To the Graduate Council:

I am submitting herewith a thesis written by Melinda Monroe Gibbs entitled "Diversity of ground-dwelling insects inhabiting a mixed hardwood southern Appalachian forest." I have examined the final 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.

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DIVERSITY OF GROUND-DWELLING INSECTS INHABITING A MIXED HARDWOOD SOUTHERN APPALACHIAN FOREST

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ABSTRACT

The southern Appalachian mountains of eastern Tennessee support a diverse array of flora and fauna, many of which are unique to specific forest ecosystems in this region. These organisms help sustain the proper functioning of these habitats, but the presence of exotic forest pests may threaten our native forests. The gypsy moth, *Lymantria dispar* L., is one such pest that can cause mass defoliation of hardwood forests. The southern limit of this pest's range is currently located near Roanoke, VA, but is expected to enter the forests of eastern Tennessee within the next decade. Some isolated infestations have been reported in the Great Smoky Mountains National Park, as well as 23 counties in Tennessee.

Currently, no studies have been performed in the southeastern United States to determine the potential impact of this pest on mixed hardwood forests. Therefore, a study was initiated in 1997 in The University of Tennessee Forestry Experiment Station and Arboretum located in Oak Ridge, TN. The objectives of this study were to: 1) assess the overall diversity of ground-dwelling insects, 2) determine the possible influence of habitat on insects collected using pitfall traps placed under three different tree species in four different collection plots, and 3) assess the species composition, seasonality, and abundance of selected insects collected.

Collections from pitfall traps yielded 20,906 insects identified with 187 species in 87 families representing 18 insect orders. The four most abundant orders collected included the Collembola (49%), Hymenoptera (20%), Diptera (15%), and Coleoptera

(9%). Ants (Formicidae) composed approximately 88% of the Hymenopterans collected with 24 species identified. Many of the beetles collected may be potential beneficial predators against exotic pests, such as the gypsy moth. Twenty one families of beetles were collected with 79% represented by four families: Staphylinidae (41%), Scarabaeidae (13%), Nitidulidae (13%), and Carabidae (12%). Of the carabid beetles, 21 species were identified.

Species diversity and evenness were significantly higher in the cove plot ($P<0.05$), most likely due to the isolated location of the plot and the increased moisture levels retained after heavy rains. Ant species diversity was highest in the cove and slope plots and lowest in the tornado plot. Natural disturbances disrupt ant activity and downed trees may deter ground-dwelling ant populations from inhabiting these areas. The slope plot had the highest ant species evenness, suggesting a more even distribution of ants in this community. Many of the ants inhabiting the slope plot may build their nests in leaf litter and debris, both of which have been accumulated and deposited in this plot due to heavy rain water runoff. Beetle species diversity and richness did not differ among the four plots, although species evenness was significantly ($P<0.05$) higher in the natural plot and lower in the tornado plot when compared among the four plots.

Significantly ($P<0.05$) more insects were collected in the cove plot and significantly fewer were collected in the slope plot. Similarly, significantly more ants and beetles were collected in the cove plot than the other three plots. Also, more ants and beetles were collected in the traps placed under sugar maple, *Acer saccharum* Marsh, and significantly fewer were collected in the traps placed under tulip poplar, *Liriodendron*

tulipifera L. The traps under white oak, *Quercus alba* L., did not yield significantly different numbers of ants and beetles in comparison to the other two tree species. Significant differences may have been found if all samples collected throughout this study had been sorted and used in the analyses.

Overall seasonality trends were similar for most of the insects collected with highest population numbers in the summer months. Collections made in these forest habitats reveal a stable community with many different guilds represented. When comparing the four collection plots, a more diverse group of organisms was represented in the cove plot. The differences found in these plots are representative of the types of disturbance found in mixed hardwood ecosystems. Similar analyses performed on data collected after the gypsy moth is established in eastern Tennessee may help determine the impact of this pest on native southern Appalachian forests.

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CHAPTER I

LITERATURE REVIEW

The southern Appalachian mountains are known for their scenic forests and are an ideal habitat for a diverse array of plant and animal species. However, the impending invasion of exotic insect pests threatens native forest habitats. The Great Smoky Mountains National Park (GSMNP), along with other old-growth forests in the southern Appalachians, provide habitat for many important animal and plant species, some of which are threatened or endangered and can be found in only specific habitat types. The GSMNP contains more than 130 native vascular plant species just within its boundaries (Peine 1989). Many more plant species exist, however, in the southern Appalachian region. For instance, approximately 140 rare plant species and six rare animal species occur in threatened southern Appalachian wetlands (Murdock 1994).

Wetlands may be defined as areas containing bottomland hardwoods adjacent to streams or rivers (Wigley and Roberts 1994). In the mountainous areas of the southern Appalachians, these wetland forests are generally continuous with upland forests, but many of the wetlands within this region have been converted to non-forest uses. These mountain environments provide niches to many invertebrates as well, but no studies have determined the overall invertebrate diversity in these areas.

A study by Hughes (1993) yielded 45 arthropod families representing 15 orders collected from Fraser fir leaf litter in the GSMNP. In 1994, Stanton collected over 541 arthropod species from a northern red oak, *Quercus rubra* L., seed orchard in Tennessee. Similarly, Metcalf and Metcalf (1993) determined that more than 1,000 insect species are

associated with oak species alone. Although the need for documenting the biodiversity of selected areas has become prevalent, much research is needed to understand the affects of various biotic and abiotic factors on our natural areas and their inhabitants.

The biodiversity and terrain of these ecosystems attract many tourists to the area and as a result have created a variety of jobs for local residents. The southern Appalachian economy relies heavily on outdoor recreation and forestry practices. Each year more than 14 million people contribute ca. 6 billion dollars to Tennessee's economy by visiting its southern Appalachian mountains (Stanton 1994). About 87% of Tennessee forests contain hardwoods, making Tennessee one of the leading hardwood lumber manufacturers in the United States (May 1991). Employment and income in the region have remained stable over the last 20 years because of the wood products industry (USDA July 1996), which contributes more than 4 billion dollars annually and employs about 46,000 Tennesseans (Hopper 1991).

Hardwood timber removals from bottomland hardwood forests across the southern United States are predicted to increase by approximately 64% between the years 1984 and 2030 (USDA For. Serv. 1988). However, the total area of bottomland hardwoods in the south is projected to decrease by about 13% between 1990 and 2030 (USDA For. Serv. 1988). Therefore, any type of disturbance (i.e., exotic insect pests) may dramatically alter the economy and the environment of the southern Appalachians.

One such pest that threatens our hardwood forests is the gypsy moth, *Lymantria dispar* L., a pest that was accidentally released in Bedford, MA, in 1869 by Etienne Leopold Trouvelot. The abundance of food, absence of natural enemies, and presence of

favorable ecological conditions have led to the successful invasion of the gypsy moth throughout the northeastern and Atlantic states. Population explosions in recently invaded areas have resulted in millions of hectares of defoliation and millions of dollars of damage (Gerardi and Grimm 1979). From 1983 to 1994, gypsy moth larvae completely defoliated more than 16 million ha (Ghent 1994, Grace 1986). Since its introduction into the United States, the gypsy moth has been responsible for decreased health in many forest ecosystems, and it is now established in 16 northeastern and midwestern states, as well as the District of Columbia (USDA Jan. 1996).

This pest continues to spread into surrounding states resulting in isolated infestations. Because adult females do not fly, the primary means of natural dispersal is by the wind-blown neonate larvae (Weseloh 1998). Upon hatching, larvae climb to the top of the tree and spin a silken thread which the wind catches and spreads the larvae by ballooning. Fosberg and Peterson (1986) determined that larvae could possibly disperse up to 21 km away. Other means of gypsy moth dispersal include egg masses attached to tourist vehicles and substrates that may be transported by people moving from an infested region to a non-infested region. The gypsy moth front, currently located near Roanoke, VA, is predicted to enter eastern Tennessee within the next decade. Some isolated infestations have already been reported in 23 counties in Tennessee, as well as the GSMNP. From January to October 1998, 395 moths were captured in Tennessee with 224 caught in Scott County, 66 in Cumberland County, and 36 captured in Sevier County (Powell, pers. comm., 1998).

Defoliation caused by the gypsy moth may affect both rural and urban environments including reduction in property values. Property value of homes may decrease and costs for treating the gypsy moth may be incurred (USDA 1995). Homeowners may have to replace damaged trees and shrubs, remove caterpillars, droppings, and egg masses and may need to repaint various structures. Health hazards from an invasion of gypsy moths or from spraying insecticides also may become prevalent.

Forest communities may be altered dramatically by a gypsy moth invasion. Forest canopy herbivores are important regulators of forest nutrient cycling (Reynolds and Crossley 1997). Under conditions of defoliation, there is an increase in nitrogen added to the forest floor via frass and litterfall (Swank *et al.* 1981). Greenfall, green leaves that fall as a direct result of herbivore feeding (Risley 1986), was found to contain more nitrogen than senescent leaves and should be a high quality substrate for decomposers (Risley and Crossley 1988). The authors also determined that insect herbivores accelerate nutrient cycling via greenfall. While defoliation may be beneficial to decomposers, large scale defoliation events can adversely affect forest stand composition.

Knowledge of species inhabiting native forests is required to fully understand the potential impact of an invasion by exotic pests. Surveys of various aspects of forest ecosystems have been conducted in the past which detail the flora and fauna of the Appalachian environment. Cole (1940) identified 86 species of ants inhabiting the Tennessee portion of the GSMNP. Cole searched every possible niche, because ants can live on the ground, in vegetation, on tree trunks, and in the canopy of trees. Surveys of this nature are inclusive and representative of the total fauna of interest. Lambdin *et. al.*

(1991) recorded 675 lepidopteran species inhabiting eastern Tennessee and the GSMNP. Many of these butterflies and moths may be adversely affected by the gypsy moth invasion. Other groups of arthropods, which help sustain a healthy forest habitat, may also suffer if trees are weakened. Ground-dwelling arthropods, such as beetles, ants, spiders, mites and springtails, make a significant contribution to nutrient cycling and the maintenance of soil structural properties (Lobry de Bruyn *et al.* 1997). Therefore, data obtained on native ground-dwelling insects would be useful to determine the impact of forest pests, such as the gypsy moth.

Various studies have addressed different types of impact by the gypsy moth on a diverse array of arthropod taxa. Researchers determined that forest thinning does not reduce the number of gypsy moth larvae and pupae surviving predation although the abundance of small mammal predators increases substantially in the silviculturally manipulated stand (Grushecky *et al.* 1998). Blair and Crossley (1988) studied the impact of clear-cutting in a southern Appalachian hardwood forest eight years after clearing. They concluded that litter decomposition rates were reduced after clear-cutting and that mean annual densities of total litter microarthropods remained 28% lower at the clear-cut site than the control site eight years after cutting. Results from this study also differed from those found in northern hardwood forest sites, suggesting that generalizations can not be made between regions.

In northern New South Wales, a section of Stringybark Forest was to be converted to grazing land by clear-cutting. Lobry de Bruyn *et al.* (1997) used pitfall traps to assess the role of soil invertebrates as "ecosystem engineers" by examining their function in the

maintenance of soil structure processes after a major disturbance. Jones and Lawton (1995) describe "ecosystem engineers" as the organisms that regulate resources to other species, thereby modifying, maintaining, and/or creating habitats. Collembola and Acarina were the two most abundant groups collected using pitfalls with ants being the third most prevalent among the invertebrates. Lobry de Bruyn's (1997) study implemented ants as indicator species to determine the affect of clearing native vegetation for grazing pastures.

Another study utilizing pitfall traps, conducted in Sweden (Atlegrim *et al.* (1997)), used carabid beetles captured in pitfall traps as indicator species in the comparison of clear-cutting, single tree selection felling, and uncut control forests. They found no significant (P=0.558) increase in carabid diversity following clear-cutting and no significant (P=0.558) difference between the selectively logged areas and the uncut control forests (Atlegrim *et al.* 1997).

Additional information, such as species composition, seasonality, abundance, and diversity, obtained on native arthropod species would be helpful in determining the present condition of southern Appalachian forest ecosystems. Also, these data could be useful as a standard for comparison with diversity data collected after a possible gypsy moth invasion. Although various arthropod sampling techniques exist, the use of pitfall traps is an effective and inexpensive means of collecting ground-dwelling arthropods (Topping and Sunderland 1992). Pitfall traps can be used to sample continuously and large catches often result with many species trapped. Pitfall trapping is used extensively to monitor the occurrence, relative abundance and activity of surface-active arthropods (Halsall and Wratten 1988). Pitfall trap catches depend on population size, locomotor activity

(Mitchell 1963, Greenslade 1964) and susceptibility of capture of the animals. Majer (1997) suggested that a combination of trapping techniques be employed if one wishes to obtain community data for an area. Baars (1979) found that the use of continuous pitfall sampling over a complete season would yield relative abundance of carabid populations.

Many factors affect the overall efficiency of pitfall trapping in determining invertebrate community composition, and limitations exist with the proper use of pitfall traps. Halsall and Wratten (1988) demonstrated, with the use of time-lapse video techniques, that different carabid beetle species have different abilities to escape from pitfall traps. Morrill and colleagues (1990) observed that beetles often turned away from traps if cones protruded above the ground surface, and many beetles were able to escape the trap cones. However, beetles that moved rapidly were more likely to be captured. It also was determined that pitfall trap size, as well as size and configuration of guides affected catch size. A survey of 185 studies, from 23 countries, on trapping arthropods and amphibians using pitfalls revealed that 40% of authors that conducted these studies and published their results between 1983 and 1992 had not "fully appreciated their limitations" (Topping and Sunderland 1992). Therefore, with any biodiversity study, researchers must be objective in their conclusions.

Arthropod biodiversity is largely unknown although arthropods can comprise more than 60% of terrestrial species (Wilson 1992). A paper published in 1996 on the insect diversity in Korea stated that only 11,028 species of insects have been recorded (Kwon *et al.* 1996). This count was estimated to be only about 20% of the total insect fauna in Korea. Because of the lack of knowledge of insect diversity, many studies have been

implemented to catalog arthropods in many different ecosystems. Although plant and animal diversity are well documented, the importance of insects in conservation (Kim 1993) and the use of insects as indicators of human impact (Halloway and Stork 1991) have only received much attention within the last decade.

An "arthropod biodiversity-sampling protocol" was developed by Carlton *et al.* (1994) to: a) assess the effectiveness of various sampling techniques (including pitfall trapping), b) demonstrate methods of presenting and analyzing biodiversity data, and c) recommend techniques for conducting long-term ecosystem management programs involving arthropod diversity. Continuous monitoring of biological diversity and ecosystem functions can be accomplished using indicator groups of non-economic insects, whose population levels and resources are readily measured (Brown 1997). Butterflies have been found to be excellent indicator taxa in neotropical forest systems. Brown (1997) determined that diversity usually increased with disturbance near or below natural levels, but low levels of interference can eliminate sensitive species. The use of many indicator groups will yield important information for conservation monitoring. Native lepidopterans associated with oak trees could serve as indicator species to assess the impact of a gypsy moth invasion on the hardwood southern Appalachian forests of eastern Tennessee.

An intensive study conducted in south-central Cameroon examined 8 different animal groups as possible indicator taxa. Lawton *et al.* (1998) used birds, butterflies, flying beetles, canopy beetles, canopy ants, leaf-litter ants, termites and soil nematodes as indicator taxa to determine the impacts of tropical forest modification. The researchers

concluded that no one group served as a good indicator taxon for changes in the species richness of other groups and that biodiversity studies require tremendous effort and time (Lawton *et al.* 1998). As presented earlier, many groups of insects are used in impact studies. Frampton and Bolger (1997) used Collembola to determine the effects of pesticide use on crops. *Lepidocyrtus* spp. showed the most substantial change in numbers, while *Sminthurinus elegans* showed the least amount of change. Dragonflies were monitored as potential indicators of biotope quality in South Africa. Clark and Samways (1996) determined that 10 ecologically meaningful biotope groups contained at least one important Odonate indicator species. Although many groups can be utilized as indicator taxa, scientists must understand how these groups provide relative biodiversity information pertaining to different habitats. Faith and Walker (1996) suggested the use of indicator species in an area or habitat that contains a representative of each different indicator taxon. This type of representation implies that the area would be generally biodiverse and would lead to a better understanding of the habitat. Faith and Walker (1996) concluded that this type of strategy allows an area to be predicted, so one does not rely on predictions made of a single group of organisms.

When considering biodiversity or indicator species, every component of an ecosystem and the community, and all of the biotic and abiotic interactions that sustain the overall balance of natural processes within the environment, become important. For example, each lepidopteran species has its compliments of natural enemies (parasitoids, predators, and pathogens) which affect their populations. Although the gypsy moth has natural regulatory mechanisms as well, it has been difficult to establish effective

parasitoids and predators to sufficiently reduce gypsy moth populations in the United States.

The beetle *Calosoma sycophanta* L. is a gypsy moth predator that has successfully colonized in North America (Leonard 1981). This carabid beetle was imported into the United States from central Europe between 1906 and 1926 (Spieles and Horn 1998) and released in New England as a biological control agent for the gypsy moth. Since its introduction, it has been helpful in reducing gypsy moth outbreaks (Bess 1961, Campbell 1967, Weseloh 1985, 1990b), but it usually only has a substantial impact on gypsy moth populations after two or more years after the initial outbreak (Spieles and Horn 1998). Little was known about the feeding behavior of *C. sycophanta* when gypsy moth numbers were low, until Spieles and Horn (1998) determined that the beetle needs a diet of gypsy moth larvae to reproduce successfully. If no larvae are found, adults will return to the ground without reproducing. Native *Calosoma* spp. also attack gypsy moths, and ants in the genus *Formica* have been known to feed on neonate gypsy moth larvae. When neonate gypsy moth larvae disperse by ballooning, many fall to the ground where they remain for several hours (Weseloh 1998). Their presence on the ground increases their likelihood for predation (Weseloh 1990a) that is almost exclusively caused by ants, such as *Formica neogagates* Emery and *F. subsericea* Say (Weseloh 1989). Perhaps other native beetle and ant species could be potential predators of the gypsy moth in the southern Appalachians.

Several native insects, including wasp and fly parasitoids, have been observed attacking gypsy moth pupae. These parasitoids sting and kill many more hosts than they

successfully parasitize (Campbell 1963). For this reason, twelve parasitoids were established in the United States as biological control agents against the gypsy moth (Fuester *et al.* 1997). *Cotesia melanoscela* Ratzberg (Hymenoptera: Braconidae) was one of the first parasitoids introduced against the gypsy moth (Kruse and Raffa 1997). Food plants most suitable for host development are likely those that most enhance host quality for larval parasitoid development, survival, and size (Kruse and Raffa 1997, English-Loeb *et al.* 1993, Werren *et al.* 1992, Greenblatt and Barbosa 1981). Kruse and Raffa (1997) state the importance of considering wasp strain and forest tree species composition when prescribing biological control for the gypsy moth. Similarly, *Ooencyrtus kuvanae* (Howard) (Hymenoptera: Encyrtidae), an egg parasitoid of the gypsy moth, was affected by host diet which affected egg mass odors of their attractiveness to the parasitoid (Hoffstetter and Raffa 1997). A pupal parasitoid, *Coccygomimus disparis* (Vierick) (Hymenoptera: Ichneumonidae), was somewhat successful in gypsy moth parasitism, but most stung pupae died as a result of other factors, such as disease, dessication, or parasitism by other parasitoids (Fuester *et al.* 1997).

These introduced predators and parasitoids have not suppressed the spread of gypsy moth populations. Neither have native predators such as the white-footed mouse, *Peromyscus leucopus*, and the masked shrew, *Sorex cinereus* Kerr, or insectivorous birds been able to keep gypsy moth numbers under control (Abrahamson and Klass 1985). Many factors determine the effectiveness of small mammal predators. Grushecky *et al.* (1998) demonstrated that silvicultural manipulations, such as thinning, did not influence the effectiveness of small mammal predators. However, in such different habitats,

predator search time for gypsy moth larvae and pupae may have increased as a result of more protective areas for gypsy moth in vegetation. Also, alternative food sources for mammals also may have increased, therefore limiting predation of gypsy moth (Grushecky *et al.* 1998). They also considered that with an outbreak of gypsy moth, small mammals may become heavily satiated and not be able to decrease gypsy moth numbers.

Several disease-causing agents including a nucleopolyhedrosis virus (NPV), a bacterium, *Bacillus thuringiensis* Berliner var. *kurstaki,* and a fungus, *Entomophaga maimaiga* Humber, Shimazu & Soper, have had an adverse effect on the gypsy moth and have helped to reduce and regulate populations of this pest in the northeastern United States (Reardon and Hajek 1993). Wilt disease is caused by NPV and has been demonstrated to kill up to 90 percent of the larvae in dense gypsy moth populations (Reardon and Hajek 1993). This disease may be associated with fluctuating population dynamics characteristic of many species of forest caterpillars. The NPV has been developed as a microbial pesticide, Gypcheck, which has an extremely narrow host range with no adverse effect on nontarget organisms (Reardon and Podgwaite 1992). However, little is known about the persistence of NPV at low host density (Dwyer and Elkinton 1993). This virus is spread as polyhedral inclusion bodies containing virions. The inclusion bodies are released into the environment upon the death of the diseased caterpillars. The released virions can accumulate in the soil and increase the infection and spread of NPV as host densities increase (Kukan and Myers 1997). They observed that levels of infection may remain high even as host densities decline from viral deaths. These high inoculum levels eventually help lead to the collapse of the population outbreak. They

also concluded that the virus was maintained in some infected caterpillars in sparse populations and that these "virus reservoirs" could provide inoculum to trigger an epizootic at high density populations.

Bacillus thuringiensis is the active ingredient in some biological insecticides that affect larvae of the gypsy moth. This bacterium produces protein crystals, which when ingested, release a toxin which disrupts the gut wall causing "paralysis" of the gut. The caterpillar ceases feeding and ultimately dies of starvation (Abrahamson and Klass 1985). Efficacy of *B. thuringiensis* varies with the timing of application, number of applications, and concentration of bacterium in pesticidal sprays (Andreadis *et al.* 1983). Because the gypsy moth is the most serious insect pest of eastern deciduous forests, over 2.3 million ha were sprayed with *B. thuringiensis* between 1980 and 1995 for suppression of the gypsy moth (USDA For. Serv. 1995). Concerns about the effect of *B. thuringiensis* on nontarget lepidopteran species have been raised in the past. Gypsy moth eradication programs often use multiple applications of *B. thuringiensis* which may increase mortality of nontarget lepidopterans. This potential increase in mortality of nontarget species may result in a decrease in species richness and abundance (Sample *et al.* 1996). Johnson *et al.* (1995) proposed that the toxicity levels for some sensitive species may reside on foliage for as much as one month after application.

Although *B. thuringiensis* is very beneficial when used against pest species, it can cause serious harm to native non-pest lepidopteran species. Whaley *et al.* (1998) tested the toxicity and developmental effects of *B. thuringiensis* on two nontarget lepidopterans in Utah. *Incisalia fotis* Strecker and *Callophrys sheridanii* W.H. Edwards (Lycanenidae),

whose phenologies match the gypsy moth, were used for this study. They determined that *B. thuringiensis* was toxic to both native species and that native populations can be adversely impacted. Drift deposition of *B. thuringiensis* on nontarget lepidopteran host plants could be found at 3,000 m from the site of application (Whaley *et al.* 1998).

Under certain environmental conditions, an exotic fungus, *Entomophaga maimaiga*, is successful in suppressing both high- and low-density gypsy moth populations. This fungus has been introduced into several pest-infested regions of the country (Reardon and Hajek 1993). *E. maimaiga* has spread throughout populations rapidly because its resting spores germinate in the soil and infect larvae, while airborne conidia cause secondary infections (Hajek *et.al.* 1996b). This fungus is only known to be pathogenic to larvae. The spores land on the hosts and a germ tube penetrates the cuticle. Inside the host, the fungus grows as protoplasts and colonizes the insect (Hajek *et al.* 1995). After *E. maimaiga* kills its host, it produces external conidia which may infect other larvae within the same season, and/or produce overwintering resting spores within cadavers.

As with any introduced biological control measure, it is important to consider its host range. From laboratory assays, Hajek *et al.* (1995) found that fungal penetration was highest among larvae with sculptured surfaces and many setae such as those in the gypsy moth family, Lymantriidae. It has been shown, however, that entomopathogens can infect hosts in the laboratory that are never infected in the field. Therefore, Hajek *et al.* (1996a) conducted another study to compare the host range of *E. maimaiga* in the field to that in the laboratory. They collected 1,511 larvae from areas in Virginia which contained high

levels of *E. maimaiga* infection rate in a moderately dense gypsy moth population. Two individuals, 1 of 318 *Malacosoma disstria* Hubner and 1 of 96 *Catocala ilia* (Cramer), were infected by *E. maimaiga*. Their laboratory assays yielded infection affecting a greater diversity of species. They concluded that laboratory host range data should be used as a liberal estimate of the environmental safety of insect pathogens because unknown factors determine the efficacy of pathogens in the field.

Diflubenzuron (Dimilin), an insect growth regulator, also was sprayed between 1980 and 1995 covering 1.7 million ha of eastern forests (USDA For. Serv. 1995). Greater suppression of gypsy moth populations is often achieved when utilizing both *B. thuringiensis* and diflubenzuron (Twardus and Machesky 1990). As discussed earlier, *B. thuringiensis* affects nontarget lepidopterans whereas diflubenzuron effects are more broad-spectrum producing reduction of mandibulate canopy arthropods (Martinat *et al.* 1988, Butler and Kondo 1993, Butler *et al.* 1997), spiders and orthopteroids in the litter layer (Martinat *et al.* 1993), and aquatic arthropods (Ali and Mulla 1978, Farlow *et al.* 1978, Eisler 1992).

A more group-specific insecticidal spray is tebufenozide (RH-5992) which acts as a mimic of natural insect molting hormones (Rohm and Haas Company 1989). Tebufenozide, an ecdysone agonist, stimulates the ecdysteroid receptors in lepidopteran larvae causing premature and lethal molts (Wing *et al.* 1988). Laboratory experiments by Smagghe and Degheele (1994) indicated that tebufenozide is specific to lepidopteran larvae. Butler *et al.* (1997) tested this hypothesis in mixed oak plots in Ohio. Their field study supported the laboratory data, and they concluded that tebufenozide is toxic to the

larvae of several lepidopteran species, but had no impact on coleopteran larvae, nymphs of Hemiptera or Orthoptera, and homopteran pests. Although this insecticide was lepidopteran-specific, it did have an adverse impact on nontarget lepidopteran species. If tebufenozide is used to effectively control gypsy moth populations, effects on nontargets may be serious causing substantial differences in macrolepidoptera species richness and abundance.

Currently, integrated pest management strategies are being incorporated into new programs for suppression and control of the gypsy moth. A database containing information on biological indicator insect species used to determine pest impact (i.e., native lepidopterans that feed on oaks) would be helpful in assessing forest health. Aspects such as relationships between hosts, predators, parasitoids, and pathogens of native species could be studied. At present, no comprehensive impact studies have been conducted in eastern Tennessee in relation to biodiversity indices before and after an invasion of gypsy moth. Information obtained on insect species native to the southern Appalachian mountains could serve as baseline data to be used in determining current forest composition. Data collected before a gypsy moth invasion would be useful to compare with post-invasive data to assess the impact of the gypsy moth on native species inhabiting southern Appalachian hardwood forests. Results from this study will be incorporated into database files to be used to assess biological control methods against the gypsy moth or to address other forest insect pest problems in Tennessee.

The objectives of this study were to:

1. assess the overall diversity of ground-dwelling insects inhabiting a mixed hardwood forest in eastern Tennessee,
2. determine the possible influence of habitat on insects collected using pitfall traps placed under three different tree species in four different collection plots, and
3. assess the species composition, seasonality, and abundance of selected insects collected in pitfall traps.

CHAPTER II

MATERIALS AND METHODS

This research was conducted in four plots (30.5 m^2 each) in a mixed hardwood forest of The University of Tennessee Forestry Experiment Station and Arboretum located in Oak Ridge, TN (Figure 1). Each plot contained three specified host tree species: white oak (tree 01), sugar maple, *Acer saccharum* Marsh, (tree 02), and tulip poplar (tree 03). These tree species were selected for their preference as a food source by the gypsy moth. The oaks are most preferred while the tulip poplar is almost never consumed. Each of the host trees was labeled with a metal tag which contained the plot number and tree number, i.e. 01-01 (Plot 01-Tree 01).

All four plots contain Fullerton series soil type based on a soil survey of Anderson County, TN, performed in 1978. This soil type consists of deep, well drained cherty soils that formed in residuum of dolomite. These soils are on ridges and hills with a range in slope from 5 to 45%.

Overstory and understory vegetation was similar in the four plots, but the plots differed in types of disturbance. Diameter at breast height (DBH) was measured for each host tree, and overstory tree composition was determined for each plot. Woody understory vegetation also was determined for those trees that grew under the canopy of each of the three selected host trees. Flora were identified using Radford *et al.* (1968). Latitude and longitude coordinates also were mapped at the center of each plot using a Global Positioning System (GPS) unit (Figure 2). Physical characteristics of each plot are described below.

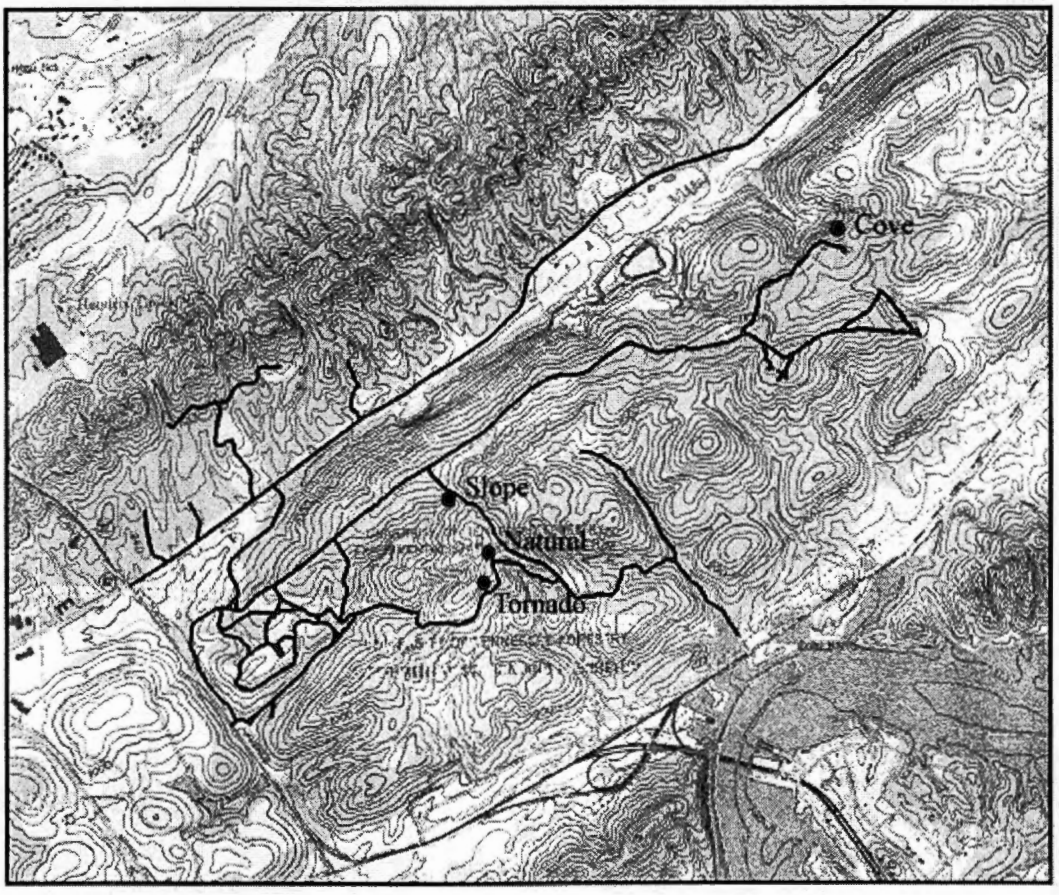


Figure 1. Location of the four collection plots in The University of Tennessee Forestry Experiment Station and Arboretum in Oak Ridge, Tennessee.

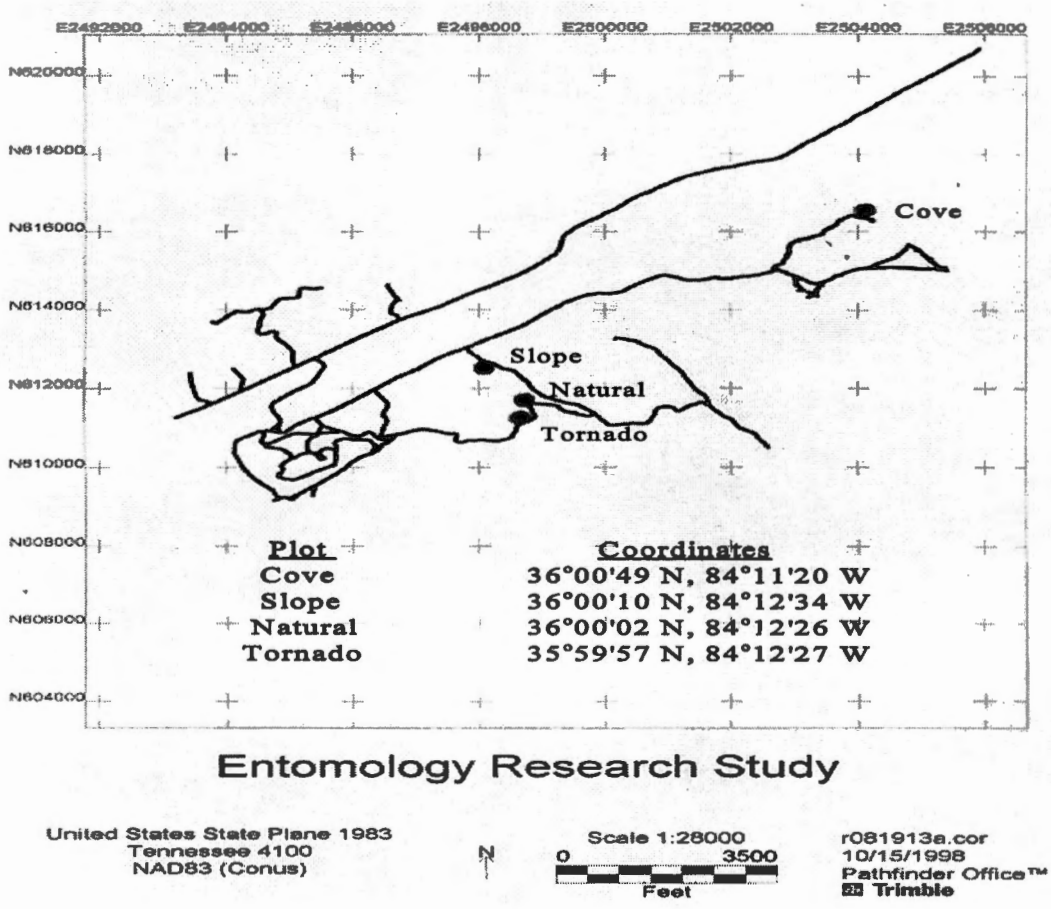


Figure 2. Global Positioning System coordinates for the four collection plots in The University of Tennessee Forestry Experiment Station and Arboretum in Oak Ridge, Tennessee.

Plot Descriptions

Cove (Plot 01): GPS coordinates = 36°00'49 N, 84°11'20 W

Plot 01 (hereafter referred to as the cove plot) was located between a quarry to the northwest and a clear-cut area to the east. This site was in a moist area that often collected rain water in the southern portion of the plot. The overstory tree composition included six white oak, six scarlet oak, *Quercus coccinea* Muenchh, five chestnut oak, *Quercus primus* L., four tulip poplar, three black gum, three mockernut hickory, *Carya tomentosa* (Poiret), three sugar maple, two northern red oak, two sourwood, *Oxydendrum arboreum* (L.), and one black oak, *Quercus velutina* Lam.

The white oak (tree 01-01) had a DBH of 11.0 cm and contained the following woody understory plants within its canopy: eight red maple, six black cherry, *Prunus serotina* Ehrhart,, four paw-paw, *Asimina triloba* (L.) Dunal., three sassafras, *Sassafras albidum* (Nuttall), two flowering dogwood, *Cornus florida* L., two mockernut hickory, two sourwood, one buckthorn, *Rhamnus caroliniana* Walter, one strawberry bush, *Euonymus americanus* L., and one sugar maple. The sugar maple (tree 01-02) had a DBH of 4.0 cm and contained the following woody understory plants within its canopy: three mockernut hickory, two black cherry, one hop-hornbeam, *Ostrya virginiana* (Miller) K. Koch, one flowering dogwood, one sourwood, and one white oak. The tulip poplar (tree 01-03) had a DBH of 7.6 cm and contained the following woody understory plants within its canopy: six sourwood, four flowering dogwood, three red maple, *Acer rubrum* L., three sassafras, two black cherry, two black gum, two mockernut hickory, two paw-

paw, two sugar maple, one buckthorn, one chestnut oak, one northern red oak, one scarlet oak, one tulip poplar, and one white oak.

Slope (Plot 02): GPS coordinates = 36°00'10 N, 84°12'34 W

Plot 02 (hereafter referred to as the slope plot) was located on a south-facing slope which was adjacent to a non-public access gravel road located within the arboretum. This site was somewhat eroded due to runoff from heavy rainfall. The overstory tree composition included 11 tulip poplar, six chestnut oak, four mockernut hickory, three black gum, three red maple, three southern red oak, three sugar maple, three white oak, one black oak, and one northern red oak.

The white oak, (tree 02-01) had a DBH of 11.4 cm and contained the following woody understory plants within its canopy: 16 buckthorn, 12 black cherry, 11 red maple, six black gum, five white oak, four flowering dogwood, four mockernut hickory, four sassafras, three black oak, three red bud (*Cercis canadensis* L.), two mulberry (*Morus rubra* L.), two northern red oak, one chestnut oak, one tulip poplar, and one white basswood (*Tilia americana* L.). The sugar maple (tree 02-02) had a DBH of 8.0 cm and contained the following woody understory plants within its canopy: 10 buckthorn, six black cherry, six mockernut hickory, three sourwood, three sugar maple, two northern red oak, two red maple, two tulip poplar, one red bud, one white basswood, and one white oak. The tulip poplar (tree 02-03) had a DBH of 14.1 cm and contained the following woody understory plants within its canopy: eight black cherry, six flowering dogwood, six red maple, five mulberry, four buckthorn, three mockernut hickory, two white basswood, one black gum, one red bud, one sugar maple, one tulip poplar, and one white oak.

Natural (Plot 03): GPS coordinates = 36°00'02 N, 84°12'26 W

Plot 03 (hereafter referred to as the natural plot) had less disturbance than the other three plots and seemed to be closer to a "natural" state than the other plots. The host trees also are larger in this plot, which has less herbaceous vegetation. The overstory tree composition included 14 sugar maple, 14 white oak, eight chestnut oak, six black gum, five sourwood, three black oak, two mockernut hickory, two tulip poplar, one black walnut, *Juglans nigra* L., and one white basswood.

The white oak (tree 03-01) had a DBH of 24.0 cm and contained the following understory plants within its canopy: 25 red maple, 17 buckthorn, seven black gum, seven sugar maple, five mockernut hickory, five mulberry, five tulip poplar, four black cherry, three sassafras, three white oak, two flowering dogwood, one northern red oak, and one unidentified hickory, *Carya* sp. Nuttall. The sugar maple (tree 03-02) had a DBH of 10.3 cm and contained the following understory plants within its canopy: eight mockernut hickory, seven sugar maple, five black cherry, four buckthorn, three black gum, three mulberry, one red bud, one red maple, one sourwood, and one tulip poplar. The tulip poplar (tree 03-03) had a DBH of 23.0 cm and contained the following understory plants within its canopy: 13 black cherry, 10 buckthorn, nine mockernut hickory, seven red maple, five sugar maple, five white oak, three black gum, two black oak, two mulberry, two sourwood, one chestnut oak, one flowering dogwood, one sassafras, and one white basswood.

Tornado (Plot 04): GPS coordinates = 35°59'57 N, 84°12'27 W

Plot 04 (hereafter referred to as the tornado plot) is a tornado-damaged area with many downed trees and new growth plants such as sassafras seedlings and blackberries, *Rubus* spp. L. This site was on top of a ridge and the overstory tree composition included 13 chestnut oak, nine black gum, four sourwood, three flowering dogwood, three northern red oak, two buckthorn, two sugar maple, one black oak, one red maple, one scrub pine, *Pinus virginiana* Miller, one tulip poplar, one white oak, and one unidentified hickory, *Carya* sp. Nuttall.

The white oak (tree 04-01) had a DBH of 11.9 cm and contained the following woody understory plants within its canopy: 75 sassafras seedlings, 12 red maple, four chestnut oak, four mockernut hickory, three black cherry, two black gum, two sourwood, two unidentified birch, *Betula* sp. L., one tulip poplar, and one winged sumac, *Rhus copallina* L. The sugar maple (tree 04-02) had a DBH of 7.0 cm and contained the following woody understory plants within its canopy: one large chestnut oak and 30 seedlings, 25 sassafras seedlings, 11 red maple, five black cherry, four mockernut hickory, three mulberry, two buckthorn, one black gum, and one black oak. The tulip poplar (tree 04-03) had a DBH of 8.4 cm and contained the following woody understory plants within its canopy: 15 red maple, seven sassafras, four buckthorn, three mockernut hickory, two black oak, two sugar maple, two white oak, one American beech, *Fagus grandifolia* Ehrhart, one black cherry, one black gum, one chestnut oak, one flowering dogwood, one sourwood, one tulip poplar, and several blackberries.

Collection of Insects

Ground-dwelling insect specimens were collected weekly from 26 June 1997 to 21 November 1997 and 26 March 1998 through 26 August 1998. During the winter season, traps were removed from the plots and replaced with an orange flag labeled with the plot number, tree number, and trap number. The traps were reinstalled during the spring of 1998. Field collections were performed by exchanging collection cups filled with propylene glycol with those collection cups that had been in the field each week. This process was repeated for each trap in all four collection plots. Forty eight samples were collected every week during the collection periods. Descriptions of the pitfall traps follows.

Pitfall Traps

Four pitfall traps were placed under each of the three specified host trees in each of the four plots. These traps were arranged approximately one-half the distance between the trunk and outer canopy edge of each selected tree and placed in the four cardinal directions with trap one in the north position.

Pitfall traps were constructed using a 450 ml metallic receptacle, with three to four holes in the bottom, holding a 120 ml specimen container filled with ca. 20 ml of propylene glycol. Holes were punched using a metal awl to ensure the proper drainage of rain water that may enter the metallic receptacle. A plastic funnel, made of overhead transparency plastic, was placed inside each receptacle to direct specimens into the collection container. A standard bulb planter and spade were used to dig a hole in the ground in which the metallic receptacles were placed. These metallic receptacles were

buried to a depth of 10.5 cm with the top of the receptacle flush with the ground. Wooden covers were constructed of a 30.5 cm^2 board supported by four baffles each measuring 40.6 cm in length. Covers were painted with brown spray paint to help camouflage them and also water-proof them. These covers were then placed over the collection containers to help direct insects into the containers and to keep rain and debris out of the collection containers. Specimen containers were easily exchanged, without damaging the soil walls, by removing the container from the metallic receptacle. Vice grips were used to ease the removal and insertion of the collection containers.

Samples were taken to the laboratory, and the contents of the collection cups were poured onto a 250 micron No. 60 mesh sieve with a collection pan below. The used propylene glycol was collected and stored in a plastic container, where it could be used again or disposed of properly. The propylene glycol was used a second time in the traps and was then deposited into recycle containers at a local car repair center. Insects were then rinsed with tap water to remove any excess propylene glycol. Cleaned insect specimens were returned to the original container with ca. 20 ml of 70% ethyl alcohol. Large organic matter was rinsed over the sieve to collect specimens, and then removed. Any fine organic matter remaining in the sieve also was returned to the original container with the insects, to insure that no small organisms were lost from each sample. Each container was labeled with collection date, plot number, tree number, and trap number.

Specimen Preparation and Species Identification

Samples were sorted for trap one, which represented the north position under each host tree, for each of the host trees every two weeks (12 samples). Time did not permit for all samples to be sorted for this project, but all unsorted samples were rinsed and stored in 70% ethyl alcohol for future sorting and identification. Therefore, 48 samples were collected weekly but only twelve of these 48 samples were sorted biweekly. Upon sorting the samples, non-insect arthropods were placed in separate vials filled with 70% ethyl alcohol and were not included in any further sorting.

All specimens sorted were identified using standard keys. Holldobler and Wilson (1990) and Cole (1940) were used in the identification of Hymenoptera: Formicidae. Downie and Arnett (1996) and Dillon and Dillon (1961) were used to identify the Coleoptera. Helfer (1953) was used for the Orthoptera and Blattaria. McAlpine *et al.* (1981) and McAlpine (1987) were used for the Diptera, and Borror *et al.* (1989) was used for all other orders. Each sample was sorted according to order, family, genus, and species when possible.

Representatives of all species collected were pinned, or stored in a vial with 70% ethyl alcohol, labeled (family and species name, locality, collector, and determiner) and systematically arranged into Cornell drawers for incorporation into the insect museum of The University of Tennessee. These representative insects will be used as voucher specimens for future identification of the unsorted samples that were collected in this study. Species codes, which were assigned to each insect species, consists of a capital letter denoting the insect order (either the first letter of the order name or some

combination of the first letters contained in the order name, or the entire order name was used) followed by a number (1, 2, 3, ...). The number was determined by how many other specimens in that order had already been identified. For instance, the second ant identified would be given the species code H2 representing the order Hymenoptera species number two. These codes were designed to be used with the database Biota. Each code is representative of a different insect type. A list of the species codes and identification of insect species is presented in the appendix.

Data Analyses

All insect data were incorporated into the database Biota (Colwell 1996). Insect samples collected provided a relative representation of the overall insect diversity existing within each plot. By using every other week's sampling data, species composition, seasonality and abundance were determined for selected insects. Population densities were graphed for the beetles and ants to better understand the seasonal trends of these groups within each plot. Some of the ants and beetles collected may be important predators of potential forest pests.

The number of insects collected was tabulated per date for each plot, tree, and trap. These numbers were grouped by species code, order, and family and analyzed using Statistical Analysis Software (SAS Institute 1997, 1989). Five models were used in the analysis: diversity, order, family, ants and beetles. Analysis of Variance (ANOVA) was used to determine significant differences ($P< 0.05$) for comparisons among plots, trees, insect orders, insect families, and dates. The means were calculated and compared using a

Least Significant Difference (LSD) mean separation to compare the overall abundance of orders, families, genera, and species. Due to unequal variances, log transformation of the data was completed before any analysis was made.

The overall diversity of insects for each plot and host tree was determined using the Shannon diversity index ($H = -\Sigma(p_i \ln p_i)$, where ln = natural log and p_i = the proportion of individuals of the total sample belonging to the i^{th} species) (Newell 1997 and Smith 1992). Species codes were used for this analysis. The index considers the number of species as well as their relative abundance. Species diversity values range from 0 to 5 but usually fall between 1.5 and 3.5, rarely exceeding 4.5. Species richness and evenness also were determined for each plot location. Species richness is simply the total number of species present in an area. This number was calculated for the plots and traps by adding the number of species collected in each plot and the total collected in each trap, respectively. Evenness (J) was determined by $J = H/H_{max}$ using $H_{max} = \ln S$ where S = number of species (Smith 1992). Species evenness values range from zero to one, with one representing the most even value. Species diversity, richness, and evenness also were determined for the ant and beetle species separately.

Comparisons also were made for the three parameters: diversity, richness, and evenness. ANOVA and LSD were utilized by SAS to determine the significant differences ($P<0.05$) for species codes, ants, and beetles in relation to plot, tree, and date.

CHAPTER III

RESULTS AND DISCUSSION

Insect Diversity

A total of 20,906 insect specimens was collected and sorted from The University of Tennessee Forestry Experiment Station and Arboretum during 1997 and 1998. These specimens were classified into 18 insect orders representing 87 families. The four most abundant orders included Collembola (49%), Hymenoptera (20%), Diptera (15%), and Coleoptera (9%). The total number of specimens collected in each of the 18 orders for all four plots is presented in Table 1. Ants (Formicidae) composed approximately 88% of the hymenopterans collected. Diptera were mostly represented by hump-backed flies in the family Phoridae (63%) and by unidentified larvae (21%). Twenty one families of beetles were collected with 79% represented by four families: Staphylinidae (41%), Scarabaeidae (13%), Nitidulidae (13%), and Carabidae (12%).

In a comparison of insect totals collected per plot, significantly ($P<0.05$) more specimens were collected in the cove plot than in any other plot, and significantly ($P<0.05$) fewer were collected in the slope plot than the other three plots. The cove plot was more habitable to a greater number of insect specimens, suggesting that most ground-dwelling insects require higher moisture levels and seek out more secluded forested areas. During the winter of 1997, a neighboring forest stand was clear-cut. This nearby disturbance may have caused more insects to migrate into the cove plot after this incidence occurred. Also, after heavy rains, a portion of the cove plot retains water, thus increasing the overall

Table 1. Total number of insects collected per plot in The University of Tennessee Forestry Experiment Station and Arboretum in 1997 and 1998.

Insect Order	Cove	Slope	Natural	Tornado	Total Collected
Blattaria	107	70	85	53	315
Coleoptera	580	410	379	460	1829
Collembola	2106	2660	2618	2816	10200
Diplura	1	0	0	1	2
Diptera	1216	563	677	655	3111
Hemiptera	50	48	56	32	186
Homoptera	12	14	16	18	60
Hymenoptera	1361	711	862	1289	4223
Isoptera	3	3	3	1	10
Lepidoptera	18	12	19	49	98
Microcoryphia	21	31	22	8	82
Neuroptera	4	1	0	1	6
Orthoptera	299	101	139	161	700
Plecoptera	0	1	0	0	1
Psocoptera	11	15	12	5	43
Siphonaptera	0	1	0	0	1
Thysanoptera	5	5	15	9	34
Thysanura	5	0	0	0	5
TOTAL	5799	4646	4903	5558	20906

moisture content of the soil in this area. Therefore, many insects inhabiting the cove plot may be able to avoid dessication during the dry summer months. This plot had a greater activity level among the insects which is revealed in the increased catches from this plot.

Similarly, significantly ($P<0.05$) more ants and beetles were collected in the cove plot in comparison to the other plots. Again, this variation can be explained by the isolated location and high moisture level of this plot. Significant differences may also be a result of the clear-cut of an adjacent forest stand, which may have caused an influx of ant and beetle species into the habitat. The slope, natural, and tornado stands could be less attractive to insect species because of the different types of disturbance or because of the different biotic components of each plot.

The overall order and family analyses did not show any significant differences in numbers of insects collected per host tree. Differences may have been revealed if all samples collected were analyzed for this study. Differences were found, however, for the ants and beetles in relation to host tree. Significantly ($P<0.05$) more ants and beetles were collected in the trap under sugar maple and significantly fewer were collected in the trap under tulip poplar. The numbers of beetles and ants collected under white oak did not significantly ($P>0.05$) differ in comparison to the other tree species.

Higher insect catches under the sugar maple may suggest that many of the ants and beetles collected were attracted to its sugary sap. The sugar maple is also a large tree with a rounded, dense crown, which may provide shelter for ground-dwelling insects. Sugar maples are generally shorter (21-30 m) than the tulip poplar (80-120 m) and the white oak (24-30 m) with a wider canopy closer to the forest floor (Little 1996).

Tulip poplar is one of the tallest eastern hardwoods with a long, straight trunk and a narrow crown (Little 1996). This tree does not provide much shelter for ground-dwellers and is probably the reason that fewer specimens were collected in traps associated with this tree species. On the other hand, white oak is a tree with many wide-spreading branches and a rounded crown. It is surprising that no significant ($P>0.05$) differences were found in relation to this species in comparison to the other two host species. Again, differences may be found when the remaining samples are sorted and analyzed with the current data. The understory vegetation was similar for each of the three host trees in each of the four plots, which may help explain the lack of significant differences among the numbers of specimens collected in traps under the three tree species.

Insects were assigned species codes and identified to species when possible. Approximately 187 species were collected in this study. Table A1 lists each species code, order, family, genus, and species when positive identification was determined. Species diversity was highest in the cove plot with a value of 1.75 and a species evenness value of 0.67 (Table 2). Higher species diversity and evenness in the cove plot suggests that significantly ($P<0.05$) more species inhabit the cove plot in comparison to the other three plots. Species richness was significantly higher in the cove plot (ca. 44) than the slope plot (ca. 39) and the tornado plot (ca. 39), while the natural plot (ca. 41) did not significantly differ among the plots. The diversity indices presented in Table 2 suggest that the four plots are generally species diverse with an even representation of the species inhabiting these plots within a mixed hardwood ecosystem.

Table 2. Diversity indices for species collected per plot in The University of Tennessee Forestry Experiment Station and Arboretum representing 22 collection dates from 1997 to 1998.

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

* Means ± SE. Means followed by different letters are not significantly different (LSD Test; P>0.05).

Diversity indices also were compared among the four plots for the Hymenoptera: Formicidae and the Coleoptera. Ant species diversity and richness was highest in the cove and slope plots and lowest in the tornado plot (Table 3). The slope plot had the highest ant species evenness (0.86). Most of the ants collected are subterranean and may require higher moisture levels as are available in the cove plot. The slope plot may be more ideal for those ant species which require leaf litter and debris to make their nests. Leaf litter and various types of debris may be accumulated in areas of the slope plot due to rain water runoff. Downed trees in the tornado plot may deter ground-dwelling ant populations from inhabiting these areas. Species that build their nests in logs or stumps may be attracted to this area after the wood becomes rotten. Many of the ants collected form nests in the soil, under stones, or in rotten logs or stumps. These characteristics can be found in all four plots and is probably the reason that few significant differences were found among the diversity indices presented in Table 3.

Beetle species diversity and richness did not differ among the four plots. However, species evenness was significantly ($P<0.05$) higher in the natural plot (0.95) and lower in the tornado plot (0.89) (Table 4). The natural plot has a denser canopy cover and a more open forest floor. Beetles may be able to move more freely throughout the natural plot in comparison to the tornado plot, which contains a lot of ground cover. Beetle activity may be hindered in the tornado plot, therefore reflecting a lower species evenness value than that of the natural plot. Beetle diversity indices may not have been different among the plots because the beetles collected were all active and able to travel in each plot with no regard to the terrain or any other differences in biotic or abiotic factors.

Table 3. Diversity indices of ant species collected in pitfall traps in The University of Tennessee Forestry Experiment Station and Arboretum representing 22 collection dates from 1997 to 1998.

	Ant Species Diversity	Ant Species Richness	Ant Species Evenness
Cove	0.87 ± 0.05 a*	10.94 ± 0.17 a	0.75 ± 0.02 b
Slope	0.90 ± 0.05 a	10.43 ± 0.19 a	0.86 ± 0.03 a
Natural	0.83 ± 0.05 ab	9.73 ± 0.18 ab	0.81 ± 0.02 ab
Tornado	0.70 ± 0.05 b	8.81 ± 0.18 b	0.81 ± 0.02 ab

* Means ± SE. Means followed by different letters are not significantly different (LSD Test; P>0.05).

Table 4. Diversity indices of beetle species collected in pitfall traps in The University of Tennessee Forestry Experiment Station and Arboretum representing 22 collection dates from 1997 to 1998.

	Beetle Species Diversity	Beetle Species Richness	Beetle Species Evenness
Cove	0.94 ± 0.07 a*	12.22 ± 0.30 a	0.92 ± 0.01 ab
Slope	0.81 ± 0.07 a	11.17 ± 0.33 a	0.92 ± 0.02 ab
Natural	0.98 ± 0.07 a	11.29 ± 0.31 a	0.95 ± 0.01 a
Tornado	0.95 ± 0.07 a	10.96 ± 0.30 a	0.89 ± 0.01 b

* Means ± SE. Means followed by different letters are not significantly different (LSD Test; P>0.05).

Insect Abundance and Seasonality

Almost all of the insects were collected evenly among the four plots except for some less commonly collected insects that may have been collected only once throughout the study. Several species of beetles were represented by only a few collected specimens. Some of these less encountered specimens were unidentified members of the families Staphylinidae, Curculionidae, Elateridae, Ptilodactylidae, Coccinellidae, and Scaphidiidae. Only one specimen of an introduced Chrysomelidae, *Demotina modestus,* was collected from the natural plot.

Other less commonly collected beetles included several carabid beetles. Only one specimen of *Pterostichus coracinus* Newman and one specimen of *Melanius caudicalis* (Say) were collected from the natural plot. Single specimens of *Chlaenius emarginatus* (Say) and *Dicaelus ambiguus* LeFerte-Senectere were collected from both the cove and slope plots, respectively. *Dicaelus dilatatus* Say was represented by two collected specimens from the slope plot and one specimen from the natural plot. Some of the identified Staphylinidae that were not frequently collected were *Philonthus cyanipennis* (Fabricius), one specimen collected from the cove plot, and *Philonthus blandus* (Gravenhorst), one from the slope plot and one from the tornado plot. Only two specimens of *Canthon hudsonias* Forester (Scarabaeidae) were collected from the natural plot. Two less commonly collected Scarabaeidae included *Phyllophaga hirticula* (Knoch), a single specimen from the cove plot, and one *Onthophagus hectate* Panzer specimen each from both the slope and tornado plots. Two silphid beetles, *Necrophilus pettiti* Horn, were collected from the tornado plot and two nitidulids, *Phenolia grossa*

(Fabricius), were collected from the cove plot. The family Troginae was represented by one specimen, *Trox variolatuss* Melsheimer, collected in the tornado plot, while two individuals of a tenebrionid, *Anaedus brunneus* (Siegler), were collected from the natural and tornado plots. *Sericoderus lateralis* (Gyllenhal) in the family Orthoperidae was collected only once in the natural plot. Four species of Nitidulidae were collected with one unidentified species represented by six specimens collected from all of the plots except for the slope plot. The beetles, as well as the ants, are important in this study because some may be potential predators of forest pests. For this reason, we must determine the overall abundance of these organisms.

Although the ants were represented by 24 species, six of these were seldomly collected. *Pheidole dentata* Mayr and *Solenopsis molesta* (Say) were both represented by one specimen each collected in the tornado plot. Also, *Leptothorax pergandei* Emery was represented by only one individual collected from the slope plot. *Aphaenogaster texana carolinensis* Wheeler had one individual collected in the cove plot and one in the slope plot. *Amblyopone* sp. Erichson was a less commonly encountered genus and was only represented by two specimens and one specimen collected from the cove plot and the natural plot, respectively.

These individuals represent some of the specimens that were less encountered in this study and represented by less than ten specimens collected during the two-year collection period. The following are some of the more frequently collected orders and families. Seasonality graphs will be presented for those species which were collected in abundance of 10 specimens each during the two-year study.

Collembola

The order Collembola was the most abundant group of insects collected. A total of 10,200 Collembola was collected representing approximately one-half of the insects collected. Twenty one percent were collected from the cove plot with 26%, 25% and 28% collected in the slope, natural, and tornado plots, respectively. Collembola were collected throughout the collection period with an increase in numbers during July and August of 1997 and in May and July in 1998 (Figure 3). Individual specimens were not identified further than order and were simply counted to determine the overall abundance of these insects in a mixed hardwood ecosystem. These insects are ecologically important organisms in leaf litter as they aid in nutrient cycling and are a valuable food source for predaceous arthropods inhabiting the forest floor.

Hymenoptera

A total of 4,223 Hymenoptera was collected with 3,733 belonging to the family Formicidae. Seasonal variation for the Hymenoptera followed that of the most abundant family, Formicidae, with more insects collected during 1997 than in 1998 (Figures 4 and 5). In the family Formicidae, four subfamilies were identifed: Formicinae, Myrmicinae, Ecitoninae, and Ponerinae. Twenty-four species of ants were identified (Table A1). The Formicinae, Myrmicinae, Ecitoninae, and Ponerinae contained 12, 9, 1, and 2 species, respectively. Seasonality graphs are presented for 11 Formicinae species, four Myrmicinae species, and one Ecitoninae species (Figures 6-21).

Paratrechina sp. is an interesting species collected. This ant feeds on both live and dead insects, seeds, and honeydew (Krombein *et al.* 1979). This omnivorous genus may

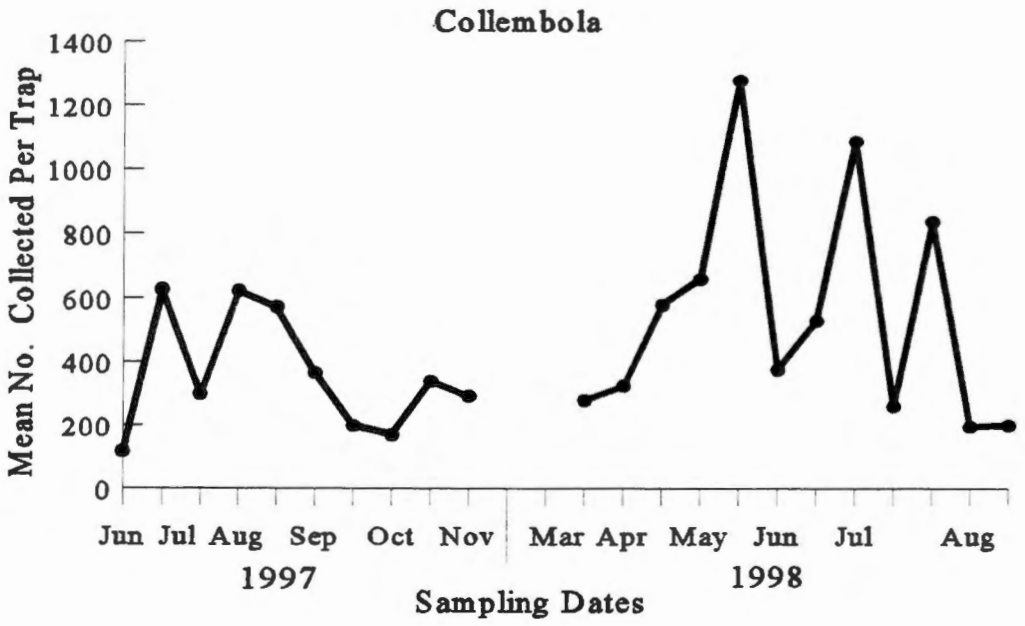


Figure 3. Mean number of Collembola collected per pitfall trap for each collection date during 1997 and 1998.

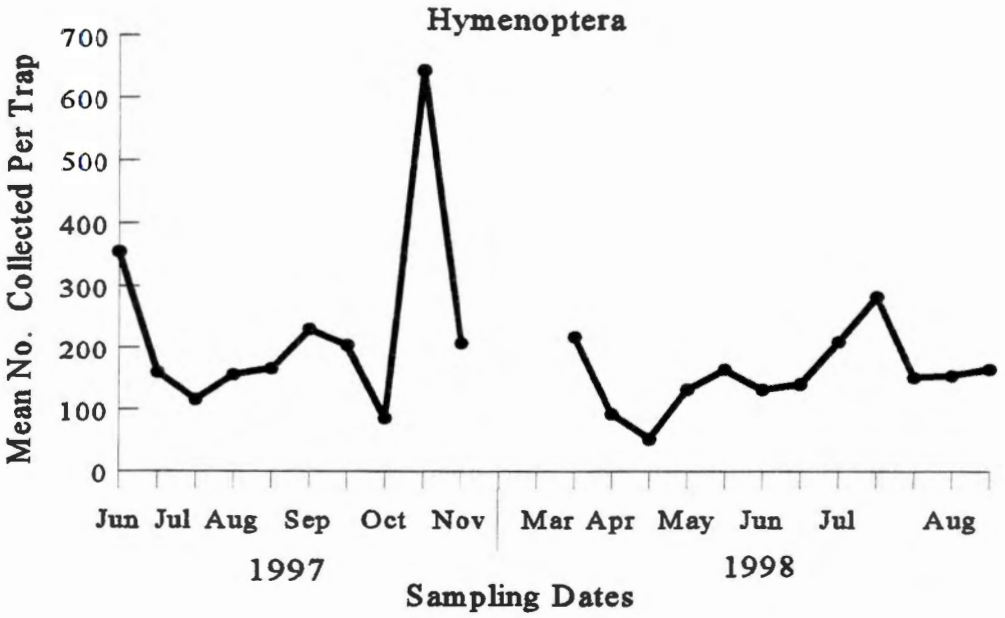


Figure 4. Mean number of Hymenoptera collected per pitfall trap for each collection date during 1997 and 1998.

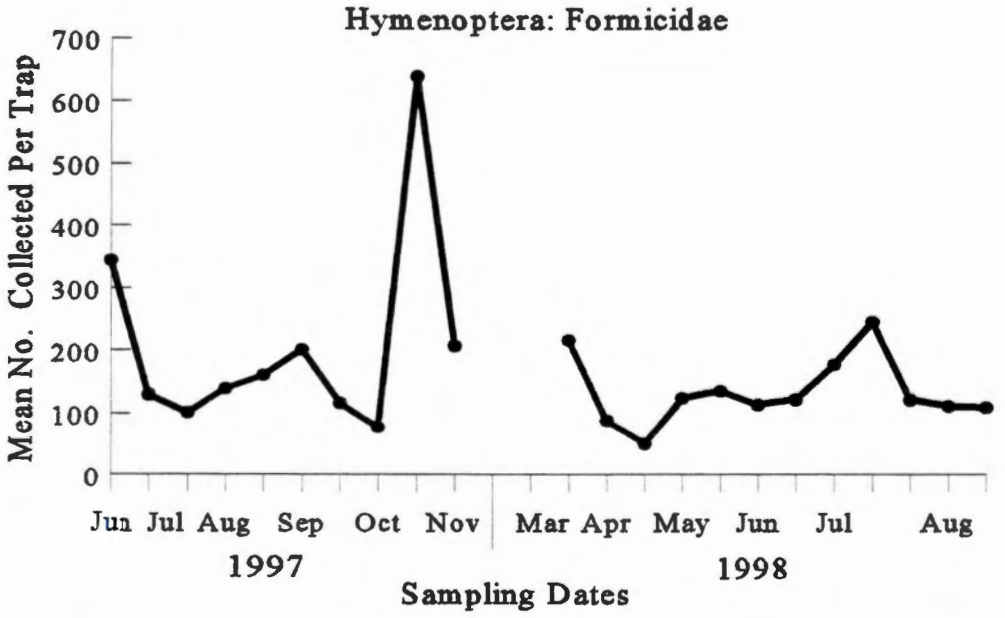


Figure 5. Mean number of Formicidae collected per pitfall trap for each collection date during 1997 and 1998.

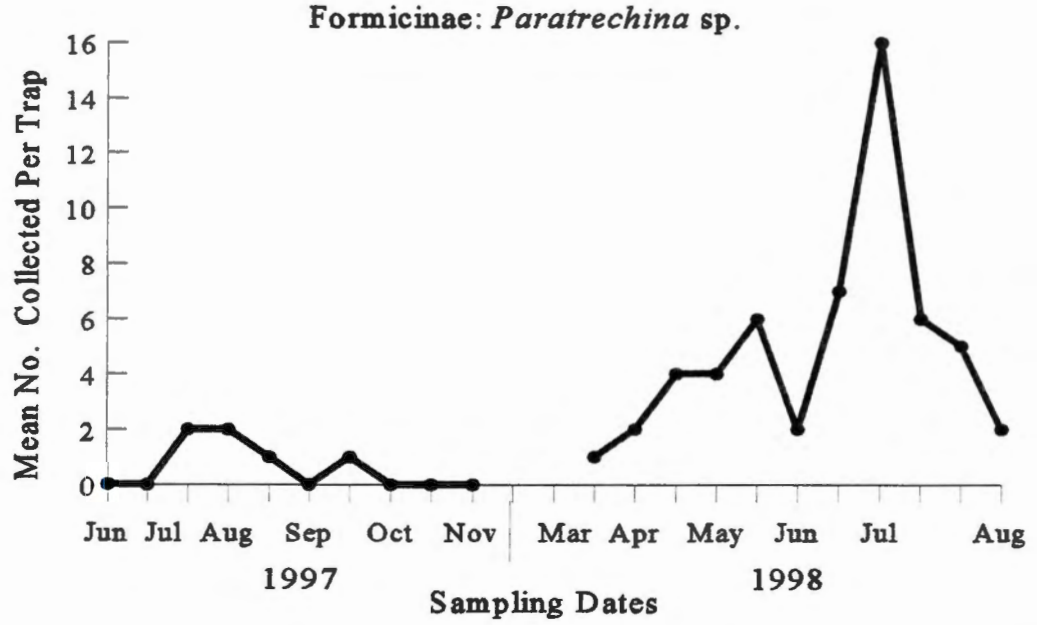


Figure 6. Mean number of *Paratrechina* sp. collected per pitfall trap for each collection date during 1997 and 1998.

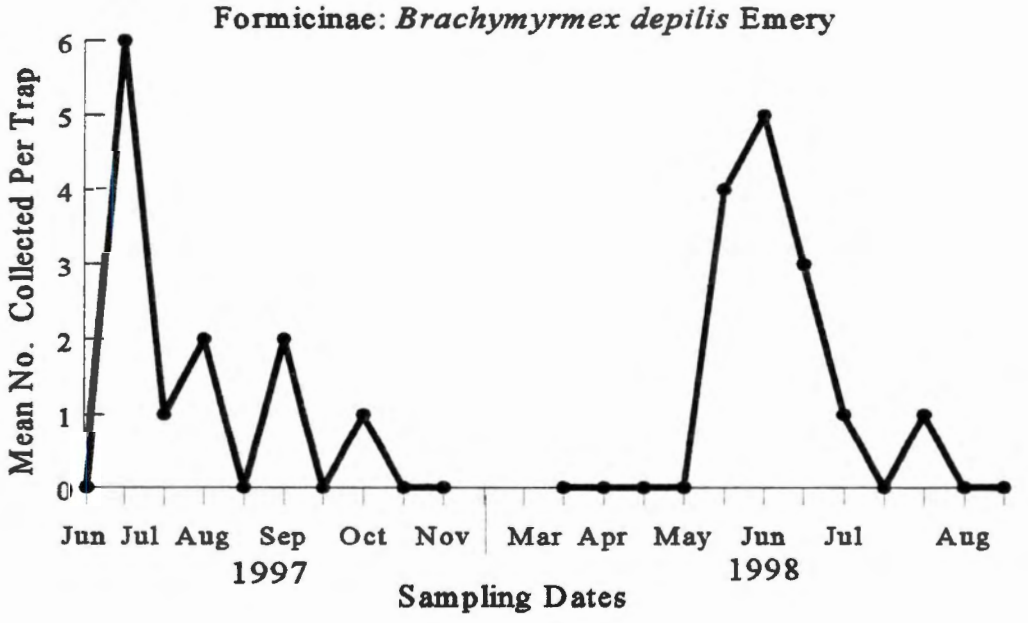


Figure 7. Mean number of *Brachymyrmex depilis* Emery collected per pitfall trap for each collection date during 1997 and 1998.

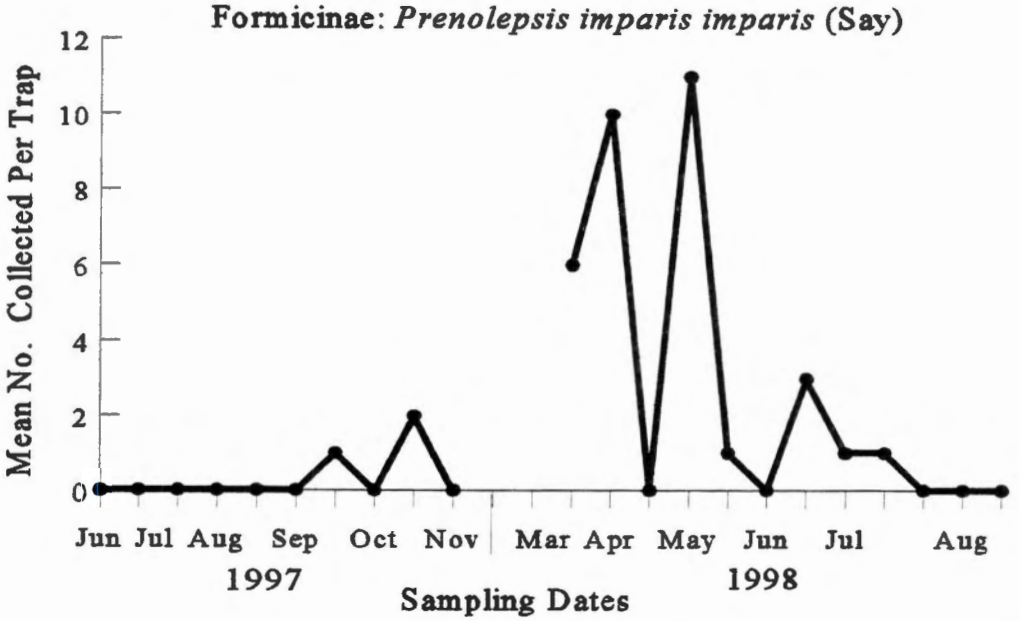


Figure 8. Mean number of *Prenolepsis imparis imparis* (Say) collected per pitfall trap for each collection date during 1997 and 1998.

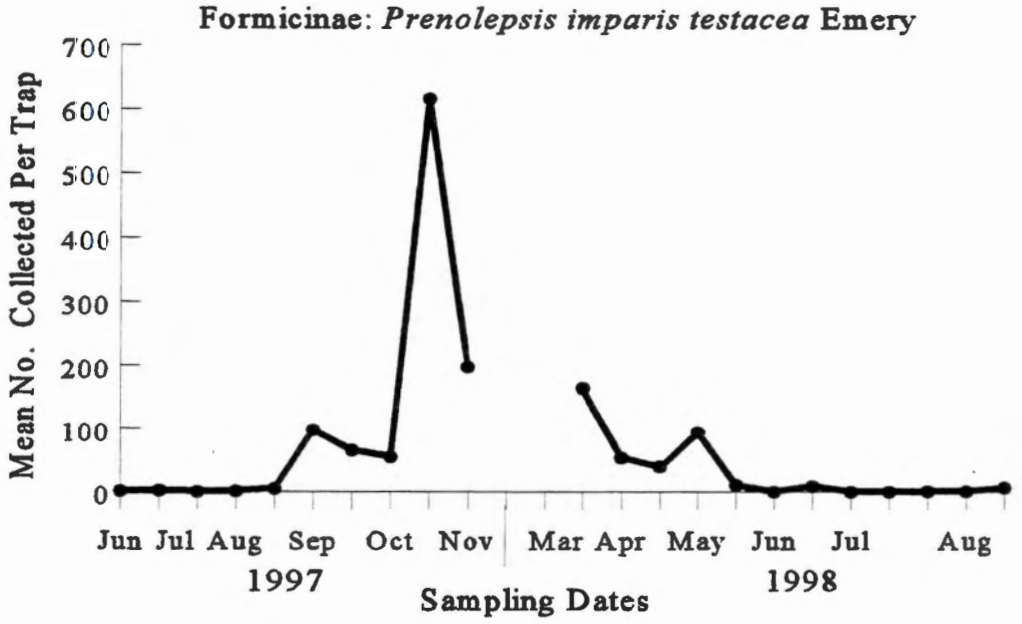


Figure 9. Mean number of *Prenolepsis imparis testacea* Emery collected per pitfall trap for each collection date during 1997 and 1998.

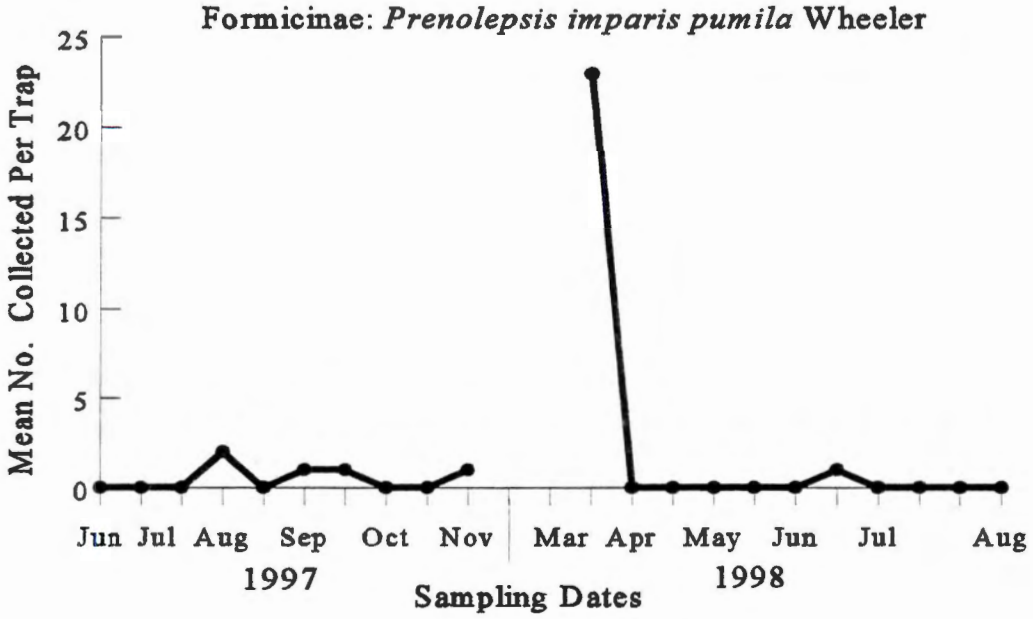


Figure 10. Mean number of *Prenolepsis imparis pumila* Wheeler collected per pitfall trap for each collection date during 1997 and 1998.

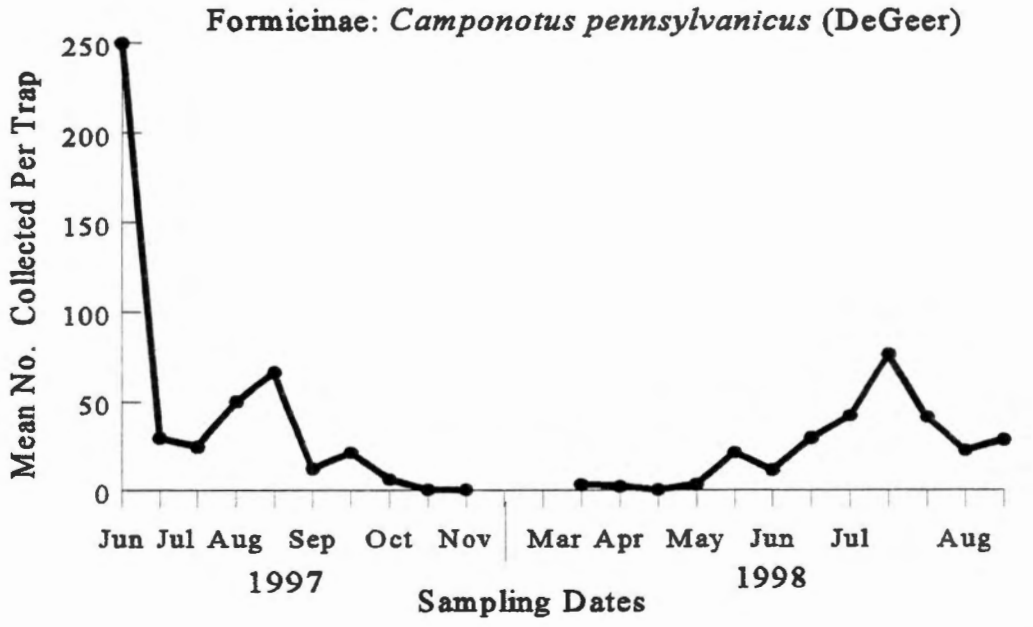


Figure 11. Mean number of *Camponotus herculeans pennsylvanicus* DeGeer collected per pitfall trap for each collection date during 1997 and 1998.

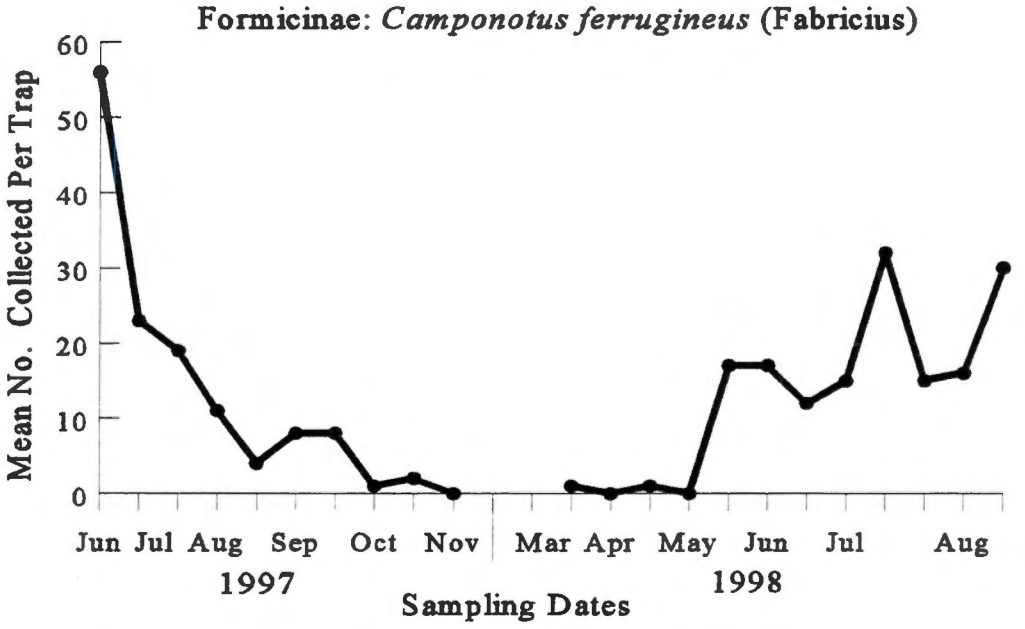


Figure 12. Mean number of *Camponotus ferrugineus* (Fabricius) collected per pitfall trap for each collection date during 1997 and 1998.

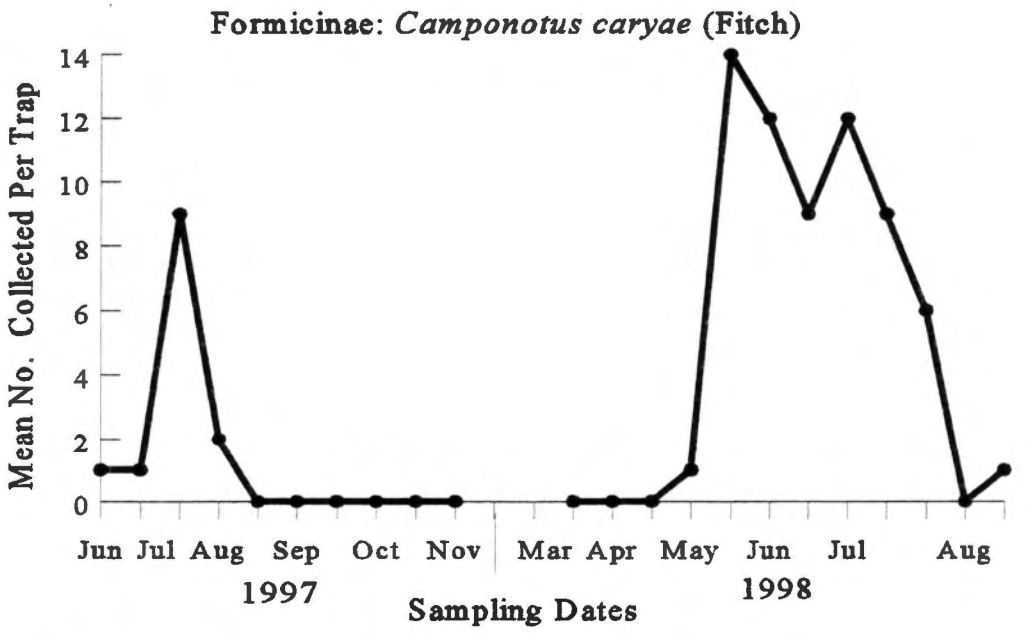


Figure 13. Mean number of *Camponotus caryae* (Fitch) collected per pitfall trap for each collection date during 1997 and 1998.

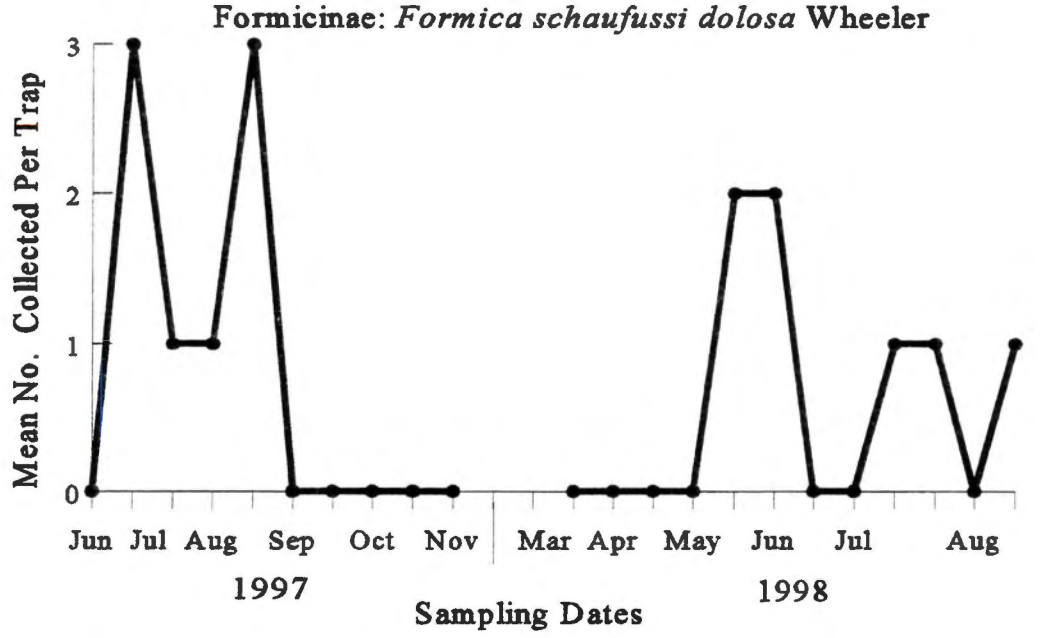


Figure 14. Mean number of *Formica schaufussi dolosa* Wheeler collected per pitfall trap for each collection date during 1997 and 1998.

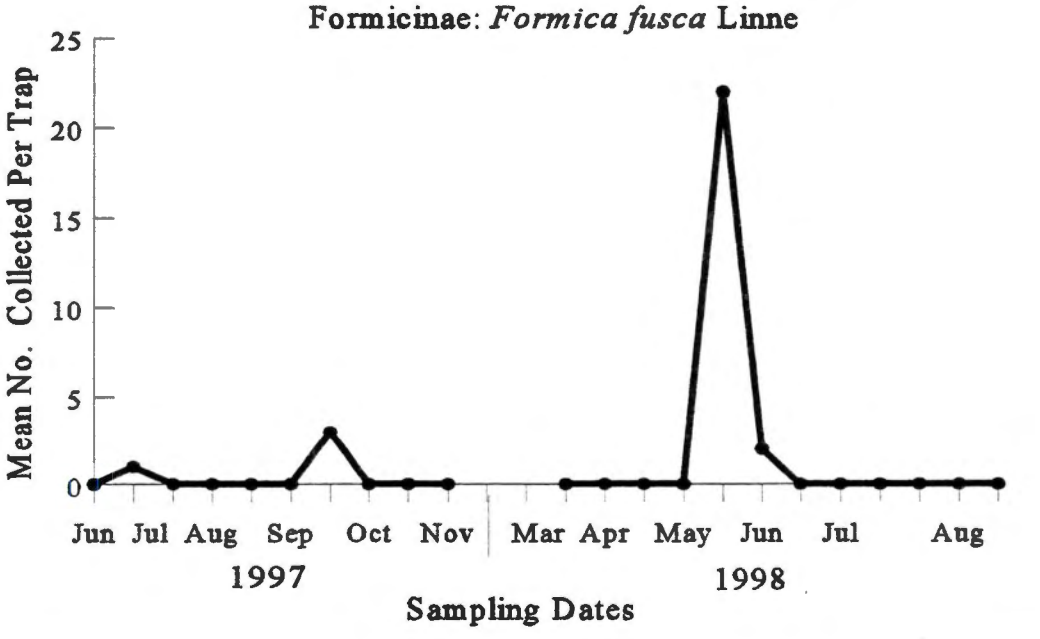


Figure 15. Mean number of *Formica fusca* Linne collected per pitfall trap for each collection date during 1997 and 1998.

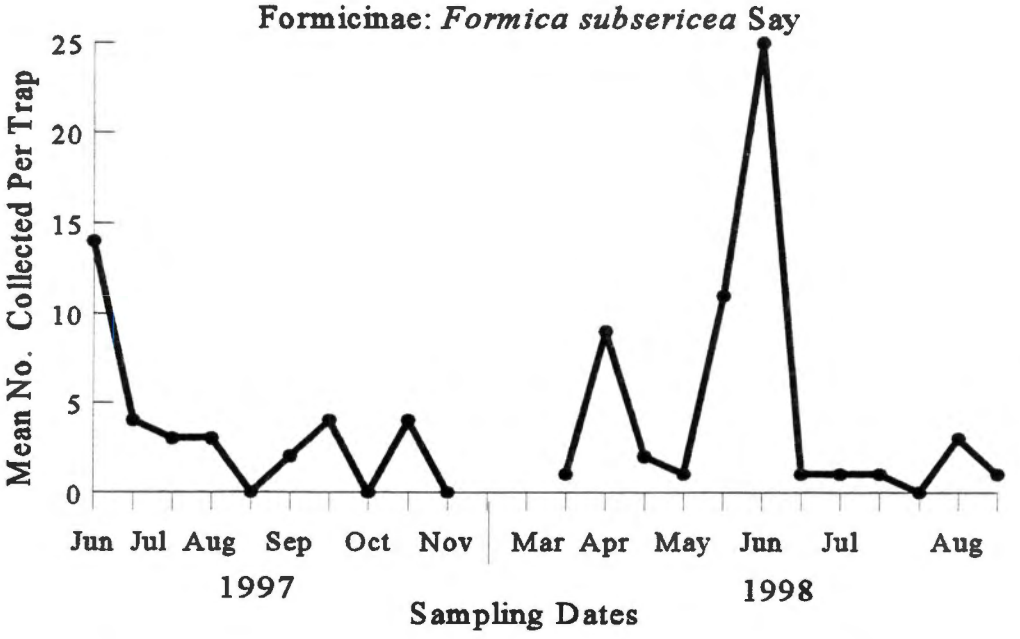


Figure 16. Mean number of *Formica subsericea* Say collected per pitfall trap for each collection date during 1997 and 1998.

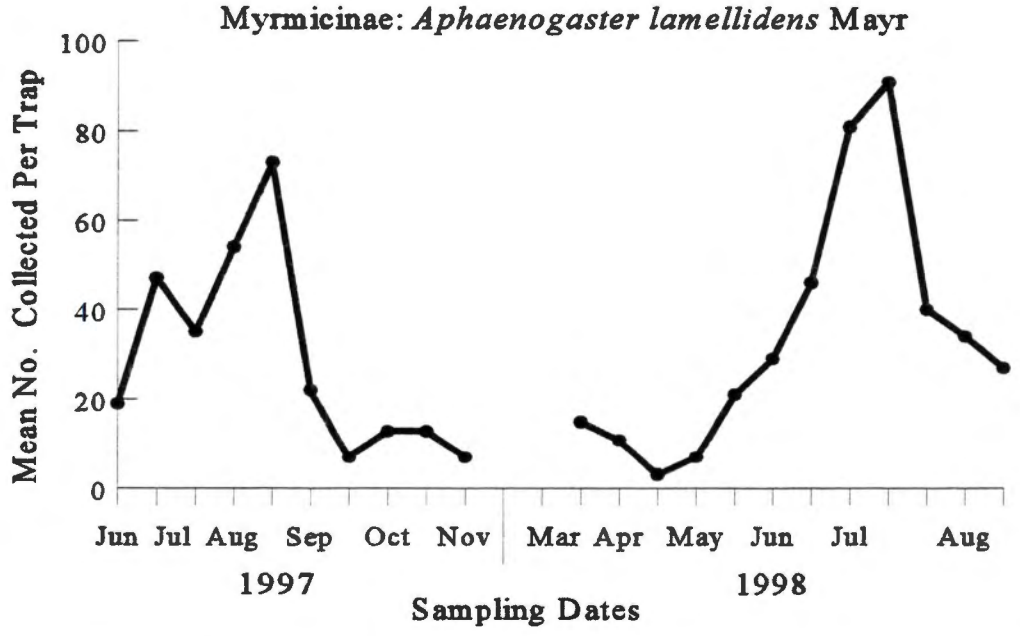


Figure 17. Mean number of *Aphaenogaster lamellidens* Mayr collected per pitfall trap for each collection date during 1997 and 1998.

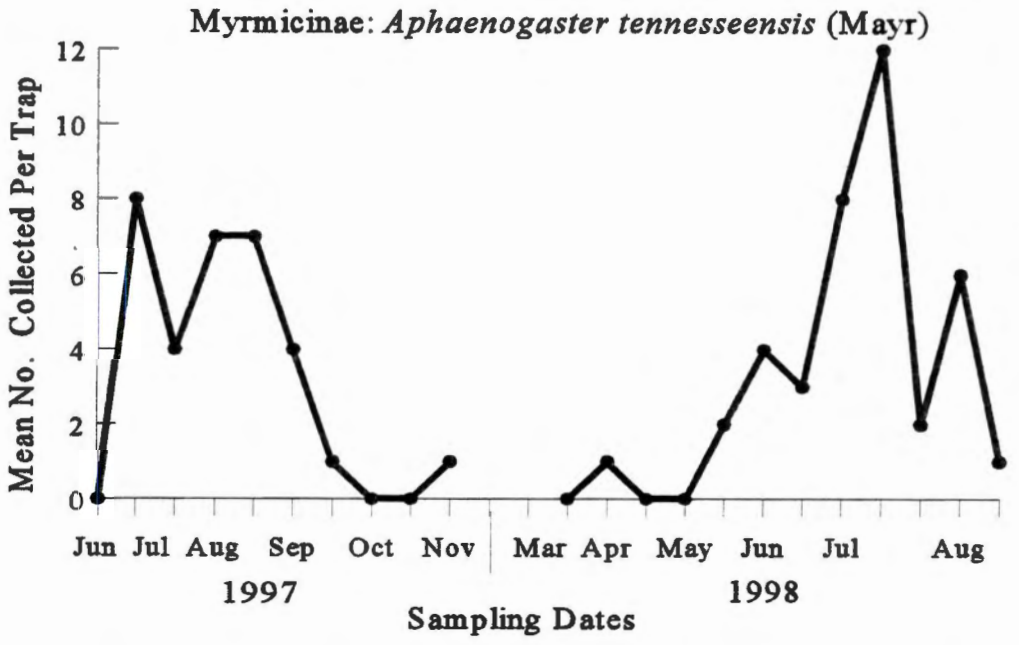


Figure 18. Mean number of *Aphaenogaster tennesseensis* (Mayr) collected per pitfall trap for each collection date during 1997 and 1998.

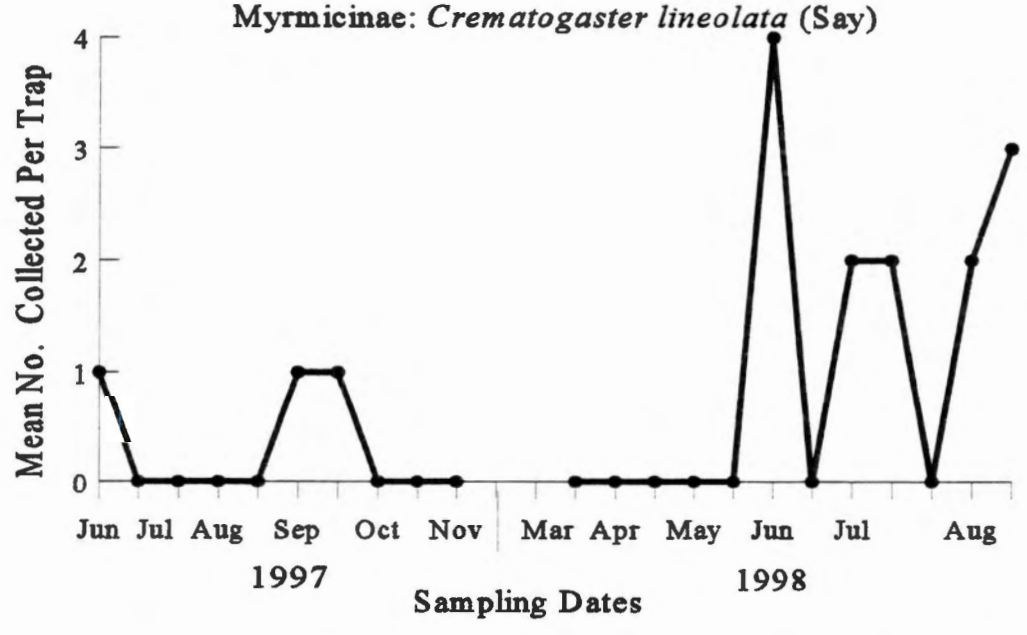


Figure 19. Mean number of *Crematogaster lineolata* (Say) collected per pitfall trap for each collection date during 1997 and 1998.

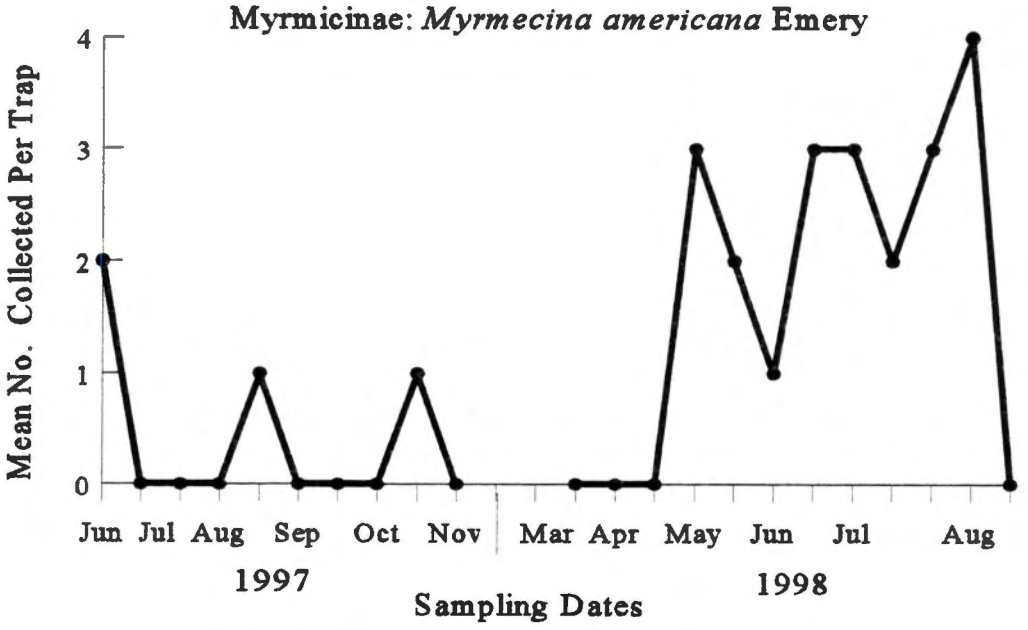


Figure 20. Mean number of *Myrmecina americana* Emery collected per pitfall trap for each collection date during 1997 and 1998.

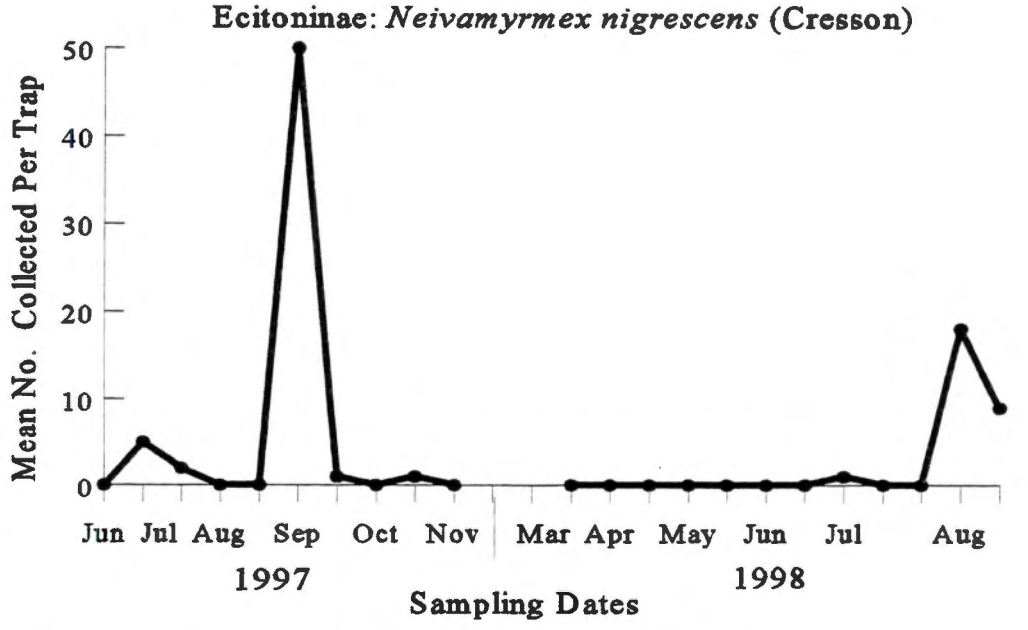


Figure 21. Mean number of *Neivamyrmex nigrescens* (Cresson) collected per pitfall trap for each collection date during 1997 and 1998.

build its nests under trees such as sugar maple, thus attributing to the higher number of ants collected in traps under this tree species. Increased numbers were collected in 1998 (Figure 6), probably because the sampling dates included their time of foraging.

Brachymyrmex depilis Emery is another species that may construct its nests under sugar maples, as these ants are fond of honeydew and attend honeydew excreting insects. Similarly, *Crematogaster lineolata* (Say) is omnivorous but does show a preference for "sweets." Few specimens of *B. depilis* Emery were collected but numbers collected were similar for both 1997 and 1998 (Figure 7). Inversely, more specimens of *C. lineolata* were collected in 1998 in comparison to 1997 (Figure 19).

Three *Prenolepsis imparis* (Say) spp. were collected with their populations peaking in the fall and early spring (Figures 8-10). *P. imparis* (Say) species nest in the soil in exposed situations or under cover in small to moderate sized colonies (Krombein *et al.* 1979). *Prenolepsis* workers feed on a variety of food sources, including: honeydew, floral secretions, gall exudates, arthropods, earthworms, and fruit. These species differ from most ant species because they forage during cool weather and aestivate during the hottest months. These trends are revealed in Figures 8-10.

Aphaenogaster spp. are known to feed on live and dead insects and some are considered temporary parasites in ground nests of other *Aphaenogaster* species (Krombein *et al.* 1979). On the other hand, some of the *Formica* species are hosts of slave-making species of *Formica*. *A. lamellidens* Mayr and *A. tennesseensis* (Mayr) showed similar trends in populations between the two years (Figures 17 and 18).

Probably the most beneficial potential predator collected was *Neivamyrmex nigrescens* (Cresson). This species is a diurnal forager that is highly predaceous on other insects (Krombein *et al.* 1979). Fewer specimens of *N. nigrescens* were collected in 1998 than in 1997 (Figure 21), but the low occurrence in 1998 is most likely a result of not sampling through October for this year. This ant species can construct large colonies containing 150,000 to 250,000 workers (Krombein *et al.* 1979).

Diptera

Diptera was the third most abundant order collected (n = 3,111). Fifteen families were identified: Calliphoridae, Cecidomyidae, Chironomidae, Chloropidae, Drosophilidae, Muscidae, Otitidae, Phoridae, Psychodidae, Rhagionidae, Sarcophagidae, Sciaridae, Sphaeroceridae, Tachinidae, and Tipulidae. Phoridae was the most abundant family with 1,965 specimens collected representing 63%. Dipteran larvae also were abundant (21%) with 657 unidentified larval specimens. Overall abundance was highest in the summer months, and substantially more Diptera were collected in 1997 than 1998 (Figures 22 and 23). However, more dipteran larvae were collected in 1998 (Figure 24). These differences are most likely reflected in different sampling dates for the two years and seasonal changes in the weather.

Coleoptera

Twenty one families of Coleoptera were identified from pitfall trap collections. This order constitutes the fourth most abundant representing 9% of all insects with 103 species identified. From the 1,829 beetles collected, the highest numbers were obtained in July of 1997 (Figure 25). The four most abundant families were Staphylinidae (14 species

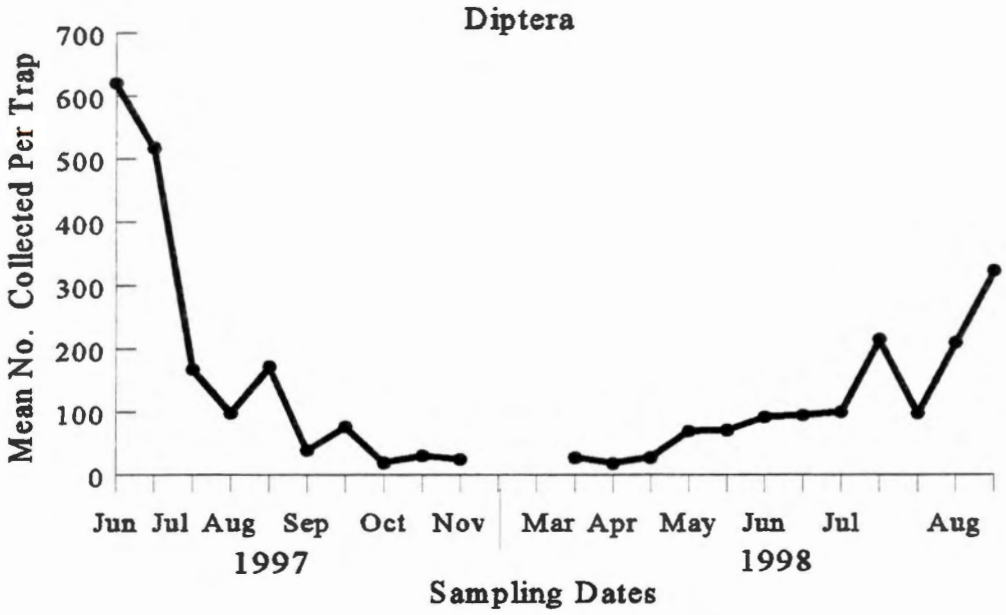


Figure 22. Mean number of Diptera collected per pitfall trap for each collection date during 1997 and 1998.

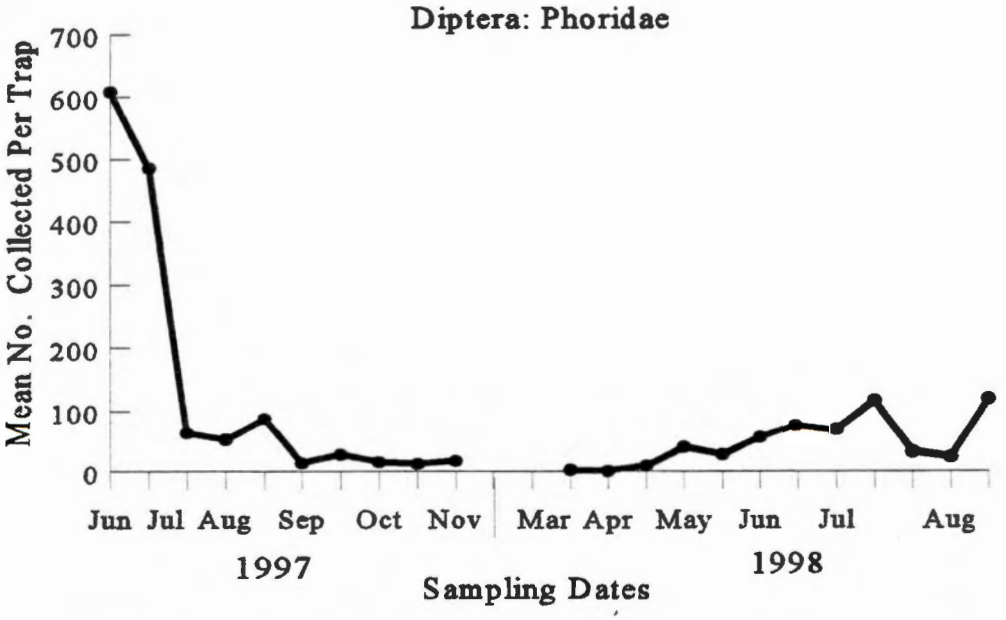


Figure 23. Mean number of Phoridae collected per pitfall trap for each collection date during 1997 and 1998.

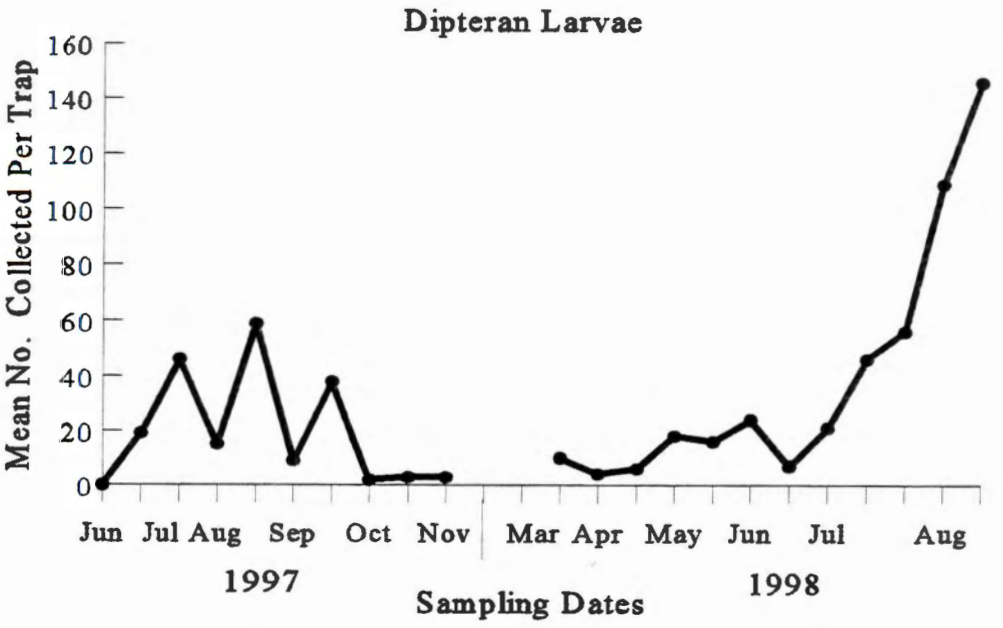


Figure 24. Mean number of dipteran larvae collected per pitfall trap for each collection date during 1997 and 1998.

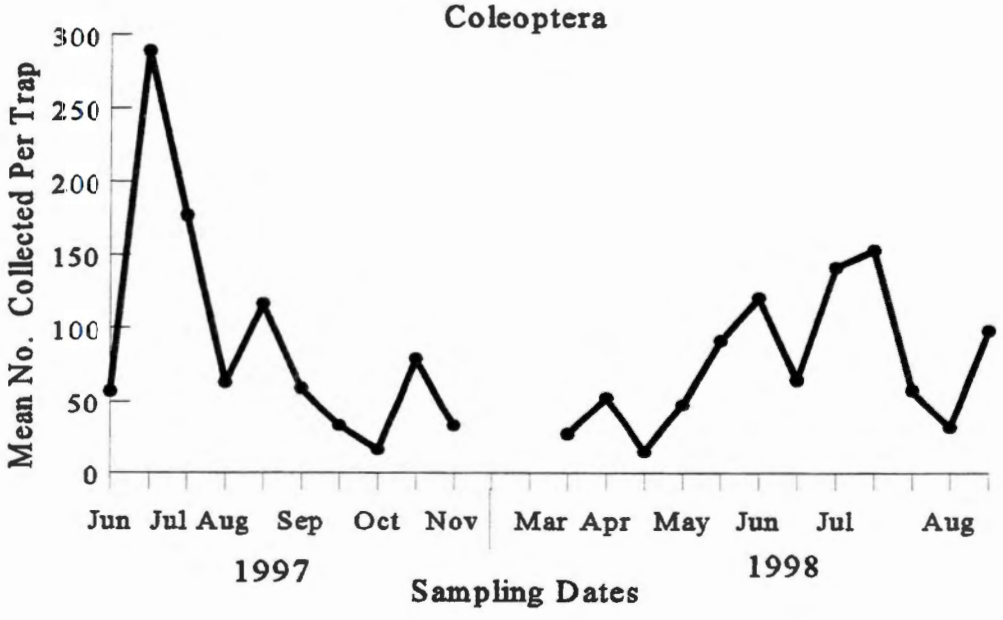


Figure 25. Mean number of Coleoptera collected per pitfall trap for each collection date during 1997 and 1998.

= 41%), Scarabaeidae (13 species = 13%), Nitidulidae (3 species = 13%), and Carabidae (21 species = 12%). Many of the beetles collected are predators both as larvae and adults. The Staphylinidae and Carabidae are two families with many predaceous members.

Staphylinidae is one of the largest Coleopteran families with 219 genera and 2,141 species in North America (Downie and Arnett 1996). Most are predatory as larvae and adults but many feed on fungus and pollen. In general, species numbers increase in the summer months from June to July for those collected in The University of Tennessee Forestry Experiment Station and Arboretum in 1997 (Figure 26). Five (Figures 27-31) of the six species presented follow this trend, but *Tachinus fimbriatus* Gravenhorst had two population peaks in 1997, one around July and one in October (Figure 32). *T. fimbriatus* Gravenhorst populations also may have increased in 1998 if sampling had not ceased in August.

Scarabaeidae (n = 236) and Nitidulidae (n = 232) were collected in similar numbers, each representing about 13% of the Coleoptera. Scarab beetles are usually found under stones and wood and many are scavengers, leaf eaters, and chafers. The scarabs collected in pitfalls are similar to the Staphylinids collected, in that population peaks occurred between June and July (Figure 33). However, one species, *Coprius miumutus* (Drury), was collected only during October and November of 1997 (Figure 34). The remaining species (Figures 35-39) occurred during the summer months and higher numbers were collected in 1997 than in 1998 with two exceptions: *Deltochilum gibbosum* (Fabricius) (Figure 38) and *Geotrupes splendidus* (Fabricius) (Figure 39), which were collected in higher numbers in 1998.

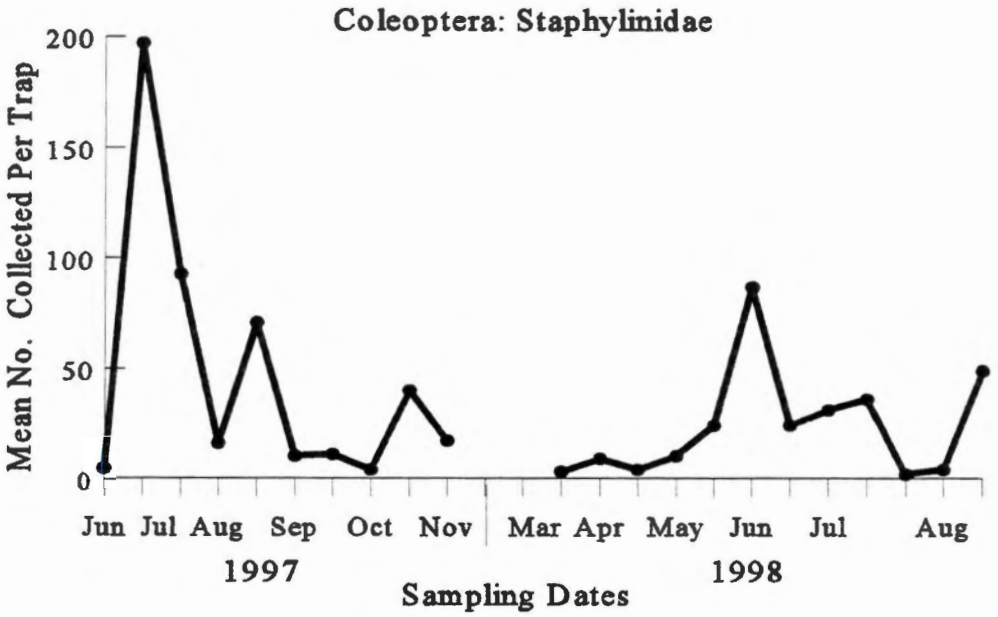


Figure 26. Mean number of Staphylinidae collected per pitfall trap for each collection date during 1997 and 1998.

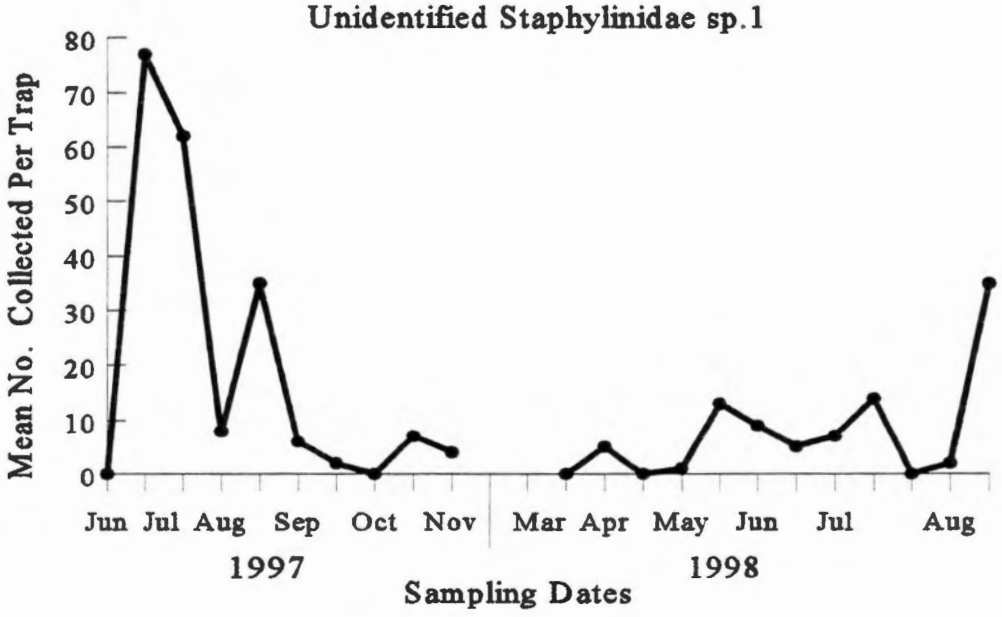


Figure 27. Mean number of Unidentified Staphylinidae sp. 1 collected per pitfall trap for each collection date during 1997 and 1998.

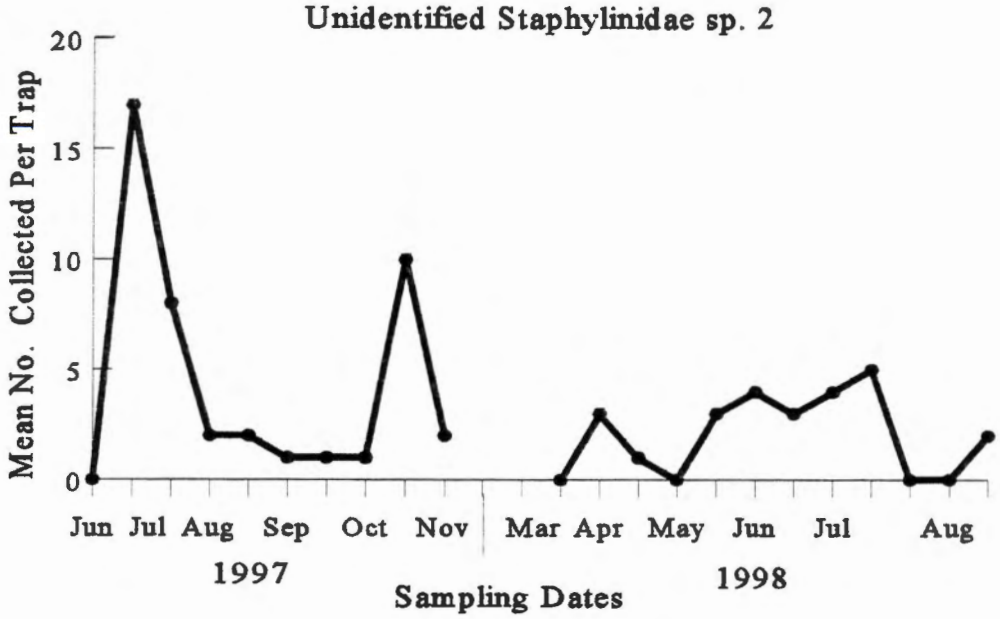


Figure 28. Mean number of Unidentified Staphylinidae sp. 2 collected per pitfall trap for each collection date during 1997 and 1998.

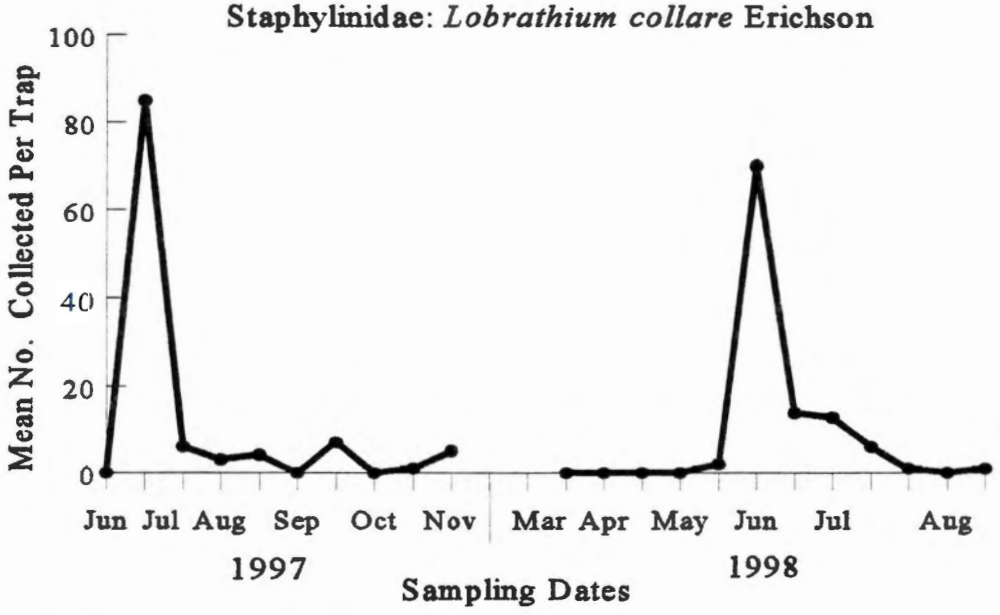


Figure 29. Mean number of *Lobrathium collare* Erichson collected per pitfall trap for each collection date during 1997 and 1998.

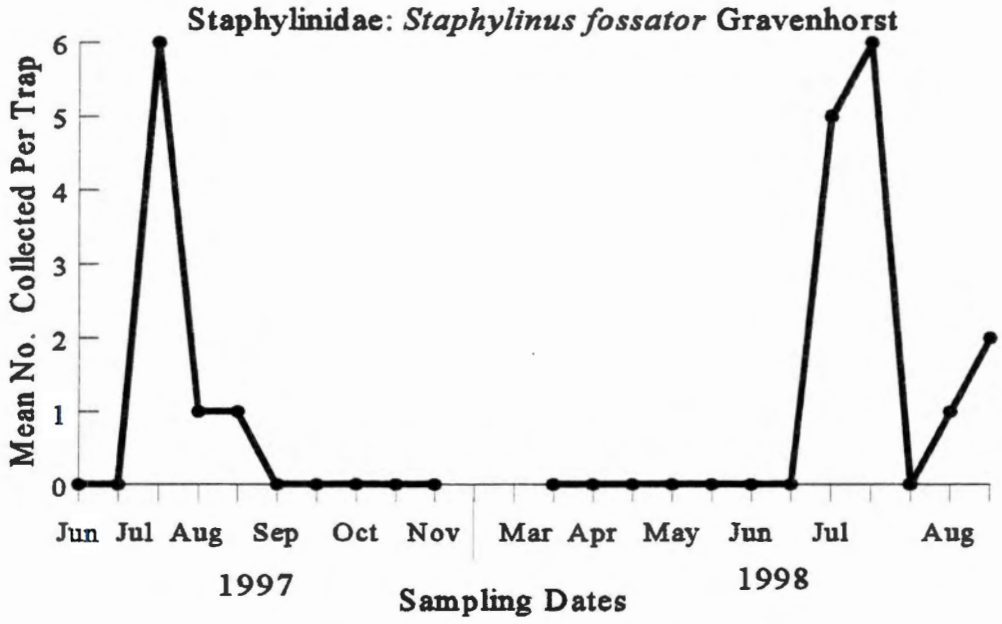


Figure 30. Mean number of *Staphylinus fossator* Gravenhorst collected per pitfall trap for each collection date during 1997 and 1998.

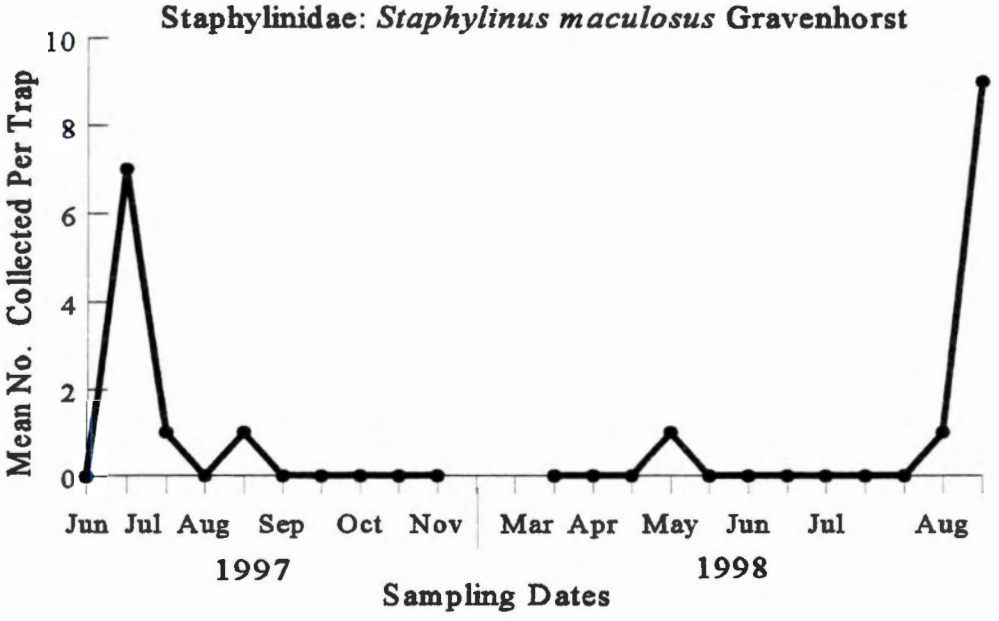


Figure 31. Mean number of *Staphylinus maculosus* Gravenhorst collected per pitfall trap for each collection date during 1997 and 1998.

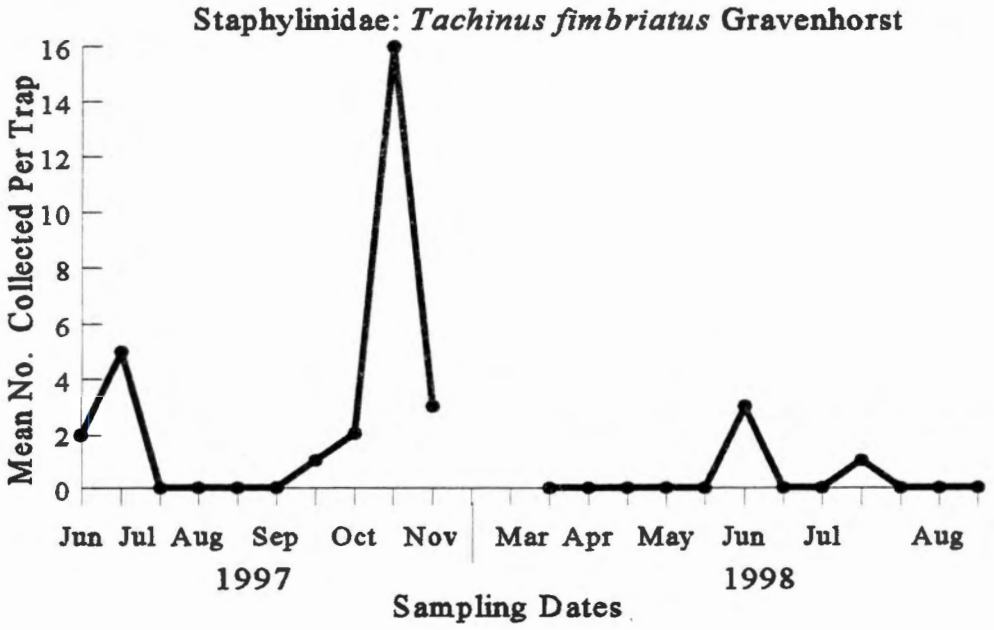


Figure 32. Mean number of *Tachinus fimbriatus* Gravenhorst collected per pitfall trap for each collection date during 1997 and 1998.

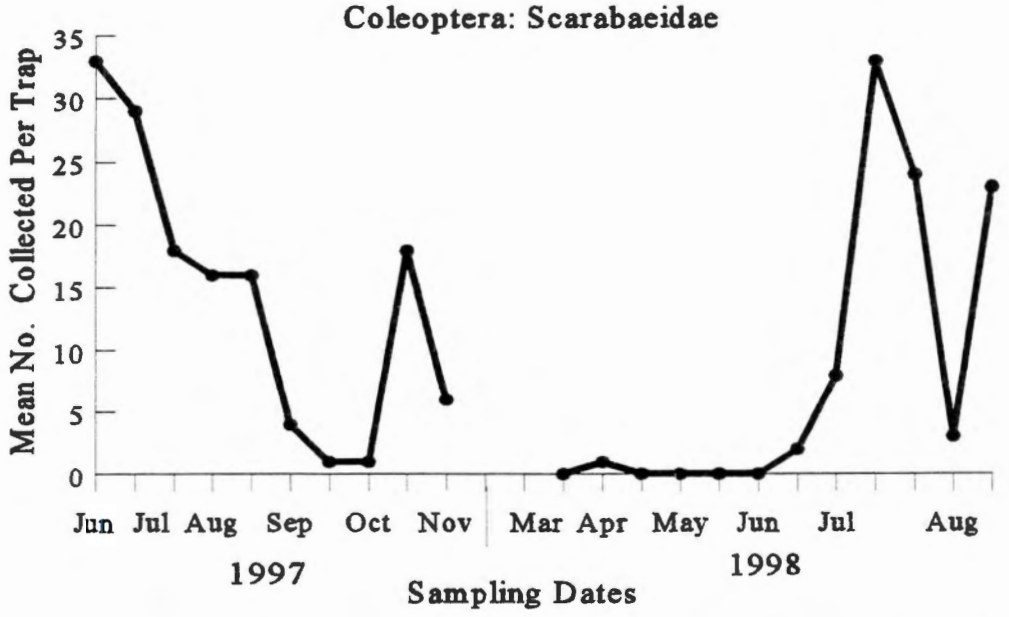


Figure 33. Mean number of Scarabaeidae collected per pitfall trap for each collection date during 1997 and 1998.

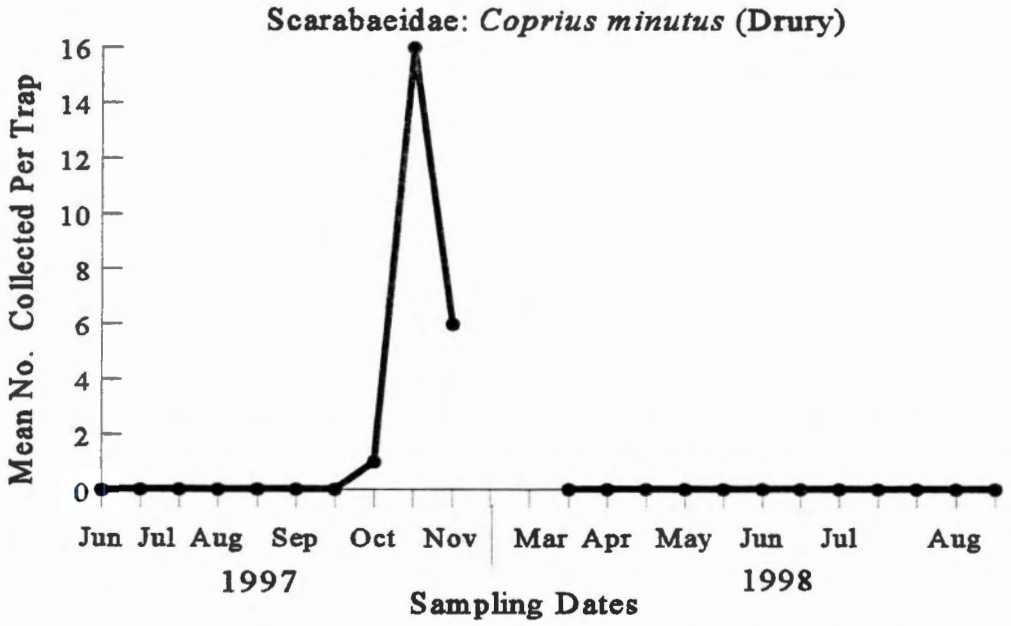


Figure 34. Mean number of *Coprius minutus* (Drury) collected per pitfall trap for each collection date during 1997 and 1998.

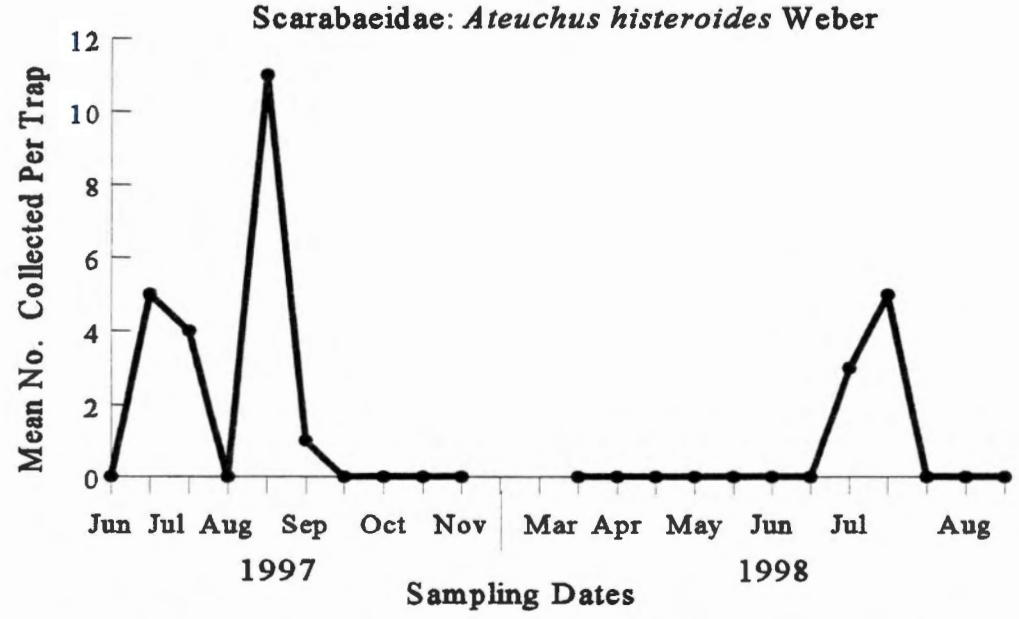


Figure 35. Mean number of *Ateuchus histeroides* Weber collected per pitfall trap for each collection date during 1997 and 1998.

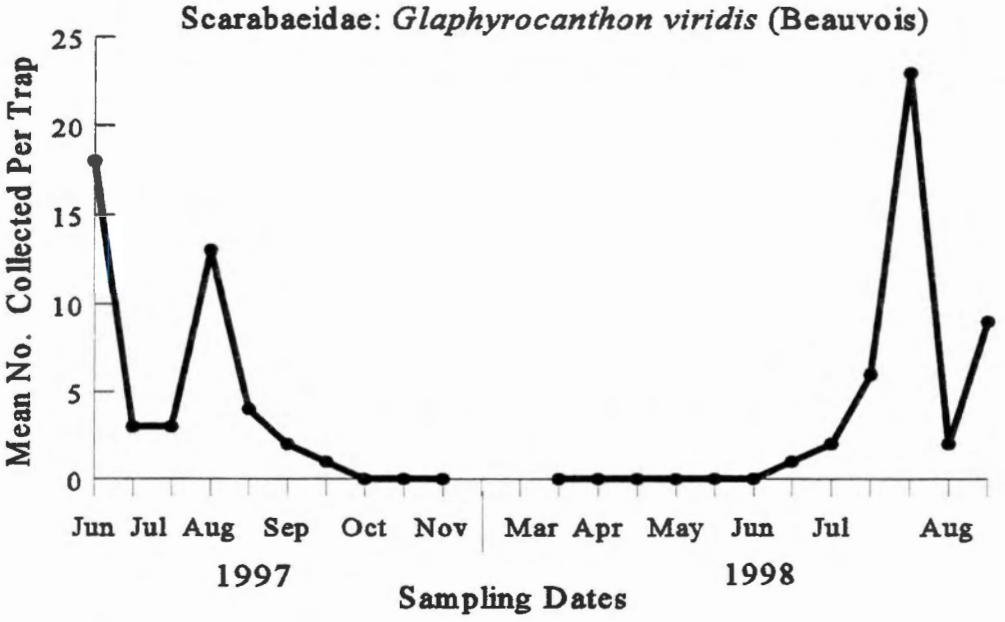


Figure 36. Mean number of *Glaphyrocanthon viridis* (Beauvois) collected per pitfall trap for each collection date during 1997 and 1998.

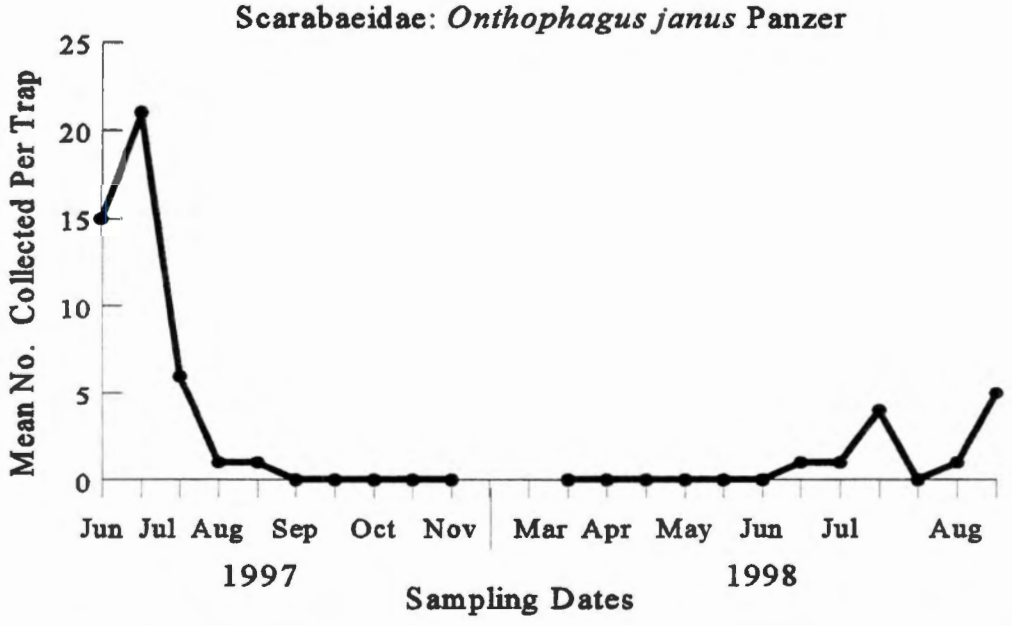


Figure 37. Mean number of *Onthophagus janus* Panzer collected per pitfall trap for each collection date during 1997 and 1998.

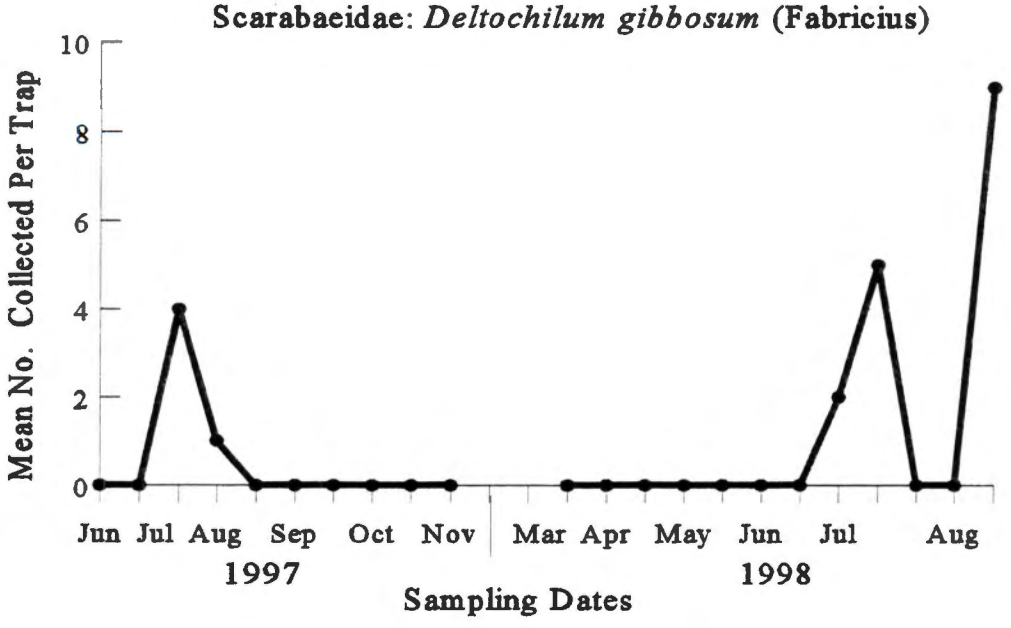


Figure 38. Mean number of *Deltochilum gibbosum* (Fabricius) collected per pitfall trap for each collection date during 1997 and 1998.

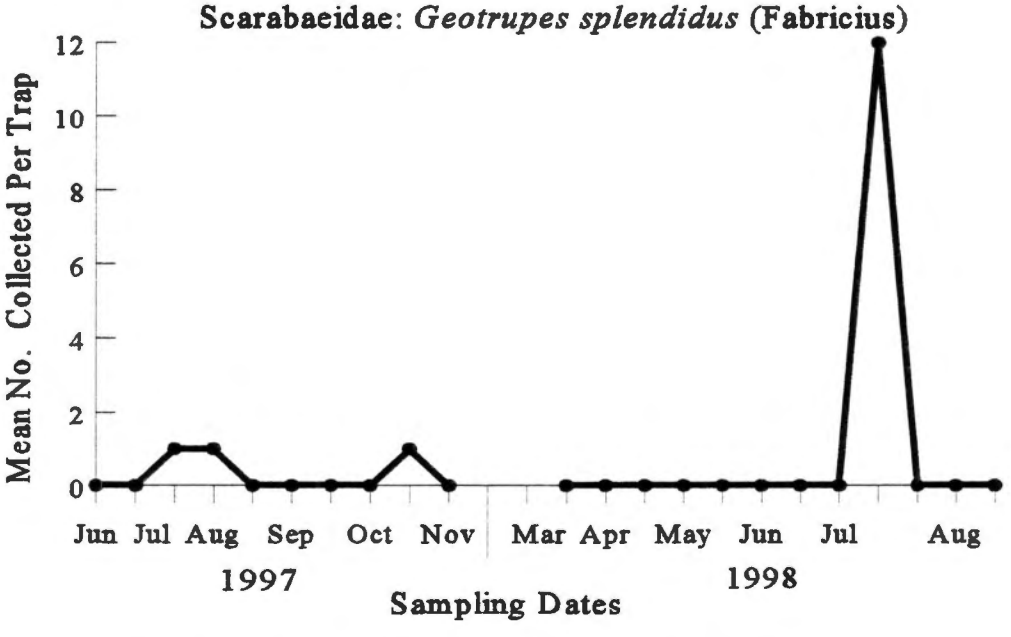


Figure 39. Mean number of *Geotrupes splendidus* (Fabricius) collected per pitfall trap for each collection date during 1997 and 1998.

Nitidulidae also contains individuals that feed on an array of organisms. Most adults are found on decaying fruit and fungi and the larvae are found under bark where they prey on Scolytidae (Downie and Arnett 1996). Only four species of Nitidulidae were collected (Figure 40). *Stelidota octomaculata* (Say) (Figure 41) was the most abundant. This species may have two generations per year or one generation every two years. More specimens were collected from August to October in 1997 and from April to August in 1998 (Figure 41). *Colopterus truncatus* (Randall) was a species that was only found during the 1998 collection period (Figure 42), so it may have one generation every two years.

Probably the most well known beetle family is the Carabidae, which is one of the largest families with 20,000 species worldwide (Downie and Arnett 1996). Both larvae and adults of most species are predaceous and, therefore beneficial as potential predators of exotic pests. Most species have one generation per year and overwinter in the adult stage. Twenty one species of Carabidae were collected in pitfall traps with more specimens collected in 1998 (Figure 43). Higher numbers in 1998 may be due to the 1998 collection period coinciding with seasonal beetle activity. *Galerita bicolor* Drury (Figure 44) was the most abundant carabid collected. Seasonal trends differ among the species (Figures 44-48). Differences among carabid populations may be beneficial when considering potential predators for specific forest pests. Yearly seasonal activities of these predaceous beetles may increase the opportunity for control of pests. Increased numbers of carabid beetles attacking the different vulnerable life stages of the pest may yield greater mortality of the pest species throughout its life cycle.

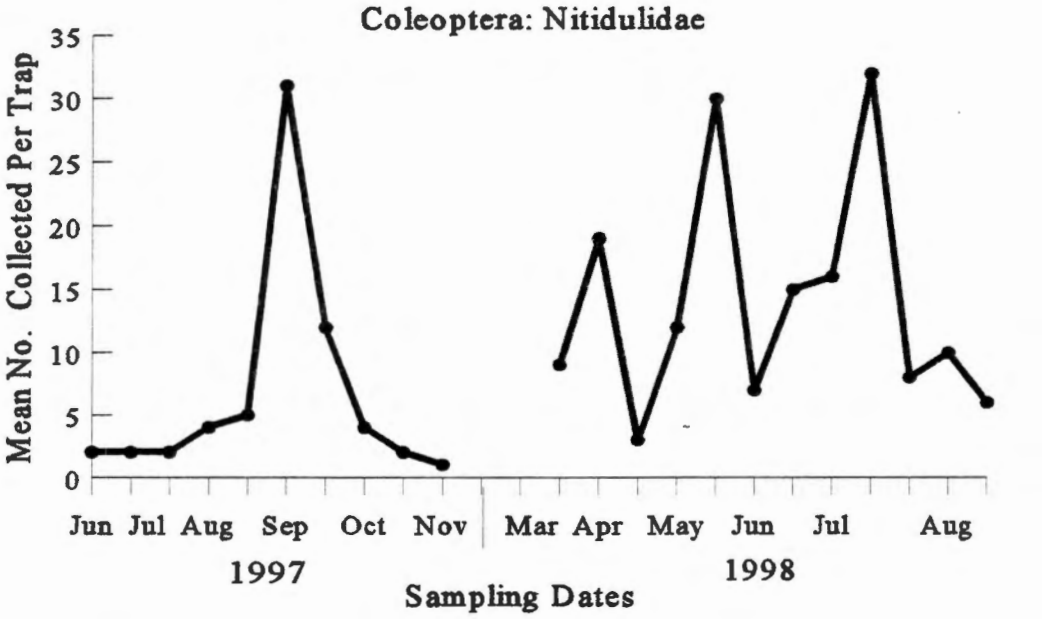


Figure 40. Mean number of Nitidulidae collected per pitfall trap for each collection date during 1997 and 1998.

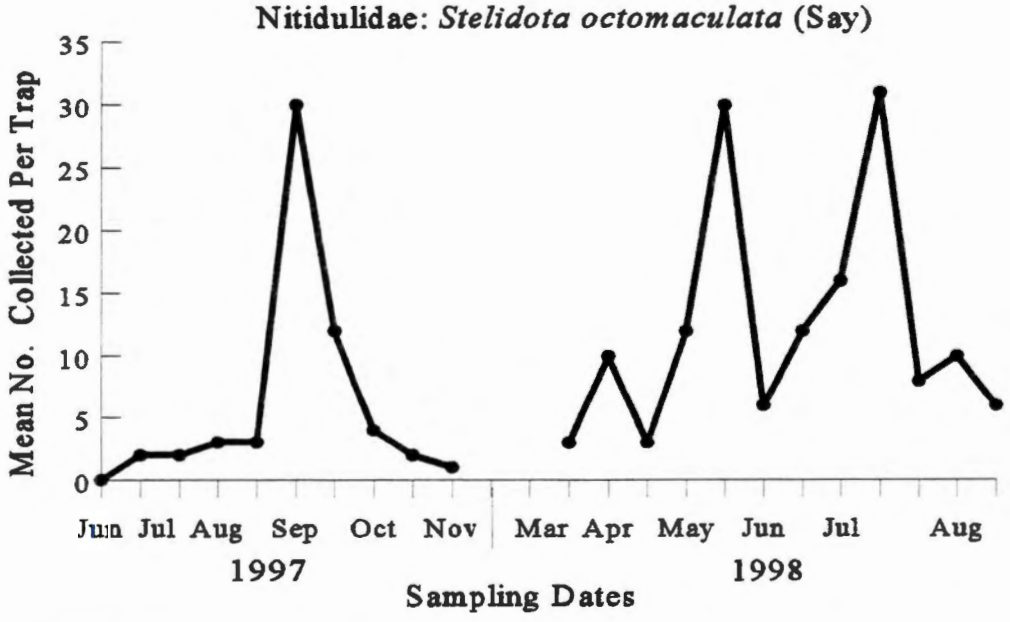


Figure 41. Mean number of *Stelidota octomaculata* (Say) collected per pitfall trap for each collection date during 1997 and 1998.

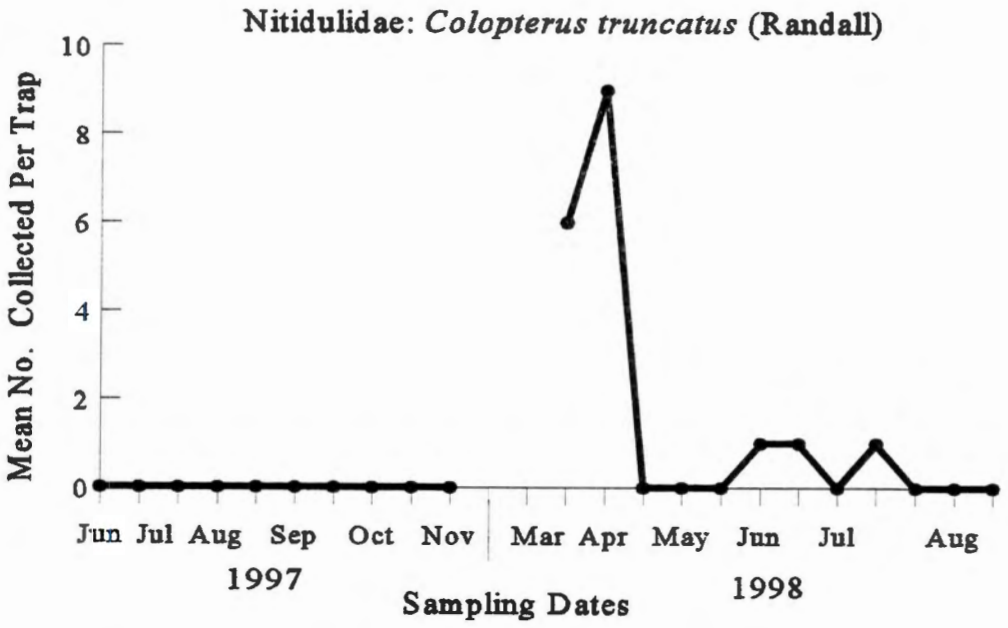


Figure 42. Mean number of *Colopterus truncatus* (Randall) collected per pitfall trap for each collection date during 1997 and 1998.

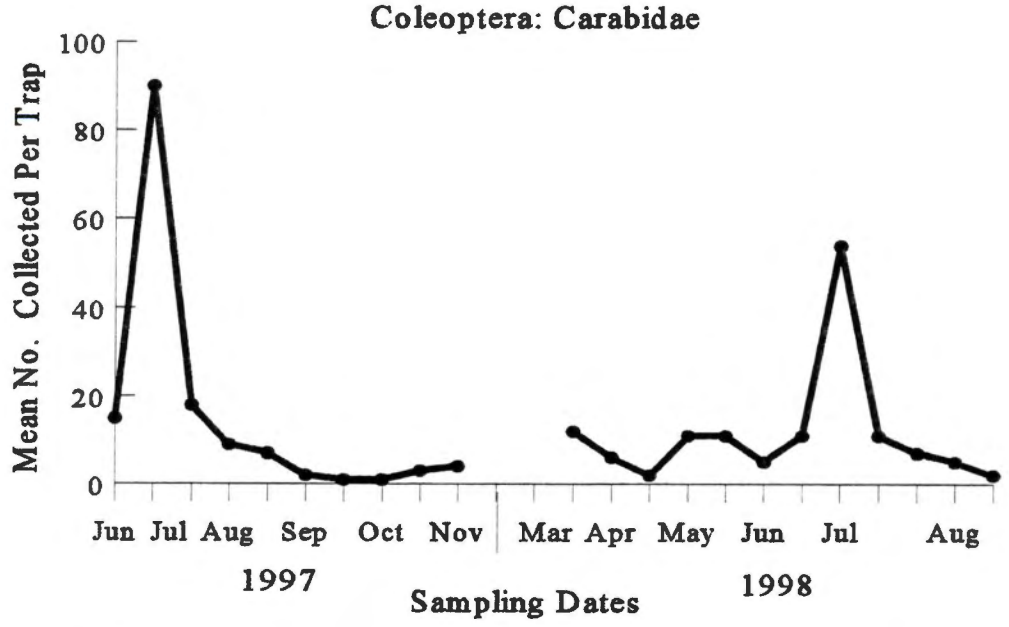


Figure 43. Mean number of Carabidae collected per pitfall trap for each collection date during 1997 and 1998.

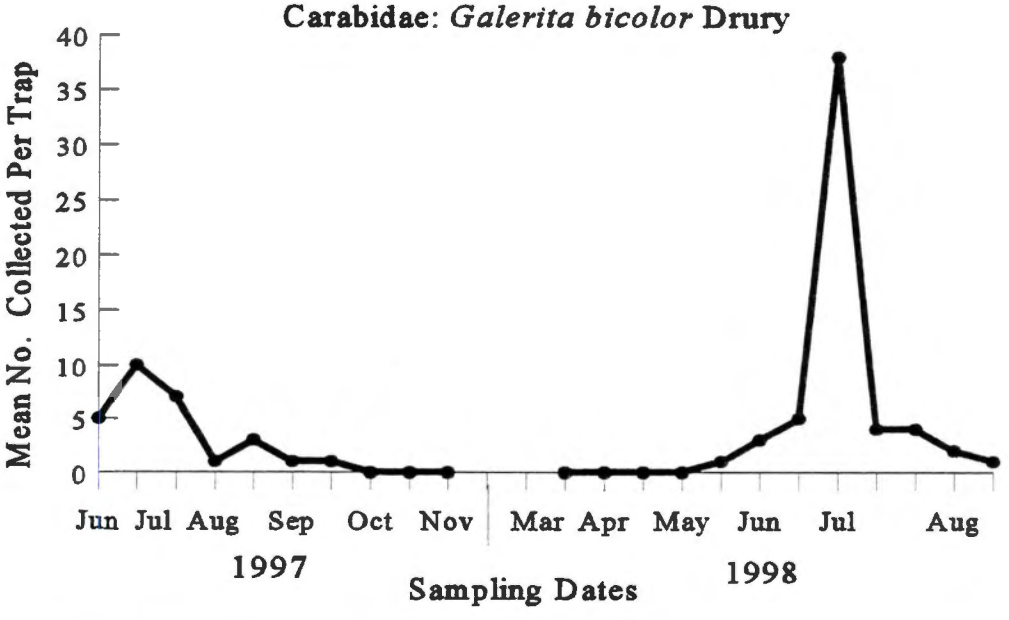


Figure 44. Mean number of *Galerita bicolor* Drury collected per pitfall trap for each collection date during 1997 and 1998.

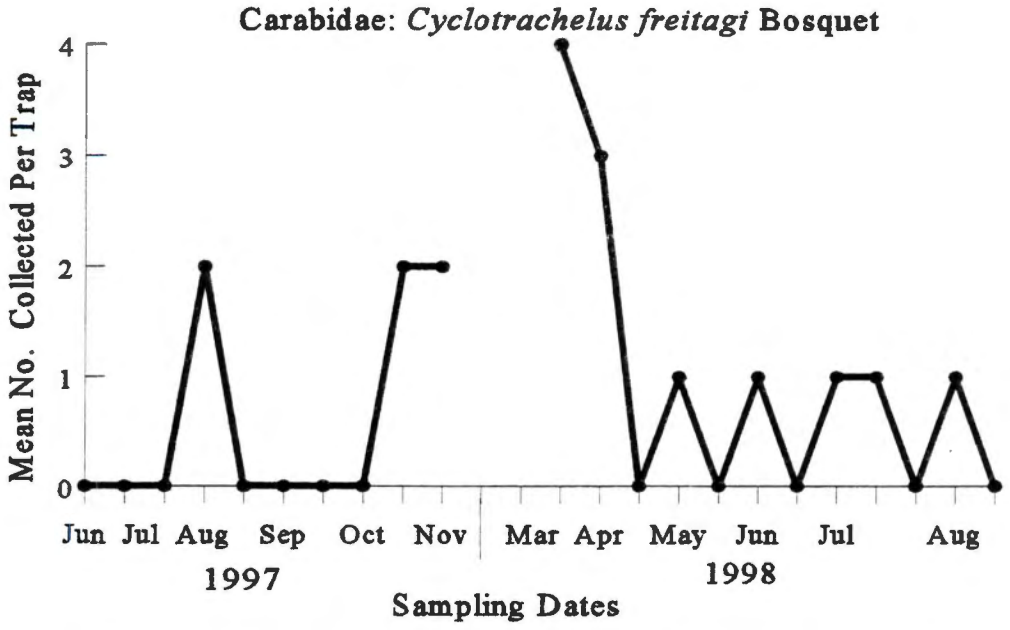


Figure 45. Mean number of *Cyclotrachelus freitagi* Bosquet collected per pitfall trap for each collection date during 1997 and 1998.

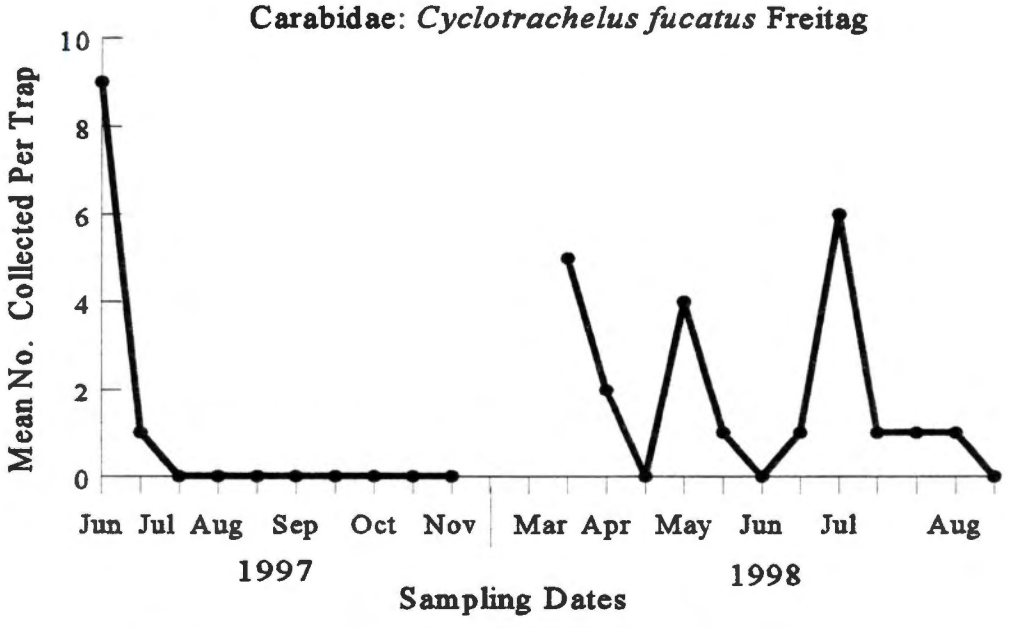


Figure 46. Mean number of *Cyclotrachelus fucatus* Freitag collected per pitfall trap for each collection date during 1997 and 1998.

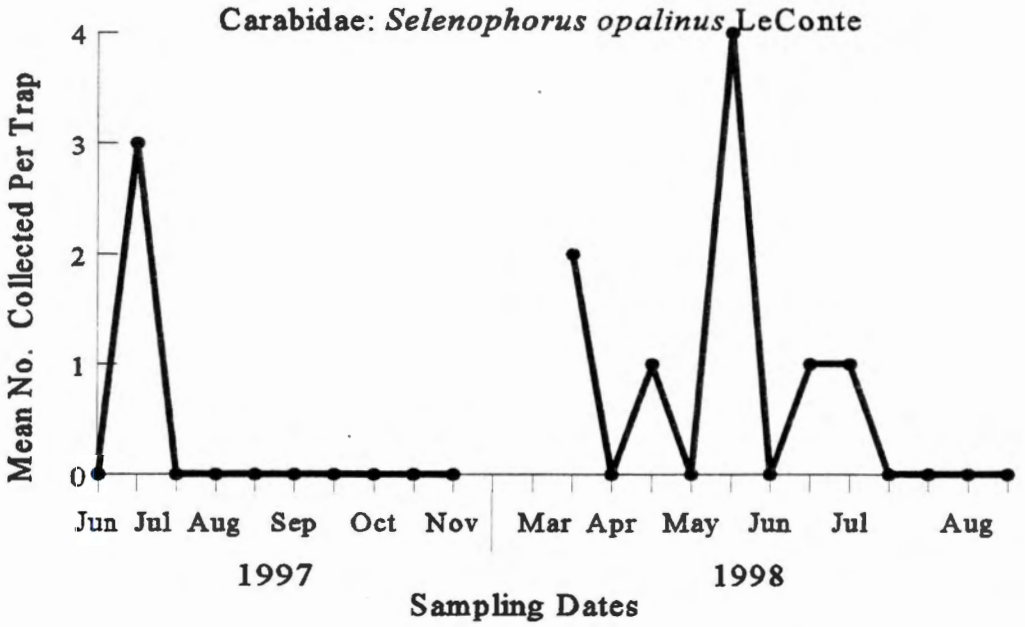


Figure 47. Mean number of *Selenophorus opalinus* LeConte collected per pitfall trap for each collection date during 1997 and 1998.

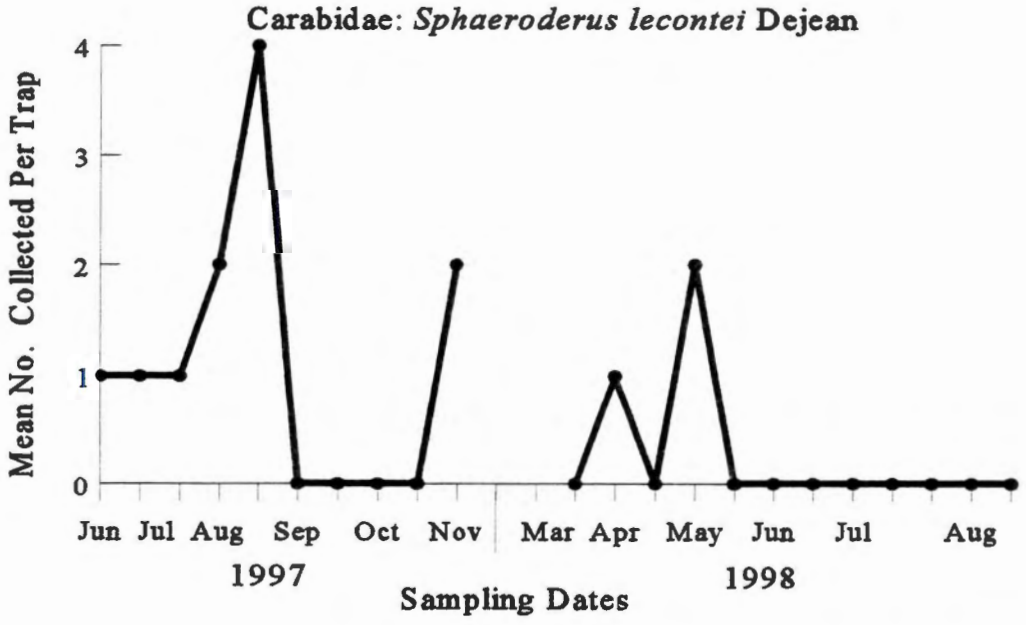


Figure 48. Mean number of *Sphaeroderus lecontei* Dejean collected per pitfall trap for each collection date during 1997 and 1998.

Five additional beetle families, Curculionidae, Leiodidae, Leptodiridae, Ptiliidae, and Silphidae, also are presented (Figures 49-53). Overall, beetle populations tend to cycle with one generation per year with slight differences in population peaks. Differences in numbers between 1997 and 1998 can most likely be explained by the different sampling dates in these two years. Weather differences also may have an affect on insect numbers.

Orthoptera

Seven hundred Orthoptera were collected representing four families: Decticidae, Gryllacridida, Gryllidae, and Nemobiidae. All specimens collected were crickets, except for one shield-backed grasshopper, *Atlanticus* sp. (Decticidae). Orthoptera populations peaked during the summer months between June and September then fell substantially in October and November of 1997 (Figure 54). More *Ceuthophilus* sp. were collected in 1997, while *Gryllus* sp. numbers were greater in 1998 (Figures 55 and 56). *Nemobius* sp. were similar in abundance between the two collection years (Figure 57).

Blattaria and Others

Cockroaches (n = 315) were represented by two species, *Ischnoptera deropeltiformis* (Brunner) and *Parcoblatta bolliana* (S. & Z.) in a single family, Blattellidae. These two species are forest dwellers and were collected regularly throughout June to August in 1997 and from July through August in 1998 (Figure 58). Other orders collected included the Hemiptera (n = 186), Lepidoptera (n = 98), Microcoryphia (n = 82), Homoptera (n = 60), Psocoptera (n = 43), Thysanoptera (n = 34), Isoptera (n = 10), Neuroptera, Thysanura, Diplura, Plecoptera, and Siphonaptera (n = 6, 5, 2, 1, and 1, respectively).

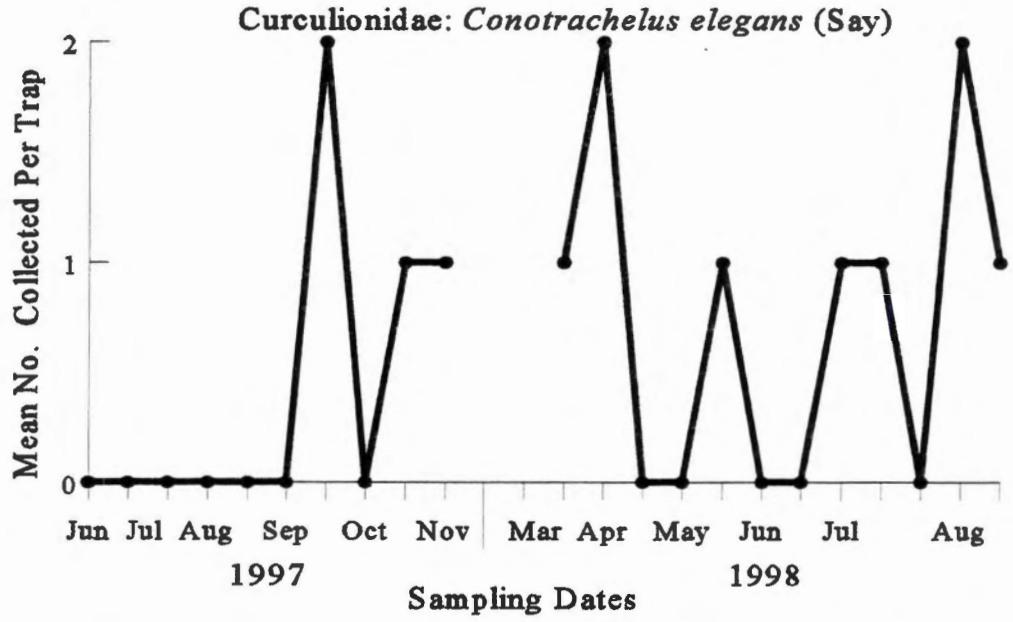


Figure 49. Mean number of *Conotrachelus elegans* (Say) collected per pitfall trap for each collection date during 1997 and 1998.

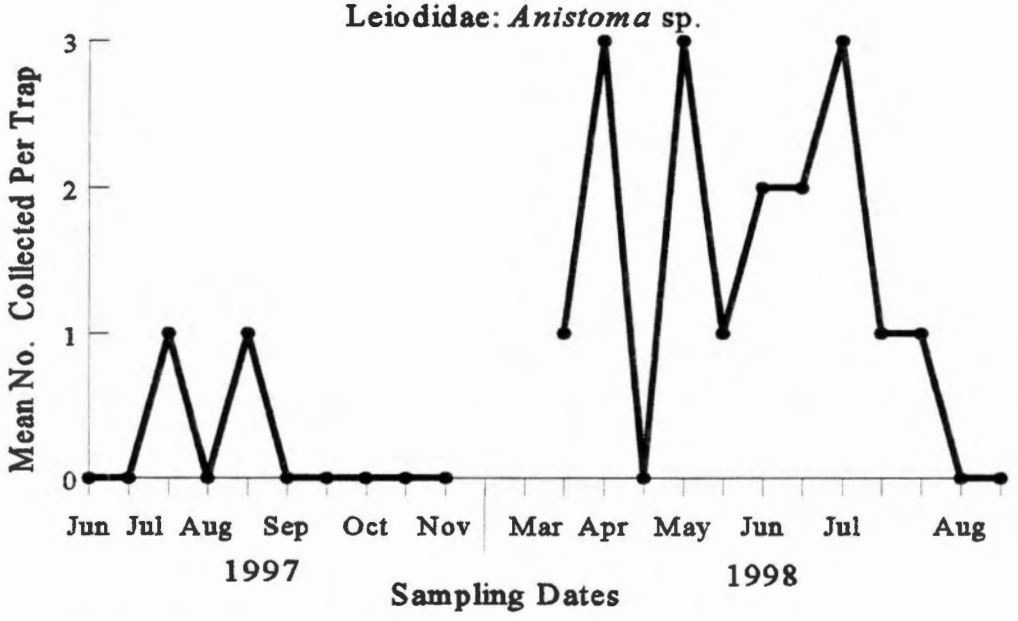


Figure 50. Mean number of *Anistoma* sp. collected per pitfall trap for each collection date during 1997 and 1998.

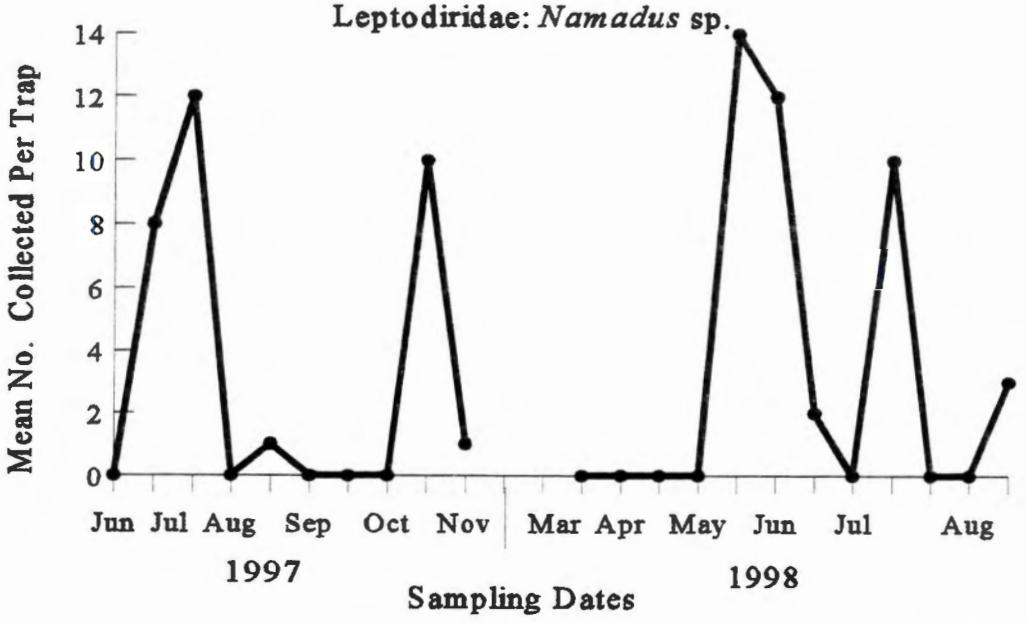


Figure 51. Mean number of *Namadus* sp. collected per pitfall trap for each collection date during 1997 and 1998.

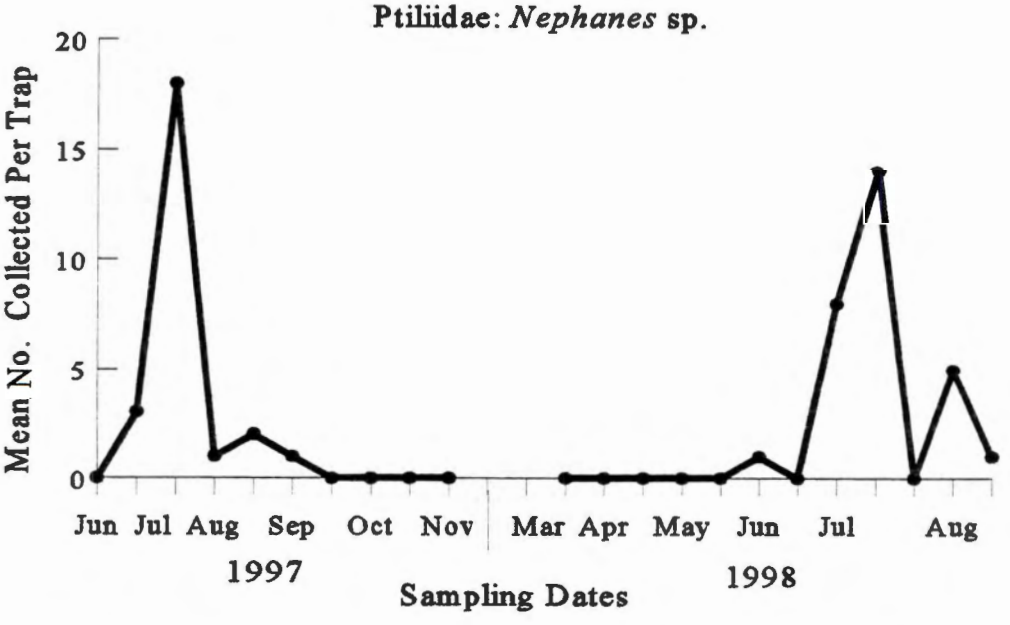


Figure 52. Mean number of *Nephanes* sp. collected per pitfall trap for each collection date during 1997 and 1998.

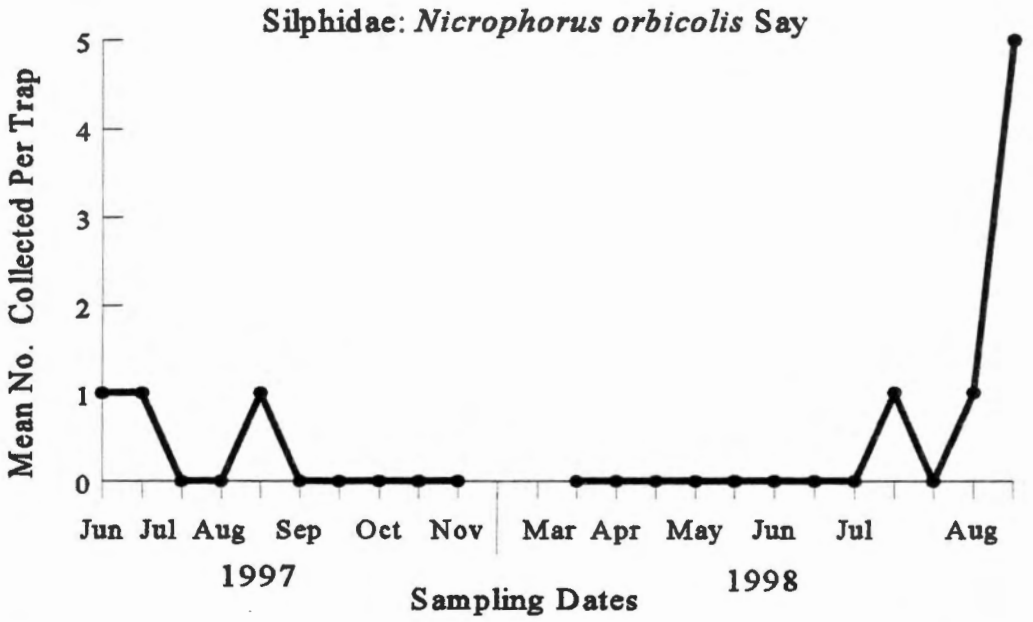


Figure 53. Mean number of *Nicrophorus orbicolis* Say collected per pitfall trap for each collection date during 1997 and 1998.

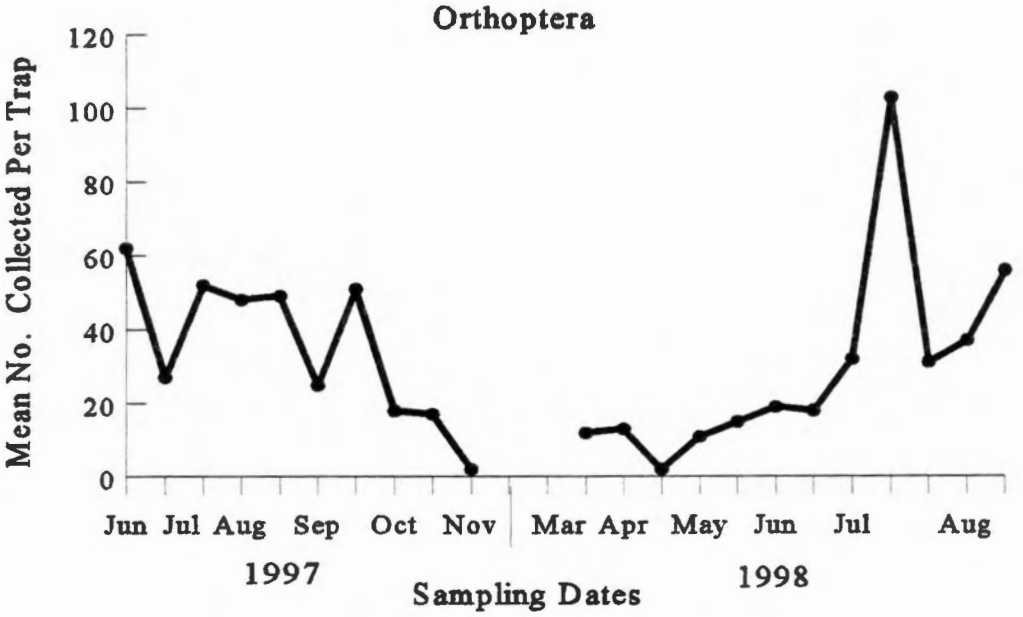


Figure 54. Mean number of Orthoptera collected per pitfall trap for each collection date during 1997 and 1998.

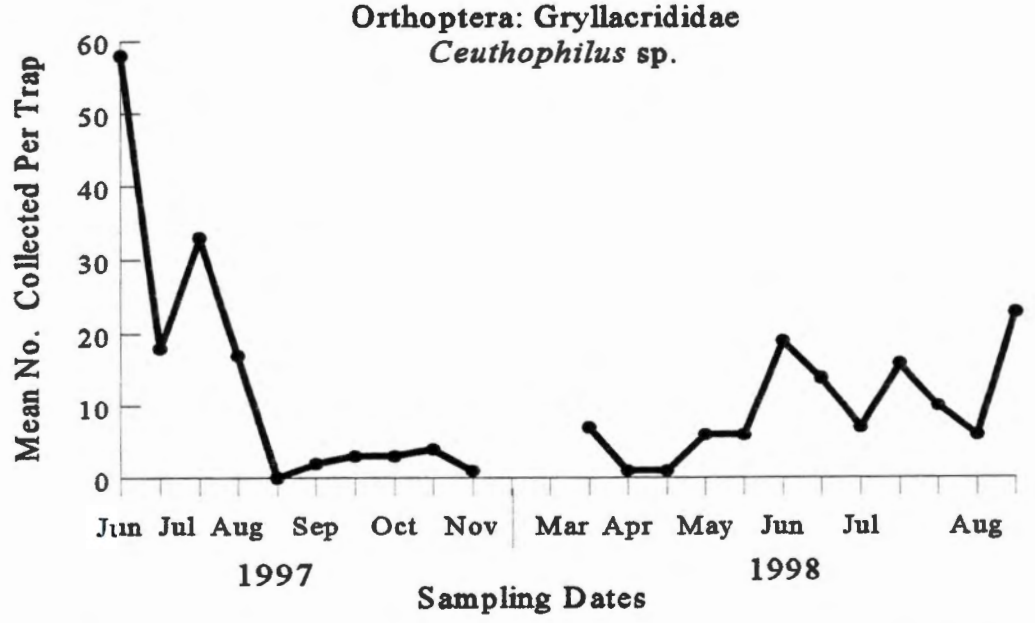


Figure 55. Mean number of *Ceuthophilus* sp. collected per pitfall trap for each collection date during 1997 and 1998.

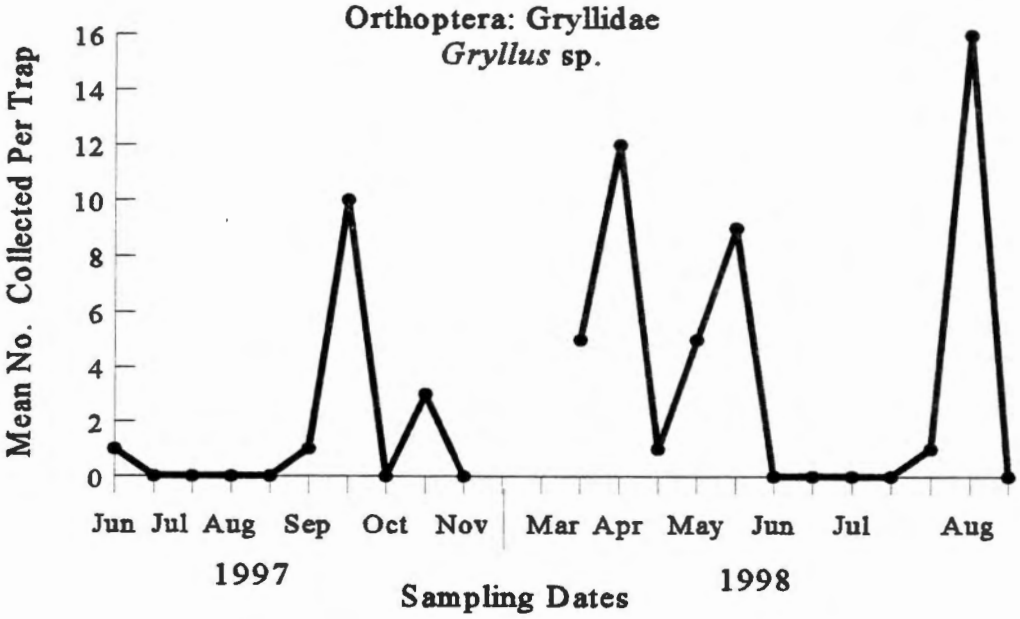


Figure 56. Mean number of *Gryllus* sp. collected per pitfall trap for each collection date during 1997 and 1998.

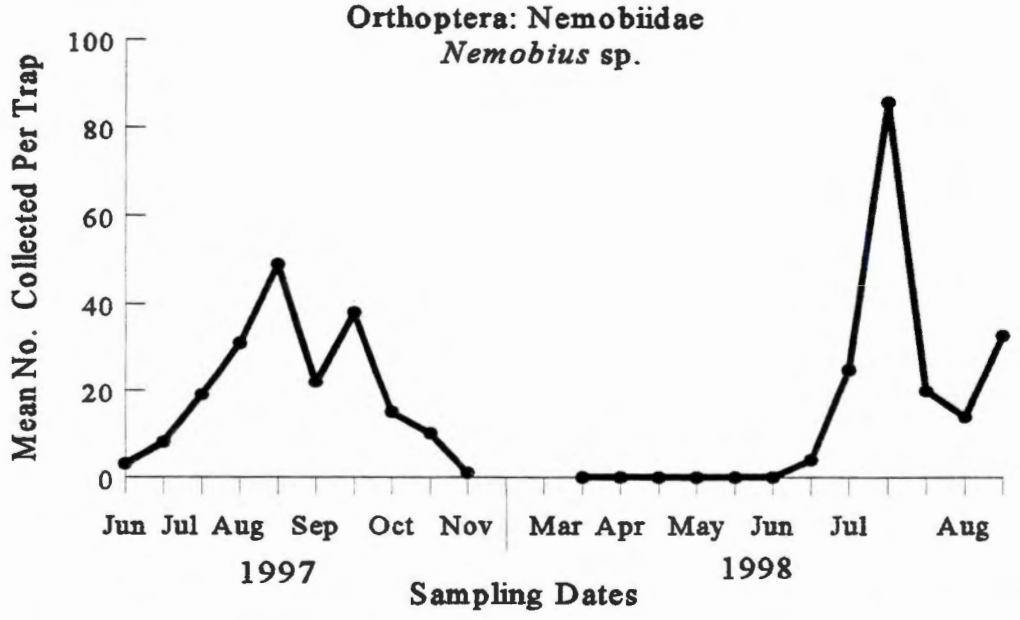


Figure 57. Mean number of *Nemobius* sp. collected per pitfall trap for each collection date during 1997 and 1998.

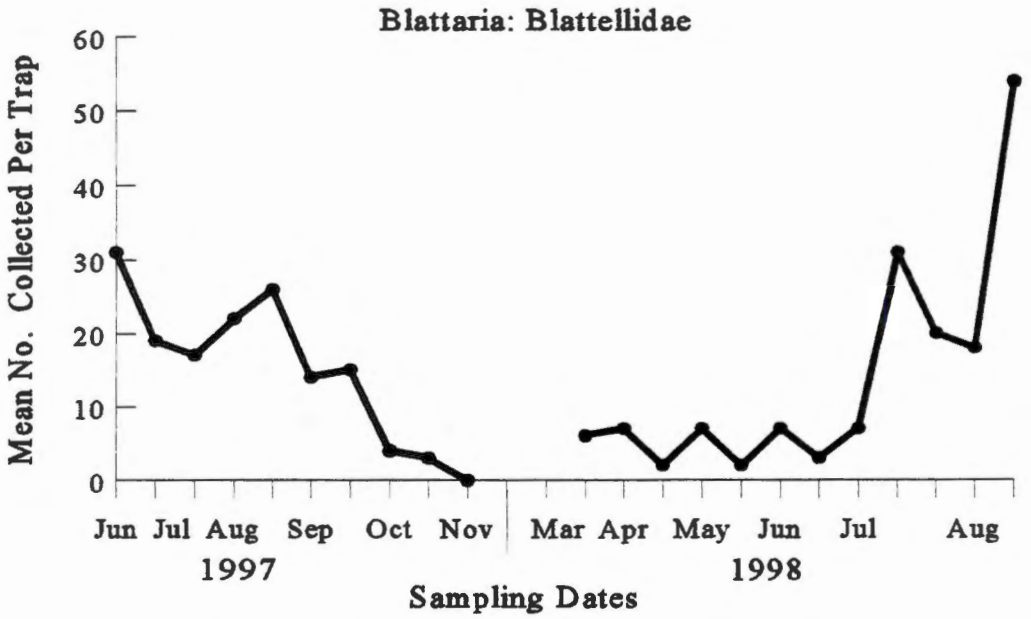


Figure 58. Mean number of Blattellidae collected per pitfall trap for each collection date during 1997 and 1998.

Several hemipteran species may be potential predators of exotic pests. Many of the lepidopterans may be adversely affected by a gypsy moth invasion. The caterpillars may have to compete for food, if their primary food source is oak species. Several of the leaf-litter inhabiting species may be affected by the increased nutrient input caused by defoliation and the accumulation of senescent leaves on the forest floor. Soil quality may become altered and temperatures may increase as a result of more leaves and a more open forest canopy. Ground-dwelling insects also may be subjected to increased dessication rates because of an overall decrease in soil moisture.

Disturbances in habitats affect ecosystems in many different ways. The cove plot had very limited amounts of disturbance, but the clear-cutting of a nearby forest stand may have contributed to increased catches in this plot. Also, increased soil moisture may have been responsible for the higher species diversity in the cove plot. The slope plot was more ideal for certain ant species which nest in heavy leaf litter. Leaf litter was accumulated and deposited by runoff during heavy rains. Possible soil erosion may have been increased in the slope plot, which may be used to explain the lower diversity indices in relation to this habitat. The natural plot had less understory vegetation which provided fewer niches. However, the natural plot was less disturbed than the other three plots and provided a more habitable environment to some beetle species. The tornado plot was highly disturbed but its downed trees and new growth provided an ideal habitat to a varying array of insects. Inversely, many ant species did not inhabit the tornado plot suggesting that this type of disturbance may have had an adverse affect on ant populations in this particular forest ecosystem.

The differences found among these four plots are representative of the types of disturbances found in mixed hardwood ecosystems. These forested communities allow differences in species composition in relation to structural differences which ultimately provide many different niches. Weather also can be an important component in determining seasonality, species composition, and abundance. All of the biotic and abiotic factors must be considered when determining the components of an ecosystem. The understanding of the interactions among these different groups of insects is important in assessing the potential impact of various factors on these habitats.

CHAPTER IV

CONCLUSIONS

The southern Appalachian mountains represent an important habitat in eastern Tennessee. These forested areas attract many tourists to this region and provide valuable timber resources (Stanton 1994, May 1991). Mixed hardwood ecosystems, especially oak-dominated habitats, are necessary to sustain native flora and fauna, many of which are threatened or endangered. Many insect species occupy niches provided only by forest ecosystems, but competition for these areas has increased as natural resources are declining and exotic pest populations are increasing.

The gypsy moth is an important hardwood defoliator which is expected to enter eastern Tennessee forests within the next decade. This pest was accidentally introduced into the northeastern United States in 1869. Since its introduction, it has been responsible for decreased health in many forest ecosystems and has defoliated millions of hectares (Ghent 1994, Grace 1986). The major front of the gypsy moth is currently located near Roanoke, VA. However, some isolated infestations have already been reported in portions of the GSMNP and in 23 counties in Tennessee. Mass defoliation events caused by the gypsy moth affect forest communities, as well as rural and urban environments.

Like many pest species, control measures have been attempted against the gypsy moth. Natural enemies, such as predators, parasitoids, and pathogens, have not been successful in reducing gypsy moth populations to levels below those causing economic and environmental injury. Biological pesticides containing bacteria and fungi, along with

various chemical insecticides, also have been used but adverse effects were documented among non-target populations (Sample *et al.* 1996, Butler *et al.* 1997). Therefore, this pest is difficult to control and populations are steadily moving into many southern and midwestern states. A study was initiated in The University of Tennessee Forestry Experiment Station and Arboretum located in Oak Ridge, TN, to obtain baseline data. These data may be used in comparison to those data collected after a gypsy moth defoliation event to determine the impact of this pest on native forests.

A research project was initiated to assess the species composition of insects inhabiting a mixed hardwood southern Appalachian forest in eastern Tennessee. Pitfall traps were used to sample ground-dwelling insects in four collection plots each containing three host tree species. Four pitfall traps were arranged in the four cardinal directions one-half the distance between the trunk and outer canopy edge. White oak, sugar maple, and tulip poplar were the tree species selected. These three species were chosen for their preference as a food source by the gypsy moth. The oaks are most preferred while the tulip poplar is almost never eaten by the gypsy moth. Samples were collected weekly from 26 June 1997 to 21 November 1997 and from 26 March 1998 through 26 August 1998. Trap 01, north position, was sorted for each host tree biweekly.

A total of 20,906 insect specimens was collected representing 87 families in 18 insect orders. The four most abundant orders were Collembola, Hymenoptera, Diptera, and Coleoptera. Significantly ($P<0.05$) more insect specimens were collected in the cove plot and significantly ($P<0.05$) fewer specimens were collected in the slope plot. The cove plot also had significantly ($P<0.05$) greater numbers of beetles and ants collected in

comparison to the other three plots. The cove plot was in a more wooded area which was moist and often collected water after heavy rains. The cove plot may have had an influx of insects in 1998 after a nearby forest stand had been clear-cut. Fewer specimens were collected in the slope plot possibly because it was located on a slope near a secondary road. Substantial runoff was accumulated after heavy rains and may have contributed to the overall lower insect abundance. The exposed soil may have been easily eroded which might have adversely affected subterranean ant species. Less ground cover may decrease soil moisture, as well as decrease habitable areas for ground-dwellers.

For the overall order and family analyses, no significant ($P>0.05$) differences were found among traps associated with each host tree. However, the beetles and ants were collected in significantly ($P<0.05$) higher numbers in the traps associated with sugar maple and significantly ($P<0.05$) fewer were collected in the traps under tulip poplar. The differences in numbers may have been a result of the size of the trees with the sugar maples having a broader canopy closer to the ground, which may provide more shelter for forest-inhabiting ground-dwelling insects. Also, some beetles and ants may have been attracted to the sugar maple's sugary sap. The tulip poplar is a tall, straight tree with a narrow crown, which would not provide shelter for ground-dwellers. White oaks also can be tall, but usually have a heavily-branched canopy. Differences may have been revealed in relation to insects collected under white oak if all of the samples had been sorted and analyzed for this study.

Diversity indices also were calculated for the species collected. Approximately 187 species were collected with 103 beetle species and 24 ant species. The cove plot had

the highest species diversity (1.75) and species evenness (0.67). Species richness was also significantly ($P<0.05$) higher in the cove plot (44) than in the slope (39) and natural (39) plots but did not significantly differ in the tornado plot (41). Ant species diversity, as well as richness, was highest in the cove and slope plots and lowest in the tornado plot. Ant species evenness was highest in the slope plot. Many of the ant species collected are subterranean nest builders and may require higher soil moisture levels which could be found in the cove plot. However, some ants require leaf litter and debris to build their nests, and these particular ant species may inhabit the slope plot. The accumulated materials deposited by rain water runoff may be utilized for shelter by some ant species found in the slope plot. The downed trees in the tornado plot may hinder certain ant species, but this plot may become attractive to many ant species as the downed trees become rotten.

No significant ($P>0.05$) differences were found among the four plots for beetle species diversity and richness, although species evenness was highest in the natural plot and lowest in the tornado plot. The open forest floor of the natural plot may allow freer movement of the beetle species and thus increases the chance of beetles being caught. Whereas the tornado plot has many obstacles, such as downed trees and new growth, thus preventing a greater dispersal of beetles throughout the plot. The overall differences among the groups of insects collected in relation to habitat (plot and host tree) would suggest that the cove plot contains a richer insect fauna and that the insects collected in this study are representative of the species inhabiting these forested environments.

Seasonality trends were similar for most insects collected. Most populations increased in numbers during the summer months and in general, more specimens were collected during the 1997 collection dates. Similar numbers of insects may have been collected for the two years, if collecting had not ceased in August of 1998. Because pitfall traps sample according to activity, most catches were probably related to foraging seasons of the particular insect groups.

Two groups of interest pertaining to this study are the predaceous beetles and ants. These predaceous insects may be used as potential predators of exotic pests. The four most abundant beetle families collected were the Staphylinidae, Scarabaeidae, Nitdulidae and Carabidae. Twenty one species of carabid beetles were collected. Some carabid beetles are important predators of pest species. Many beetles in the family Staphylinidae are also predatory and may be useful in biological control measures. Beetle populations differed somewhat in relative abundance throughout the collection period. Knowing the population cycles of particular predaceous insects may be advantageous when trying to target different life cycles of specific insect pests.

Twenty four ant species were collected with increased numbers during the summer months with the exception of *Prenolepsis imparis* spp., whose populations tend to peak in the fall and early spring. Four subfamilies were identified with many members feeding on both live and dead insects, as well as honeydew, gall exudates, earthworms, and fresh or decaying fruit. One potential predator, *Neivamyrmex nigrescens* (Cresson), is a highly predaceous ant species that forages during the day (Krombein *et al.* 1979). This species can construct large colonies containing 150,000 to 250,000 workers. *N. nigrescens* was

collected in higher numbers in 1997 than 1998, which can most likely be explained by not sampling past August in 1998.

Data collected from this study may be useful in assessing the impact of the gypsy moth, or other forest pests, by serving as baseline information. These data may be compared to those data collected after a possible defoliation event to determine any possible fluctuations in native populations. Information obtained on native species is important when addressing forest problems and when trying to determine different control measures to be used against pest species. Understanding insect communities will allow scientists the knowledge required to determine the interactions among different species within these habitats. This knowledge may ultimately help scientists lessen the harmful effects of exotic species on native biological diversity.

REFERENCES CITED

Abrahamson, L. and C. Klass. 1985. Gypsy moth. Univ. Tenn. Agric. Ext. Serv. Publi. 1153: 9-10.

Ali, A. and M.S. Mulla. 1978. Impact of the insect growth regulator diflubenzuron on invertebrates in a residential lake. Arch. Environ. Contam. Toxicol. 7: 438-491.

Andreadis, T.G., N.R. Dubois, R.E.B. Moore, J.F. Anderson, and F.B. Lewis. 1983. Single application of high concentrations of *Bacillus thuringiensis* for control of gypsy moth (Lepidoptera: Lymantriidae) populations and their impact on parasitism and diseases. J. Econ. Entomol. 76: 1417-1422.

Atlegrim, O., K. Sjoberg, and J.P. Ball. 1997. Forestry effects on a boreal ground-beetle community in spring: selective logging and clear-cutting compared. Entomologica Fennica. 8: 19-26.

Baars, M.A. 1979. Catches in pitfall traps in relation to mean densities of carabid beetles. Oecologica 41: 251-259.

Beck, D.E. 1977. Twelve-year acorn yield in Southern Appalachian oaks. USDA For. Serv. No. SE-244: 8.

Bess, H.A. 1961. Population ecology of the gypsy moth *Porthetria dispar* (L.) (Lepidoptera: Lymantriidae). Conn. Agric. Exp. Sta. Bull. (New Haven). 646 pp.

Blair, J.M. and D.A. Crossley Jr. 1988. Litter decomposition, nitrogen dynamics and litter microarthropods in a Southern Appalachian (USA) hardwood forest 8 years following clearcutting. J. Appl. Ecol. 25: 683-698.

Borror, D.J., C.A. Triplehorn, and N.F. Johnson. 1989. An introduction to the study of insects sixth ed. Saunders College Publishing. New York. 875 pp.

Brown, K.S. Jr. 1997. Diversity, disturbance, and sustainable use of neotropical forests: insects as indicators for conservation monitoring. J. Insect Conserv. 1: 25-42.

Butler, L., V. Kondo, and D. Blue. 1997. Effects of Tebufenozide (RH-5992) for gypsy moth (Lepidoptera: Lymantriidae) suppression on nontarget canopy arthropods. Environ. Entomol. 26: 1009-1015.

Butler, L. and V. Kondo. 1993. Impact of Dimilin on non-target Lepidoptera: results of an operational gypsy moth suppression program at Coopers Rock State Forest, West Virginia. W. Va. Univ. Exp. Sta. Bull. 710 pp.

Campbell, R.W. 1967. The analysis of numerical change in gypsy moth populations. For. Sci. Mono. 15. Society of American Foresters, Bethesda, MD.

Campbell, R.W. 1963. Some ichneumonid-sarcophagid interactions in the gypsy moth, *Porthetria dispar* (L.) (Lepidoptera: Lymantriidae). Can. Entomol. 95: 337-345.

Carlton, C.E., J. Bollinger, and L.C. Thompson. 1994. Arthropod biodiversity-sampling protocol development. Gen. Tech. Rep. Southern For. Exp. Stat. 112: 144-153.

Clark, T.E. and M.J. Samways. 1996. Dragonflies (Odonata) as indicators of biotope quality in the Kruger National Park, South Africa. J. Appl. Ecol. 33: 1001-1012.

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

Colwell, R.K. 1996. Biota: The Biodiversity Database Manager. Sinauer Assoc., Inc., Publishers, Sunderland, MA. 574 pp.

Dillon, E.S. and L.S. Dillon. 1961. A manual of common beetles of Eastern North America. Row, Peterson and Co., Elmsford, NY. 884 pp.

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

Dwyer, G. and J.S. Elkinton. 1993. Using simple models to predict virus epizootics in gypsy moth populations. J. Anim. Ecol. 62: 1-11.

Eisler, R. 1992. Diflubenzuron hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Dep. Inter. Fish Wildl. Serv. Biol. Rep. 4 pp.

English-Loeb, G.M., A.K. Brody, and R. Karban. 1993. Host-plant-mediated interactions between a generalist folivore and its tachinid parasitoid. J. Anim. Ecol. 62: 465-471.

Faith, D.P. and P.A. Walker. 1996. How do indicator groups provide information about the relative biodiversity of different sets of areas?: On hotspots, complementarity and pattern-based approaches. Biodiversity Letters 3: 18-25.

Farlow, J.E., T.P. Breaud, C.C. Steelman, and P.E. Schiling. 1978. Effects of the insect growth regulator diflubenzuron on non-target aquatic populations in a Louisiana intermediate marsh. Environ. Entomol. 7: 194-204.

Fosberg, M.A. and M. Peterson. 1986. Modeling airborne transport by the gypsy moth (Lepidoptera: Lymantriidae) larvae. Agric. For. Meteor. 38: 1-8.

Frampton, G.K. and T. Bolger. 1997. The potential of Collembola as indicators of pesticide usage: evidence and methods from the UK arable ecosystem. Pedobiologia 41: 1-3, 179-184.

Fuester, R.W., P.T. Sandridge, N.H. Dill, J.M. McLaughlin, P.B. Taylor, J.O.D. Sigmond, and C.J. Newlon. 1997. Apparent fate of gypsy moth (Lepidoptera: Lymantriidae) pupae stung by the introduced parasite *Coccygomimus disparis* (Hymenoptera: Ichneumonidae). Environ. Entomol. 26: 1442-1451.

Gansner, D.A. and O.W. Herrick. 1985. Host preference of gypsy moth on a new frontier of infestation. U.S. For. Serv. Res. Note NE 0(330): 1-3.

Gerardi, M.H. and J.K. Grimm. 1979. The history, biology, damage, and control of the gypsy moth. Assoc. Univ. Presses, Inc. 13-18.

Ghent, J. 1994. The gypsy moth. pp. 13-16. *In* Ferguson, C. and P. Bowman (eds)., Threats to forest health in the southern Appalachians. Southern App. Man and the Biosphere Coop., Gatlinburg, TN. 36 pp.

Grace, J.R. 1986. The influence of gypsy moth on the composition and nutrient content of litter fall in a Pennsylvania oak forest. For. Sci. 32: 855-870.

Greenblatt, J.A. and P. Barbosa. 1981. Effects of host's diet on two pupal parasitoids of the gypsy moth: *Brachymeria intermedia* (Nees) and *Coccygomimus turionellae* (L.). J. Appl. Ecol. 18: 1-10.

Greenslade, P.J.M. 1964. Pitfall trapping as a method for studying populations of Carabidae (Coleoptera). J. Anim. Ecol. 33: 301-310.

Grushecky, S.T., A.M. Liebhold, R. Greer, and R.L. Smith. 1998. Does forest thinning affect predation on gypsy moth (Lepidoptera: Lymantriidae) larvae and pupae? Environ. Entomol. 27: 268-276.

Hajek, A.E., L. Butler, and M.M. Wheeler. 1995. Laboratory bioassays testing the host range of the gypsy moth fungal pathogen *Entomophaga maimaiga.* Biol. Control 5: 530-544.

Hajek, A.E., L. Butler, S.R.A. Walsh, J.C. Silver, F.P. Hain, F.L. Hastings, T.M. Odell, and D.R. Smitley. 1996a. Host range of the gypsy moth (Lepidoptera: Lymantriidae) pathogen *Entomophaga maimaiga* (Zygomycetes: Entomophthorales) in the field versus laboratory. Environ. Entomol. 25: 709-721.

Hajek, A.E., L. Butler, S.R.A. Walsh, J.C. Silver, F.P. Hain, F.L. Hastings, T.M. Odell, and D.R. Smitley. 1996b. The gypsy moth pathogen, *Entomophaga maimaiga*, in the field versus laboratory. Gypsy Moth News. December 1996. Issue Number 42.

Halloway, J.D. and N.E. Stork. 1991. The dimensions of biodiversity: the use of invertebrates as indicators of human impact. CASAFA report series; no. 4, CAB International. 37-62.

Halsall, N.G. and S.D. Wratten. 1988. The efficiency of pitfall trapping for polyphagous predatory Carabidae. Ecol. Entomol. 13: 293-299.

Helfer, J.R. 1953. How to know the grasshoppers, cockroaches and their allies. Wm. C. Brown Company Publishers, Dubuque, Iowa. 353 pp.

Hoffstetter, R.W. and K.F. Raffa. 1997. Effects of host diet on the orientation, development, and subsequent generations of the gypsy moth (Lepidoptera: Lymantriidae) egg parasitoid *Ooencyrtus kuvanae* (Hymenoptera: Encyrtidae). Environ. Entomol. 26: 1276-1282.

Holldobler, B. and E.O. Wilson. 1990. The ants. The Belknap Press of Harvard Univ. Press, Cambridge, MA. 732 pp.

Hopper, G. 1991. Forest management: recommendations to improve profits on Tennessee's forest land. Univ. Tenn. Agric. Ext. PB 1392. 19 pp.

Hughes, D.N. 1993. Arthropods associated with leaf litter of Fraser fir in the Great Smoky Mountains National Park. M.S. Thesis, Univ. Tenn., Knoxville. 66 pp.

Johnson, K.S., J.M. Scriber, J.K. Nitao, and D.R. Smitley. 1995. Toxicity of *Bacillus thuringiensis* var. *kurstaki* to three nontarget Lepidoptera in field studies. Environ. Entomol. 24: 288-297.

Jones, C.G. and J.H. Lawton (eds). 1995. Linking species and ecosystems. Chapman and Hall, London.

Kim, K.C. 1993. Biodiversity, conservation and inventory: why insects matter. Biodiversity and Conservation 2: 3, 191-214.

Krombein, Karl V., P.D. Hurd, Jr., D.R. Smith, and B.D. Burks. 1979. Catalog of hymnenoptera in America north of Mexico. 3 v. Smithsonian Institution Press, Washington. 2735 pp.

Kruse, J.J. and K.F. Raffa. 1997. Effects of selected midwestern larval host plants on performance by two strains of the gypsy moth (Lepidoptera: Lymantriidae) parasitoid *Cotesia melanoscela* (Hymenoptera: Braconidae). Environ. Entomol. 26: 1155-1166.

Kukan, B. and J.H. Myers. 1997. Prevalence and persistence of nuclear polyhedrosis virus in fluctuating populations of forest tent caterpillars (Lepidoptera: Lasiocampidae) in the area of Prince George, British Columbia. Environ. Entomol. 26: 882-887.

Kwon, TS., BK. Byun, T.S. Kwon, and B.K. Byun. 1996. Insect fauna (Hemiptera, Coleoptera, Lepidoptera) in Odaesan National Park. Korean J. Environ. and Ecol. 9: 2, 99-114.

Lambdin, P.L., D. Paulson, J.K. Watson, and K. Langdon. 1991. Checklist of the Lepidoptera in the Great Smoky Mountains National Park. Univ. Tenn. Agric. Exp. Stat. Res. Report 91-24.

Lawton, J.H., D.E. Bignell, B. Bolton, G.F. Bloemers, P. Eggleton, P.M. Hammond, M. Hodda, R.D. Holt, T.B. Larsen, N.A. Mawdsley, N.E. Stork, D.S. Srivastava, and A.D. Watt. 1998. Biodiversity inventories, indicator taxa and effects of habitat modification in tropical forest. Nature-London 391: 6662, 72-76.

Leonard, D.E. 1981. Bioecology of the Gypsy Moth. *In* C.C. Doane and M.L. McManus (ed)., The gypsy moth: research toward integrated pest management. USDA Tech. Bull. 1584: 9-28.

Little, E.L. 1996. National Audubon Society field guide to North American trees: eastern region. Chanticleer Press, Inc., New York. 714 pp.

Lobry de Bruyn, L.A., B.A. Jenkins, and Sutrisno. 1997. Soil invertebrate biodiversity in Stringybark Forest in the New England Tablelands before clearing. Mem. Mus. Victoria 56: 295-303.

Majer, J.D. 1997. The use of pitfall traps for sampling ants-a critique. Mem. Mus. Victoria 56: 323-329.

Martinat, P.J., C.C. Coffman, K.M. Dodge, R.J. Cooper, and R.C. Whitmore. 1988. Effect of Dimilin 25-W on the canopy arthropod community in a central Appalachian forest. J. Econ. Entomol. 81: 261-267.

Martinat, P.J., D.T. Jennings, and R.C. Whitmore. 1993. Effects of diflubenzuron on the litter spider and orthopteroid community in a central Appalachian forest infested with gypsy moth (Lepidoptera: Lymantriidae). Environ. Entomol. 22: 1003-1008.

May, D.M. 1991. Forest resources of Tennessee. USDA For. Serv. Res. Bull. SO-160. 65 pp.

McAlpine, J.F. (ed). 1987. Manual of Neartic Diptera Vol. II. Minister of Supply and Services, Canada. 675-1332.

McAlpine, J.F., B.V. Peterson, G.E. Shewell, H.J. Teskey, J.R. Vockeroth, and D.M. Wood (eds). 1981. Manual of Neartic Diptera Vol. I. Minister of Supply and Services, Canada. 674 pp.

McManus, M., N.Schneeberger, R. Reardon, and G. Mason. 1992. Gypsy moth. U.S. Dept. Agric. For. Serv. Forest Insect & Disease Leaflet 162: 5-7.

Metcalf, R.L. and R.A. Metcalf. 1993. Destructive and useful insects: their habits and control. McGraw-Hill, Inc., New York. 1984 pp.

Mitchell, B. 1963. Ecology of two carabid beetles, *Bembidion lampros* (Herbst) and *Trechus quadristriatus* (Schrank). I. Life cycles and feeding behavior. J. Anim. Ecol. 32: 289-299.

Morrill, W.L., D.G. Lester, and A.E. Wrona. 1990. Factors affecting efficacy of pitfall traps for beetles (Coleoptera: Carabidae and Tenebrionidae). J. Entomol. Sci. 25: 284-293.

Murdock, N.A. 1994. Rare and endangered plants and animals of Southern Appalachian wetlands. Water, Air and Soil Pollution 77: 385-405.

Newell, G.R. 1997. The abundance of ground-dwelling invertebrates in a Victorian forest affected by 'dieback' (*Phytophthora cinnamomi*) disease. Australian J. Ecol. 22: 206-217.

Peine, J. 1989. Managing the Great Smoky Mountains National Park Biosphere Reserve for biological diversity. Air pollution effects on vegetation: Proceedings of the second US-USSR Symposium. NE For. Exp. Sta. 173-179.

Powell, S. 1998. Tenn. Dept. Agric., Nashville, Tennessee (pers. comm.).

Radford, A.E., H.E. Ahles, and C.R. Bell. 1968. Manual of the vascular flora of the Carolinas. The Univ. of North Carolina Press, Chapel Hill, NC. 1183 pp.

Reardon, R. and A. Hajek. 1993. *Entomophaga maimaiga* in North America: a review. USDA Appalachian Integrated Pest Management. NA-TP-15-93: 1-18.

Reardon, R. and J. Podgwaite. 1992. The gypsy moth nucleopolyhedrosis virus product. USDA Appalachian Integrated Pest Management. NA-TP-02-92: 2-4.

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

Risley, L.S. 1986. The influence of herbivores on seasonal leaf-fall: premature leaf abscission and petiole clipping. J. Agric. Entomol. 3: 152-162.

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

Rohm and Haas Company. 1989. Technical information bulletin RH-5992 insect growth regulator. AG-2255. Rohm and Haas, Philadelphia, PA.

Sample, B.E., L. Butler, C. Zivkovich, R.C. Whitmore, and R. Reardon. 1996. Effects of *Bacillus thuringiensis* and defoliation by the gypsy moth on native arthropods in West Virginia. Can. Entomol. 128: 573-592.

SAS Institute. 1997. SAS/STAT Software: change and enhancements through release 6.12. SAS Institute, Inc.,Cary, N.C.

SAS Institute. 1989. SAS/STAT User's guide, Ver. 6. SAS Institute, Inc., Cary, N.C.

Smagghe, G. and D. Degheele. 1994. Action of a novel nonsteroidal ecdysteroid mimic, Tebufenozide (RH-5992), on insects of different orders. Pestic. Sci. 42: 85-92.

Smith. R.L. 1992. Elements of Ecology, Third Edition. HarperCollins Publishers Inc. New York, NY. 617 pp.

Spieles, D.J. and D.J. Horn. 1998. The importance of prey for fecundity and behavior in the gypsy moth (Lepidoptera: Lymantriidae) predator *Calosoma sycophanta* (Coleoptera: Carabidae). Environ. Entomol. 27: 458-462.

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. Tenn., Knoxville. 82 pp.

Swank, W.T., J.B. Waide, D.A. Crossley Jr., and R.L. Todd. 1981. Insect defoliation enhances nitrate export from forest ecosystems. Oecologia 51: 297-299.

Topping, C.J. and K.D. Sunderland. 1992. Limitations to the use of pitfall traps in ecological studies exemplified by a study of spiders in a field of winter wheat. J. App. Ecol. 29: 485-491.

Twardus, D.B. and H.A. Machesky. 1990. Gypsy moth suppression in the Northeast. A three-year summary of the treatment monitoring data base. U.S. Dep. Agric. For. Serv. For. Pest Manage. Tech. Pap. NA-TP-18.

United States Department of Agriculture (USDA). April 1995. Gypsy moth management in the United States: a cooperative approach. Draft, Environmental Impact Statement Summary:12-15.

United States Department of Agriculture (USDA). January 1996. Gypsy moth management in the United States: a cooperative approach. Record of Decision: 1.

United States Department of Agriculture (USDA). July 1996. The southern Appalachian assessment summary report. Report 1 of 5. R8-TP 25: 12-29.

USDA Forest Service. 1995. Gypsy moth digest. FHP-USDA Forest Service. Morgantown, WV.

USDA Forest Service. 1988. The South's fourth forest: alternatives for the future. USDA For. Serv. For. Resour. Rep. No. 24.

Werren, J.H., M.J. Raupp, C.S. Sadoff, and T.M. Odell. 1992. Host plants used by gypsy moths affect survival and development of the parasitoid *Cotesia melanoscela.* Environ. Entomol. 21: 173-177.

Weseloh, R.M. 1998. Modeling the influence of forest characteristics and ant (Formicidae: Hymenoptera) predation on dispersal and survival of neonate gypsy moths (Lymantriidae: Lepidoptera). Environ. Entomol. 27: 287-296.

Weseloh, R.M. 1990a. Simulation of litter residence times of young gypsy moth larvae and implications of predation by ants. Entomol. Exp. Appl. 57: 215-221.

Weseloh, R.M. 1990b. Experimental forest release of *Calosoma sycophanta* (Coleoptera: Carabidae) against the gypsy moth. J. Econ. Entomol. 83: 2229-2234.

Weseloh, R.M. 1989. Simulation of predation by ants based on direct observations of attacks on gypsy moth larvae. Can. Entomol. 121: 1069-1076.

Weseloh, R.M. 1985. Predation by *Calosoma sycophanta:* evidence for a large impact on gypsy moth, *Lymantria dispar,* pupae. Can. Entomol. 117: 1117-1126.

Whaley, W.H., J. Anhold, and G.B. Schaalje. 1998. Canyon drift and dispersion of *Bacillus thuringiensis* and its effects on select nontarget Lepidopterans in Utah. Environ. Entomol. 27: 539-548.

Wigley, T.B. and T.H. Roberts. 1994. Forest management and wildlife in forested wetlands of the Southern Appalachians. Water, Air, and Soil Pollution 77: 445-456.

Wilson, E.O. 1992. The diversity of life. Cambridge, Massachusetts: The Belknap Press of Harvard University Press. 424 pp.

Wing, K.D., R.A. Slawecki, and G.R. Carlson. 1988. RH-5849, a nonsteroidal ecdysone agonist: effects on larval Lepidoptera. Science (Wash., D.C.) 241: 470-472.

APPENDIX

Table A1. Species codes assigned to insect taxa collected using pitfall traps in The University of Tennessee Forestry Experiment Station and Arboretum in 1997 and 1998.

Species Code	Order	Family	Genus	Species
B1	Blattaria	Blattellidae	*Ischnoptera*	*deropeltiformis*
B2	Blattaria	Blattellidae	*Parcoblatta*	*bolliana*
C0	Coleoptera	Staphylinidae	--	--
C1	Coleoptera	Carabidae	*Galerita*	*bicolor*
C100	Coleoptera	Scarabaeidae	*Onthophagus*	*janus*
C101	Coleoptera	Staphylinidae	--	--
C102	Coleoptera	Curculionidae	--	--
C103	Coleoptera	--	--	--
C104	Coleoptera	Scaphidiidae	--	--
C105	Coleoptera	Elateridae	--	--
C106	Coleoptera	Ptilodactylidae	*Ptilodactyla*	sp.
C107	Coleoptera	Coccinellidae	--	--
C108	Coleoptera	Leptodiridae	*Colon*	sp.
C109	Coleoptera	Staphylinidae	--	--
C11	Coleoptera	Staphylinidae	*Tachinus*	*fimbriatus*
C110	Coleoptera	Tenebrionidae	*Mercantha*	*contracta*
C111	Coleoptera	Scarabaeidae	*Canthon*	*hudsonias*
C112	Coleoptera	Chrysomelidae	*Demotina*	*modestus*
C113	Coleoptera	Elateridae	--	--
C114	Coleoptera	Curculionidae	--	--
C116	Coleoptera	Anobiidae	--	--
C12	Coleoptera	Carabidae	*Selenophorus*	*opalinus*

Table A1. (Continued)

Species Code	Order	Family	Genus	Species
C13	Coleoptera	Carabidae	*Apenes*	*lucidula*
C14	Coleoptera	Scarabaeidae	*Bolboceras*	sp.
C15	Coleoptera	Silphidae	*Nicrophorus*	*orbicolis*
C16	Coleoptera	Carabidae	*Pterostichus*	*coracinus*
C17	Coleoptera	Carabidae	*Dicaelus*	*dilatatus*
C18	Coleoptera	Scarabaeidae	*Canthon*	*viridis*
C19	Coleoptera	Carabidae	–	–
C2	Coleoptera	Carabidae	*Cyclotrachelus*	*fucatus*
C20	Coleoptera	Tenebrionidae	*Anaedus*	*brunneus*
C21	Coleoptera	Scarabaeidae	*Ateuchus*	*histeroides*
C22	Coleoptera	Stahpylinidae	*Philonthus*	*blandus*
C23	Coleoptera	Scarabaeidae	*Phyllophaga*	*implicata*
C24	Coleoptera	Carabidae	*Galerita*	sp. (larva)
C25	Coleoptera	Scarabaeidae	*Parastasia*	*brevipes*
C26	Coleoptera	--	–	–
C27	Coleoptera	Curculionidae	*Conotrachelus*	*elegans*
C28	Coleoptera	Staphylinidae	*Philonthus*	*cyanipennis*
C29	Coleoptera	Nitidulidae	*Phenolia*	*grossa*
C30	Coleoptera	Staphylinidae	*Lobrathium*	*collare*
C32	Coleoptera	Scaphidiidae	*Scaphidium*	*quadriguttatum*
C33	Coleoptera	Carabidae	*Galerita*	sp. (larva #2)
C34	Coleoptera	Lampyridae	*Lucidota*	*atra*
C35	Coleoptera	Carabidae	*Chlaenius*	*emarginatus*
C36	Coleoptera	Staphylinidae	–	–

Table A1. (Continued)

Species Code	Order	Family	Genus	Species
C37	Coleoptera	Carabidae	*Platynus*	*melanius*
C38	Coleoptera	Carabidae	*Stenolophus*	sp.
C39	Coleoptera	--	--	--
C4	Coleoptera	Carabidae	*Sphaeroderus*	*lecontei*
C40	Coleoptera	Carabidae	*Pterostichus*	sp.
C41	Coleoptera	Staphylinidae	--	--
C42	Coleoptera	Staphylinidae	--	--
C44	Coleoptera	--	--	--
C45	Coleoptera	--	--	--
C46	Coleoptera	Ptiliidae	*Nephanes*	sp.
C47	Coleoptera	Scarabaeidae	*Deltochilum*	*gibbosum*
C48	Coleoptera	Histeridae	*Euspilotus*	sp.
C49	Coleoptera	Scydmaenidae	*Noctophus*	sp.
C50	Coleoptera	Carabidae	*Cyclotrachelus*	*sigilatus*
C51	Coleoptera	Staphylinidae	*Staphylinus*	*fossator*
C52	Coleoptera	Scarabaeidae	*Geotrupes*	*splendidus*
C53	Coleoptera	Carabidae	*Cyclotrachelus*	*freitagi*
C54	Coleoptera	Nitidulidae	*Stelidota*	*octomaculata*
C55	Coleoptera	--	--	--
C56	Coleoptera	Staphylinidae	--	--
C57	Coleoptera	Curculionidae	*Cyrtepistomus*	*castaneus*
C58	Coleoptera	--	--	--
C6	Coleopte	Carabidae	*Melanius*	*caudicalis*
C60	Coleoptera	Nitidulidae	--	--

Table A1. (Continued)

Species Code	Order	Family	Genus	Species
C61	Coleoptera	Scarabaeidae	*Onthophagus*	*hectate*
C62	Coleoptera	--	--	--
C63	Coleoptera	--	--	--
C64	Coleoptera	--	--	--
C65	Coleoptera	Scarabaeidae	*Coprius*	*minutus*
C66	Coleoptera	Staphylinidae	--	--
C67	Coleoptera	Leptodiridae	*Namadus*	sp.
C68	Coleoptera	Troginae	*Trox*	*variolatuss*
C69	Coleoptera	Silphidae	*Necrophilus*	*pettiti*
C7	Coleoptera	Staphylinidae	*Staphylinus*	*maculosus*
C70	Coleoptera	Staphylinidae	unidentified	sp. 1
C71	Coleoptera	Staphylinidae	unidentified	sp. 2
C72	Coleoptera	--	--	--
C74	Coleoptera	Staphylinidae	--	--
C75	Coleoptera	--	--	--
C76	Coleoptera	--	--	--
C77	Coleoptera	Leiodidae	*Anistoma*	sp.
C78	Coleoptera	Curculionidae	--	--
C79	Coleoptera	Orthoperidae	*Sericoderus*	*lateralis*
C8	Coleoptera	Rhysodidae	*Clinidium*	*sculptile*
C80	Coleoptera	Staphylinidae	--	--
C81	Coleoptera	--	--	--
C82	Coleoptera	Staphylinidae	--	--
C83	Coleoptera	--	--	--

Table A1. (Continued)

Species Code	Order	Family	Genus	Species
C84	Coleoptera	--	--	--
C85	Coleoptera	Scaphidiidae	--	--
C86	Coleoptera	--	--	--
C87	Coleoptera	Chrysomelidae	--	--
C88	Coleoptera	Carabidae	*Dicaelus*	*ambiguus*
C89	Coleoptera	Carabidae	*Cyclotrachelus*	*sodalis*
C9	Coleoptera	Carabidae	*Dicaelus*	*politus*
C90	Coleoptera	Nitidulidae	*Colopterus*	*truncatus*
C91	Coleoptera	Scolytidae	*Dendroctonus*	*frontalis*
C92	Coleoptera	Scarabaeidae	*Phyllophaga*	*hirticula*
C93	Coleoptera	Staphylinidae	--	--
C94	Coleoptera	Staphylinidae	--	--
C95	Coleoptera	--	--	--
C96	Coleoptera	--	--	--
C97	Coleoptera	Scarabaeidae	*Phyllophaga*	sp.
C98	Coleoptera	Eucinetidae	*Eucinetus*	sp.
C99	Coleoptera	--	--	--
Collembola	Collembola	--	--	--
D10	Diptera	Sarcohagidae	--	--
D11	Diptera	Tachinidae	--	--
D12	Diptera	--	--	(Larvae)
D13	Diptera	Drosophilidae	--	--
D14	Diptera	Muscidae	--	--
D15	Diptera	Otitidae	--	--

Table A1. (Continued)

Species Code	Order	Family	Genus	Species
D16	Diptera	Rhagionidae	–	–
D17	Diptera	Calliphoridae	–	–
D2	Diptera	Phoridae	–	–
D3	Diptera	Sphaeroceridae	–	–
D4	Diptera	Psychodidae	–	–
D5	Diptera	Sciaridae	–	–
D6	Diptera	Chloropidae	–	–
D7	Diptera	Chironomidae	–	–
D8	Diptera	Tipulidae	–	–
D9	Diptera	Cecidomyidae	–	–
Diplura	Diplura	--	–	–
Eulophidae	Hymenoptera	Eulophidae	–	–
H1	Hymenoptera	Formicidae	*Ponera*	*pennsylvanica*
H10	Hymenoptera	Formicidae	*Aphaenogaster*	*tennesseensis*
H11	Hymenoptera	Formicidae	*Myrmecina*	*americana*
H12	Hymenoptera	Formicidae	*Camponotus*	*ferrugineus*
H13	Hymenoptera	Formicidae	*Camponotus*	*caryae*
H14	Hymenoptera	Formicidae	*Formica*	*schaufussi dolosa*
H15	Hymenoptera	Formicidae	*Formica*	*fusca*
H16	Hymenoptera	Formicidae	*Prenolepsis*	*imparis pumila*
H17	Hymenoptera	Formicidae	*Amblyopone*	sp.
H18	Hymenoptera	Formicidae	*Brachymyrmex*	*depilis*
H19	Hymenoptera	Formicidae	*Paratrechina*	sp.

Table A1. (Continued)

Species Code	Order	Family	Genus	Species
H2	Hymenoptera	Formicidae	*Neivamyrmex*	*nigrescens*
H20	Hymenoptera	Formicidae	*Prenolepsis*	*imparis imparis*
H21	Hymenoptera	Formicidae	*Camponotus*	sp.
H22	Hymenoptera	Formicidae	*Smithistruma*	sp.
H23	Hymenoptera	Formicidae	*Aphaenogaster*	*texana carolinensis*
H24	Hymenoptera	Formicidae	*Pheidole*	*dentata*
H3	Hymenoptera	Formicidae	*Solenopsis*	*molesta*
H4	Hymenoptera	Formicidae	*Crematogaster*	*lineolata*
H5	Hymenoptera	Formicidae	*Leptothorax*	*pergandei*
H6	Hymenoptera	Formicidae	*Aphaenogaster*	*lamellidens*
H7	Hymenoptera	Formicidae	*Camponotus*	*pennsylvanicus*
H8	Hymenoptera	Formicidae	*Formica*	*subsericea*
H9	Hymenoptera	Formicidae	*Prenolepsis*	*imparis testacea*
HE	Hemiptera	--	--	--
HE1	Hemiptera	--	--	--
Hemiptera	Hemiptera	--	--	--
HomAph	Homoptera	Aphididae	--	
HomCic	Homoptera	Cicadellidae	--	--
HomCix	Homoptera	Cixiidae	--	--
Homoptera	Homoptera	--	--	--
Hymen*	Hymenoptera	--	--	--
Hymenoptera	Hymenoptera	--	--	--
HyVes1	Hymenoptera	Vespinae	--	--

Table A1. (Continued)

Species Code	Order	Family	Genus	Species
HyVes2	Hymenoptera	Vespinae	*Dolichovespula*	*maculata*
Isoptera	Isoptera	--	--	--
Japygid	Diplura	Japygidae	--	--
Lepidoptera	Lepidoptera	--	--	--
Microcoryhia	Microcoryphia	--	--	--
N1	Neuroptera	Myrmeleontidae	*Ascaloptynx*	sp.
NeuChr	Neuroptera	Chrysopidae	--	--
O1	Orthoptera	Gryllacrididae	*Ceuthophilus*	sp.
O2	Orthoptera	Decticidae	*Atlanticus*	sp.
O3	Orthoptera	Nemobiidae	*Nemobius*	sp.
O4	Orthoptera	Gryllidae	*Gryllus*	sp.
P2	Psocoptera	Psocidae	*Indiopsocus*	sp.
Plecoptera	Plecoptera	--	--	--
Psocoptera	Psocoptera	--	--	--
Siphonaptera	Siphonaptera	--	--	--
Thysanoptera	Thysanoptera	Thripidae	--	--
Thysanura	Thysanura	--	--	--

VITA

Melinda Monroe Gibbs was born in Atlanta, Georgia on April 10, 1974. She was raised in Dahlonega, Georgia where she graduated from Lumpkin County High School as salutatorian in June 1992. In June 1996, she received her Bachelor of Science in Biology from North Georgia College in Dahlonega, Georgia. In January 1997, she was accepted into the Department of Entomology and Plant Pathology at The University of Tennessee, Knoxville. Under the direction of Dr. Paris L. Lambdin and Jerome F. Grant, she completed the requirements for a Master of Science degree in Entomology and Plant Pathology in December 1998. Melinda Monroe Gibbs is a member of the Entomological Society of America and the Tennessee Entomological Society. Upon graduation, Melinda wishes to pursue a career in biological control.

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