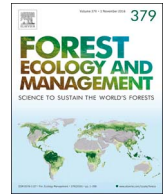




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## Variable responses of non-native and native ants to coarse woody debris removal following forest bioenergy harvests

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### ABSTRACT

Timber harvests may facilitate ant invasions of forested landscapes, fostering interactions between non-native and native ants. Harvests that include removal of low-value woody biomass as forest bioenergy feedstock may reduce residual coarse woody debris, thereby altering food and cover resources for ant species. We manipulated: (1) volume and distribution of coarse woody debris in stand-scale treatments ranging from intensive coarse woody debris removal to no coarse woody debris removal; and (2) coarse woody debris availability at microsite locations within stand-scale treatments, including piles of hardwood stems, piles of conifer stems, and no pile locations in North Carolina, USA and windrows (i.e., long, linear piles of harvest residues) and no windrows in Georgia, USA, in recently clearcut pine plantations ( $n = 4$  per state). We captured ants in regenerating stands and tested treatment- and location-level effects on non-native and native ant relative abundances. Invasive ants represented 19% of ant taxa richness, but comprised 94% of total ant captures. Red imported fire ant (*Solenopsis invicta* Buren, hereafter “RIFA”) dominated the ant community in young plantations. RIFA avoided windrows, but its relative abundance did not differ among stand-scale treatments. Coarse woody debris retention in stand-scale treatments and at microsite locations favored non-RIFA ants, including Asian needle ant (*Brachyponera chinensis* Emery) and several native ant species. Dual invasions of RIFA and Asian needle ant in young plantations of the eastern United States may commonly occur because the two species may not compete for resources on the forest floor. Reduction of coarse woody debris via intensified woody biomass harvesting may negatively affect non-RIFA ant species and promote RIFA colonization, thereby indirectly increasing deleterious effects of RIFA on other wildlife.

### 1. Introduction

Globally, ants are among the most dominant and detrimental invasive species (Holway et al., 2002; Tsutsui and Suarez, 2002). Invasive ants may pose human health risks associated with medical complications from stings and inflict costly damage to agroecosystems (e.g., interference with integrated pest management practices, crop damage) and property (e.g., ground disturbance from mounds) (DeShazo et al., 1990; Pimentel et al., 2005). Non-native ants may cause significant decreases in biodiversity and disturb ecological networks germane to ecosystem function and integrity (Ness et al., 2004). In addition to displacing some native ants, non-native ants may negatively affect soil

biota, other invertebrates, and vertebrates via soil disturbance, competition for resources, and predation (Lessard et al., 2009; Lach and Hooper-Bui, 2010). Non-native ants are difficult to control and nearly impossible to eradicate once established, so their management often is a conservation priority (Holway et al., 2002).

Successful colonization and relatively high abundances of non-native ant species are often linked to anthropogenic disturbance (King and Tschinkel, 2008). For example, timber harvests in intensively managed plantations of the southeastern United States create conditions conducive to disturbance-mediated colonization of non-native ants (Zettler et al., 2004; Todd et al., 2008). These harvests create widely distributed patches of disturbed forest over large land areas, which likely facilitates

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range expansions of non-native ants in the region (Zettler et al., 2004). Approximately 22% of all timberland in the southeastern United States is plantation forest in the Coastal Plain and Piedmont Physiographic Regions; most of these plantations are harvested via clearcutting (Siry, 2002; Oswalt et al., 2014). Red imported fire ant (*Solenopsis invicta*; hereafter “RIFA”) are well-known invaders of disturbed forests in the Coastal Plain and Piedmont Physiographic Regions of the southeastern United States. RIFA is a notorious invasive species throughout most of the southern United States, especially in areas with frequent anthropogenic disturbance, and has well-documented, deleterious effects on other wildlife (e.g., displacement, mortality) in the region (see Allen et al., 2004). Meanwhile, Asian needle ant (*Brachyponera chinensis* Emery) is known to have invaded relatively undisturbed, mature forests in the southeastern United States (Canter, 1981; Guénard and Dunn, 2010). Most studies of Asian needle ant were conducted in mature forests of the eastern United States; these studies reported localized reductions in abundances of native ants caused by competitive displacement from Asian needle ant invasions (Guénard and Dunn, 2010). Current literature suggests that RIFA is a more noxious invasive species than Asian needle ant in the eastern United States because it has larger colony sizes and it can rapidly exploit disturbed areas. However, studies on ecosystem effects of RIFA invasions currently far outnumber those on Asian needle ant.

Although non-native ant colonization of young plantations often is attributable to anthropogenic disturbance (e.g., timber harvest and site preparation for replanting; see Zettler et al., 2004), species’ success may also be linked to their ability to exploit available habitat structure following timber harvests, including coarse woody debris (e.g., harvest residues) and colonizing pioneer plant species. As such, studies explicitly addressing response of non-native (and native) ants to experimental manipulations of habitat structure in young plantations are warranted. Importantly, both coarse woody debris and vegetation could be managed, especially in production forests, to reduce persistence of non-native ants, should studies suggest that relationships between non-native ants and habitat structure in young plantations indeed exist.

Recent interest in woody biomass as forest bioenergy feedstock may lead to increased extraction of low-value woody material following clearcutting, which may, in turn, affect availability of food and cover resources for ants associated with coarse woody debris (Riffell et al., 2011). Some ant species use coarse woody debris for nesting, while others (e.g., RIFA) nest in bare ground (Harmon et al., 1986; Higgins and Lindgren, 2006). Areas directly adjacent to coarse woody debris piles often provide favorable microhabitat conditions for nesting ants, including a deep litter layer, high concentrations of fine woody debris, and stable microclimate conditions (Spears et al., 2003; Higgins and Lindgren, 2006; Remsburg and Turner, 2006). Additionally, coarse woody debris may support arthropod prey consumed by predatory and omnivorous ant species (Holway et al., 2002; Castro and Wise, 2010). Despite accumulated knowledge of relationships between ants and coarse woody debris in forests, little is known about effects of woody biomass harvesting on interactions between non-native and native ants.

We hypothesized that reduced volume and distribution of coarse woody debris in young plantations would lead to increased RIFA relative abundance because it often nests in bare ground. We also hypothesized that relative abundance of native ants would be greater in areas with greater coarse woody debris availability because they may be competitively excluded from areas with less coarse woody debris by RIFA and because coarse woody debris provides food and cover for several native ant species in the southeastern United States. To test these hypotheses, we quantified ant response to stand-scale, manipulative coarse woody debris removal treatments and microsite manipulations of coarse woody debris availability at locations in recently clearcut stands. Our objectives were to: (1) measure effects of coarse woody debris removal treatments on ant relative abundances in young plantations; and (2) measure effects of groundcover and coarse woody debris availability and pile type (i.e., conifer or hardwood) on ant

relative abundances at microsite locations. The goals of this study were to inform broad forest and coarse woody debris management geared towards native ant conservation and non-native ant management and to improve understanding of local, ecological relationships and interactions among non-native ants, native ants, and coarse woody debris.

## 2. Methods

### 2.1. Study area and design

We studied ants in eight replicate clearcuts (hereafter “blocks”) in intensively managed loblolly pine (*Pinus taeda*) forests within the Coastal Plain Physiographic Region of the southeastern United States. Prior to harvest, blocks were comprised of a planted loblolly pine overstory and a hardwood midstory [e.g., red maple (*Acer rubrum*), American sweetgum (*Liquidambar styraciflua*)]. Our study included four blocks [ $70.5 \pm 6.1$  (mean  $\pm$  SE) ha] in Beaufort County, North Carolina (NC) and four blocks ( $64.64 \pm 3.1$  ha) in Georgia (GA): three in Glynn County and one in Chatham County. Blocks were in the temperate/subtropical biogeographic regions. Frequent, low-intensity, human- and lightning-caused fire was the historical forest disturbance in the southeastern United States, but fire is suppressed in most managed industrial forests of the region (see Grodsky et al., 2016a for management history and site descriptions).

Following clearcut harvests in 2010–2011, we implemented coarse woody debris (i.e., operational harvest residue) removal treatments (hereafter “treatments”) in each block. We used a randomized complete-block experimental design, dividing each block into the following six, stand-scale treatments: (1) clearcut with intensive harvest residue removal (INTREM); (2) clearcut with 15% retention of harvest residues evenly dispersed throughout the treatment (15DISP); (3) clearcut with 15% retention of harvest residues clustered in large piles throughout the treatment (15CLUS); (4) clearcut with 30% retention of harvest residues evenly dispersed throughout the treatment (30DISP); (5) clearcut with 30% retention of harvest residues clustered in large piles throughout the treatment (30CLUS); and (6) clearcut with no harvest residue removal (i.e., clearcut only; NOREM), which served as a reference (see Fritts et al., 2014; Grodsky et al., 2016b; Grodsky et al., 2018 for detailed methods on and maps of stand-scale treatment implementation). We designed harvest residue percent retention and distribution treatments to emulate prescriptions recommended in pre-existing biomass harvesting guidelines for the southeastern United States (see Perschel et al., 2012). In NC, treatment areas averaged  $11.7 \pm 0.5$  ha. In GA, treatment areas averaged  $10.7 \pm 0.4$  ha. We defined harvest residues as non-roundwood stems (i.e., stems unused for pulpwood or sawtimber) and pine tops and limbs traditionally considered non-merchantable prior to the advent of forest bioenergy-driven woody biomass markets. Fritts et al., 2014 published estimates of pre-harvest standing volume ( $\text{m}^3 \text{ha}^{-1}$ ) of non-roundwood stems and coarse woody debris and estimates of post-harvest volume ( $\text{m}^3 \text{ha}^{-1}$ ) of harvest residues in each treatment in NC (see Quantifying stand- and micro-scale habitat characteristics).

Treatment implementation was similar in NC and GA, but preparation of the harvested sites for replanting differed between states. In NC, site preparation occurred following clearcut harvest and implementation of treatments in the winter of 2010–2011. Blocks were sheared using a V-shaped blade, bedded into continuous, mounded strips of soil (hereafter “beds”) approximately 3 m wide and < 1 m tall, and planted with loblolly pine during the fall/winter of 2011–2012 at a density of  $\approx 1100$  trees  $\text{ha}^{-1}$ . Prior to establishment of unplanted vegetation, pine beds consisted of bare soil and pine seedlings. Shearing moved retained coarse woody debris into the 3-m space between pine beds (hereafter “interbeds”). Consequently, coarse woody debris was rearranged following shearing into long, linear rows in interbeds parallel to pine beds (Fig. 1). However, volume of coarse woody debris largely was unaltered by shearing (Fritts et al., 2014). Blocks were

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