JOURNAL OF THE TENNESSEE ACADEMY OF SCIENCE 80(3-4):60–69 JULY-OCTOBER 2005

# INSECT SPECIES ASSOCIATED WITH EASTERN HEMLOCK IN THE GREAT SMOKY MOUNTAINS NATIONAL PARK AND ENVIRONS

L. BUCK, P. LAMBDIN, D. PAULSEN, J. GRANT, AND A. SAXTON

*The University of Tennessee, Department of Entomology and Plant Pathology, Knoxville, TN 37996 (LB,PL,DP,JG)*
*The University of Tennessee, Department of Animal Science, Knoxville, TN 37996 (AS)*

**ABSTRACT—Eastern hemlock, *Tsuga canadensis* (L.), Carr is an integral part of forested systems in eastern North America now threatened by invasions of exotic pests. Due to the threat of exotic pests, information on the species associated with eastern hemlocks was collected to compile a species listing. The insect fauna associated with eastern hemlock was assessed at four sites representing new and old growth trees and ten alternate sites in the Great Smoky Mountains National Park and adjacent areas in eastern Tennessee. Sites were sampled using malaise/pan traps, pitfall traps and direct collection. Species diversity was assessed using the Shannon index and species richness estimates were made using the program estimates. The rich insect fauna of eastern hemlocks yielded 2,832 specimens representing 292 species in 101 families and ten orders. Species richness and abundance were highest at Chimney Tops old growth site with 107 species and 801 specimens. Species richness estimators projected between 415 and 550 species associated with eastern hemlock. Several pests of eastern hemlock, including the hemlock woolly adelgid, *Adelges tsugae* (Annand), elongate hemlock scale, *Fiorinia externa* Ferris, hemlock scale, *Abgrallaspis ithacae* (Ferris), and hemlock looper, *Lambdina fiscellaria* (Guenẽe), as well as natural enemies of these pests, were collected.**

Eastern hemlock, *Tsuga canadensis* (L.), Carr is an important component of forests throughout the eastern United States and possesses both intrinsic and unique values. Eastern hemlocks are ecologically important representing an integral component of many old growth communities providing distinct microclimates for an array of wildlife. The areas dominated by eastern hemlocks are cool and shaded making them attractive to both wildlife and people. This tree is often found near streams where it reduces the water temperature making the stream favorable to native brook trout. Within forests where eastern hemlocks are threatened can be found a myriad of outdoor recreational opportunities, a rich and diverse assemblage of regional flora and fauna, scenic waterfalls and historic structures, as well as a variety of environmental and outdoor educational opportunities. Also, eastern hemlock is among the most widely grown evergreens in ornamental landscapes. Because of these scenic mountains in the Southern Appalachians, more than 14 million visitors annually contribute over five billion dollars to the local economy of eastern Tennessee.

Forest decline is an issue confronting the southern Appalachian region with significant damage caused by several invasive insect pests. Introduced species such as *Adelges tsugae* (Annand), hemlock woolly adelgid, and *Fiorinia externa* Ferris, elongate hemlock scale, represent pernicious pests with the potential to cause widespread destruction to eastern hemlocks in the eastern United States (Danoff-Burg and Bird, 2002; McClure and Fergione, 1977; Stimmel, 1980, 2000). Wallace and Hain (2002) concluded that none of the four established predators collected from eastern hemlock had a significant impact on populations of hemlock woolly adelgid. The Great Smoky Mountains National Park (GSMNP) includes some of the largest remnants of eastern hemlock in the world, which are presently confined to about 35,399 ha at various elevations. Because information on the status of the insect fauna on eastern hemlock within the region is lacking, this study was initiated to identify and assess those insect species associated with this important tree.

## MATERIALS AND METHODS

Four primary test sites (each 20 m by 40 m), each consisting of three trees, were established representing mature and new growth hemlocks at high and low elevation gradients within the GSMNP in eastern Tennessee. Two lower sites (760 m) at Elkmont representing new (35°39′56.388″N, 83°35′04.915″W) and old (35°39′47.733″N, 83°35′10.036″W) growth trees and two higher sites (1,149 m) at the Chimney Tops representing new (35°38′1.74″N, 83°28′11.4″W) and old (35° 37′49.44″N, 83°28′3.18″W) growth trees were selected for study. These sites were located in areas not infested by the hemlock woolly adelgid. Each site consisted of three old growth (diameter at breast height $>$ 20 cm) or new growth (diameter at breast height; dbh $<$ 20 cm) trees. The Elkmont new growth site is located in a xeric oak forest (type 7) and the Elkmont old growth site is part of a pine forest (type 9). Chimney Tops old growth is located in a tulip poplar forest (type 6), while the Chimney Tops new growth site is located in cove hardwoods (type 3). Specimens were obtained from these four sites using Malaise/pan traps, pitfall traps, and direct

(beat-sheet, sweep-net and handpicking) sampling from 1 June 2002 through 30 November 2002 and from 5 June 2003 through 2 September 2003.

Modified malaise/pan traps were placed in the tree canopy of each of three trees at the four primary test sites in the GSMNP to sample the insect fauna. Trap frames were constructed using PVC pipe (60 cm by 60 cm by 60 cm) and covered with polyester netting (#156). The collecting unit consisted of a plastic cup (60 mm wide by 65 mm deep, 120 mL volume) that contained 30–60 mL of 50% propylene glycol (Sierra®) and tap water. The pan (15 cm wide by 65 cm wide by 12 cm deep) was hung under the frame and contained 900–1000 mL of 50% propylene glycol and water. Samples were obtained from all collection units and pans biweekly, labeled, and taken to the laboratory for processing. Pitfall traps were used to sample ground-dwelling species at two trees per site. Four shallow holes (8 cm deep; one in each cardinal direction at the canopy's peripheral edge) per tree were dug into the ground for placement of traps. Each trap consisted of two plastic cups (60 mm wide by 65 mm deep/120 mL volume) with a plastic cover. One cup was placed inside the other to aid in sample collection and reduce flooding. The outer cup had a drainage hole, while the inner cup was filled with a 50% mixture of propylene glycol and tap water. Plastic covers with 90° directional fans were placed on the surface of the ground above the pitfall traps to prevent flooding and direct insects into the trap. Two pitfall traps at each tree were retrieved every 14 days/site and taken to the laboratory for processing and identification. On each sampling date, the collection cup with preservative was removed and replaced with fresh preservative. Visual observations and direct sampling of insects were conducted every 14 days (15–20 min/tree) within each study site using beat sheet, sweep-net and handpicking to obtain specimens from the branches and foliage. Sweep-net (a canvas net bag 38 cm diameter and 82 cm deep) and beat-sheet (1 $m^2$) samples were collected, placed into 2 d vials or zip-lock bags, labeled (date, site number, host number), and taken to the laboratory for processing and identification.

Specimens also were obtained during this time period using direct sampling (beat-sheet, sweep-net, handpicking) from 12–13 trees at eight additional sites in the GSMNP that had been found to be recently infested with the hemlock woolly adelgid (2002). These included: Anthony Creek (83°44′ 32.99″W, 35°34′47.45″N), Cataloochee Cove (83°5′38.86″W, 35°36′8.65″N), Gregory Ridge (83°50′1.47″W, 35°32′53.16″N), Laurel Falls (83°33′57.26″W, 35°40′47.75″N), Lynn Camp (83° 38′8.78″W, 35°36′2.42″N), Meigs Creek (83°36′33.98″W, 35° 38′51.92″N), Panther Creek (83°58′58.96″W, 35°33′50.52″N) and Stoney Branch (83° 50′53.04″W, 35°37′15.38″N). Also, collections at Lynnhurst Cemetery (83°55′46.843″W, 36°01′ 24.177″N), Knoxville, Tennessee and Biltmore Estates (82°32′53.142″W, 35°32′22.481″N), Asheville, North Carolina were made from June through December 2004. Species identified from these collection sites were included in the species listing for eastern hemlock.

Some specimens were sent to specialists for identification [L. Davis (USDA-ARS-CMAVE, Gainesville, Florida 32608); R. Gordon (Northern Plains Entomology, Willow City, South Dakota 58384); A. Mayor (Great Smoky Mountains National Park, Gatlinburg, Tennessee 37738); M. Peterson (Iowa State University, Ames, Iowa 50011); K. Vail and J. Skinner (University of Tennessee, Knoxville, Tennessee 37996)]. Other specimens were identified using standard keys, and voucher specimens were placed in the University of Tennessee Insect Museum. All identified species were systematically arranged into Cornell drawers for incorporation into the GSMNP and University of Tennessee insect museum.

*Data Analysis*—A species list was developed from specimens obtained from all collection methods at all sites. Data entered into a computer database (Excel®) consisted of species, family, order, site, number of specimens, collection type and collection date. To determine species richness for each new or old growth site, the database was sorted by site and the species for each site were counted. Species richness data for uncommon or rarely encountered species was determined by dividing those species represented by a single specimen by the total number of species at the sites to obtain a collection ratio. All species were compared to the Tennessee Natural Heritage Program "Rare Invertebrates List" to determine their threatened/endangered status at the state level (Withers, 1997). The malaise/pan trap sampling method data were used to assess the insect fauna in relationship to their association with the host tree. Insect diversity, basic composition, and evenness were determined for insects at the sites using the Shannon index (Vandermeer, 1981). Significant differences were determined by using chi-square analysis, and output values were considered significant at $P \leq 0.05$. To determine how many species may potentially be present at a given primary study site, species richness estimators (ACE, ICE, Chao 1, and Jackknife 1) were obtained from the program EstimateS (Colwell, 2000).

## Results and Discussion

During this study, 2,832 specimens representing 292 species in 101 families and ten orders (Table 1) were collected. Five dominant orders [Coleoptera (127 species), Diptera (79 species), Lepidoptera (27 species), Hymenoptera (23 species) and Hemiptera (19 species)] represented 94.2% of all species collected. Species richness was more varied at the Chimney Tops new growth and old growth sites with 85 and 107 species, respectively, compared to the Elkmont new growth (106 species) and old growth (103) sites. The number of species collected only at a specific site was highest (41) at the Chimney Tops old growth site and lowest (26) at the Elkmont new growth site. More site-specific species were collected at the old growth sites (73 species) than at the new growth sites (53 species). Although the lowest number of species was recorded at the Chimney Tops new growth site, the number of species (n = 27) unique to this site was similar to that at the Elkmont new growth site. As a result, 43.1% of the species recorded were obtained at one of the four primary sites. When all sites are included, 61.9% of all species collected were from a specific site. The number of specimens collected also varied among the four primary sites (ranging from 486 at the Chimney Tops new growth site to 801 at Chimney Tops old growth site). However, specimen abundance differed significantly only for Chimney Tops old growth site ($\lambda^2 = 245$, *d.f.* = 3, $P = 0.05$).

Significant differences ($F = 103.30$, *d.f.* = 5, 3, $P < 0.05$) were noted in the monthly abundance for 2002 and 2003 with the highest numbers occurring in the spring and early fall as expected. When the same months are compared across both years, significantly more insects were captured in 2002 ($\lambda^2 =$

TABLE 1. Insects associated with eastern hemlock in the Great Smoky Mountains National Park.

| Order | Family | Genus | Species | Author | Site[a] | Method[b] | *n* |
|---|---|---|---|---|---|---|---|
| Orthoptera | Acrididae | *Arphia* | *sulphureus* | (F.) | 1 | PF | 1 |
| | Gryllacrididae | *Camptonotus* | *carolinensis* | Gershacker | 1,2,3 | PF | 18 |
| | Gryllidae | *Gryllus* | *assimilis* | (F.) | 1 | PF | 2 |
| | Gryllidae | *Allonemobius* | *fasciatus* | (DeGeer) | 1,2 | PF | 10 |
| | Gryllidae | *Oecanthus* | *exclamationis* | Davis | A1 | DI | 1 |
| | Rhaphidophoridae | *Ceuthophilus* | *brevipes* | Scudder | 1,2,3,4 | PF | 25 |
| | Rhaphidophoridae | *Ceuthophilus* | *maculatus* | Harris | 1,2,3,4 | MA,PF | 80 |
| Blattodea | Blattellidae | *Ischnoptera* | *deropeltiformis* | Brunner | 1,2 | MA,PF | 3 |
| | Blattidae | *Periplaneta* | *americana* | (L.) | 1,2 | MA | 2 |
| Hemiptera | Acanthosomatidae | *Elasmucha* | *lateralis* | (Say) | 3,A2,A3 | PF,DI | 3 |
| | Adelgidae | *Adelges* | *tsugae*[c] | (Annand) | A1–A8 | DI | 100 |
| | Cicadellidae | *Gyponana* | sp. | DeLong | 2,3 | MA | 2 |
| | Cicadellidae | *Osbornellus* | *limosus* | DeLong | 1 | MA | 1 |
| | Cicadellidae | *Scaphoideus* | sp. | Delong & Beery | 1,2 | MA | 2 |
| | Cicadidae | *Tibicen* | *canicularis* | (Harris) | 2 | MA | 1 |
| | Coreidae | *Acnthocephala* | *terminalis* | (Dallas) | 1 | MA | 1 |
| | Coreidae | *Leptoglossus* | *oppositus* | (Say) | A1 | DI | 1 |
| | Diaspididae | *Abgrallaspis* | *ithacae* | (Ferris) | A1 | DI | 8 |
| | Diaspididae | *Chionaspis* | *pinifolia* | (Fitch) | A1,A4 | DI | 3 |
| | Diaspididae | *Fiorinia* | *externa* | Ferris | A4 | DI | 6 |
| | Lygaeidae | *Kleidocerys* | *resedae* | (Panzer) | A1 | DI | 1 |
| | Membracidae | *Glossonotus* | sp. | | A2 | DI | 1 |
| | Membracidae | *Platycotis* | *vittatus* | (F.) | 1,2,3,4 | MA | 9 |
| | Pentatomidae | *Banasa* | *calva* | (Say) | A1,A2 | DI | 2 |
| | Pentatomidae | *Mormidea* | *lugens* | (F.) | A1 | DI | 1 |
| | Scutelleridae | *Tetyra* | *bipunctata* | (Herrich-Schaeffer) | 1 | MA | 1 |
| | Thyreocoridae | *Corimelaena* | *pulicaria* | (Germar) | A1 | DI | 1 |
| | Tingidae | *Corythuca* | *pruni* | Osborn & Drake | A1 | DI | 1 |
| Psocoptera | Caeciliidae | | sp. 1 | | A9 | DI | 2 |
| | Ectopscocidae | | sp. 2 | | A9 | DI | 8 |
| | Lachesillidae | | sp. 3 | | A10 | DI | 4 |
| | Peripsocidae | | sp. 4 | | A9 | DI | 3 |
| Coleoptera | Agyrtidae | *Necrophilus* | *pettiti* | Horn | 1,2,3,4 | MA,PF | 24 |
| | Alleculidae | *Capnochroa* | *fuliginosa* | (Melsheimer) | 1,2 | PF | 10 |
| | Alleculidae | *Isomira* | *quadristriata* | Couper | A5 | DI | 1 |
| | Alleculidae | *Isomira* | *sericea* | (Say) | 1,2,3, A4 | MA | 26 |
| | Bruchidae | *Cryptocephalus* | *quadruplex* | Newman | 2 | MA | 1 |
| | Buprestidae | *Dicerca* | *tuberculata* | (LaPorte & Gory) | A2 | DI | 1 |
| | Cantharidae | *Podabrus* | *tomentosus* | (Say) | A1,A2 | DI | 2 |
| | Cantharidae | *Silis* | *bidentatus* | (Say) | A5 | DI | 1 |
| | Cantharidae | *Trypherus* | *latipennis* | (Germar) | A5 | DI | 3 |
| | Carabidae | *Agonum* | *melanarium* | (DeJean) | 3 | PF | 1 |
| | Carabidae | *Agonum* | *tenuis* | (LeConte) | 4 | PF | 1 |
| | Carabidae | *Calosoma* | *externus* | (Say) | 1,2,3 | PF | 21 |
| | Carabidae | *Calosoma* | *marginalis* | Casey | 1,2,3,4 | PF | 32 |
| | Carabidae | *Carabus* | *sylvosus* | Say | 1,2,3,4 | PF | 8 |
| | Carabidae | *Cyclotrachelus* | *conviva* | LeConte | 1,2 | PF | 19 |
| | Carabidae | *Dicaelus* | *politus* | DeJean | 1,2,3,4 | PF | 21 |
| | Carabidae | *Dicaelus* | *teter* | Bonelli | 1,2,4 | PF | 26 |
| | Carabidae | *Harpalus* | *pensylvanicus* | DeGeer | 3 | PF | 1 |
| | Carabidae | *Lebia* | *analis* | DeJean | A1 | DI | 1 |
| | Carabidae | *Scaphinotus* | *debilis* | (LeConte) | 3,4 | PF | 28 |
| | Carabidae | *Scaphinotus* | *andrewsii* | Harris | 3,4 | PF | 13 |
| | Carabidae | *Scaphinotus* | *guyotii* | (LeConte) | 4 | PF | 1 |
| | Carabidae | *Scarites* | *subterraneus* | F. | 1,2,3 | PF | 35 |
| | Carabidae | *Sphaeroderus* | *stenostomus* | Weber | 1,2,3,4 | PF | 199 |

TABLE 1. Continued.

| Order | Family | Genus | Species | Author | Site[a] | Method[b] | *n* |
|---|---|---|---|---|---|---|---|
| | Cerambycidae | *Analeptura* | *lineola* | (Say) | 1,3,4 | MA,PF | 11 |
| | Cerambycidae | *Anthophylax* | *cyaneus* | (Haldeman) | A6 | DI | 1 |
| | Cerambycidae | *Bellamira* | *scalaris* | (Say) | 3 | MA | 2 |
| | Cerambycidae | *Brachyleptura* | *circumdata* | (Olivier) | 3 | MA | 1 |
| | Cerambycidae | *Brachysomida* | *bivittata* | (Say) | 2 | PF | 1 |
| | Cerambycidae | *Clytus* | *ruricola* | (Olivier) | 1,2,3,4 | MA | 15 |
| | Cerambycidae | *Cyrtophorus* | *verrucosum* | (Olivier) | 4 | MA | 1 |
| | Cerambycidae | *Idiopidonia* | *pedalis* | (LeConte) | 3,4 | MA | 5 |
| | Cerambycidae | *Leptorhabdium* | *pictum* | (Haldeman) | 4 | MA | 1 |
| | Cerambycidae | *Leptura* | *emarginata* | F. | 2 | MA | 1 |
| | Cerambycidae | *Leptura* | *subhamata* | Randall | 1,2 | MA | 5 |
| | Cerambycidae | *Microgoes* | *oculatus* | (LeConte) | 2 | MA | 1 |
| | Cerambycidae | *Pidonia* | *aurata* | (Horn) | 3,4 | MA | 36 |
| | Cerambycidae | *Pidonia* | *densicollis* | (Casey) | 3,4 | MA,PF | 16 |
| | Cerambycidae | *Pidonia* | *ruficollis* | (Say) | 3 | MA | 1 |
| | Cerambycidae | *Prionus* | *imbricornis* | (L) | 1 | DI | 1 |
| | Cerambycidae | *Prionus* | *laticollis* | (Drury) | A8 | DI | 2 |
| | Cerambycidae | *Strangalepta* | *abbreviata* | (Germar) | 1,2,4 | MA | 20 |
| | Cerambycidae | *Typocerus* | *velutina* | (Olivier) | 2 | MA | 1 |
| | Cerambycidae | *Urgleptes* | *faceta* | (Say) | 2 | DI | 1 |
| | Ceratocanthidae | *Germarostes* | *globosus* | (Say) | 2 | PF | 1 |
| | Chrysomelidae | *Altica* | *viridana* | Schaeffer | A3 | DI | 2 |
| | Chrysomelidae | *Diabrotica* | *undecimpunctata howardi* | Barber | 2,A2 | PF,DI | 2 |
| | Cleridae | *Cymatodera* | *bicolor* | (Say) | 2,3,4 | MA,PF | 7 |
| | Cleridae | *Placopterus* | *thoracicus* | (Olivier) | 4 | MA | 1 |
| | Coccinellidae | *Anatis* | *labiculata* | (Say) | A3,A4 | DI | 4 |
| | Coccinellidae | *Chilocorus* | *stigma* | (Say) | A4 | DI | 8 |
| | Coccinellidae | *Cycloneda* | *munda* | (Say) | A2 | DI | 1 |
| | Coccinellidae | *Harmonia* | *axyridis* | (Palles) | A1,A2 | DI | 17 |
| | Coccinellidae | *Hyperaspis* | *signata* | Olivier | 1 | MA | 1 |
| | Coccinellidae | *Psyllobora* | *vigintimaculata* | (Say) | A2,A3 | DI | 29 |
| | Coccinellidae | *Rhyzobius* | *lophanthae* | Blaisdell | A9,A10 | DI | 34 |
| | Coccinellidae | *Sasajiscymnus* | *tsugae*[d] | (Sasaji & McClure) | A1,A3 | DI | 4 |
| | Coccinellidae | *Scymnillus* | *horni* | Gordon | A9,A10 | DI | 11 |
| | Coccinellidae | *Scymnus* | *loewii* | Mulsant | A9,A10 | DI | 6 |
| | Curculionidae | *Curculio* | *caryae* | (Horn) | A3 | DI | 1 |
| | Curculionidae | *Cyrtepistomis* | *castaneus* | (Roelofs) | 1,2,A3 | MA,PF | 11 |
| | Curculionidae | *Hypera* | *punctata* | (F.) | 1,2,A5 | PF,MA | 4 |
| | Curculionidae | *Myrmex* | *myrmex* | (Herbst) | 1 | MA | 1 |
| | Curculionidae | *Odontopus* | *calceatus* | (Say) | 1,A2,A3,A4,A5 | MA,DI | 28 |
| | Curculionidae | *Panscopus* | *erinaceus* | (Say) | A8 | DI | 1 |
| | Elateridae | *Agriotes* | *oblongicollis* | (Melsheimer) | 1,2,4 | MA,PF | 10 |
| | Elateridae | *Athous* | *brightwelli* | (Kirby) | 1,2,A5 | PF,DI | 9 |
| | Elateridae | *Athous* | *posticus* | (Melsheimer) | 2 | MA | 1 |
| | Elateridae | *Athous* | *rufifrons* | (Randall) | 3 | MA | 1 |
| | Elateridae | *Athous* | *scapularis* | (Say) | 3 | MA | 1 |
| | Elateridae | *Conoderus* | *lividus* | (DeGeer) | 4 | PF | 1 |
| | Elateridae | *Ctenicera* | *signaticollis* | (Melsheimer) | 1,2,4 | MA | 7 |
| | Elateridae | *Hemicrepidius* | *memnonius* | (Herbst) | 1,2 | MA | 2 |
| | Elateridae | *Danosoma* | *obtectus* | (Say) | 1 | PF | 1 |
| | Elateridae | *Lacon* | *discoidea* | (Weber) | 3 | PF | 1 |
| | Elateridae | *Limonius* | *griseus* | Beauvois | 2 | MA | 1 |
| | Elateridae | *Melanactes* | *piceus* | (DeGeer) | 4 | MA | 1 |
| | Elateridae | *Melanotus* | *americanus* | (Herbst) | 1,2 | MA | 8 |
| | Elateridae | *Melanotus* | *decumanus* | (Erichson) | 3 | MA | 1 |
| | Elateridae | *Melanotus* | *hyslopi* | Zwaluwenburg | 1,2 | MA | 14 |
| | Elateridae | *Melanotus* | *pertinax* | (Say) | 1,2 | MA | 5 |

TABLE 1. Continued.

| Order | Family | Genus | Species | Author | Site[a] | Method[b] | *n* |
|---|---|---|---|---|---|---|---|
| | Erotylidae | *Megalodacne* | *heros* | (Say) | 2,3,4 | PF,DI | 7 |
| | Eucnemidae | *Isorhipis* | *ruficornis* | (Say) | 1,2,3,4 | MA,PF | 51 |
| | Geotrupidae | *Bolboceras* | *simi* | (Wallis) | 1,2 | MA,PF | 2 |
| | Geotrupidae | *Geotrupes* | *blackburnii* | (F.) | 1 | PF | 1 |
| | Geotrupidae | *Geotrupes* | *hornii* | Blanchard | 1,2,4 | MA,PF | 118 |
| | Geotrupidae | *Geotrupes* | *semiopacus* | Jekel | 1,2,3 | PF | 11 |
| | Geotrupidae | *Geotrupes* | *splendidus* | (F.) | 1,2 | PF | 7 |
| | Lampyridae | *Ellychnia* | *corrusca* | (L.) | 1,A1 | PF | 2 |
| | Lampyridae | *Pyropyga* | *decipiens* | (Harris) | 2 | MA | 1 |
| | Lycidae | *Plateros* | *centralis* | Green | 1,2 | PF | 2 |
| | Melandryidae | *Dircaea* | *liturata* | LeConte | 2,3 | MA,PF | 2 |
| | Meloidae | *Meloe* | *americanus* | Leach | 4 | PF | 8 |
| | Mordellidae | *Mordellistena* | *arida* | LeConte | 1 | MA | 8 |
| | Mordellidae | *Mordellistena* | *limbalis* | (Melsheimer) | 1 | MA | 1 |
| | Mordellidae | *Mordellistena* | *ornata* | (Melsheimer) | 1 | MA | 1 |
| | Mordellidae | *Tomoxia* | *serval* | (Say) | 4 | MA | 3 |
| | Nemonychidae | *Cimberis* | *pilosus* | (LeConte) | A2 | DI | 1 |
| | Nitidulidae | *Cryptarcha* | *ampla* | Erichson | 1,2 | MA | 2 |
| | Nitidulidae | *Glischrochilus* | *fasciatus* | (Olivier) | 1,2,3,4 | MA,PF | 19 |
| | Nitidulidae | *Glischrochilus* | *quadrisignatus* | (Say) | 4 | MA | 1 |
| | Nitidulidae | *Glischrochilus* | *sanguinolenta* | (Olivier) | 1,2,3,4 | MA,PF | 84 |
| | Nitidulidae | *Stelidota* | *octomaculata* | (Say) | 1,2,4 | MA,PF | 6 |
| | Pyrochroidae | *Dendroides* | *concolor* | (Newman) | 3,4 | MA | 6 |
| | Scarabaeidae | *Copris* | *minutus* | (Drury) | 2 | MA | 2 |
| | Scarabaeidae | *Dichelonyx* | *albicollis* | Burmeister | 1,2 | MA | 5 |
| | Scarabaeidae | *Dichelonyx* | *linearis* | (Gyllenhal) | 3 | MA | 1 |
| | Scarabaeidae | *Dichelonyx* | *subvittata* | LeConte | 1,2,3,4 | MA | 11 |
| | Scarabaeidae | *Onthophagus* | *hecate* | (Panzer) | 1 | PF | 1 |
| | Scarabaeidae | *Onthophagus* | *striatulus* | (Beauvois) | 1,2 | PF | 2 |
| | Scarabaeidae | *Serica* | *atracapilla* | (Kirby) | 1,2,3 | MA | 13 |
| | Scarabaeidae | *Serica* | *georgiana* | Leng | 1,2,3,4 | MA,PF | 23 |
| | Scolytidae | *Dendroctonus* | *terebrans* | (Olivier) | A1 | DI | 1 |
| | Scolytidae | *Pityogenes* | *plagiatus* | (LeConte) | A2 | DI | 1 |
| | Silphidae | *Nicrophorus* | *defodiens* | Mannerheim | 2,3,4 | MA,PF | 29 |
| | Silphidae | *Nicrophorus* | *marginatus* | (F.) | 1 | MA | 1 |
| | Silphidae | *Nicrophorus* | *orbicollis* | Say | 2,3,4 | PF | 68 |
| | Silphidae | *Nicrophorus* | *pustulatus* | Herschel | 2 | PF | 2 |
| | Silphidae | *Nicrophorus* | *sayi* | Laporte | 3 | PF | 1 |
| | Staphylinidae | *Bisnius* | *blandus* | (Gravenhorst) | 3 | PF | 1 |
| | Staphylinidae | *Philonthus* | *cyanipennis* | (F.) | 1,2 | PF | 5 |
| | Staphylinidae | *Tachinus* | *fimbriatus* | Gravenhorst | 1,2 | PF | 17 |
| | Tenebrionidae | *Arthromacra* | *aenea* | Say | 2,3 | MA | 3 |
| | Tenebrionidae | *Helops* | *aereus* | Germar | 1 | MA | 1 |
| | Tenebrionidae | *Meracantha* | *contracta* | (Beauvois) | 1,2 | MA | 7 |
| | Tenebrionidae | *Tarpela* | *micans* | (F.) | 4 | PF | 1 |
| | Tenebrionidae | *Tarpela* | *undulatus* | (LeConte) | 1 | MA | 1 |
| Neuroptera | Chrysopidae | *Chrysopa* | sp. | | A9 | DI | 2 |
| | Coniopterygidae | *Coniopteryx* | sp. | | A9 | DI | 4 |
| | Hemerobiidae | *Hemerobius* | *stigma* | Stephens | A10 | DI,MA | 12 |
| Lepidoptera | Arctiidae | *Halysidota* | *tesselaris* | (J.E. Smith) | 1 | MA | 1 |
| | Geometridae | *Lambdina* | *fiscellaria* | (Guenee) | 3,4,A1, A2,A3,A5 | MA, DI | 9 |
| | Geometridae | *Melanolophia* | *canadaria* | (Guenee) | A4 | DI | 4 |
| | Geometridae | *Nematocampa* | *limbata* | (Haworth) | 2 | MA | 1 |
| | Geometridae | *Prochoerodes* | *transversata* | (Drury) | 1,3,4 | MA,PF | 5 |
| | Geometridae | *Stamnodes* | *gibbiocostata* | (Walker) | 3 | MA | 1 |
| | Hesperiidae | *Epargyreus* | *clarus* | Cramer | 3,4 | MA | 2 |
| | Lymantriidae | *Orgyia* | *leucostigma* | (Smith) | A1 | DI | 1 |

TABLE 1. Continued.

| Order | Family | Genus | Species | Author | Site[a] | Method[b] | *n* |
|---|---|---|---|---|---|---|---|
| | Noctuidae | *Catocala* | *cerogama* | (Guenee) | 3 | MA | 7 |
| | Noctuidae | *Catocala* | *epione* | Drury | 2 | MA | 1 |
| | Noctuidae | *Cucullia* | *intermedia* | (Speyer) | 4 | MA | 1 |
| | Noctuidae | *Feralia* | *comstocki* | (Grote) | A4 | DI | 4 |
| | Noctuidae | *Hypena* | *baltimoralis* | (Guenee) | 4 | MA | 1 |
| | Noctuidae | *Hypena* | *madefactalis* | (Guenee) | 4 | MA | 1 |
| | Noctuidae | *Hyppa* | *xylinoides* | (Guenee) | 3 | MA | 3 |
| | Noctuidae | *Lithophane* | *baileyi* | Grote | 3 | MA | 1 |
| | Noctuidae | *Lithophane* | *petulca* | (Grote) | 3 | MA | 1 |
| | Noctuidae | *Orthodes* | *cynica* | Guenee | 3 | MA | 1 |
| | Noctuidae | *Parallelia* | *bistriaris* | Hübner | 3 | MA | 1 |
| | Noctuidae | *Pseudorthodes* | *vecors* | (Guenee) | 4 | MA | 1 |
| | Noctuidae | *Sunira* | *bicolorago* | (Guenee) | 3 | MA | 1 |
| | Nymphalidae | *Speyeria* | *diana* | (Cramer) | 1 | MA | 1 |
| | Papilionidae | *Papilio* | *glaucus* | L. | 3 | DI | 1 |
| | Pyralidae | *Herpetogramma* | *thestealis* | (Walker) | 2 | MA | 7 |
| | Pyralidae | *Pantographa* | *limata* | (Grote & Robinson) | 3 | MA | 1 |
| | Thyatiridae | *Pseudothyatira* | *cymatophoroides* | (Guenee) | 4 | MA,PF | 11 |
| | Zygaenidae | *Pyromorpha* | *dimidiata* | Herrich-Schäffer | A4 | DI | 2 |
| Mecoptera | Panorpidae | *Panorpa* | *appalachia* | Byers | 1,3,4 | MA,PF | 13 |
| Diptera | Acroceridae | *Eulonchus* | *marialiciae* | Brimley | 4 | MA | 1 |
| | Anthomyiidae | *Anthomyia* | *pluvialis* | (L.) | 2 | MA | 1 |
| | Anthomyiidae | *Emmesomyia* | *socialis* | (Stein) | 3 | MA | 5 |
| | Anthomyiidae | *Hydrophoria* | sp. | | 3, 4 | MA | 8 |
| | Anthomyiidae | *Hylemya* | *alcathoe* | (Walker) | 3 | MA | 2 |
| | Anthomyiidae | *Pegomya* | sp. | | 2,3,4 | MA | 15 |
| | Asilidae | *Efferia* | *aestuans* | (L.) | 1 | PF | 1 |
| | Bibionidae | *Penthetria* | *heteropterus* | (Say) | A1 | DI | 1 |
| | Calliphoridae | *Calliphora* | *vomitoria* | (L.) | 2,3,4 | MA | 7 |
| | Calliphoridae | *Lucilia* | *coeruleiviridis* | (Macquart) | 4 | MA | 1 |
| | Calliphoridae | *Lucilia* | *pallescens* | (Shannon) | 3,4 | MA,PF | 30 |
| | Calliphoridae | *Pollenia* | *rudis* | (F.) | 1,2 | MA | 3 |
| | Ceratopogonidae | *Atrichopogon* | sp. | | A2 | DI | 1 |
| | Ceratopogonidae | *Culicoides* | *sanguisuga* | (Coquillett) | A6 | DI | 1 |
| | Chironomidae | *Chasmatonotus* | *bicolor* | Rempel | 4 | MA | 1 |
| | Chironomidae | *Parametriocnemus* | *lundbeckii* | Johannsen | A1 | DI | 1 |
| | Drosophilidae | *Amiota* | sp. | | 4 | MA | 6 |
| | Drosophilidae | *Drosophila* | sp. | | 2,4 | MA | 6 |
| | Dryomyzidae | *Dryomyza* | *simplex* | Loew | 3 | MA | 5 |
| | Empididae | *Rhamphomyia* | sp. | | A3 | DI | 1 |
| | Heleomyzidae | *Allophyla* | *atricornis* | (Meigen) | 1,2,3 | MA,PF | 3 |
| | Heleomyzidae | *Amoebaleria* | sp. | | 3,4 | MA | 3 |
| | Heleomyzidae | *Suillia* | sp. | | 3,4 | MA | 7 |
| | Lauxaniidae | *Camptoprosopella* | sp. | | 4,A1 | MA | 2 |
| | Lonchaeidae | *Lonchaea* | *caerulea* | Walker | A2 | DI | 1 |
| | Lonchaeidae | *Lonchaea* | sp. | | 3,4 | MA | 5 |
| | Micropezidae | *Rainieria* | *antennaepes* | (Say) | 1 | PF | 1 |
| | Muscidae | *Helina* | sp. | | 1,3 | MA,PF | 9 |
| | Muscidae | *Mesembrina* | *latreillii* | Robineau-Desvoidy | 3,4 | MA,PF | 25 |
| | Muscidae | *Mydaea* | sp. | | 2,3,4 | MA,PF | 7 |
| | Muscidae | *Phaonia* | sp. | | 3 | MA | 3 |
| | Muscidae | *Potamia* | sp. | | 2 | MA | 1 |
| | Muscidae | *Thricops* | *rufisquama* | (Schnabl) | 3,4 | MA | 33 |
| | Mycetophilidae | *Boletina* | sp. | | 1 | MA | 3 |
| | Mycetophilidae | *Brevicornu* | sp. | | 4 | MA | 1 |
| | Mycetophilidae | *Dynatosoma* | *fulvidum* | Coquillett | 3 | PF | 5 |
| | Mycetophilidae | *Dynatosoma* | *placidum* | Johannsen | 3 | MA | 1 |
| | Mycetophilidae | *Leptomorphus* | *subcaerulea* | (Coquillett) | 2 | PF | 1 |

TABLE 1. Continued.

| Order | Family | Genus | Species | Author | Site[a] | Method[b] | *n* |
|---|---|---|---|---|---|---|---|
| | Mycetophilidae | *Monoclona* | *rufilatera* | Walker | 1,3,4 | MA | 122 |
| | Mycetophilidae | *Mycetophila* | sp. | | 1,2,3,4 | MA | 32 |
| | Mycetophilidae | *Mycomya* | sp. | | 3 | MA | 2 |
| | Mycetophilidae | *Orfelia* | sp. | | 4 | MA | 1 |
| | Mycetophilidae | *Phronia* | sp. | | 2,3 | MA | 54 |
| | Mycetophilidae | *Saigusaia* | *cincta* | (Johannsen) | A1 | DI | 1 |
| | Mycetophilidae | *Synapha* | *tibialis* | (Coquillett) | 3 | MA | 1 |
| | Mycetophilidae | *Zygomyia* | *ornata* | Loew | 1 | MA | 1 |
| | Periscelididae | *Periscelis* | *annulata* | (Fallen) | 2 | MA | 1 |
| | Phoridae | *Dohrniphora* | *cornuta* | (Bigot) | 1,2 | MA | 2 |
| | Phoridae | *Megaselia* | sp. | | 4 | MA | 1 |
| | Sarcophagidae | *Blaesoxipha* | *atlanis* | Aldrich | 1,2,4 | MA,PF | 6 |
| | Sarcophagidae | *Boettcheria* | *cimbicis* | (Townsend) | 1 | MA | 1 |
| | Sarcophagidae | *Boettcheria* | sp. | | 1,2,3 | MA,PF | 5 |
| | Sarcophagidae | *Fletcherimyia* | sp. | | 2 | PF | 1 |
| | Sarcophagidae | *Sarcophaga* | sp. | | 1,2 | MA,PF | 8 |
| | Sarcophagidae | *Tripanurga* | sp. | | 1 | PF | 1 |
| | Sarcophagidae | *Udamopyga* | *niagarana* | (Parker) | 3 | MA | 1 |
| | Scathophagidae | *Scathophaga* | *nigrolimbata* | Cresson | 1 | MA | 1 |
| | Sciaridae | *Bradysia* | sp. | | 3 | MA | 1 |
| | Sciaridae | *Phytosciara* | *flavipes* | (Meigen) | 3 | MA | 6 |
| | Sciomyzidae | *Euthycera* | *arcuata* | (Loew) | 3,4 | MA,PF | 4 |
| | Simuliidae | *Prosimilium* | *mixtum* | Syme & Davies | A1 | DI | 2 |
| | Syrphidae | *Eristalis* | sp. | | 3 | MA | 1 |
| | Syrphidae | *Ferdinandea* | *buccata* | (Loew) | 1,2 | MA | 2 |
| | Syrphidae | *Ferdinandea* | *dives* | (Osten Sacken) | 1,2 | MA | 2 |
| | Syrphidae | *Mallota* | *bautias* | (Walker) | 1 | MA | 4 |
| | Syrphidae | *Spilomyia* | sp. | | 1,3 | MA | 3 |
| | Syrphidae | *Syrphus* | *rectus* | Osten Sacken | 3 | MA | 7 |
| | Syrphidae | *Syrphus* | sp. | | 1,3,4 | MA | 4 |
| | Syrphidae | *Xylota* | sp. | | 3,4 | MA | 2 |
| | Tabanidae | *Chrysops* | *geminatus* | Wiedemann | 2 | MA | 1 |
| | Tachinidae | *Trigonospila* | *pallipes* | (Reinhard) | 3 | MA | 1 |
| | Tipulidae | *Austrolimnophila* | *toxoneura* | (Osten Sacken) | 4 | MA | 2 |
| | Tipulidae | *Epiphragma* | *fasciapennis* | (Say) | 3 | MA | 1 |
| | Tipulidae | *Limonia* | *indigena* | (Osten Sacken) | 2 | MA,PF | 5 |
| | Tipulidae | *Limnophila* | *politissima* | (Alexander) | A2 | DI | 1 |
| | Tipulidae | *Elephantomyia* | *westwoodi* | Osten Sacken | 4 | MA | 1 |
| | Tipulidae | *Metalimnobia* | *cinctipes* | Say | 3 | MA | 1 |
| | Tipulidae | *Tipula* | *duplex* | Walker | 4 | PF | 1 |
| | Xylophagidae | *Dialysis* | sp. | | 1 | PF | 1 |
| Hymenoptera | Aphelinidae | *Encarsia* | *citrina* | Craw | A9,A10 | DI | 100 |
| | Apidae | *Bombus* | *bimaculatus* | Cresson | 2,3,4 | MA | 30 |
| | Apidae | *Bombus* | *fervidus* | (F.) | 2,3,4 | MA | 34 |
| | Apidae | *Bombus* | *impatiens* | Cresson | 2,3,4 | MA | 33 |
| | Apidae | *Bombus* | *perplexus* | Cresson | 2,3,4 | MA | 51 |
| | Formicidae | *Acanthomyops* | *claviger* | (Roger) | 2 | PF | 2 |
| | Formicidae | *Acanthomyops* | *interjectus* | Mayr | 1 | MA | 2 |
| | Formicidae | *Camponotus* | *pensylvanica* | (DeGeer) | 2 | PF | 7 |
| | Formicidae | *Camponotus* | *americanus* | Mayr | 1 | DI | 1 |
| | Formicidae | *Aphaenogaster* | *fulva* | Emery | 1,2,3 | MA,PF | 102 |
| | Formicidae | *Prenolepis* | *impairs* | (Say) | 1 | PF | 45 |
| | Halictidae | *Augochloropsis* | *metallica* | (F.) | 4 | MA | 1 |
| | Halictidae | *Augochlora* | *purus* | (Say) | 2,3,4 | MA | 15 |
| | Halictidae | *Augochlorella* | *striata* | (Provancher) | 1,2,3,4 | MA | 14 |
| | Halictidae | *Lasioglossum* | *bruneri* | (Crawford) | 4 | MA | 1 |
| | Ichneumonidae | | sp. 1 | | 3 | MA | 12 |
| | Ichneumonidae | | sp. 2 | | 3 | MA | 1 |

TABLE 1. Continued.

| Order | Family | Genus | Species | Author | Site[a] | Method[b] | *n* |
|---|---|---|---|---|---|---|---|
| | Ichneumonidae | | sp. 3 | | 3 | MA | 1 |
| | Sphecidae | *Cerceris* | sp. | | 2 | MA | 1 |
| | Tenthredinidae | *Tenthredo* | *carolina* | (Rohwer) | 1 | MA | 1 |
| | Vespidae | *Dolichovespula* | *maculata* | (L.) | 1,2,4 | PF | 3 |
| | Vespidae | *Vespula* | *vulgaris* | (L.) | 1,3,4 | MA,PF | 86 |
| | Vespidae | *Vespula* | sp. | | 2 | PF | 2 |

[a] Primary Sites: 1 = Elkmont new growth, 2 = Elkmont old growth, 3 = Chimney Tops old growth, and 4 = Chimney Tops new growth. Alternate Sites: A1 = Anthony Creek, A2 = Cataloochee Cove, A3 = Gregory Ridge, A4 = Laurel Falls, A5 = Lynn Camp, A6 = Meigs Creek, A7 = Panther Creek, A8 = Stoney Branch, A9 = Lynnhurst Cemetery, and A10 = Biltmore Estates.

[b] Methods of sampling: DI = direct sampling (beat-sheet, handpicking, sweep-net), MA = Malaise/pan trap, PF = pitfall traps.

[c] *Adelges tsugae* Annand (Adelgidae), a recent invasive species, was collected at sites A1–A8 by direct sampling.

[d] *Sasajiscymnus tsugae*, a biocontrol agent released in 2002 against *Adelges tsugae* was observed at sites A1 and A3.

63.177, *d.f.* = 1, $\alpha = 0.05$). Specimen abundance for the months of June and July was quite variable (range 88–456) when compared among years (2002 and 2003). Some 44 species represented by 15 or more specimens were collected constituting 72.9% of the total abundance and 15.1% of the total species richness. Species (127) represented by a single individual collected during this study denoted 43.5% of the total species richness at the study sites.

No significant differences ($\lambda^2 = 3.339$, *d.f.* = 3, $\alpha = 0.05$) were detected for diversity and evenness among the four primary sites (Table 2). Malaise/pan traps were the most successful single collection method used to sample the insect fauna on eastern hemlock. Malaise/pan traps accounted for 176 species or 60.3% of species richness and also had the highest Shannon diversity value at 4.14 (Table 3). Pitfall traps, considered both an ecologically sensitive and cost-effective collection method (Work et al., 2002), captured only 90 species resulting in the lowest Shannon diversity value (2.91). However, 53 species were collected only from pitfall traps. Direct collection (handpicking, beat sheet, and sweep netting) accounted for 66 species from all sites with 59 species obtained specifically from this collection method. Direct collection had the highest Shannon evenness value of any single collection method at 0.83 (Table 3). Some 40 species were collected by multiple collection methods (any combination of the trap types) that accounted for 13% of the total species richness. These data demonstrate that various collection methods are essential to comprehensively sample the diverse fauna on eastern hemlock.

Species richness estimators varied for the number of insect species collected at the four primary sites. The estimators ACE and Jack 1 resulted in the most conservative estimates at every site including the estimates of overall species richness. The ICE estimator provided the most liberal estimates at every site, except Chimney Tops new growth site. The range for Elkmont new growth site was from 175 to 225 species with 104 species observed (Sob). Elkmont old growth site estimates ranged from 175 to 245 species with 102 species observed (Sob), Chimney Tops old growth site estimates ranged from 185 to 270 species with 107 species observed (Sob), and species estimates for Chimney Tops new growth site was 145 to 230

TABLE 2. Shannon diversity (H') and evenness (E) values for insect fauna at new and old growth eastern hemlock sites, Great Smoky Mountains National Park, 2002–2003.

| Site | Shannon's H' | Shannon's E |
|---|---|---|
| Elkmont New Growth | 3.94* | 0.84 |
| Elkmont Old Growth | 3.77 | 0.80 |
| Chimney Tops Old Growth | 3.62 | 0.76 |
| Chimney Tops New Growth | 3.64 | 0.81 |
| All Sites | 4.51 | 0.79 |

* No significant differences ($\lambda^2 = 3.339$, *d.f.* = 3, $\alpha < 0.05$, $n$=282 species) noted among sites for species diversity or evenness.

TABLE 3. Shannon diversity (H') and evenness (E) values for collection methods used to sample the insect fauna associated with eastern hemlock, Great Smoky Mountains National Park, 2002–2003.

| Collection Method | Shannon's H' | Shannon's E |
|---|---|---|
| Malaise/pan traps | 4.14 | 0.79 |
| Pitfall traps | 2.91 | 0.72 |
| Direct sampling | 3.18 | 0.83 |
| Multiple traps[a] | 3.31 | 0.85 |

[a] Multiple traps include samples obtained from all three collection methods at the four primary sites evaluated in the Great Smoky Mountains National Park.

species. The species estimates for all of the sites combined ranged from 415 (Chao 1) to 550 (Sob) species. The $r^2$ values for all of these estimates are strong (above 0.950) suggesting a high level of confidence in each estimate. Except for those species that specifically feed on mature trees, it can be inferred from these data that the insect community is rather stable.

Species of interest that could have a significant impact on survival of eastern hemlock and the existing habitats are the two exotic pests, hemlock woolly adelgid and elongate hemlock scale. The hemlock woolly adelgid has become a significant pest of eastern hemlock in several areas throughout the eastern United States. The hemlock woolly adelgid was discovered at eight alternate sites within the Park and continues to increase its range and damage to the host trees. The exotic elongate hemlock scale is a bisexual species with two generations annually in the southern Appalachians often co-existing with the hemlock woolly adelgid (Kosztarab, 1996; McClure, 2002). We recently discovered this species infesting eastern hemlocks in the GSMNP and in Knox County, Tennessee (Buck, 2004). Another hemipteran that is commonly found infesting eastern hemlock within the region is the hemlock scale, *Abgrallaspis ithacae* (Ferris), a native species that feeds on the underside of the needles of eastern hemlock. This species occurs throughout the eastern hemlock range but rarely reaches damaging levels in forests due to presence of natural enemies (Stimmel, 2000).

The carabid beetle, *Sphaeroderus stenostomus* Weber, the most abundant species (199 specimens) captured, feeds exclusively on snails often located on the forest floor (Downie and Arnett, 1996). *Sphaeroderus stenostomus* is reported to be established in several southeastern states and overwinters as both larvae and adults (Downie and Arnett, 1996). Due to these qualities, the cool moist nature of the hemlock forest floor makes an excellent hunting ground for this predator, which was represented at all four primary sites. Another carabid, *Scaphinotus andrewsii* Harris, is a generalist predator collected in the unique microclimates produced by eastern hemlock (Ball and Bousquet, 2001). This beetle was represented by 13 specimens at the two Chimney Tops sites. The family Agyrtidae is represented by 11 species in six genera in North America north of Mexico. However, only one species, *Necrophilus pettiti* Horn, is found in eastern North America (Peck, 2001). Members of this family are adapted to cool climates often near mountainous regions, cool streams, or high elevation snowfields. Although not commonly collected (Peck, 2001), 24 specimens of this species were collected from all four sites. The buprestid beetle, *Dicerca tuberculata* (Laporte and Gory), was collected at the Anthony Creek site and is known to feed on *Pinus* spp., *Picea* spp., *Abies* spp., *Larix* spp., *Thuja* spp., and *Tsuga* spp. (Downie and Arnett, 1996). The cerambycid beetle, *Leptura subhamata* Randall, is known to feed on decaying hemlock and pine (Yanega, 1996). Five specimens of this species were found at Elkmont new and old growth sites. The larvae of these beetles bore into roots and wood. In all, 123 cerambycid beetles representing 20 species were collected.

A geotrupid beetle, *Geotrupes hornii* Blanchard, was represented by 118 specimens from both Elkmont sites and the Chimney Tops new growth site constituting the third most abundantly collected species. This beetle species is common throughout the eastern United States and feeds on fungi (Arnett, 2000; Downie and Arnett, 1996). Another commonly collected beetle (84 specimens) was *Glischrochilus sanguinolenta* (Olivier). This nitidulid was collected at all four GSMNP sites. Five species of nitidulids (112 specimens) were collected during this study (Table 1). The family Nitidulidae, commonly known as sap beetles, is represented by 2,800 species in 172 genera worldwide of which 165 species and 30 genera are found in the United States. Members of this family are primarily saprophagous or mycetophagus except a few species that live in flowers, decaying fruit, or fungi (Habeck, 2002).

Another insect species collected that feeds on snails was a sciomyzid dipteran, *Euthycera arcuata* (Loew). About 200 dipteran species worldwide feed on terrestrial or freshwater snails, their eggs, and larvae (Berg and Knutson, 1978). This insect lays its eggs on the backs of snails and feeds on the snail larvae. The second most commonly occurring species of Diptera was *Monoclona rufilatera* Walker, a mycetophilid represented by 122 specimens collected from the Elkmont new growth site and both the mature and new growth Chimney Tops sites. Mycetophilids are commonly found in shady, damp places near fungi or decaying vegetation. Although a few species are predaceous as larvae, most feed on fungi and few are considered pests (Borror et al., 1989). Five specimens of the rarely collected fly, *Dryomyza simplex* Loew (Dryomyzidae), were collected from the Chimney Tops old growth site. These insects are found as larvae in decaying organic matter similar to that found in moist forest situations (Borror et al., 1989).

The most abundant Hymenoptera collected was the ant, *Aphaenogaster fulva* Emery. All 102 specimens of *A. fulva* collected were found at the two Elkmont sites except for one specimen at the Chimney Tops old growth site. Abundance was concentrated at these two sites because of several colonies of *A. fulva* located around and between the Elkmont sites. These ants are indigenous to the southern Appalachian Highlands, New England, and Nova Scotia (Creighton, 1950).

## CONCLUSIONS

In assessing the insect biodiversity associated with eastern hemlock, 2,832 specimens representing 292 species were collected and identified. The number of species identified from eastern hemlock falls within the expected range for the number of species recorded on other trees (LaForest, 2000; Trieff, 2002) within the region. From these data, we conclude that a rich, stable insect fauna associated with eastern hemlocks exists within the test sites at this time. Species richness and abundance were highest at the two old growth sites, and species richness ranged from 85 to 107 species at the Chimney Tops new and old growth sites, respectively. Species estimates for all sites combined ranged from 415–550 species.

Some 101 families in ten orders were represented in this study with species of Coleoptera comprising 43.5% of all insects collected. Because of the importance of biodiversity to the well being of forest systems and the intricate nature of insect communities, information on the status and function of eastern hemlock forest systems is imperative for the development of management decisions. Eastern hemlocks are valuable for their aesthetics, contribution to ecological stability of the species-rich forests in eastern North America and economic benefit to the region. Unfortunately, the health of these trees and the habitat structure of the forest

systems are severely threatened by the invasion of exotic insect species.

## ACKNOWLEDGMENTS

We are grateful to K. Johnson (Great Smoky Mountains National Park, Gatlinburg, Tennessee 37738), B. Hascher (Biltmore Estates, Asheville, North Carolina), R. Rhea (USDA Forest Service, Asheville, North Carolina) and C. Limebarger (Lynnhurst Cemetery, Knoxville, Tennessee) for providing the study sites. We also thank L. Davis (USDA-ARS-CMAVE, Gainesville, Florida 32608), R. Gordon (Northern Plains Entomology, Willow City, South Dakota 58384), A. Mayor (Great Smoky Mountains National Park, Gatlinburg, Tennessee 37738), M. Peterson (Iowa State University, Ames, Iowa 50011), K. Vail and J. Skinner (University of Tennessee, Knoxville, Tennessee 37996) for identifying several of the species collected. We are also grateful to the Great Smoky Mountains National Park (DLIA/ATBI) and the USDA Forest Service for their partial support of this project.

## LITERATURE CITED

ARNETT, R. 2000. American insects. A handbook of the insects of America North of Mexico. CRC Press, Washington, DC.

BALL, G. E., AND Y. BOUSQUET. 2001. Carabidae. Pp. 32–132 *in* American beetles. Vol. 1: Archostemata, Myxophaga, Adephaga, Polyphaga: Staphyliniformia (R. H. Arnett Jr., and M. C. Thomas. eds.). CRC Press, Washington, DC.

BERG, C., AND L. KNUTSON. 1978. Biology and systematics of Sciomyzidae. Ann. Rev. Entomol., 23:239–258.

BORROR, D., C. TRIPLEHORN, AND N. JOHNSON. 1989. An introduction to the study of insects. 6th ed., Saunders College Publishing. Chicago, Illinois. 657–658.

BUCK, S. E. 2004. Insect fauna associated with eastern hemlock, *Tsuga canadensis* (L.), in the Great Smoky Mountains National Park. MS thesis, Univ. Tennessee, Knoxville, Tennessee.

COLWELL, R. 2000. EstimateS: Statistical estimation of species richness and shared species from samples. Vol. 6. Available via Internet. (*http://viceroy.eeb.uconn.edu/estimators*; Oct. 2003).

CREIGHTON, W. 1950. The ants of North America. Bull. Museum Comp. Zool., 104:148.

DANOFF-BURG, J., AND S. BIRD. 2002. Hemlock woolly adelgid and elongate hemlock scale: Partners in crime? Pp. 254–268 *in* Proc. Hemlock Woolly Adelgid in the Eastern United States Symposium (B. Onken, R. Reardon, and J. Lashomb, eds.), East Brunswick, New Jersey, USDA Forest Service.

DOWNIE, N. M., AND R. H. ARNETT JR. 1996. The beetles of northeastern North America, vol. I. Introduction, suborders Archostemata, Adephaga, and Polyphaga thru superfamily Cantharoidea. Sandhill Crane Press, Gainesville, Florida.

HABECK, D. 2002. Nitidulidae Latreille 1802. Pp. 311–318 *in* American Beetles. Polyphaga: Scarabaeoidea through Curculionidae. (R. H. Arnett Jr., M. C. Thomas, P. E. Skelley, and J. H. Frank, eds.). CRC Press, New York.

KOSZTARAB, M. 1996. Scale insects of northeastern North America. Virginia Museum Nat. Hist. Spec. Publ. no. 3, Martinsville, Virginia.

LAFOREST, J. 2000. Diversity and distribution of the insect fauna associated with tulip-poplar in east Tennessee. MS thesis, Univ. Tennessee, Knoxville, Tennessee.

MCCLURE, M., AND J. FERGIONE. 1977. *Fiorinia externa* and *Tsugaspidiotus tsugae* (Homoptera: Diaspididae): distribution, abundance, and new hosts of two destructive scale insects of eastern hemlock in Connecticut. Environ. Entomol., 6:807–811.

MCCLURE, M. 2002. The elongate hemlock scale, *Fiorinia externa* Ferris (Homoptera: Diaspididae): a new look at an old nemesis. Pp. 248–253 *in* Proc. Hemlock Woolly Adelgid in the Eastern United States Symposium (B. Onken, R. Reardon, and J. Lashomb, eds.), East Brunswick, New Jersey, USDA Forest Service.

PECK, S. B. 2001. Agyrtidae. Pp. 247–249 *in* American beetles. Vol. 1: Archostemata, Myxophaga, Adephaga, Polyphaga: Staphyliniformia (R. H. Arnett Jr, and M. C. Thomas, eds.). CRC Press, Washington, DC.

STIMMEL, J. 1980. Seasonal history and occurrence of *Fiorinia externa* Ferris in Pennsylvania (Homoptera: Diaspididae). Proc. Entomol. Soc. Wash., 82:700–706.

———. 2000. Hemlock scale, *Abgrallaspis ithacae* (Ferris) Homoptera: Diaspididae. Regulatory Hort., 197:15–17.

TRIEFF, D. 2002. Composition of the Coleoptera and associated insects collected by canopy fogging of northern red oak (*Quercus rubra* L.) trees in the Great Smoky Mountains National Park and the University of Tennessee arboretum. MS thesis, Univ. Tennessee, Knoxville, Tennessee.

VANDERMEER, J. 1981. Elementary mathematical ecology. John Wiley and Sons, USA.

WALLACE, M., AND F. HAIN. 2002. Field surveys and evaluation of native predators of the hemlock woolly adelgid (Homoptera: Adelgidae) in the southeastern United States. Pp. 104–109 *in* Proc. Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America. (K. A. McManus, K. S. Shields, and D. R. Souto, eds.), Durham, New Hampshire, USDA Forest Service Gen. Tech. Rep.

WITHERS, D. 1997. Tennessee natural heritage program: rare invertebrates list. Div. Nat. Heritage, Tennessee Dept. Environ. Conser. Nashville, Tennessee.

WORK, T., C. BUDDLE, L. KORINUS, AND J. SPENCE. 2002. Pitfall trap size and capture of three taxa of litter-dwelling arthropods: Implications for biodiversity studies. Environ. Entomol., 31:438–448.

YANEGA, D. 1996. Field guide to northeastern longhorned beetles (Coleoptera: Cerambycidae). Illinois Nat. Hist. Survey Manual, 6:36.