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Insect Fauna Associated with Eastern Hemlock, Tsuga canadensis (L.), in the Great Smoky Mountains National Park

Stanley Earl Buck III
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Stanley Earl Buck III entitled "Insect Fauna Associated with Eastern Hemlock, Tsuga canadensis (L.), in the Great Smoky Mountains National Park." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Entomology and Plant Pathology.

Paris Lambdin, Major Professor

We have read this thesis and recommend its acceptance:

Jerome Grant, John Skinner, Kristine Johnson

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Stanley E. Buck III

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Abstract

Eastern hemlock, *Tsuga Canadensis* (L.), is an integral part of the forest system in eastern North America. These trees contribute to the biological diversity, environmental health, and economic stability of the regions that they inhabit by producing unique microclimates, cool shady recreational areas, and unmatched beauty. Information regarding the insect fauna associated with eastern hemlock is sparse and scattered with in the literature. Because of this, the insect fauna associated with eastern hemlock was assessed at four sites, representing new and old growth, and nine alternate sites in the Great Smoky Mountains National Park (GSM). Sites were sampled using malaise traps, pitfall traps, beat sheeting, and direct collection. Species diversity was assessed using the Shannon-Weiner diversity indices and species richness estimates were made using the program estimateS.

The rich insect fauna of the eastern hemlocks in the GSM yielded 2,516 specimens representing 280 species in 87 families and eight orders. Species richness and abundance was highest and at site 3 (Chimney tops old growth) with 801 specimens and 113 species. Species richness estimators determined that species richness associated with eastern hemlock is between 420 and 550 species. Pests of eastern hemlock including the hemlock looper, *Lambdina fiscellaria* (Guenẽe), were collected, as well as nine species that are predators of the exotic pest hemlock woolly adelgid, *Adelges tsuga* (Annand).

Data collected in this study offer a listing of insect fauna associated with eastern hemlock in the GSM. These results will assist in the development and management of forest containing and dominated by eastern hemlock. In addition, due to the threat of

hemlock woolly adelgid, information collected in this study provides a baseline of the insect fauna associated with eastern hemlock prior to disturbances altering species composition.

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Chapter I. Introduction

The stability of ecosystems depend on the diversity of life within them. The total diversity of the life on earth, known as biodiversity, is estimated to consist of ten million species (Pimm et. al. 1995). About 750,000 species are native to the United States (Wilson 1988). Humans are dependent upon these species to provide stability to habitats, as well as for food, fuel, medicines, and basic building supplies. Other organisms recycle organic waste and nutrients, break down chemical pollutants, and pollinate plants, but people do not depend on just a few important species. Roughly, 20,000 plant species have been used for human consumption (Pimentel et. al. 1997). This number does not include those species that provide nitrogen through waste, the biota in the ground that creates and aerates the soil, or the thousands of organisms that pollinate the plants we eat.

Included within the concept of biodiversity is a diverse and stable gene pool. Through biotechnology, the application of the principles of genetic engineering and technology to the life sciences, a strong gene pool can both improve crop and livestock yields and protect organisms from devastating loss from disease. Genetic engineering and breeding programs make it possible to use attributes that occur naturally in other organisms to protect crops or help them compete for resources. For example, cotton can be modified using genetic material from *Bacillus thuringiensis* (Bt) to prevent damage from the cotton bollworm, *Helicoverpa armigera* (Hubner), saving farmers in the United States approximately 171 million dollars annually (Head 1992), while preventing environmental damage by reducing the use of chemical pesticides.

Economic and recreational benefits stem from a biologically diverse environment. Sport and commercial fishing account for 4,990 kg of harvested wild biota worth two and one-half billion dollars annually in the United States (USBC 1995). Other wild biota harvested annually in the United States include small game, deer, bear, elk, moose, nuts, blue berries, maple syrup, and algae. Overall, the wild food harvested in the United States is estimated to be valued at three billion dollars annually (USBC 1995), but staggering dollar amounts are commonly associated with biodiversity. "The annual economic and environmental benefits of biodiversity in the United States have a net worth of approximately 300 billion dollars" (Pimentel et. al. 1997).

Despite obvious economic value, human activity is continually detrimental to the fragile habitats on which biodiversity depends. According to the Ecological Society of America, the major threats to biodiversity include habitat loss and destruction, over-exploitation, pollution and contamination, changes in ecosystem composition, global climate change, and introduction of exotic species (ESA 2003).

According to Simberloff (2000), "biological invasions are the second greatest cause of species endangerment and extinction in the United States and worldwide". An estimated 7,000 exotic species have become established in the United States since Columbus's landing in 1492 (Scherer 2000). Fifteen percent, less than 600 species, harm crops, forest systems, or do some kind of ecological harm (Scherer 2000) resulting in millions of dollars in damage annually. A report from the Congressional Office of Technology Assessment states, "by the mid-twenty first century, biological invasions will become one of the most prominent ecological issues on earth" (Scherer 2000).

Exotic organisms have historically impacted our, food, dwellings, and quality of life. For example, an exotic bacterium from Asia transmitted to humans and other mammals by fleas is the causative agent of Bubonic Plague resulting in the deaths of one-third of the European population. The introduction of smallpox by early explorers in North and South America is responsible for the deaths of hundreds of thousands of Native Americans (Fenn 2001). In 1845, a fungus imported from America into Ireland resulted in the starvation of millions of Irish citizens prompting a mass migration of people to the United States. More recently, the American chestnut tree neared extinction due to chestnut blight and changed the landscape of eastern North America (Burnham 1986).

The hemlock woolly adelgid (HWA), *Adelges tsuga* (Annand), now threatens to join the ranks of chestnut blight and other invasive species that have done irreversible damage to our environment by destroying the existing eastern hemlock stands. Eastern hemlock (*Tsuga canadensis* (L.) Carriere) forest can be described as beautiful, majestic, enormous, and even cathedral-like. Due to biological invasion we describe these precious resources as fleeting, finite, short-lived, and in some cases memories. The hemlock woolly adelgid (HWA) was first discovered in the western United States during the 1920s (Stoetzel 2002). By the 1950s it had been introduced into Richmond, Virginia. HWA has subsequently spread to 15 eastern states leaving millions of dead trees in its wake. Eastern hemlock mortality has reached 90% in some areas, such as Shenandoah National Park in Virginia (Evans 2002). A tree health assessment survey of 157 plots of eastern hemlock, greater than four hectares, was conducted in 2001 by the New Jersey Department of Agriculture. Only 23% of the plots surveyed were considered healthy

(Mayer et al. 2002). Due to land clearing, logging, and HWA, only ½% of the original abundance of eastern hemlock currently remains in Wisconsin and Michigan (Evans 2002).

Chapter II. Literature Review

Biodiversity:

The term biodiversity, a combination of the terms biological and diversity, is a relatively new term that refers to the total diversity of life on earth. Biodiversity was coined by the National Academy of Sciences (1986) during the first National Forum on Biodiversity was held in Washington D.C. This event triggered a boom in interest and made biodiversity a commonly used word in education and research, as well as attracted specialists from many disciplines. Taxonomists are used to identify specimens, ecologists study relationships, economists design biological models, ethnobotanists search for medically useful plants, and politicians control environmental polices all to better understand biodiversity. Because the study of biodiversity is far-reaching and complex, it is divided into the three general categories of genetic diversity, taxonomic diversity, and ecological diversity (Becher 1998).

Genetic diversity alludes to the diversity of genes available to a given taxonomic division (e.g., family) (Becher 1998). Genetic makeup is responsible for an organism's traits including size, shape, and resistance to drought, disease, or poison. A population with great genetic variability contains individuals with traits that could improve that organism's ability to survive hardships (e.g., drought). Traits that improve survival eventually become dominant, allowing the population to persist, by adapting to the changing conditions. Populations with reduced genetic variation may not adapt resulting in the extinction of that population. Genetic diversity has come to the forefront in recent years with the advancement of biotechnology, which is the application of the principles of engineering and technology to the life sciences. Several major crops are engineered to utilize genetic material from other organisms to improve yield, resist disease, become cold hardy or drought resistant. This places a premium on the value of genetic material, but valuable genes do not only reside in the plants we use. Useful traits are found in a variety of organisms including wild plants or exotic fungi making each species an asset.

Taxonomic diversity, also referred to as species diversity, deals with differences in taxonomic levels (e.g., species). Global species richness estimates are as high as 10 million (Pimm et. al. 1995), but taxonomic diversity is not only described by species richness. Population size, species rarity, habitat variability, and an organism's role (e.g., predator) all describe taxonomic diversity (Becher 1998).

Ecological communities are habitats and the existing biotic and abiotic organisms. Variation among ecological communities is referred to as ecological diversity (Becher 1998). Scientists have split these communities up into levels such as ecosystems or the biosphere, which is the largest ecological community. When studying ecological diversity one must consider species interaction as well as species interaction with the environment. These interactions produce feeding guilds and nutrient cycles (e.g. carbon cycle) that allow these habitats to be self-sustaining. These communities also interact with one another. For example, pollution in a river may destroy an estuary that changes the population dynamics of ocean-living fish. This is evidence of the wealth of scientific knowledge that can be obtained from knowing genetic variability of a given species and the way that species adapts to the environment.

Biodiversity is extensive and plays a role in everyday life. Humans have consumed about 20,000 species of plant (Pimentel et. al. 1997). Consumer goods, such as oil, coal, and natural gas, are used daily and rely on biodiversity. More than 40% of prescription drugs, as well as many over the counter remedies like aspirin, are plant-based. Ecotourism is estimated to contribute 500 billion dollars to the United States economy annually (Novacek 2001). In addition, diverse insect populations decrease pest populations, such as mosquitoes, that may spread disease.

Unfortunately, habitat loss, changes in ecosystem composition, over exploitation, pollution and contamination, global climate change, and introduction of exotic species threaten biodiversity. Extinction rates are estimated to be between 50 and 150 species each day or 0.2 to 0.6% per year. The present rate of extinction is 10,000 times that of projected natural situations (Novacek 2001). These circumstances jeopardize the environment's ability to carry out normal functions, such as the hydrogen cycle and pollination. However, in an effort to raise awareness about the importance of biodiversity, a convention on biological diversity was held at the Earth Summit of 1992. During this convention 156 nations including the members of the European Union signed an outline to take steps toward preserving biodiversity (Novacek 2001).

Biodiversity of Insect Fauna in Host Trees:

Most biodiversity studies of insect fauna associated with trees have been concentrated on hardwoods. This focus is primarily attributed to the monetary value of the host trees. Recently, studies in east Tennessee have been conducted on yellow poplar, southern magnolia, and northern red oak (LaForest 1999, Werle 2002, Trieff 2002). These studies varied greatly in both species richness and abundance. Laforest (1999) reported the highest species richness (727) on yellow poplar, while Trieff (2002) reported the greatest abundance (11,468) associated with northern red oak. Differences in sampling methods attributed to variation in species richness and abundance. Another more extensive study was conducted by Southwood et. al. (1982). This experiment compared insect fauna of nine species of trees. Species richness was highest in *Quercus* sp. (465) and lowest in *Robinia* sp. (105), while abundance was highest on *Betula* sp. (19,355) and lowest in *Salix carpensis* L. (461). The canopy insects of sitka spruce, *Picea sitchensis* (Bong) Carriere were evaluated by Winchester (1997) who found 56 species associated with sitka spruce. Fifteen of the associated species were undescribed. These studies provide perspective concerning the abundance and diversity of insect fauna associated with trees, but differences in species, collection methods, and geography make comparisons loosely correlated.

Eastern Hemlock:

Eastern hemlock is both beautiful and integral part of eastern forest systems in North America. Eastern hemlock, also known as Canada hemlock and hemlock spruce, fills a unique niche as a slow growing, shade tolerant tree. It can persist in the understory becoming mature at 250 to 300 years with a total life span up to 800 years. According to the National Register of Big Trees the largest eastern hemlock is located in the Great Smoky Mountains National Park. This champion tree is 50 m (165 ft) tall with a circumference of 513 cm (202 in) (Blozan et al. 1995). Industrial uses of eastern hemlock uses include boxes, crates, railway ties, pulpwood, timbers, and general construction. Other uses include tannin for leather, poultice for wounds and sores, oil from the needles and twigs that can be used in liniments, and as a popular addition to many ornamental settings.

The native range of eastern hemlock extends from northern Michigan and south-central Ontario, east to New Brunswick and Nova Scotia, and south through New England, Pennsylvania, New York, and the southern Appalachian Mountains into Northern Georgia and Alabama (Figure 1). Isolated populations occur in southern Michigan, Ohio, Indiana, and in the Mid-Atlantic States east of the Appalachians (Brisbin 1970).

Eastern hemlock occurs in cool humid climates. Precipitation can range from 740 mm (29 in) in areas prone to high snowfall to 1,520 mm (60 in) in the southern Appalachian Mountains. The average January temperature in the northern range of eastern hemlock is about -12° C (10° F) with a frost-free period of about 80 days, and in southern regions the average January temperature is about 6° C (42° F) with as many as 200 days without frost (Rogers 1980).

Due to a dense canopy, heavy shade, and a deep layer of duff, mature stands of eastern hemlock develop unique microclimates. Microclimates are small but important components that influence larger climatic conditions and allow organisms that favor such conditions the opportunity to survive and persist. This includes organisms, such as the hemlock looper, *Lambdina fiscellaria* Guenẽe, which is dependent on the microclimates produced by eastern hemlock. Acidic soil, water retention, uniformly low temperatures, and a poorly developed understory distinguish these microclimates (Rogers 1980, USDA 1965). Despite the exacting microclimates created by a mature stand of eastern hemlock, these trees can persist in a variety of topographical situations. In eastern hemlock's

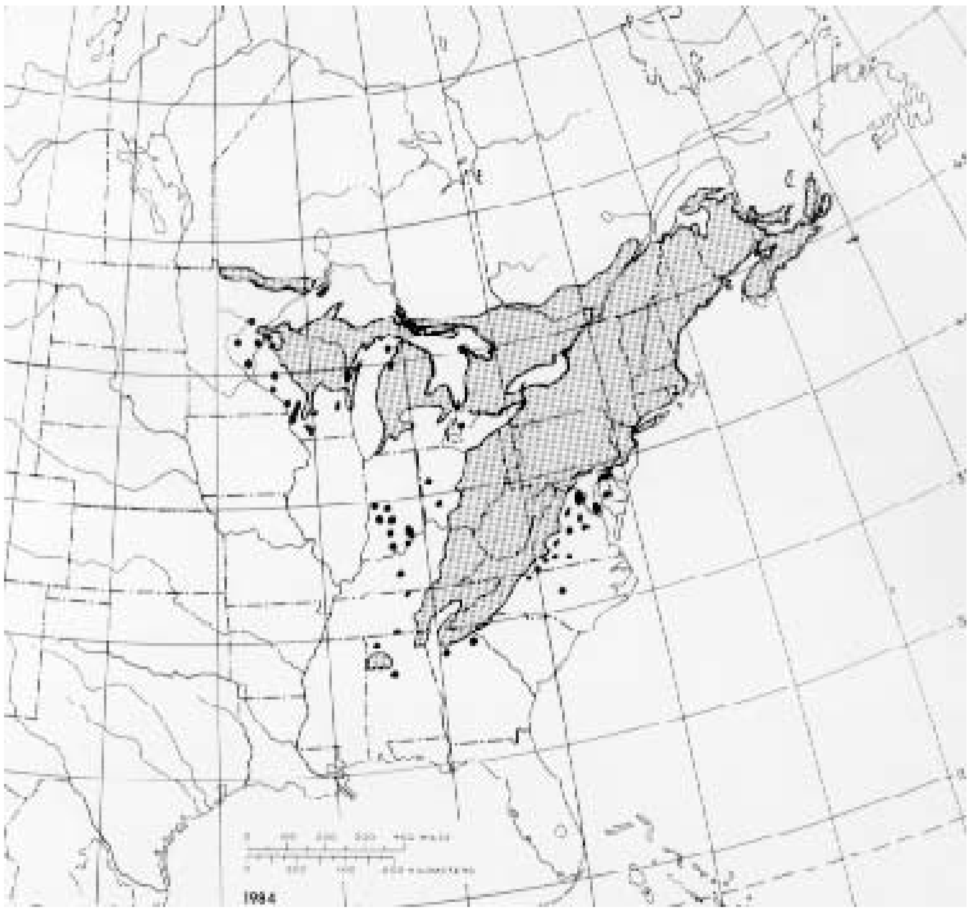

Figure 1. Native range of eastern hemlock (Godman and Lancaster 2003).

northeastern range, it can grow from elevations of 730 m (2,400 ft) down to sea level. According to the USDA, a majority of eastern hemlock occurs between 300 m and 910 m (1,000 – 3,000 ft) in New York and Pennsylvania (USDA 1965). The southern Appalachian region presents a different set of ecological conditions with a generally warmer environment interrupted by taller peaks. Thus, most eastern hemlocks grow between the elevations of 610 m and 1,520 m (2,000 – 5,000 ft), and a majority of the individual trees occur on north and/or east facing slopes and cool valleys (USDA 1965).

Eastern hemlock is often found associated with other tree species in the forest system. According to the Society of American Foresters, this tree exists in 29 forest types (Eyre 1980). Eastern hemlock is a main component of four forest types: eastern hemlock (Type 23), white pine-hemlock (Type 22), hemlock-yellow birch (Type 24), and tulip poplar-eastern hemlock (Type 58). It is also commonly associated with seven other forest types (Table 1), and a minor species in another eighteen forest types (Eyre 1980).

The understory of a mature stand of eastern hemlock stand is poorly developed due to the lack of sunlight reaching the forest floor. Despite the lack of resources, some plants do survive including woodfern (*Dryopteris* spp.), goldthread (*Coptis groenlandica* Salisbury), seges (*Carex* spp.), moss (*Polytrichum* spp.), starflower (*Trientalis borealis* (Hook) Hulten), and clubmoss (*Lycoopodium* spp.) (Rogers 1980, Willis no date).

Life History of Eastern Hemlock:

Eastern hemlocks flower during late April and continue through early June. These monoecious trees begin producing male strobili at roughly age fifteen and form stalked yellow flower clusters in the axis of needles formed the previous year. After the

Table 1. Forest types commonly associated with eastern hemlock (Eyre 1980).

Type	Name	Type	Name
20	White Pine-Northern Red Oak-Red Maple	21	Eastern White Pine
22	Pine-Hemlock	23	Eastern Hemlock
24	Hemlock-Yellow Birch	30	Yellow Birch
31	Red Spruce-Sugar Maple-Beech	32	Red Spruce
33	Red Spruce-Balsam Fir	34	Red Spruce-Fraser Fir
58	Tulip Poplar-Eastern Hemlock		

strobili are produced, bud scales surround them making a male conelet. Erect female conelets are developed from shorter ovulate flowers which form on the terminals of the branchlets of the previous year (Neinstaedt and Kriebel 1955).

Once the female conelet has begun to open, the leaf buds burst from which pollen is dispersed by wind over a two-week period. After pollination, the female conelets close, but fertilization takes about six weeks to complete. By late August through early September, the cones grow to their full size. The cones open in October, and the seeds are dispersed throughout the winter months (Nienstaedt and Kriebel 1955)

Individual seeds are 1.6 mm (0.06 in) long with a terminal wing that becomes ripe when cones change from green to brown. The seeds drop from the cones once the cones are dry and deep brown (USDA 1965). Eastern hemlock produces the smallest cones (13 mm – 19 mm) in the genus *Tsuga*, but eastern hemlock trees are prolific cone producers (USDA 1974). Producing more cones than any eastern species of conifer (Godman 1979). In Wisconsin, good cone crops were produced 61% of the time over a 32-year period (Wang 1974). Trees have been recorded with substantial cone crops in excess of 450 years of age (USDA 1965), but only 25% of the seeds produced are viable (USDA 1974).

Upon reaching maturity, eastern hemlock seeds enter a dormant stage. For successful germination, about ten weeks of temperatures at or just above freezing is needed. This condition is usually met during the winter months following dispersal (USDA 1965).

When dormancy is broken, germination begins. "Achieving desirable temperatures for germination under natural conditions is difficult because eastern hemlock seeds require from 45 to 60 days to reach their peak in germinative energy" (USDA 1965). During this time, a constant temperature of 7° - 18° C (44° - 64° F) with an optimum temperature of 15° C (59° F) is needed (USDA 1965).

Eastern hemlock undergoes germination in an epigeal manner (i.e., at or above the ground). This situation leaves seeds susceptible to drying during this life stage. In a study reported by the USDA (1989), 60% of tested seeds were damaged after two hours of drying. After seeds were dried for six hours, 80% of the seeds were unable to recover. In natural settings, a stand of eastern hemlock usually has groups of trees roughly the same age. Older larger trees almost always accompany these groups. In this natural situation, new stands of eastern hemlock can be established with over stories as dense as seventy to 80% crown cover, which can help prevent drying (Eckstein 1980, Godman 1973, 1979, USDA 1965). This information is supported by a seeding study from northwestern Pennsylvania. "No hemlock germinated on prepared spots in the open (hemlock rarely germinates and becomes established in open areas) and only a few germinated under a light overstory because of the moisture stress created under these conditions" (Jordan and Sharp 1967). However, germination was successful under stands that consist of immature trees especially those on north facing slopes (Jordan and Sharp

1967). Without the moist warm conditions of a natural setting or prepared site, regeneration in eastern hemlock is limited to places with higher water retention and warmer surface temperatures than the forest floor such as stumps, rotten logs, or mounds of organic matter.

The first year in the life of an eastern hemlock is one of slow development. After a year of growth, most seedlings are between 25 mm and 38 mm (1.0 to 1.5 ft) tall with roots reaching only about 13 mm (0.5 in) into the soil. As in previous life stages eastern hemlock seedlings are susceptible to drying as well as high temperatures. "Once the root system has reached a soil depth not radically affected by surface drying, usually after the second year, the seedlings grow more rapidly without interference of overhead shade. Seedlings are fully established when they are 0.9 m to 1.5 m (3 to 5 ft) tall and, at that time can be released completely from overhead competition without fear of mortality" (Godman and Lancaster 2003).

In ornamental situations, propagation is possible by cuttings and grafting (USDA 1965), but most nursery stock is planted and grown from seed. Unlike a natural setting, planted eastern hemlock will survive in both partial overstories and in open field conditions (Godman and Lancaster 2003).

After eastern hemlock has completed the sapling life stage, it enters the pole stage. The pole stage consists of adolescent trees with a diameter at breast height (d b h) less than 20 cm (8 in). During this stage, growth is usually slow due to suppression from the overstory and crowding. A tree of only 2.5 cm (1 in) d b h. may be 100 years old, while a tree 200 years old may have a d b h. of only 5 cm to 8 cm (2 to 3 in). Despite long periods of suppression these trees can retain good health, stem form, and live crown ratios (Tubbs 1977).

At maturity eastern hemlocks can be both ancient and tremendous. The oldest reported tree was 988 years of age (Godman and Lancaster 2003), and the champion has a d b h. of 513 cm (202 in) and stands 50 m (165 ft) tall (Blozan et al. 1995). Mature stands of eastern hemlock average of 89 to 102 cm (35 – 40 in) d b h, and heights of 30 m (100 ft) are common (Table 2). These large trees result in yields higher than most other forest types. An 80 year-old eastern hemlock stand in New England produces about twice the volume of an equivalent oak stand (USDA 1965). Eastern hemlock and yellow birch stands in Wisconsin that are 110 years of age can achieve volumes of 154 m^3/ha. Stands of eastern hemlock mixed with hardwoods can have volumes of 217 m^3/ha by age 100. Pure stands of mature eastern hemlock in Wisconsin have been reported to have volumes greater than 322 m^3/ha, while similar stands in New England exceed 560 m^3/ha (Secrest 1943, USDA 1965).

Table 2. Average dimensions of dominant eastern hemlock trees (Godman 2003)

	Southern Appalachians		**Michigan**		**New York**	
Age (years)	**d b h (cm/in)**	**Height (m/ft)**	**d b h (cm/in)**	**Height (m/ft)**	**d b h (cm/in)**	**Height (m/ft)**
40	23/9	16/53	14/5.7	13/42	11/4.4	Dec-39
60	33/13.1	22/71	24/9.4	19/62	19/7.4	18/58
80	43/16.9	26/86	33/12.8	23/76	27/10.5	22/73
100	52/20.6	30/98	41/16.1	26/85	35/13.8	26/84
120	62/24.3	33/107	49/19.4	28/91	43/17.1	28/91
140	71/28	35/114	57/22.6	29/96	52/20.4	30/97
160	81/31.9	37/120	65/25.7	30/100	61/23.9	31/102
180	91/35.7	38/125	-/-	-/-	70/27.4	-/-
200	100/39.5	39/129	-/-	-/-	78/30.9	-/-

Pests of Eastern Hemlock:

Eastern hemlock seeds are susceptible to molds including *Botrytis* spp. (Botrytis blight) and *Aureobasidum pullulans* (de Bary) Arnaud. Both of these molds can stop or delay germination (LeMadeleine 1980). Botrytis blight, often called gray mold blight or gray mold rot, affects hundreds of plant species worldwide, and it flourishes in cool wet conditions that eastern hemlock inhabit (Sinclair et. al. 1987). This mold has been isolated in both seed coats and embryonic tissue. In one study, 73% of all seed coats contained *A. pullulans* (Godman and Lancaster 2003). Often referred to as blue stain mold, it grows in moist climates leaving black-blue stripes on its host (Anonymous 2001).

As young seedlings, damping-off fungi and root rots are the most deleterious agents (Hepting 1971). *Pythium* spp. and *Rhizoctonia* spp. are both damping-off fungi commonly associated with eastern hemlock. Each of these fungi grows well in the moist soil of eastern hemlock forest. *Cylindrocladium scoparium* Morgan, *Rhizina undulata* (Schaeff.), and *Fusarium moniliforme* Sheldon all commonly occur on eastern hemlock (LeMadeleine 1980). *Cylindrocladium scoparium* is also common in *Rhododendron* spp. and *Azalea spp., which* can be associated with eastern hemlock in forest settings. Symptoms include root and stem rot as well as necrotic flecks on leaves (Backhaus 1994). *Rhizina undulata* commonly occurs in areas recently burned. Apothecia, fruiting bodies, within 0.5 m of possible host are indicators of infestation. Damage appears similar to other root rots or drought damage, and mortality in seedlings can reach 80 % (Callan 1993, Ginns 1973). *Fusarium moniliforme* has been isolated in both embryonic tissue and seed coats of eastern hemlock (Lemadeleine 1980). Also known as pitch canker, this fungus produces pink fruiting bodies called sporodochia. Damage on needles and bark are evident as well as dieback of new shoots (USDA 1989).

As an eastern hemlock tree matures, different disease complexes affect the tree. One of the most damaging agents affecting the needles and twigs is *Melampsora farlowii* (Arthur) Davis. *Melampsora farlowii* is an autoecious, micro cyclic rust fungus that causes twigs to twist and curl downward resulting in shoot blight. Cone abortion can occur (Hepting 1971). "*M. abietiscanadensis* (Farlow) Ludw. infects cones, needles, and green stems of eastern hemlock from Nova Scotia to North Carolina and Wisconsin" (Sinclair et. al. 1987). Swollen and curled shoots as well as an orange-yellow coating around the infected area indicate infection (Sinclair et. al. 1987). *Pucciniastrum hydrangeae* (Magn.) Arth. and *P. vaccinii* (Wint.) Joerst. are other rusts that can occur on eastern hemlock (Hepting 1971).

Fabrella tsuga (Farl.) Kirschst. is an ascomycete that causes individual needles to brown and die. The result is browning throughout the crown (Wulf and Pehl 1996). The lower foliage of eastern hemlocks can be affected by *Rosellinia herpotrichiodes* Fuckel in shady wet areas. Symptoms include white to gray mycelium covering needles that results in the death of the needles (Hepting 1971, Shea 1964). *Dimerosporium tsugae* Dearn is a sooty mold forming dark patches on needles resulting in defoliation (Hepting 1971).

Tyromyces borealis (Sclerotinia) attacks the heartwood of eastern hemlock. This fungus leaves white flecks in the wood and is common in the northeastern United States. *Pholiota adiposa* (Fr.) Kummer is another commonly occurring fungus on eastern hemlock, *P. adiposa*, causes a cavity to rot out in the pith axis. Some other rots include a brown, red ring rot called *Phellinus pini* (Thore) Fr. and *P. robustus* (Fomes) a red heart rot (Hepting 1971).

Several fungi occur on the roots of mature eastern hemlock, but a root related fungus rarely does enough damage to mature eastern hemlock trees to result in mortality. *Armillaria mellea (*Vahl. Fr.), the shoestring fungus, and *Phaeolus schweinitzii* (Fr.) are among the most common fungi found on eastern hemlock (Hepting 1971).

Eastern hemlock is known to be attacked by 24 species of insects, but a majority of these species do little damage and are of no economic importance (Godman and Lancaster 2003). The hemlock borer, *Melanophila fulvoguttata* (Harris), was once considered the most important economic pest of eastern hemlock (Godman and Lancaster 2003). Now considered a secondary pest, this buprestid beetle forms galleries on the surface of the sapwood while in the larval stage. Evidence of hemlock borer attack includes oval holes, about 3 mm in diameter, indicating emergence of adults (Evans 2003).

The hemlock looper, *Lambdina fiscellaria* (Guenẽe), is a pest of eastern hemlock subject to prolonged outbreaks. This lepidopteron, in the family Geometridae, overwinters in the egg stage and hatch in May or June. The larvae feed on new foliage until they exhaust the resource and move on to the older foliage. Feeding results in partially destroyed leaves that turn brown by late summer (Rose 1994).

Spruce budworm, *Choristoneura fumiferana* (Clemons), utilizes eastern hemlock as a secondary host. After defoliating all of the balsam fir or spruce in an area it moves on to eastern hemlock. In the spring, spruce budworm larvae spin a silk web around two needles and bore into one of them. Once new growth appears the larvae quite the mining process and feed on the new growth. This can cause severe defoliation and death (Godman 2003, Rose 1994).

In nursery settings, the strawberry root weevil, *Otiorhynchus ovatus* L., and the black vine weevil, *Otiorhynchus sulcatus* (F.), are both pests of eastern hemlock (Wilson 1977). The overwintering larvae of the strawberry root weevil feed on the roots of young trees often resulting in death of the plant (Rose and Lindquist 1994). The black vine weevil, an exotic pest introduced from Europe, feeds on the needles as an adult leaving notches along the margins, which often results in defoliation (Shetlar 2003).

The Indian or Japanese wax scale is a soft scale (Coccidae) with a wide host range that includes many ornamental plant species. This pest was introduced from the oriental region and has spread to 16 states. Adult females are pink to brown with a white waxy test over the body. One adult can lay up to 1,000 eggs, but the infestation seldom kills the plant, although these scales induce a haggard appearance (USDA 1985).

Hemlock scale, *Abgrallaspis ithacae* (Ferris) (Diaspididae), is a common widespread pest that causes defoliation and death in young trees. It is found in eight states in northeastern North America as well as Virginia and Tennessee. Hemlock scale has two generations each year and overwinters as second instars (Kosztarab 1996). Another Diaspidid species that is a pest of hemlock is the elongate hemlock scale, *Fiorina externa* Ferris, which can be found from southern New England south to Virginia and west to Ohio. *Fiorina externa* utilizes 40 tree species of conifer, 14 of which are native to the United States. Feeding by elongate hemlock scale causes defoliation, branch dieback, and death. It has two generations per year in southern states and one generation in northeastern states overwintering as eggs or inseminated females (McClure 1986).

In 1951, the hemlock woolly adelgid (HWA), *Adelges tsugae* Annand (Homoptera: Adelgidae), was observed in Richmond, Virginia for the first time in the eastern United States (Stoetzel 2002). At this time, HWA was considered a minor pest of hemlock trees. By 1969, it had spread to forest settings in Pennsylvania and on to Maryland by 1973 (Stoetzel 2002). During the 1980's, HWA established itself as a serious pest in Virginia, Pennsylvania, Connecticut, and New Jersey. Researchers now consider HWA to be a threat to eastern hemlock forest in 15 states from New Hampshire to Georgia.

Hemlock woolly adelgid, a native of Honshu, Japan, is mainly a non-destructive inhabitant of *Tsuga diversifola* Masters and *T. sieboldii* Carriere (McClure 1995). In Taiwan and China it also occurs on *T. chinesis* (Franch.) Pritz., *T. dumosa* (Don) Eichler, and *T. forrestii* Downie (Annand 1924, Yu et. al. 1977, Montgomery et. al. 1998). In western North America, HWA can be found on *T. heterophylla* Sargent and *T. mertensiana* Carriere where it is considered an innocuous species (Annand 1924).

Until recently, HWA was believed to have a simple monomorphic life cycle restricted to hemlock. Studies conducted by McClure (1985) uncovered a polymorphic life cycle for this species involving hemlock and spruce (*Picea* spp.) (McClure 1987, 1989). "However, experiments revealed that none of 15 native and exotic spruce species that commonly occur in the eastern United States are suitable alternate hosts" (McClure et. al. 1999).

Hemlock woolly adelgid overwinters as an adult. In mid-February, adults begin depositing eggs into spherical woolly ovisacs, process that continues for 16 weeks. By April, first instar nymphs (crawlers) begin to emerge, and position themselves below the abscission layer of newly developed needles and insert their stylists. HWA feeds on the cellular fluids of xylem ray parenchyma cells (Young et. al. 1995). Over a four week period, HWA undergoes four instars and become adults. Once fully developed, HWA are either wingless progediens or winged sexuparae. The winged individuals leave in search of a suitable spruce species to serve as a host. The progrediens will produce a second generation on hemlock and lay eggs in June (McClure 1987, 1989).

The second generation of crawlers emerge in July and move to new growth. Soon after becoming settled the first instar nymphs reach the aestivation stage. During this period, they are inactive until October when feeding resumes. After feeding begins, the young adelgids develop into adults by February, which concludes their bivoltine development on hemlock (McClure 1987, 1989). In Japan, sexuparae adults complete their development on *P. jezoensis hondoensis* (Sieb. and Zucc.) and *P. polita* (Carriere) (McClure 1996, Inouye 1953).

Taxa Dependent on Eastern Hemlock:

Eastern hemlock is an extremely valuable component of our environment providing shelter and food for a variety of fauna. The blackburnian warbler, *Dendroica fusca* (Muller), blue-throated green warbler, *Dendroica virens* (Gmelin), blue-headed vireo, *Vireo solitarius* Bonap., and Acadian flycatcher, *Empidonax virens* Brewster, are all bird species that depend on eastern hemlock for nesting (Ross 2001). The brook trout, *Salvelinus fontinalis* Mitchill, is heavily dependent on eastern hemlock. Areas of streams that drain eastern hemlock forest are 3 - 4º C cooler than areas that drain hardwood forest (Evans et. al. 1996). This few degrees keep stream temperatures at tolerable levels during the hot summer months. In addition, aquatic micro-invertebrate taxon was found to be 37% higher in hemlock draining streams than in hardwood draining streams. Three species found only in streams drained by hemlock include: *Hydropsyche ventura* Ross, *Polycentropus* sp., and *Natarsia* sp. Because of these habitat conditions, brook trout are three times more likely to be found in hemlock streams as opposed to hardwood streams (Evans 2002).

Many insect species, including several species of Lepidoptera, utilize the resources provided by eastern hemlock. *Coleotechnites apicitripunctella* (Clemens), a small leaf mining moth in the family Gelechiidae, is distinguished by narrow forewings and hindwings with concave outer margins. Found in Quebec and northeastern United States, *C. apicitripunctella* overwinters as a larva in mined leaves and emerges in early summer with only one generation annually. Although the immature individuals feed on the leaves, this insect is not considered a pest (USDA 1985). *Eufidonia notataria* (Walker) is another Lepidoptera species in the family Geometridae that depends on eastern hemlock. It may also be found on white pine, tamarack, balsam fir, and spruce. Eufidonia *notataria* lay eggs in the leaf axils and forks of new growth branches. Larvae are present from July through September, but this species overwinters in the pupal stage (USDA 1985). The white pine cone borer, *Eucosma tocullionana* Heinrich (Tortricidae), is found from Ontario to Tennessee. This moth feeds on the cones of several conifers including white pine, spruce, balsam fir, and eastern hemlock. Larvae are present from April through July, and pupae overwinter in the soil (USDA 1985).

Aphrophora parallela (Say), the pine spittlebug (Cercopidae), has a wide host range encompassing at least 14 species including eastern hemlock. In addition to a large host range, the pine spittlebug is found from southern Canada down the eastern United States to Alabama. The production of spittle like masses on the branches does negligible damage to its host, except on Scotch pine. This insect overwinters in the egg stage under bark and has only one generation per year (USDA 1985).

The cryptomeria scale, *Aspidiotus cryptomeriae* Kuwana (Diaspididae), also feeds on hemlock leaves as well as other species of evergreen. This armored scale was imported from Japan and is now established in Connecticut, Indiana, Maryland, New York, and Pennsylvania (USDA 1985).

A study conducted in the southeastern United States cites 22 predaceous species found on eastern hemlock including two species of Coleoptera, three species of Diptera, and two species of Neuroptera (Wallace and Hain 1999). However, these species do not constitute all the species associated with or dependent upon eastern hemlock.

Resources at Risk:

Insects and animals are not the only organisms threatened by the invasion of HWA. On June 15, 1934, Congress passed a bill establishing the Great Smoky Mountains National Park (GSM). Containing 211,100 hectares (521,621 acres) and having elevations ranging from 266 to 2025 m (875 to 6,643 feet), the GSM supports ecosystems similar to those from Georgia up the east coast to Maine. This unique area provides some of the richest biodiversity on earth. For example, 10,000 species of organisms have been documented in the GSM, and scientists estimate this number represents only one ninth of the total biodiversity. Some of the organisms include 66 species of mammals, 200 species of birds, 50 species of native fish, and 80 species of reptiles and amphibians. In addition, 100 native tree species, 1,500 species of flowering plant, 450 bryophytes, and 50 species of fern have been documented in the GSM. The GSM contains 12 major forest types, five of which have eastern hemlock as a dominant component. Important plant communities like grassy and heath balds contain rare plants. Overall the GSM is home to three endangered species and 76 species of threatened plants. In recognition of the area's rich biodiversity, the GSM was declared an International Biosphere Reserve.

In addition to the five forest types dominated by eastern hemlock, this tree occurs in many of the other vegetation types (Taylor 2002). Hemlock-dominated forests cover an estimated 1,546 hectares (3,820 acres) in the park (Johnson 1995). Of this area, 294 hectares (726 acres) is considered old growth with many trees ranging from 400 to 500 years old (Yost 1994). This area continues to be occupied by eastern hemlock despite 33 million board feet of hemlock being removed from the park by the Champion Fiber Company from 1920 to 1925, and another one billion board feet removed by the Little River Lumber Company from 1903 to 1939 (Lambert 1958, 1961).

HWA threatens to drastically change the forest composition of GSM. Studies in southern New England were conducted to assess the changing composition of hemlock forest as a result of HWA. In southern New England, eastern hemlock mortality has increased at a rate of 5 to 15 % annually since 1995. HWA infestations have led to a mortality rate of as high as 95 % (Orwig 2002). This mortality rate and live trees reaching 25 to 95 % defoliation has cleared the canopy allowing other species to replace hemlock. Some of these replacement tree species are: black birch, *Betula lenta* L., red maple, *Acer rubrum* L., and various oak species, *Quercus* spp. In the understory, mountain laurel, *Kalmia latifolia* L., partridgeberry, *Mitchella repens* L., and blackberry and raspberry *Rubus* spp. all have increased (Orwig 2002). Some herbs and grasses have shown increases including hay-scented fern, *Dennstaedtia punctilobula* (Michx.) Moore, sedge, *Carex spp.*, and Canada mayflower, *Maianthemum canadense* Desf. Populations of an invasive species, Japanese stilt grass, *Microstegium vimineum* (Trin.) A. Camus, which is present in the GSM, have increased (Orwig 2002).

The compositions of other ecosystems in the GSM have been threatened by invasive insect species. The balsam woolly adelgid, *Adelges picea* Ratzeburg, has destroyed mature stands of Fraser fir, *Abies fraseri* (Pursh) Poire, and changed high elevation forest in the southern Appalachians. As a result, many mature trees have been removed from the native range (Nicholas et. al. 1992). Feeding by the beech scale, *Cryptococcus fagisuga* Lindinger, an invasive insect from Europe, provides entry for the causative agent of beech bark disease, which causes mortality in American beech, *Fagus grandifolia* Ehrhlich (Peine 1999). In both circumstances, insect pest control maybe achieved through insecticide application or the use of insecticidal soap, but these methods are not practical on a wide scale. Rough terrain isolates many of the individual trees that need treatment, and the amount of insecticide needed to treat that many individual trees make the task financially impractical.

Biological Control:

To efficiently reduce insect pest populations, biological control (biocontrol) agents are often incorporated into the management strategy. Biocontrol agents used consist of natural predators, parasitoids, or pathogens that reduce pest populations through disrupting their ecological status. An effective biocontrol agent has at least some of the following characteristics. It is host specific, environmentally safe, cost effective, self-sustaining, and can effectively locate the pest species. Biological control agents can be effective in forest settings. *Operophtera brumata* (L.), the winter moth, is endemic to Europe and Asia. In the 1930s, it was introduced to Nova Scotia becoming a serious pest of hardwoods including oak and apple after only two decades (Gillot 1980). From over 60 known parasitiods of the winter moth, only two, a tachinid, *Cyzenis albicans* (Fallen), and an ichneumonid, *Agrypon flaveolatum* (Gravenhorst), became established as biological control agents. These two parasitiods worked in supplemental fashion to bring the winter moth populations under control by 1963 (Huffaker 1971).

In 1992, Mark McClure conducted a survey for biological control agents for use against the HWA (McClure 1997). He discovered the lady beetle, *Pseudoscymnus tsugae* McClure and Cheah, in Honshu, Japan. These ladybeetles are black, oval-shaped, and about the size of a poppy seed. As larvae, *P. tsugae* ranges from 1.1 mm to 2.7 mm long with a reddish-brown to gray appearance. The eggs are 0.25 mm to 0.48 mm long with an opaque sheath that covers the reddish-orange color. *Pseudoscymnus tsugae* feeds on HWA as well as balsam woolly adelgid, cooley spruce adelgid, *Adelges cooleyi*, and pine bark adelgid, *Pineus strobi* (Cheah 1996). The development of this lady beetle is closely synchronized with that of HWA, and effectively feds on this adelgid pest as both larvae and adult capable of consuming all life stages of HWA. An adult *P. tsugae* can consume up to 50 adelgid nymphs per week (Cheah 1996). The lady beetle is bivoltine with the first generation of eggs laid in the spring around April. Development from first instar to adult ranges from 22 - 25 days. Upon reaching maturity, *P. tsugae* undergos a 14 day period of aestivation during the summer. In July, the adults become active and produce a second generation of eggs. A single female can potentially lay as many as 500 eggs during her lifetime. This lady beetle overwinters as an adult (Carole et. al. 2000). Unfortunately, it is not yet known if *P. tsuga* has become established or is it controlling HWA populations in the southeastern United States.

Objectives:

1) To identify and determine the incidence of insect species associated with eastern hemlock.
2) To determine differences in the insect fauna of old and new growth eastern hemlock.

Chapter III. Materials and Methods

Sites:

This study was conducted at four sites in the Great Smoky Mountains National Park in east Tennessee. Two sites were located at Elkmont and represent new and old growth. The other two sites were located at the Chimney tops which also represented new and old growth (Figure 2). Each site was 20 m x 40 m, and insect specimens were collected from eastern hemlock beginning 1 June 2002 through 30 November 2002 and from 5 June 2003 through 2 September 2003.

Elkmont old and new growth were located at, 35º 39' 56.388N / 83º 35' 04.915W and 35º 39' 47.733N / 83º 35' 10.036W, respectively. Elkmont new growth is a located in a xeric oak forest (type 7), and Elkmont old growth is a part of a pine forest (type 9). Chimney tops new growth and old growth were located at, 35º 38'1.74N/83º 28'11.4"W and 35º 37'49.44"N/83º 28'3.18"W, respectively. Chimney tops old growth is located in a tulip poplar forest (type 6), while Chimney tops new growth is located in cove hardwoods (type 3).

These sites were selected based on tree maturity, elevation, and lack of human disturbance. Elkmont and Chimney tops each had a site that consisted of old growth eastern hemlock (dbh > 20), and a site that consisted of new growth eastern hemlock (dbh < 20). Sites one and two were low elevation sites (ca. 760 m), while sites three and four were high elevation sites (ca. 1,149 m). All four sites were located away from highways and hiking trails.

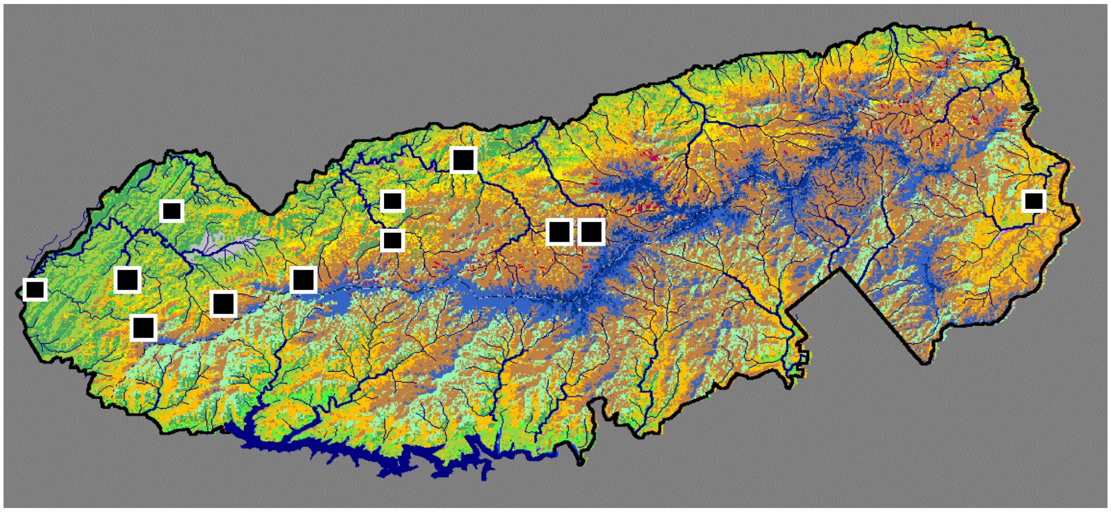

Figure 2. Location of sites sampled in the Great Smoky Mountains National Park, 2002 and 2003.

Traps:

Three trees per site were selected and marked with metal tags. Malaise/pan traps were selected as the primary collecting method based on their ability to sample insect fauna in the tree canopy. A malaise/pan trap was hung in the canopy of each of the three trees. Trap frames were constructed using PVC pipe (60cm x 60cm x 60cm) and covered with polyester netting (156). The collecting unit consisted of a plastic cup (ca. 60mm wide x 65mm deep; 120ml vol) that contained 30 – 60 ml of 50% propylene glycol (Sierra®) and water. The pan (15cm wide x 65cm long x 12cm deep) was hung under the frame and also contained 900 - 1000 ml of 50% propylene glycol and water**.** Samples were collected from all collection units and pans biweekly, labeled, and taken to the lab for processing.

Ground-dwelling insect species were sampled at two trees per site using pitfall traps. Four shallow holes (ca. 8 cm deep) (one in each cardinal direction at the canopy's peripheral edge) were dug into the ground for placement of traps. Each trap consisted of two plastic cups (60mm wide x 65mm deep/120ml vol). 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 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 randomly sampled biweekly and taken to the lab for processing.

Direct Sampling:

Visual observations were made on each tree biweekly for 15 – 20 minutes per tree using a sweep-net (a canvas bag ca. 38cm in diam., 82cm deep), tweezers, and ethyl acetate charged killing jars at each site. These specimens were placed into zip-lock bags, labeled, and taken to the lab for processing.

Supplemental Sites Sampled:

Eight additional sites were selected to more extensively sample insect fauna. The site names and corresponding GPS coordinates are listed in Table 3. At each site, a central tree was selected along with three trees in each cardinal direction representing as many as 13 trees per site that were located within 29 m from the central tree. A canvas beat sheet (1m x 1m) was used to sample insects on the trees. Ten branches on each site tree and four branches on each of the additional trees were sampled for insects. Insects were collected from the beat sheet by hand and placed into vials containing alcohol (10 ml), labeled, and taken to the lab for processing and identification. The sites at Laurel Falls, Gregory Ridge, and Anthony Creek were each sampled twice, while the sites at

Table 3. Names and corresponding GPS coordinates of alternate sites in the Great Smoky Mountains National Park

Site	Location	Site	Location
Anthony Creek	83º 44’ 32.99” W	Cataloochee Cove	83º 5’ 38.86” W
	35º 34’ 47.45” N		35º 36’ 8.65” N
Gregory Ridge	83º 50’ 1.47” W	Laurel Falls 1	83º 33’ 57.26” W
	35º 32’ 53.16” N		35º 40’ 47.75 N
Lynn Camp	83º 38’ 8.78” W	Meigs Creek	83º 36’ 33.98” W
	35º 36’ 2.42” N		35º 38’ 51.92” N
Panther Creek	83º 58’ 58.96” W	Stoney Branch	83º 50’ 53.04” W
	35º 33’ 50.52” N		35º 37’ 15.38” N

Lynn Camp, Panther Creek, Chataloochee Cove, Meigs Creek, and Stoney Branch were sampled once between October 2002 and September 2003.

Preserving and Identification of Specimens:

Specimens were retained in the field using plastic sample cups (ca. 60mm x 65mm deep; 120ml vol). Each of these cups were labeled in the field using a black magic marker. The label information consisted of date, site number, tree number, and trap type.

In the laboratory, insect specimens were drained of any excess preservative. The contents of a given sample cup were transferred to a standard petri dish (ca. 100mm x 15mm), and the biotic information from that sample cup (date, site number, tree number, and trap type) was transferred to a petri dish or dishes, if necessary. This process was repeated for each sample cup retrieved from the field. The contents of each petri dish were then weighed separately. The sum of the biomass of all the petri dishes for a given site on a given date was recorded in an Excel file. This process was repeated for each site on each sampling date.

Alcohol was added to the contents of each petri dish, and insect specimens were subsequently sorted into species. All specimens of a given species in a petri dish were removed and placed into a smaller petri dish (ca. 60mm x 15mm), which was labeled with the appropriate biotic data. This process was repeated for every species species. Up to five specimens from each petri dish were mounted with labels containing the biotic information. The remaining specimens were counted, placed into a vial, labeled with the appropriate biotic data, and the total number of specimens recorded on a label placed in the vial. Lot numbers were then assigned to each specimen, and the biotic information was recorded with the lot number. The specimens in vials were also assigned a lot number that corresponded with the mounted specimens. This process in its entirety was repeated for each sample retrieved from the field.

Specimens were identified using standard keys and voucher specimens located in the University of Tennessee Insect Museum. The assistance of several specialists was enlisted for the more difficult specimens. Specialists are listed in Table 4. All identified species were systematically arranged into Cornell drawers for incorporation into the GSM and University of Tennessee insect museums.

Data Analysis:

A species list was developed from specimens obtained from all collection methods at all sites. Data, which was entered into a computer database (Excel®), consisted

Table 4. Specialists assisting in the identification of specimens from the Great Smoky Mountains National Park, 2002 and 2003

Specialist's Name	Address
Adriean Mayor, Ph.D. Coleoptera	Great Smoky Mountains National Park 107 Park Headquarters Rd. Gatlinburg, TN 37738
Dave Paulsen Diptera and Lepidoptera	147 Biotechnology Bldg. 2505 E. J. Chapman Dr. University of Tennessee Knoxville, TN 37996-4560
John Skinner Ph.D. Hymenoptera	105 Biotechnology Bldg. 2505 E. J. Chapman Dr. University of Tennessee Knoxville, TN 37996-4560
Karen Vail Ph.D. Hymenoptera	2431 Center Dr. 205 Plant Science Bldg. University of Tennessee Knoxville, TN 37996-4560
Lloyd Davis Ph.D. Hymenoptera	USDA-ARS-CMAVE 1600 S. W. 23rd Dr. Gainesville, FL 32608
Matt Peterson Diptera	Iowa State University Dept. Entomology 110 Insectary Ames, IA 50011
Paris Lambdin Ph.D. Heteroptera	130 Biotechnology Bldg. 2505 E. J. Chapman Dr. University of Tennessee Knoxville, TN 37996-4560

of: species name, family name, order, site, number of specimens, collection date. To determine species richness for each site, the database was sorted by site and the species for each site counted. Uncommon or rarely encountered species collected were determined by dividing those species represented by a single specimen by the total number of species to obtain a ratio. In addition, all species were compared to the Tennessee Natural Heritage Program: Rare Invertebrates List to determine endangerment status at the state level (Withers 1997). The malaise/pan trap sampling method data was used to assess the insect fauna in relationship to their association with the host plant. Insect diversity, basic composition, and evenness were determined for each site and all sites combined using the Shannon Weiner index (Vandermeer 1981). The Shannon Weiner index (H') utilizes the equation $H' = -\Sigma p_i \ln p_i$. To assess evenness the Shannon Weiner evenness index (J) was also ($E = H'/ \ln S$). Significant differences were determined by using the Chi-square (X^2) formula $X^2 = {}^k\Sigma (f_i - f'_i)^2 / f'_i$, and output values were considered significant at ≤ 0.05. The statistical package EstimateS version 6 (Colwell 2000) was used to calculate species estimates. The following species richness estimators are utilized in the program EstimateS: abundance coverage (ACE), incidence coverage (ICE), Chao 1, and jackknife 1. EstimateS, which was used in this study, is a program used to estimate species richness based on collection patterns.

Chapter IV. Results and Discussion

During this study, 2,517 specimens, representing 281 species in 86 families and nine orders, were collected and identified (Appendix), with the number of species per site ranging from 88 to 115. The majority (n = 123, 43.9%) of species collected were members of the order Coleoptera, while Diptera (81 species) and Lepidoptera (26 species) were well represented (Figure 3).

Species Richness and Abundance:

Species richness varied among new and old growth sites. Eastern hemlocks at the Elkmont new growth site yielded 104 species with 33 of the 280 species identified found only at this site. A similar number of species (106) was recorded at the Elkmont old growth site with 27 site-specific species. A higher number of species (115) was documented at Chimney tops old growth site of which 42 species were site specific.

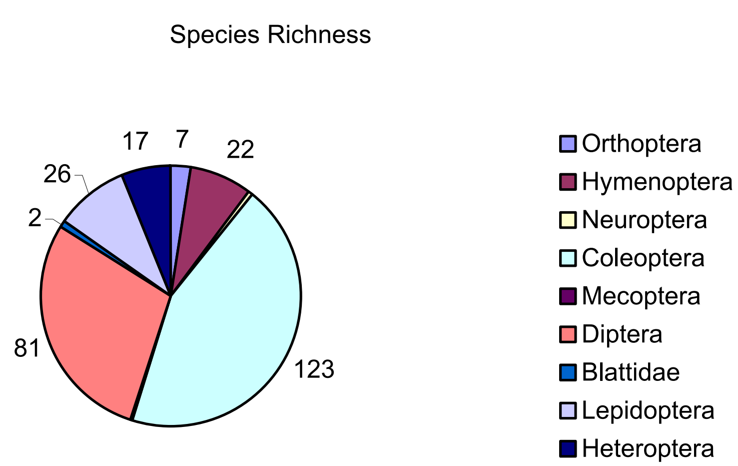

Figure 3. Insect species richness by order collected in the Great Smoky Mountains National Park, 2002 and 2003 (n = 281 species collected)

Conversely, the lowest number of species (88) was recorded at the Chimney tops new growth site, although the number of species (28) unique to this site was similar to that at the Elkmont old growth site. As a result, including 10 site-specific species from a combination of the alternate sites, 50% (140) of all the species collected were found at only one sample site. The number of specimens collected varied among sites ranging from 486 at site four to 801 at site three. Specimen abundance differed significantly only for site three ($\lambda^2 = 245.976$, df = 3, p = 0.05) (Figure 4). Species present throughout the spring and summer were determined. The highest number of species (105) was documented in June 2002, while the lowest number (10 species) occurred in September 2003 as a result of fewer sampling dates (Figure 5). The highest number of specimens (466) was collected in October 2002, while the lowest monthly abundance (25) occurred in November 2002 as a result of a fewer number of samples taken. Significant differences (F = 103.30, df = 5, 3, p = 0.05) in monthly abundance for 2002 and 2003 are illustrated in Table 5. The total abundance collected at all sites from June

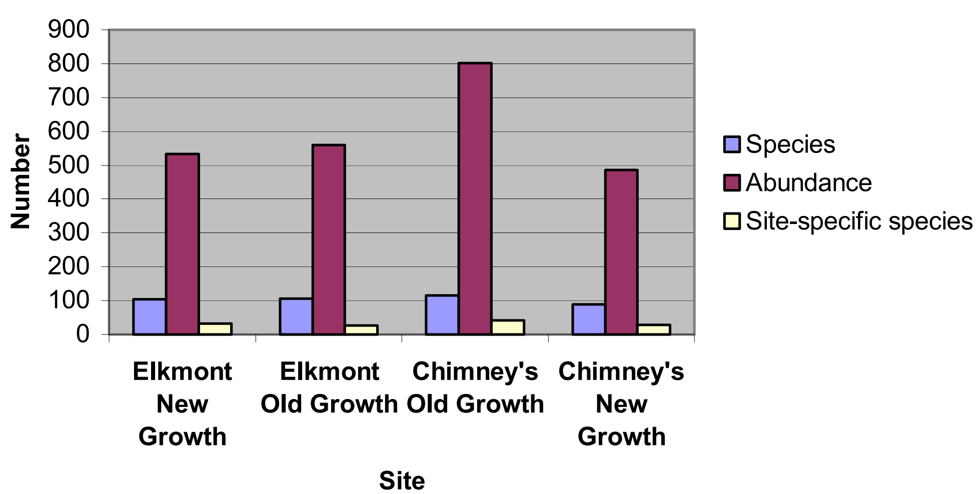

Figure 4. Species richness and abundance by month, Great Smoky Mountains National Park, 2002 and 2003

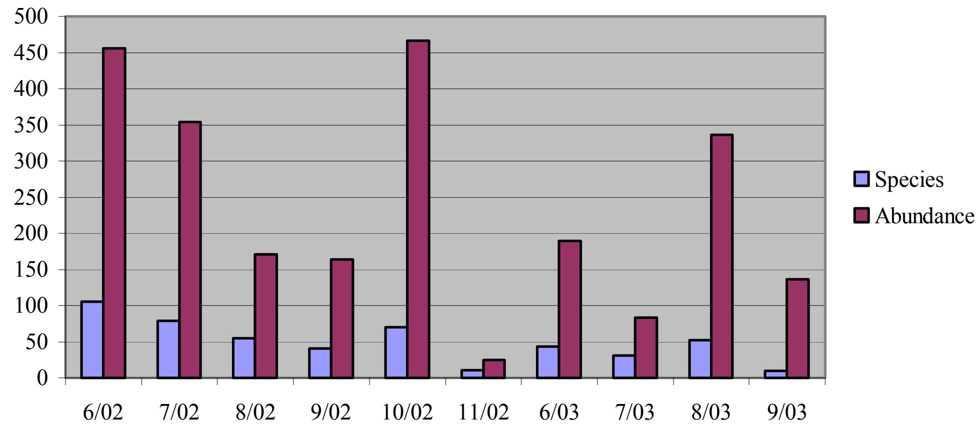

Figure 5. Species richness and abundance by month, Great Smoky Mountains National Park, 2002 and 2003

Table 5. Specimen abundance by month, Great Smoky Mountains National Park, 2002 and 2003

Month	Specimens Collected 2002	Specimens Collected 2003
June	456a*	189b
July	354b	88c
August	166c	336a
September	164c	136b
October	466a	--
November	25d	--

*Numbers followed by the same letter are not significantly different ($F = 103.30$, $df = 5, 3$, $p = 0.05$)

through November 2002 was 1,631 specimens. In 2003, only June through September. When the same months are compared across both years, significantly more insects were captured in 2002 ($\lambda^2 = 63.177$, df = 1, $\alpha = 0.05$). From June through August 2002, 976 specimens were collected, while only 613 were collected during the same months in 2003. The months of June and July show a great deal of variance (range 88 - 456) when abundance is compared across the years 2002 and 2003, which is possibly due to the end of a period of drought that was followed by considerable rainfall during June and July 2003. The effect of rain on collecting was twofold: 1) rain can limit arthropod activity and 2) the pans fill with water and wash the samples out of the traps (Bergh 2000).

A list of the most abundant species (15 or more specimens) is presented in Table 6. These 1,814 specimens and 42 species represent 72% of the total abundance and 15% of the total species richness, respectively. The dominant order represented was Coleoptera with 984 specimens and 24 species. Hymenoptera had 396 individuals and 8 species, followed by Diptera with 311 individuals and 7 species, and Orthoptera with 123 specimens and 3 species.

The carabid *Sphaeroderus stenostomus* Weber, which was the most abundant species (199 specimens) captured, feeds exclusively on snails often located on the forest floor (Arnett 1996). Carabids, commonly called ground beetles, are a large family widely distributed with many various feeding habits. The genus *Sphaeroderus* consists of 10 taxa grouped into six species ranging from northern Newfoundland to north Georgia and west into the eastern part of the Mississippi Basin (Iowa, Minnesota, and Manitoba) and northward to Saskatchewan (Arnett and Thomas 2002). This species has been reported in Virginia, North Carolina, and Tennessee, as well as other southeastern states. It can

Table 6. Most abundant species collected at old and new growth eastern hemlock sites (15 or more specimens), Great Smoky Mountains National Park, 2002 and 2003.

Order	Family	Genus	Species	Author	# Specimens
Coleoptera	Agyrtidae	Necrophilus	pettiti	Horn	24
	Alleculidae	Isomira	sericea	(Say)	26
	Carabidae	Cyclotrachelus	convivus	LeConte	19
	Carabidae	Calosoma	externum	(Say)	21
	Carabidae	Dicaelus	politus	DeJean	21
	Carabidae	Dicaelus	teter	Bonelli	26
	Carabidae	Maronetus	debilis	(LeConte)	28
	Carabidae	Calosoma	marginale	Casey	32
	Carabidae	Scarites	subterraneus	F.	35
	Carabidae	Sphaeroderus	stenostomus	Weber	199
	Cerambycidae	Clytus	ruricola	(Olivier)	15
	Cerambycidae	Pidonia	densicollis	(Casey)	16
	Cerambycidae	Strangalepta	abbreviata	(Germar)	20
	Cerambycidae	Pidonia	aurata	(Horn)	36
	Coccinellidae	Psyllobora	vigintimaculata	(Say)	29
	Curculionidae	Odontopus	calceatus	(Say)	28
	Eucnemidae	Isorhipis	obliqua	(Say)	51
	Nitidulidae	Glischrochilus	fasciatus	(Olivier)	19
	Nitidulidae	Glischrochilus	sanguinolentis	(Olivier)	84
	Scarabaeidae	Serica	georgiana	Leng	23
	Scarabaeidae	Geotrupes	horni	Blanchard	118
	Silphidae	Nicrophorus	defodiens	Mannerheim	29
	Silphidae	Nicrophorus	orbicollis	Say	68
	Staphylinidae	Tachinus	fimbriatus	Gravenhorst	17
Diptera	Anthomyiidae	Pegomya	sp.		15
	Calliphoridae	Phaenicia	pallescens	(Shannon)	30
	Muscidae	Mesembrina	latreillii	Robineau-Desvoidy	25
	Muscidae	Thricops	rufisquama	(Schnabl)	33

Table 6. Continued

Order	Family	Genus	Species	Author	# Specimens
	Mycetophilidae	Phronia	sp.		54
	Mycetophilidae	Monoclona	elegantula	Johannsen	122
	Mycetophilidae	Mycetophila	sp.		32
Hymenoptera	Apidae	Bombus	bimaculatus	Cresson	30
	Apidae	Bombus	impatiens	Cresson	33
	Apidae	Bombus	fervidus	(F)	34
	Apidae	Bombus	perplexus	Cresson	51
	Formicidae	Prenolepis	impairs	(Say)	45
	Formicidae	Aphaenogaster	picea	Emery	102
	Halictidae	Augochlorella	pura pura	(Say)	15
	Vespidae	Vespula	vulgaris	(L.)	86
Orthoptera	Gryllacrididae	Camptonotus	carolinensis	Gershacker	18
	Gryllacrididae	Ceuthophilus	brevipes	Scudder	25
	Gryllacrididae	Ceuthophilus	maculatus	Harris	80

overwinter as both a larvae and adult (Downie 1996). Due to these qualities, the cool moist nature of the hemlock forest floor makes an excellent hunting ground for *S. stenostomus*, which was represented at all four sites. Another carabid species, *Scaphinotus andrewsi* L., is a generalist predator collected in the unique microclimates produced by eastern hemlock (Arnett 2002). This beetle was represented at two sites by 13 specimens.

Other insect taxa collected that feed on snails *Euthycera arcuata* (Loew) (Diptera: Sciomyzidae). Sciomyzid flies are medium to large (1.8 to 11.5 mm long), and usually dull gray (Berg and Knutson 1978). About 200 species throughout the world feed on terrestrial or freshwater snails, their eggs, and larvae (Berg and Knutson 1978). This insect is a parasitoid that lays its eggs on the backs of snails. When the egg hatches, the larvae feed on the snail.

The second most commonly occurring species of Diptera was *Monoclona elegantula* Johannsen a mycetophilid represented by 122 specimens collected from the Elkmont new growth site and both Chimney tops sites. Mycetophilids, also known as fungus gnats, are mosquito-like in appearance and are found in shady, damp places near fungi or decaying vegetation. Although a few species are predaceous as larvae, most feed on fungus and few are considered pests (Borror et. al. 1989).

The most abundant Hymenoptera collected was *Aphaenogaster picea* Emery, an ant in the family Formicidae. Some 102 specimens of *A. picea* were collected at both Elkmont sites and the Chimney tops old growth site. However, all but one of the specimenswere collected from the two Elkmont sites. Abundance was concentrated at these two sites because of several colonies of *A. picea* located around and between the

Elkmont sites. These ants are indigenous to the southern Appalachian highlands, New England, and Nova Scotia (Creighton 1950).

Geotrupes horni Blanchard (Scarabaeidae) was represented by 118 specimens collected from both Elkmont sites and the Chimney tops new growth site. This medium to large dark species (11 - 18 mm), which was the third most commonly collected species, is common throughout the eastern United States, and lives in fungi (Downie and Arnett 1996). A total of 13 species and 196 specimens of scarabaeid beetles were collected in this study. Scarabaeidae is a large family with 27,800 species with species variable in size and colors (Arnett and Thomas 2002).

Another commonly collected beetle (84 specimens) was *Glischrochilus sanguinolentis* (Olivier). This nitidulid was collected at all four sites. *G. sanguinolentis* is a small beetle (4.5 - 6.2 mm) with a black pronotum and red elytra that is found on sap or fungi (Downie and Arnett 1996). Five species of nitidulids (112 specimens) were collected in this study (Table 6). The family Nitidulidae, commonly known as sap beetles, has 2,800 species and 172 genera worldwide with 165 species and 30 genera 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 (Arnett and Thomas 2002).

Rarely Collected Species:

Singletons are species represented by a single individual. During this study, 127 singletons were recorded representing 45% of the total species richness. These individuals represented 25% of the species richness at the Elkmont new growth site, and 26% of the species richness at both Chimney tops sites. The lowest percentage of singletons (19%) occurred at site 2. Species richness at all four sites was composed of 42% singleton species. Alternate sites had the highest composition of singleton species at 52%. The high percentage of singleton species at alternate sites is largely due to the collection methods used and the number of times the area was sampled. Collection methods at alternate sites included beat sheeting and hand picking.

The family containing the most singleton species was Noctuidae, 10 of 13 species were singletons. Noctuidae is the largest family in Lepidoptera represented by 2,900 species in the United States and Canada. Most species are foliage feeders with a few boring and fruit feeder species (Borror et. al. 1989). Of the 10 singleton species collected, all were foliage feeders. None of these singletons feed on eastern hemlock. Instead, various plants were fed upon by these species including birch, alder, hickory, basswood, cherry, black walnut, maple, plantain, and asters. All of these noctuid species are considered common except *Lithophane baileyi* Grote (Covell 1984). This species, known as Bailey's pinion, feeds primarily on birch, apple, cherry and willow. It is distinguished by its greenish gray wings with black spots and U-shaped orbicular spots (Covell 1984). Due to the unrelated feeding habits and low abundance, these insects are considered transient species. Other families that were represented by a high singleton species ratio include Tipulidae (5 of 7 species) and Tenebrionidae (3 of 4 species).

Insect Diversity:

To compare diversity and evenness among sites, Shannon Wiener diversity and evenness values were used (Table 8). No significant differences ($\lambda^2 = 3.339$, df = 3, $\alpha < 0.05$) were detected among sites. In a biodiversity study conducted on insect fauna associated with yellow poplar, *Liriodendron tulipifera* L., in east Tennessee, Shannon-

Wiener diversity values were 3.69 and 2.96 for each respective site with evenness values of 0.77 and 0.69 (LaForest 1999). These values for the insect fauna on this host tree are lower than the overall Shannon Wiener diversity and evenness values calculated for insect fauna associated with eastern hemlock in this study of 4.505 and 0.799, respectively.

Sampling methods are made more effective by standardizing them and limiting bias (Southwood 1994). Therefore, these collection methods were analyzed using species richness, abundance, and Shannon Wiener diversity and evenness values. Malaise traps were the most successful single collection method used to sample the insect fauna on eastern hemlock. Malaise traps accounted for 858 specimens or 34% of abundance, which comprised 141 species or roughly 50% of species richness. Malaise traps also had the highest Shannon Weiner diversity value at 4.137 (Table 7). Pitfall traps, considered

Table 7. Shannon-Wiener diversity and evenness values for insect fauna at new and old growth eastern hemlock sites, Great Smoky Mountains National Park, 2002 and 2003.

Site	Shannon's H'	Shannon's E
Elkmont New Growth	3.94	0.836
Elkmont Old Growth	3.769	0.8
Chimney Tops Old Growth	3.614	0.764
Chimney Tops New Growth	3.636	0.808
All Sites	4.505	0.799

($\lambda^2 = 3.339$, df = 3, $\alpha < 0.05$)

both an ecologically sensitive and cost-effective collection method, recorded 679 specimens and 55 species that resulted in the lowest Shannon-Weiner diversity value with 2.912 (Work 2002). Direct collection (hand picking, beat sheet, and sweep netting) accounted for 107 specimens and 47 species. Direct collection had the highest Shannon Weiner evenness value of any single collection method at 0.831 (Table 8). Most specimens were collected by multiple collection methods (any combination of the above listed trap types) that accounted for 872 specimens, but only 37 species, which constitutes35% of total abundance and 13% of species richness, respectively (Figure 6).

Table 8. Shannon-Wiener diversity and evenness values for collection methods used to sample the insect fauna associated with eastern hemlock, Great Smoky Mountains National Park 2002 and 2003

Collection Method	Shannon's H'	Shannon's J
Malaise	4.137	0.799
Pitfall	2.912	0.720
Direct	3.18	0.831
Multiple traps	3.306	0.845

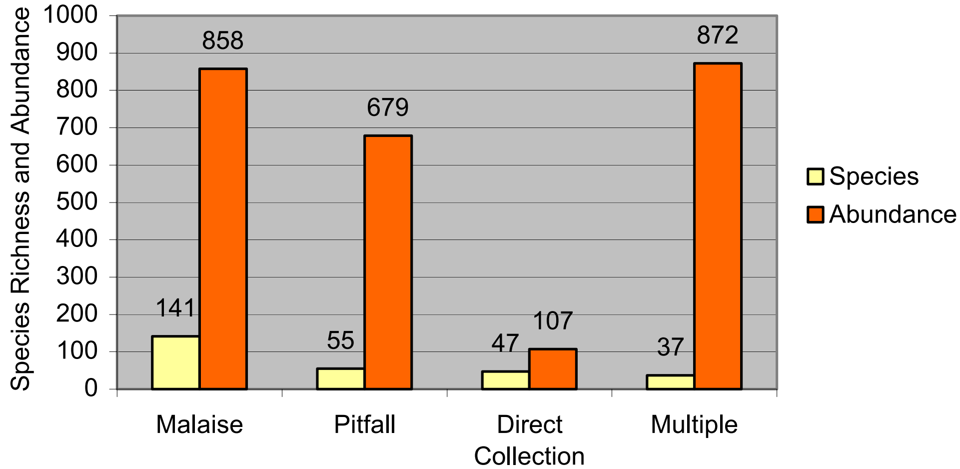

Figure 6. Species richness and abundance by collection method, Great Smokey Mountains National Park, 2002 and 2003

Species Richness Estimates:

To determine how many species were potentially present in a given site, the species richness estimators (ACE, ICE, Chao 1, and Jack 1) were used (Colwell 2000). Although the results varied for each estimator, 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 175 and 225 species with104 species observed (Sob), representing the smallest species estimate range (50 species) among the four sites. Elkmont old growth site estimates ranged from 175 to 245 species with 106 Sob, and Chimney tops old growth site estimates ranged from 185 to 270 species with 115 Sob. These two sites accounted for the largest species estimate range (85 species) among the four sites. The range of species estimates for Chimney tops

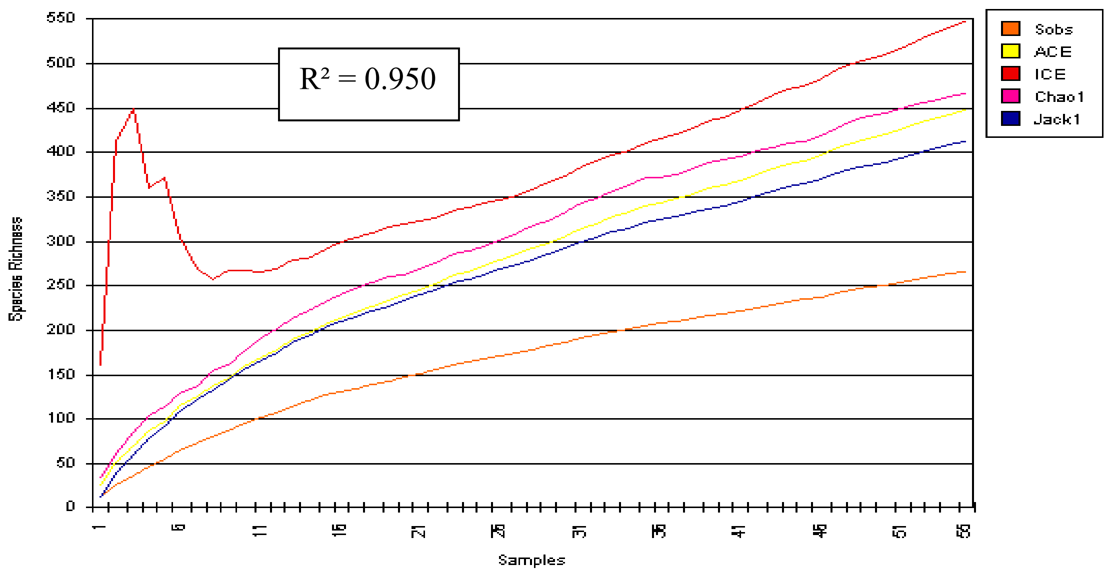

Figure 7. Species richness estimates for all sites combined, Great Smoky Mountains National Park, 2002 and 2003.

new growth site was 145 to 230 species. The species estimates for all of the sites combined ranged from 415 to 550 species (Figure 7). The R^2 value for all of these estimates are strong (above 0.900) suggesting a high level of confidence in each estimate. Few studies have been conducted on arthropod species richness on conifers, but these estimates are low when comparing estimates to species richness found on other tree species. For example, LaForest (1999) found 727 species associated with tulip poplar, *Liriodendron tulipifera* L. These higher numbers could be a result of sampling method. In the future, other collection methods such as fogging and sticky traps may be used to supplement the collection methods used in this study.

Biomass:

To evaluate the amount of biotic material removed from the GSM, the biomass collected at each site was measured in grams. Biomass, which included any living material collected including all arthropod taxa, is important because it provides a quantitative measure that is comparable among sites. The highest biomass occurred at the Elkmont and Chimney tops old growth sites (Table 9).

Insect Guilds:

Feeding habits of insects collected were arranged into three guilds: phytophagous, scavenger, and predaceous. Phytophagous insects comprised the highest species richness(159 species) and a high abundance (1,002 individuals). The highest abundance occurred in scavenger insects (1,054 individuals), but species richness among scavenger was considerably lower (84 species). Predaceous insects had the lowest abundance and species richness (38 species, 460 individuals). Five species (27 specimens) that feed on eastern hemlock were found: Comstock's sallow, *Feralia comstocki* (Grote), hemlock scale, *Abgrallaspis ithacae* (Ferris), *Leptura subhamata* Randall, hemlock looper, *Lambdina fiscellaria* (Gueneẽ), and *Dicerca tuberculata* (Laporte and Gory). These species were members of three orders and represented five families.

Table 9. Biomass collected by site, Great Smoky Mountains National Park, 2002 and 2003.

Site	Biomass
Elkmont New Growth	15.872 ab*
Elkmont Old Growth	23.672 ab
Chimney tops Old Growth	24.639 ab
Chimney tops New Growth	12.099 c

*Numbers followed by the same letter are not significantly different ($F = 3.861$, $df = 3$, $\alpha = 0.05$)

An additional 11 (LeConte), *Arthromacra aenea* Say, *Glischrochilus quadrisignatus* (Say), *Glischrochilus sanuinolentis* (Olivier), and Glischrochilus fasciatus (Olivier). Several species known to

be associated with eastern hemlock were not found: *Coleotechnites apicitripunctella* (Clemens), *Eufidonia notataria* (Walker), *Choristoneura fumiferana* (Clemensy), *Eucosma tocullionana* Heinrich, *Ceroplastes ceriferus* (F.), *Melanophila fulvoguttata* (Harris), *Otiorhynchus ovatus* L., *Otiorhynchus sulcatus* (F.), and *Riorinaia externa* Ferris.

Important species collected that feed on eastern hemlock included the hemlock looper, which is in the family Geometridae. The Geometrid family is known as the measuring worms because of their looping or measuring crawling style. Several species in this family are pests of woody plants. The hemlock looper range extends from northern Georgia to southern Canada and west to Wisconsin often following mountainous terrain. This pest became a serious problem in the late 1980s and early 1990s in Maine where it defoliated 101,200 hectares of hemlock and fir in the southern one-half of the state. The hemlock looper is capable of damaging a great deal of its host's foliage in a short period of time. The hemlock looper deposits its eggs, starting in late August, in twigs, branches, or the trunk of the host. The eggs hatch in June, and the larvae feed on new foliage. During this stage an infestation can be detected by an increase in cut foliage around the base of the tree from larval feeding. The pupa have no cocoon and are found in cracks in the tree trunk, nearby objects, or leaf litter. After a 2-3 week pupal period, mid-August, the adults emerge and are present through October (Maine Dept.

Conservation 2001). The hemlock looper (nine specimens) was found at sites 3, 4, Laurel Falls, Anthony Creek, Gregory Ridge, and Meigs Mountain.

Another lepidopteran (four specimens) collected at Stoney Branch was the noctuid moth commonly called Comstock's sallow. It can feed on firs, pines, spruces, and hemlock. The range of this species is from Newfoundland south to North Carolina west across Canada and south to Kentucky (Covell 1984). This insect is not known as a pest.

Hemlock scale is a native species that feeds on eastern hemlock. This species rarely reaches damaging levels due to natural enemies including parasitic Hymenoptera. The hemlock scale occurs throughout the range of eastern hemlock and also feeds on various species of firs (*Abies* spp.) and pines (*Pinus* spp.) (Stimmel 2000). All eight specimens were collected at Laurel Falls.

The buprestid beetle, *Dicerca tuberculata* (Laporte and Gory), commonly known as the metallic wood-boring or jewel beetles, is between 13 and 19 mm long with a green iridescent hue. One specimen of this species was collected at the Anthony Creek site. *D. tuberculata* is also known to feed on *Pinus* spp., *Picea* spp., *Abies* spp., *Larix* spp., *Thuja* spp., and *Tsuga* spp. (Downie and Arnett 1996). Some 762 species of buprestids are recorded in North America. These species are distinguished by their spindle-like shape and bright iridescent colors. The larvae of most species generally bore into dead or dying trees or branches. A few species bore into green wood or form galls (Arnett 2002).

The cerambycid, *Leptura subhamata* Randall, is between 11 and 17 mm long and can be found throughout northeastern North America. It is known to feed on decaying hemlock and pine (Yanega 1996). Five members of this species was found at sites 1 and

2. The family Cerambycidae is commonly called the longhorn beetles for their distinctly long antennae. It is a large family containing more than 20,000 species throughout the world and 900 species in North America north of Mexico. The larvae of these beetles bore into roots and wood (Arnett and Thomas 2002). In all, 123 longhorn beetles representing 20 species were collected.

Hemlock Woolly Adelgid Predators:

Predators are often used to suppress populations of destructive exotic pests such as the HWA. In previous work to survey for native predators of HWA in the southeastern United States, 22 species of native predators were collected from eastern hemlock (Wallace and Hain 1999). Nine species of predators in three families collected in this study may feed on HWA. From mass releases of the coccinellid species, *Pseudoscymnus tsugae* Sasaji and McClure, made in June 2002, four specimens were collected at the Laurel Falls and Anthony Creek sites. This lady beetle feeds exclusively on adelgid eggs, larvae, and the soft-bodied adults. The abundance HWA predator species collected was only 20 which was not unexpected. According to Allison et. al. (1993) predaceous insects tend to have high number of singletons. This is due in part to the fact that these species are not directly associated with a particular plant. Therefore, predaceous species are more evenly distributed throughout the forest system.

The family Coccinellidae has almost 6,000 species distributed worldwide and 475 species in North America north of Mexico (Arnett and Thomas 2002). Beetles in this family have been used successfully as biocontrol agents but with widely varying abundance from year to year (Elliott et. al. 2002). Other lady beetle species collected were *Anatis labiculata* (Say), *Hyperaspis signata* Olivier, *Cycloneda munda* (Say), and

Harmonia axyridis (Palles). In all, six species of lady beetles and 41 individuals, not all of which feed on insects, were collected in this study. These predator species have the potential to impact HWA populations, but more analysis must be done to determine if they can establish themselves as effective biological control agents.

Cantharidae is a large family with 5,083 species in 137 genera with 473 species in North America north of Mexico (Delkeskamp 1978, Arnett and Thomas 2002). This family, commonly known as soldier beetles, is soft-bodied and varies greatly in size (1.2 - 28.0 mm). Adults are found in vegetation and forested habitats as well as open areas. Many cantharids are predaceous as adults. Species in the genus *Podabrus* are known to feed on small soft-bodied insects such as aphids (Arnett and Thomas 2002). Three cantharid beetles (six speciemens) were collected in this study including *Podabrus tomentosus* (Say), *Silis bidentatus* (Say), and *Trypherus latipennis* (Germar).

The family Chrysopidae is known as the green lacewings and recognized by their yellowish-green hue and lacelike wings. This family is predaceous as both larvae and adults feeding on soft-bodied insects such as mites, thrips, aphids, and mealybugs. Other members of this family have been successfully used as biocontrol agents such as the goldeneye lacewing, *Chrysopa oculata* Say (USDA 1985). In this study two specimens of *Chrysopa* sp. were the only chrysopids collected.

Uncommon Families Identified:

The family Agyrtidae consists of 61 species and eight genera worldwide. Six of these genera and 11 species can be found 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, known as the primitive carrion beetles, were until recently considered part of the family Silphidae and are associated with decaying organic matter. Members of this family are adapted to cool climates often near mountainous regions, cool streams, or high elevation snowfields. Specimens of this family are not commonly collected (Peck 2001). However, 24 specimens were collected from all four sites.

Five specimens of *Dryomyza simplex* Loew (Diptera: Dryomyzidae) were collected from site 3. These insects are found as larvae in decaying organic matter similar to that found in moist forest situations. These flies are considered rare (Borror et. al. 1989).

Chapter V. Conclusions

Insects represent the largest taxa in the animal kingdom with three times as many species as any other group. There are an estimated 30 million species of insects (Borror et. al. 1989), and forests are a strong hold for biodiversity in the insect community (Stork and Hammond1997). Studies conducted in rain forests have produced high species richness and abundance (545 species and 1339 abundance) (Elton 1973). Studies involving one species of tree have reported species richness values closer to what was found to be associated with eastern hemlock (280 species). Southwood et. al. (1982) reported 337 species on *Betula* sp., 249 species on *Buddleia* sp., and 465 species on *Quercus* sp. in regions of South Africa. Eastern hemlock trees are valuable for their aesthetics, tourism, and are an integral part of the species rich forests in eastern North America. Unfortunately, the health of these trees and the structure of the forest systems they are a part of are threatened by over harvesting, loss of habitat, and the exotic insect HWA.

Because of the importance of biodiversity to the well being of forest systems and the intricate nature of insect communities, information on the state and function of eastern hemlock forest systems is imperative when making management decisions. However, an interstice exists in research data concerning insect relationships to eastern hemlock trees. Because of this gap, a research project was initiated in 2001 to assess the insect diversity associated with eastern hemlock. Four sites and eight alternate sites were selected and sampled utilizing malaise trapping, pitfall trapping, and direct collection as sampling methods to assess the insect fauna on eastern hemlocks in the GSM and to record differences in insect community structure at new and old growth sites. In assessing biodiversity associated with eastern hemlock 2,517 insects representing 281 species were collected and identified. Species richness, abundance, and biomass were highest at the two old growth sites, and species richness ranged from 88 to 115 species for test sites 1 through 4. Species estimates for all sites combined ranged from 415 - 550 species. The highest species richness (105) occurred in June, 2002 , while the most specimens were collected (466) in October 2002.

Nine orders and 86 families were represented in this study. Coleoptera was the most abundant order comprising 45% of all insects collected. In addition, beetles had the highest species richness making up 44% of all species identified with 123 coleopteran species represented. The most abundant species was the coleopteran *S. stenostomus* that represented by 199 specimens.

The dominant feeding guild were phytophagous insects, which made up 56% of all species collected. Though predaceous species occurred in lower abundance and richness, nine species were identified as predators of HWA.

Information obtained in this study can be used to evaluate forest management decisions in forests containing stands of eastern hemlock. Information presented in this study also provides baseline data for arthropod faunal composition on eastern hemlock that is a valuable commodity in the face of the impending threat of HWA.

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Appendix

Insects associated with eastern hemlock in the Great Smoky Mountains National Park, 2002 and 2003

Order	**Family**	**Genus**	**Species**	**Author**	**Site**	**Method**	**N**
Orthoptera	Gryllacrididae	Camptonotus	carolinensis	Gershacker	1, 2, 3	PF	18
	Gryllacrididae	Ceuthophilus	brevipes	Scudder	1, 2, 3, 4	PF	25
	Gryllacrididae	Ceuthophilus	maculatus	Harris	1, 2, 3, 4	MA/PF	80
	Gryllidae	Acheta	assimilis	(F.)	1	PF	2
	Gryllidae	Allonemobius	fasciatus	(DeGeer)	1, 2	PF	10
	Gryllidae	Oecanthus	exclamationis	Davis	A1	DI	1
	Tetrigidae	Arphia	sulphurea	(F.)	1	PF	1
Blattodea	Blattidae	Ischnoptera	deropeltiformis	Brunner	1, 2	MA/PF	3
	Blattidae	Periplaneta	americana	(L.)	1, 2	MA	2
Heteroptera	Cicadellidae	Gyponana	conferta	DeLong	2, 3	MA	2
	Cicadellidae	Osbornellus	limosus	DeLong	1	MA	1
	Cicadellidae	Scaphoideus	chelus	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
	Lygaeidae	Ischnorrhynchus	resedae	(Panzer)	A1	DI	1
	Membracidae	Gloaaonutus	unillatus		A2	DI	1
	Membracidae	Platycotis	vittatus	(F.)	1, 2, 3, 4	MA	9
	Pentatomidae	Banasa	calva	(Say)	A1, A2	DI	2
	Pentatomidae	Elasmucha	lateralis	(Say)	3	PF	1
	Pentatomidae	Meadorus	lateralis	(Say)	A2, A3	DI	2
	Pentatomidae	Mormidae	lugens	(F)	A1	DI	1
	Scutelleroidea	Tetyra	bipunctata	(Herrich-Schaeffer)	1	MA	1
	Thyreocoridae	Corimelaena	Pulicaria	(Germar)	A1	DI	1
	Tingidae	Corythuca	pruni	Osborn & Drake	A1	DI	1
Neuroptera	Chrysopidae	Chrysopa	sp.		A2, A3	DI	2
Coleoptera	Agyrtidae	Necrophilus	pettiti*[1]	Horn	1, 2, 3, 4	MA/PF	24

[1] * Indicates identification by specialist

Order	Family	Genus	Species	Author	Site	Method	N
	Alleculidae	Isomira	sericea	(Say)	1, 2, 3, A4	MA	26
	Bruchidae	Cryptocephalus	quadruplex	Newman	2	MA	1
	Buprestidae	Dicerca	tuberculata	(LaParte & 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	tenue	(LeConte)	4	PF	1
	Carabidae	Calosoma	externum	(Say)	1, 2, 3	PF	21
	Carabidae	Calosoma	marginale	Casey	1, 2, 3, 4	PF	32
	Carabidae	Carabus	sylvosus	Say	1, 2 ,3, 4	PF	8
	Carabidae	Cyclotrachelus	convivus	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	HP	1
	Carabidae	Maronetus	debilis	(LeConte)	3, 4	PF	28
	Carabidae	Scaphinotus	andrewsi	L.	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
	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	Cyrtophorus	verrucosus	(Olivier)	4	MA	1
	Cerambycidae	Idiopidonia	pedalis	(LeConte)	3, 4	MA	5
	Cerambycidae	Leptorhabidium	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	Clytus	ruricola	(Olivier)	1, 2, 3, 4	MA	15

Order	Family	Genus	Species	Author	Site	Method	N
	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	velutinus	(Olivier)	2	MA	1
	Cerambycidae	Urgleptes	facetus	(Say)	2	DI	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	Cycloneda	munda	(Say)	A2	DI	1
	Coccinellidae	Harmonia	axyridis	(Palles)	A1, A2	DI	2
	Coccinellidae	Hyperaspis	signata	Olivier	1	MA	1
	Coccinellidae	Pseudoscymnus	tsugae	Sasaji & McClure	A1, A2	DI	4
	Coccinellidae	Psyllobora	vigintimaculata	(Say)	A2, A3	DI	29
	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, DI	4
	Curculionidae	Myrmex	myrmex	(Herbst)	1	MA	1
	Curculionidae	Neocimberis	pilosus	(LeConte)	A2	DI	1
	Curculionidae	Odontopus	calceatus	(Say)	1, A2, A3, A4, A5	MA, DI	28
	Curculionidae	Panscopus	erinaceus	(Say)	A9	DI	1
	Elateridae	Agriotes	oblongicollis	(Melsheimer)	1, 2, 4	MA/PF	10
	Elateridae	Athous	brightwelli	(Kirby)	1, 2, A5	MA, 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

Order	Family	Genus	Species	Author	Site	Method	N
	Elateridae	Ctenicera	signaticollis	(Melsheimer)	1, 2, 4	MA	7
	Elateridae	Hemicrepidius	memnonius	(Herbst)	1, 2	MA	2
	Elateridae	Lacon	obtecta	(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
	Erotylidae	Megalodacne	heros	(Say)	2, 3, 4	PF/DI	7
	Eucnemidae	Isorhipis	obliqua	(Say)	1, 2, 3, 4	MA/PF	51
	Lampyridae	Ellychnia	corrusca	(L.)	1, A1	PF	2
	Lampyridae	Pyropyga	decipiens	(Harris)	2	MA	1
	Langriidae	Arthromacra	aenea	Say	2, 3	MA	3
	Lycidae	Plateros	centralis	Green	1, 2	PF	2
	Melandryidae	Dircaea	quadrimaculata	(Say)	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
	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	sanguinolentis	(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	Bolboceras	simi*	(Wallis)	1, 2	MA/PF	2
	Scarabaeidae	Cloeotus	globosus	Say	2	PF	1
	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	Geotrupes	blackburni	(F.)	1	PF	1

Order	Family	Genus	Species	Author	Site	Method	N
	Scarabaeidae	Geotrupes	horni	Blanchard	1, 2, 4	MA/PF	118
	Scarabaeidae	Geotrupes	semiopacus	Jekel	1, 2, 3	PF	11
	Scarabaeidae	Geotrupes	splendidus	(F.)	1, 2	PF	7
	Scarabaeidae	Onthophagus	striatulus	(Beauvois)	1, 2	PF	2
	Scarabaeidae	Onthophagus	hecate	(Panzer)	1	PF	1
	Scarabaeidae	Serica	atracapilla*	(Kirby)	1, 2, 3	MA	13
	Scarabaeidae	Serica	georgiana*	Leng	1, 2, 3, 4	MA/PF	23
	Scolytidae	Dendroctonus	tenebrans	(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	Philonthus	blandus	(Gravenhorst)	3	PF	1
	Staphylinidae	Philonthus	cyanipennis	(F.)	1, 2	PF	5
	Staphylinidae	Tachinus	fimbriatus	Gravenhorst	1, 2	PF	17
	Tenebrionidae	Helops	aereus	Germar	1	MA	1
	Tenebrionidae	Meracantha	contracta	(Beauvois)	1, 2	MA	7
	Tenebrionidae	Tarpela	micans	(F.)	4	PF	1
	Tenebrionidae	Tarpela	undulata	(LeConte)	1	MA	1
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	heteroptera	(Say)	A1	DI	1
	Calliphoridae	Calliphora	vomitoria*	(L.)	2, 3, 4	MA	7
	Calliphoridae	Phaenicia	coeruleiviridis*	(Macquart)	4	MA	1
	Calliphoridae	Phaenicia	pallescens*	(Shannon)	3, 4	MA/PF	30

Order	Family	Genus	Species	Author	Site	Method	N
	Caliphoridae	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	sp.		3, 4	MA	5
	Lonchaeidae	Lonchaea	caerulea	Walker	A2	DI	1
	Lymantriidae	Orgyia	leucostigma	(Smith)	A1	DI	1
	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	subcaeruleus*	(Coquillett)	2	PF	1
	Mycetophilidae	Monoclona	elegantula*	Johannsen	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

Order	Family	Genus	Species	Author	Site	Method	N
	Mycetophilidae	Sargusaia	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	Bercaeopsis	sp.		1, 2	MA/PF	8
	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	Metoposarophaga	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 & Davie	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	1
	Syrphidae	Mallota	fascialis*	Hunter	1	MA	3
	Syrphidae	Spilomyia	sp.		1, 3	MA	3
	Syrphidae	Syrphus	rectus*	Osten Sacken	3	MA	7
	Syrphidae	Syrphus	sp.		1, 3, 4	MA	4
	Syrphidae	Xylotomima	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

Order	Family	Genus	Species	Author	Site	Method	N
	Tipulidae	Limonia	indigena*	(Osten Sacken)	2	MA/PF	5
	Tipulidae	Prionolabis	politissima	(Alexander)	A2	DI	1
	Tipulidae	Tipula	duplex*	Walker	4	PF	1
	Tipulidae	Elephantomyia	westwoodi	Osten Sacken	4	MA	1
	Tipulidae	Metalimnobia	cinctipes	Say	3	MA	1
	Xylophagidae	Dialysis	sp.		1	PF	1
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	gibbocostata*	(Walker)	3	MA	1
	Hesperiidae	Epargyreus	clarus	Cramer	3, 4	MA	2
	Noctuidae	Bomolocha	baltimoralis*	(Guenee)	4	MA	1
	Noctuidae	Bomolocha	madefactalis*	(Guenee)	4	MA	1
	Noctuidae	Catocala	cerogamma*	(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	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*	Hubner	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	Pentographa	limata*	(Grote & Robinson)	3	MA	1
	Thyatiridae	Pseudothyatira	cymatophoroides*	(Guenee)	4	MA/PF	11

Order	Family	Genus	Species	Author	Site	Method	N
	Zygaenidae	Pyromorpha	dimidiata	Herrich-Schäffer	A4	DI	2
Hymenoptera	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	pensylvanius*	(DeGeer)	2	PF	7
	Formicidae	Camponotus	americanus	Mayr	1	DI	1
	Formicidae	Aphaenogaster	picea*	Emery	1, 2, 3	MA/PF	10 2
	Formicidae	Prenolepis	impairs	(Say)	1	PF	45
	Halictidae	Augochlorella	metallica	(F.)	4	MA	1
	Halictidae	Augochlorella	pura pura	(Say)	2, 3, 4	MA	15
	Halictidae	Augochlorella	striata	(Provancher)	1, 2, 3, 4	MA	14
	Halictidae	Dialictus	bruneri	(Crawford)	4	MA	1
	Ichneumonidae	sp	1		3	MA	12
	Ichneumonidae	sp	2		3	MA	1
	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
						Total	25 16

VITA

Stanley Earl Buck III was born October 25, 1978 in Plymouth, North Carolina. He graduated from Tarboro High School in Tarboro, NC in June 1997. In the fall of that year Stanley accepted an academic scholarship to attend Mount Olive College in Mount Olive, NC. There he was a laboratory technician under the direction of Dr. Richard Bounds. In 2000, Stanley attended East Carolina University and graduated in 2001 with a Bachelor of Science degree in Biology. In 2002 he accepted a research assistantship at the University of Tennessee, Knoxville. Under the direction of Dr. Paris L. Lambdin, he received a Master's of Science degree in Entomology and Plant Pathology in May 2004. Upon graduation, he accepted the position of Project Supervisor at Enviracon Incorporated.