DIVERSITY OF GROUND-DWELLING INSECTS IN A MIXED HARDWOOD SOUTHERN APPALACHIAN FOREST IN EASTERN TENNESSEE

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ABSTRACT—Insects were sampled using pitfall traps during a two-year study in four mixed hardwood forest sites (cove, slope, open, and tornado-damaged) to determine their diversity beneath three dominant tree species: white oak, *Quercus alba* L.; sugar maple, *Acer saccharum* Marsh; and tulip poplar, *Liriodendron tulipifera* L. From pitfall traps, 191 species were identified representing 69 families in 15 orders. Significantly greater numbers of insects were collected in the cove site than in the slope or tornado-damaged sites. Also, species diversity and evenness were significantly greater in the cove site. Beetles represented 65% of the species identified at the four sites. Beetle diversity and richness did not differ significantly among the four sites, although species evenness was significantly lower in the tornado-damaged site.

The natural beauty and biodiversity of southern Appalachian forests attract more than 14 million people to the region annually. As a result, tourism contributes over 12 billion dollars per year to Tennessee's economy (Travel Industry Association, 2006). The Great Smoky Mountains National Park attracts more than nine million visitors annually who contribute to the local economy. The southern Appalachian economy relies heavily on the resulting public service, retail sales, outdoor recreation and forestry practices generated (Travel Industry Association, 2006). About 87% of Tennessee forests are comprised of hardwoods, making Tennessee one of the nation's leading hardwood lumber manufacturers. Employment and income in the region have remained stable over the last 20 years due in large part to the tourism and wood products industries (Travel Industry Association, 2006; Southern Appalachian Man and Biosphere Cooperative, 1996) which annually create more than 225,000 jobs.

The Appalachian mountains of eastern Tennessee support a diverse array of flora and fauna and many species are unique to these forest ecosystems (Buck et al., 2005). These species contribute to the overall forest stability and health. Invasion and establishment of exotic pests are considered one of the primary causes for disruption of habitats, posing significant threats to native insect species and the forests in which they occur. For example, population outbreaks of the gypsy moth, *Lymantria dispar* (L.), have caused defoliation of millions of hectares of forests, resulting in millions of dollars of damage (Ghent, 1994; Grace, 1986). Since its introduction into the United States, the gypsy moth has become established in most of the northeastern and midwestern states and the District of Columbia (USDA, 1996). The movement of the gypsy moth front, currently located near Roanoke, Virginia, has been reduced from 10.9 to 4.8 km per year by the "Slow the Spread Program". This slower movement has delayed the predicted time this pest will significantly impact forests in eastern Tennessee (Sharov et al., 2002). However, isolated infestations have been reported in the Great Smoky Mountains National Park, as well as in 71 counties in Tennessee (Strohmeier, 2006).

The gypsy moth is capable of repeated defoliation of trees over vast regions, resulting in major changes in flora, fauna and leaf litter composition, the quality of streams and rivers draining affected marshlands, and food availability for species residing in forest habitats. Understanding the ground-dwelling insect species composition of this hardwood forest may help to determine the impact of the gypsy moth, once established, on the insect composition and on the health of native southern Appalachian hardwood forests in eastern Tennessee. To date, no comprehensive study on the diversity of ground-dwelling insects in hardwood forests in eastern Tennessee has been conducted. Insect data collected prior to the anticipated gypsy moth invasion will be useful to assess the impact of the gypsy moth on native species inhabiting southern Appalachian hardwood forests. Such information also may be useful in identifying potential natural enemies of this exotic pest and provide a better understanding of the importance of species composition, seasonality, abundance, and diversity in southern Appalachian forest habitats. Over the past two decades, several exotic pests, such as the balsam woolly adelgid, *Adelges piceae* (Rathzeburg), beech scale, *Cryptococcus fagisuga* Lind., elongate hemlock scale, *Fiorinia externa* Ferris, and hemlock woolly adelgid, *Adelges tsugae* (Annand), have become established in Tennessee and have the potential to dramatically change the composition of the fauna and flora within the area (Hughes, 1993; Lambdin et al., 2005; Vance, 1995). These data will be useful as a standard for comparing the impact of such invasive pests on insect diversity. Therefore, a study was initiated in 1997 to: 1) determine the overall diversity of ground-dwelling insects associated with three dominant tree species, and 2) determine the size of the ground-dwelling beetle populations within the area.

TABLE 1. Total number of insect species collected using pitfall traps at four mixed hardwood sites in The University of Tennessee Forestry Experiment Station and Arboretum in 1997 and 1998.

Order	Family	Genus	Species	Author	No. Collected
Diplura	Japygidae	Undet.	sp.		1
Microcoryphia	Machilidae	*Thermobia*	*domestica*	(Pack.)	1
Thysanura	Lepismatidae	*Lespisma*	*saccharina*	(L.)	2
Orthoptera	Gryllacrididae	*Ceuthophilus*	sp.		5
Orthoptera	Gryllidae	*Gryllus*	sp.		1
Orthoptera	Nemobiidae	*Nemobius*	sp.		3
Orthoptera	Tettigoniidae	*Atlanticus*	sp.		1
Blattaria	Blattellidae	*Ischnoptera*	*deropeltiformis*	(Brunner)	4
Blattaria	Blattellidae	*Parcoblatta*	*bolliana*	(Saussure and Zehntner)	1
Isoptera	Rhinotermitidae	Undet.	sp.		1
Plecoptera	Undet.	Undet.	sp.		1
Psocoptera	Psocidae	*Indiopsocus*	sp.		1
Psocoptera	Psocidae	Undet.	sp.		2
Hemiptera	Undet.	Undet.	sp. 1		1
Hemiptera	Undet.	Undet.	sp. 2		1
Hemiptera	Undet.	Undet.	sp. 3		1
Hemiptera	Aphididae	Undet.	sp.		1
Hemiptera	Cicadellidae	Undet.	sp. 1		1
Hemiptera	Cicadellidae	Undet.	sp. 2		1
Hemiptera	Cixiidae	Undet.	sp.		1
Thysanoptera	Thripidae	Undet.	sp.		1
Neuroptera	Chrysopidae	*Chrysopa*	sp.		1
Neuroptera	Myrmeleontidae	*Ascaloptynx*	*appendiculatus*	(F.)	1
Coleoptera	Agyrtidae	*Necrophilus*	*pettiti*	Horn	4
Coleoptera	Anobiidae	*Tricorynus*	sp.		1
Coleoptera	Anthicidae	*Tomoderus*	sp.		1
Coleoptera	Carabidae	*Chlaenius*	*emarginatus*	Say	2
Coleoptera	Carabidae	*Cyclotrachelus*	*conviva*	LeConte	5
Coleoptera	Carabidae	*Cyclotrachelus*	*freitagi*	Bousquet	12
Coleoptera	Carabidae	*Cyclotrachelus*	*fucatus*	Freitag	15
Coleoptera	Carabidae	*Cyclotrachelus*	*sigillata*	(Say)	4
Coleoptera	Carabidae	*Cyclotrachelus*	*sodalis*	(LeConte)	4
Coleoptera	Carabidae	*Dicaelus*	*ambiguus*	Laferte	1
Coleoptera	Carabidae	*Dicaelus*	*dilatatus*	Say	4
Coleoptera	Carabidae	*Dicaelus*	*politus*	Dejean	12
Coleoptera	Carabidae	*Dicaelus*	*teter*	Bonelli	10
Coleoptera	Carabidae	*Galerita*	*bicolor*	Drury	136
Coleoptera	Carabidae	*Galerita*	sp.		1
Coleoptera	Carabidae	*Harpalus*	*fulgens*	Csiki	2
Coleoptera	Carabidae	*Melanius*	*caudicalis*		1
Coleoptera	Carabidae	*Notobia*	sp.		36
Coleoptera	Carabidae	*Notiophilus*	*novemstriatus*	LeConte	1
Coleoptera	Carabidae	*Platynus*	*decentis*	(Say)	2
Coleoptera	Carabidae	*Pterostichus*	*coracinus*	Newman	1
Coleoptera	Carabidae	*Scaphinotus*	*andrewsi*	L.	1
Coleoptera	Carabidae	*Selenophorus*	*opalinus*	LeConte	2
Coleoptera	Carabidae	*Sphaeroderus*	*lecontei*	Dejean	17
Coleoptera	Carabidae	*Sphaeroderus*	*stenostomus*	Weber	5
Coleoptera	Carabidae	*Stenolophus*	sp.		1
Coleoptera	Chrysomelidae	*Demotina*	*modesta*	Baly	1
Coleoptera	Chrysomelidae	*Lupraea*	*picta*	(Say)	1
Coleoptera	Chrysomelidae	Undet. Alticinae	sp.		1
Coleoptera	Chrysomelidae	Undet.	sp.		1
Coleoptera	Cicindellidae	*Cicindela*	*unipunctata*	F.	1

TABLE 1. Continued.

Order	Family	Genus	Species	Author	No. Collected
Coleoptera	Coccinellidae	Undet.	sp.		1
Coleoptera	Corylophidae	*Bathona*	sp.		1
Coleoptera	Cryptophagidae	*Cryptophagus*	sp.		1
Coleoptera	Cryptophagidae	*Cryptophagus*	sp.		1
Coleoptera	Curculionidae	*Conotrachelus*	*elegans*	(Say)	12
Coleoptera	Curculionidae	*Conotrachelus*	*posticatus*	Boheman	2
Coleoptera	Curculionidae	*Cyrtepistomus*	*castaneus*	(Roelofs)	7
Coleoptera	Curculionidae	*Dryophthorus*	*americanus*	Bedel	1
Coleoptera	Curculionidae	*Odontopus*	*calceatus*	(Say)	3
Coleoptera	Elateridae	*Hemicrepidus*	*memnonius*	(Herbst)	2
Coleoptera	Elateridae	*Melanotus*	sp.		1
Coleoptera	Elateridae	Undet.	sp. 1		1
Coleoptera	Elateridae	Undet.	sp. 2		1
Coleoptera	Eucinetidae	*Eucinetus*	*strigiosus*	LeConte	1
Coleoptera	Geotrupidae	*Geotrupes*	*blackburnii*	Say	3
Coleoptera	Geotrupidae	*Geotrupes*	*splendidus*	(F.)	15
Coleoptera	Histeridae	*Euspilotus*	sp.		9
Coleoptera	Histeridae	*Hister*	sp.		1
Coleoptera	Histeridae	*Onthophilus*	*pleuricostatus*	LeConte	1
Coleoptera	Hydrophilidae	*Cercyon*	sp. 1		20
Coleoptera	Hydrophilidae	*Cercyon*	sp. 2		1
Coleoptera	Leiodidae	*Anisotoma*	sp.		19
Coleoptera	Leiodidae	*Catops*	*simplex*	Say	1
Coleoptera	Leiodidae	*Catops*	sp.		5
Coleoptera	Leiodidae	*Colon*	sp. 1		1
Coleoptera	Leiodidae	*Colon*	sp. 2		1
Coleoptera	Leiodidae	*Dissochaetus*	*oblitus*	(LeConte)	6
Coleoptera	Leiodidae	*Geomysaprinus*	*posthumus*	(Marseul)	2
Coleoptera	Leiodidae	*Geomysaprinus*	sp.		3
Coleoptera	Leiodidae	*Nemadus*	sp.		1
Coleoptera	Leiodidae	*Prionochaeta*	*opaca*	(Say)	1
Coleoptera	Leiodidae	*Ptomophagus*	sp.		48
Coleoptera	Leptinidae	*Leptinus*	*testaceous*	Meuller	1
Coleoptera	Leptodiridae	*Namadus*	sp.		73
Coleoptera	Mordellidae	*Mordellistena*	*pubescens*	(F.)	1
Coleoptera	Nitidulidae	*Colopterus*	*truncata*	(Randall)	18
Coleoptera	Nitidulidae	*Epuraea*	sp.		1
Coleoptera	Nitidulidae	*Pallodes*	*palidus*	(Beauvois)	5
Coleoptera	Nitidulidae	*Phenolia*	*grossa*	(F.)	2
Coleoptera	Nitidulidae	*Stelidota*	*octomaculata*	(Say)	206
Coleoptera	Nitidulidae	Undet.	sp.		1
Coleoptera	Orthoperidae	*Sericoderus*	*lateralis*	(Gyllenhal)	1
Coleoptera	Ptiliidae	*Acrotrichis*	sp.		1
Coleoptera	Ptiliidae	*Nephanes*	sp.		54
Coleoptera	Ptiliidae	Undet.	sp.		8
Coleoptera	Ptilodactylidae	*Ptilodactyla*	sp.		3
Coleoptera	Rhysodidae	*Clinidium*	*sculptile*	(Newman)	7
Coleoptera	Scaphidiidae	*Scaphidium*	*quadriguttatum*	Melsheimer	3
Coleoptera	Scaphidiidae	Undet.	sp.		1
Coleoptera	Scarabaeidae	*Aphodius*	sp.		10
Coleoptera	Scarabaeidae	*Ateuchus*	*histeroides*	Weber	29
Coleoptera	Scarabaeidae	*Canthon*	*hudsonias*	Forster	2
Coleoptera	Scarabaeidae	*Canthon*	*viridis*	(Palisot de Beauvois)	87
Coleoptera	Scarabaeidae	*Copris*	*minutus*	(Drury)	23
Coleoptera	Scarabaeidae	*Deltochilum*	*gibbosus*	(F.)	21
Coleoptera	Scarabaeidae	*Glaphyrocanthon*	*viridis*	(Beauvois)	159

TABLE 1. Continued.

Order	Family	Genus	Species	Author	No. Collected
Coleoptera	Scarabaeidae	*Onthophagus*	*hecate*	Panzer	5
Coleoptera	Scarabaeidae	*Onthophagus*	*janus*		56
Coleoptera	Scarabaeidae	*Onthophagus*	*pennsylvanicus*	Harris	2
Coleoptera	Scarabaeidae	*Onthophagus*	*striatulus*	(Beauvois)	135
Coleoptera	Scarabaeidae	*Phyllophaga*	*hirticula*	(Knoch)	1
Coleoptera	Scarabaeidae	*Phyllophaga*	*ilicis*	(Knoch)	1
Coleoptera	Scolytidae	*Dendroctonus*	*frontalis*	Zimmermann	9
Coleoptera	Scolytidae	Undet.	sp.		1
Coleoptera	Scydmaenidae	*Noctophus*	sp.		2
Coleoptera	Silphidae	*Nicrophorus*	*orbicolis*	Say	10
Coleoptera	Silphidae	*Nicrophorus*	*pustulatus*	Herschel	1
Coleoptera	Staphylinidae	*Bryoporus*	*rufescens*	LeConte	2
Coleoptera	Staphylinidae	*Dasycerus*	sp.		1
Coleoptera	Staphylinidae	*Hoplandria*	*laeviventris*	Casey	64
Coleoptera	Staphylinidae	*Hoplandria*	sp.		197
Coleoptera	Staphylinidae	*Lobrathium*	*collare*	Erichson	218
Coleoptera	Staphylinidae	*Oxytelus*	*exiguus*	Erichson	381
Coleoptera	Staphylinidae	*Philonthus*	*blandus*	Erichson	2
Coleoptera	Staphylinidae	*Philonthus*	*cyanipennis*	(F.)	1
Coleoptera	Staphylinidae	*Philonthus*	sp.		1
Coleoptera	Staphylinidae	*Platydracus*	*fossator*	Gravenhorst	22
Coleoptera	Staphylinidae	*Platydracus*	*maculosus*	Gravenhorst	20
Coleoptera	Staphylinidae	*Tachinus*	*fimbriatus*	Gravenhorst	33
Coleoptera	Staphylinidae	Undet.	sp. 1		86
Coleoptera	Staphylinidae	Undet.	sp. 2		6
Coleoptera	Staphylinidae	Undet.	sp. 3		2
Coleoptera	Staphylinidae	Undet.	sp. 4		17
Coleoptera	Staphylinidae	Undet.	sp. 5		1
Coleoptera	Staphylinidae	Undet.	sp. 6		9
Coleoptera	Staphylinidae	Undet.	sp. 7		1
Coleoptera	Staphylinidae	Undet.	sp. 8		1
Coleoptera	Staphylinidae	Undet.	sp. 9		5
Coleoptera	Staphylinidae	Undet.	sp. 10		8
Coleoptera	Staphylinidae	Undet.	sp. 11		1
Coleoptera	Tenebrionidae	*Anaedus*	*brunneus*	(Ziegler)	5
Coleoptera	Troginae	*Trox*	*variolatus*	Melsheimer	1
Siphonaptera	Ctenophthalmidae	*Ctenophthalmus*	sp.		1
Diptera	Calliphoridae	Undet.	sp.		1
Diptera	Cecidomyiidae	Undet.	sp.		1
Diptera	Chironomidae	Undet.	sp.		1
Diptera	Chloropidae	Undet.	sp.		4
Diptera	Drosophilidae	Undet.	sp.		1
Diptera	Muscidae	Undet.	sp.		1
Diptera	Otitidae	Undet.	sp.		1
Diptera	Phoridae	Undet.	sp.		221
Diptera	Psychodidae	Undet.	sp.		5
Diptera	Rhagionidae	Undet.	sp.		1
Diptera	Sarcophagidae	Undet.	sp.		2
Diptera	Sciaridae	Undet.	sp.		1
Diptera	Sphaeroceridae	Undet.	sp.		1
Diptera	Tachinidae	Undet.	sp.		2
Diptera	Tipulidae	Undet.	sp.		1
Hymenoptera	Eulophidae	Undet.	sp.		1
Hymenoptera	Formicidae	*Amblyopone*	*pallipes*	(Halderman)	3
Hymenoptera	Formicidae	*Aphaenogaster*	*lamellidens*	Mayr	695
Hymenoptera	Formicidae	*Aphaenogaster*	*tennesseensis*	(Mayr)	71
Hymenoptera	Formicidae	*Aphaenogaster*	*texana* var. *carolinensis*	Wheeler	2

TABLE 1. Continued.

Order	Family	Genus	Species	Author	No. Collected
Hymenoptera	Formicidae	*Brachymyrmex*	*heeri depilis*	Emery	26
Hymenoptera	Formicidae	*Camponotus*	*caryae*	(Fitch)	77
Hymenoptera	Formicidae	*Camponotus*	*chromaiodes*	Bolton	288
Hymenoptera	Formicidae	*Camponotus*	*herculeans pennsylvanicus*	DeGeer	741
Hymenoptera	Formicidae	*Crematogaster*	*lineolata*	(Say)	16
Hymenoptera	Formicidae	*Formica*	*fusca*	L.	28
Hymenoptera	Formicidae	*Formica*	*fusca* var. *subsericea*	Say	90
Hymenoptera	Formicidae	*Formica*	*pallide-fulva schaufussi* var. *dolosa*	Wheeler	15
Hymenoptera	Formicidae	*Leptothorax*	*pergandei*	Emery	1
Hymenoptera	Formicidae	*Leptothorax*	*tennesseensis*	Cole	1
Hymenoptera	Formicidae	*Myrmecina*	*graminicola americana*	Emery	25
Hymenoptera	Formicidae	*Neivamyrmex*	*nigrescens*	(Cresson)	87
Hymenoptera	Formicidae	*Paratrechina*	*terricola*	(Buckley)	63
Hymenoptera	Formicidae	*Pheidole*	*dentata*	Mayr	1
Hymenoptera	Formicidae	*Ponera*	*pennsylvanica*	Buckley	9
Hymenoptera	Formicidae	*Prenolepis*	*imparis*	(Say)	36
Hymenoptera	Formicidae	*Prenolepis*	*imparis* var. *pumila*	Wheeler	29
Hymenoptera	Formicidae	*Prenolepis*	*imparis* var. *testacea*	Emery	1424
Hymenoptera	Formicidae	*Pyramica*	*pergandei*	(Emery)	5

MATERIALS AND METHODS

Site Description—Four collection sites (cove: 36°00′49″N, 84°11′20″W, slope: 36°00′10 N, 84°12′34″W, open: 36°00′02″N, 84°12′26″W, and tornado-damaged: 35°59′57″N, 84°12′27″W) within a mixed hardwood forest were selected in the University of Tennessee Forestry Experiment Station and Arboretum located in Oak Ridge, Tennessee. At each site (30.5 m^2), one tree from each of three host tree species (white oak, *Quercus alba* L.; sugar maple, *Acer saccharum* Marsh; and tulip poplar, *Liriodendron tulipifera* L.) was selected. These trees were chosen based on their demonstrated susceptibility to the gypsy moth as determined by Montgomery (1990) and Twery (1990). All four sites contain a Fullerton series soil type consisting of deep, well-drained cherty soils that formed in dolomite. Sites were located on ridges and hills with a range in slope from 5 to 45°. Overstory and understory vegetation present within the sites was reported by Gibbs et al. (2003).

Collection of Insect Specimens—Four pitfall traps were placed under the canopy (one in each cardinal direction near drip line) of each of three trees in each site in mid-June 1997. Two pitfall samples were alternately collected weekly from each tree from 26 June to 21 November 1997 and from 26 March to 26 August 1998. In late November 1997, pitfall traps were removed from the sites and returned to the same location in early March 1998. Each pitfall trap consisted of a metal receptacle (450 ml) with holes in the bottom for drainage, and a specimen container (120 ml) filled with 20 ml of a 50/50 composition of propylene glycol and water. A plastic funnel was nested within the container to direct specimens into the unit. 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) supported by four baffles (each 40.6 cm long) were painted brown for camouflage and water-proofing. These covers were placed over the pitfall traps to help direct insects into the containers and prevent entry of rain or debris.

Insect 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. Specimens were later removed from the alcohol vials and pinned, 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.

Data Analyses—Data were incorporated into Excel® and Biota® databases (Colwell, 1996). The overall insect and tree species diversity for each site was determined with the Shannon diversity index (Newell, 1997; Smith, 1992). This index considers the number of species as well as their relative abundance to define species richness. A separate Shannon evenness measurement was calculated. Species evenness values range from 0 to 1, with one representing the most even value. Mean estimates were calculated separately using Proc GLM (SAS Institute, 1997) for overall abundance of species. Data were analyzed using SAS procedures (SAS Institute, 1997, 1989) with analysis of variance (ANOVA) used to determine significant differences ($P < 0.05$) in species diversity, species richness, and species evenness, as well as differences among beetle species, among sites and tree species.

RESULTS AND DISCUSSION

From 6,504 insect specimens collected from pitfall traps during 1997 and 1998, 191 species were determined from 69 families representing 15 orders (Table 1). The highest number of species was in the orders Coleoptera (123 species), Hymenoptera (24 species) and Diptera (15 species). Significantly ($P < 0.05$) greater numbers of insect species (species richness) were collected in the cove site (44) than in the slope

TABLE 2. Mean (± *SE*) diversity indices for species collected at each site in The University of Tennessee Forestry Experiment Station and Arboretum[a], 1997 and 1998.

	Species Diversity[b]	Species Richness	Species Evenness
Cove	1.75 ± 0.05 a	44.14 ± 0.52 a	0.67 ± 0.02 a
Slope	1.44 ± 0.05 b	38.68 ± 0.56 b	0.59 ± 0.02 b
Open	1.56 ± 0.05 b	40.64 ± 0.55 ab	0.62 ± 0.02 b
Tornado-damaged	1.51 ± 0.05 b	38.82 ± 0.54 b	0.61 ± 0.02 b

[a] Data represent 22 collection dates from 26 June to 21 November 1997 and from 26 March to 26 August 1998. Means followed by the same letters are not significantly different (LSD Test; $P > 0.05$).

[b] Shannon diversity index ($H = -\exists(p_i \ln p_i)$, 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). Evenness (J) was determined by $J = H/H_{max}$ using $H_{max} = \ln S$ where S = number of species (Smith, 1992).

(38) or tornado-damaged sites (38), while the open site (41) did not differ significantly ($P > 0.05$) from the other sites (Table 2). The higher number of insects associated with the cove site may be the result of most ground-dwelling insects requiring habitats in sheltered forested areas with high moisture levels. Species diversity (1.75) and species evenness (0.67) was highest among insects collected in the cove site, possibly as a result of a denser canopy cover and a more open forest floor. In the winter of 1997, a neighboring forest stand was clear-cut, and this disturbance may have caused more insects to move into the cove site. Also, after heavy rains, a portion of the cove site retains water. The associated increase in overall soil moisture content may benefit many insects inhabiting the cove site by helping them avoid desiccation during the dry summer months. Diversity indices suggest the four sites are generally species diverse with an even representation of the species inhabiting this mixed hardwood ecosystem.

Thirty-two families of beetles were collected with 84% of the specimens collected in four families: Staphylinidae (43%), Scarabaeidae (21%), Carabidae (11%) and Nitidulidae (9%). Beetle species diversity and richness did not differ among the four sites. However, species evenness was significantly ($P < 0.05$) lower in the tornado-damaged site (0.89) when compared to the open site (0.95) (Table 3). The increased availability of habitats and food may have contributed to the lower species evenness value throughout the open site compared to the tornado-damaged site.

No significant differences were noted for the number of insect species collected from underneath the canopy of sugar maple, tulip popular, or white oak. Differences were found, however, for beetles in relation to host tree. Significantly ($P <= 0.05$) greater numbers of beetles were collected under sugar maple and fewer under tulip poplar. However, the number of beetles collected under white oak did not differ significantly ($P < 0.05$) from that obtained under sugar maple or tulip poplar trees. The higher number of beetle specimens collected under sugar maple may suggest that many species are attracted to its sugary sap when exposed on the surface (or to other insects that feed on these sugars). Sugar maple and white oak are generally shorter but have sparser and wider canopies than tulip poplar (Little, 1996). The large, dense canopy of sugar maple may provide more shelter for these ground-dwelling insects. White oak also has many wide-spreading branches and a rounded crown. Conversely, the 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 dwellers and may be the reason fewer beetles were collected in pitfall traps associated with this tree species.

TABLE 3. Mean (± *SE*) diversity indices of beetle species collected in pitfall traps at each site in The University of Tennessee Forestry Experiment Station and Arboretum[a], 1997 and 1998.

	Species Diversity[b]	Beetles Species Richness	Species Evenness
Cove	0.94 ± 0.07 a	12.22 ± 0.30 a	0.92 ± 0.01 ab
Slope	0.81 ± 0.07 a	11.17 ± 0.33 a	0.92 ± 0.02 ab
Open	0.98 ± 0.07 a	11.29 ± 0.31 a	0.95 ± 0.01 a
Tornado-damaged	0.95 ± 0.07 a	10.96 ± 0.30 a	0.89 ± 0.01 b

[a] Data represent 22 collection dates from 26 June to 21 November 1997 and from 26 March to 26 August 1998. Means followed by the same letter do not differ significantly (LSD Test; $P > 0.05$)

[b] Shannon diversity index ($H = -\exists(p_i \ln p_i)$, 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). Evenness (J) was determined by $J = H/H_{max}$ using $H_{max} = \ln S$ where S = number of species (Smith, 1992).

CONCLUSIONS

The higher species diversity and evenness in the cove site was most likely a result of the site's sheltered location and higher moisture levels compared to the other three sites. Beetle species diversity and richness did not differ significantly ($P > 0.05$) among the four sites, although species evenness was significantly ($P < 0.05$) higher in the open site and lower in the tornado-damaged site. Also, more beetles were collected in pitfall traps placed under sugar maple, and significantly fewer were collected under tulip poplar. Pitfall traps placed under white oak did not yield significantly different numbers of beetles in comparison to the other two tree species.

These forest habitats provide a stable community with many different guilds represented. Although various arthropod sampling techniques exist, the use of pitfall traps is an effective and uniform means of collecting ground-dwelling arthropods (Topping and Sunderland, 1992). For example, the carabid beetle, *Calosoma sycophanta* L., is a gypsy moth predator that has successfully colonized in North America (Leonard, 1981). *Calosoma sycophanta* was imported into the United States from central Europe between 1906 and 1926 (Spieles and Horn, 1998) and released in New England as a biological control agent for the gypsy moth. Since its introduction, it has been helpful in reducing gypsy moth outbreaks (Bess, 1961; Weseloh, 1985, 1990), but it has a substantial impact on gypsy moth populations beginning two or more years after the initial outbreak (Spieles and Horn, 1998). Ward et al. (2001) demonstrated that widely spacing pitfall traps at the sample site provided a more effective means of sampling some insects, such as beetles. Similar analyses performed on data collected after the gypsy moth is established in eastern Tennessee will better quantify the impact of this invasive, introduced pest on native southern Appalachian forests as well as the impact of potential biological control agents on this important pest species.

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