GROUND-INHABITING ANTS COLLECTED IN A MIXED HARDWOOD SOUTHERN APPALACHIAN FOREST IN EASTERN TENNESSEE

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ABSTRACT—The ant fauna in four eastern Tennessee mixed hardwood forest sites (cove, slope, open, and tornado-damaged) was sampled using pitfall traps during a two-year study. Ground-dwelling ants were collected at the base of three tree species (*Quercus alba* L., *Acer saccharum* Marsh, and *Liriodendron tulipifera* L.) selected based on their suitability as a food source by the gypsy moth, *Lymantria dispar* L. Twenty-one species of ants representing four subfamilies (Formicinae, Myrmicinae, Ecitoninae, and Ponerinae) were identified. Significantly greater numbers of ants were collected in the cove site (1,361) than in any other site, and significantly fewer were collected in the slope site (711). Also, species diversity was greater in the slope (0.90) and cove (0.87) sites, respectively, and lowest in the tornado-damaged site (0.70).

The Appalachian Mountains of eastern Tennessee support a diverse array of flora and fauna with many species unique to these forest habitats. This biodiversity contributes to the overall forest stability and health. The natural beauty of these forests annually attracts more than 14 million people who contribute more than six billion dollars to Tennessee's economy (May, 1991; Stanton, 1994). In addition, the lumber industry contributes an additional four billion dollars to the economy and provides over 46,000 jobs (Hopper, 1991).

Invasion and establishment of exotic pests, such as the gypsy moth, *Lymantria dispar* L., pose a threat to native insect species and the forests in which they occur. Gypsy moth population outbreaks in recently invaded areas have caused defoliation of millions of hectares resulting in millions of dollars of damage (Gerardi and Grimm, 1979; Ghent, 1994; Grace, 1986). Since its introduction into the United States, the gypsy moth has become established in 16 northeastern and midwestern states and the District of Columbia (USDA, 1996). The gypsy moth front, currently located near Roanoke, Virginia, is predicted to enter the forests of eastern Tennessee within the next decade. Already, isolated infestations have been reported in the Great Smoky Mountains National Park, as well as 23 counties in Tennessee. The repeated defoliation of trees over a vast region may result in major changes in the composition of the fauna and flora, the leaf litter on the forest floor, the quality of streams and rivers, and the availability of food for species residing in forest habitats. When neonate gypsy moth larvae disperse by ballooning, many fall to the ground where they remain for several hours (Weseloh, 1998). Their presence on the ground increases their likelihood for predation (Weseloh, 1990) that is almost exclusively caused by ants, such as *Formica neogagates* Emery and *Formica subsericea* Say (Weseloh, 1989). Other native ant species may be potential predators of the gypsy moth in the southern Appalachians.

Ground-dwelling arthropods such as ants contribute substantially to nutrient cycling and the "maintenance" of soil structural properties (Holldobler and Wilson, 1990; Lobry de Bruyn et al., 1997). Also, ants are important in the dispersal of seeds and fruits of 68 tree species in European forests (Nierhaus, 1995). A gap exists in the knowledge base regarding the ant species inhabiting the diverse hardwood forests in eastern Tennessee. Cole (1940) identified 86 species of ants inhabiting the Tennessee region of the Great Smoky Mountains National Park. Different species of ants live in a variety of habitats and exhibit a diversity of behaviors. Some of the niches occupied include the soil, vegetation, tree trunks, and the canopy of trees. Data collected prior to the massive gypsy moth invasion would be useful to compare with data obtained after the invasion to assess the impact of this exotic pest on native species inhabiting southern Appalachian hardwood forests. Therefore, the objective of this study was to assess the diversity of ground-dwelling ant fauna collected in pitfall traps placed under three tree species known to be susceptible to infestation by the gypsy moth. The overall goal of this study was to identify the potential predators present for use as biological control agents of the gypsy moth in eastern Tennessee.

MATERIALS AND METHODS

The study areas consisted of: 1) cove (36°00′49″N, 84°11′20″W); 2) 45° north facing slope (36°00′10″N, 84°12′34″W); 3) open (36°00′02″N, 84°12′26″W); and 4) the 1993 tornado-damaged (35°59′57″N, 84°12′27″W) sites. All sites were located within a mixed hardwood forest at the University of Tennessee Forestry Experiment Station and Arboretum located in Oak Ridge (Anderson County), Tennessee. At each site (30.5 m^2), three host tree species (white oak, *Quercus alba* L.; sugar maple, *Acer saccharum* Marsh; and tulip poplar, *Liriodendron tulipifera* L.) were selected based on their susceptibility to the gypsy moth and evaluated. All four sites contained a Fullerton series soil type consisting of deep, well-drained cherty soils that formed in residuum dolomite. Sites were located on ridges and hills with a range in slope from 5–45°.

TABLE 1. Understory trees and shrubs associated with *Quercus alba* L., *Acer saccharum* Marsh, and *Liriodendron tulipifera* L. in the University of Tennessee Forestry Experiment Station and Arboretum.

	Number of trees (>1 cm diameter) per species per site											
	White Oak				Sugar Maple				Yellow Poplar			
Host species	1[a]	2	3	4	1	2	3	4	1	2	3	4
Acer rubra L., red maple	8	11	25	12	—	2	1	11	4	6	7	15
Acer saccharum Marsh, sugar maple	1	—	7	—	—	3	7	—	2	1	5	2
Asimina triloba (L.) Dunal., paw-paw	4	—	—	—	—	—	—	—	2	—	—	—
Betula sp., birch	—	—	—	2	—	—	—	—	—	—	—	—
Carya tomentosa (Poir.), mockernut hickory	2	4	5	4	3	6	8	4	2	3	9	3
Cercis canadensis L., red bud	—	3	—	—	—	1	1	—	—	1	—	—
Cornus florida L., flowering dogwood	2	4	2	—	1	—	—	—	4	6	1	—
Euonymus americanus L., strawberry bush	1	—	—	—	—	—	—	—	—	—	—	—
Fagus grandifolia Ehr., American beech	—	—	—	—	—	—	—	—	—	—	—	1
Liriodendron tulipfera L., yellow poplar	—	1	5	1	—	2	1	—	1	1	—	1
Morus rubra L., mulberry	—	2	5	—	—	—	3	3	—	5	2	—
Nyssa sylvatica Mar., black gum	—	6	7	2	—	—	3	1	2	1	3	1
Ostrya virginiana (Miller), hophornbeam	—	—	—	—	1	—	—	—	—	—	—	—
Oxydendrum arboreum (L.), sourwood	2	—	—	—	1	3	1	—	6	—	2	1
Prunus serotina Ehrhart, black cherry	6	12	4	3	2	6	5	4	2	8	13	1
Quercus alba L., white oak	5	—	3	—	1	1	—	—	1	1	5	2
Quercus coccinea Muench., scarlet oak	—	—	—	—	—	—	—	—	1	—	—	—
Quercus prinus L., chestnut oak	1	—	1	4	—	—	—	31	1	—	1	1
Quercus rubra L., northern red oak	—	2	1	—	—	2	—	—	1	—	—	—
Quercus velutina Lam., black oak	—	—	3	—	—	—	—	1	—	—	2	2
Rhamnus caroliniana Walt., buckthorn	1	16	17	—	6	10	4	2	1	4	10	4
Rhus copallina L., winged sumac	—	—	—	1	—	—	—	—	—	—	—	—
Sassafras albidum (Nuttall), sassafras	3	4	3	75	—	—	—	25	3	—	1	7
Tilia americana L., white basswood	—	1	—	—	—	—	—	1	—	2	1	—

[a] Sites: 1 = cove, 2 = slope, 3 = open, and 4 = tornado-damaged.

A listing and analysis of all under story vegetation revealed the four sites to be similar in composition (Table 1).

Four pitfall traps were placed under each of three trees in each site. Each tree had one pitfall trap placed in each of the four cardinal directions from the trunk to one-half the distance to the canopy drip line. Each pitfall trap consisted of a metal receptacle (450 ml) with three to four holes in the bottom for drainage, and a plastic container (120 ml) filled with 20 ml of propylene glycol. A plastic funnel was nested within the container to direct specimens into the unit. Metal receptacles were buried to a depth of 10.5 cm with the top of the receptacle flush with the ground. Wooden covers (30.5 cm by 30.5 cm by 1 cm) supported by four baffles (each 40.6 cm long by 5.1 cm wide) were painted brown for camouflage and waterproofing. These covers were then placed over the pitfall traps to prevent entry of rain or debris.

From the four pitfall traps per tree, specimens were randomly collected weekly from two traps from each of the three trees per site due to the high number of specimens to process. Collections were made from 26 June to 21 November 1997, and from 26 March to 26 August 1998. All specimens were taken to the laboratory, poured onto a pore sieve (250 μm) with a collection pan below to collect the propylene glycol, rinsed with tap water to remove excess propylene glycol, and placed in vials containing 20 ml of 70% ethyl alcohol. Each vial was labeled with collection date, site number, tree number, and trap number. Other arthropods collected were placed in separate vials filled with 70% ethyl alcohol and were not included in this study. In late November 1997, pitfall traps were removed from the plots and returned to the same locations in early March 1998. Specimens collected were pinned, or stored in a vial with 70% ethyl alcohol, identified to species, labeled (family and species name, locality, collector, determiner), and systematically arranged into Cornell drawers for incorporation into the insect museum of The University of Tennessee. Specimens were identified with the assistance of specialists: Karen Vail (University of Tennessee, Knoxville, Tennessee) and Lloyd Davis (USDA, Gainesville, Florida). The identification and classification of the ants follows that presented by Bolton, 1995; Holldobler and Wilson, 1990; and Krombein et. al., 1979.

Data Analysis—All insect data were entered into Excel® and Biota® (Colwell, 1996). The number of ants collected was tabulated per date for each species, site, tree, and trap, and analyzed using SAS (SAS Institute, 1989). Analysis of variance (ANOVA) was used to determine significant differences ($P < 0.05$) among sites and tree species. Means were calculated and separated with a Least Significant Difference (LSD) test for overall abundance of species. Due to unequal variances, data were log transformed before analysis.

Comparisons were made for three parameters: diversity, richness, and evenness in relation to sites and tree species (SAS

TABLE 2. Species of Formicidae collected from pitfall traps in The University of Tennessee Forestry Experiment Station and Arboretum.

Species	Sites collected[a]	Tree[b]	Total specimens collected
Amblyopone pallipes (Halderman)	1, 3	2, 3	3
Aphaenogaster lamellidens Mayr	1, 2, 3, 4	1, 2, 3	695
Aphaenogaster tennesseensis (Mayr)	1, 2, 3, 4	1, 2, 3	71
Aphaenogaster texana Wheeler	1, 2	1	2
Brachymyrmex depilis Emery	1, 3	1, 2, 3	26
Camponotus caryae (Fitch)	1, 2, 3, 4	1, 2, 3	77
Camponotus chromaiodes Bolton	1, 2, 3, 4	1, 2, 3	288
Camponotus pennsylvanicus (DeGeer)	1, 2, 3, 4	1, 2, 3	741
Crematogaster lineolata (Say)	1, 2, 3, 4	1, 3	16
Formica fusca L.	1, 2, 3, 4	1, 2, 3	28
Formica subsericea Say	1, 2, 3, 4	1, 2, 3	90
Formica schaufussi dolosa Buren	1, 2, 3, 4	1, 2, 3	15
Leptothorax pergandei Emery	2	1	1
Myrmecina americana Emery	1, 2, 3, 4	1, 2, 3	25
Neivamyrmex nigrescens (Cresson)	1, 2, 3, 4	1, 2, 3	87
Paratrechina nr. *terricola* (Buckley)	1, 2, 3, 4	1, 2, 3	63
Pheidole dentata Mayr	4	3	1
Ponera pennsylvanica Buckley	1, 2, 3, 4	1, 2	9
Prenolepis imparis (Say)	1, 2, 3, 4	1, 2, 3	1,489
Pyramica pergandei (Emery)	1, 2, 3	1, 2, 3	5
Solenopsis molesta (Say)	4	2	1
			3,733 (Total)

[a] Sites: 1 = cove, 2 = slope, 3 = open, and 4 = tornado-damaged.
[b] Trees: 1 = *Quercus alba* L., 2 = *Acer saccharum* Marsh, and 3 = *Liriodendron tulipifera* (L.).

Institute, 1989). The overall ant diversity for each site and tree species was determined with the Shannon diversity index ($H = -\Sigma(p_i \ln p_i)$, where ln = natural log and p_i = the proportion of individuals of the total sample belonging to the i^{th} species) (Newell, 1997; Smith, 1992). This index considers the number of species as well as their relative abundance. Species richness (*S*) is the total number of species present in an area. Evenness (*J*) was determined by $J = H/H_{max}$ with $H_{max} = \ln S$ where S = species richness (Smith, 1992). Species evenness estimates the equitability, or species density relative to other species, for the group of species collected. Species evenness values range from 0 to 1, with one representing the most even value.

Results and Discussion

Ants collected from pitfall traps during 1997 and 1998 represented 88% (3,733) of all hymenopterans (4,223) captured. These specimens represented 21 species (Table 2) in four subfamilies: Formicinae (12), Myrmicinae (9), Ponerinae (2), and Ecitoninae (1). Significantly ($F = 1.94$; $d.f. = 24$; $P < 0.05$) more ants were collected in the cove site (1,361) than the tornado-damaged site, while the fewest specimens were collected in the slope site (711). Three species *Prenolepis imparis* (Say) (1,489), *Camponotus pennsylvanicus* (DeGeer) (736), and *Aphaenogaster lamellidens* Mayr (695) made up 76.5% of all specimens collected. Diversity and richness of ant species were highest in the cove (0.87, 10.94) and slope (0.90, 10.43) sites, respectively, and lowest in the tornado-damaged (0.70, 8.81) site (Table 3).

Although the slope site had the highest ant species evenness (0.86), it differed significantly only from the cove site. The undisturbed cove habitat with high moisture levels in combination with significant changes in the clear-cut adjacent forest stand attracted 18 ant species. The number of ant species associated with the slope, open, and tornado-damaged sites may be due to the different types of disturbance or because of the different biotic components of each site by reducing canopy cover and available food materials. The tornado-damaged site likely increased potential niches by providing high amounts of dead wood and shade spaces under logs. Most of the ants collected were subterranean and may require higher moisture levels such as were available in the cove site. The slope site may be more suitable for those ant species requiring leaf litter and debris to make their nests. Leaf litter and various types of debris accumulated in areas of the slope site due to water runoff. Downed trees in the tornado-damaged site that reduce canopy cover and contributed to a change in the moisture level of the site may have deterred some ground-dwelling ant populations from moving into these areas. Species that build their nests in logs or stumps would be attracted to this area as the wood rots. Many of the ant species collected form nests in the soil, under stones, or in rotten logs or stumps. Because the ant species generally occurred in all four habitat sites, fewer differences are exhibited within the diversity indices (Table 3). No significant differences ($F = 0.67$; $d.f. = 16$; $P > 0.52$) were found in the number of ant species collected under sugar maple, tulip poplar, or white oak.

Species of *Aphaenogaster* are known to feed on live and dead insects and some species are considered temporary parasites

TABLE 3. Diversity indices of ant species collected in pitfall traps in The University of Tennessee Forestry Experiment Station and Arboretum.[a]

	Species diversity[b]	Species richness	Species evenness[c]
Cove	0.87 ± 0.05 a[d]	10.94 ± 0.17 a	0.75 ± 0.02 b
Slope	0.90 ± 0.05 a	10.43 ± 0.19 a	0.86 ± 0.03 a
Open	0.83 ± 0.05 ab	9.73 ± 0.18 ab	0.81 ± 0.02 ab
Tornado	0.70 ± 0.05 b	8.81 ± 0.18 b	0.81 ± 0.02 ab

[a] Data represent 22 collection dates from 26 June to 21 November 1997 and from 26 March to 26 August 1998.

[b] Shannon diversity index ($H = -\Sigma(p_i \ln p_i)$, where ln = natural log and p_i = the proportion of individuals of the total sample belonging to the i^{th} species) (Newell, 1997; Smith, 1992).

[c] Evenness (J) was determined by $J = H/H_{max}$ using $H_{max} = \ln S$ where S = number of species (Smith, 1992).

[d] Values are means ± *SE.* Means within a column followed by different letters are significantly different (Least Significant Difference Test; $P < 0.05$).

in ground nests of other *Aphaenogaster* species (Krombein et al., 1979). Two species, *Aphaenogaster lamellidens* Mayr and *Aphaenogaster tennesseensis* (Mayr), often produce medium to large colonies in areas within nests in moist rotten logs or limbs. *Aphaenogaster tennesseensis* often is found living in habitats associated with *Aphaenogaster fulva* Roger. Cole (1940) collected both species within similar time periods during his study of the ant fauna in the Great Smoky Mountains National Park. *Brachymyrmex depilis* Emery is the only species of this genus known to the area. Members of this species construct nests in the soil and collect honeydew from root-feeding aphids and scale insects in addition to nectar. Similarly, *Crematogaster lineolata* (Say) is omnivorous, but also shows a preference for nectar and honeydew. Species of *Camponotus* are commonly found at elevations under 1,200 m (Cole, 1940), and were abundant in all research sites (Table 2). *Paratrachina* nr. *terricola* (Buckley) feed on both live and dead insects, seeds, and honeydew (Krombein et al., 1979). Species of this omnivorous genus often build nests under trees; thus, explaining their presence and collection in traps under all tree species. Specimens of *Prenolepis imparis* (Say) were collected during the early spring and fall, and *P. impairs* was the most dominant species collected during the study (Table 2). Species in this genus build nests in the soil in exposed areas or under cover in small to moderate sized colonies (Krombein et al., 1979). *Prenolepis* species are known as "honey ants", with workers called repletes. They feed on a variety of food sources including honeydew, floral secretions, gall exudates, arthropods, and fruit. *Prenolepis* species differ from most ant species because they forage during cool weather and aestivate during the hottest months. Cole (1940) found only five specimens of *P. imparis* in his study of ants. Some species collected appear to be either rare or poorly represented in the ant fauna of these habitats. Only nine specimens of *Ponera pennsylvanica* Buckley were collected, perhaps due to its preference for moist, shady woods and areas where they can build their nests beneath stones and logs (Cole, 1940). Three species (*Leptothorax pergandei* Emery, *Pheidole dentata* Mayr, and *Solenopsis molesta* (Say)), were each represented by only one specimen. Cole (1940) reported that members of the genus *Leptothorax* (and some species of *Pheidole*) often form colonies in the soil with 25 to 50 individuals. Cole (1940) noted that some species of these genera live as guests in the nests of larger ant species. *Pheidole dentata* is unique in its feeding behavior of tending aphids on grasses for the honeydew. Populations of *S. molesta* are usually small as a result of their behavior of living independently in more open areas where they nest beneath stones, wood, or in the galleries of other ant species.

From the 21 species collected, only *Formica fusca* L. is known to be an exotic. This species is found in moderate numbers at both low and high elevations in the area. Probably the most beneficial potential predator collected was *Neivamyrmex nigrescens* (Cresson). This species is a diurnal forager that is highly predaceous on other insects, and can construct large colonies containing 150,000–250,000 workers (Krombein *et al.,* 1979). We did not collect the gypsy moth predator *F. neogagates,* but did find 90 specimens of *F. subsericea* associated with all three host trees in all sites.

The high species diversity and evenness in the cove site suggest this site provides the microclimatic environment, habitat requirements, and food resources necessary to support a wide range of species. Diversity indices suggest that the four sites are generally species diverse with an even representation of the species inhabiting these mixed hardwood habitats. Ant diversity was highest in the cove and slope sites and lowest in the tornado-damaged site. Natural disturbances may have disrupted ant activity and downed trees may have lowered the suitability of this area to ant activity. The slope site had the highest evenness for ant species. Many of the ant species inhabiting the slope site typically build their nests in leaf litter and debris, both of which were accumulated and deposited in this site due to heavy rain water runoff. These findings support the conclusion by Weseloh (1998) that ant numbers are correlated to the habitat types present in a forest.

Although more ants also were collected in pitfall traps placed under sugar maple than in traps placed under tulip poplar, no significant differences were noted among tree species. The large, dense canopy of sugar maple may provide more shelter for these ground-dwelling insects. The higher number of ants collected under sugar maple suggests that many ant species are attracted to its sugary sap when exposed on the surface. Sugar maples (21–30 m in height) and white oak (24–30 m in height) are generally shorter with sparser, but wider canopies than tulip poplar (80–120 m in height) (Little, 1996). Conversely, tulip poplar has a long, straight trunk and a narrow crown occurring high above the forest floor (Little, 1996). This tree may not provide as much shelter for ground-dwelling ant species and may be the reason fewer ants were collected in pitfall traps associated with this tree species. The wide spread branches and rounded crown of white oaks also may be a factor in the number of species associated with the ground cover under these trees. The under story vegetation was similar for each of the three host trees in each of the four sites, which may, in part, explain the lack of significant differences among the numbers of insects collected in traps under the three tree species.

Collections made in these forest habitats suggest a stable community with several different ecological guilds represented. A comparison of the ants collected after the gypsy moth is established in eastern Tennessee may help to determine the impact of this exotic pest on native southern Appalachian forests. We found the predaceous species, *F. subsericea,* to be widely distributed throughout the area, which may provide the opportunity to use this species in the future to suppress populations of the invasive gypsy moth. Additional studies to find predaceous ant species or to establish them in the area may aid in protecting the forest against invasive pest species such as the gypsy moth.

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