Harvest of wood for renewable energy may limit the downed woody debris that is available to ground-dwelling wildlife. Although woody biomass has been used as a local energy source (Stuart et al. 1981, Van Hook et al. 1982, Watson et al. 1986, Puttock 1987), the relative cost of woody biomass-generated energy has not been competitive with traditional fossil fuels for broader energy needs (White 2010). However, recent and expected legislation requiring a proportion of energy generation in the United States and Europe to come from renewable sources has increased interest in wood from forests as a major feedstock for bioenergy (Cook and Beyea 2000, Perlack et al. 2005, Hillring 2006, Mantau et al. 2010, REN21 2013). Woody biomass harvests in southern pine
(Pinus spp.) plantations often coincide with clearcut harvests and remove treetops, limbs, and lower value trees that would otherwise contribute downed woody debris during the next rotation (Rudolphi and Gustafsson 2005, Fritts et al. 2014). Thus, clearcut harvests with an additional biomass removal may result in lower volumes of downed woody debris available to wildlife compared to clearcut harvests without a biomass removal; whether this leads to changes in wildlife populations is not clear.

The southeastern United States is a wood basket for the nation and is the largest global exporter of wood pellets for bioenergy production (Hanson et al. 2010, Evans et al. 2013, Goh et al. 2013). Southeastern forests supply much of the wood-based bioenergy feedstock needed to meet the projected 60% increase in demand during the next 10–15 years (Sedjo and Sohngen 2009). Further, as advanced biofuel production and technology expands, southeastern United States forests are predicted to supply approximately 50% of second generation biofuels (i.e., biofuels developed from lignocellulosic biomass and agricultural residues) required to meet United States biofuel mandates (United States Department of Agriculture 2010).

Rodents serve critical roles in ecosystem function, such as seed dispersal and herbivory, and are predators of and prey for many species. Downed wood is important for rodents to meet numerous life-history needs, including refugia from predators, to rear young, and to mediate environmental extremes (Frank and Layne 1992, Weltzin et al. 1997, Jones et al. 1998, Wilson and Ruff 1999). In southeastern United States pine forests, downed woody debris contributes habitat components for many rodent species (Loeb 1999, Mengak and Guynn 2003). For example, cotton mice (Peromyscus gossypinus) use rotting stumps, root boles, brush piles, and logs as daytime refuge (McCay 2000, Hinkelman and Loeb 2007) and select burrows with nearby woody debris structure, particularly when mesopredators are near (Derrick et al. 2010). Further, white-footed mice (P. leucopus) use downed woody debris for navigational landmarks and travel routes (Barry and Franq 1980, Barnum et al. 1992). Therefore, community composition and relative abundance of rodent species may depend largely on the availability of downed woody debris and other structural cover (Arkeson and Johnson 1979, Carey and Johnson 1995, Loeb 1999).

State agencies and conservation organizations have developed Biomass Harvesting Guidelines (BHGs) that specify recommended amounts or spatial arrangements of woody biomass to retain as downed woody debris (e.g., Minnesota Forest Resources Council 2007, Röser et al 2008, Pennsylvania Department of Conservation and Natural Resources 2008, Perschel et al. 2012). Biomass Harvesting Guidelines assume that biological diversity and site productivity are positively and linearly related to the amount of downed woody debris (Harmon and Hua 1991, Ranius and Fahrig 2006), but the BHG goal of sustaining rodent populations has not been studied.

An improved understanding of effects of woody debris removal on wildlife, especially taxa closely linked to downed wood, is important for evaluating the sustainability of woody biomass harvest. To examine effects BHGs have on rodent abundances in southeastern United States pine forests, we experimentally manipulated retention of woody biomass following clearcut harvesting. Our objectives were to examine differences in species’ abundance among treatments and to evaluate the influence of downed woody debris and vegetation on species abundances, primarily to understand the mechanisms responsible for potential differences among treatments. Because of known relationships with forest structure, we predicted that native rodent abundances, including deer mouse (Peromyscus spp.), eastern harvest mouse (Reithrodontomys humulis), and hispid cotton rat (Sigmodon hispidus), would increase with greater volumes of retained downed woody debris (McCay 2000, Mengak and Guynn 2003). Conversely, we predicted that house mouse (Mus musculus) abundance would decline as retained debris volume increased, given the species’ ability to invade and occupy disturbed areas with little cover, and potentially because of its generalist behaviors and competition with deer mice (Gentry 1966).

STUDY AREA

We tested our hypotheses at 8 regenerating clearcut harvests (i.e., blocks; 57–85 ha) in the southeastern United States Coastal Plain physiographic region: 4 in Beaufort County, North Carolina (−077º00’W to −076º53’50”W and 35º34’0”N to 35º38’20”N; Fig. S1, available online in Supporting Information); 3 in Glynn County, Georgia (−081º44’40”W to −081º45’42”W and 31º07’31”N to 31º11’14”N); and 1 in Chatham County, Georgia (−081º11’26”W to −081º10’37”W and 32º18’46”N to 32º19’21”N; Fig. S2), USA in 2011–2013. All sites had a warm–temperate, humid climate and were <8 m elevation. North Carolina soils were predominately loam and silt loam. Georgia soils were predominantly loam, clay loam, and fine sandy loam. Before clearcut, dominant vegetation included loblolly pine (Pinus taeda), sweetgum (Liquidambar styraciflua), and red mulberry (Morus rubra).

All study sites were in intensively managed loblolly pine plantations. North Carolina sites were managed for sawtimber production, had 2 commercial thinning entries before the final clearcut harvest, and were 32–39 years old at final harvest. Georgia sites were managed primarily for lumber, fuel, and pulpwood production and were 25–33 years old at the time of final clearcut harvest. Three Georgia sites had 1 commercial thinning entry and 1 site had 2 commercial thinning entries before harvest. Clearcut harvesting with treatment implementation was completed in 2010–2011. North Carolina clearcuts were 70.5 ± 6.1 ha (x ± SE) in size and Georgia clearcuts were 64.4 ± 3.1 ha in size.

METHODS

Treatment Implementation

We employed a randomized complete block design to examine effects of a range of woody biomass retention treatments on rodent abundance. Before harvest, we divided
blocks into 6 treatment units (North Carolina: $\bar{x}=11.7 \pm 0.5$ ha, range = 8.4–16.3 ha; Georgia: $\bar{x}=10.7 \pm 0.4$ ha, range = 7.6–14.3 ha) and randomly assigned woody biomass retention treatments. We based woody biomass retention rates and spatial allocations on existing BHGs (Minnesota Forest Resources Council 2007, Röser et al. 2008, Pennsylvania Department of Conservation and Natural Resources 2008, Perschel et al. 2012). We identified 6 treatments in order of increasing woody biomass retention. Treatments were 1) clearcut with a conventional woody biomass harvest (all merchantable woody biomass harvested) and no retention requirements (no BHG), 2) clearcut with 15% retention with woody biomass clustered in large piles throughout the treatment unit (15% clustered), 3) clearcut with 15% retention with woody biomass evenly dispersed throughout the treatment unit (15% dispersed), 4) clearcut with 30% retention with woody biomass clustered in large piles throughout the treatment unit (30% clustered), 5) clearcut with 30% retention with woody biomass evenly dispersed throughout the treatment unit (30% dispersed), and 6) clearcut with no woody biomass harvest (i.e., clearcut only; no biomass harvest). The sixth treatment served as a reference. Treatment units were close to each other within each block (Fritts et al. 2014) and we did not sample rodents within 50 m of the boundary of each treatment unit.

In North Carolina, harvest operators moved woody debris into long rows using a bulldozer with a V-shaped blade that sheared stumps before any sampling occurred. Year 2 post-harvest, after 1 year of sampling, sites were bedded with a tractor that moved soil into elevated rows to improve survival and productivity of planted loblolly pine seedlings. Site preparation activities in North Carolina altered woody debris distribution because immediately following harvest, V-shearing moved scattered debris into small piles (compared to debris piles created through treatment implementation in the clustered treatments), particularly in the dispersed treatments. During and immediately following harvest in Georgia, harvest operators moved debris into long windrows and large circular piles (i.e., spot piles); therefore, the clustered and dispersed treatments in Georgia did not differ as planned. Because one project goal was to assess operational treatment implementation, we gave harvest operators latitude on how to implement the harvests as they typically would. Similar to North Carolina, Georgia sites were prepared for planting with bedding and planted year 2 post-harvest. Additional details of treatment implementation are in Fritts et al. (2014).

**Livetrapping Rodents and Vegetation Sampling**

We livetrapped rodents from mid-April to early-August in 2011–2013 in North Carolina and Georgia. Sampling began in all 4 blocks in North Carolina and 2 blocks in Georgia the first year after the clearcut harvest and initial mechanical site preparation (2011) to prepare the site for regeneration. Sampling began the following year for the 2 remaining blocks in Georgia, after mechanical site preparation. We captured rodents using 7.6 × 8.9 × 22.9 cm$^3$ Sherman folding live traps (H.B. Sherman Traps, Tallahassee, FL, USA). We placed 50 traps in each treatment unit in a 5 × 10 grid with 15-m spacing between traps. Traps were ≥50 m from unit boundaries to minimize influence of movements from adjacent treatment units or other forest stands. We baited traps with rolled oats daily and trapped each treatment unit for 5 consecutive nights. All 6 treatment units in a block were trapped concurrently. We sampled all blocks 3 times/year, except 1 North Carolina block, which we sampled twice in 2011 because of time constraints. We sampled all treatments within the same block concurrently and with 2 to 4 weeks separating trapping events in each block. We checked traps before 1000 hours Eastern Daylight Time to prevent heat-related trap mortality and stress. We identified all captured individuals to species; however, we lumped white-footed mice and cotton mice by genus (i.e., deer mice) because they were difficult to distinguish in the field and both potentially occurred in the study area. We placed a uniquely numbered Monel ear tag (no. 1005-1 National Band and Tag, Newport, KY, USA) in the right ear of each captured individual. Sampling procedures followed American Society of Mammalogists guidelines (Sikes et al. 2011) and were approved by the North Carolina State University Institutional Animal Care and Use Committee (11-022-O), the Georgia Department of Natural Resources (scientific collection permit no. 29-WJH-13-156), and the North Carolina Wildlife Resources Commission (scientific collection permit no. 115C00534).

In 2011, we measured downed woody debris using a line-intercept sampling technique (Van Wagner 1968). We established 7.3-m transects from the plot center point at 0°, 120°, and 240° azimuths for sampling coarse woody debris (downed woody debris ≥7.6 cm in diameter for a length ≥0.91 m; Woodall and Monleon 2008), and 3.1-m transects for sampling fine woody debris (debris smaller than coarse woody debris). Although the line-intercept sampling method worked well for scattered downed woody debris, few downed woody debris piles fell within line intersect sampling plots. Therefore, we used a visual encounter method to census piled downed woody debris in each treatment unit. In North Carolina, we calculated volume (m$^3$/ha) of all debris piles by measuring length, height, and width and visually estimated the relative density of wood (0–100%) of all hardwood and large pine piles. We defined hardwood piles as ≥2 hardwood trees retained on the ground resulting from retention treatments (i.e., retention of 15%, 30%, or all woody biomass), whereas we defined large pine piles as any pine residue pile >1.6 m in height or 3.8 m in length and <50% soil. Pines were stripped of their limbs at harvest, and pine piles were created when pine limbs were pushed together during shearing. In Georgia, we measured volume of wood of all windrows and spot piles, which were comprised primarily of pine stems. Several windrows were created by operators in each treatment unit. Windrows often were the length of the entire treatment unit, so we measured lengths using post-harvest aerial imagery (Google Maps, Mountain View, CA, USA) in ArcGIS version 10.2.2 (Environmental Systems Research Institute, Redland, CA, USA).
For both states, we summed volume of piled debris estimated from the visual encounter method and volume of scattered debris estimated using the line intersect sampling method to generate total debris volume (m³/ha) for each treatment unit. Each block contained 2 to 3 logging decks (i.e., the area(s) felled logs are weighed and loaded into trucks) from harvesting the 6 treatment units. Large ends of trees from the entire clearcut were retained at the logging decks, but deck materials were not included in final debris volume estimates for individual treatment units. We recorded latitude and longitude of all debris piles to ensure we did not double count piles.

In 2011, vegetation was not well-established and we did not estimate vegetation cover or groundcover. In 2012 and 2013, when vegetation structure was greatest, we measured horizontal vegetation structure and groundcover using the same 9 sampling plots used for line-intercept sampling. At each plot, we measured vegetation at 10 sampling points separated by 1-m increments along the same 3 transect directions used for the line-intercept sampling. We recorded whether vegetation touched a 2-m tall, 4.8-cm diameter pole at each of the 10 points for the following vegetation categories: forb, grass, and woody vegetation. We calculated horizontal vegetation structure of each category by dividing the number of sampling points where vegetation intersected the pole by the number of sampling points (n = 270) measured in a treatment unit (Moorman and Guynn 2001). We estimated groundcover of downed woody debris, bare ground, vegetation, and litter by calculating percentage of points with a hit recorded at the 1-dm increment of the pole. Combined horizontal vegetation cover and combined groundcover could be >100%, because >1 type may have been present at a point.

Statistical Analyses

We attempted to estimate annual rodent abundance for each treatment unit using Program MARK version 7.2 (White and Burnham 1999); however, because of low sample sizes in some treatment units, many models were unable to estimate abundance reliably as indicated by standard errors of 0 and confidence intervals spanning 0–1. Therefore, we calculated the minimum number known alive as a surrogate for abundance (Krebs 1966) of all captured rodent species (i.e., deer mice, house mouse, hispid cotton rat, marsh rice rat [Oryzomys palustris], and eastern harvest mouse in each treatment unit). Because we ear-tagged rodents, we were able to assess movement across treatments. During the study, we detected only 2 individuals that crossed treatment boundaries.

Response to treatments.—We assessed differences among treatments in each captured species’ abundance using mixed effects linear regression analyses. The maximum number of eastern harvest mice captured in 1 state and 1 year in all treatment units combined was 34 and we did not include this species in the treatment-level regression analyses. For deer mice, house mouse, and hispid cotton rat, we used abundance as the Poisson response variables, treatment as a fixed effect, and block and year as random effects in separate generalized linear mixed models (Zuur et al. 2009) using the R package lmer (Bates et al. 2015). We examined differences in least square means among treatments using the R package lsmeans (Lenth 2016). We considered treatment effects significant when the 95% confidence interval did not overlap 0. We did not capture house mice in Georgia and thus included only North Carolina in the statistical analysis of this species. We captured >96% of marsh rice rats in 2013 and 55% in 4 treatment units (block 4 30% clustered, block 4 30% dispersed, block 6 30% dispersed, and block 7 15% dispersed) likely because of proximity to water. Therefore, we did not include the marsh rice rat in analysis. We conducted analyses in software R 3.2.2 (R Core Team 2012).

Response to vegetation and groundcover.—We assessed differences in downed woody debris using Friedman’s tests and analysis of variance. We separated states because site preparation and estimated volumes of retained downed woody debris were different. We assessed differences in vegetation among treatments using multivariate analysis of variance. We used the vegetation measurements as the response variable and year, block, and treatment as independent factor covariates.

We used generalized linear modeling to determine population responses of deer mice, (NC 2011–2013; GA 2012–2013), house mouse (NC 2011–2013), and hispid cotton rat (GA 2013) to varying volumes of downed woody debris retention and vegetation composition and structure. We used separate models for each state and year because site preparation activities differed by state, retained downed woody debris volume estimates varied by state, and vegetation composition and structure changed across years. We examined relationships between abundance and the following independent explanatory variables: volume of downed woody debris in the treatment; percent horizontal cover of forb, grass, and woody vegetation; and percent groundcover of bare ground, downed woody debris, vegetation, and litter. We used the estimate of retained downed woody debris volume in each treatment unit as a continuous predictor variable instead of using the class variable treatment as a factor because focusing on habitat characteristics allowed us to understand mechanisms affecting the responses to woody biomass harvests complementary to treatment classification. We did not include a covariate in the generalized linear modeling that distinguished between clustered and dispersed treatments because scattered downed woody debris was pushed into piles by V-shearing and windrowing, which occurred before livetrapping.

We scaled independent variables by subtracting the mean and dividing by the standard deviation. We assessed collinearity of covariates using variation inflation factors (VIF) and dropped the covariate if the factor was >3.0 (Zuur et al. 2010). We selected the best models at predicting abundance of each species by dropping one explanatory variable in turn, and each time applying an analysis of deviance test between the previous and current models (Zuur et al. 2009). We validated each selected model by graphically examining residuals and using Cook’s distance to assess the model for influential observations (Cook 1979, Fox 2002,
RESULTS

We had 97,500 trap nights across both states and 3 years. In North Carolina, we captured 960 house mice, 83 marsh rice rats, 2,772 deer mice, 57 eastern harvest mice, and 53 hispid cotton rats across all years and treatments. In Georgia, we captured 50 marsh rice rats, 405 deer mice, 6 eastern harvest mice, 869 hispid cotton rats, and 0 house mice.

Relationships between treatments and rodent abundances were not consistent. Deer mice abundance was 6% lower in 15% dispersed than 30% dispersed, 13% lower in 15% dispersed than no BHG, 2% lower in 30% dispersed than 30% clustered, and 19% lower in no BHG than 30% clustered (Table 1). House mouse abundance was 34% lower in 15% clustered than 30% clustered, 29% lower in 15% dispersed than 30% clustered, 39% lower in no biomass harvest than 30% dispersed, and 29% lower in no biomass harvest than 30% dispersed (Table 1). *S. hispidus* abundance was 32% lower in no biomass harvest than 30% dispersed (Table 1).

In North Carolina, adding a woody biomass harvest component to a clearcut reduced volumes of downed woody debris by 81% (Fritts et al. 2014; Table S1). Although the 30% treatments had greater volumes of downed woody debris than the 15% treatments, differences were not significant. Because of high variability among blocks in Georgia, downed woody debris did not differ among treatments ($F_{5,17} = 0.21$, $P = 0.95$; Table S2). Vegetation measurements did not differ among treatments ($F_{49, 80} = 1.18$, $P = 0.19$; Tables S1 and S2). In 2011 in North Carolina, abundances of deer mice ($\beta = -0.14$, $SE = 0.04$, $Z = -3.64$, $P < 0.01$) and house mice ($\beta = -0.42$, $SE = 0.09$, $Z = -4.83$, $P < 0.01$) were negatively related to the volume of downed woody debris in the treatment unit (Fig. 1). In 2012 in North Carolina, deer mice abundance had a positive relationship with volume of downed woody debris in the treatment unit ($\beta = 0.01$, $SE = 0.001$, $Z = 5.731$, $P < 0.01$) and negative relationships with downed woody debris groundcover ($\beta = -6.11$, $SE = 0.89$, $Z = -6.88$, $P < 0.01$) and litter groundcover ($\beta = -3.67$, $SE = 0.45$, $Z = -8.13$, $P < 0.01$; Fig. 1). In 2012 in North Carolina, house mouse abundance had a negative relationship with downed woody debris groundcover ($\beta = -0.33$, $SE = 0.04$, $Z = -8.93$, $P < 0.01$; Fig. 1). In 2013 in North Carolina, house mouse abundance had a positive relationship with grass groundcover ($\beta = 0.79$, $SE = 0.04$, $Z = 19.22$, $P < 0.01$; Fig. 1). In 2013 in Georgia, hispid cotton rat abundance was negatively influenced by volume of downed woody debris in the treatment unit ($\beta = -0.33$, $SE = 0.04$, $Z = -8.74$, $P < 0.01$) and litter groundcover ($\beta = -0.13$, $SE = 0.04$, $Z = -3.61$, $P < 0.01$) but had a positive relationship with grass groundcover ($\beta = 0.21$, $SE = 0.03$, $Z = 6.29$, $P < 0.01$; Fig. 1).

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<th>Treatment</th>
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**Table 1.** Minimum number known alive estimates (± SD) of rodent species captured in 6 woody biomass harvest treatments in loblolly pine (*Pinus taeda*) plantations in Beaufort County, North Carolina ($n = 4$) in 2011–2014 and Glynn and Chatham counties, Georgia, USA ($n = 4$). Treatments were 1) no Biomass Harvesting Guidelines (NOBHG), 2) 15% woody biomass retention in piles (15CLUS), 3) 15% woody biomass retention distributed evenly throughout the treatment unit (15DISP), 4) 30% woody biomass retention in piles (30CLUS), 5) 30% woody biomass retention distributed evenly throughout the treatment unit (30DISP), and 6) no woody biomass harvesting (NOBIOHARV). Different letters indicate significantly different means at a p < 0.05. The house mouse was not captured in Georgia; therefore, averages are for North Carolina only. We did not perform statistical analyses on the eastern harvest mouse or marsh rice rat because of small sample sizes.
DISCUSSION

Contrary to our predictions, abundances of the 3 most commonly captured rodent species were not negatively influenced by biomass removal treatments following clearcut harvests in loblolly pine plantations in the southeastern United States. Although we detected differences in abundances among treatments for some species in some years, rodent responses were not related to treatment classification in a consistent manner. These experimental harvests removed up to 81% of woody biomass at North Carolina sites (Fritts et al. 2014), but rodent abundances in the treatment with the greatest removal of woody material (no BHG) did not differ from abundances where there was no woody biomass harvest component. Similarly, a concurrent study in intensively managed pine plantations in North Carolina showed that removal of approximately 85% of woody biomass had little influence on rodent abundance or diversity (Marshall et al. 2012, Homyack et al. 2014). Collectively, these results suggest rodents are not sensitive to current levels of woody biomass harvests in southeastern United States pine plantations.

Rodent responses to habitat characteristics also were inconsistent across species, states, and years. The negative relationships between deer mice and downed woody debris in this research contradict several previous studies. These differences in results may be attributed to stand age, stand type, type of harvest, and scale of habitat measurements. For example, white-footed mice used microhabitat with more coarse woody debris in hardwood forest (Kellner and Swihart 2014). McCay (2000) reported that cotton mice used woody debris for daytime refuge, were often located near fallen logs during the night, and selected longer logs than were available, but forest stands in the study were older (45 yr) than in our study. Results from Mengak and Guynn (2003) suggest that downed woody debris was important to deer mice and hispid cotton rats, but they measured habitat characteristics at the micro scale (i.e., around each trap). Conversely, we measured groundcover at the scale of the treatment unit, and relationships between rodent abundance and retained woody debris may have been mediated at the larger scale of our study.

As plantations regenerate following site preparation and replanting, vegetation structure and complexity increases for several years, providing habitat structure for wildlife communities (Fritts et al. 2016; Grodsky et al. 2016a,b; Larsen et al 2016). Thus, our observations of positive responses of *S. hispidus* to grass cover is consistent with published descriptions of the species’ habitat requirements (Moorman et al. 2013). Cotton rats are habitat generalists (Lidicker et al. 1992) and are linked to early succession grasses and ample herbaceous vegetation. For example, cotton rats are abundant in old-fields and grasslands (Atkeson and Johnson 1979, Cameron and Spencer 1981) and are more abundant in pine plantations in which switchgrass was planted between rows of pine trees compared to plantations without planted switchgrass (Homyack et al. 2013, King et al. 2014, Larsen et al. 2016). Similarly, cotton rat abundance increased through time as grasses became well-established in our study (e.g., 2013).

The warm and humid climate, coupled with lightning-caused and anthropogenic fires that are characteristic of southeastern forests, may result in weaker relationships between downed wood and rodents in this region. The climate leads to more rapid decay rates of woody debris relative to other regions and ecosystems (Moorman et al. 1999), and hence ground-dwelling wildlife may not be as reliant on downed wood. Additionally, ground-dwelling wildlife may have developed tolerances to the fire intervals historically characteristic of the region and the environmen-
tional conditions they promoted (Frost 1998). Therefore, rodent species in this region may not be as dependent on downed wood as in other ecosystems where woody debris persists for decades or multiple rotations. This is supported by our larger effort to assess wildlife response to woody biomass harvests, in which we found similar results that suggest reptile, amphibian, shrew, and avian populations were not linked to woody debris retention volumes (Fritts et al. 2015b, 2016; Grodsky et al. 2016a, b).

Despite large decreases from experimental manipulations, substantial volumes of downed woody debris remained in all treatment units. The minimum volume retained in a no BHG treatment unit in North Carolina was 16.28 m$^3$/ha (7.81 tons/ha; Fritts et al. 2014), which exceeded by over 3-fold the Forest Guild’s volume recommendations of 2.24 m$^3$/ha in pine forests of the Piedmont and Coastal Plain physiographic regions of the United States (Perschel et al. 2012). In another study in North Carolina Coastal Plain pine plantations, 15% of total woody biomass was retained following harvest after removing as much downed woody debris as possible (Homayack et al. 2013). Despite biomass harvests, stumps and root boles remained in treatments and may have provided similar structure as downed trees and limbs as compared to the no biomass harvest treatment. In the Coastal Plain region of South Carolina, USA, Hinkelman and Loeb (2007) documented similar abundances of cotton mice in treatments with 60 m$^3$/ha and 10 m$^3$/ha of downed woody debris. Therefore, if a minimum volume of downed woody debris is needed to sustain rodent populations in southeastern pine forests, it may be below 10 m$^3$/ha and less than the volume retained in our treatment units.

Although we did not detect declines in rodents, shrews (Fritts et al. 2015b), herpetofauna (Fritts et al. 2016), wintering birds (Grodsky et al. 2016b), or breeding birds (Grodsky et al. 2016a) following biomass harvests, more research of wildlife response to woody biomass harvest is warranted. One potential downfall in community-level assessments is that rare or elusive species’ responses could be overlooked. Other research indicated that ground beetles (Coleoptera: Carabidae) and crickets (Orthoptera: Gryllidae) were more abundant in treatments with no woody biomass harvest than in treatments with an intensive woody biomass harvest (S. M. Grodsky, North Carolina State University, unpublished data). These effects on invertebrates could cascade to other trophic groups, including sensitive species, and possibly include a time-lag before the effects are detectable. Additionally, targeted approaches, including radio-telemetry, may show species-level responses or behaviors that we did not detect, such as fine-scale use of downed woody debris. For example, results of a broad-scale study suggested that southern toad (Anaxyrus terrestris) populations were not influenced by retained woody debris volumes (Fritts et al. 2016). However, a concurrent study that assessed meso- and micro-habitat use suggested that southern toads used woody debris for cover, particularly under hot and dry conditions (Fritts et al. 2015a). Lastly, minimum number known alive assumes detection rates are consistent across groups (Pocock et al. 2004) and we assumed equal detection among treatments. Minimum number known alive also can be a low-biased index of abundance. Although we have no evidence that detection differed among treatments, methods that increase capture rates and correct for imperfect detection may be beneficial.

**MANAGEMENT IMPLICATIONS**

Based on operational and experimental manipulation of retained woody debris in this study, harvesting logging residues and low value trees for bioenergy may be compatible with maintaining rodent populations in southeastern United States Coastal Plain pine plantations. This study adds to the growing body of research indicating that wildlife in southeastern pine plantations generally are not influenced by harvest of low-value trees or other logging residue for bioenergy (Fritts et al. 2015a, b, 2016; Grodsky et al. 2016a, b).

**ACKNOWLEDGMENTS**

We thank K. H. Pollock, T. B. Wigley, and E. D. Vance for contributions to statistical analyses and reviews of early versions of this manuscript. Special thanks to M. E. Adams, J. W. Bowser, J. L. Eells, J. M. Kiser, J. S. Kraus, W. M. Moore, and J. H. O’Connor, for field data collection. Funding was provided by the United States Department of Agriculture National Institute of Food and Agriculture Managed Ecosystems Program, the Department of the Interior Southeast Climate Science Center, the Biofuels Center of North Carolina, the North Carolina Bioenergy Initiative, Weyerhaeuser Company, Plum Creek, Georgia Pacific, and the National Council for Air and Stream Improvement

**LITERATURE CITED**


Fritts et al.  Rodent Response to Woody Biomass Harvest


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Associate Editor: Amy Kuenzi.

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher’s website.