12-2002

Composition of the Coleoptera and Associated Insects Collected by Canopy Fogging of Northern Red Oak (*Quercus rubra* L.) Trees in the Great Smoky Mountains National Park and The University of Tennessee Arboretum

Danny D. Trieff
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Danny D. Trieff entitled "Composition of the Coleoptera and Associated Insects Collected by Canopy Fogging of Northern Red Oak (*Quercus rubra* L.) Trees in the Great Smoky Mountains National Park and The University of Tennessee Arboretum." 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

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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

To the Graduate Council:

I am submitting herewith a thesis written by Danny D. Trieff entitled "Composition of the Coleoptera and Associated Insects Collected by Canopy Fogging of Northern Red Oak (*Quercus rubra* L.) Trees in the Great Smoky Mountains National Park and The University of Tennessee Arboretum". 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.

Dr. Paris Lambdin
Major Professor

We have read this thesis and
recommend its acceptance:

Dr. Jerome Grant

Dr. John Skinner

Accepted for the Council:

Dr. Anne Mayhew
Vice Provost and Dean of Graduate Studies

(Original signatures are on file with official student records)

COMPOSITION OF THE COLEOPTERA AND ASSOCIATED INSECTS COLLECTED BY CANOPY FOGGING OF NORTHERN RED OAK (*Quercus rubra* L.) TREES IN THE GREAT SMOKY MOUNTAINS NATIONAL PARK AND THE UNIVERSITY OF TENNESSEE ARBORETUM

A Thesis

Presented for the

Master of Science
Degree

The University of Tennessee, Knoxville

Danny D. Trieff

December 2002

ACKNOWLEDGEMENTS

I would like to sincerely thank my major professor, Dr. Paris L. Lambdin, for his constant guidance and unwavering support during the course of this project. His assistance and patience in the preparation of this document were invaluable. I would also like to show gratitude to the other committee members, Drs. Jerome Grant and John Skinner, for their advice, assistance, and kind words of encouragement during the past two years.

I would like to recognize David Paulsen (Diptera) and Dr. Adriean J. Mayor (Coleoptera and Hymenoptera) for their technical assistance in helping to collect and identify the insect specimens and Dr. Richard Evans for his assistance in the collection at the Arboretum. Special thanks are also extended to Matthew Petersen, Brandy Earhart, and Christopher Werle who assisted in the collecting efforts at the Arboretum, Dr. C. Charles McClaugherty, my undergraduate advisor, who piqued my interest in learning, and Kathie J. Lavery, my intercollegiate swimming coach, for teaching me the true meaning of the word “perseverance”.

I would especially like to thank my parents, Dan and Rosine Trieff, siblings Mary Trieff, Rachel Trieff, and John and Rebecca Cola, and trusted friends, Lee Buck and Dr. Jenny S. Weaver for their love, support, and encouragement throughout this excruciating endeavor.

ABSTRACT

Oak forests dominate the forested landscape of Tennessee. These forests are vital to the economic and environmental health of the state. Northern red oak (NRO) trees, *Quercus rubra* L., are crucial components of these forests. Information regarding the status of coleopteran diversity associated with NRO is scattered and fragmented within the literature. Because of this, the insect fauna on NRO was assessed at three sites (Bee Tree Ridge, Mount Sterling, and Rich Mountain) in the Great Smoky Mountains National Park (GRSM), and at one site at The University of Tennessee Arboretum (UT arboretum) by using the fogging method. These four sites represent elevational gradients ranging from 262-1,377 m. The canopy of one randomly selected tree per site was sampled monthly using a Dyna-Fog Golden Eagle fogger. Specimens (11,167) were collected, processed, and identified for the sampling periods. Identification efforts were focused on the 2,270 specimens of Coleoptera collected. Species diversity of coleopterans collected at the GRSM was assessed using the Shannon-Weiner and Berger-Parker diversity indices.

Two hundred, three species of beetles representing 45 families were identified from the GRSM and represent a rich assemblage of beetle fauna. The highest number of specimens (713) and species (124) were located at the lowest GRSM elevation site (841 m). However, Shannon-Weiner diversity values were highest (3.70) at the highest elevation site and lowest (3.04) at the low elevation site. Eleven beetle pest species of NRO, represented by 403 (27.36%) specimens, were collected from GRSM. Specimens of the Asiatic oak weevil, *Cyrtepisomus castaneus* (Roelofs), were found at all sites and

comprised 18.68% of the total beetles collected. Sixty-four species of Coleoptera not previously recorded in the GRSM were identified and represent a 5.5% increase to the All Taxa Biodiversity Inventory database**.** Eighty-seven species of Coleoptera were collected from the UT arboretum (262 m). AOW was the most commonly collected species at the UT arboretum with 84 specimens. Fifty-five of coleopteran species from the UT arboretum were not recorded in the GRSM collection.

These data and findings are significant in that they are the first recorded listing of insect fauna on large (over 20 m tall) NRO in eastern Tennessee. Results of this study will assist in developing management strategies in northern red oak-dominated forests to enhance Tennessee forests. In addition, due to the threat of invasive species activity, this study provides an important baseline of the arthropod faunal composition found on mature NRO before disturbances alter species composition.

TABLE OF CONTENTS

LIST OF TABLES

TABLE **PAGE**

LIST OF TABLES (CONT.)

LIST OF FIGURES

FIGURE **PAGE**

CHAPTER I
INTRODUCTION

Insect Diversity

Insects are the most diverse class of animals on this planet with more than a million described species (Arnett 2000). Erwin (1991) estimates that as many as 30 million species of arthropods may exist, but more recent and conservative estimation methods suggest a global arthropod species richness of 5 to 10 million species (Odegaard 2001). Over 95,000 insect species have been described in North America north of Mexico (*Nomina Insecta Nearctica* 2002), and many new species are identified annually.

Insects are so successful because they possess unique combinations of diverse physical characters and reproductive traits. The primary physical characteristics that allow insects to survive and explore a variety of habitats include small size, wings, an exoskeleton, six legs, variable mouthparts, and compound and simple eyes. The small size of insects permits subdivision of available resources to many individuals. Wings allow insects to travel relatively long distances in search of food and mates as well as provide a method of rapid escape from predators. The exoskeleton of insects prevents desiccation and is a shield from changes in the environment. Six legs facilitate rapid directional changes to assist in catching prey or avoid being eaten and are further modified for specific functions, such as grasping, running, swimming, clasping, digging, or jumping. The variable mouthparts of insects allow them to feed on a variety of food sources. Lastly, insects have large compound eyes, a trait few arthropods possess, that permit a panoramic view of their environment. Some insects have additional simple eyes, ocelli, which function in detecting changes in light intensity.

Many insects also are capable of mass reproduction by laying hundreds to thousands of eggs in a short amount of time. This high fecundity rate also allows for genetic and environmental selection of adapted individuals. Insects can locate mates chemically, visually, by sound, or a combination of these. Some insects are even hermaphroditic and can reproduce without mates while others demonstrate sperm selection to ensure fertilization by only the most preferred donor.

These modifications, along with many others, allow insects to occupy a wide array of habitats and niches, establishing them as the most diverse group of animals on earth. Of the 30 recognized orders of insects (McGavin 2001), Coleoptera (i.e., the beetles) is the most diverse containing approximately 370,000 known species worldwide (McGavin 2001). As of 2000, 23,701 species of beetles representing 3,145 genera were recorded from Canada and the United States (Arnett 2000). In the Great Smoky Mountains National Park (GRSM), the All-Taxa Biodiversity Inventory (ATBI) project lists 1,103 beetle species (as of 23 April 2002) within the park (Louisiana State Arthropod Museum 2002).

Beetles have been able to adapt to varied environmental niches primarily because of their forewing modification (McGavin 2001). These hardened elytra provide a tough armor that protects the insect from injury and allows for survival in low-water periods by covering spiracles, which minimizes dehydration. The elytra of some beetles can even act as air storage devices that facilitate underwater exploration and occupation of unique niches in aquatic environments.

Arboreal insect diversity, and particularly beetle diversity, is important to forest health because of the interwoven nature of species to each other and their environment. Beetles are vital in decomposition cycles by breaking down dead vegetation, consuming carrion, and grazing on leaf litter. Beetles, as both predator and prey, also are crucial components in forest food webs.

Oak Forests

With approximately 500 species globally, *Quercus* ranks among the largest genera of trees worldwide (Smith 1993), and the 58 species of native oaks make it the largest genus in the United States (Mullis 2001). *Quercus* is the classical name for the European oaks derived from Celtic as "Fine" (*Quer*) "Tree" (*cus*) (Bennett 1971, Little 1979). Oaks have historically been considered favorable lumber trees in the United States because of many qualities, such as wood strength, straightness, grain pattern, and character. These characteristics make oak the most popular timber used for furniture. Additionally, oaks are often planted in a variety of urban areas because of their drought resistance and beauty (Abrams 1990).

Over 90% of the harvested oaks are located in the eastern half of the United States (Quigley 1971) with half of the harvest taking place in the southern States (Solomon *et al.* 1987). Oak-Pine and Oak-Hickory forests dominate Tennessee where 78% of the trees are hardwoods and 89% of forest is hardwood (Tennessee Forestry Division 2002). These forests comprise over half of Tennessee, encompassing 5.76 million hectares (Tennessee Forestry Division 2002) and are a vital source of revenue in the state. The wood products industry provides direct benefits to citizens that include:

78,000 jobs, annual wages of $2.3 billion, and an annual industrial output of $10.1 billion (University of Tennessee Institute of Agriculture 1998). When associated industries are included, the economic impact is increased to 166,400 jobs, $4.4 billion in wages, and a $17.1 billion contribution to the economy (University of Tennessee Institute of Agriculture 1998). Wood products are among the state's top five agricultural products resulting in the state ranking first nationally in production of hardwood flooring and pencils, and second in hardwood lumber production (Tennessee Forestry Division 2002).

The 2,072 km^2 Great Smoky Mountains National Park (GRSM), the largest protected area in the eastern United States, also lies within this region. In addition to the park's immense aesthetic and scientific values, millions of visitors worldwide generate substantial economic inflow into the state. About 95% of the GRSM is forested and contains most of the remaining old growth oak stands found east of the Mississippi River (Langdon, previous communication).

Red oaks rank as the ninth most common type tree species in Tennessee counting all trees 2.5 cm or greater in diameter, and the second most common for trees larger than 12.7 cm in diameter (Tennessee Forestry Division 2002). The southern red oak, *Q. falcata* Michx., is the most prevalent representative of the red oak group in the mid-South (Ohio State University 2001). Other common red oaks in Tennessee include: northern red oak (NRO), *Q. rubra* L., pin oak, *Q. palustris* Muench., scarlet oak, *Q. coccinea* Muench., cherry bark oak, *Q. falcata* var. *pagodafolia* (Ell.), and black oak, *Q. velutina* Lam. (Stringer 1998).

Northern red oak is an important component of the communal structure of hardwood forests, not only in the GRSM and eastern Tennessee, but also throughout the

Appalachian mountain range. NRO belongs to the red oak-black oak subgenus (*Erythrobalanus*) in the family Fagaceae (Little 1979). The species name, *rubra,* means "red", reflects the red color of the petioles, fall foliage, or interior wood (Ohio State University 2001). Other common names for NRO are: red oaks, buck oaks, leopard oaks, Maine red oaks, spotted oaks, swamp oaks, water oaks, gray oaks, American red oaks, Canadian red oaks, West Virginia soft red oaks, Spanish Oaks, eastern red oaks, and mountain red oaks (Bonner and Vozz 1987). NRO is the official tree of New Jersey and the Canadian province of Prince Edward Island (National Arbor Day Foundation 2002).

Q. rubra is a monoecious tree having separate male and female flowers on the same tree with large acorns (1.2 to 2.5 cm long) with flat caps that barely cover the nuts, and occurs singularly or in clusters of 2 to 5 on the tree (Duncan and Duncan 1988). The acorns fully mature in two years, which accounts for their location 0.3 to 0.6m from the apex of the terminal branch rather than at the tip of the branch as in white oak, *Q. alba* L. (Stringer 1998). Acorns are brown when mature and ripen from late August to late October depending on geographic location (Duncan and Duncan 1988). The stringy flower is borne in a catkin that develops from leaf axils of the previous year and emerges before or at the same time as the current leaves in April or May (Duncan and Duncan 1988).

The tree is moderate to fast growing, reaching heights of 20 to 30 m with a diameter of 0.61 to 0.91 m (Core 1971). Many NRO reach heights over 49 m and 2.4 m in diameter (Sander 1990). The typical life span of a NRO is 200 years, but some 400-year-old trees exist (Little 1979). Trees are tall, straight, and columnar with a large crown in forested stands but are characterized by a short bole and spreading crown in open areas (Sander 1990). NRO have strongly developed taproot systems with networks of deep, spreading laterals (Hosie 1969, Kelty 1989). The key recognition character for NRO is smooth leaves with teeth whose length is less than half the distance from the points to the mid-vein (Sander 1990). The bark, smooth and light gray, also develops a characteristic "ski-track-like" feature in middle-age that persists throughout maturity (Sander 1990).

The range of NRO extends from eastern Canada southward to Georgia and westward through eastern Kansas, Nebraska, and Oklahoma (Godfrey 1988, Sander 1990). NRO also occurs locally in eastern and southwestern Louisiana and western Mississippi (Godfrey 1988, Little 1979). Pure stands of NRO, or forests in which it is predominant, are classified as Society of American Foresters Type 55 (Sander 1990). NRO is also a major component of White-Pine-Northern Red Oak-Red Maple forests (Type 20) and a principle species in White Oak-Black Oak-Northern Red Oak forests (Type 52) (Sander 1990, Eyre 1980). In addition, NRO is listed as an associated species in 24 cover-types (Eyre 1980).

Although NRO can be found in all topographic positions, the best growth is attained on lower well-drained mesic slopes with a northerly or easterly aspect containing a deep “Type A" soil horizon (Sander 1990). In the upland hardwood forests of southern Appalachia, NRO grows on a wide range of topographic positions, and some of the largest pure NRO stands east of the Mississippi River occur within this region. The tree is rated as intermediate to intolerant of shade, and optimal growth rates are often attained in full sunlight (Sander 1957). NRO is hardy to elevations of 1,676 m in the southern Appalachians and 1,680 m in West Virginia (Little 1980, Sander 1990). However, conspecific trees growing at high and low elevations encounter different growing conditions, such as water availability, temperature, nutrient levels, and suitability as hosts for herbivorous insects that often affect hardiness (Reynolds and Crossley 1997).

Value and Importance of Northern Red Oak

Commercial applications of harvested NRO timber include railroad ties, flooring, ships, lumber, veneer, furniture, cabinets, as well as many other products. NRO are often planted as shade and street trees in cities, and is a favored ornamental for many golf courses, schools, parks, and residential areas. The tree is an important restoration species in stressed environments, such as coal mine spoils in the mid-central United States (Clark and Watt 1971, Limstrom and Merz 1949, Brothers 1988).

Q. rubra acorns have high tannin levels (4.34-15.90%) making them too bitter to serve as human food (Smith and Follmer 1972, Briggs and Smith 1989, Weaver 1960, Weckerly *et al.* 1989). NRO tannin has been utilized in industrial inks, as a dyeing mordant, as an astringent, and for the treatment of burns. Native Americans immersed NRO acorns in boiling water to yield tannic acid that was used on animal hides to make leather (USDA NRCS 2001). Some Native American tribes also used NRO bark as a medicine for cardiac dysfunction and bronchial infections or as a cleanser, disinfectant, and astringent (USDA NRCS 2001).

Q. rubra is often browsed by generalist mammalian herbivores including meadow voles, *Microtus pennsylvanicus* Ord, white-tailed deer, *Odocoileus virginianus* Boddaert, rabbits (*Sylvilagus* sp.), pocket gophers (Geomyidae), and elk and moose (Cervidae)

(Bergeron *et al.* 1998, Telfer 1972, Van Dersal 1940, Huntly and Inouye 1988, Myers *et al.* 1989). Rates of browsing vary by habitat as evident in several studies conducted on white-tailed deer. Deer browsed 2.8% of NRO leaves in Canada to 15.1-30.2% in New Hampshire (Perkins and Mautz 1988, Telfer 1972). White-tailed deer, when offered different choices of browse species, neither avoided nor preferred NRO in a Connecticut based experiment (Kittredge and Ashton 1995).

Q. rubra acorns are an important food source for many forest inhabitants. Mice (Heteromyidae), squirrels *Sciurus* spp., white-tailed deer, and American black bears, *Ursus americanus* Pallas, consume NRO acorns (Briggs and Smith 1989, Sork *et al.* 1983, Van Dersal 1940). In a NRO forest in central Pennsylvania, 38.6% of autumn acorns were destroyed or removed by vertebrate foragers with white-tailed deer being the dominant consumer (Steiner *et al.* 1995). In New Hampshire, NRO acorns varied from 5-55% (composition dry matter) of deer diets (Perkins and Mautz 1988) and are a preferred fall and winter food of the gray squirrel, *Sciurus carolinensis* Gmenlin (Lewis 1982, Gorman and Roth 1989). Red-backed voles, *Clethrionomys gapperi* Vigors, consume NRO acorns and cache them at high rates (Plucinski and Hunter 2001). NRO acorns also are an important fall food source for *U. americanus* (Elowe and Dodge 1989, Rogers 1976) and the abundance of fall mast crops can affect black bear reproductive success during the following year (Elowe and Dodge 1989).

Pigs (Suidae) will consume large quantities of NRO acorns (Van Dersal 1940). Early Anglo-Saxon English oak plantations were principally developed to fatten swine, and stiff penalties existed for any tree damage (Web of Species 2002).

NRO acorns also are dietary staples of several families of birds, such as: Phasianidae (bobwhites, quail, and pheasants), Picidae (woodpeckers and sapsuckers), Corvidae (blue jays), Paridae (the tufted titmouse and white-breasted nuthatches), Icteridae (grackles), and Tetraonidae (ruffed grouses) (Sork *et al.* 1983, Martin *et al.* 1951, Van Dersal 1940). Acorns also are important to numerous waterfowl in the family Anatidae (Martin *et al.* 1951, Van Dersal 1940). Turkeys (Meleagrididae) also depend heavily on oak acorns and one turkey is able to consume more than 200 acorns during a single feeding session (Reid and Goodrum 1957).

The size of NRO acorns varies but is not a factor in mammal and insect predation (Auchmoody *et al.* 1994). However, apical portions of NRO acorns have substantial tannin levels making seeds less palatable to vertebrates (Steele *et al.* 1993). Eastern chipmunks, *Tamias striatus* L., preferred white oak acorns to those from the higher tannin leveled NRO (Pyare *et al.* 1993). Tannin can reach toxic levels in mammals if acorns are consumed in high quantities. White-footed mice, *Peromyscus leucopus* Rafinesque*,* fed strict diets of NRO acorns, developed fatal cases of tannin poisoning (Briggs and Smith 1989).

This tree provides good refuge and protection for many forest dwellers. Leaves on young NRO often persist longer than other plant associates, and low branches serve as a particularly good winter cover (Shaw 1971). These young oaks may represent the only brushy winter cover in dense pole stands. NRO are frequently perching or nesting sites for various songbirds as well as many cavity nesters, such as the red-bellied, *Melanerpes carolinus* L., and hairy, *Picoides villosus* L., woodpeckers (Carey *et al.* 1980). The well-developed crowns of NRO also provide hiding cover for small mammals, such as squirrels.

Pathogenic Threats to Oak Forests

Eastern oak forests are threatened by an array of pathogens including fungi and disease. Oak wilt, an aggressive fungus caused by *Ceratocystis fagacearum* (Bretz), is considered one of the "most serious diseases in the eastern United States" by killing thousands of oaks (USDA 2002). The fungus infects trees either through connected root systems or by fungal-carrying insects (e.g., long-horned beetle larvae and sap beetles) that transport the pathogen (Rexrode and Jones 1970, USDA 2002).

Oak decline, caused by a disease complex, is marked by a gradual degradation of tree health leading to death. The speed and level of decline is positively correlated to the amount of other stresses, such as drought, frost, root fungi, and insect defoliation and larval burrowing. Oak decline occurs throughout the eastern United States and is common in the Southern Appalachian regions of North Carolina, Tennessee, and Virginia (USDA 2002).

Sudden oak death, first reported in 1995, occurs in California and Oregon and has killed tens of thousands of oaks. The pathogenic agent was recently identified as the fungus *Phytophthora ramorum* Rizzo. Although this disease has not been found in other states, it has the potential to be transported, especially on widely traded rhododendron ornamentals, to eastern forests causing significant loss to oak stands (USDA 2002).

Insects Associated with Oaks

Oak forests are home to an array of organisms including a rich community of insects, which can be found on all parts of trees from roots to leaves. Some of these insects are casual visitors, while others use the tree to complete part or all of their life cycle. Few general-taxa studies have been conducted on NRO. Stanton (1994) used a hand-held insecticide mist method to collect 26,536 specimens from a NRO seed orchard in northeastern Tennessee in 1992-1994. Insects collected included 541 species representing 143 families in 15 orders. The orders Coleoptera, Diptera, Hymenoptera, and Homoptera represented a large amount (ca. 94%) of the specimens collected. Linit *et al.* (1986) hand-collected insects from small NRO seedlings in the Missouri Ozarks weekly from April to October in 1979 and 1980 and identified seven insect orders, 24 families, and 46 species. The order Lepidoptera had the most families (10) and species (29) with Coleoptera, Homoptera, and Hemiptera the next most diverse.

Little information exists on specific associations between oaks and insects with most of the literature accounting for pest species. Over 1,000 different insect species are recorded to feed on North American oaks (Rexrode 1971). Only a few of these cause significant damage to the trees: the leaf feeders (defoliators, skeletonizers, and miners), the borers and stem-feeders (bark, phloem, wood, root, and limb), and acorn pests (acorn ovipositors).

Insect Defoliators

Defoliating insects are the most serious insect threat to oak trees (Rexrode 1971). Insects that feed on leaves limit the tree's ability to attain maximum levels of photosynthesis causing stunted growth and reduced health. Factors attributing to oak mortality include degree of defoliation, the period of the season which defoliation occurs, and frequency of successive defoliations. If defoliation occurs early in the growing season, wood production is greatly reduced. Successive defoliations cause branch dying and tree mortality (Rexrode 1971). Insect damage to roots and foliage, combined with water stress, was noted to be a significant factor in the poor survival of NRO in an Ohio forest (Wright *et al.* 1989). Insects responsible for oak defoliation include Lepidoptera, Phasmatodea, Orthoptera, and Coleoptera.

Lepidopterans are considered the most substantial NRO defoliating pests due to larval feeding activity. Many lepidopteran families are capable of feeding on NRO foliage and some do considerable damage. European researchers recorded 97 lepidopteran species belonging to 18 families from NRO in Slovakia. The most abundant families were Geometridae, Noctuidae, Lymantriidae, and Coleophoridae (Kulfan *et al.* 1997). Lepidoptera larvae also were collected from the overstory canopy, shrub stratums and the ground of a NRO-dominated forest in Michigan. Over 77% of the larvae collected were from the families Tortricidae, Noctuidae, Lyonetiidae and Geometridae. *Hydriomena* sp. and *Blepharomastix ranalis* Guenee were the most abundant species (Work *et al.* 1998).

Gypsy moths, *Lymantria dispar* (L.), are the primary lepidopteran defoliator of NRO in eastern American forests (Baker 1972). The gypsy moth, an invasive species, has caused considerable problems to North American oak forests over the last century. Silk entrepreneur E. Leopold Trouvelot introduced the moth to Boston, Massachusetts, from France in 1868 or 1869. Unfortunately, moths failed to produce silk and escaped to the wild, becoming a major pest in the northeastern United States and southeastern Canada. Gypsy moths now threaten red oaks of the Appalachian region and eastern United States as they move westward and southward. Damage to the tree occurs from the voracious feeding habits of the moth larvae. This activity kills saplings and weakens adult trees, which increases their susceptibility to secondary agents (e.g., shoestring root rot fungus, *Armillara* spp., and two-lined chestnut borer, *Agrilus bilineatus* Weber).

Resulting mortality from defoliation can be caused by chronic or acute defoliations that reach high levels in susceptible oak forests. Over a ten-year period, 30% mortality of oaks occurred where defoliation by gypsy moth averaged 37% (Baker 1941). In New Jersey, in 1968-70, over 1 million oaks were killed on 7,200 hecatres^2 because of severe gypsy moth defoliations (Kegg 1970).

Gypsy moth larvae feed on a wide range of host plants, but prefer oaks of the *Erythrobalanus* subgenus. Larvae of gypsy moth fed on NRO leaves in Massachusetts consumed more food, produced heavier pupae and developed faster than those reared on red maple, *Acer rubrum* L. (Barbosa and Capinera 1977). A similar experiment noted greater larval development in NRO trees than six other tree species in a mixed hardwood forest (Barbosa 1978). In mixed forest stands, gypsy moth damage to pines, *Pinus* spp., was greatest where pines were the primary understory tree in NRO-dominated stands

(Brown *et al.* 1988). Moths feed on all levels of the tree canopy, but prefer the lower canopy of mature NRO trees to middle and upper canopies (Ticehurst and Yendol 1989).

Gypsy moths also play a role in oak forest dynamics and succession stage development. Vegetation structures of Appalachian NRO stands in southwestern Pennsylvania were examined before and four years after defoliation by gypsy moths. Results indicated that gypsy moths were responsible for alteration of floral and faunal species composition in previously oak-dominated stands (Fajvan and Wood 1997). Over a period of 23 years (1968-91), gypsy moth defoliation resulted in 54% mortality of oak den trees in Shenandoah National Park, Virginia, which could result in deleterious effects to black bear denning behavior (Kasbohm *et al.* 1996).

Gypsy moths have one generation per year with a life cycle mirroring that of the oak leaf tier, *Croesia semipurpurana* Kearfoot (Rexrode 1971). Larvae hatch about mid-April, migrate to expanding buds and feed on foliage until late May. Pupation occurs primarily in the litter and adults can be found in early June (Beckwith 1963).

Traditional control of gypsy moth populations is through direct suppression of populations using ground applications of pesticides to individual trees or aerial applications of pesticides in large stands. Materials used in these treatments include the chemical pesticide "Dimilin" or the biological pesticides, *Bacillus thuringiensis* and "Gypchek", a formulation of the naturally occurring gypsy moth virus. Recently, a parasitic Tachinidae fly, *Ceranthia samarensis* Villeneuve, and a fungus, *Entomophaga maimaiga* Hubner, have shown promise as successful non-chemical control methods (Quednau and Lamontagne 1998, Schneeberger 1996).

The pink gypsy moth, *L. mathura* Moore, is a polyphagous defoliator of forest and fruit trees in the Russian Far East, Japan, India, and China and could cause serious damage, if it became established in North America. Larvae of this insect had high survivability rates when reared on North American species of white oak and moderate levels on NRO (Zlotina *et al.* 1998).

Other lepidopteran NRO pests include *C. semipurpurana*, orange-striped oakworm, *Anisota senatoria* Smith, winter moth, *Operophtera brumata* L., variable oakleaf caterpillar, *Heterocampa manteo* Doubleday, and browntail moth, *Nygmia phaeorrhoea* Donovan (Rexrode 1971, Porter *et al.* 1997, and Embree *et al.* 1991).

The true walkingstick (Phasmatodea), *Diapheromera femorata* Say, is a defoliating pest of NRO trees in the southeastern United States (Hefler 1953). This insect sometimes occurs in high numbers, completely defoliating oaks and other trees and shrubs (Hefler 1953).

Forty-five species of Orthoptera in eastern North American are also known to feed on oak foliage. The post oak grasshopper, *Dendrotettix zimmermanni* Saussure, a tree-inhabiting species, is commonly found on NRO in the Carolinas (Helfer 1953). The jumping bush cricket, *Orocharis saltator* Uhler, also is found on many species of oak trees in high numbers from New Jersey to Florida (Hefler 1953). Grasshoppers also can damage trees by their ovipositional activity.

Some families of Coleoptera have oak leaf-feeding species that are capable of causing significant damage. Adult leaf beetles (Chrysomelidae), a diverse group of destructive insects, feed on leaves and flowers and the larvae that may also feed both internally and externally on stems, roots, and leaves of plants. Some species are capable of mass defoliations causing tree decline and death. Some tree species are susceptible to defoliations by this group, but NRO is usually excluded from this list. However, a local outbreak of the locust leafminer, *Odontota dorsalis* Thunberg, in a Virginia forest in 1987 caused moderate damage to NRO trees in the surveyed area (Williams 1988).

Another beetle threatening defoliation to NRO in eastern United States is the Asiatic Oak weevil (Curculionidae), *Cyrtepistomus castaneus* Roelofs. This insect is an introduced pest from northeastern Asia, first documented by Davis in 1933 in New Jersey (Johnson and Lyon 1991). The weevil moved westward to New York, the central Atlantic states, and eventually to Missouri and the Ozarks. This greenish gray insect begins feeding on the lower leaves of hosts in mid-July and moves upwards into the canopy by early August (Evans 1959, Roling 1979, Johnson and Lyon 1991, and Triplehorn 1955). In a 1985 feeding experiment in Missouri, adult Asiatic oak weevils that were fed NRO or black oak leaves in the laboratory lived significantly longer and laid more eggs than weevils that were fed white oak or sugar maple, *Acer saccharum* Marsh, leaves (Ferguson *et al.* 1991).

In addition to tree damaging effects, leaf feeding has been linked to the manipulation of trophic level forest dynamics. Insects feeding on NRO leaves have been associated with increased amounts of freshly fallen leaves (greenfall). The main sources of this greenfall are clipped stems, mined leaves, and discarded leaf fragments (orts). Although NRO greenfall represented only 5% of the total greenfall in an Appalachian forest study, they are important resources for forest decomposers (Risley and Crossley 1988).

Wood Borers and Phloem Feeders

Wood-boring insects do not cause as much tree mortality as defoliators, but their activity generates poor quality timber. The two most oak damaging families of wood boring insects are the long-horned beetles (Cerambycidae) and, to a far lesser extent, the metallic-jewel beetles (Buprestidae). Tree damage results from larval boring into the cambial layers and the subsequent exposure of the tree to wood-decaying fungi. Damaged wood is marred and unmarketable, thus, making borers the most economically destructive insect pest of oaks. Bryan (1960) concluded that insect damage by borers was second only to knots as a defect in lumber and, of the 35% of trees damaged by insects, oaks incurred the most damage.

Most Cerambycidae have larval stages that feed by boring into dead or live wood. This activity causes damage to trees by causing defects in the softwood used by the lumber industry. These holes, produced by borers, often facilitate infection by fungi that can lead to tree death. Yanega (1996) lists 48 species of Cerambycidae that inhabit dead or living oak trees in the northeastern United States and southeastern Canada, and at least 30 species are known to attack living or recently dead oaks in the Appalachian region (Rexrode 1971). The most important species in the eastern United States are the oak branch borer, *Goes debilis* LeConte, the Columbian timber beetle, *Corthylus columbianus* Hopkins, the red oak borer, *Enaphalodes rufulus* Haldeman, and the carpenter worm, *Prionoxystus robinae* Peck (Rexrode 1971). The oak stem borer, *Aneflomorpha subpubescens* LeConte, may occur in great numbers, killing large numbers of seedlings and sprouts in the southeastern United States (Yanega 1996).

The most oak-damaging Cerambycidae in Tennessee include the white oak borer, *Goes tigrinus* (De Geer), and the red oak borer. The white oak borer usually lays eggs in trees of 2.54 cm to 20.32 cm in diameter and the developing larvae create galleries up to 1.27 cm in diameter (USDA 1972). The gallery tunnels often reach deep into the heartwood of the tree causing large amounts of damage.

Red oak borers prefer trees in the red oak group throughout eastern North America and are a major pest of living oak trees by causing permanent damage to lumber (Baker 1972). This insect is native to North America occurring from southeastern Canada and Maine to Florida, and west to Minnesota, Iowa, Oklahoma, and Texas. In addition to the boring damage of the insect, other wood-inhabiting insects such as carpenterworms, timberworms, and carpenter ants use red oak borer tunnels to enter the softwood and increase the damage to the tree (Donley 1978). Decay organisms, such as fungi and molds, may enter the hole and further damage and weaken the tree (Berry 1978). Red oak borer larvae are of particular concern to red oak species in the eastern United States because their boring activity facilitates oak decline (USDA 2002). Woodpeckers, *Dendrocopus villosus* L. and *D. pubescens* L., are primary biological control agents decreasing larval numbers by 40% (Hay 1972). Additionally, culling stunted trees has proven successful in eliminating red oak borer outbreaks because trees experiencing poor vigor have higher infestation rates than healthy trees (USDA 1972).

Members of the homopteran families Aphididae and Membracidae and the superfamily Coccoidea are capable of NRO damage as phloem feeders. Three aphids (Aphididae) cause damage to NRO: the North American aphid, *Myzocallis walshii* Monell, the giant bark aphid, *Longistigma caryae* Harris, and oak leaf aphids, *Myzocallis* spp. The North American aphid causes damage to NRO trees by feeding and honeydew emission (Patti and Lozzia 1994). However, control is only necessary during times of heavy infestation on trees of primarily ornamental interest. Oak leaf aphids infest the undersides of leaves, leaf stalks, and tender twigs of trees in the red and white oak groups throughout the eastern United States. The giant bark aphid prefers the bark of trees in the same range. Heavy infestations distort the foliage and weaken the plants, while honeydew and sooty molds inhibit growth and reduce plant vigor as well as detract from the aesthetic beauty of ornamentals.

Several scale insects (Coccoidea) are recorded as minor pests of NRO: obscure scales, *Melanaspis obscura* Comstock; pit scales, *Asterolecanium* spp.; and kermes scales, *Kermes* spp. Scale insects feed by extracting sap from the phloem, which limits new growth as well as weakens limbs that break under high winds (Lambdin, personal communication). The obscure scale often covers the trunks and branches of red and white oaks. Infestations are often heavy and layered, killing branches, or resulting in general weakening, and sometimes death of the tree. The parasitic wasp, *Encarsia aurantii* Howard, has been successfully used as a biological control of this scale in California (Ehler 1997). Pit scales, *Asterolecanium* spp., are often found on twigs, branches, and trunks of red and white oaks and produce open galls on new growth. The maturing females produce ring-like swellings or pits on the bark causing a rough appearance resulting in dead branches and trees.

Treehoppers (Membracidae) are potential pests of many shrubs and woody plants because of their feeding activity. *Platycotis vittata* F. is a species that favors oak trees (Wood *et al.* 1984) and was collected in high numbers from NRO in a seedling plantation

(Stanton 1994). Other species frequently inhabit oaks and could reach pestiferous quantities.

The oak lace bug, *Corythuca arcuata* Say, is a hemipteran pest that favors many species of oak and hibernates under bark (Arnett 2000). Adults and nymphs feed on NRO and white oak foliage from Alabama and the Carolinas to southern Canada. By the end of August, damaged leaves are discolored and photosynthesis is reduced.

Pests of Acorns

Oak acorn pests reduce seed vigor, which leads to reduced germination and seedling development (Gribko *et al.* 1995). Many species of the beetle family Curculionidae, as well as a few species from the orders Hymenoptera and Diptera, oviposit into oak acorns. The acorns provide a food source and shelter for the larvae. This activity has potential to reach relatively high rates in oak forests. In Europe, insect pests infested 5.6% of NRO acorns which was substantially lower than infestation of durmast oak, *Quercus petraea* L. (36.9%) and English oak, *Quercus robur* L. (19.9%) (Kelbel 1996). Approximately 7.9% of NRO acorns in a forest in central Pennsylvania were destroyed by insects or decay (Steiner *et al.* 1995).

Weevils damage oaks by acorn oviposition damage. Primary weevil pests occur in the genera *Curculio* spp. and *Conotrachelus* spp. Gibson (1982) states that *Curculio spp*. weevils can only oviposit in damaged or infected nuts and she lists five species, *Curculio proboscideus* F., *C. sulcatulus* (Casey), *C. nasicus* (Say), *C. orthorhynchus* (Chittenden), and *C. longidens* Chittenden, that prefer NRO acorns. A study in a German NRO forest revealed the main beetle pest was the acorn weevil, *Curculio glandium*

Marsh (Kelbel 1996). Control of these pests is difficult, because the tough acorn shell shields the beetle from control measures and fire is not sufficient to kill larvae. In a survey of fire charred acorns in northwestern Pennsylvania, Auchmoody and Smith (1993) reported that larvae of *Curculio* spp. were able to survive.

Members of the genus *Conotrachelus* are reported to be pests of various oaks (Galford and Cotrill-Weiss 1991, Gibson 1982, Solomon *et al.* 1987). In West Virginia, *Conotrachelus* spp. weevils and sap beetles (Nitidulidae) were noted as the main pests of NRO acorns (Gribko *et al.* 1995).

Oak weevil larvae from acorns play a significant role in the diet of many vertebrates. The blue jay, *Cyanocitta cristata* L., eats a significant portion of weevil larvae during caching flights in autumn. The larvae may counteract the high levels of tannin in NRO acorns and allow the birds to subsist on them overwinter (Johnson *et al.* 1993). Some vertebrate foragers appear to cache or immediately consume acorns based on their state of infestation. A Pennsylvania study found that squirrels cached 20-35% more non-infested oak acorns and immediately discarded or consumed infested acorns. Some 76% of weevil larvae, *Curculio spp.,* found in acorns were consumed and represents a significant dietary supplement for the squirrels (Steele *et al.* 1996).

Some species of Hymenoptera and Diptera oviposit into acorns. Drosphilidae, Psychodidae, and Anthomyiidae fly larvae and Stony cell gall wasps, *Callirhytis fructuosa* Weld, were recorded to infest NRO acorns in a NRO forest in West Virginia (Gribko and Jones 1995).

Elevation and Insect Activity

Altitude affects precipitation, temperature, and humidity (Cole 1940). These variables influence soil composition, vegetation, and water availability and ultimately effect floral and faunal populations. An example could be found concerning soil acidification rates, that decreased with increases in altitude, and strongly influenced the composition of collembolan communities (Loranger *et al*. 2001). Thus, elevation may be important in regulating insect community composition. Nowhere is this statement as manifest than in the montane regions where steep grades rapidly alter elevation.

Considerable research has been done on the influence of altitude on insect and arachnid diversity. In Mexico, the coffee leaf-miner, *Leucoptera coffeella* Guerin Meneville, had significantly higher populations in low elevations marked by high temperatures and low precipitation than at high elevations (Nesael *et al.* 1994). Species diversity among ants in a Madagascar mountain range decreased substantially with increased elevation (Fisher 1996). A similar trend was noted among ant species in the Philippines where species richness and relative abundance peaked at middle elevation sites and declined sharply with increased elevation (Samson *et al.* 1997). Grasshopper populations examined along a 1650 m elevational gradient in southwestern Montana showed distinctly different assemblages of species between high and low elevations (Wachter *et al.* 1999). Three genera of spiders studied in the GRSM showed higher levels of species richness, diversity, and evenness in middle to low elevation study sites (Stiles and Coyle 2001). Watson *et al.* (1994) recorded a decrease in scale species and families in the GRSM as elevation increased.

As elevation increases and insect abundance and diversity decreases, herbivorous insect activity would be expected to decrease. In a recent study, the percentages of red maple leaf area removed decreased significantly as elevation increased in an eastern deciduous forest in North Carolina (Reynolds and Crossley 1997).

The Great Smoky Mountains National Park and The University of Tennessee Arboretum

The GRSM is located in the southern Appalachian mountains of western North Carolina and eastern Tennessee. The park was established on 15 June 1934, and classified as an International Biosphere Reserve in 1976. In 1983, the GRSM was designated by the United Nations Educational, Scientific and Cultural Organization (UNESCO) (Peine 1989) that embrace wilderness resources available to scientific investigators, educators, and recreation enthusiasts. This area contains a wide array of endemic flora and fauna that is unrivaled in the eastern United States. More than 4,000 species of plants occur within the park boundaries. In addition, this area is a popular site for recreation enthusiasts, which is manifest in over 10 million recreational visits in 1999 and an operational budget for 2000 exceeding 13 million dollars.

The arboretum is located at the University of Tennessee Forestry Experiment Station, located 48.27 km northwest of Knoxville, TN, on State Route 62, and is one of eight state-certified arboretums in Tennessee. The mission of the arboretum is to "provide a natural laboratory for studies in plant uses, genetics and adaptability, insect and disease control, and the management of associated natural resources." The Tennessee Wildlife Resources Agency (TWRA) recognizes this area as an official

Wildlife Observation Area and part of the National Watchable Wildlife Program (NWWP). It is also recognized by the Holly Society of America as an official holly test garden, and the trails within the arboretum are part of the Tennessee Recreational Trail System.

The arboretum comprises over 880 $acres^2$ of forested land and harbors approximately 1,500 plant specimens representing over 800 plant species. In addition to arboretum's research role, the station maintains a system of public trails covering 100 $acres^2$ and hosts an average of 30,000 visitors per year.

Research Objectives and Importance

Old-growth forest ecosystems are becoming increasingly rare throughout North America, due in part to society's demand for timber and the ever-expanding cities and suburbs. Understanding the interwoven tapestry of arboreal coleopteran communities is an important step in making wise land-management decisions for the state's forests because biodiversity within a natural system is believed to represent the system's constancy, efficiency, and complexity (Tilman *et al.* 1996).

Most studies have focused on species with substantial public appeal and have tended to overlook most of the invertebrate fauna (Watson *et al.* 1994). Lack of information on the invertebrate species and their role in the communal structure of the ecosystem is an important barrier to development of conservation strategies, especially when the stability of the ecosystem is threatened by the invasion of exotic species (e.g., balsam woolly adelgid, *Adelges piceae* (Ratzeburg)), human encroachment, or naturally occurring environmental changes. Unless the basic taxonomic and biological information is obtained for those species that currently are important in the communal structure of ecosystems, it will be difficult if not impossible to determine their value.

The current loss of flora and fauna from the invasion of exotic insect species, habitat destruction, conversion, pollution, and over-exploitation of entire ecosystems has the potential to impact whole assemblages of mature NRO. Therefore, this study was initiated to assess the current coleopteran fauna on NRO.

It is hypothesized that elevation will be a significant variable in the amount and diversity of beetle specimens within the GRSM. More specimens and species should be found at the lower elevation site because of elevation's influence on environmental factors. Significantly higher levels of Asiatic oak weevil also are expected based on previous study results (Stanton 1994).

The objectives of this study were To:

1. document the coleopteran biodiversity within the canopy of mature NRO in the GRSM,
2. identify potential coleopteran threats to the health of these particular stands.
3. assess feeding guild structure of the beetle population

CHAPTER II
MATERIALS AND METHODS

Site Localities

The insect fauna was sampled at three sites within the GRSM in 1992-95 (Figure 1). The three sites sampled were: (1) Bee Tree (Thomas Divide) [35° 35' 03.396"N 83° 23'55.687"W] located in Swain Co., NC, at an elevation of 1377.7 m, (2) Mount Sterling (Long Bunk Trail) [35° 42' 19.590"N 83° 06' 47.278"W] located in Swain Co., NC, at an elevation of 1262.1 m, and (3) Rich Mountain (Cold Springs Gap) [35° 37' 31.639" N 83° 49' 29.972"W] located in Blount Co., TN, at an elevation of 823.94 m

An additional collection was made in May to October 2001 at the UT arboretum [36° 0'39"N 84° 11' 34"W] located in Anderson Co., TN, at an elevation of 262.0 m.

Site Characteristics

Using mapping software, geology, disturbance histories, and vegetation types for each GRSM site were recorded. All three sites had sandstone as a major geological foundation but slightly differed in the type. Bee Tree and Mount Sterling sites were classified as having thunderhead sandstone geology, while the Rich Mountain site was primarily Cades sandstone. In terms of disturbance levels, Rich Mountain had a history of light commercial cutting, the Mount Sterling site had a history of selective cutting, and the Bee Tree site was undisturbed. Vegetation analysis showed the Rich Mountain and

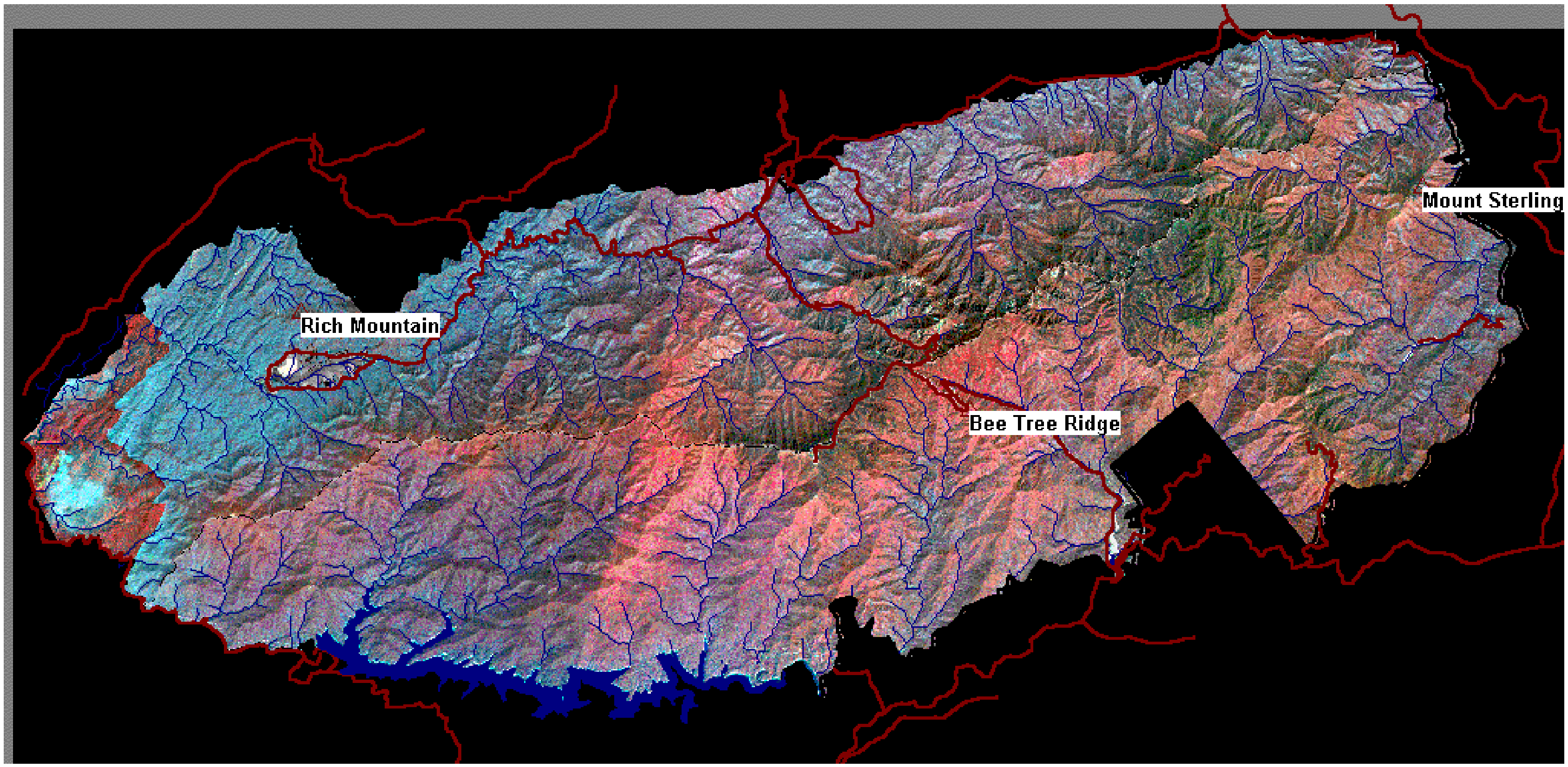

Figure 1. Satellite map of Great Smoky Mountains National Park marking three northern red oak insect collection sites, 1992-95

Mount Sterling sites as mixed mesic hardwood forests while the Bee Tree site was a cove hardwood forest.

Sampling Procedure

Insects were collected using canopy fogging because of its expediency, accuracy, and general nondestructive nature (Stein and Doran 1975). At the GRSM sites, Barton Tree Service was hired to place a system of pulleys and ropes in the trees to attach the fogging unit. At the UT arboretum, ropes were placed in the trees using a modified Zebco™ fishing reel system or a Rawlings™ baseball with a fishing line attached.

Ten trees at each GRSM site and three trees at the UT arboretum were selected, identified, and measured (tree height, diameter). The average height of each tree sampled was 27.98 m with an average basal area of 30.468 m^2 at Bee Tree, 30.58 m with an average basal area of 25.38 m^2 at Mount Sterling, 30.6 m with an average basal area of 26.43 m^2 at Rich Mountain, 17.07 m with an average basal area of 18.52m^2 at the UT arboretum. A numbered metal tag was placed ca. 2 m from ground level on each GRSM tree for identification. One tree per GRSM site was sampled every 14 days from May to October (Table 1) with a standard broad-spectrum, synthetic, pyrethroid insecticide (Asana XL, 0.66 emulsifiable concentrate). One UT arboretum tree was sampled every 30 days from May to October using the same method. On each fogging date, insecticide was applied using a modified Dyna-Fog Golden Eagle model 2610 fogger, when wind conditions were less than 5 mph. Plastic tarps (12 m x 6 m) were placed on the ground underneath the tree canopy to collect fallen specimens. The insecticide was formulated to deliver fog for 10 to 20 minutes. After 2 to 4 hours, arthropods were removed from the

Table 1. Collection dates by month and year for northern red oak collection sites in the Great Smoky Mountains National Park, 1992-95.

Month	Year	Bee Tree	Rich Mountain	Mount Sterling
Aug.	1992	0	1	0
Sept.		2	1	1
Oct.		1	1	0
May	1993	0	1	1
Jun.		1	2	1
July		2	1	1
Aug.		2	2	2
Sept.		1	2	2
Oct.		1	0	1
May	1994	1	3	1
Jun.		2	1	1
July		1	1	2
Aug.		2	2	2
Sept.		1	1	1
Oct.		1	1	1
May	1995	0	0	0
Jun.		0	1	0
TOTAL		**18**	**21**	**17**

tarps using a hand-held, modified DustBuster® vacuum, placed into plastic bags, labeled, and taken to the laboratory.

Processing of Specimens in the Laboratory

In the laboratory, insects were stored in a freezer or placed in vials containing 70% ETOH until they could be sorted and processed. Processed specimens were separated into similar taxa (i.e., order, family, or morphologically similar groups). Specimens were cleaned and individually pinned, placed in vials or on mounting points, with an identification label for site, date, county, tree number, and sampling method. Specimens of each species were placed into collection trays where they were identified using standard keys. Once identified, a label with order, family, genus, and species names was included for each specimen. Specimens were then systematically arranged into Cornell drawers for incorporation into the UT insect museum. Collection and specimen data were entered into a Biota® database and exported to a Microsoft Excel® spreadsheet for data analysis. GRSM overlay maps were incorporated with site coordinates to illustrate vegetation, geology, and disturbance histories for each site. Information about each site was compared with insect data.

Analysis of Data

Specimen data were computed to provide specimen totals (total specimens, order and family abundance) for each site. These data were separated by date to provide specimen sums for each collection year. Site differences in specimen abundance and yearly totals for the GRSM specimens were evaluated using a Chi-Square Analysis (P=0.05) (SAS Institute 1997).

GRSM coleopteran taxa were assessed using two different measurements [(Berger-Parker Dominance Index and Shannon-Weiner Index) (Simpson 1949, Magurran 1988, Price and Waldbauer 1994)] to assess α-diversity and dominance within sites.

The Berger-Parker Dominance Index (Di) was used to estimate the degree of influence of the site's most common species. Di was calculated as $Di = n_{max}/\Sigma n_i$ where

n_{max} is the abundance of the most common species and Σn_i is the total number of individuals from that site.

The Shannon-Weiner diversity index *(H')* takes into account species richness and proportion of each species within a local community. This index assumes that the area sampled contains an infinite number of individuals. The equation for *H'* is *H' = -sum (Pi natural log [Pi])* where p_i is the number of beetles in species *'i'* divided by the total number of beetles from that site. Values can range from zero to the amount of species in the sample with higher numbers representing higher levels of diversty.

Species evenness was also calculated for each GRSM site. Evenness (E) is calculated as $E = H/\log_e S$ where *S* is the number of species in the sample. In addition to these measures, a Chi-Square Analysis (P=0.05) was used to compare GRSM sites for significant differences in species composition and abundance.

Species accumulation curves for each GRSM site (randomization value = 1000) were developed using Effort Predictor V1.0 2001. The theoretical maximum number of species (Smax) after 75 samples for each site was then calculated.

Species also were plotted on a graph in terms of their specimen abundance to provide rarity information. Specimens represented by a single specimen (singletons) were plotted together followed by those represented by more specimens.

Beetle species were categorized into groups based on their adult feeding preferences (phytophagous, entomophagous, both, or unknown) (Downie and Arnett 1996). These data were tabulated and significant differences were calculated using a Chi-Square Analysis (P=0.05). In addition, the feeding preference (e.g., acorn, leaf, pollen, etc.) or type of carnivorous activity (e.g., scavenger, predator, etc.) for each species was determined from the literature.

Geographical and distribution data for collected beetle species new to the GRSM were compiled using available literature (Downie and Arnett 1996, GRSM All-Taxa Biodiversity Inventory records, State of Tennessee insect records and Tennessee Agricultural Extension reports).

CHAPTER III
RESULTS AND DISCUSSION

GRSM Specimen Collection Data

Arthropod surveys using the fogging method are successful in collecting large numbers of specimens representing a wide range of orders (LaForest 2000, Stork and Hammond 1997, Basset *et al.* 1997). From 56 collection dates, 11,468 arthropods were collected from NRO in the GRSM during 1992-95. Of these, 9,320 (ca. 81.23%) adult insect specimens were classified into 19 orders with approximately 97.62% belonging to the orders Orthoptera, Psocoptera, Hemiptera, Homoptera, Coleoptera, Hymenoptera, and Diptera (Table 2). These seven orders are expected to occur in high numbers in an arboreal environment and results from this study are similar to other recent studies (LaForest 2000, Stanton 1994, Linit *et al.* 1986).

Three orders (Phasmida, Plecoptera, and Thysanura) were represented by less than 10 specimens and a single specimen represented three orders (Dermaptera, Odonata, and Microcoryphia). Some 2,148 immature insects also were collected with 1,341 (62.43%) of these insects being Lepidoptera.

Although a substantial amount of larval Lepidoptera was collected, only twelve adult Lepidoptera specimens were obtained. These numbers indicate that lepidopteran adults were either not susceptible to our fogging methods or were not found on mature GRSM NRO. This hypothesis supports earlier conclusions by Stanton (1994) and McCasland (1993) who also recorded low adult Lepidoptera populations in Tennessee oaks.

Table 2. Total number of adult insects collected from northern red oak in the Great Smoky Mountains National Park from 1992-95.

Order	**1992**	**1993**	**1994**	**1995**	**Total**
Blattaria	2	4	24	5	35
Coleoptera	117	523	753	83	1,476
Collembola	11	4	28	4	47
Dermaptera	0	1	0	0	1
Diptera	72	382	2,463	530	3,447
Hemiptera	17	80	332	8	437
Homoptera	56	117	736	34	943
Hymenoptera	116	364	1,573	116	2,169
Lepidoptera	0	7	5	0	12
Mecoptera	0	8	20	2	30
Microcoryphia	1	0	0	0	1
Neuroptera	0	1	9	0	10
Odonata	0	0	1	0	1
Orthoptera	69	63	69	15	216
Phasmida	1	3	4	0	8
Plecoptera	0	0	6	0	6
Psocoptera	11	9	383	8	411
Thysanoptera	0	0	64	0	64
Thysanura	1	1	3	1	6
TOTAL	**474**	**1,567**	**6,473**	**806**	**9,320**

Noticeable differences are apparent among annual adult specimen counts from 1992-95 as collections revealed substantial differences in the numbers of specimens collected each year. The higher number of specimens obtained in 1993 and 1994 is a result of more collection dates as seven collections were made in 1992 and just one in 1995 compared to 24 collections in 1993 and 25 in 1994.

What is more striking is the significantly greater (χ^2= 182.395, df=2, P<0.005) amount of specimens (approximately 5,000) collected in 1994 than in 1993. This is attributed to substantially more specimens from the orders Hymenoptera, Diptera, Hemiptera, and Psocoptera being collected in 1994 than in 1993.

The high abundance of dipterans collected is a possible result of swarming behavior of many small species. The most prevalent fly family in our collection, Sciaridae, are normally gregarious (Arnett 2000). It would not be surprising if the fogging mist encapsulated a large mass of these insects causing them to be collected *en masse*. Further identification of these insects to species level could further elucidate this hypothesis.

For Hymenoptera, the high number of ants collected could be a result of foraging activity. High numbers of *Camponotus* spp., were collected during the sampling period. Cole (1940) stated these ants were relatively numerous in many areas of the park, even at elevations of 1,219 m. This ant genus nests either in the ground beneath logs and stones or in dead wood (Cole 1940). Nearly all the ants collected were workers with only a single soldier and a single winged-specimen collected. This further supports the foraging theory proposed as workers normally forage for larval food among the forest floor and canopies of surrounding trees (Cole 1940).

During collecting at the arboretum, large numbers of *Camponotus* spp. were observed running onto the tarps from the surrounding forest floor. Over the course of the 4-hr waiting period for the insects killed in the canopy to fall, these ants became numerous. Some were seen dragging insects killed by the fogging mist from the tarps. Inevitably, many of these ants were collected along with the specimens killed by canopy fogging. This raises a question about incidental catches of insects not associated with the tree canopy. Stork and Hammond (1997) document using rope-suspended sampling trays that could alleviate incidental catches from tarps laid on the forest floor.

The other most represented families of Hymenoptera, Braconidae and Ichneumonidae, are large families of wasps. Many of these species are ubiquitous throughout the eastern United States (Arnett 2000) and their abundance in this collection is not unexpected.

Despite similar amounts of collections (Bee Tree = 18, Rich Mountain = 21, and Mount Sterling = 17), slightly more specimens were collected at the Rich Mountain site than at the other two sites (Table 3). Four orders (Dermaptera, Odonata, Microcoryphia, and Thysanura) were found at only one site. Four other orders (Blattaria, Lepidoptera, Phasmida, and Plecoptera) were found at only two sites.

From all adult insect specimens collected, 193 families were identified. The orders Diptera, Coleoptera, and Hymenoptera were the most diverse containing 51, 45, and 30 families, respectively. Among dipteran families, Sciaridae, dark-winged fungus flies, was the dominant family with 1,966 specimens representing 57.03% of all flies collected. Chironomidae, Ceciodomyiidae, Empididae, and Phoridae were the next most

Table 3. Total number of adult insects collected from northern red oak in the Great Smoky Mountains National Park from 1992-95 distributed by collection site.

Order	**Bee Tree**	**Rich Mountain**	**Mount Sterling**	**Total**
Blattaria	1	34	0	35
Coleoptera	398	713	365	1,476
Collembola	18	16	13	47
Dermaptera	0	0	1	1
Diptera	928	1,359	1,160	3,447
Hemiptera	186	104	147	437
Homoptera	350	222	371	943
Hymenoptera	543	1,037	589	2,169
Lepidoptera	6	6	0	12
Mecoptera	19	5	6	30
Microcoryphia	1	0	0	1
Neuroptera	1	2	7	10
Odonata	0	1	0	1
Orthoptera	57	127	32	216
Phasmida	0	7	1	8
Plecoptera	5	0	1	6
Psocoptera	229	59	123	411
Thysanoptera	3	10	51	64
Thysanura	0	6	0	6
TOTAL	**2,745**	**3,708**	**2,867**	**9,320**

specimen rich Diptera families (Appendix A). Formicidae, with 766 specimens (ca. 35.31%), was the most represented Hymenoptera family. Hymenoptera unidentified to family level, Ichneumonidae, and Braconidae were the next highest specimen groups of Hymenoptera (Appendix B).

Excluding Coleoptera, 3,600 specimens were identified to 107 genera (Appendix C). In addition, 829 non-coleopteran specimens were identified to 91 species (Appendix D). This number represents a conservative estimate of non-coleopteran species collected as no attempt was made to identify many specimens beyond the family level.

Beetle abundance per collection effort varied from zero to 104 specimens with an average of 29.3 beetles per collection. Two collections yielded no beetle specimens from the tree sampled. However, both of these collections occurred in October, a month of comparably low insect activity. In addition, these two collections did not produce many other insect specimens. Archival weather data for the sites were not available but an extended period of cold and precipitation could have limited insect activity substantially. The highest number of specimens was collected in June and the lowest in October (Table 4). Rich Mountain had a significantly (χ^2=166.298, df=2, P<0.005) higher numbers of specimens (713) followed by Bee Tree (407) and Mount Sterling (353).

Forty-five families of beetles were found on NRO in the GRSM (Table 5). Combining all sites, Curculionidae was the most represented family with 426 (ca. 28.16%) specimens. The high number of *C. castaneus* was responsible for the weevils being the most abundant beetle family. This insect represented 79.81% of all weevils and 23.04% of all beetles collected. High abundances were recorded in August, which correlates to this insect's proclivity to move into the upper canopy to feed on leaves

Table 4. Number of collections and distribution of beetle specimens by month from the Great Smoky Mountains National Park, 1992-95.

Month	**Number of Collections**	**Specimens**
May	7	143
June	9	431
July	8	154
August	12	361
September	12	321
October*	9	66
TOTAL	**55**	**1,476**

*-*Two collections in October yielded zero beetles.*

during this month (Evans 1959, Roling 1979, Johnson and Lyon 1991, and Triplehorn 1955). Substantially more *C. castaneus* specimens were collected at the lower elevation site, Rich Mountain, than the other sites. This could mean the insect is limited by elevation or that sufficient populations have not had a chance to reach the levels of lower elevations.

Twenty-two other weevil species represented by eighty-six specimens also were collected. This is not surprising considering the feeding and ovipositing association of weevils and acorns.

Curculionidae was followed by Carabidae, Lagriidae, and Staphylinidae, respectively. When analyzed by site, Carabidae was the most dominant family at the Mount Sterling and Bee Tree sites, while Curculionidae was dominant at the Rich Mountain site (Table 6). Fourteen families were found at only one site. The number of unique families was highest at Bee Tree (6) followed by Rich Mountain (5), and Mount Sterling (3). Ten families were located at two sites and 19 families were present at all three sites.

Table 5. Families of Coleoptera collected from northern red oak trees in the Great Smoky Mountains National Park, 1992-95.

Family	**Common Name**	**Abundance**	
		Species	**Specimens**
Alleculidae	Comb-clawed bark beetles	10	46
Anobiidae	Deathwatch beetles	3	10
Anthicidae	Antlike flower beetles	1	1
Anthribidae	Fungus weevils	1	2
Attelabidae	Tooth-nosed snout beetles	1	1
Brentidae	Straight-snouted weevils	1	6
Buprestidae	Metallic jewel beetles	6	17
Byturidae	Fruit-worm beetles	1	1
Cantharidae	Soldier beetles	8	35
Carabidae	Ground beetles	7	185
Cephaloidae	False longed-horn beetles	1	2
Cerambycidae	Longed-horn beetles	18	73
Chrysomelidae	Leaf beetles	23	84
Cicindelidae	Tiger beetles	3	4
Ciidae	Minute tree-fungus beetles	1	12
Cleridae	Checkered beetles	4	23
Coccinellidae	Ladybird beetles	5	16
Colydiidae	Cylindrical bark beetles	2	3
Cucujiidae	Flat bark beetles	3	7
Curculionidae	Weevils	23	426
Derodontidae	Tooth-necked fungus beetles	1	17
Elateridae	Click beetles	17	55
Endomychidae	Handsome fungus beetles	2	3
Erotylidae	Pleasing fungus beetles	2	3
Geotrupidae	Geotrupine beetles	1	2
Histeridae	Clown beetles	3	5
Lagriidae	Long-jointed beetles	1	128
Lathridiiae	Minute brown scavenger beetles	1	3
Leiodidae	Round fungus beetles	2	2
Lycidae	Net-winged beetles	2	2
Melandryidae	False-darkling beetles	3	8
Meloidae	Blister beetles	1	1
Mordellidae	Tumbling flower beetles	4	10
Nitidulidae	Sap-feeding beetles	5	20
Oedemeridae	Pollen feeding beetles	1	1
Pedilidae	Fire beetles	1	1
Platypodidae	Ambroisa beetles	1	1
Pyrochoridae	Fire-colored beetles	1	2
Ptilodactylidae	Toed-winged beetles	1	1
Scarabaeidae	Lamellicorn beetles	8	45
Scolytidae	Bark-gnawing beetles	2	10
Silphidae	Carrion beetles	1	2
Staphylinidae	Rove beetles	7	99*
Tenebrionidae	Darkling beetles	12	67
Trogossitidae	Bark-gnawing beetles	1	5
Unidentified		na	29
TOTAL		**203**	**1,476**

*- *Staphylinidae include specimens identified to family level*

Table 6. Site distribution of coleopteran families collected from northern red oak in the Great Smoky Mountains National Park, 1992-95

Family	**Rich Mountain**		**Bee Tree**		**Mount Sterling**	
	Species	**Specimens**	**Species**	**Specimens**	**Species**	**Specimens**
Alleculidae	8	30	3	7	4	9
Anobiidae	2	6	1	2	2	2
Anthicidae	0	0	0	0	1	1
Anthribidae	1	2	0	0	0	0
Attelabidae	0	0	0	0	1	1
Brentidae	1	4	1	2	0	0
Buprestidae	5	15	1	1	1	1
Byturidae	0	0	1	1	0	0
Cantharidae	4	6	6	16	3	13
Carabidae	2	33	6	72	3	80
Cephaloidae	1	1	0	0	1	1
Cerambycidae	9	13	11	36	3	24
Chrysomelidae	20	35	7	18	7	31
Cicindelidae	2	2	1	1	1	1
Ciidae	1	12	0	0	0	0
Cleridae	4	15	2	6	1	2
Coccinellidae	3	8	1	4	4	4
Colydiidae	2	3	0	0	0	0
Cucujiidae	3	4	1	2	1	1
Curculionidae	13	297	10	59	9	70
Derodontidae	0	0	1	15	1	2
Elateridae	9	24	9	26	4	5
Endomychidae	0	0	2	3	0	0
Erotylidae	0	0	1	2	1	1
Geotrupidae	0	0	1	2	0	0
Histeridae	1	1	2	3	1	1
Lagriidae	1	70	1	29	1	29
Lathridiiae	1	1	1	2	0	0
Leiodidae	0	0	1	1	1	1
Lycidae	1	1	0	0	1	1
Melandryidae	1	1	1	2	1	5
Meloidae	0	0	1	1	0	0
Mordellidae	3	5	1	5	0	0
Nitidulidae	4	13	2	6	1	1
Oedemeridae	0	0	0	0	1	1
Pedilidae	1	1	0	0	0	0
Platypodidae	0	0	1	1	0	0
Ptilodactylidae	0	0	0	0	1	2
Pyrochroidae	0	0	0	0	1	1
Scarabaeidae	6	6	5	34	3	5
Scolytidae	2	10	0	0	0	0
Silphidae	0	0	1	2	0	0
Staphylinidae*	2	26	1	18	5	55
Tenebrionidae	11	58	0	0	3	9
Trogossitidae	0	0	1	1	1	4
Unidentified	NA	10	NA	18	NA	1
Total	**124**	**713**	**85**	**398**	**69**	**365**

**- Staphylinidae include specimens identified to family level.*

The high numbers of beetle families documented in this study was unexpected. Only 42.22% of the beetle families were found at all three sites. However, an equal amount of families were represented by single species, and a single specimen represented 42.13% of these families. Still, the absence of darkling beetles (Tenebrionidae), a common beetle family (Arnett 2000), at the high elevation site and low numbers at the mid-elevation site, could mean certain families are intolerant to elevational influences.

Scattered accounts of elevation's influence on beetle family abundance exist in the literature. Jakus (1995) noted that bark beetle (Scolytidae) abundance was significantly inversely correlated with altitude in a Norway spruce primeval forest in Central Slovakia. These results are comparable to those found in the GRSM collection as the lowest elevation site contained the only bark beetles found in the survey. DuMerle and Attie (1992) also found that elevation was a significant variable in the numbers of jewel beetles (Buprestidae) collected from an oak forest in France. They collected higher numbers of jewel beetles at lower elevation sites, which also compares favorably with our results.

Excluding 84 rove beetles (Staphylinidae) and 29 severely damaged specimens, 1,363 (92.34%) beetles were identified to 203 species (Table 7). Ninety-seven species of Coleoptera were represented by one specimen (singleton) and accounted for 48.02% of all coleopteran species identified but only 6.57% of the total number of coleopteran specimens collected (Figure 2). Typically, canopy fogging produces a significant amount of species, and a singleton usually represents a large proportion (37.5-57.8%) of species (Basset and Kitching 1991, Novotny 1993, and Morse *et al.* 1988). Approximately 47.2% of our GRSM beetle specimens were singletons and are therefore within the

Table 7. Species of Coleoptera (N=203) collected from northern red oak at three sampling sites in the Great Smoky Mountains National Park, 1992-95.

Family	Species	BT	RM	MS	Specimens
Alleculidae	*Androchirus erythropus* (Kirby)*	X	X		6
	Hymenochara rufipes (J.E. LeConte)*		X		3
	Hymenorus niger (Melshiemer)	X	X	X	7
	Isomira quadrisriata Couper	X	X	X	17
	Isomira sericea (Say)			X	1
	Lobopoda punctulata (Melshiemer)		X		1
	Mycetochara bicolor (Couper)*		X		2
	Mycetochara binotata (Say)*	X			1
	Mycetochara foveata (LeConte)		X	X	3
	Mycetochara haldemani (LeConte)*		X		3
	Hemicoelus carinatus (Say)			X	1
	Trichodesma gibbosa (Say)		X		1
Anobiidae	*Tricorynus confusus* (Fall)	X	X	X	10
Anthicidae	*Ischalia costata* (LeConte)			X	1
Anthribidae	*Tropideres fasciatus* (Olivier)		X		2
Attelabidae	*Atellibus bipustulatus* F.			X	1
Brentidae	*Arrhenodes minuta* (Drury)	X	X		6
Buprestidae	*Agrilus arcuatus* Say*		X		1
	Brachys ovatus (Weber)	X			1
	Chrysobothris femorata (Olivier)		X		1
	Chrysobothris rugosiceps Melsheimer		X	X	8
	Chrysobothris sexsignata (Say)		X		2
	Dicerca lurida (F.)		X		4
Byturidae	*Byturus unicolor* Say	X			1
Cantharidae	*Cantharis nigriceps* LeConte	X	X		2
	Cantharis rectus Melsheimer		X	X	5
	Cantharis scitulus Say	X	X		5
	Malthodes concavus LeConte*	X			1
	Podabrus frater LeConte			X	5
	Podabrus modestus (Say)*	X			1
	Podabrus tomentosus (Say)	X			9
	Silis percomis (Say)	X	X	X	7
Carabidae	*Bembidion simplex* Haywood	X			1
	Calathus gregarius (Say)	X	X	X	94
	Calathus opaculus LeConte			X	1
	Dicaelus politus Dejean	X			1
	Platynus decentis (Say)	X	X	X	77
	Pterostichus honestus (Say)	X			10
	Stenolophus plebejus Dejean	X			1
Cephaloidae	*Cephaloon lepturides* Newman		X	X	2
Cerambycidae	*Anoplodera rubrica* Say	X	X		3
	Atimia confusa Say*	X			2
	Ecyrus dasycerus (Say)		X		1
	Encyclops caerulea Newman*	X			2
	Goes tigrinus (Degeer)*		X		1
	Hyperplatys aspersa (Say)*	X			1
	Leptura cordifera (Olivier)		X		1
	Megacyllene robiniae (Forster)		X		1
	Michthisoma heterodoxum LeConte	X	X	X	46
	Microgoes oculatus (LeConte)	X			1
	Monochamus titillator (F.)	X			2
	Pidonia ruficollis (Say)	X			1
	Pogonocherus mixtus Haldeman*	X			1
	Typocerus octonotatus (Haldean)*			X	1

Table 7 (cont). Species of Coleoptera (N=203) collected from northern red oak at three sampling sites in the Great Smoky Mountains National Park, 1992-95.

Family	**Species**	**BT**	**RM**	**MS**	**Specimens**
(Cerambycidae)	*Urgleptes querci* (Fitch)*	X	X	X	4
	Urographis fasciatus (Degeer)		X		1
	Xestoleptyra octonota (Say)*	X			2
	Xylotrechus colonus (F.)		X		1
Chrysomelidae	*Altica marevagans* Horn		X		1
	Anoplitis inaequalis Weber			X	4
	Baliosis ruber Weber	X	X	X	4
	Capaita sexmacticula (Illigier)	X	X	X	9
	Capraita quercata (F.)*		X	X	2
	Chaetocnema denticulata (Illigier)*		X		1
	Chaetocnema pulicaria Melsheimer		X		1
	Chalepus dorsalis (Thunberg)*	X	X		4
	Chrysochus auratus (F.)		X		1
	Derocrepsis erythropus (Melshiemer)		X	X	2
	Diabrotica undecimpunctata howardi Barber		X		1
	Diactius auratus (F.)	X	X	X	17
	Jonthonota nigripes (Olivier)*	X			1
	Luperodes meraca (Say)	X	X	X	17
	Odontota dorsalis Thunberg		X		2
	Pachybrachis cephalicus Fall*		X		1
	Pachybrachis hepaticus Melsheimer*		X		3
	Pachybrachis tridens (Melshiemer)		X		2
	Phyllecthris dorsalis (Olivier)		X		1
	Rhabdopterus picpes (Olivier)*	X			1
	Syneta ferruginea (Germar)		X		6
	Systena marginalis (Illigier)		X		1
	Xanthonia decemnotata (Say)		X		2
Cicindelidae	*Cicindela punctulata* Olivier	X		X	2
	Cicindela sexguttata F.		X		1
	Cicindela unipunctata F.		X		1
Ciidae	*Cis cornutus* Blatchley		X		12
Cleridae	*Cymatodera bicolor* (Say)*		X	X	7
	Enoclerus quadriguttatus (Say)*		X		2
	Phyllobaenus pallipennis (Say)	X	X		10
	Phyllobaenus verticalis (Say)	X	X		4
Coccinellidae	*Anatis quindecimpunctata* (Olivier)		X		4
	Coccinella septempunctata (L.)			X	1
	Harmonia axyridas (Pallas)			X	1
	Psyllobora vigintimaculata (Say)	X	X	X	8
	Scymnus rubricaudus Casey		X	X	2
Colydiidae	*Aulonium parallelopipedum* (Say)*		X		1
	Coxelus guttulatus (F.)*		X		2
Cucujiidae	*Cucujus clavipes* F.	X	X	X	4
	Laemophloeus biguttatus (Say)*		X		1
	Oryzaephilus surinamensis (L.)*		X		2
Curculionidae	*Anthonomus signatus* Say			X	1
	Apion patruele Smith*	X			1
	Apion rostrum Say*		X		1
	Attelabus bipustulatus F.*			X	1
	Conotrachelus anaglypticus(Say)			X	1
	Conotrachelus elegans (Say)*		X		3
	Conotrachelus juglandis LeConte*		X		1

Table 7 (cont). Species of Coleoptera (N=203) collected from northern red oak at three sampling sites in the Great Smoky Mountains National Park, 1992-95.

Family	Species	BT	RM	MS	Specimens
(Curculiondiae)	*Conotrachelus posticatus* Boheman			X	9
	Cophes obtentus (Herbst)	X			1
	Cossonius platalea Say	X	X	X	3
	Curculio iowensis (Casey)*	X			3
	Curculio proboscideus F.	X	X	X	41
	Curculio sulcatulus (Casey)*	X		X	2
	Cylindrocopturus quercus (Say)		X		1
	Cyrtepistomus castaneus (Roelofs)	X	X	X	340
	Dryophthorus americanus Bedel	X			1
	Hyperodes solutus (Say)	X			1
	Ithycerus noveboracensis Forster		X	X	2
	Lechriops oculata (Say)*		X		1
	Merhynchites bicolor (F.)*		X		1
	Odontopus calceatus (Say)	X	X		8
	Pandeleteius hilaris (Herbst)*		X		2
	Rhinoncus pyrrhopus Boheman		X		1
Derodontidae	*Derodontus maculatus* (Melsheimer)*	X		X	17
Elateridae	*Aeolus mellius* (Say)*	X			1
	Agriotes oblongicollis (Melshiemer)	X			5
	Agriotes pubescens Melsheimer	X			1
	Ampedus areolatus (Say)*		X		3
	Ampedus collaris (Say)		X	X	3
	Ampedus luctuosus (LeConte)*			X	2
	Athous brightwelli (Kirby)		X		8
	Athous carolinus Van Dyke		X		1
	Athous cucullatus (Say)*			X	1
	Cardiophorus convexus (Say)		X		1
	Conoderus lividus (Degeer)	X	X		3
	Hemicrepidus asaphes (LeConte)*	X			3
	Lepidotus objecta (Say)	X			1
	Limonius aurifer LeConte	X	X		5
	Limonius ectypus Say	X			1
	Limonius quercinus Say		X	X	2
	Melanotus americanus (Herbst)*	X	X		14
Endomychidae	*Mycetina perpulchra* (Newman)	X			1
	Phymaphora pulchella Newman*	X			2
Erotylidae	*Dacne quadrimaculatta* (Say)*			X	1
	Triplax festiva Lacordaire*	X			2
Geotrupidae	*Geotrupes splendidus* (F.)*	X			2
Histeridae	*Geomysaprinus obsidianus* (Casey)*	X	X		3
	Hister abbreviatus F.*			X	1
	Margarinotus interruptus Beauvois	X			1
Lagriidae	*Arthromacra aenea* Say	X	X	X	128
Lathridiiae	*Corticaria serrata* Paykull	X	X		3
Leiodidae	*Cainosternum imbricatum* Notman	X			1
	Colenis impunctata LeConte			X	1
Lycidae	*Celetes basalis* LeConte*			X	1
	Lycus lateralis Melsheimer*		X		1
Melandryidae	*Anaspis rufa* Say*		X		1
	Orchesia castanea (Melsheimer)			X	5
	Prothalpia undata LeConte*	X			2
Meloidae	*Meloe americanus* Leach	X			1
Mordellidae	*Mordella marginata* Melsheimer		X		2

Table 7 (cont). Species of Coleoptera (N=203) collected from northern red oak at three sampling sites in the Great Smoky Mountains National Park, 1992-95.

Family	**Species**	**BT**	**RM**	**MS**	**Specimens**
(Mordellidae)	*Mordellistena bihamata* (Melsheimer)*	X			5
	Mordellistena pubescens (F.)		X		2
	Tomoxia discoidea (Melsheimer)		X		1
Nitidulidae	*Carpophilus sayi* Parsons*		X		3
	Cryptarcha ampla Erichson		X		1
	Prometopia sexmaculata (Say)		X		2
	Stelidota germinata (Say)	X	X	X	13
	Thalycra carolina (Wickham)	X			1
Oedemeridae	*Oxycopis thoracica* (F.)			X	1
Pedilidae	*Macratia confusa* (F.)*		X		1
Platypodidae	*Platypus quadridentatus* (Olivier)*	X			1
Ptilodactylidae	*Ptilodactula serricollis* Say			X	2
Pyrochroidae	*Ischalia costata* (Leconte)*			X	1
Scarabaeidae	*Dichelonyx linearis* (Gyllenhal)*	X	X	X	17
	Dichelonyx subvitta LeConte	X	X	X	13
	Maladera castanea (Arrow)		X		1
	Onthophagus hecate (Panzer)		X		1
	Serica atracapilla (Kirby)*	X			6
	Serica georgiana Leng	X	X		4
	Serica sericea (Illigier)	X		X	2
	Trichiotinus bibens (F.)		X		1
Scolytidae	*Scolytus rugulosus* Ratzeberg*		X		1
	Xyleborus xylographus (Say)*		X		9
Silphidae	*Nicrophorus sayi* Laporte	X			2
Staphylinidae	*Aleochara fumata* Gravenhorst	X			1
	Anotylus sp. 1		X		2
	Anotylus insignitus (Gravenhorst)			X	1
	Anthobium hornii (Say)*		X	X	8
	Psedopsis subulata Herman*			X	1
	Tachinus fimbriatus Gravenhorst			X	1
	Trichiusa robustula Casey			X	1
Tenebrionidae	*Cynaeus angustatus* (Leconte)*		X		1
	Haplandrus fulvipes (Herbst)*		X		1
	Helops aereus Germar			X	5
	Meracantha contracta (Beauvois)		X		12
	Merinus laevis (Olivier)		X	X	3
	Neatus tenebriodes (Beauvois)		X		5
	Platydema subcostatum Laporte and Brulle'		X		11
	Platydema teleops Triplehorn*		X		1
	Scotobates calcaratus F.		X		1
	Strongylium tenevicolle (Say)		X		1
	Tarpela micans (F.)		X	X	25
	Xylopinus saperdiodes (Olivier)		X		1
Trogossitidae	*Tenebroides mauritanicus* L.	X		X	5

**-Denotes species new to Great Smoky Mountains Park as of 23 April,, 2002 (n=64).*
BT-Bee Tree
MS-Mount Sterling
RM-Rich Mountain

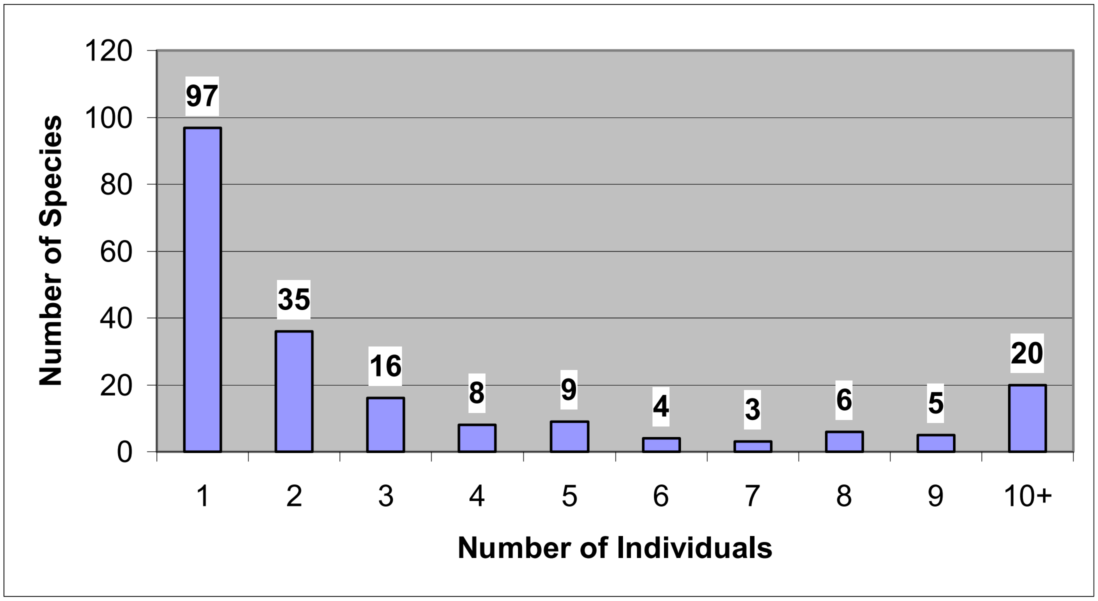

Figure 2. Comparison of total number of beetle individuals collected per species for all three sites from northern red oak in the Great Smoky Mountains National Park, 1992-95 (n=203).

expected range for this type of study. Such high values for singleton specimens make correlating life history information with species distribution difficult and may indicate a high possibility of uncollected species (Novotny 1993).

A fogging sample represents a "snapshot" of the insect fauna present within the tree canopy at a particular moment in time. The possible collection of incidental tourist species alighting on the tree is relatively high with such a sample. Therefore, continuous sampling methods (i.e. malaise and "sticky" traps") should be used in concert with the discrete fogging method to provide a more thorough sample.

Species richness, which averaged 92.67 coleopteran species per site, ranged from 69 species in the Mount Sterling site to 124 at the Rich Mountain site. A significant

(χ^2=17.856, df=2, P<0.005) difference was noted for the number of species found at Rich Mountain compared to the other sites.

About 9.91% of all beetle species are considered “widespread” and were collected at all three sites (Table 7). Approximately 72.64% of those species identified were collected at only one site (Table 7). The number of unique species was highest at Rich Mountain (74) followed by Bee Tree (45) and Mount Sterling (29).

The most species diverse families were Curculionidae and Chrysomelidae with 23 species each followed by Cerambycidae, Elateridae, Tenebrionidae, and Alleculidae each with at least 10 species (Table 5). Nineteen families were represented by only one species. Species representing five families of beetles (Cephaloidae, Colydiidae, Pedilidae, Platypodidae, and Scolytidae) not previously recorded in the GRSM were identified. In addition, some 26 genera and 64 coleopteran species not previously recorded to the GRSM were identified (Table 7).

The most common species collected was *C. castaneus*, the Asiatic oak weevil, with 340 specimens. Adults were collected throughout the collection period with highest numbers obtained in August and September (Figure 3). *Arthromacra aenea* Say, the only species of Lagriidae collected, was the next most common beetle represented by 128 specimens. Two ground beetles, *Calathus gregarious* (Say) and *Platynus decentis* (Say), followed with 94 and 77 specimens, respectively.

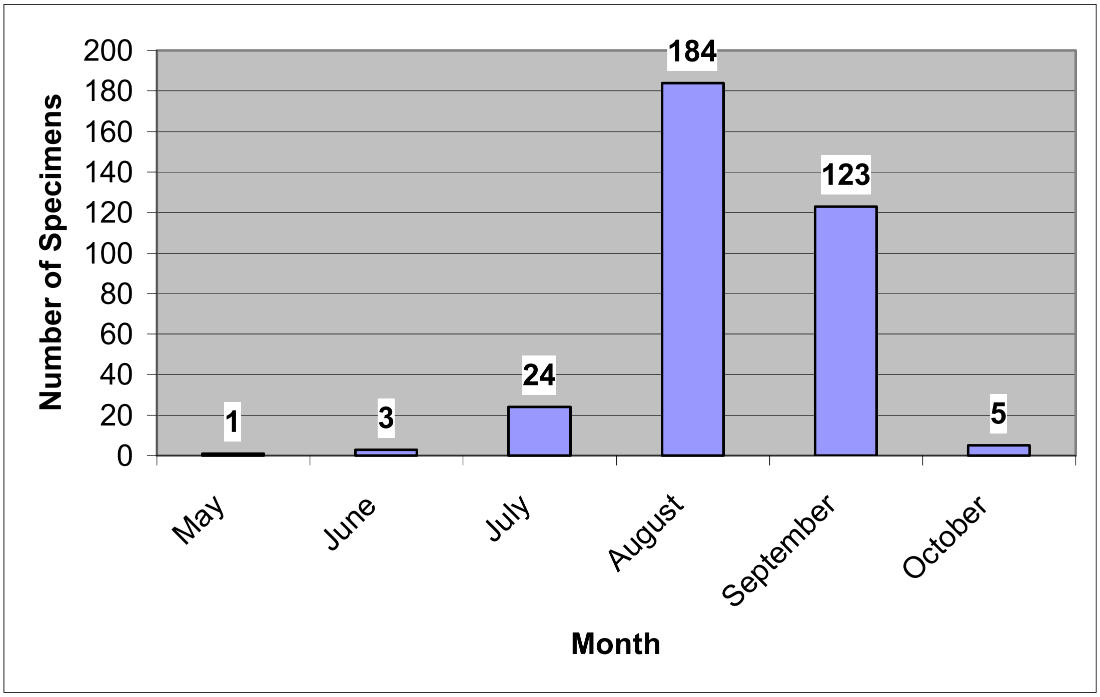

Figure 3. Distribution of Asiatic oak weevil*, C. castaneus*, from May to October collected from northern red oak in the Great Smoky Mountains National Park, 1992-95.

Significantly more (χ^2 =166.298, df = 2, P<0.005) beetles, represented by 153 species and 1,036 adult specimens (75.62%), are known as phytophagous (Table 8). Of the 153 phytophagous species identified, 69 species feed exclusively on the leaves and 27 are known primarily from oaks.

Eleven (5.47% of all GRSM beetle species) beetle pests of NRO represented by 403 (27.36%) specimens were collected from GRSM. The most threatening species to NRO was the Asiatic oak weevil. Specimens (340) were collected at all three sites with most being collected in August. Four other species of weevils were listed as potential pests of NRO including *Curculio sulcatulus* (Casey), a weevil that prefers to oviposit in NRO acorns, was collected at the Mount Sterling and Bee Tree sites. *Curculio*

Table 8. Number of coleopteran specimens grouped by feeding guild collected from northern red oak in the Great Smoky Mountains National Park, 1992-95.

Feeding Guild	Rich Mountain # Spp.	#S	%	Bee Tree # Spp.	#S	%	Mount Sterling # Spp.	#S	%
Phytophagous	94	571	80.08%*	68	294	73.87%*	46	235	64.38%*
Entomophagous	17	82	11.50%	15	101	25.38%	17	120	32.88%
Omnivorous	13	60	8.42%	2	3	0.75%	4	10	2.74%

 # Spp.- Number of species
#S- Number of specimens
%- Percentage of total specimens at each site
**-Indicates significant amount in total of phytophagous beetles* (χ^2 =166.298, df = 2, P<0.005)

proboscideus oviposits on over 20 species of oak and was found at all three sites, while *Curculio iowensis* (Casey) was found at the Bee Tree site. In addition, *Ithycerus noveboracensis* Forster, the New York weevil, a relatively large beetle, and was collected from the Rich Mountain and Mount Sterling sites.

Of the 82 specimens of Chrysomelidae represented by 23 species, the black locust leafminer, *Chalepus dorsalis* (Thunberg), was listed as a potential pest of oaks. Four specimens were found at the Bee Tree and Rich Mountain sites.

Of the Cerambycidae collected, four of 18 species are known to be pests of NRO. These include *Xestoleptyra octonota* (Say) collected at Bee Tree, *Microgoes oculatus* (LeConte) at Bee Tree, *Xylotrechus colonus* (F.) at Rich Mountain, and *Goes tigrinus* (Degeer) at Rich Mountain.

Another beetle considered to be a pest of oaks was *Arrhenodes minuta* (Drury), the oak timberworm. Six specimens were found at the Bee Tree and Rich Mountain sites. This species lays eggs in the bark of oaks and larvae tunnel into the softwood.

The significantly higher proportion of phytophagous beetles collected is similar to other coleopteran fogging studies (Davies *et al*. 1997 and Hammond *et al*. 1997). This high proportion is expected in a study of this nature because phytophagous insects are numerous in a forest ecosystem. Because such a broad interpretation of feeding guild was used to classify the species, it is difficult to extrapolate these results further. For example, many of the species in this study classified as "phytophagous" are fungivores who have no affiliation to the host tree. Guild assignment, although functional to a degree, is limited in providing substantial information (Hammond *et al*. 1997 and Hammond 1990).

Thirty-four species were known to be entomophagous because of their predatory habits. Sixteen species were scavengers of dead insects and rotting plant materials and thus omnivorous.

Allison *et al.* (1997) proposed that entomophagous insects would be expected to be represented by higher singletons than phytophagous counterparts due to host-plant affiliation. In other words, because predators are not dependant on specific plant associations, they would be expected to occur widely in the forest ecosystem. Exactly half of the entomophagous beetles collected in our study were singletons as compared to 46.10% of the phytophagous species. If only leaf-feeding species are examined, 45.59% of the leaf-feeders were singletons. These differences are not substantial enough to support this theory in the scope of this study.

The cerambycid, *Michthisoma heterodoxum* LeConte, is rarely collected (Yanega 1996). This ant-like long-horned beetle,collected at all three collection sites, is endemic in the Appalachian range, so its presence was not unexpected.

The species, *Prothalpia undata* LeConte (Melandryidae), has not been previously recorded in this region of the United States. This species is common in Canada, but its range extends throughout much of the eastern half of the country. The only source of distribution data on this species lists Ohio and Louisiana as the only areas in the United States where this beetle has been found (Downie and Arnett 1995). Two specimens were found at the Bee Tree site.

The highest number of Coleopteran specimens (713) and species (124) were located at the lowest elevation site, Rich Mountain. Bee Tree, the highest elevation site, had the next highest specimens (398) and species (85). The mid-elevation site, Mount Sterling, had the lowest specimens (365) and species (69) (Table 9). The dominance index was higher at Rich Mountain than the other sites due to the high abundance of the dominant species, *C. castaneus*.

Shannon-Weiner diversity index for families and species revealed the Bee Tree site to be the most diverse site. Interestingly, the most species rich site, Rich Mountain, had the lowest Shannon-Weiner index. The high proportion of *C. castaneus* at Rich Mountain influenced these indices ratings. The high dominance index at Rich Mountain is an indicator of the influence of this species on the abundance of beetle specimens.

Table 9. Measures of Diversity for beetle families and species collected from Northern Red Oak at three sites in the Great Smoky Mountains National Park, 1992-95.

Measure	**Bee Tree**	**Mount Sterling**	**Rich Mountain**
Number of Specimens	398.00	365.00	713.00
Number of Families	32.00	31.00	30.00
Shannon-Weiner Index-Families	2.75	2.44	2.33
B-P Dominance Index-Families	0.22	0.28	0.44
Evenness-Families	0.79	0.71	0.68
Number of Species	85.00	69.00	124.00
Shannon-Weiner Index-Species	3.70	3.23	3.04
B-P Dominance Index-Species	0.12	0.18	0.41
Evenness-Species	0.83	0.77	0.63

Analysis of the data derived from geographical map software revealed subtle differences in geology, disturbance history, and predominant vegetation among sites that could influence macro-environmental factors affecting species diversity and abundance. The Rich Mountain site, with a cades sandstone underlayer, was slightly different than the other two sites containing thunderhead sandstone. However, cades sandstone is similar to thunderhead sandstone with the main difference being slightly more conglomerate beds of metagranite in cades sandstone; thunderhead sandstone has slightly more quartz conglomerate beds (USGS 2002). Because all three sites had a sandstone-derived layer as its main component, little differences in floral and faunal composition attributed to geology would be expected.

Each site had distinctly different disturbance histories ranging from light commercial cutting to an undisturbed classification. Because the type or number of trees removed is unknown, it is difficult to quantify this difference. However, an undisturbed site would provide a more stable environment for specific fauna than a disturbed site. Disturbed sites should have higher levels of mixed succession flora in an amount correlated to the amount and degree of disturbance. This could also influence the amount of available niches for fauna to occupy. Because Rich Mountain has a history of light commercial cutting, more understory and lower succession tree growth would be expected at this site due to disturbances. This could account for the higher amount of species and specimens found at that site.

Vegetation types also were slightly different among sites. The cove hardwood type is considered the GRSM's most diverse ecosystem with large trees, warm temperatures, long growing season, and high amounts of precipitation (GRSM 2002). Mixed mesic forests also are considered diverse in terms of fauna mixing many species of other forest types but have lower environmental conditions (i.e.- temperature, precipitation, and growing season) than the cove hardwood forest type. The Bee Tree site, classified as a cove hardwood forest, had a higher Shannon index representing higher species diversity than the other two sites. This higher index value could be attributed to the site lying in a cove hardwood forest.

Collection information for each site was extrapolated to 75 samples to estimate the maximum number of species (Smax) present at each location. For the Rich Mountain site, Smax was 189.86, the Bee Tree and Mount Sterling sites were estimated to contain 116.90 and 110.52 species, respectively (Figures 4, 5, and 6). These theoretical values for Smax predict numbers of species that could be expected at the three sites, if more sampling was conducted. Sampling done at different times (i.e.- nocturnal or crepuscular) would probably yield different species but consistent collections at these times is not practical. Another alternative to this would be the utilization of different collection methods.

UT Arboretum Specimen Collection Data

Exactly 1,847 adult specimens were collected from the arboretum in only six sampling dates. This number is higher than the 1993 GRSM collection, which had 24 sampling dates, by 279 specimens. The arboretum trees are, however, surrounded by a

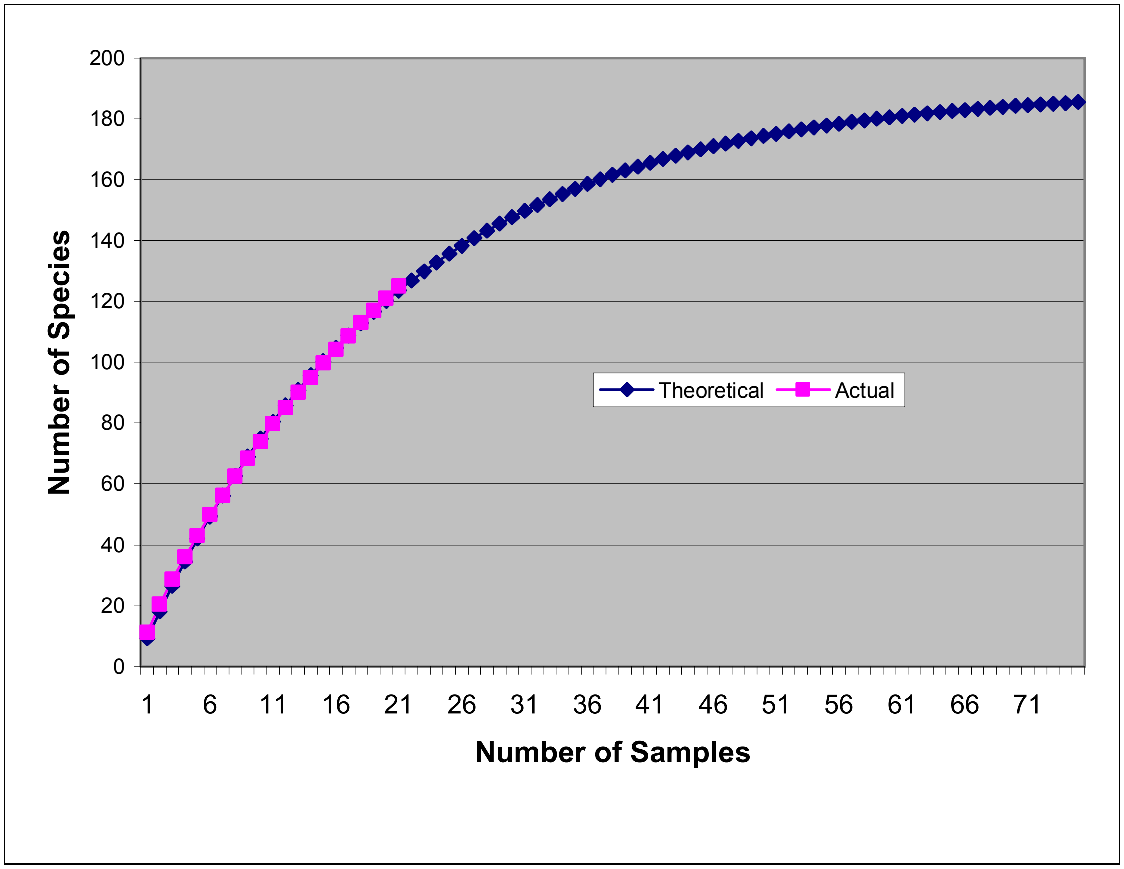

Figure 4. Theoretical and actual species accumulation curves for beetle species collected from northern red oak at Rich Mountain site *(Extrapolated Species Accumulation Curve Using Exponential: Smax(1-e(-kx)) Smax:189.86 k:0.050123 Pearsons Correlation* ^{2} *:0.99935).*

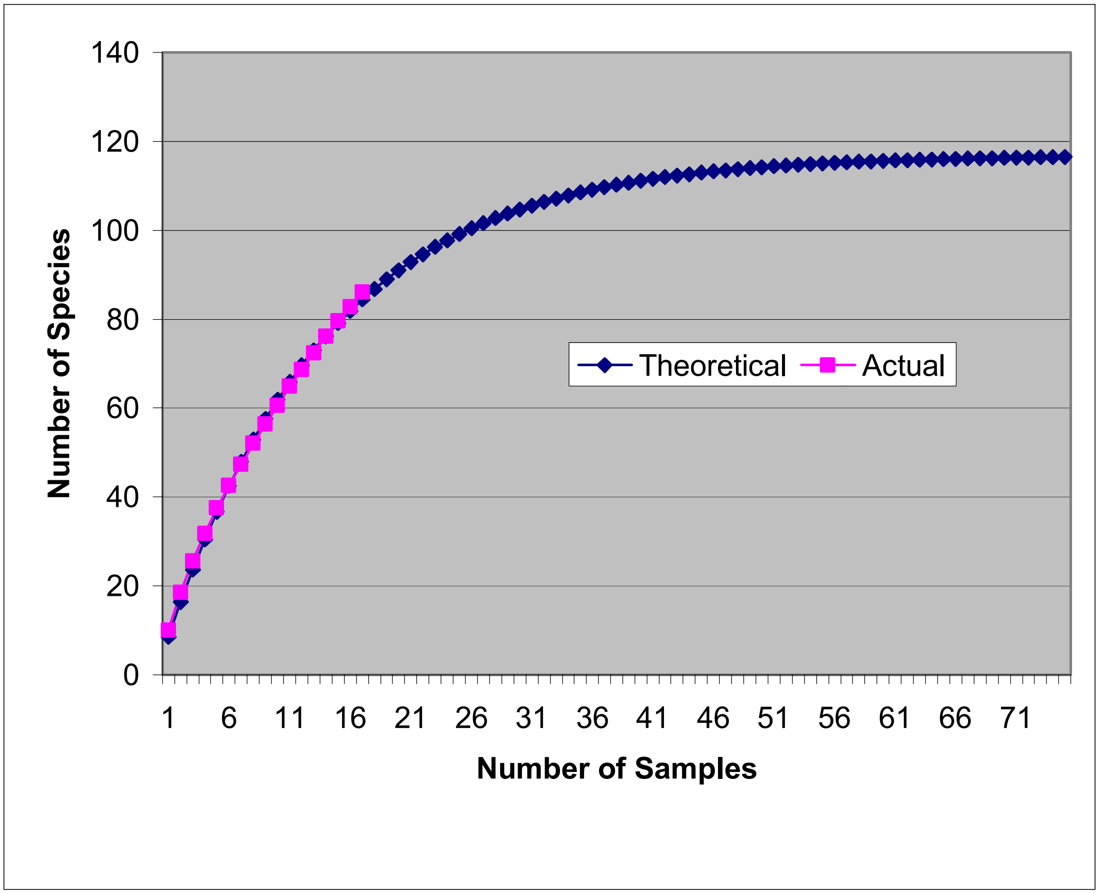

Figure 5. Theoretical and actual species accumulation curves for beetle species collected from northern red oak at Bee Tree site *(Extrapolated Species Accumulation* Curve Using Exponential: Smax(1-e(-kx)) Smax:116.9 k:0.075349 Pearsons Correlation ^{2}:0.9981).

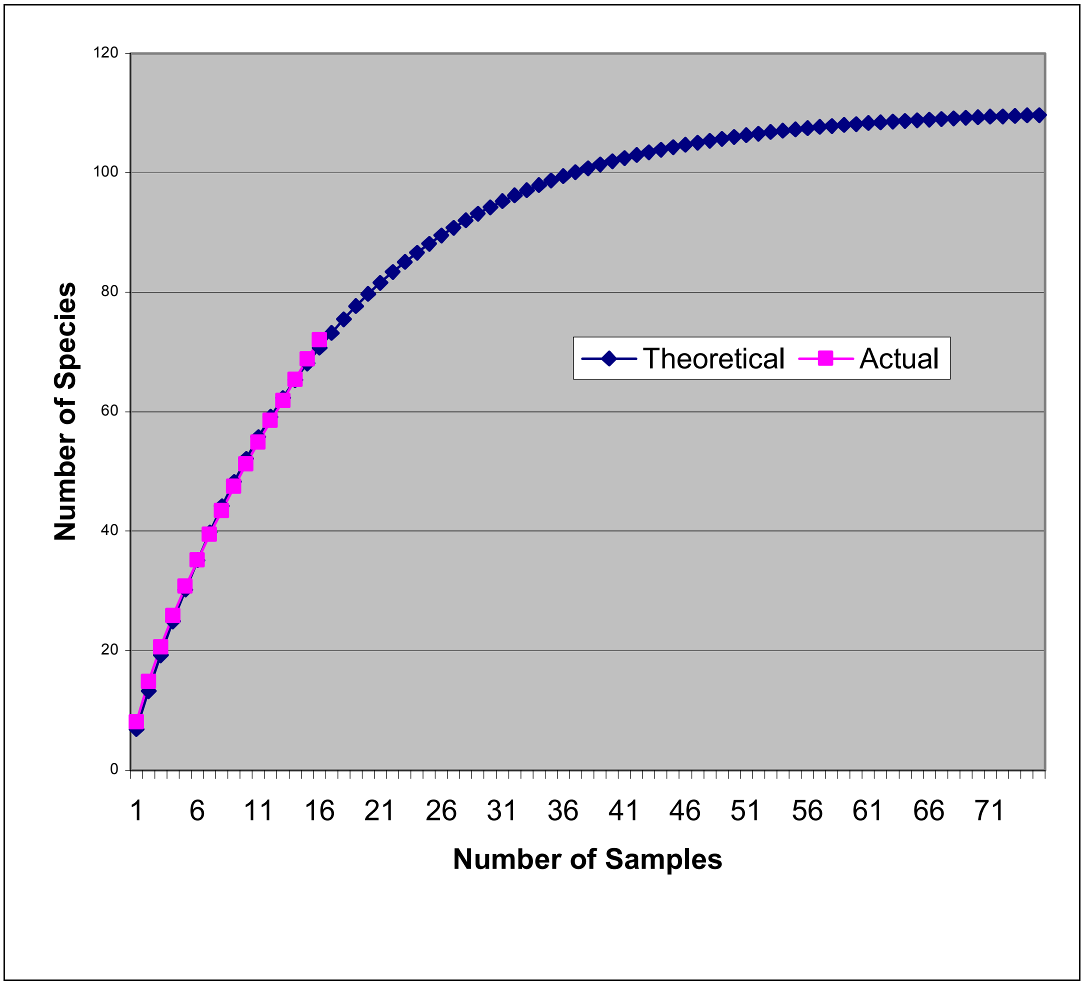

Figure 6. Theoretical and actual species accumulation curves for beetle species collected from northern red oak at Mount Sterling site *(Extrapolated Species* Accumulation Curve Using Exponential: Smax(1-e(-kx)) Smax:110.52 k:0.063777 Pearsons Correlation ^{2}:0.99845).

rich forest with many different understory plant species. Thus, the mature NRO stands in the GRSM have less vegetative "noise" around them that attract "tourist" insects to NRO.

The most specimens were collected in May and the lowest in October (Figure 7). The 1,847 adult specimens were arranged into 11 orders. The most specimen rich order was Hymenoptera followed by Coleoptera, Diptera, and Homoptera (Table 10). The other insects (ca. 15.40%) belonged to Lepidoptera, Psocoptera, Thysanoptera, Orthoptera, Blattaria, and Neuroptera. An additional 337 immature specimens also were collected representing five orders. Lepidopteran specimens accounted for approximately 88.98% of these specimens.

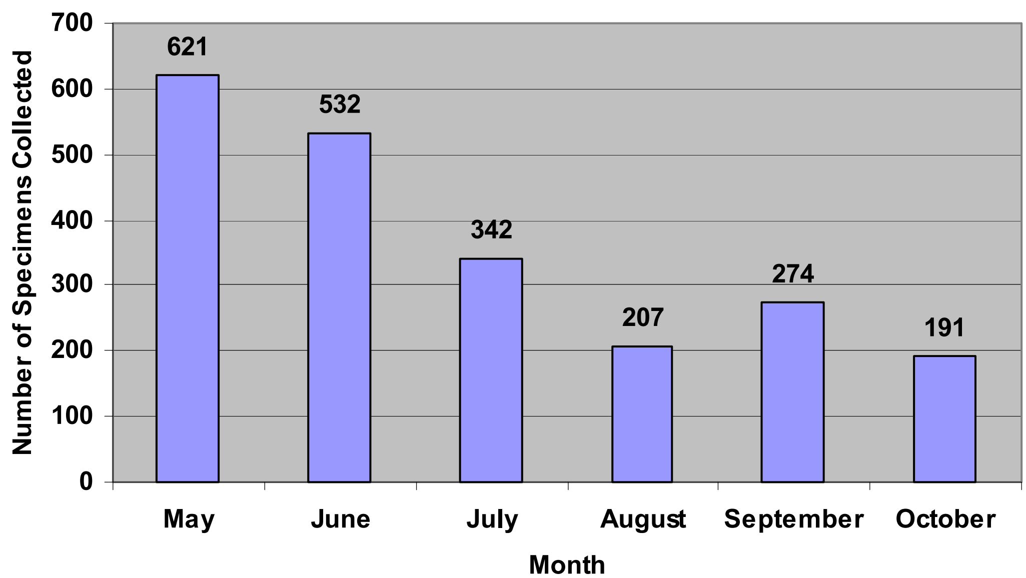

Figure 7. Specimen counts per collection date from northern red oak in The University of Tennessee Arboretum, 2001.

Table 10. Adult specimen counts per order collected from northern red oak at The University of Tennessee Arboretum, 2001.

Order	**Specimens**
Blattaria	11
Coleoptera	524
Diptera	305
Hemiptera	69
Homoptera	250
Hymenoptera	565
Lepidoptera	39
Neuroptera	2
Orthoptera	16
Psocoptera	38
Thysanoptera	28
TOTAL	**1,847**

The 1,323 non-coleopteran specimens were classified into 44 families. Membracidae and Formicidae were the most specimen rich families accounting for 32.88% of non-coleopteran insects collected. Diptera was the most family rich order with 16 families.

Three-hundred, forty-three (25.93%) of the non-coleopteran specimens were identified to 25 species (Appendix E). The membracid, *Ophiderma salamandra* Fairmaire, was the most prevalent with 177 specimens followed by 28 specimens of the thysanopteran *Leptothrips mali* Fitch. An additional 117 specimens were identified to 16 genera and are listed in Appendix F.

Beetle data from the arboretum, although not comparable statistically to the GRSM collections, were similar in that *C. castaneus* was the most abundant beetle species found. Eighty-four specimens of this beetle were collected during the sampling period.

Some 524 beetle specimens, representing 26 families, were collected on six sampling dates. Four families (Aderidae, Mylabridae, Lampyridae, and Throscidae) collected in the arboretum were not found in the GRSM collections. The most specimen rich families were Chrysomelidae, Curculionidae and Coccinellidae (Table 11). Five families were each represented by a single specimen. The most species diverse families were Chrysomelidae and Cleridae, both with nine species. Lycidae and Curculionidae followed with eight and seven species, respectively.

Excluding six Staphylinidae and seven female Lycidae specimens, 97.51% of the beetles were identified to 47 genera and 87 species (Table 12). The most common species collected was *C. castaneus* with 84 specimens, which represents a dominant species index of 16.20. *Harmonia axyridas* Pallas was the next most common species with 70 specimens. Twelve species were listed as common oak affiliates in their species notes. Thirty-five species (41.17%) were singletons and 11 (12.94%) were doubletons. Fifty-five species, represented by 247 specimens, were not found during the GRSM NRO collection.

Sixty-two species (71.26%), represented by 362 (69.08%) specimens were phytophagous as adults. *C. castaneus* was the dominant phytophagous insect. Nineteen species (21.83%), represented by 143 specimens were entomophagous. *H. axyridas* was the dominant species of predator. Six species, represented by 19 specimens were scavengers.

Table 11. Families of Coleoptera collected from northern red oak in The University of Tennessee Arboretum, 2001.

Family	Common Name	Abundance	
		Specimens	Species
Aderidae*	Ant-like leaf beetles	14	2
Alleculidae	Comb-clawed bark beetles	43	3
Anthribidae	Fungus weevils	1	1
Buprestidae	Metallic wood-boring beetles	16	7
Cantharidae	Soldier beetles	2	1
Carabidae	Ground beetles	1	1
Cerambycidae	Longed-horn beetles	12	3
Chrysomelidae	Leaf beetles	107	10
Cleridae	Checkered beetles	32	9
Coccinellidae	Ladybird beetles	87	5
Colydiidae	Cylindrical bark beetles	3	1
Curculionidae	Weevils	99	7
Elateridae	Click beetles	4	3
Endomychidae	Handsome fungus beetles	2	2
Lagriidae	Long-jointed beetles	7	2
Lampyridae*	Firefly Beetles	13	2
Lycidae	Net-winged beetles	19	8
Melandryidae	False-darkling beetles	1	1
Mordellidae	Tumbling flower beetles	1	1
Mylabridae*	Pea and bean weevils	4	1
Nitidulidae	Sap-feeding beetles	3	3
Ptilodactylidae	Toed-winged beetles	1	1
Scarabaeidae	Lamellicorn beetles	16	4
Staphylinidae	Rove beetles	11	2
Tenebrionidae	Darkling beetles	19	6
Throscidae*	False metallic wood-boring beetles	7	1
TOTALS		**524**	**87**

**- Indicates family not found in Great Smoky Mountain National park collection, 1992-95.*

Table 12. Species of Coleoptera collected in The University of Tennessee Arboretum, from northern red oak, 2001.

Family	Species	Abundance
Aderidae	*Zonantes subfasciatus* (LeConte)*	10
	Emerlinus melsheimeri (LeConte)*	4
Alleculidae	*Isomira quadrisriata* Couper	36
	Mycetochara foveata (LeConte)	2
	Isomira sericea (Say)	5
Anthribidae	*Toxonotus cornutus* (LeConte)*	1
Buprestidae	*Chrysobothris rugosiceps* Melsheimer	1
	Chrysobothris sexsignata (Say)	2
	Chrysobothris femorata (Olivier)	3
	Agrilus egenus Gory*	6
	Brachys aerosus Melsheimer*	2
	Agrilus bilineatus (Weber)*	1
	Agrilus fallax Gory*	1
Cantharidae	*Tytthonyx erythrocephalus* (F.)*	2
Carabidae	*Bembidion nigrum* Say*	1
Cerambycidae	*Urgleptes querci* (Fitch)	3
	Urographis fasciatus (Degeer)	8
	Cyrtophorus verrucosus (Olivier)*	1
Chrysomelidae	*Odontota dorsalis* Thunberg	6
	Diabrotica undecimpunctata howardi Barber	1
	Pachybrachis pectoralis (Melshiemer)*	37
	Paria fragariae Wilcox*	20
	Demotina modestus (Lewis)*	18
	Cryptocephalus quadruplex Newman*	18
	Colaspis brunnea (F.)*	3
	*Tymnes metasternalis Crotch**	2
	Gastrophysa cyanea Melsheimer*	1
	Luperaltica senilis (Say)*	1
Cleridae	*Phyllobaenus pallipennis* (Say)	4
	Cymatodera bicolor (Say)	1
	Phyllobaenus verticalis (Say)	3
	Phyllobaenus humeralis (Say)*	13
	Thanasimus dubius (F.)*	4
	Placopterus thoracicus (Olivier)*	3
	Isohydnocera curtipennis (Newman)*	2
	Priocera castanea Newman*	1
	Cymatodera undulata (Say)*	1
Coccinellidae	*Psyllobora vigintimaculata* (Say)	5
	Harmonia axyridas (Pallas)	70
	Chilocorus stigma (Say)*	7
	Scymnus puncticollis LeConte*	3
	Scymus germinata (Say)*	1
	Hyperaspis signata Olivier*	1
Colydiidae	*Namunaria guttulata* (LeConte)*	3
Curculionidae	*Cyrtepistomus castaneus* (Roelofs)	84
	Curculio proboscideus F.	2
	Conotrachelus posticatus Boheman	9
	Curculio iowensis (Casey)	1

Table 12 (cont.). Species of Coleoptera collected in The University of Tennessee Arboretum, from northern red oak, 2001.

Family	Species	Abundance
	Conotrachelus anaglypticus (Say)	1
	Eugnamptus collaris (F.)*	1
	Odontocorynus scutellum-album (Say)*	1
Elateridae	*Melanotus americanus* (Herbst)	1
	Ampedus luctuosus (LeConte)	2
	Dalopius lateralis Eschscholtz*	1
Endomychidae	*Phymaphora pulchella* Newman	1
	Bystus ulkei (Crotch)*	1
Lagriidae	*Arthromacra aenea* Say	6
	Arthromacra lengi Parsons*	1
Lampyridae	*Photinus marginellus* LeConte*	12
	Pyractomena marginalis Green*	1
Lycidae	*Plateros sp.* female*	5
	Plateros batillifer Green*	3
	Calopteron discrepans (Newman)*	3
	Calopteron reticulatum (F.)*	3
	Eropterus female*	2
	Caenia dimidiata (F.)*	1
	Plateros flavoscoellatus Blatchley*	1
	Eropterus trilineatus Melsheimer*	1
Melandryidae	*Orchesia cultriformis* Laliberte*	1
Mordellidae	*Mordellistena pubescens* (F.)	1
Mylabridae	*Gibbobruchus mimus* (Say)*	4
Nitidulidae	*Stelidota germinata* (Say)	1
	Amphicrossus ciliatus (Olivier)*	1
	Stelidota octomaculata (Say)*	1
Ptilodactylidae	*Ptilodactula serricollis* Say	1
Scarabaeidae	*Popillia japonica* Newman*	12
	Canthon hudsonias Forester*	2
	Anomala marginata (F.)*	1
	Onthophagus pennsylvanicus Harold*	1
Staphylinidae	Unidentified Staphylinidae	6
	Paliminus hudsonicus Casey*	5
Tenebrionidae	*Tarpela micans* (F.)	5
	Meracantha contracta (Beauvois)	1
	Platydema subcostatum Laporte and Brulle'	2
	Platydema teleops Triplehorn	3
	Platydema excavatum (Say)*	5
	Platydema laevipes Haldeman*	3
Throscidae	*Drapetes quadripustlatus* Bonvouloir*	7
TOTAL		**524**

**-Indicates species not found in the Smoky Mountain red oak collection 1992-95.*

CHAPTER IV
CONCLUSIONS

Insects are the most prolific and ubiquitous group of animals on this planet and there are more known species of insects than all other known organisms. Because of the sheer size and diversity of this group, much remains unknown about their biology, taxonomy, role in the environment, and current status. The largest order of insects, Coloeptera, contains many pestiferous and beneficial species to forest ecosystems.

Northern red oaks are valuable trees in the eastern United States in terms of economics, aesthetics, and the environment. Many forest organisms depend on these trees for food and shelter and humans utilize these trees in a variety of ways. However, the increased development of America's forest areas, coupled with exotic species introduction and disease pathogens, threaten current northern red oak forests.

Because of the interwoven nature of arboreal coleopteran communities and importance of biodiversity to the health of natural systems, information concerning the current status of these systems is vital for land management decisions. However, a paucity of research data exists concerning beetle relationships to northern red oak trees. For this reason, an insect diversity study was initiated in 1992. 30 trees were selected in the GRSM at three sites and one tree per site was sampled every two weeks from May to October 1992-1995 using the fogging method. An additional collection took place at the UT arboretum in 2001 where, of three test trees, one tree was sampled monthly. The objectives of this study were to document the coleopteran diversity of the GRSM and UT arboretum's northern red oak canopy, identify any pest beetle species, and determine the feeding guild structure of the coleopteran community present.

Of the 11,167 adult insects collected from the GRSM and UT Arboretum, 2,270 were beetles. Fifty beetle families were recorded and represent a diverse, well-established community within the northern red oak tree canopies of these sites. The most species diverse families were Curculionidae, Chrysomelidae, Cerambycidae, Elateridae, Tenebrionidae, and Alleculidae.

Two hundred, fifty-eight beetle species were identified in this study. Just over 5.45% of these beetle species are considered pests of northern red oaks and were represented by 495 specimens.

The most commonly collected species, the Asiatic oak weevil, is considered to be a pest of northern red oak and was represented by 424 specimens. This species was found at all collection sites with most being collected in August.

Approximately 75% of the beetle specimens and species collected at the four sites were phytophagous. Roughly 20% were entomophagous with the rest being omnivorous. The high numbers of plant feeding beetles shows a strong relationship to the forest ecosystem and associated beetle communities within the canopy.

Administrators of forests containing NRO stands could use this information in making land-management decisions such as seedling planting and timber harvesting. In addition, due to the threat of invasive species activity, this study provides an important baseline of the arthropod faunal composition found on mature NRO before impending disturbances alter species composition.

References

Abrams, M. D. 1990. Adaptations and responses to drought in *Quercus* species of North America. Tree Physiol. 7:29-37.

Allison, A., G. A. Samuelson, and S. E. Miller. 1993. Patterns of beetle species diversity in *Castanopis acuminatissima* (Fagacea) trees studied with canopy fogging in mid-montane New Guinea rainforest. In: Stork, N. E., J. Adis, and R. K. Didham (eds.). 1997. Canopy arthropods. Chapman and Hall. London. 184-223.

Arnett Jr., R. H. 2000. American insects: A handbook of the insects of America north of Mexico (2nd ed.). Boca Raton: CRC Press. 1024pp.

Auchmoody, L. R. and H. C. Smith. 1993. Survival of northern red oak acorns after fall burning. NE For. Exp. Stn. USDA For. Serv. No. NE-678:5.

Auchmoody, L. R., H. C. Smith, and R.S. Walters. 1994. Planting northern red oak acorns: is size and planting depth important? NE For. Exp. Stn. USDA For. Serv. No.NE-693:5.

Baker, W. L. 1941. Effect of gypsy moth defoliation on certain forest trees. J. For. 39:1017-1022.

Baker, W. L. 1972. Eastern forest insects. Washington, DC. USDA Misc. Publ. 1175. 642pp.

Barbosa, P. 1978. Distribution of endemic larval gypsy moth population among various tree species. Environ. Entomol. 7:526-527.

Barbosa, P. and J. L. Capinera. 1977. The influence of food on developmental characteristics of the gypsy moth. Can. J. Zool. 55:1424-1429.

Basset, Y. and R. L. Kitching. 1991. Species number, species abundance, and body length of arboreal arthropods associated with an Australian rainforest tree. Ecol. Entomol. 16:391-402.

Basset, Y., N. D. Springate, H. P. Aberlenc, and G. Delvare. 1997. A review of methods for sampling arthropods in tree canopies. In: Stork, N. E., J. Adis, and R. K. Didham (eds.). 1997. Canopy arthropods. Chapman and Hall. London. 27-52.

Beckwith, R. C. 1963. An oak leaf tier, *Croesia semipurpurana* in Connecticut. Ann. Entomol. Soc. Am. 56:741-744.

Bennett. H. D. 1971. Past, present, and potential products from oak. In Proc. Oak Symposium; 1971 Aug 16-20; Morgantown, WV. Upper Darby, PA: USDA For. Serv., NE For. Exp. Stn. p.90-93.

Bergeron, J. M., R. Goulet, and V. Gonzalez. 1998. The use of coniferous seedlings as alternative food to protect red oak from vole girdling. Scand. J. For. Res. 13:50-53.

Berry, F. H. 1978. Decay associated with wounds in living oaks. Washington, D.C. USDA For. Res. Note NE-268:2.

Bonner, F. T. and J. A. Vozz. 1987. Seed biology and technology of *Quercus*. Washington, D.C. USDA For. Serv. Gen. Tech. Rep. SO-66:21.

Briggs, J. M. and K.G. Smith. 1989. Influence of habitat on acorn selection by *Peromyscus leucopus*. J. Mammal. 70:35-43.

Brothers, T. S. 1988. Indiana surface-mine forests: historical development and composition of a human-created vegetation complex. Southeastern Geographer. 28:19-33.

Brown, J. H., V. B. Cruickshank, W. P. Gould, and T. P. Husband. 1988. Impact of gypsy moth defoliation in stands containing white pine. Northern J. Appl. For. 5:108-111.

Bryan, W. C. 1960. Losses from defect in Piedmont hardwoods. Washington, D.C. USDA For. Serv. C.J. For. Exp. Sta. Tech. Paper. 148:14.

Carey, A. B. and J. D. Gill. 1980. Firewood and wildlife. Broomall, PA. USDA For. Serv. NE For. Exp. Stn. Res. Note. 299:5.

Clark, F. B. and R. F. Watt. 1971. Silvicultural methods for regenerating oaks. In: Proc. Oak Symposium. 1971. Aug 16-20; Morgantown, WV. Upper Darby, PA. USDA For. Serv., NE For. Exp. Stn. 37-43.

Cole Jr., A. C. 1940. A guide to the ants of the Great Smoky Mountains National Park, Tennessee. Amer. Midland Nat. 24:1-88.

Core, E. L. 1971. Silvical characteristics of the five upland oaks. In: Proc. Oak Symposium. 1971. Aug 16-20; Morgantown, WV. Upper Darby, PA. USDA For. Serv., NE For. Exp. Stn. 19-22.

Davies, J. G., N. E. Stork, M. J. D. Brendell, and S. J Hine. 1997. Beetle species diversity and faunal similarity in Venezuelan rainforest tree canopies. In: Stork, N. E., J. Adis, and R. K. Didham (eds.). 1997. Canopy arthropods. Chapman and Hall. London. 85-104.

Donley, D. E. 1978. Oviposition by the red oak borer. Ann. Entomol. Soc. Am. 65:1243-1244.

Downie, N. M. and R. H. Arnett, Jr. 1996. The beetles of Northeastern North America, Vols. I & II. Sandhill Crane Press, Gainsville, FL. 1721pp.

Duncan, W. H. and M. B. Duncan. 1988. Trees of the southeastern United States. The Univ. of GA Press, Athens, GA. 322pp.

DuMerle, P. and M. Attie. 1992. *Corebus undatus* (Coleoptera: Buprestidae) on core oak forests in Southeastern France: an estimate of damage and its relationship to environmental factors. *Annales des Sciences Foirestieres*. 49:571-588.

Ehler, L. E. 1997. Obscure scale declines after parasitic wasp introduced. CA. Agric. 51:29-32.

Elowe, K. D. and W. E. Dodge. 1989. Factors affecting black bear reproductive success and cub survival. J. Wildlife Manage. 53:962-968.

Embree, D. G., A. G. Raske, and B. E. Wickman. 1991. The winter moth *Operophtera brumata* in eastern Canada. In: *Towards integrated pest management of forest defoliators* Proc. 18th Inter'l. Congress of Entomol., 1988. Vancouver, Can. 47-54.

Erwin, T.L. 1991. How many species are there? Revisited. Conser. Biol. 5:330-333.

Evans, D. 1959. Notes on the biology of the Asiatic oak weevil in Maryland. J. Econ. Entomol. 52:177.

Eyre, F. H. 1980. Forest cover types of the United States and Canada. Washington, DC. Soc. of Am. For. 148pp.

Fajvan, M. A. and J. M. Wood. 1997. Stand structure and development after gypsy moth defoliation in the Appalachian Plateau. For. Entomol. and Mgmt. 89:79-88.

Ferguson, C. S., M. J. Linit, and G. Krause. 1991. Host-plant preferences of the Asiatic oak weevil (Coleoptera: Curculionidae). Environ. Entomol. 20:1427-1432.

Fisher, B. L. 1996. Ant diversity patterns along an elevational gradient in the Reserve Naturelle Integrale d' Andringitra, Madagascar. Fieldiana-Zool. 0:93-108.

Galford, J. and D. Cotrill-Weiss. 1991. Responses of insects to damaged and undamaged germinating acorns. NE USDA For. Serv. Exp. Stn. Publ. *The Station* :6

Gibson, L. P. 1982. Insects that damage northern red oak acorns. Washington, D.C. USDA For. Serv. Res. Paper. NE-220:7.

Godfrey, R. K. 1988. Trees, shrubs, and woody vines of northern Florida, adjacent Georgia, and Alabama. The Univ. of GA Press. Athens, GA. 734pp.

Gorman, O. T. and R. R. Roth. 1989. Consequences of a temporally and spatially variable food supply for an unexploited gray squirrel (*Sciurus carolinensis*) population. Am. Midland Natur. 121:41-60.

Gribko, L. S., K. W. Gottschalk, and S. L. C. Fosbroke. 1995. The effect of acorn insects on the establishment and vigor of northern red oak seedlings in north-central WV. In: Proc. 10th Central Hardwood For. Conference; 5-8 March 1995; Morgantown, WV. Gen. Tech. Rep. NE For. Exp. Stn. USDA For. Serv. No NE 197:430-441.

Gribko, L. S. and W. E. Jones. 1995. Test of the float method of assessing northern red oak acorn condition. Tree Planters' Notes. 46:143-147

GRSM. 2002. Great Smoky Mountains flora and fauna. GRSM. Accessed August 4, 2002. http://www.nps.gov/grsm/gsmsite/natureinfo.html.

Hammond, P. M. 1990. Insect abundance and diversity in the Dumoga_Bone National Park, N. Sulawesi, with special reference to the beetle fauna of lowland rain forest in the Toraut region. In: Knight, W.J. and J. D. Holloway (eds.). 1990. Insects and the rain forests of South East Asia (Wallacea). Royal Entomol. Soc. London. 197-254.

Hammond, P. M., N. E. Stork, and M. J. D. Brendall. 1997. Tree crown beetles in context: a comparison of canopy and other ecotone assemblages in a lowland tropical forest in Sulawesi. In: Stork, N. E., J. Adis, and R. K. Didham (eds.). 1997. Canopy arthropods. Chapman and Hall. London. 184-223.

Hay, C. J. 1972. Woodpecker predation on red oak borer in black, scarlet, and northern red oak. Ann. Entomol. Soc. Am. 71:1421-1423.

Hefler, J. R. 1953. How to know the grasshoppers, cockcroaches [sic] and their allies; pictured-keys for identifying many of the grasshoppers, crickets, Katydids, earwigs, termites, cockroaches, praying mantids, rock-crawlers, and walkingsticks occuring in North America north of Mexico. W. C. Brown Co. Dubuque, IA. 353pp.

Hosie, R. C. 1969. Native trees of Canada. 7th ed. Ottawa, ON: Can. For. Serv., Dept. of Fish. and For. 380pp.

Huntly, N. and R. Inouye. 1988. Pocket gophers in ecosystems: patterns and mechanisms. BioScience. 38:786-793.

Jakus, R. 1995. Bark beetle communities and host and site factors on tree level in Norway spruce primeval natural forests. J. Applied Entomol. 119: 643-651.

Johnson, W. T. and H. H. Lyon. 1991. Insects that Feed on Trees and Shrubs, 2nd ed. rev. Cornell Univ. Press. Ithaca, NY. 560pp.

Johnson, W. C., L. Thomas, and C. S. Adkisson. 1993. Dietary circumvention of acorn tannins by blue jays. Implications for oak demography. Oecologia. 94:159-164.

Kasbohm, J. W., M. R. Vaughan, and J. G. Kraus. 1996. Black bear denning during a gypsy moth infestation. Wildlife Soc. Bull. 24:62-70.

Kelbel, P. 1996. Damage to acorns by insects in Slovakia. Biologia-Bratslava. 51:575-582.

Kegg, J. D. 1970. New Jersey For. Pest Reporter. NJ Dept. Agric. Trenton, NJ:2.

Kelty, M. J. 1989. Productivity of New England Hemlock/ hardwood stands as affected by species composition and canopy structure. For. Ecol. and Mgmt. 28:237-257.

Kittredge, D. B. and P. M. S. Ashton. 1995. Impact of deer browsing on regeneration in mixed stands in southern New England. Northern J. Appl. For. 12:115-120.

Kulfan, M., L. Septak, and P. Degma. 1997. Lepidotera larvae communities in S.W. Slovakia. Conf. Insects and Envir., Zvolen, Slovakia, 5-6 September, 1995. Biolga-Bratislava. 52:247-252.

LaForest, J. 2000. Insects associated with yellow-poplar (*Liriodendron tulipifera* L.) in eastern Tennessee. MS Thesis. Univ. of Tenn., Knoxville. 110pp.

Lewis, A. R. 1982. Selection of nuts by gray squirrels and optimal foraging theory. Amer. Midland Nat. 107:250-257.

Limstrom, G. A. and R. W. Merz. 1949. Rehabilitation of lands stripped for coal in Ohio. Columbus, OH: OH Reclamation Association. In cooperation with: USDA, For. Serv., Cent. States For. Exp.Stn. Tech. Paper No. 113:41.

Linit, M. J., P. S. Johnson, R.A. McKinney, and W. H. Keraby. 1986. Insects and leaf area losses of planted northern red oak seedlings in an Ozark forest. For. Sci. 32:11-20.

Little, E. L. 1979. Checklist of United States trees (native and naturalized). Washington, DC. USDA, For. Serv. Agric. Handb. 541:375pp.

Little, E. L. 1980. Audubon society field guide to North American trees (Eastern Region). Alfred A. Knopf Publ., NY. 407pp.

Loranger, G., I. Bandyopadhyaya, B. Razaka, and J. F. Ponge. 2001. Does soil acidity explain altitudinal sequences in collembolan communities? Soil Bio. & BioChem. 33:381-393.

Louisiana State Arthropod Museum. 2002. All taxa biodiversity inventory beetle species results. Accessed June 18 2002. http://www.agctr.lsu.edu/Inst/Research/Departments/arthropodmuseum/smokybeetles.htm

Magurran, A. E. 1988. Ecological diversity and its measurement. Princeton Univ. Press. Princeton, NJ. 179pp.

Martin, A. C., S. N. Zim, and L. Arnold. 1951. American wildlife and plants. McGraw-Hill, NY. 500pp.

McCasland, C. 1993. Larval lepidopteran tree use in bottomland hardwood forests: preliminary results. Firefly 8:6.

McGavin, G. 2001. Essential entomology: an order-by-order introduction. Oxford Univ. Press, Oxford. 318pp.

Morse, D. R., N. E. Stork, and J. H. Lawton. 1988. Species number, species abundance, and body length relationships of arboreal beetles in Bornean lowland rainforest trees. Ecol. Entomol. 13:25-37.

Mullis, S. 2001. Oak trees are good choices for the yard. Augusta Chronicle. Sept. 28, 2001. Augusta, GA.

Myers, R. K., B. C. Fischer, and G. M. Wright. 1989. Survival and development of underplanted northern red oak seedlings: 6-year results. In: Rink, G. and C.A. Budelsky. eds. Proc. 7th central hardwood conf. 1989 March 5 -8. Carbondale, IL. St. Paul, MN: USDA Gen.Tech. Rep. NC-132.For. Serv., N. Cent. For. Exp. Stn. 150-155.

National Arbor Day Foundation. 2002. State trees of the United States. Accessed January 15, 2002. http://www.arbordayfoundation.com/arborday/arbordaydates.html.

Nesael, D., F. Dikschen, and M. A. Altieri. 1994. Seasonal and spatial population loads of a tropical insect: The case of the coffee leaf-miner in Mexico. Ecol. Entomol. 19:159-167.

Nomina Insecta Nearctica. 2002. A checklist of the insects of North America. Visited April 8, 2002. http://www.nearctica.com/nathist/insects/insect.htm

Novotny, V. 1993. Spatial and temporal components of species diversity in Auchenorryncha (Insecta: Hemiptera) communities of Indochinese montane rainforest. J. Trop. Ecol. 9:93-100.

Odegaard, F. 2001. How many species of arthropods? Erwin's estimate revised. Biol. J. Linnean Soc. 71:583-597.

Ohio State University. 2002. *Quercus rubra*. Accessed January 20, 2001 http://www.hcs.ohiostate.edu/hcs/TMI/Plantlist/qu_rubra.html

Patti, I. and G. C. Lozzia. 1994. The presence in Italy of the Nearctic aphid of red oak, *Myzocallis walshii* (Mon.). *Bollettino di Zoologia Agaria e di Bachicoltura*. 26:141-145.

Peine, J. 1989. Visitor use patterns at Great Smoky Mountains National Park. Atlanta, GA. U.S. Dept.of the Interior, Natl. Park Serv., SE Region. 93pp.

Perkins, P. J. and W. W. Mautz. 1988. Digestibility and nutritional value of autumn diets of deer. J. Wildlife Manage. 52:328-332.

Plucinski, K. E. and M. L. Hunter. 2001. Spatial and temporal patterns of seed predation on three tree species in an oak-pine forest. Ecography. 24:309-317.

Porter, A. H., S. J. Cadaret, and S. A. Johnson. 1997. Relatedness and gregariousness in the orange striped oakworm, *Anisota senatoria* (Saturniidae). J. Lepidopterists' Soc. 51:208-217.

Price, P. W. and G. P. Waldbauer. 1994. Ecological Aspects of Pest Management. In: Metcalf, R. L. and W. H. Luckman. *Introduction to Insect Pest Management*. John Wiley and Sons. NY. 35-65.

Pyare, S., J. A. Kent, D. L. Noxon, and M. T. Murphy. 1993. Acorn preference and habitat use in eastern chipmunk. Amer. Midland Nat. 130:173-183.

Quednau, F. W. and K. Lamontagne. 1998. Principles of mass culture of the gypsy moth parasitoid *Ceranthia samarensis* (Villeneuve). Cana. For. Serv., Laurention For. Centre, Inform. Rep. LAU-X-121:24.

Quigley K. L. 1971.The supply and demand situation for oak timber. In: Proc. Oak Symp. 1971. Aug 16-20. Morgantown, WV. Upper Darby, PA: USDA For. Serv., NE For. Exp. Stn. p.30-36.

Reid, V. H. and P. D. Goodrum. 1957. The effect of hardwood removal on wildlife. In: Proc. of the Soc. of Am. Foresters meeting. 1957 November 10-13; Syracuse, NY. Washington, DC. Soc. of Am. For. 141-147.

Rexrode, C. O. 1971. Oak Threats. In: Proc. Oak Symp. 1971. Aug 16 -20.Morgantown, WV. Upper Darby, PA: USDA For. Serv., NE For. Exp. Stn. 129-133.

Rexrode, C. O. and T. Jones. 1970. Oak bark beetles important vectors of oak wilt. J. For. 68:294-297.

Reynolds B. C. and D. A. Crossley. 1997. Spatial variation in herbivory by forest canopy arthropds along an elevational gradient. Environ. Entomol. 26:1232-1239.

Risley, L. S. and D. A. Crossley. 1988. Herbivore caused greenfall in the southern Appalachians. Ecol. 69:1118-1127.

Rogers, L. 1976. Effects of mast and berry crop failures on survival, growth, and reproductive success of black bears. Trans. North Am. Wildlife Conf. 41:431-438.

Roling, M. 1979. Biology of the Asiatic oak weevil in central Missouri. Ph.D. Dissertation. Univ. of Missouri-Columbia. 79 pp.

Samson, D. A., E. A. Rickhart, and P. C. Gonzales. 1997. Ant diversity and abundance along an elevational gradient in the Philippines. Biotropica. 29:349-363.

Sander, I. L. 1990. *Quercus rubra* L. northern red oak. In: Burns, R.M. and B.H. Honkala, technical coordinators. Silvics of North Am. Vol. 2. Hardwoods. Agric. Handb. 654. Washington, DC. USDA For. Serv. 727-733.

Sander, I. L. 1957. Silvical characteristics of northern red oak. USDA For. Serv. Cent. States For. Exp. Stn. Misc: Release 17:15.

SAS Institute. 1997. SAS/STAT software: Changes in enhancements through release 6.12. SAS Inst. Cary, NC.

Schneeberger, N. F. 1996. Gypsy moth populations plummet in 1996 while "The Fungus" skyrockets. Gypsy Moth News (http://www.fsl.wvnet.edu/gmoth/gmnews/gmnews.html), 42:1-2.

Shaw, S. P. 1971. Wildlife and oak management. In: Proc. Oak Symp.1971 Aug 16-20. Morgantown, WV. Upper Darby, PA: USDA For. Serv., NE For. Exp. Stn. p.84-89.

Simpson, E. H. 1949. Measurement of diversity. Nat. 163:688.

Smith, C. C. and D. Follmer. 1972. Food preferences of squirrels. Ecol. 53:82-91.

Smith, D. W. 1993. Oak regeneration: the scope of the problem. USDA For. Serv. Gen. Tech. Rep. SE-84:40-52.

Solomon, J. D., F. I. McKracken, R. L. Anderson, R. Lewis, Jr. F. L. Oliveria, T. H. Filer, and P. J. Barry. 1987. Oak pests: a guide to major insects, diseases, air pollution and chemical injury. USDA For. Serv. So. Reg. Protec. Rpt. R8-PR 7:69.

Sork, V. L., P. Stacey, and J. E. Averett. 1983. Utilization of red oak acorns in non-bumper crop year. Oecologia. 59:49-53.

Stanton, R. C. 1994. Insect diversity and abundance within the canopy of a northern red oak *(Quercus rubra* L.) orchard in eastern Tennessee. M.S. Thesis, Univ. of Tenn., Knoxville. 82pp.

Steele, M. A., C. Hadj, and J. Hazeltine. 1996. Caching and feeding decisions by *Sciurus carolinensis*: responses to weevil-infested acorns. J. Mammal. 77:305-314.

Steele, M. A., T. Knowles, K. Bridle and E. L. Simms. 1993. Tannins and partial consumption of acorns: implications for dispersal of oaks by seed predators. Am. Midland Nat. 130:229-238.

Stein, J. D. and D. J. Doran. 1975. A nondestructive method of whole-tree sampling for spring cankerworm. USDA For. Serv. Res. Note RM-290:3.

Steiner, K. C., K.W. Gottschalk, and S. L. C. Fosbroke. 1995. Autumn predation in northern red oak seed crops. In: Proc. 10th Central Hardwood For. Conf. Morgantown, WV. 5-8 March 1995. Gen. Tech. Rep. NE For.Exp. Stn., USDA For. Serv. No. NE 197:489-494.

Stiles, J. G. and F. A. Coyle. 2001. Habitat distribution and life history of species in the spider genera Theridion, Rugathodes, and Wamba in the Great Smoky Mountains National Park (Araneae, Theridiidae). J. Arachnology. 29:396-412.

Stork, N.E. and P. M. Hammond. 1997. Sampling arthropods from tree-crowns by fogging with knockdown insecticides: lessons from studies of oak tree beetle assemblages in Richmond Park (UK). In: Stork, N. E., J. Adis, and R. K. Didham (eds.). 1997. Canopy arthropods. Chapman and Hall. London. 3-26.

Stringer, J. W. 1998. Tree species: Northern red oak. For. Landowner Mag. Atlanta, GA. 57:40-44.

Telfer, E. S. 1972. Browse selection by deer and hares. J.Wildlife Manage. 36:1344-1349.

Tennessee Forestry Division. 2002. Tennessee forest facts. Accessed January 22, 2002. http://www.state.tn.us/agriculture/forestry/tdfff.html

Ticehurst, M., and W. Yendol. 1989. Distribution and abundance of early instar gypsy moth in forests during day and night. Environ. Entomol. 18:459-464.

Tilman, D., D. Wedin, and J. Knops. 1996. Productivity and sustainability influenced by biodiversity in grassland Systems. Nat. 379:718-720.

Triplehorn, C.A. 1955. The Asiatic oak weevil in Delaware. J. Econ. Entomol. 48:289-293.

USDA. 1972. Insects and Diseases of Trees in the South. Atlanta, GA. USDA For. Serv., S. Reg. 81pp.

USDA, NRCS. 2001. The PLANTS Database, Version 3.1. Nat. Plant Data Center, Baton Rouge, LA. http://plants.usda.gov

USDA. 2002. Pest Alert: Sudden Oak Death. USDA NE Area. NA-PR-02-02:2.

USGS. 2002. Cades sandstone. USGS. Accessed July 27, 2002. http://geology.er.usgs.gov/eespteam/smoky/cades_cove

University of Tennessee Institute of Agric. 1998. 2002 Tennessee forest facts. Tenn. For. Division. Accessed January 22, 2002.http://www.state.tn.us/agriculture/forestry/tdfff.html

Van Dersal, W. R. 1940. Utilization of oaks by birds and mammals. J. Wildlife Mgmt. 4:404-428.

Wachter, D. H., K. M. O'Neill, and W. P. Kemp. 1998. Grasshopper (Orthoptera:Acrididae) communities on an elevational gradient in southwestern Montana. J. Kansas Entomol. Soc. 71:35-43.

Watson, J. K., P. L. Lambdin, and K. Langdon. 1994. Diversity of scale insects (Homoptera: Coccoidea) in the Great Smoky Mountains Natl. Park. Ann. Entomol. Soc. Am. 87:225-230.

Weaver, J. E. 1960. Flood plain vegetation of the central Missouri Valley and contacts of woodland with prairie. Ecol. Monogr. 30:37-64.

Web of Species. 2002. Diversity. Wellesley College. Accessed February 26, 2002. http://www.wellesley.edu/Activities/homepage/web/Species/poakred.html

Weckerly, F. W., D. W. Sugg, and R. D. Semlitsch. 1989. Germination success of acorns (*Quercus*): insect predation and tannins. Can. J. For. Res. 19:811-815.

Williams, C. E. 1988. Damage to woody plants by the locust leafminer, *Odontota dorsalis*, during a local outbreak in an Appalachian oak forest. J. Entomol. Sci. 100:183-187.

Wood, T. K., S. I. Guttman, and M. C. Taylor. 1984 Mating behavior of *Platycotis vittata* (F.) (Homoptera: Membracidae). Amer. Midland Nat. 112:305-313.

Work, T. T., D. G. McCullough, and W. J. Mattson. 1998. Moth and carabid beetle species associated with two ecological landscape phases in northern Michigan. Gen. Tech. Rep. NC-201:25.

Wright, S.L., R.W. Hall, and J.W. Peacock. 1989. Effects of simulated insect damage on growth and survival of northern red oak seedlings. Environ. Entomol. 18:235-239.

Yanega, D. 1996. Field guide to the northeastern longhorned beetles (Coleoptera: Cerambycidae). Il. Nat. Hist. Surv. Man. 6. 184pp.

Zlotina, M.A, V.C. Mastro, D.E. Leonard, and J.S. Elkington. 1998. Survival and development of *Lymantria mathura* on North American, Asian, and European tree species. J. Econ. Entomol. 91:1162-1166.

Appendices

Table A. Families of Diptera collected from northern red oak in the Great Smoky Mountains National Park, 1992-95.

Family	Common Name	Abundance
Acartophthalmidae	Acartophthalmid flies	4
Acroceridae	Small-headed flies	2
Agromyzidae	Leaf flies	9
Anisopodidae	Wood gnats	5
Anthomyiidae	Anthomyiid flies	3
Asilidae	Robber flies	4
Aulacigastridae	Aulacigastrid flies	4
Bibionidae	March flies	40
Ceciodomyiidae	Gall midges	133
Ceratopogonidae	Biting midges	25
Chamaemyiidae	Chamaemyiid flies	1
Chironomidae	Midges	117
Chloropidae	Frit flies	62
Conopidae	Thick-headed flies	1
Culicidae	Mosquitos	3
Diastatidae	Diastatid flies	1
Dolichopodidae	Long-legged flies	52
Drosophilidae	Pomace flies	25
Dryomyzidae	Dryomyzid flies	2
Empididae	Dance flies	189
Ephydridae	Shore flies	5
Lauxaniidae	Lauxanid flies	20
Lonchaeidae	Lonchaeid flies	49
Megaspilidae	Megaspilid flies	9
Micropezidae	Stilt-legged flies	5
Milichiidae	Milichiid flies	2
Muscidae	House flies	43
Mycetophilidae	Fungus gnats	29
Odiniidae	Odiniid flies	4
Otitidae	Picture-winged flies	2
Periscelididae	Periscelid flies	2
Phoridae	Hump-backed flies	339
Platypezidae	Flat footed flies	4
Psilidae	Rust flies	6
Psychodidae	Moth and sand flies	7
Rhagionidae	Snipe flies	13
Ropalomeridae	Ropalomerid flies	1
Sarcophagidae	Flesh flies	10
Scaphidiidae	Scaphid flies	1
Scathephagidae	Dung flies	4

Table A (cont.). Families of Diptera collected from northern red oak in the Great Smoky Mountains National Park, 1992-95.

Family	Common Name	Abundance
Scatopsidae	Large dung flies	11
Sciaridae	Dark-winged fungus gnats	1,966
Sciomyzidae	Marsh flies	2
Simuliidae	Black flies	43
Sphaeroceridae	Small dung flies	4
Stratiomyidae	Soldier flies	11
Syrphidae	Hover flies	2
Tachinidae	Parasitic flies	27
Tephritidae	Fruit flies	1
Tethinidae	Tethinid flies	1
Tipulidae	Crane flies	32
Unidentified Diptera		110
Total		3,447

Table B. Families of Hymenoptera collected from northern red oak in the Great Smoky Mountains National Park, 1992-95.

Family	Common Name	Abundance
Andrenidae	Andrenid bees	1
Aphelinidae	Aphid wasps	5
Apidae	Bumble and honey bees	1
Bethylidae	Bethylid wasps	2
Braconidae	Braconid wasps	146
Ceraphronidae	Ceraphronid wasps	98
Chalcidae	Chalcid wasps	60
Chrysididae	Cuckoo wasps	3
Cynipidae	Cynipid wasps	84
Diapriidae	Diapriid wasps	105
Encyrtidae	Encyrtid wasps	69
Eucoilidae	Eucoilid wasps	27
Eulophidae	Eulophid wasps	57
Eupelmidae	Eupelmid wasps	6
Eurytomidae	Seed chalcid wasps	8
Evaniidae	Ensign wasps	1
Formicidae	Ants	766
Halictidae	Sweat bees	20
Ichneumonidae	Ichneumonid wasps	208
Mymaridae	Fairfly wasps	8
Ormyridae	Ormyrid wasps	3
Pelecinidae	Pelecinid wasps	1
Pompilidae	Spider wasps	49
Pteromalidae	Pteromalid wasps	49
Sphecidae	Digger wasps	5
Tenthredinidae	Common sawflies	29
Tiphiidae	Tiphiid wasps	1
Torymidae	Torymid wasps	5
Trichogrammatidae	Trichogrammatid wasps	1
Vespidae	True wasps	5
Unidentified Hymenoptera		346
TOTAL		**2,169**

Table C. Non-coleopteran insects found on northern red oak in the Great Smoky Mountains National Park, 1992-95

Order	Family	Species	Abundance
Blattaria	Cryptoceridae	*Cryptocercus punctulatus* Scudder	35
Dermaptera	Labiduridae	*Labidura riparia* Pallas	1
Diptera	Agromyzidae	*Japanagromyza viridula* Coquillett	7
	Anisopodidiae	*Mycetobia divergens* Walker	1
	Asilidae	*Neoitamus flavofemoratus* Hine	2
	Aulacigastridae	*Aulacigaster leucopeza* (Meigen)	4
	Bibionidae	*Penthetria heteroptera* Say	19
	Ceratopogonidae	*Culicoides biguttatus* Coquillett	3
	Chloropidae	*Eugaurax floridensis* Malloch	1
	Culicidae	*Aedes triseriatus* Say	3
	Dolichopodidae	*Xanthochlorus helvinus* Loew	1
	Drosophilidae	*Chymomyza amoena* Loew	4
		Leucophenga maculosa Coquillett	1
		Mycodrosophila dimidiata Loew	1
		Scaptomyza graminum Falle'n	3
	Lauxaniidae	*Trisapromyza vittigera* (Coquillett)	5
	Micropezidae	*Rainieria antennaepes* Say	3
	Muscidae	*Fania fuscula* Fallen	1
		Piezura graminicola Zetterstadt	1
		Synthesiomyia nudiseta (Wulp)	1
	Mycetophilidae	*Rondaniella dimidata* (Meigen)	1
	Odiniidae	*Traginops irrorata* Coquillett	1
	Periscelididae	*Periscelis annulata* Fallen	2
	Phoridae	*Metopine subarevata* Meigen	1
		Woodiphora magnipalpus Meigen	6
	Psilidae	*Chyliza apicalis* Loew	6
	Scaphidiidae	*Scaphisoma convexum* Say	1
	Scatopsidae	*Anapausis cismarina* McAtee	2
	Sciomyzidae	*Atrichomelina pubera* (Loew)	1
		Poecilographa decora Loew	1
	Syrphidae	*Ferdinandea dives* Osten Sacken	1
		Rhingia nasica Say	1
Hemiptera	Anthocoridae	*Anthocoris musculus* Say	11
	Cydnidae	*Amnestus pusillus* Uhler	1
		Sehirus cinctus Palisot de Beauvois	2
	Lygaeidae	*Geocoris bullatus* Say	2
		Geocoris punctipes Say	5
	Miridae	*Deraecoris nebulosus* Uhler	16
		Hyaliodes harti Knight	2
		Plagiognathus delicates Uhler	1
		Pseudoxenetus scutellatus Uhler	1
	Pentatomidae	*Euschistus ictericus* L.	1
		Podisus modestus Dallas	1
	Reduviidae	*Arilus cristatus* L.	1
	Saldidae	*Pentacora hirta* Say	1
		Saldula interstitialis Say	1
	Tingidae	*Corythuca arcuata* Say	1
		Drakella ovata Osborn and Drake	1
		Leptoypha mutica Say	2

Table C (Cont.). Non-coleopteran insects found on northern red oak in the Great Smoky Mountains National Park, 1992-95

Order	**Family**	**Species**	**Abundance**
Homoptera	Cicadellidae	*Erythroneura hamata* Beamer	1
		Graphocephala coccinea Forster	3
		Jassus olitorius Say	6
		Menosoma cincta Osborn and Ball	2
	Flatidae	*Anormenis septentrioalis* Spinola	1
	Membracidae	*Erythronea comes* Say	1
		Ophiderma evelyna Woodruff	111
		Ophiderma salamandra Fairmaire	1
		Telamona monticola F.	7
Hymenoptera	Apidae	*Apis mellifera* L.	1
	Formicidae	*Aphaenogaster tennesseensis* Mayr	184
		Aphenogaster rudis Haskins and Enzmann	9
		Camponotus pennsylvanicus DeGeer	136
	Pelecinidae	*Pelecinus polyturator* Drury	1
	Pompilidae	*Auplopus architectus* Say	4
		Auplopus mellipes Say	3
		Calicurgus hyalinatus alienatus Smith	3
		Dipogon graenicheri Banks	4
		Dipogon papago Banks	3
		Priocnemis hestia Banks	1
		Priocnessus nebulosus Dahlbom	2
	Vespidae	*Vespula maculata* L.	1
Lepidoptera	Noctuidae	*Agrotis ipsilon* (Hufnagel)	2
	Papillionidae	*Pterourus glaucus* (L.)	1
Mecoptera	Panorpidae	*Panorpa helena* Byers	9
		Panorpa isolata Carpenter	21
Orthoptera	Acrididae	*Melanoplus gracilis* Bruner	18
		Melanoplus punctulatus Scudder	1
	Dectidae	*Atlanticus testaceus* Scudder	3
	Gryllacrididae	*Camptonotus carolinensis* Gerstaecker	1
		Ceuthophilus brevipes Scudder	6
		Ceuthophilus maculatus Harris	9
	Gryllidae	*Myrmecophila pergandei* Bruner	7
		Nemobius fasciatus De Geer	1
		Neoxabea bipunctata De Geer	1
		Oecanthus angustipennis Fitch	21
		Oecanthus exclamationis Davis	19
		Orocharis saltator Uhler	11
	Tettigoniidae	*Pterophylla camellifolia* F.	30
Phasmida	Heteronemiidae	*Diapheromera blatchleyi* Caudell	4
		Diapheromera femorata Say	4
Psocoptera	Lepidopsocidae	*Echmepteryx hageni* Packard	4
TOTAL			829

Table D. Non-coleopteran specimens identified to genus collected from northern red oak in the Great Smoky Mountains National Park, 1992-95.

Order	Family	Genus	Abundance
Diptera	Acroceridae	*Acrocera spp.*	2
	Agromyzidae	*Japanagromyza spp.*	2
	Anisopodidae	*Sylvicola spp.*	4
	Bibionidae	*Bibio spp.*	21
	Ceratopogonidae	*Forcipomyia spp.*	4
		Atrichopogon spp.	9
		Dashyhelea spp.	9
	Chamaemyiidae	*Parcleucopis sp.*	1
	Chironomidae	*Thaumatomyia spp.*	2
	Chloropidae	*Apotropina sp.*	1
		Neoscinella sp.	1
		Liohippelates spp.	2
		Rhopalopterum spp.	3
		Fiebrigella spp.	8
		Tricimba spp.	14
	Diastatidae	*Campichoeta sp.*	1
	Dolichopodidae	*Asyndetus sp.*	1
		Campsicnemus sp.	1
		Diaphorus sp.	1
		Hercostomus sp.	1
		Paraclius sp.	1
		Sciapus sp.	1
		Gymnopternus spp.	2
		Syntormon spp.	2
		Medetera spp.	3
	Drosophilidae	*Drosophila spp.*	3
		Scaptomyza spp.	3
	Dryomyzidae	*Dryomyza spp.*	2
	Empididae	*Megagrapha sp.*	1
		Platyura sp.	1
		Syndyas sp.	1
		Thanategia sp.	1
		Bicellaria spp.	2
		Empis spp.	2
		Leptopeza spp.	2
		Drapetis spp.	3
		Oedalea spp.	3
		Platypalpus spp.	4
		Euthyneura spp.	10
		Tachypeza spp.	10
		Rhamphomyia spp.	140
	Ephydridae	*Discocerina sp.*	1
		Leptopsilopa sp.	1
		Pelina sp.	1
	Lauxaniidae	*Poecilolycia sp.*	1
		Minettia spp.	2
		Homoneura spp.	3
	Lonchaeidae	*Lonchaea spp.*	49
	Milichiidae	*Phyllomyza sp.*	1
	Muscidae	*Fania spp.*	5
		Thricops spp.	8

Table D (cont.) Non-coleopteran specimens identified to genus collected from northern red oak in the Great Smoky Mountains National Park, 1992-95.

Order	Family	Genus	Abundance
	Mycetophilidae	*Exechia sp.*	1
		Rymosia sp.	1
		Boletina spp.	3
		Mycomya spp.	3
		Orfelia spp.	8
	Odiniidae	*Taginops sp.*	1
	Otitidae	*Callopistromyia sp.*	1
	Phoridae	*Apocephalus spp.*	2
		Beckerina spp.	2
		Chaetopleurophora spp.	2
		Phora spp.	13
		Dorniphora spp.	15
		Megaselia spp.	18
		Triphleba spp.	22
	Platypezidae	*Platypeza spp.*	2
	Rhagionidae	*Rhagio spp.*	13
	Sarcophagidae	*Camptops sp.*	1
	Scatopsidae	*Coboldia sp.*	1
		Ectaetia spp.	2
		Anapausis spp.	3
	Sciaridae	*Sciara spp.*	3
		Scatopsciara spp.	6
		Corynoptera spp.	37
		Lycoriella spp.	416
		Bradysia spp	437
	Simuliidae	*Cnephia sp.*	1
		Prosimulium sp.	1
		Simulium spp.	32
	Sphaeroceridae	*Leptocera sp.*	1
	Stratiomyidae	*Cephalochrysa sp.*	1
		Zabrachia sp.	1
		Neopachygaster spp.	5
	Tachinidae	*Peleteria spp.*	2
	Tethinidae	*Tethina sp.*	1
	Tipulidae	*Ctenophora sp.*	1
		Limonia sp.	1
		Tipula spp.	2
Hemiptera	Miridae	*Lygus sp.*	1
	Piesmatidae	*Piesma sp.*	1
Homoptera	Cicadellidae	*Eutettix sp.*	1
		Gyponana spp.	2
	Membracidae	*Cyrtolobus spp.*	10
		Microcentrus spp.	119
Hymenoptera	Formicidae	*Leptothorax sp.*	1
		Camponotus spp.	150
	Ichneumonidae	*Ophion spp.*	2
	Pteromalidae	*Spalangia spp.*	7
	Tenthredinidae	*Amauronematus sp.*	1
	Vespidae	*Vespula spp.*	4
Neuroptera	Chrysopidae	*Chrysopa spp.*	5
Orthoptera	Acrididae	*Melanoplus spp.*	17

Table D (cont.) Non-coleopteran specimens identified to genus collected from northern red oak in the Great Smoky Mountains National Park, 1992-95.

Order	Family	Genus	Abundance
	Gryllacrididae	*Ceuthophilus spp.*	4
	Gryllidae	*Oecanthus spp.*	9
	Tettigoniidae	*Amblycorypha sp.*	1
		Scudderia spp.	20
Psocoptera	Lepidopsocidae	*Echmepteryx spp.*	26
TOTAL			**3,600**

Table E. Non-coleopteran specimens identified to genus from northern red oak inThe University of Tennessee Arboretum, 2001.

Order	**Family**	**Species**	**Abundance**
Diptera	Agromyzidae	*Agromyza spp.*	2
	Asilidae	*Cerotainia sp.*	1
	Calliphoridae	*Phaenicia sp.*	1
	Dolichopodidae	*Argyra sp.*	1
		Campsicnemus sp.	1
		Gymnopternus sp.	1
		Condylostylus spp.	10
	Lauxaniidae	*Homoneura spp.*	4
	Stratiomyidae	*Oxycera sp.*	1
	Syrphidae	*Ocyptamus sp.*	1
	Tephritidae	*Rhyneneina sp.*	1
Homoptera	Membracidae	*Cyrtolobus spp.*	44
Hymenoptera	Formicidae	*Camponotus spp.*	45
Hymenoptera	Vespidae	*Vespula sp.*	1
Neuroptera	Chrysopidae	*Chrysopa sp.*	1
Orthoptera	Acrididae	*Melanoplus spp.*	2
TOTAL			**117**

Table F. Non-coleopteran species identified from northern red oak inThe University of Tennessee Arboretum, 2001.

Order		**Family**	**Species**
Blattaria	Cryptoceridae	*Cryptocercus punctulatus* Scudder	8
Diptera	Asilidae	*Leptogaster tipulagaster-glabrata* Wideman	1
	Chloropidae	*Ceratobarys eulophus* (Loew)	1
	Culicidae	*Aedes triseriatus* (Say)	1
	Pipunculidae	*Pipunculus fuscus* Loew	2
	Stratiomyidae	*Actina viridis* Say	1
	Syrphidae	*Ferdinandea dives* Osten-Sacken	1
	Tipulidae	*Elephantomyia westwoodi* Osten-Sacken	1
Hemiptera	Aradidae	*Mezira granulatus* Say	2
	Lygaeidae	*Cryphula parallelograma* Stal	3
		Kleidocerys resedae Panzer	5
	Miridae	*Hyaliodes harti* (Knight)	26
	Phymatidae	*Phymata fasciata* Gray	1
	Reduviidae	*Sinea diadema* F.	1
	Tingidae	*Corythuca elegans* Drake	6
Homoptera	Fulgoridae	*Acanalonia bivittata* Say	4
	Membracidae	*Glossonotus acuminatus* F.	1
		Telamona monticola F.	2
		Ophiderma salamandra Fairmaire	177
Hymenoptera	Formicidae	*Camponotus pennsylvanicus* DeGeer	54
	Halictidae	*Augochlora striata* (Provancher)	1
	Vespidae	*Vespula maculata* (L.)	2
Orthoptera	Gryllidae	*Orocharis saltator* Uhler	3
	Tettigoniidae	*Pterophylla camellifolia* F.	11
Thysanoptera	Phlaeothripidae	*Leptothrips mali* Fitch	28
TOTAL			**343**

VITA

Danny David Trieff was born February 17, 1974 in Indianapolis, Indiana. He graduated from Perry Meridian High School in Indianapolis, IN, in June 1992. In the fall of that year, Danny entered Mount Union College in Alliance, OH. He graduated in 1996 with a Bachelor of Science degree in Biology. After graduation, he worked as an entomology technician for Mycogen Seed Company in Indianapolis until May 1997. He was the Chief of Ocean Rescue Operations for the Atlantic Beach, NC Fire Department during the summers and a Resident Director at Mount Olive College in Mount Olive, NC during the other seasons of 1997-2000. In the summer of 2000, 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 December 2002. Upon graduation, he accepted a commission into the United States Army Reserves as a Second Lieutenant in the capacity of military entomologist. He also accepted a Horace B. Rackham Fellowship at the University of Michigan-Ann Arbor where he will complete the requirements for a Doctor of Philosophy degree in University Administration and Public Policy Studies.

Danny D. Trieff is a member of the Entomological Society of America and the national agricultural honorary society of Gamma Sigma Delta.