1: continued.

SITE	TREATMENT	VOLUME
GA6	NOBIOHARV	444.5917
	30CLUS	501.3350
	30DISP	332.0989
	15CLUS	325.7848
	15DISP	635.7240
	NOBHG	345.4359
GA7	NOBIOHARV	438.8459
	30CLUS	167.4974
	30DISP	219.2837
	15CLUS	127.4624
	15DISP	174.0812
	NOBHG	242.4317
GA8	NOBIOHARV	668.3084
	30CLUS	739.7213
	30DISP	552.2969
	15CLUS	600.0724
	15DISP	557.0432
	NOBHG	627.4090

Appendix 2: Mean percent cover type of vegetation categories by site and treatment on harvested loblolly pine (*Pinus taeda*) stands in the Coastal Plain of North Carolina and Georgia, 2012.

Site	Treatment	Woody	Woody Vine	Forbs	Grass	Cane	Herbaceous Vine	Bare	Debris	Litter
NC1	NOBIOHARV	2.22	4.07	2.22	4.44	0.00	0.00	59.26	10.74	21.85
	30CLUS	1.48	2.22	9.26	8.52	2.59	0.00	47.04	9.63	15.19
	30DISP	2.96	6.30	6.67	6.67	8.89	0.00	38.52	10.74	19.26
	15 CLUS	0.74	2.59	1.11	5.19	2.22	0.00	50.37	8.89	21.11
	15DISP	1.48	1.85	4.81	11.11	15.56	0.00	37.04	7.41	15.19
	NOBHG	0.37	6.67	6.30	2.22	0.00	0.00	53.33	9.26	25.19
NC2	NOBIOHARV	1.85	1.48	2.22	3.70	0.00	0.00	52.96	15.93	31.48
	30CLUS	1.11	0.00	0.74	1.11	0.00	0.00	54.07	12.22	35.19
	30DISP	2.59	1.85	1.48	10.00	0.37	0.00	58.89	10.37	23.33
	15CLUS	0.74	0.37	0.74%	4.44	0.37	0.00	57.41	7.41	28.89
	15DISP	0.37	0.00	0.74	1.85	0.00	0.00	59.63	9.63	31.85
	NOBHG	1.85	1.48	1.48	7.04	0.00	0.00	59.26	12.22	22.22
NC3	NOBIOHARV	0.74	5.93	7.04	5.19	0.00	0.00	42.59	10.37	32.22
	30CLUS	1.48	6.30	8.52	8.52	0.37	0.00	50.74	9.26	19.63
	30DISP	1.48	8.52	7.41	7.78	0.00	0.00	48.89	12.59	19.63
	15CLUS	1.11	4.81	7.78	8.89	0.37	0.00	49.26	9.63	21.11
	15DISP	1.85	3.70	8.52	2.22	0.00	0.00	51.85	5.56	28.89
	NOBHG	1.11	6.30	10.00	4.44	1.85	0.00	42.59	5.93	27.78
NC4	NOBIOHARV	1.85	6.67	8.89	11.11	1.85	0.00	35.93	13.33	24.44
	30CLUS	0.74	4.44	4.44	12.22	6.30	0.00	47.41	11.11	18.52
	30DISP	1.85	0.74	5.56	21.85	1.11	0.00	45.56	14.81	14.44
	15CLUS	1.85	2.96	3.70	9.26	10.00	0.00	52.96	9.26	16.30
	15DISP	0.74	1.11	3.33	14.81	1.48	0.00	51.48	13.70	17.04
	NOBHG	0.37	2.96	5.19	22.59	0.37	0.00	56.67	7.41	10.37

Appendix 2: continued.

Site	Treatment	Woody	Woody Vine	Forbs	Grass	Cane	Herbaceous Vine	Bare	Debris	Litter
GA5	NOBIOHARV	6.14	9.06	17.47	31.00	0.00	0.00	32.00	0.77	3.56
	30CLUS	15.11	5.94	18.12	36.79	0.00	1.05	18.41	1.05	2.10
	30DISP	12.15	3.90	23.81	35.65	0.00	1.46	17.60	0.74	3.60
	15CLUS	18.86	15.17	9.12	19.67	0.00	0.00	31.32	0.00	5.87
	15DISP	14.86	5.45	13.00	27.73	0.00	3.30	22.51	4.48	7.08
	NOBHG	10.99	17.38	17.13	27.37	0.00	2.18	22.80	0.36	1.45
GA6	NOBIOHARV	4.70	3.18	6.80	14.52	0.00	0.00	67.13	1.45	0.74
	30CLUS	7.11	3.80	11.10	27.55	0.00	0.00	48.00	0.36	1.38
	30DISP	4.33	2.19	7.93	21.05	0.00	0.00	56.72	2.52	4.25
	15CLUS	6.04	11.31	9.14	23.87	0.00	0.00	46.01	3.29	0.35
	15DISP	5.50	2.92	6.63	19.10	0.00	0.00	61.09	1.85	1.09
	NOBHG	5.47	5.81	6.97	18.34	0.00	0.00	50.62	1.84	9.50
GA7	NOBIOHARV	10.70	5.34	23.11	39.44	0.00	0.00	17.56	1.75	1.37
	30CLUS	12.48	1.84	23.89	48.43	0.00	0.00	9.73	0.34	3.30
	30DISP	26.92	10.20	19.78	32.07	0.00	1.63	7.32	0.00	2.09
	15CLUS	11.25	1.80	13.31	46.24	0.00	0.57	16.10	1.48	7.57
	15DISP	14.02	5.01	20.71	43.47	0.00	0.71	13.54	0.00	2.55
	NOBHG	9.31	1.41	8.77	42.08	0.00	0.00	28.11	3.21	7.12
GA8	NOBIOHARV	1.45	4.36	11.19	25.68	0.00	0.00	48.65	3.59	5.09
	30CLUS	2.59	6.57	15.31	29.14	0.00	0.00	38.68	4.79	2.92
	30DISP	4.14	3.81	10.11	29.60	0.00	0.34	45.44	0.74	5.83
	15CLUS	2.18	7.01	13.18	31.71	0.00	0.71	36.67	1.42	7.12
	15DISP	2.11	3.97	7.60	27.70	0.00	0.00	51.45	3.61	3.19
	NOBHG	1.66	20.79	10.62	31.30	0.00	0.36	29.52	1.67	3.51