# ABUNDANCE AND DISTRIBUTION OF

# POTENTIAL ARTHROPOD PREY SPECIES

# IN A TYPICAL GOLDEN-CHEEKED WARBLER HABITAT

A Thesis

by

MICHAEL ANDREW QUINN

# ABUNDANCE AND DISTRIBUTION OF

# POTENTIAL ARTHROPOD PREY SPECIES

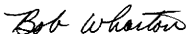# IN A TYPICAL GOLDEN-CHEEKED WARBLER HABITAT

A Thesis

by

MICHAEL ANDREW QUINN

Submitted to Texas A&M University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE
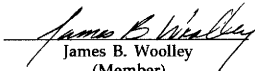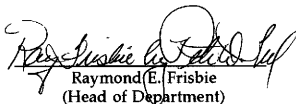
Approved as to style and content by:

_____
Robert A. Wharton
(Chair of Committee)

_____
Kirk O. Winemiller
(Member)

_____
James B. Woolley
(Member)

_____
Raymond E. Frisbie
(Head of Department)

December 2000

Major Subject: Entomology

# ABSTRACT

Abundance and Distribution of Potential Arthropod Prey Species

in a Typical Golden-cheeked Warbler Habitat. (December 2000)

Michael Andrew Quinn, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Robert A. Wharton

Arthropods have diverse functions in ecosystems, including providing food for resident breeding birds. The Golden-cheeked Warbler, *Dendroica chrysoparia* Sclater & Salvin is an endangered insectivorus song bird that nests exclusively in the juniper/oak woodlands of central Texas. This study was conducted to determine the availability of arthropods to the Golden-cheeked Warbler in its breeding habitat. Regular surveys were made of the arthropods on four tree species in which the warbler commonly forages. Arthropod abundance by tree species, height class, date, year and site was estimated. We surveyed the Long Hollow site for two years and the Shellberg site concurrently the second year. In general, the difference between our two study sites was significant but not as great as the differences among tree species within sites. Although the difference between sites for some taxa was significant, usually those differences were proportional across the tree species. Most taxa showed large differences in abundance between years, particularly those taxa that were associated with the two species of oaks in our study. In general, arthropods were more abundant at the lowest height class and were

progressively less abundant with increasing height. Oaks supported large populations of hemipterans, homopterans and lepidopteran larvae early in the warbler's nesting season. Ashe juniper supported large populations of homopterans and lepidopteran larvae in the middle of the warbler's nesting season. Hymenopterans showed less of a tree species association than other orders and were abundantly available for a longer period of time than most orders. Beetles were most abundant in April. Spiders were the dominant arthropods in terms of overall abundance, with numbers gradually increasing throughout the period that the warbler is present in Texas. Twenty-two Golden-cheeked Warbler gizzards were available for examination. The dominant taxa in these gizzards were lepidopteran larvae, Hymenoptera, Araneae, Coleoptera, and Homoptera, closely matching the dominant arthropod taxa found in the warbler breeding habitat.

This thesis is dedicated to Allan S. Quinn

## ACKNOWLEDGEMENTS

# TABLE OF CONTENTS

Page

# CHAPTER I

# INTRODUCTION

The Golden-cheeked Warbler, *Dendroica chrysoparia* Sclater & Salvin, is an endangered songbird that nests exclusively in Texas. Due to its restricted range and apparent rarity, the U.S. Fish and Wildlife service listed the Golden-cheeked Warbler in 1990 under the Endangered Species Act. The following year, the Texas Parks and Wildlife Department also listed the Golden-cheeked Warbler as endangered. Relatively little is known about the biology of this species, though attempts to learn more have intensified over the past few years. Issues involving the ability of the federal government to restrict activities on privately-held lands under authority of the endangered species act make it imperative that we learn as much as possible about this species prior to setting land use policies.

Much of the concern about the decline in populations of this species has focused on the larger issue of reduction and fragmentation of available habitat. Reduction in habitat affects many things, including potential food sources. Knowledge of the availability of such resources is thus relevant to our understanding of this species. Unfortunately, little is known about the feeding preferences of the Golden-cheeked Warbler. What is known comes from an analysis of approximately 25 stomach contents (Attwater 1892, Woolfenden 1967, Pulich 1976). Attempts to add to our knowledge of the

_____

This thesis follows the style and format of Environmental Entomology.

warbler's feeding habits are complicated by the bird's protected status. Previous methods involving shooting one or more birds to examine their gut contents (or even live capture and flushing of crops) are now unacceptable. The examination of gut contents tends to be unsatisfactory for other reasons including small sample sizes, the loss of critical characters used in arthropod identification, possible under-representation of soft bodied arthropods such as aphids, and over-representation of hard bodied arthropods like beetles.

There were three specific objectives of this study, whose overall goal was an improved understanding of the prey availability in Golden-cheeked Warbler breeding habitat. The first objective was to measure seasonal patterns of arthropod abundance in Golden-cheeked Warbler breeding habitat and test the hypothesis that peaks in arthropod abundance are associated with the energy requirements of the Golden-cheeked Warbler. The second was to determine the spatial pattern of arthropods in Golden-cheeked Warbler breeding habitat and test the hypothesis that prey are uniformly available on all tree species and in all height classes through time. This objective addresses the issue of whether foraging height is dictated by prey availability. The third objective was to determine patterns in arthropod abundance between sites and between years in preferred Golden-cheeked Warbler breeding habitat and test the hypothesis that between-site and between-year variation is not significant.

### Golden-cheeked Warbler Biology

**Warbler Phenology.** Of the 53 species of warblers recorded from Texas

(Texas Ornithological Society 1995), only 7 breed on the Edwards Plateau in Central Texas. Two of these, the Golden-cheeked Warbler and the Yellow-throated Warbler, *Dendroica dominica albilora* Ridgway are members of the genus *Dendroica*. Most Golden-cheeked Warblers arrive in central Texas from overwintering sites in Central America by the end of the second week of March (Pulich 1976). This is early spring in Texas, coinciding with emergence of overwintering insects. Catkins are beginning to form and new leaves appear on deciduous trees within a month, attracting a wide variety of potential insect prey. Nesting activities thus appear to be correlated with a peak in insect abundance.

Pulich (1976) compiled egg-laying data on 61 completed egg-sets that ranged from April 3 to June 27. The mean date of the first nesting attempt was April 17 while the overall median egg-laying date was April 26. The warbler usually lays 3 to 4 eggs, rarely 5. The 3 five-egg clutches that Pulich cites were laid in the early part of the nesting season, April 3, 15 and 16. Four of the 5 three-egg sets were laid later in the nesting season, between May 7-21. If the first attempt fails, a second clutch may be laid. Mean date for the second attempt is May 13. The female warbler begins incubation the day the penultimate egg is laid and continues incubation for 12 days, so the range for egg-hatching would be April 15 to July 9. The median hatch date would be May 8. The male plays an active roll in the feeding and care of the young. The young leave the nest when 8 or 9 days old. The fledglings remain with

their parents for at least four weeks. About the third week out of the nest, the young begin to forage for themselves but are not yet totally independent from their parents. The end of the breeding season for first nesting attempts thus averages mid to late May and for the second attempt, mid June (Pulich 1976).

Little is known about the fall departure of the Golden-cheeked Warbler (Pulich 1976). Toward the end of the breeding season, the males become quiet and are as difficult to locate as the females. In banding studies, the number caught dropped off sharply after the breeding season ended. Pulich (1976) states that the main population of warblers migrates by the end of July.

**Texas Habitats.** Texas contains a great diversity of environments for plant and animal life. One of the major controlling factors for the distribution of these environments is the climatic conditions. The north-south line dividing the continent into regions of moisture sufficiency and moisture deficiency passes through central Texas (Blair 1950).

According to Blair (1950), three major biotas are recognized in Texas, a Sonoran fauna, an Austroriparian fauna and a Neotropical fauna. Blair (1950) based his classification system on the "distribution of topographic features, climate, vegetation types, and terrestrial vertebrates exclusive of birds." The first two biotas belong to the Nearctic realm, the last represents the Neotropic realm. The Sonoran fauna is characteristic of the arid southwestern United States and Mexican tablelands. This biota is represented in Texas by the Chihuahuan biotic province of the Trans-Pecos, exclusive of the Guadalupe Mountains. The Austroriparian fauna is represented by the

mesic forests of extreme eastern Texas to the Atlantic. The Neotropical fauna extends northward along the eastern coast of Mexico and reaches Texas in the Lower Rio Grande Valley. It is represented by the Tamaulipan province which extends to the southern edge of the Edward's Plateau. The central Texas area, from the Pecos to the forests of east Texas is principally a region of transition between the Sonoran and Austroriparian biotas. Here the two major biotas integrate, and few Neotropical species enter the area (but see the discussion of Durden's data below). Three biotic provinces, the Balconian, the Texan and the Kansan, are recognized in this transition area (Blair 1950). The Golden-cheeked Warbler nests in all three of these transitional provinces but has its highest density in the Balconian which includes the Edwards Plateau, the Lampasas Cut Plain, and the Llano Uplift region.

The most characteristic plant association of the Balconian is an oak-juniper scrub forest. The predominant woody species over most of the Golden-cheeked Warbler's nesting range include ashe juniper, *Juniperus ashei* Buchholz; live oak, *Quercus fusiformis* Small; Texas oak, *Q. buckleyi* Nixon & Dorr; scrub oak, *Quercus sinuata* var. *breviloba* (Torr.) C.H. Muller; cedar elm, *Ulmus crassifolia* Nuttall; netleaf hackberry, *Celtis laevigata* var. *reticulata* (Torr.) L. Benson; Texas ash, *Fraxinus texensis* (Gray) Sarg.; and Texas persimmon, *Diospyros texana* Scheele (Pulich 1976, Kroll 1980, Beardmore 1994). Here and elsewhere in the thesis we follow Flora of North America Editorial Committee (1997) for plant nomenclature.

**Avian Insectivorous Foraging.** Robinson and Holmes (1982) in their

extensive paper on foraging behavior of forest birds in New Hampshire, determined that an insectivorous bird's foraging behavior largely determines what types of prey it is likely to obtain. Their study included 3 species of *Dendroica* warblers: Black-throated Green Warbler, *D. v. virens* (Gmelin); Black-throated Blue Warbler, *D. caerulescens* (Gmelin): and the Blackburnian Warbler, *D. fusca* (Miller). They categorized the warblers as "rapid searchers" changing positions at rates over 24 times per minute. The warblers hopped more often than they flew, giving them a hop per flight ratio over 1. The warblers performed many short (<0.9 m) search flights. Gleaning, defined as a standing or hopping bird taking a stationary prey item from a substrate, was the primary attack method for 2 of the 3 *Dendroica* warblers. Gleaned prey are usually spotted nearby (<0.3 m) and the attack does not involve a flight component.

Robinson and Holmes (1982) sum up the foraging behavior of gleaning birds as moving short distances at a high speed while searching nearby substrates. They conclude that this leads to the capture of small to medium-sized, cryptically colored prey. Pulich (1976) states that "gleaning while hopping along a branch" is the Golden-cheeked Warbler's most frequent method of foraging.

**Diet of Other Wood-Warblers.** Forbush (*in* Chapman, 1917) discusses the known arthropod prey of 12 species of warblers in 5 genera (Emberizidae, Parulinae). He lists 35 species of arthropods in 19 families and 10 orders. Among these were 9 families of moths (Bombycidae, Colephoridae,

Geometridae, Lasiocampidae, Lymantriidae, Noctuidae, Pyralidae, Saturniidae, and Tortricidae), 8 families of Coleoptera (Buprestidae, Carabidae, Chrysomelidae, Cicindelidae, Coccinellidae, Curculionidae, Elateridae, and Scolytidae) and a variety of Homoptera and Hymenoptera. In addition to Forbush's more comprehensive summary, dietary information is available on several species of *Dendroica*. The studies of Mayfield (1960) and Nolan (1978) are the most detailed of these.

Mayfield (1960) in his monograph on the now endangered Kirtland's Warbler (*Dendroica kirtlandi*) stated that "the bird seems to be an opportunist, eating whatever animal matter is available and sampling many other items (ants, pine needles, twigs, grass, pitch, and automobile grease) some rejected as unpalatable, others eaten though of doubtful nutritional value. During the summer, food does not appear to be a problem to the adult warblers. They seem able to fulfill their needs in a small part of the daylight hours."

Entomologist J. Speed Rogers spent 3 hours observing a warbler nest with 2 five-day-old cowbirds (Mayfield 1960). Twelve insects were brought to the nest by the warblers during this period, including 5 lepidopteran or sawfly larvae, 3-5 flies, a grasshopper nymph and a moth. Mayfield (1960) also cited reports of the warbler feeding on other insects such as deer flies, cicadas, antlions, damselflies, and beelike insects. When the blueberries ripen early in August, the Kirtland's Warbler feeds extensively on them (Mayfield 1960).

Nolan (1978) has made the most exhaustive study of any species of

*Dendroica.* He presented the stomach content data from 250 Prairie Warblers (*Dendroica discolor*). They were collected between 1885 and 1950, most before 1920. The birds were collected from 18 states, the District of Columbia, and Ontario. Analysis suggested no location, sex, and age difference (the sample contained no nestling stomachs) in diet. The following arthropod taxa were identified: Acari; Araneae; Odonata (2 families); Ephemeroptera, Ephemeridae; Orthoptera (2 families); Psocoptera, Liposcelidae; Pthiraptera; Hemiptera (4 families); Homoptera (7 families); Neuroptera, Corydalidae; Coleoptera (15 families); Trichoptera; Lepidoptera, Pyralidae; Diptera (13 families); Hymenoptera (9 families).

Nolan observed an additional 8 families of insects (in 4 orders) being fed upon by the Prairie Warbler but not represented in the above stomach contents data. Ninety-seven percent of the arthropods found in 208 stomachs of *D. d. discolor* were represented by 7 orders: Coleoptera, Lepidoptera, Diptera, Hymenoptera, Araneae, Homoptera, and Hemiptera. Beetles of the families Chrysomelidae and Curculionidae are eaten especially frequently (Nolan, 1978).

Diet: *Dendroica chrysoparia.* Data on the diet of the Golden-cheeked Warbler are based on the publications of Attwater (1892), Woolfenden (1967), Pulich (1976), and Kroll (1980). Attwater (1892) collected a number of young Golden-cheeked Warblers and found their stomachs "all contained (with other insects), a number of small black lice (*Aphis* sp.)" which he watched the adults collect from juniper limbs. Woolfenden (1967) collected a stray

Golden-cheeked Warbler in Florida whose stomach contained "lepidopteran larvae (possibly two or three), one anthribid, one curculionid weevil, a few spider fragments, and many unidentified insect fragments." The specimen was collected in an area dominated by sand live oak, *Quercus geminata* Small. Warren Pulich, Jr. (Pulich 1976) analyzed the stomach contents of 21 Golden-cheeked Warblers from 15 counties in Texas. Seventy-two arthropods were identified as follows: 24 Coleoptera (including 9 Curculionidae), 13 unidentified Lepidoptera, 13 Homoptera; 10 Hemiptera, 8 Araneae, 2 Diptera, 2 Hymenoptera, and 1 insect egg. These data correspond well with those of Nolan (1978) on Prairie Warbler.

Field observations suggest an even wider diet than is evident from analysis of stomach contents. Pulich (1976), for example, found the bird "to have fed on spiders, brown and green caterpillars, green lacewings, small green cicadas, katydids, walkingsticks, deer flies, crane flies, adult flies, adult moths and small butterflies." Other small insects were eaten before they could be identified. Kroll (1980) made 153 observations of Golden-cheeked Warbler prey items in Bosque County, Texas during April-June 1975. He observed the warblers eating 82 Lepidoptera larvae and 1 adult; 20 Orthoptera; 8 Neuroptera; 2 Diptera; 1 mollusc; and 39 unidentified prey types.

## Insects

**Insect Fauna of Central Texas.** The insect fauna of Central Texas has been sampled and studied in sporadic fashion over the past 150 years. One of the first insect collectors to make significant contributions to our knowledge of

the Texas fauna was Horace Haldeman (Burke 1977). From 1848 to 1854 he collected a large number of beetles, many of which were sent to John L. LeConte, the leading coleopterist in the U.S. of the time. Due to their popularity amoung amateurs, the larger Coleoptera of Texas are particularly well-known.

The first comprehensive taxonomic publication on any large group of Texas insects was *Hymenoptera Texana* (Cresson 1872). It covered nearly 600 species of Hymenoptera. Almost one-half of these were described as new. Subsequent studies by Wheeler (1910, 1920), Creighton (1950), and Wheeler and Wheeler (1976) have contributed greatly to our knowledge of Texas ants, making this one of the best known families of insects in Texas.

The Lepidoptera of Central Texas have also received considerable attention. Roy O. Kendall, for example, has amassed a collection of over 100,000 pinned adults and 2,000 vials of immature Lepidoptera (Arnett et al. 1993) largely reared with plant associations. Additionally, Durden (1990) has been surveying the butterflies in Austin since 1968, and has found 97 genera, including 38 tribes and 13 families. He has determined that 41% of the species that he's collected are at or near the northern boundary of their range, 39% are in midrange, 18% are near the eastern boundary of their range, 17% are at the southern or southwestern boundary of their range, and 7% are at the western boundary of their range.

A center for biodiversity studies, Brackenridge Field Laboratory (BFL) was

started in 1967 by the University of Texas and encompasses 88 acres on the north shore of the Colorado River in southwest Austin. The total number of insect species found at BFL is 1913, including 211 species of beetles, 548 species of Hymenoptera, 83 species of butterflies and 887 species of moths (Bramblett 2000). But these totals are very skewed by the extensive work of Hook (Hymenoptera) and Gillaspie (moths).

Jackman and Nelson (1995) conducted a diversity and phenological study of mordellid beetles throughout 1990 at this study site. They collected a total of 35 species using a Malaise trap with 28 of these species recorded for the first time from Texas. Specimens taken from April 9 to July 2 represent 89% of the specimens and 94% of the species collected in this study. Both number of specimens and number of species basically have a single annual peaks in May. Only a few specimens were collected in the fall. The authors suggest that all species of mordellids are probably univoltine in central Texas.

Palmer (1987) also conducted a 4 year survey of phytophagous insects on 2 species of *Baccharis*, a bushy member of the Asteraceae common along roadsides and disturbed areas. His surveys, primarily using a sweep net, were centered around Temple, TX. At irregular intervals, Palmer surveyed the southern Edwards Plateau. Excluding pollen and nectar gatherers, Palmer recorded 133 species of phytophagous insects from 6 orders. The number of species and frequency of those orders is as follows: Orthoptera 5 (4%), Hemiptera 27 (20%), Homoptera 27 (20%), Lepidoptera 17 (13%), Coleoptera 46 (35%) and Diptera 11 (8%).

Aside from Palmer's (1987) work, there is little in the way of published survey of arthropods associated with specific trees or shrubs in Central Texas. Although considerable information is available for crops, surveys of arthropods on native trees are more appropriate for assessment of Golden-cheeked Warbler foodbase. Of the publications on insects in Texas, perhaps the most relevant to the present study are those by Ehler and Frankie (1979a, 1979b), Frankie et al. (1979) and Vincent and Frankie (1985) on the fauna of live oaks in urban and natural stands in central Texas. Results from this survey published for both mites (Acari) (Ehler and Frankie 1979a, 1979b) and spiders (Araneae) (Vincent and Frankie 1985) form an excellent baseline for the survey work conducted here.

**Insect Fauna of Trees.** Numerous studies of the insect fauna of trees have been conducted in other states and in other countries. These range in scope from simple inventories (Southwood 1961) to more intensive ecological studies that are either taxon specific (Opler 1974) or directed towards assessment of entire communities (Lawton 1978, Southwood et al. 1982, Basset and Kitching 1991, Le Corff et al. 2000).

Community-level surveys most relevant to our work include those by Basset and Kitching (1991) and Jackson and Resh (1989). Basset and Kitching (1991) continuously trapped arthropods over a two year period from a single rainforest tree species in Australia. They collected a total of 20,500 individuals and identified 759 species. The sorted material included 55 species of chewers, 93 of sap-suckers, 282 of predators, 42 of fungal-feeders and 162 of scavengers.

Taxonomically, the most speciose arthropod families included Curculionidae, Cicadellidae, Staphylinidae, Cerambycidae, Theridiidae and Chrysomelidae. The Coleoptera alone represented 302 species (39.8%). Jackson and Resh (1989) collected a total of 5,402 individual aquatic insects in 27 taxa from sticky traps hung in oak trees, *Quercus kelloggii* Newberry, at three heights (2, 5, and 8 m) adjacent to a stream in northern California. They found that species richness, number of individuals, and biomass of aquatic insects showed no relationships to height above the ground.

**Host Specificity.** There is a considerable amount of anecdotal information on host plant specificity in insects. Published data that suggest varying degrees of plant fidelity are often difficult to assess due to lack of vouchers and/or lack of evidence of a thorough exploration for alternate hosts. Nevertheless, there is excellent documentation of both narrow host specificity and broad polyphagy for selected herbivorous insects. The monarch and *Heliothis virescens* (F.) are good examples of specialists and generalists, respectively, associated with herbacious plants, and Opler (1974) provides specific examples for species associated with trees.

Some insects are monophagous, that is they feed on only one species or genus of plant. Oligophagous insects usually feed on a few closely related plants, i.e. plants of the same genus or in the same family. Polyphagous insects that feed on a wide variety of unrelated plants are often considered to be pests. The larvae of the Gray Hairstreak, *Strymon melinus* Hübner, for example, has been recorded feeding on over 80 species of plants in 59 genera

in 29 different families (Scott, 1986).

Palmer (1987) in a 4 year insect survey of *Baccharis halimifolia* L. and *B. neglecta* Britt. centered at Temple, Texas where these two plant species' ranges overlap, collected 133 species of phytophagous insects representing 6 orders. Only 11 species (8% of the total species) of these insects restricted their feeding to *Baccharis* and were considered monophagous. Two additional species restricted their feeding to the tribe Astereae and were classified as oligophagous. The remaining 118 species were considered either polyphagous, host range unknown or hosts unknown but probably polyphagous. Palmer and Bennett (1988) in a survey of *Baccharis halimifolia* conducted between southern Florida and Washington, D.C., recorded 174 phytophagous insects and found nearly identical percentages of monophagous, oligophagous, and polyphagous insects. Interestingly, only 27 (16%) of the total number of insect species were common to both surveys.

Claridge and Wilson (1976) collected over 20,000 adult leafhoppers (Cicadellidae) from 12 species of broad-leaved trees in South Wales in 1974. They identified 35 species of leafhoppers and determined that 16 of these were monophagous, 12 were oligophagous and only 3 were polyphagous. Only one species of leafhopper was found on all trees sampled. Interestingly, some of the oligophagous species showed preferences for unrelated hosts.

Roginskaya (1966) collected over 13,000 weevils (Attelabidae and Curculionidae) from the Moscow Province between 1953 and 1956. His collection contained 30 species of weevils from 7 species of trees that he

assigned to the following groups: (1) species for which more than 80% of the total number of specimens in the collection were found on a single kind of tree; (2) species found mainly (at least 80%) on two kinds of trees; (3) species found on three of more kinds of trees. The first group comprised 6 species, the second group comprises 4 species, and the third 4. The remaining 16 species were classified as rare or not very plentiful.

**Phenology.** Insects living in the temperate zone tend to have discrete seasonal cycles, with a period of population growth or buildup in the spring or summer and an overwintering period or diapause of varying length. Univoltinism in insects is particularly common in temperate regions, but the same insect that may have only one generation per year in the northern United States often can produce two or even three generations per year in Texas. Regardless of the number of generations, the yearly cycle for Texas insects may be interrupted not only by a winter diapause but also by a resting period during the hot summer months. Food availability may also be seasonal, and is directly related to the degree of host specificity of the insects in question.

Most of our knowledge about seasonal activity in insects comes from detailed studies of pest species. While many of these studies are associated with field crops, there are excellent studies on the seasonal patterns and population dynamics of insects associated with fruit trees, shade trees, and timber production. These include species characterized by massive periodic outbreaks such as gypsy moth (Campbell et al. 1978), southern pine beetle

(Coulson 1980), and spruce budworm (Royama 1984), as well as yearly pests such as codling moth, a key pest of apples (Metcalf et al. 1962).

Insects that restrict their feeding to deciduous trees must diapause or migrate during the winter. Those feeding on evergreens could conceivably extend their activities through the year if climatic conditions are favorable. However, foliage is not uniformly suitable as food through the year. For example, Opler (1974) conducted an extensive study of the lepidopterous larvae associated with *Quercus agrifolia* Neé in coastal south and central California. He found that immense numbers of lepidopterous larvae complete development by feeding on emergent oak foliage during the month after foliation has begun, while external feeding larvae of only a few species feed in low numbers on mature summer foliage and develop slowly despite the seemingly amenable conditions provided by summer weather. Opler (1974) found that 13 out of 18 external feeding lepidopterous larvae ate only young spring foliage or catkins and, as such, must be univoltine. The larvae of two other species begin their development on hardened foliage and reach maturity by feeding on young spring foliage, and therefore must also be univoltine. Only one external feeder, a polyphagous species that fed on sucker growth, was multivoltine.

Bivoltinism is another pattern in phytophagous, arboricolous insects. The Sycamore aphid, *Drepanosiphum plantanoides,* is an example of a bivoltine species. It reproduces in response to spring and fall increases in soluble nitrogen (Strong et al. 1984).

Seasonal patterns in abundance of the arboricolous insects of central Texas are largely unknown. To better understand the feeding habits and dietary preferences on the Golden-cheeked Warbler in its breeding habitat, it will be helpful to know if these insects fit the pattern seen in Opler's study on California oaks, or whether the bivoltine or multivoltine pattern is more prevalent.

# CHAPTER II

## SEASONAL PATTERNS IN ARTHROPOD ABUNDANCE IN GOLDEN-CHEEKED WARBLER HABITAT DURING THE BREEDING SEASON

The Golden-cheeked Warbler breeds and forages in woodland habitats in a transition zone between the eastern forests and the Chihuahuan Desert. The insect fauna of irrigated and dryland crops in this area, including the relatively few tree crops such as pecan and peach, has received considerable attention from the standpoint of pest monitoring and control (Sterling and Pieters 1974, McWhorter et al. 1976). However, detailed faunal analyses of the native vegetation, and in particular the native trees in which Golden-cheeked Warblers forage, have rarely been attempted and most surveys do not provide information on seasonal patterns. Notable exceptions in this regard are the survey of three sites conducted by Ehler and Frankie (1979a, 1979b) and Vincent and Frankie (1985) on the live oaks of Travis county. Unfortunately, only the arachnid portion of this survey has been published.

Little is known about the Golden-cheeked Warbler's feeding preferences. Pulich (1976) inspected the contents of 21 Golden-cheeked Warbler stomachs and identified 75 food items, but none of these were identified below the family level. Prior to these findings, only 5 arthropods were recorded as taken from this bird's stomach. With so little data on this bird's food preferences, the impact of habitat loss on the warbler's food base thus can not be adequately assessed and specific prey items cannot be targeted for in-

depth analysis. Our objective is to look at patterns of abundance for the insect fauna as a whole for selected tree species on which the warbler is known to forage.

## Materials and Methods

**Site Selection.** Arthropods were collected from known breeding sites of the Golden-cheeked Warbler in western Travis County, Texas. The number of sites available were limited to public property and a few cooperative private-property landowners. Given these limitations, final site selection was based on easy access to a suitable number of trees with sufficient foliage in the full range of warbler foraging heights from ground level to at least 5 m. Previous work on warbler activity suggested that these birds spend large portions of their time in the upper levels ($\geq$ 5m) of trees (Beardmore 1994), and commonly forage there (Pulich 1976). It was therefore essential to choose sites with adequate numbers of tall, accessible trees. Collections were timed to coincide with the presence of Golden-cheeked Warblers in Travis county. The earliest warblers arrive during the first week of March, with the majority of the warblers beginning their return migration by the end of July (Pulich 1976).

Surveys were initiated in 1993, and were expanded to include a second site in 1994. The 1993 collection site, Long Hollow, was primarily on Lower Colorado River Authority land in the Long Hollow drainage northeast of Lake Travis. A few of the trees from this collection site were on adjacent Nature Conservancy property. In 1994, samples were taken from a second

site, Shellberg, along the eastern shore of Lake Travis. Male Golden-cheeked Warblers, which have a distinct vocalization, were present in the collecting sites in both 1993 and 1994.

**Site Description.** These two sites are covered by an oak-juniper woodland. Live oak and ashe juniper are common throughout the area. Texas oaks are mostly on the hillsides while the cedar elms are usually restricted to the deeper soils at the bottom of the many ravines or along the mostly intermittent streams. Rocky limestone outcrops are abundant. The average annual rainfall recorded in nearby Austin from 1933-1963 was 827.5mm (32.58 inches). The average July temperature in Austin over a 30-year period was 29.2 °C (84.5 °F).

**Tree Species.** Four tree species, Ashe juniper, *Juniperus ashei* Buchholz; Texas oak, *Quercus buckleyi* Nixon & Dorr; live oak, *Q. fusifomis* Small; and cedar elm, *Ulmus crassifolia* Nuttall were sampled based on the work of Beardmore (1994) on forage utilization by nesting Golden-cheeked Warblers. A minimum of twelve clusters of trees of each of the four tree species were uniquely marked at each site prior to the first sample. Four individual clusters of trees per species were randomly selected for sampling on each collection date. The small size of most of the trees in the two collection sites precluded the use of single trees for most sweep samples, thus the need to select clusters of trees. Samples were collected from the lower (0-3m), middle (3-5m), and upper (≥5m) section of each tree cluster on each sample date.

Samples were taken biweekly from February 29 through August 1. In 1993

the first sampling date was missed due to problems associated with site selection and access. Thus, sampling in 1993 began on March 13th. The first complete set of samples was collected on March 26th. Each set of samples from the 16 trees (four sets of trees from each of four tree species) required one full day to complete. Samples from 1994 were taken on consecutive days at the two different sites.

   **Collection Methods.** Two different collection methods were initially selected for the biweekly samples, beat sheets and sweep nets. These two techniques were somewhat complementary, leading to a greater diversity of insects than using one alone. On the first sampling date, however, we discovered that we could not employ the beat sheet above the lower height for logistical reasons. In 1993, we used sweep nets of two different sizes (79cm diameter and 37cm diameter) in an attempt to compensate for the absence of beat sheet samples from the middle and upper sections. In 1994, only the larger of the two sweep nets was employed to facilitate quantitative comparisons among heights.

   Five subsamples were taken from each tree/tree cluster: two from the lower section, two from the middle section, and one from the upper section. There were not enough trees with foliage above 5m at the Long Hollow site to enable us to take two subsamples from the upper section. Thus, a total of 80 subsamples was collected at each site on each collection date (5 subsamples per tree x 4 trees per species x 4 tree species = 80 subsamples).

   From the lower section of the tree/tree cluster, half of the samples for each

tree species were taken with a beat sheet and half with a sweep net. Beat sheet samples were taken by holding a rectangular sheet (92cm sq and supported by cross bars attached at each corner) beneath a branch and striking the branch vigorously two times to dislodge the arthropods. The procedure was repeated for two different branches to form a single sample. All arthropods falling on the sheet were quickly removed with forceps or an aspirator and placed directly into an appropriately labelled vial containing a preservative. We used 70% ethanol as our standard preservative for most arthropod taxa and a larval fixative for lepidopteran and other soft bodied immatures.

Half of the lower, and all of the middle and upper tree heights were sampled with a sweep net. A sweep sub-sample was taken by placing a well-foliated branch inside of the large net (79cm diameter) and shaking the net vigorously. This process was repeated 7 more times to complete one subsample. The small sweep net (37cm diameter) was swept through the foliage eight times to make one sweep sample. The insects along with the plant foliage of the sweep sample were then dumped into a gallon sized sealable plastic bag along with an ethyl acetate wick and chilled in an ice chest for the return trip to the laboratory. Insects that clung to the net (i.e. not easily dumped into the plastic bag) were removed with soft forceps and placed directly into an appropriately labelled vial containing ethanol or larval fixative.

Plastic bags containing the samples were stored in a freezer in the lab until the dead arthropods could be separated from the foliage with the aid of

dissecting microscopes. Dissecting microscopes were used to avoid missing minute arthropods such as mites, thrips and chalcidoid wasps. Thus separated, these insects were placed in alcohol together with the insects that had been preserved directly in the field.

   **Invertebrate Specimen Processing and Data Capture.** Hard-bodied insects were removed from alcohol and pinned or point mounted. The Hymenoptera and Diptera were treated similarly, but specimens were dehydrated first using a critical-point-dryer to prevent collapse. Soft bodied insects such as spiders, Psocoptera and all larvae were stored permanently in 80% ethyl alcohol. Thrips were slide-mounted. All arthropods were labelled with locality, date, height, tree species, and collection method.

   Once curated, all specimens were identified at least to morphospecies (except as noted below). Most identifications were done by collaborators from the Department of Entomology, Texas A&M University. Ed Riley, who currently handles all entomological identifications for Texas Agricultural Extension Service, coordinated the curation and identification. Allen Dean provided identifications for the spiders (our largest group) and Charles Cole identified all the thrips. Faculty members Horace Burke, Joseph Schaffner, Robert Wharton and James Woolley each took responsibility for providing identifications in their areas of expertise. A few taxa [most notably mites (Acari), midges (Nematocera), and many of the barklice (Psocoptera)] were largely unidentified beyond these broader categories. The amount of time that would have been required to obtain authoritative identifications at the

generic or species level for these taxa would not have been cost-effective nor would have added significant information to the database.

Supplemental collections of Lepidoptera larvae (caterpillars) were made for the purpose of rearing in the laboratory since larvae are difficult to identify. Larvae were collected from various unmarked trees at the collection site and brought back alive to the laboratory in College Station to rear through to adulthood. The larvae were fed fresh foliage collected on the College Station campus every two to three days as needed. The larvae were reared in plastic gallon containers along with a sprig of foliage kept fresh by putting the cut end in a 4 dram vial of water. Parafilm was wrapped around the top of each vial to prevent any larvae from entering the vial and drowning. We also identified two moths that were partially fed upon by Golden-cheeked Warblers during the survey.

All specimens of suitable condition were eventually integrated into the Insect Collection of the Department of Entomology at Texas A&M University. Representatives of each species were specifically retained as voucher specimens. A second voucher collection was delivered to Texas Department of Transportation in Austin.

The ecological data associated with each specimen were transcribed from the labels and then manually entered into the data base. The database used was FileMaker Pro 3.0v2 by Claris (1996). For every species collected in a sample, a record was created in the database. Each record had an input field for all associated ecological data, e.g. date, site, tree species, height, collection

method and quantity. Taxonomic information was also entered for each specimen, e.g. order, family, genus and species if known. Recording the data in many separate fields allowed the data to be sorted by any given category or any number of categories, for instance, all the longhorn beetles collected mid-height on Ashe juniper, April 9, 1994, at the Long Hollow site could quickly be found. For the quantitative comparisons in this chapter, the database was sorted primarily by date and taxon to determine the number of specimens collected per date.

**Statistical Analysis.** The StatView statistical package (SAS Institute 1998) was used for data analysis. Analysis of variance was followed by separation of treatment of means using Scheffé's $F$ (Scheffé 1953). The data were transformed by $\log(x + 1)$ to equalize variances among categories and presented in graphical and tabular form following analyses.

In order to test the hypothesis that peaks in arthropod abundance are associated with appearance of the first Golden-cheeked Warbler brood, the overall arthropod abundance and the abundance of particular well-represented taxa were determined for each sample date. These quantities were compared to the average hatch date for Golden-cheeked Warbler nestlings, the period of greatest need for arthropod food.

Companion data on Golden-cheeked Warbler activity were taken from several sources. Pulich (1976), who provided specific dates on 61 nests, was the primary source. Another source was a series of observations made in the vacinity of our Travis Co. study sites during the period of our study: TxDOT

personnel conducted nest observations, Gass (1996) studied nesting behavior, and Cade Coldren monitored 365 territories between 1993 and 1994. We also re-examined stomach contents of birds examined by Pulich (1976) to facilitate comparison of arthropods we sampled with known dietary items.

## Results

A total of 48,196 arthropods was collected during the 2-year period. 17,198 of these were collected at Long Hollow in 1993, 14,784 from Long Hollow in 1994, and 14,217 from Shellberg in 1994. The most frequently collected arthropods (Fig. 1, in Appendix A) were Araneae (12,115 individuals, 108 morphospecies), Hymenoptera (5,659 individuals, 522 morphospecies), Homoptera (5,012 individuals, 125 morphospecies), Psocoptera (4,994 individuals, 24 morphospecies) and Coleoptera (4,590 individuals, 274 morphospecies). Total numbers by sample date are plotted in Fig. 2. Phenotypical patterns for these taxa are shown in Figs. 3, 7, 14, 16, and 23.

One measure of the diversity of an order is the number of species represented by five or fewer individuals. Hymenoptera were by far the most diverse order, with 195 of the 522 morphospecies represented by 5 or fewer individuals. Araneae had 57 morphospecies with five or fewer individuals, Coleoptera had 176, Diptera had 131, Homoptera had 88 and Hemiptera had 44. Of the major orders, Lepidoptera appeared to be the least diverse with only 27 morphospecies represented by five or fewer individuals.

**All Arthropods.** A steep increase in the abundance of arthropods occurred primarily between mid and late March, then a plateau was reached that

generally exceeded 5,000 individuals per date (Fig. 2). This plateau of abundance lasted from the end of March until the first week in June. From there, the numbers decreased to approximately 3,000 arthropods at the end of July. The overall pattern of a single broad peak is (Fig. 2) is a result of a relatively early peak in 1993 and a somewhat later peak in 1994. In 1994, for example, the peak number of arthropods at Shellberg occurred on May 19-20 and the peak at Longhollow occurred on the following sampling date, June 2. The peak at both sites was approximately 2,000 individual arthropods.

Araneae. There were 12,115 spiders, representing 24% of the total arthropods collected during this study. The dominant families were Anyphaenidae (2,597), Thomisidae (1,732), Salticidae (1,708) and Araneidae (1,685). The spiders generally increased through the sampling season and reached a plateau in late June that exceeded 1,500 spiders per date for the last four sample dates (Fig. 3). Due to the large number of immatures in our samples, many of the individuals could not be determined to species. Results for three representative genera are thus presented here.

*Misumenops* (family Thomisidae) was the most common genus of spiders collected. *Misumenops* generally showed a mid to late season peak (Fig. 4). More than 200 *Misumenops* were collected per date from early May through early June. Members of this family, known as crab spiders, spin no webs but forage for their prey or lie in ambush for it.

*Hibana* (family Anyphaenidae) was the second most common genus of spiders collected. *Hibana* showed an end of the collecting season peak (Fig. 5).

More that 200 *Hibana* were collected on the last two collecting dates. Members of this family wander over foliage in search of prey.

*Philodromus* (family Anyphaenidae) was the third most common genus of spiders collected. A sustained peak in abundance of *Philodromus* occurred from the first week in June until the end of our sampling period (Fig. 6). *Philodromus* are hunting spiders that do not form webs.

**Coleoptera.** There were 4,673 beetles collected during this study. The dominant families were Chrysomelidae (1,928) and Coccinelidae (397). Coleoptera abundance was greatest in April (Fig. 7). More than 1,000 beetles were collected on both dates in April while less than 600 beetles each were collected in late March and early May. From mid May on, the decrease in beetle abundance was gradual.

*Xanthonia* sp. 1 (family Chrysomelidae) was the most commonly collected species of Coleoptera. Over 250 individuals were collected in early April (Fig. 8). There was a rapid fall off in abundance after April. The decrease in abundance for this species was almost as rapid as was its increase. Fewer than 20 individuals were collected per date after early May. *Xanthonia* sp. 2 was the second most frequently collected beetle. The phenology of this species was atypical for beetles (Fig. 9). It had one of the earliest peaks and was present longer than other species studied. More than 50 individuals were collected per date from mid March through early May. Chrysomelids are phytophagous beetles.

*Brachypnoea tristis* (Olivier) (family Chrysomelidae) had a later and

sharper peak than other beetles examined (Fig. 10). Approximately 150 were collected between April 23-24. Forty or fewer were collected on the sample dates on either side of this peak.

*Malthinus occipitalis* LeConte (family Cantharidae) was the fifth most commonly collected coleopteran. Almost all members of this species were collected in April, none were collected after early May (Fig. 11). Its abundance rose quickly from near zero to over 100 two weeks later on April 9-10. The dropoff was almost as rapid. Adults of this species probably feed on pollen; the larvae are predaceous.

**Hemiptera.** There were 2,167 true bugs collected during this survey. The dominant families were Miridae (1,647) and Reduviidae (316). Most hemipterans were collected between late March and early June (Fig. 12). At least 200 individuals were collected per date during this time. Over 500 were collected on April 23-24.

*Tropidosteptes quericola* (Johnston) (family Miridae) was the most common species of Hemiptera collected. Its phenology was typical of nearly all Miridae (Fig. 13). Over 160 individuals were collected on April 23-24. Less than 20 were collected prior to this date and none afterwards. Most mirids are phytophagous.

**Homoptera.** There were 5,012 homopterans collected during this survey. The dominant familes were Cicadellidae (2,317) and Membracidae (1,315). Homopterans were most abundant from late April through early June (Fig. 14). Over 650 individuals were collected on each of the four collecting dates

from April 23 through June 5. More than 300 were collected for most other dates.

*Platycotis vittata* (Fabricius) (family Membracidae), was one of the most common homopterans collected. Its phenology (Fig. 15) was similar to that of most membracids. The number of immatures collected peaked on March 26-27. Total abundance peaked on April 23-24. Fewer than 10 individuals were collected per date after mid-May. Membracids feed mostly on trees and shrubs.

**Hymenoptera.** There were 5,669 hymenopterans collected during the survey. The dominant families were Formicidae (1,847) and Platygastridae (679). The hymenopterans showed a phenology similar to the arthropods as a whole (Fig. 16). The abundance of hymenopterans steeply increased during March. Over 600 were collected each date from the end of March through the first week in May. From there, the numbers collected gradually tapered off.

*Solenopsis invicta* Buren (family Formicidae) was the most abundant hymenopteran. Its phenology was nearly opposite that of the Hymenoptera as a whole (Fig. 17). Generally low abundance was observed through the first half of the collecting season. From June onward, this species exhibited a highly variable abundance. Ants are common, widespread, eusocial insects.

*Monomorium minimum* (Buckley) (family Formicidae) was the second most common hymenopteran. Its phenology was similar to that of *S. invicta* (Fig. 18). Uniformly low numbers of individuals were collected from February through the first week of May. During the last portion of our study period, the number of individuals collected per date was highly variable.

**Lepidoptera.** We collected 2,371 lepidopteran larvae in our samples. The dominant families were Tortricidae (1,064), Geometridae (490) and Gelechiidae (393). Lepidoptera larvae rapidly increased in abundance through March (Fig. 19). Over 500 were collected on March 26-27. Over 600 were collected on April 9-10. Approximately 200 were collected on April 23-24. Very few Lepidoptera larvae were collected after June. Almost all Lepidoptera larvae are phytophagous.

Larvae of the families Gelechiidae and Tortricidae (leaf tiers and leaf rollers) showed similar patterns of abundance (Fig. 20) to that of Lepidoptera as a whole. *Cudoniger houstonana* (Grote) (family Tortricidae) was the most common species of lepidopteran larvae. They were abundant principally from the first week in May through the first week in June (Fig. 21).

Larvae of the family Geometridae (inchworms) also showed a similar pattern to that displayed by the order (Fig. 22). This family peaked on March 26-27 at just over 180 individuals. Their numbers decreased over the next six weeks. Less that 30 specimens were collected per date after April.

**Psocoptera.** There were 4,994 psocopterans collected during our study. The abundance of psocopterans rose gradually from February through the third week in April, never exceeding more than 200 individuals per date (Fig. 23). Their abundance increased through May and peaked on June 2-5 at approximately 1,100 individuals. Their abudance decreased over the following eight weeks and was again below 200 individuals on our last collecting date. Psocids are soft-bodied insects that feed on a wide variety of

food items.

Arthropods from Golden-cheeked Warbler gizzards. A re-examination of the Golden-cheeked Warbler gizzards showed the dominant orders to be Lepidoptera (22%), Hymenoptera (16%), Araneae (14.5%), Coleoptera (14.5%), Homoptera (14%), Isoptera (9%), and Hemiptera (6%) (Table 1, at end of Appendix A). At least 200 individuals were found in the 22 gizzards. All 18 isopterans came from a single gizzard.

### Discussion

Invertebrate Abundance Relative to Warbler Diet. Based on our re-analysis of Golden-cheeked Warbler gizzards (Table 1), Lepidoptera larvae, Hymenoptera, spiders, beetles and Homoptera are among the most common dietary items of this species. With these background data in mind, arthropod taxa that peak in abundance near or shortly after the appearance of the warbler's first brood (mid April through mid May) may be food resources that the bird depends on most to rear its young.

Four orders: Coleoptera, Diptera, Hemiptera, and Lepidoptera larvae all showed a somewhat similar pattern of abundance through time. They were particularly uniform in their rapid increase in abundance during March, peaking in April, and declining in May. Homoptera and Hymenoptera exhibited a similar pattern, but with a more extended peak and consequently a slightly later decline. Other orders of arthropods showed a different phenological pattern. Araneae, our dominant taxon in terms of numbers of individuals, exhibited a unique pattern of abundance through time. They

were the only order to continue to increase in numbers throughout the summer. The number of spiders collected during the last six weeks was nearly 1,500 individuals per date, an abundance not attained by any other order for even one date. Psocoptera (4,994 individuals), Polyxenida (915 individuals), and Orthoptera (974 individuals) were unusual in several ways. Instead of peaking in March or April, they were collected in greatest numbers between May 19 and June 2. Approximately 600 were collected on each date in 1994 at Long Hollow and at Shellberg.

Although spiders dominated our samples overall, there were at least 200 more beetles in our samples during the April collection dates than for any other order. The lepidopteran peak was the most abrupt of any order as it rose dramatically with the onset of new foliage and then declined precipitously from its high on April 9-10. Coleoptera, Homoptera, and Hymenoptera each had six or more weeks with an abundance greater than 500. Hymenoptera exceeded 500 per date for 10 weeks from the last week in March all the way to the first week in June. More than 300 homopterans and hymenopterans were collected per date through the end of the study.

Lepidoptera larvae, especially the cryptic inchworms, were over-represented in the Golden-cheeked Warbler gizzards (Table 1) as compared to our sampling from trees. Nolan (1978) also found a high percentage of Lepidoptera caterpillars in Prairie Warbler stomachs. In terms of volumetric percentage of animal matter in the stomachs of race *discolor*, Lepidoptera were second only to Coleoptera. In race *paludicola*, Lepidoptera constituted

the greatest percentage by volume. Caterpillars are particularly important to Prairie Warbler nestlings. Of the 761 arthropods delivered to nestlings that Nolan (1978) could determine to class or order, caterpillars numbered 622 (82%). Holmes et al. (1986) found that the three most common *Dendroica* warblers at their study site increased during a period of plentiful caterpillar food.

Spiders were slightly under-represented in gizzards as compared to our survey results. The relative abundance of Hymenoptera, Homoptera, Coleoptera and Hemiptera in the Golden-cheeked Warblers gizzards was the same as in our samples. No Psocoptera were identified from gizzards though they were a substantial proportion of the total arthropods collected.

**Arthropod and Host Tree Phenology.** Live oaks maintain leaves year round. The old leaves fall in February and March. New leaves begin forming immediately following the major period of leaf drop. New leaves continue to grow for three months (Frankie et al. 1979). Texas oaks and live oaks both produce catkins in the spring concurrent with new leaf production. The pollen on these reproductive structures provides nourishment for a wide variety of insects that have a peak in population which is associated with the peak in catkin production. Thus, it is not surprising that the peak abundance for many of the insects in our survey coincided with catkin and new leaf production. Spiders were exceptional in this regard. Vincent & Frankie (1985) found "no relationship [was] apparent between the phenological patterns of spider collections and the major phenological events of the host plant." Our

data support this observation.

   **Comparisons with Other Studies on Arboreal Arthropod Abundance.** Fig. 2, showing the total number of individuals collected through time, is comparable to what Basset and Kitching (1991) recorded during their two year survey of arboreal arthropods associated with an Australian rainforest tree. They identified 20,500 individuals to the species level. Their data collected from intercept traps showed a better correlation of species richness with mean maximum and mean minimum weekly temperatures than with host leaf production.

   Our ten most-frequently collected orders, Araneae (12,115), Hymenoptera (5,669), Homoptera (5,012), Psocoptera (4,994), Coleoptera (4,673), Acari (3,275), Diptera (2,930), Lepidoptera (2,371), Hemiptera (2,167), and Thysanoptera (1,939 for 1993 only) were the same dominant taxa that Southwood et al. (1982) collected from six native tree species in Britain and in South Africa. They found these orders to encompass over 90% of the more than 41,000 arthropods they collected, as did we.

   Southwood et al. (1982) found that more individuals of Hemiptera (= our Hemiptera and Homoptera) were collected from native trees of Britain than any other taxon. However, this was only our second-most collected taxon (Hemiptera + Homoptera = 7,179). We actually collected over twice as many Arachnida (Spiders + Mites = 15,390). The main taxon we collected within Arachnida was Araneae or spiders. Our data showed that the spiders increased throughout our five-month collecting season. Although

Southwood's survey was conducted between 24 July and 2 August, due to their more northerly latitude this time frame actually corresponds to a date earlier in our summer when spiders were less common and most of the other taxa were more numerous. Nevertheless, spiders were always more abundant than Hemiptera and Homoptera in our samples.

Karban & Ricklefs (1983) analyzed insects collected by the Canadian Forest Insect Survey. They recorded 19,755 individuals of more than 300 species of insects from 33 species of broad-leaved, deciduous trees. Lepidoptera made up the majority of insect species collected in their study, but not in ours. Of the Lepidoptera larvae we collected in 1994, the greatest number came from the one broad-leaved deciduous species in our study, the Texas oak. They collected more individuals from American elm, *Ulmus americana* L. than any other species of host. Cedar elm was a distant third in the number of Lepidoptera larvae collected in our study, behind Ashe juniper.

Thysanoptera had the most dramatic spike of any order. Frank & Huber (1987) found a similar rapid drop-off in abundance for the western flower thrips, *Franklinella occidentalis* (Pergande) on Arizona pistachios. In five days, the mean number of western flower thrips dropped from 19 per male blossom to just 3 per male blossom. The decline was attributed to the male blossoms desiccating and the thrips dispersing.

Vincent and Frankie (1985) conducted a low-intensity sampling regime over a 12 month period, at three sites in Austin, Texas. They sampled from *Quercus virginiana* P. Mill., *Q. fusiformis* and/or intermediates between the

two. They collected a total of 196 spiders which were represented by 26 species in 15 families. Seventy-two percent of the spiders they identified were in the families Anyphaenidae, Theridiidae and Salticidae. These families plus Araneidae and Thomisidae were our five most common families. Vincent and Frankie (1985) collected five or fewer individuals from Araneidae and Thomisidae.

# CHAPTER III

# PATTERNS IN ARTHROPOD ABUNDANCE BETWEEN SITES IN GOLDEN-CHEEKED WARBLER HABITAT DURING THE BREEDING SEASON

Arthropod abundance varies in time and place, sometimes dramatically. There has been considerable debate as to whether abiotic factors are more important than biotic factors in governing arthropod abundance. Clearly, both are significant. An understanding of population fluctuations under natural conditions, due to the combined impact of biotic and abiotic factors, is essential for determining the impact of habitat loss.

## Materials and Methods

Site selection and general sampling methods were presented in Chapter II. Data from 1994 were used for site comparisons since only one site was sampled in 1993. A three-way ANOVA (Ott 1993) was used to compare the variation in the number of arthropods collected per sample from the two sites, the four trees species, and each date to see if there were significant ($p<0.05$) differences between the sites, or among trees or dates. Data from different tree heights, for a given tree species, were combined.

## Results

A total of 48,196 arthropods in nearly 1,500 species was collected during the 2-year period of this survey.

**All Arthropods.** The two sites were significantly different for arthropods as a whole as were the main effects of tree and date (Table 2, in Appendix B).

More arthropods were collected at Long Hollow than Shellberg. Date, followed by tree, had the greatest effects on arthropod abundance. There was no significant interaction between site and tree (Fig. 24, in Appendix B) indicating that the number of arthropods collected from each tree species was proportional between the two sites. There were significant interactions between site and date, particularly from mid May through July when the greatest number of arthropods collected per date alternated frequently between sites (Fig. 25).

Araneae. The two sites were not significantly different for spiders (Table 3). The main effects of tree and date were both significant. Date had the greatest effect on the dependent variable followed by tree. All combined effects followed the interaction pattern seen in the analysis of all arthropods. There was no site by tree interaction (Fig. 26). The site by date interaction was significant (Fig. 27).

For *Misumenops* spp., the main effect of site was not significant (Table 4). The main effects of tree and date were both significant. Tree had a much greater effect on the sample mean than date. All two-way interactions were significant (Figs. 28 and 29).

For *Hibana* spp., the main effect of site was not significant (Table 5). The main effects of tree and date were both significant. Again, tree had a greater effect than date on the mean abundance per sample. There was no interaction between site and tree (Fig. 30). This is one of the few cases with no interaction between site and date (Fig. 31). In 1994, on average less than 25 individuals

were collected on any one date.

For *Philodromus* spp., the main effects of site, tree and date were all significant (Table 6). Date followed by site had the greatest effects on sample mean. The interaction between site and tree was negligible (Fig. 32). The combined effect of site by date (Fig. 33) was significant. From mid May on, there were consistently more *Philodromus* spp. collected at Long Hollow.

Coleoptera. The number of coleopterans were significantly different between sites and among dates (Table 7). The site differences were apparently due to the significantly larger number of coleopterans on Ashe juniper and live oak at Long Hollow (Fig. 34). One early and two later collecting dates yielded greater means for Long Hollow (Fig. 35). Date had, by far, the greatest effect on the mean followed by site. The site by tree interaction was significant, apparently due to the disproportionate number of coleopterans on live oaks and Ashe junipers at Long Hollow versus Shellberg. This difference was less pronounced than the similar trend noted below for hemipterans on live oaks. Site by date and tree by date interactions were also significant for the coleopterans.

For *Xanthonia* sp. 1, the site effect was not significant (Table 8). The main effects of tree and date were significant. The site by tree (Fig. 36) and the site by date (Fig. 37) interactions were negligible. The tree by date interaction was significant due to this species being almost completely monophagous on elm.

For *Xanthonia* sp. 2, the site effect was not significant (Table 9). Both the tree and date effects were significant due to this species being monophgous on

Ashe juniper (Fig. 38). Statistically, *Xanthonia* sp. 2 and *Xanthonia* sp. 1 were very similar. Both species shared the unusual trait of not having a significant site by date interation (Figs. 37 and 39). There was no site by date combined effect for this species (Fig. 39). Although the mean abundance varied frequently between sites for each date, the variance was so great that there were no significant differences between sites within dates.

Hemiptera. The main effect of site was significant for the hemipterans (Table 10). The main effects of tree and date were also significant with the tree contributing slightly more to the variation of sample abundance than the date effect. All two- and three-way combined effects were significant. Interestingly, there was a significant interaction between site and tree (Fig. 40) largely due to there being many more hemipterans on live oak at Long Hollow than at Shellberg. The site by date combined effect (Fig. 41) was significant due to the greater numbers of hemipterans collected at Long Hollow on April 9-10 and June 2-5, while Shellberg was significantly more productive for this order on May 7-8.

All main (Table 11) and combined effects (Figs. 42 and 43) were also significant for the most common hemipteran: *Tropidosteptes quercicola* (Family Miridae). Almost all specimens were collected from Long Hollow, thus the main effect of site had the greatest impact on the sample abundance.

Homoptera. There was no site effect for the homopterans as a whole (Table 12). Both the tree and date effects were significant. Date followed by tree had the greatest effect on the sample abundance of homopterans. There was no

interaction between site and tree (Fig. 44). The site by date (Fig. 45) and tree by date interactions were significant. Long Hollow had significantly more homopterans in mid March and early June, Shellberg had more during May.

**Hymenoptera.** The site effect for hymenopterans was significant (Table 13). More hymenopterans were found at Long Hollow than at Shellberg, particularly from late February through early April and on live oak. The date effect was significant. The combined effect of site by tree was significant and apparently due to the difference in mean abundance on live oak at Long Hollow versus Shellberg (Fig. 46). Combined effect of site by date was significant due to the oscillation in abundance between the two sites from early May through July (Fig. 47).

*Solenopsis invicta* showed a dramatic difference between sites (Table 14). All other main and combined effects were also significant. Between the sites, more *S. invicta* were collected at Shellberg on almost every date (Fig. 49) and from every tree except Texas oak (Fig. 48). Most other taxa that showed a demonstrable site preference were more abundant at Long Hollow.

Significantly more *Monomorium minimum* were collected at Long Hollow than Shellberg (Table 15). This species seemed to show more variability than most species, but perhaps due to the low total number collected, neither the site by tree (Fig. 50), nor the site by date (Fig. 51) combined effect were significant. This species peaked at both sites in mid-June.

**Lepidoptera.** The site effect for lepidopteran larvae was significant (Table

16), as were the other main effects of tree and date. More lepidopteran larvae were found on every tree species at Long Hollow versus Shellberg (Fig. 52). But as these differences between sites were equivalent among the trees, the site by tree interaction was minimal. The site by date combined effect was significant (Fig. 53), most noticeably due to a greater Long Hollow abundance in late March and mid-June.

For geometrid larvae, the site effect was significant as were the tree and date main effects (Table 17). The preference for Ashe juniper (Fig. 54) and the low and fairly even abundance through time (Fig. 55) accounts for the results. As with the order as a whole, there was no interaction between the site and tree. The combined effect of site by date was significant. There were significantly more geometrid larvae collected at Long Hollow on three dates between late March and early May.

The site effect was also significant for gelechiid and tortricid larvae (Table 18). Except for *Cudoniger houstonana*, found largely on juniper, caterpillars in these two families were most abundant on live oak (Fig. 56). The site by date pattern (Fig. 57) was similar to that for Lepidoptera as a whole.

## Discussion

**Site Effects.** Based on a three-way ANOVA for site, tree species, and date, the following taxa showed significant differences between the two sites: all arthropods, *Philodromus* spp., Coleoptera, Hemiptera, *Tropidosteptes quericola, Malthinus occipitalis*; Lepidoptera larvae, Geometridae larvae, Hymenoptera, *Solenopsis invicta,* and *Monomorium minimum.* Arthropods

were generally more abundant at Long Hollow.

Although arthropods as a whole were significantly different between sites in 1994, the site effect contributed less to the variation in the number of arthropods collected per sample than did the tree effect. In other words, the variation in arthropod abundance was greater among trees within both sites than the total variation between sites. The tree effect was more consistently significant across the various taxa examined that was the site effect. Only the orders Coleoptera and Hymenoptera and one species of ant were not significantly different in abundance among the trees.

Although there were widespread significant differences among the trees and frequently significant differences between the sites, it was much less common to find a significant combined site by tree effect. This suggests that if arthropods are less abundant on one tree species at a site, that lower abundance is not compensated for by a higher abundance on another tree species when compared with another site.

Of those that varied significantly in abundance between sites, all (except *Solenopsis invicta*) were significantly more common at Long Hollow than at Shellberg. Thus, low abundance of one or more taxa at one site was not off set or compensated for by a higher abundance of another taxa at the same site. One ordinal taxon that did show a dramatic difference between sites and a preference for Shellberg, was the Polyxenida (millipedes). On June 2, 1994, 219 millipedes were collected at Shellberg, but only two were collected on that same day at Long Hollow. No millipedes were detected in the Golden-

cheeked Warbler gizzards.

Ehler & Frankie (1979a, b) examined the mite (Acari) fauna of live oak in urban vs. natural stands in the vicinity of Austin, Texas. They found that "despite the variation in habitat duration (and other features) among the various sites, the acarine fauna at each site was similar." Vincent & Frankie (1985) systematically sampled spiders (Araneae) from live oak in one natural and two different urban sites in Austin, Texas. They found few differences in abundance of individuals and taxa. Our results provide a marked contrast to theirs, but are not unexpected, given the general nature of population fluctuations in time and space for small arthropods.

# CHAPTER IV

## SPATIAL PATTERNS OF ARTHROPODS IN GOLDEN-CHEEKED

## WARBLER HABITAT DURING THE BREEDING SEASON BY

## TREE SPECIES AND HEIGHT

Previous work suggests that Golden-cheeked Warblers spend large portions of their time in the upper levels (above 5m) of certain tree species (Beardmore 1994) and commonly forage there (Pulich 1976). Given these apparent height and tree preferences, it is of interest to determine whether potential arthropod prey show the same patterns.

### Materials and Methods

Site selection and general sampling methods were presented in Chapter II. Final site selection was based on easy access to a suitable number of Ashe juniper, live and Texas oaks, and elm trees with sufficient foliage in three different height classes (0-3m, 3-5m and > 5m) so that the arthropod faunas on different trees and at different heights could be compared. In order to test the hypothesis that prey were uniformly available on all tree species and in all tree height classes through time, I have compared the data for each date from an equal number of large sweep net samples at all three heights in 1994 on both Long Hollow and Shellberg sites using three-way ANOVA (Ott 1993). Two-way, tree by date comparisons were made using a larger data set (1993 and 1994).

### Results

The following taxa showed significant differences in abundance among

tree heights: Arthropoda; Araneae; *Misumenops* spp.; *Philodromus* spp.; Hemiptera; *Tropidosteptes quericola*; *Xanthonia* sp. 1; Lepidoptera larvae; larvae of Gelechiidae and Tortricidae (excluding *Cudoniger houstonana*); Hymenoptera; and *Monomorium minimum*. Those showing no differences included *Hibana* spp.; Homoptera; *Platycotis vittata*; Coleoptera; *Malthinus occipitalis*; *Brachypnoea tristis*; *Xanthonia* sp. 2; Geometridae larvae; *Cudoniger houstonana*; and *Solenopsis invicta*.

All Arthropods. The main effect of height for arthropods as a whole was significant (Table 19, in Appendix C). The height by tree interaction was negligible (Fig. 58, in Appendix C) as abundance was inversely proportional to height across all trees. Height by date interaction was significant. Significantly more arthropods were collected from the lower height class on most dates from the end of February through early June (Fig. 59). The tree by date interaction was significant for all arthropods ($F = 5.816$, df = 33, $P < .0001$). More arthropods were collected from Ashe juniper from May through June, while Texas oak supported the largest number of arthropods at the end of March, but had the fewest of any tree species during June and July (Fig. 60).

Araneae. The main effects of height, tree and date were all significant for spider abundance (Table 20). Spider abundance was inversely proportional to the height classes (Fig. 61), although the middle and upper heights were not significantly different. More spiders were consistently found at the lowest height class for each tree and on almost every date (Fig. 62). The live oaks produced the more spiders than the other tree species during April (Fig. 63).

Spiders were most abundant on Ashe juniper in June. Texas oaks were the least productive of all trees from May through July.

For *Misumenops* spp., the main effects of height, tree and date were all significant (Table 21). Most *Misumenops* spp. were on live oak and fewest were on Ashe juniper and Texas oak (Figs. 64 and 66). The height by date interaction was significant. The mean per height class was particularly variable between dates in March and April (Fig. 65).

For *Hibana* spp., there were no significant differences among the heights (Table 22). Significantly fewer *Hibana* were found on Ashe juniper (Fig. 67). They were most abundant on live oak in April and on cedar elm during July (Fig. 69). The height by date interaction was negligible probably due to the high level of variability among the heights (Fig. 68).

**Coleoptera.** Coleopterans were one of the few orders found to have equal means among tree species and among heights (Table 23). The height by tree interaction was not significant (Fig. 70), nor was the height by date interaction, despite the fact that there were significantly more beetles at mid-height on April 9-10 (Fig. 71). The tree by date interaction was significant ($F = 5.456$, df = 33, $P < .0001$) due in large part to the Ashe juniper not showing the spike in abundance that the other three trees showed in April (Fig. 72). However, one of our most commonly collected species, *Xanthonia* sp. 2, was found almost exclusively on Ashe juniper (Figs. 73 and 75). It's abundance was not significantly different among heights (Table 24; Fig. 74).

**Hemiptera.** Hemipterans were not significantly different among heights

except on Ashe juniper (Table 25). The mean abundance of hemipterans was greater on Ashe juniper than on each of the other trees (Fig. 76), with one unusual record for live oak in late April (Fig. 78). More hemipterans were collected from the lower height class through most dates until late June (Fig. 77).

**Homoptera.** Homoptera were not significantly different among heights (Table 26; Fig. 80). There were significantly more homopterans on the cedar elms than the other trees (Fig. 79), and the tree by date interaction was significant ($F = 9.766$, df = 33, $P < .0001$). Early in the season, more homopterans were collected on Texas oak than on Ashe juniper, with live oak intermediate in homoptera abundance (Fig. 81).

**Hymenoptera.** A significant difference was found between the number of hymenopterans collected at each height (Table 27). Hymenopteran abundance was inversely proportional to height (Figs. 82 and 83). The mean number of hymenopterans was evenly distributed among the four tree species (Fig. 84). There was no combined effect between the heights and the trees. Among the trees, more *S. invicta* were collected from live oak and cedar elm than from Texas oak, with the numbers found on Ashe juniper being intermediate. Results for *S. invicta* are shown in Table 28 and Figs. 85 - 87.

**Lepidoptera.** There was a significant difference between the number of lepidopteran larvae collected at the three heights (Table 29; Fig. 88). Significantly more lepidopteran larvae were collected at the lower height than at either the middle or upper height, with most of that difference due to

a large sample from the lower height of juniper in early April (Fig. 89). There were no significant differences in abundance due to height at the middle and upper levels. More larvae were found on Ashe juniper (May - early June) and Texas oak (late March - early April) than on live oak or cedar elm (Fig. 90). There was no significant combined effect found between heights and tree species. Although geometrid larvae are not monophagous as a group, they showed a significant preference for Ashe juniper (Table 30; Fig. 91).

## Discussion

**Tree Preferences.** Southwood (1961) hypothesized that the number of species of plant-feeding insects associated with a certain tree reflects the abundance of the tree. In Britain, oaks are the dominant trees and have the most insect species associated with them. In Cyprus, junipers are one of the more important trees and they have the most species of Hemiptera and Homoptera Auchenorrhycha (cicadas and hoppers). However, Karban and Ricklefs (1983) found no relationship in southern Ontario between the local abundance of a host and the local species richness of Lepidoptera larvae when the effect of sampling intensity was accounted for. Of the Lepidoptera larvae we collected in 1994, the greatest number came from the one broad-leaf deciduous species in our study, the Texas oak. Ashe juniper and Texas oaks were the dominant tree species in our study site. Karban and Ricklefs (1983) collected more lepidopteran larvae from American elm, *Ulmus americana* L. than any other species of host. Cedar elm, a species with much smaller leaves, was a distant third in the number of Lepidoptera larvae collected in

our study behind Ashe juniper and Texas oak. Leaf size and clustering affects leaf roller abundance, and this represented our largest category of lepidopteran larvae.

We collected four species of *Xanthonia* during this survey. Our data suggest a pattern of niche partitioning by host plant species in *Xanthonia*, one that would be worth exploring in other species of the genus.

Holmes and Robinson (1981) studied the tree species preferences of insectivorous birds in a northern hardwood forest dominated by sugar maple, *Acer saccharum* Marsh, American beech, *Fagus grandifolia* Ehrh. and yellow birch *Betula alleghaniensis* Britt. They found that of the 10 insectivorous birds studied, all departed significantly from random in their use of trees as foraging sites. All species favored yellow birch and for seven birds including Black-throated Green and Blackburnian Warblers, it was the tree foraged on most frequently, even though it was the least common of the dominant species. Yellow Birch consistanly supported a greater number of total arthropods and lepidopteran larvae for three sampling dates between June and July. Holmes and Robinson (1981) conclude that at least some of the preferences shown by birds for yellow birch were due to the greater food resources there.

Holmes and Schultz (1988) sampled Lepidoptera larvae from the dominant American beech, sugar maple, and yellow birch trees during late June and early July in a New Hampshire experimental forest. They found a significant interaction between tree species and time period. They attributed this

significance to the fact that American beech consistently supported more larvae than other tree species and to lower larval abundance on yellow birch in late June than in early July. Ticehurst and Yendol (1989) found no significant differences in gypsy moth, *Lymantria dispar* (L.) (Lepidoptera: Lymantriidae) larval distribution among three species of oaks in Pennsylvania (see below for details of study).

**Height Preferences.** Opler (1974) studied the spatial specialization of nine species of external feeding microlepidoptera larvae on a single tree of *Quercus agrifolia* on April 11, 1968 in the San Francisco Bay area of California. He found only slight differences in the number of larvae between heights of 2 to 3.5m above ground and above ground.

Holmes and Schultz (1988) sampled Lepidoptera larvae in late June and in early July over two years. They found larvae to be significantly more abundant in the lower canopy in all three dominant trees in all time periods and years at their site in New Hampshire.

Ticehurst and Yendol (1989) studied the gypsy moth larval distribution within canopies of codominant northern red oak, *Quercus rubra* L., white oak, *Q. alba* L., and chestnut oak, *Q. prinus* L. at three sites in Pennsylvania on three dates over a two year period. They sampled five to six trees of each species of oak. Canopies were divided into equal thirds and absolute counts of larvae were conducted on the entire tree. Over 20,000 larvae were observed. Larval distribution among canopy levels was significant among and within the three sites. Larval abundance was inversely proportional to height with

43.5% of the larvae observed within the lower third of the canopy. The combined effect of oak species by height class was minimal at each site.

McClure (1990) examined the vertical distribution of hemlock woolly adelgid, *Adelges tsugae* Annand (Homoptera: Adelgidae), an important introduced pest of eastern hemlock, *Tsuga canadensis* (L.) Carrière, in the eastern United States. Sticky traps were placed 5, 10, and 15m above ground for five 2-wk intervals. No significant differences in the number of *A. tsugae* were found among the three heights of the forest canopy.

**Golden-cheeked Warbler Foraging Substrates.** Sexton (1987) recorded 32.23min. of foraging observations. He found that the Golden-cheeked Warbler foraged in live oak 41.1% of the time; in Ashe juniper 16.8% of the time; in cedar elm 4.1% of the time; and in Texas oak 2.3% of the time. Sexton's Edward's Plateau Laboratory study site was within 3.2km of both Long Hollow and Shellberg. Ashe juniper was the most common species on Sexton's study site, followed by Texas oak, live oak, and cedar elm.

Beardmore (1994) found Ashe juniper, cedar elm and 3 species of oaks constituted 82 percent of the trees encountered in Golden-cheeked warbler territory clusters on two sites in Travis County. Of 603 foraging observations made by Beardmore, over 94% were of warblers in ashe juniper, live oak, Texas oak and cedar elm. During March and April 88% of the foraging observed by Beardmore (1994) occurred in live oaks. During May through June, the warbler was observed foraging more evenly with Ashe juniper being preferred (49% or the observations) followed by live oak (27%), Texas

oak (10%) and cedar elm (8%). We collected significantly more arthropods from Ashe juniper and cedar elm than from oaks. However, lepidopteran larvae, the primary dietary item found in gizzards (Table 1) were found more abundantly on Ashe juniper and Texas oaks than on the other two tree species.

**Golden-cheeked Warbler Foraging Heights.** During 32.23 minutes of foraging observations, Sexton (1987) recorded the Golden-cheeked Warbler foraging in the 0-3m height class 33.1% of the time, 26.4% of the time between 3.0 and 4.6m, and in the 4.6-6.1m height class 29.9% of the time. Beardmore (1994) found birds foraging primarily at upper levels early in the season (March - April), but that the percentage of foraging observations almost doubled in the 0-3m height class later in the season (May - June). The observations by Sexton suggest no height preferences but those by Beardmore suggest a shift in height preferences to the lower height class later in the breeding season when fledglings are more likely to be present. Our results suggest that arthropods are abundant at all heights on all trees through the season, but that the lower heights support more arthropods in general.

# CHAPTER V

## PATTERNS IN ARTHROPOD ABUNDANCE BETWEEN YEARS

## IN GOLDEN-CHEEKED WARBLER HABITAT

## DURING THE BREEDING SEASON

Seasonal effects on insects and other arthropods are well known. This is particularly apparent in outbreak pests, such as the gypsy moth and southern pine beetle. Such year to year differences undoubtedly have a tremendous impact on the breeding success of insectivorous birds. In this chapter I examine seasonal differences in arthropod abundance in the breeding territory of the Golden-cheeked Warbler.

### Materials and Methods

The Long Hollow site was used for between-year comparisons, with analyses limited to data collected by methods that were consistent from year to year (lower beats, middle and upper large sweeps). A three-way ANOVA was performed to compare the mean number of arthropods on the four trees species in each of the two years.

### Results

**All Arthropods.** The main effect of year was significant for all arthropods as a whole (Table 31, in Appendix D). The abundance of arthropods in Ashe juniper was relatively stable between years while live and Texas oaks showed dramatic annual differences (Fig. 92, in Appendix D). Significantly more arthropods were also found on cedar elm in 1993. The annual differences

among dates were most pronounced between the end of March through the first half of May (Fig. 93).

   **Araneae.** The main effect of year was significant for spiders (Table 32). Although there were significantly more spiders collected on all tree species in 1993 than in 1994 (Fig. 94), the combined effect of year by tree was not significant. On all but three dates, more spiders were collected in 1993 versus 1994 (Fig. 95).

   *Hibana* spp. showed one of the greatest annual differences in abundance of any taxonomic group examined (Fig. 96 and 97). All main effects and combined effects were significant for *Hibana* spp. (Table 33).

   The numbers of *Misumenops* spp. were significantly different for every main and combined effect (Table 34). More *Misumenops* spp. were collected in 1993 than in 1994, particularly from the end of March through April (Fig. 99). Significantly more *Misumenops* spp. were collected from Texas oak in 1993 than in 1994 (Fig. 98). The annual sample mean for the other trees did not appear to be significantly different.

   The numbers of *Philodromis* spp. were not significantly different between years (Table 35; Fig. 100). The main effects of tree and date were significant. All combined effects were negligible.

   **Coleoptera.** Significantly more beetles were collected in 1993 versus 1994 (Table 36), particularly during late April and early March (Fig. 102). Although the combined effect of year by tree was negligible, live oak showed the most variation between years (Fig. 101).

Over 140 specimens of *Brachypnoea tristis* were collected in late April, 1993. Approximately 20 were collected in early April and early May, 1993. Almost no specimens were collected before or after these dates. The peak numbers collected in 1994 never exceeded 20 specimens per date.

**Hemiptera.** Hemipterans were significantly different for every main and combined effect (Table 37). For the tree effect, live oak once again proved to be highly variable. Dramatically more hemipterans were recorded on live oak in 1993 (Fig. 103). This was due largely to a spike in abundance in late April (Fig. 104). A mean of more than 5 hemipterans per sample were collected on that date. Nearly all other collection dates recorded less than two hemipterans per sample. In late April 1993, nearly 400 specimens were collected. The number of specimens collected on either side of this date numbered less than 100 individuals. In 1994, no such pronounced peak was observed. The second year, the rise and fall off was gradual through the collecting season. In 1994, Long Hollow peaked in early April and Shellberg peaked in early May.

*Tropidosteptes quercicola* was typical of most mirids, the dominant family of the hemipterans in our study. The main effect of year was not significant, either for this species or for mirids as a group. As almost all *T. quercicola* were collected on live oak in the second half of April, the main effects of tree and date are significant. The combined effect of year by tree was not significant. This mirid was one of the contributors of the 1993 late April peak in hemipteran abundance. Over 140 were collected on April 23, 1993.

**Homoptera.** The main effect for homopterans was significant (Table 38).

All other main and combined effects were also significant. The major difference between years occurred from late April through May, primarily on oaks (Fig. 105 and 106).

There was a significant difference in abundance of *Platycotis vittata* between years due primarily to the large number of insects collected in late April of 1993. The numbers collected in 1994 showed no real peaks and barely exceeded 10 specimens for either site per date.

**Hymenoptera.** Hymenoptera were significantly more abundant in 1993 than in 1994. Long Hollow showed a minor peak in the abundance of *Solenopsis invicta* in early July during 1994. There was no significant difference in abundance of *S. invicta* between years.

**Lepidoptera Larvae.** Lepidoptera larvae showed one of the greatest differences in abundance between years of any order (Table 39; Fig. 107). Larval numbers exceeded 500 on April 9, 1993, but there were never more than 100 for any collection date in 1994 (Fig. 108).

The pattern for gelechiid and tortricid larvae almost exactly matches the phenology of the order. The 1993 peak is in early April and quickly drops to a lower plateau that is maintained through early June. The 1994 data show two minor peaks in early April and late June.

## Discussion

Most invertebrate orders that were similar in numbers between sites in 1994 (Coleoptera, Hemiptera, Homoptera, and Lepidoptera larvae) but were significantly more abundant in 1993 than in 1994. Psocoptera were unusual in

this regard, finding conditions in 1994 more favorable than in 1993. The 1993 peak in numbers collected was markedly synchronized across orders on April 23, except for the Lepidoptera larvae which peaked on April 9th. Exceptions included Hymenoptera, which had a series of peaks from March 26th through May 8th at both sites for both years. Lepidoptera larvae responded similarly across sites in 1994, but showed significant differences between years at Long Hollow with caterpillar numbers in 1993 peaking at over five times the numbers collected in 1994.

Holmes and Schultz (1988) studied Lepidoptera larvae on sugar maple, American beech and yellow birch for two years. They found a significant interaction between tree species and year. A large portion of the significance of this interaction can be attributed to greater fluctuation in the abundance of larvae on maple as opposed to the other two dominant trees.

Holmes et al. (1986) in their discussion of the irregular periodicity of caterpillar irruptions in temperate forests report that Black-throated Blue Warbler's, *Dendroica caerulescens* (Gmelin) have shown reduced clutch sizes, slow growth rates, increased nestling mortality due to starvation, and reduced number of nestling attempts in breeding seasons during the years between caterpillar outbreaks.

# CHAPTER VI

## CONCLUSIONS

Key events in the life history of the Golden-cheeked Warbler are closely correlated with arthropod abundance in our study. Their arrival on the breeding territory in mid-March (Wahl et al. 1990) overlaps precisely with the rapid increase in the numbers of arthropods collected in our samples (Fig. 2, in Appendix A). The Golden-cheeked Warbler's breeding season is primarily in April and May (Pulich 1976), a period encompassed by a sustained peak in arthropod abundance. Similarly, the dominant groups of insects found in Golden-cheeked Warbler's gizzards (Coleoptera, Homoptera, Hymenoptera, and larval Lepidoptera) all showed dramatic peaks in abundance during this period. Araneae were the only major dietary item with a different pattern of abundance. Spiders increased in abundance gradually throughout the sampling period, peaking in July. Spiders are therefore the primary resource available to Golden-cheeked Warblers late in the season as they prepare for their return migration to overwintering sites.

The early-season peak in phytophagous arthropods is in turn correlated with on-set of leaves and catkins in deciduous trees and new growth in evergreens. As tannins increase and new growths hardens, populations drop. The continuous increase in spiders through the spring and summer is more difficult to explain. Spiders are the overwhelmingly dominant predators in this system. One possibility is that as females feed on the spring flush of insects early in the year, their offspring production increases, giving rise to

large numbers of immatures later in the season. This seems to fit the pattern in our data. It is also well-known that spiders feed on one-another, thus late season dominance of predators can be explained by the fact that spiders fill the role of both predators and prey.

# REFERENCES CITED

Arnett, R. H., G. A. Samuelson, and G. M. Nishida. 1993. The insect and
spider collections of the world. Sandhill Crane Press, Inc., Gainesville, FL.

Attwater, H. P. 1892. List of birds observed in the vicinity of San Antonio,
Bexar County, Texas. Auk 9: 337-345.

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

Beardmore, C. J. 1994. Habitat use of Golden-cheeked Warblers in Travis
County, Texas. M.S. thesis. Texas A&M University, College Station.

Blair, W. F. 1950. The biotic provinces of Texas. Texas J. Sci. 2: 93-117.

Bramblett, S. 2000. Faunal and floral species lists and collections.
(http://www.utexas.edu/research/bfl/collections/)

Burke, H. R. 1977. Horace Haldeman, early insect collector in Texas.
Melsheimer Entomol. Ser. 22: 1-6.

Campbell, R. W., L. C. Levitan, E. R. Sobecki, and M. F. Tardiff. 1978.
Population dynamics of the gypsy moth: an annotated bibiolgraphy. U.S.
Forest Service General Technical Report NE-48.

Chapman, F. M. 1917. The warblers of North America. D. Appleton & Co.,
New York.

Claridge, M. F., and M. R. Wilson. 1976. Diversity and distribution patterns of
some mesophyll-feeding leafhoppers of temperate woodland canopy. Ecol.
Entomol. 1: 231-250.

Claris Corporation. 1996. FileMaker Pro 3.0v2. Santa Clara, CA.

Coulson, R. N. 1980. Population dynamics, pp. 71-105. *In*: R. C. Thatcher, J. L. Searcy, J. E. Coster, and G. D. Hertal [eds.], The southern pine beetle. USDA Forest Serv. Techn. Bull. 1631.

Creighton, W. S. 1950. The ants of North America. Bull. Mus. Comp. Zool. 104: 1-513.

Cresson, E. T. 1872. Hymenoptera Texana. Trans. Am. Entomol. Soc. 4: 153-292.

Durden, C. J. 1990. Guide to the butterflies of Austin. Texas Botanical Garden Society, Austin.

Ehler, L. E., and G. W. Frankie. 1979a. Arthropod fauna of live oak in urban and natural stands in Texas. II. Characteristics of the mite fauna (Acari). J. Kansas Entomol. Soc. 52: 86-92.

1979b. Arthropod fauna of live oak in urban and natural stands in Texas. III. Oribatid mite fauna (Acari). J. Kansas Entomol. Soc. 52: 344-348.

Flora of North America Editorial Committee. 1997. Flora of North America north of Mexico. Oxford University Press. New York.

Frank, W. A., and R. T. Huber. 1987. Seasonal population trends and damage associated with western flower thrips, *Frankliniella occidentalis* Pregrande, on Arizona pistachios. Southwest. Entomol. 12: 299-303.

Frankie, G. W., J. M. Tucker, and J. B. Welch. 1979. Arthropod fauna of live oak in urban and natural stands in Texas: I. Site descriptions, oak taxonomy and sampling methods. J. Kansas Entomol. Soc. 52: 71-85.

Gass, L. R. 1996. Nesting behavior of Golden-cheeked Warblers in Travis County, Texas. M.A. thesis, Southwest Texas State University, San Marcos.

Holmes, R. T., and S. K. Robinson. 1981. Tree species preferences of foraging insectivorous birds in a northern hardwood forest. Oecologia 48: 31-35.

Holmes, R. T., and J. C. Schultz. 1988. Food availability for forest birds: effects of prey distribution and abundance on bird foraging. Can. J. Zool. 66: 720-728.

Holmes, R. T., T. W. Sherry, and F. W. Sturges. 1986. Bird community dynamics in a temperate deciduous forest: long-term trends at Hubbard Brook. Ecol. Monographs. 56: 201-220.

Jackman, J. A., and C. R. Nelson. 1995. Diversity and phenology of tumbling flower beetles (Coleoptera: Mordellidae) captured in a malaise trap. Ent. News 106: 97-107.

Jackson, J. K., and V. H. Resh. 1989. Distribution and abundance of adult aquatic insects in the forest adjacent to a northern California stream. Environ. Ent. 18: 278-283.

Karban, R., and R. E. Ricklefs. 1983. Host characteristics, sampling intensity, and species richness of Lepidoptera larvae on broad-leaved trees in southern Ontario, Canada. Ecology 64: 636-641.

Kroll, J. C. 1980. Habitat requirements of the Golden-cheeked Warbler: management implications, J. Range Manage. 33: 60-65.

Lawton, J. H. 1978. Host-plant influences on insect diversity: the effects of space and time. Symp. R. Entomol. Soc. London 9: 105-125.

Le Corff, J., R. J. Marquis, and J. B. Whitfield. 2000. Temporal and spatial variation in a parasitoid community associated with the herbivores that feed on Missouri *Quercus*. Environ. Ent. 29: 181-194.

Mayfield, H. 1960. The Kirtland's Warbler. Cranbrook Institute of Science, Bloomfield Hills, MI.

McClure, M. S. 1990. Role of wind, birds, deer, and humans in the dispersal of hemlock woolly adelgid (Homoptera: Adelgidae). Environ. Entomo. 19: 36-43.

McWhorter, G. M., J. G. Thomas, M. K. Harris, and H. W. van Cleave. 1976. Pecan insects of Texas. TAEX MP-1270, 18 p.

Metcalf, C. L., W. P. Flint, and R. L. Metcalf. 1962. Destructive and useful insects. McGraw-Hill, New York.

Nolan, V. 1978. The ecology and behavior of the Prairie Warbler, *Dendroica discolor*. The American Ornithologists' Union. Lawrence, KS.

Opler, P. A. 1974. Biology, ecology, and host specificity of microlepidoptera associated with *Quercus agrifolia* (Fagaceae). Univ. California Publ. Entomol. 75: 1-85.

Ott, R. L. 1993. An introduction to statistical methods and analysis. Duxbury Press, Belmont, CA.

Palmer, W. A. 1987. The phytophagous insect fauna associates with *Baccharis halimifolia* L. and *B. neglecta* Britton in Texas, Louisiana, and Northern Mexico. Proc. Entomol. Soc. Wash. 89: 185-199.

Palmer, W. A., and F. D. Bennett. 1988. The phytophagous insect fauna

associated with *Baccharis halimifolia* L. in the eastern United States. Proc. Entomol. Soc. Wash. 90: 216-228.

Pulich, W. M. 1976. The Golden-cheeked Warbler: a bioecological study. Bull. Texas Parks and Wildl. Dept., Austin.

Robinson, S. K., and R. T. Holmes. 1982. Foraging behavior of forest birds: the relationships among search tactics, diet, and habitat structure. Ecology 63: 1918-1931.

Roginskaya, Y. Y. 1966. On the food specialization of dendrophilous weevils (Coleoptera, Attelabidae, Curculionidae) of the Moscow province. Entomol. Rev. 50: 1-28.

Royama, T. 1984. Population dynamics of the spruce budworm *Choristoneura fumiferana*. Ecol. Monogr. 54: 429-462.

SAS Institute. 1998. StatView 5.0.1. SAS Institute, Cary, NC.

Scheffé, H. 1953. A method for judging all contrasts in the analysis of variance. Biometrika. 40: 87-104.

Scott, J. A. 1986. The butterflies of North America: a natural history and field guide. Stanford Univ. Press, Stanford, CA.

Sexton, C. W. 1987. A comparative analysis of urban and native bird populations in central Texas. Ph.D. dissertation, University of Texas, Austin.

Southwood, T. R. E. 1961. The number of species of insect associated with various trees. J. Animal Ecol. 30: 1-8.

Southwood, T. R. E., V. C. Moran, and C. E. J. Kennedy. 1982. The assessment

of arboreal insect fauna: comparisons of knockdown sampling and faunal lists. Ecol. Entomol. 7: 331-340.

Sterling, W. L., and E. P. Pieters. 1974. A sequential sampling package for key cotton arthropods in Texas. Tex Agr. Exp. Stn. Tech. Rept. 74-32, 28 p.

Strong, D. R., J. H. Lawton, and T. R. E. Southwood. 1984. Insects on plants: community patterns and mechanisms. Harvard Univ. Press, Cambridge.

Texas Ornithological Society. 1995. Checklist of the birds of Texas, 3rd edition. Capital Printing, Inc. Austin, TX.

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

Vincent, L. S., and G. W. Frankie. 1985. Arthropod fauna of live oak in urban and natural stands in Texas. IV. The spider fauna (Araneae). J. Kansas Entomol. Soc. 58: 378-385.

Wahl, R., D. D. Diamond, and D. Shaw. 1990. The Golden-cheeked Warbler: a status review. Ecological Services, U. S. Fish and Wildlife Service, Fort Worth, TX.

Wheeler, G. C., and J. Wheeler. 1976. Ant larvae: review and synthesis. Mem. Entomol. Soc. Washington. 7: 1-108.

Wheeler, W. M. 1910. Ants. Columbia Univ. Press. New York.
1920. Subfamilies of Formicidae, and their taxonomic notes. Psyche 27: 46-55.

Woolfenden, G. E. 1967. A specimen of the Golden-cheeked Warbler from

Florida. Auk. 84: 115.

**APPENDIX A**
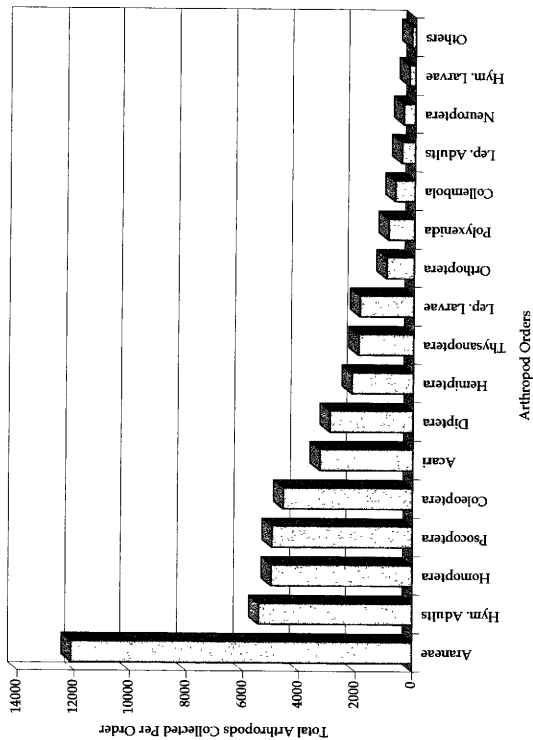
Fig 1. Bar graph of all arthropods collected at Long Hollow (1993-94) and Shellberg (1994). Thysanoptera data for 1993 only.
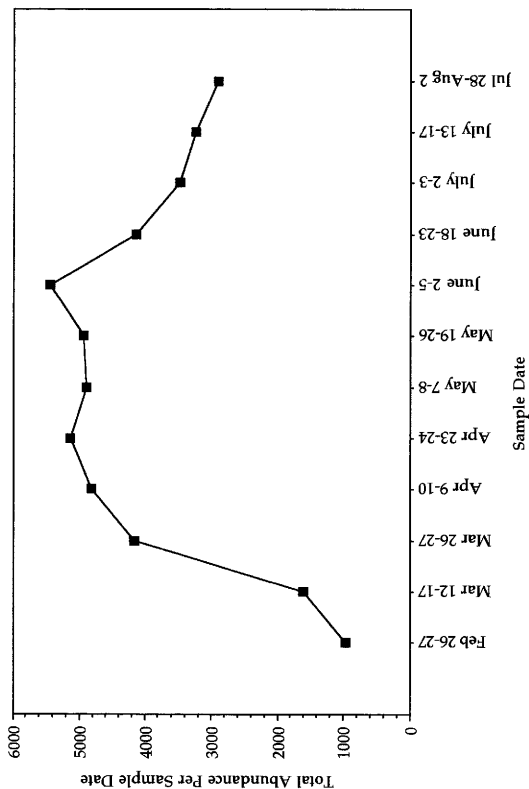
**Fig. 2** Seasonal pattern of all Arthropods (excluding Thysanoptera) at Long Hollow (1993-94) and Shellberg (1994). Data for first two dates from 1994 only.
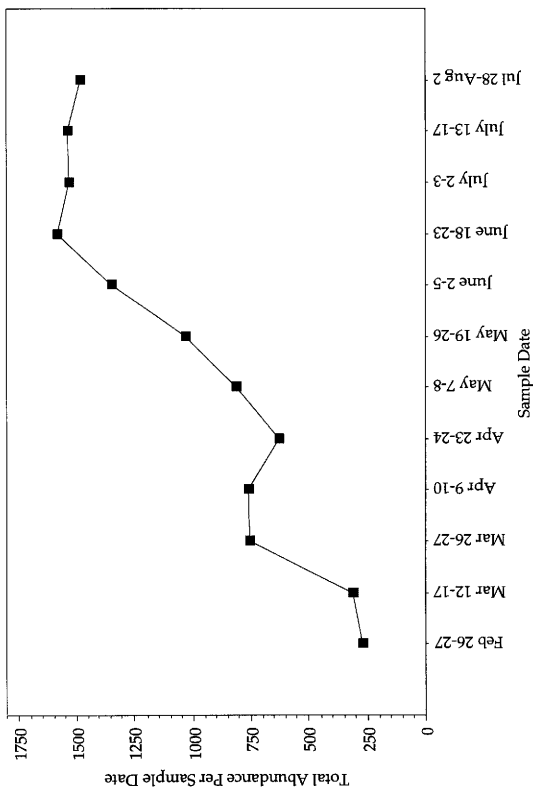
**Fig. 3.** Seasonal pattern for Araneae at Long Hollow (1993-94) and Shellberg (1994). Data for first two dates from 1994 only.
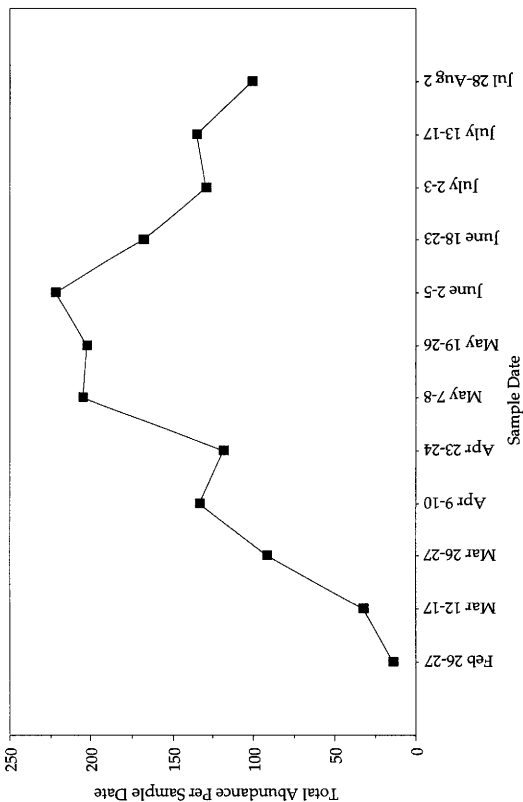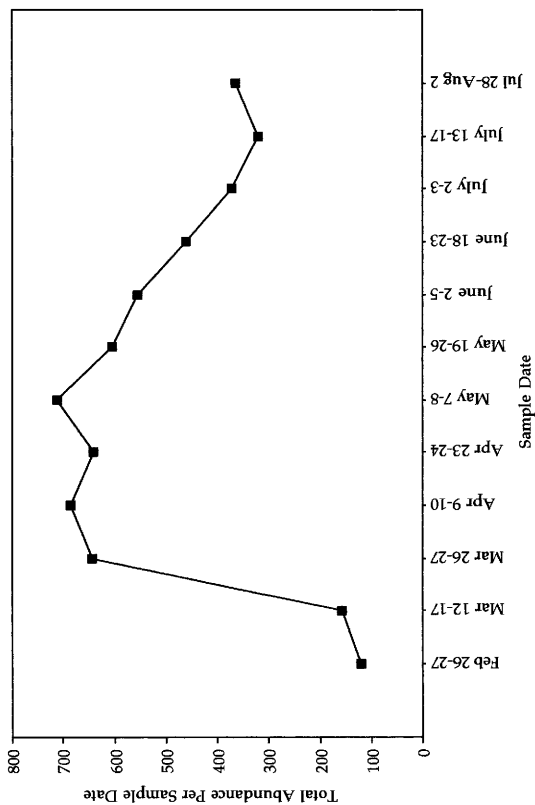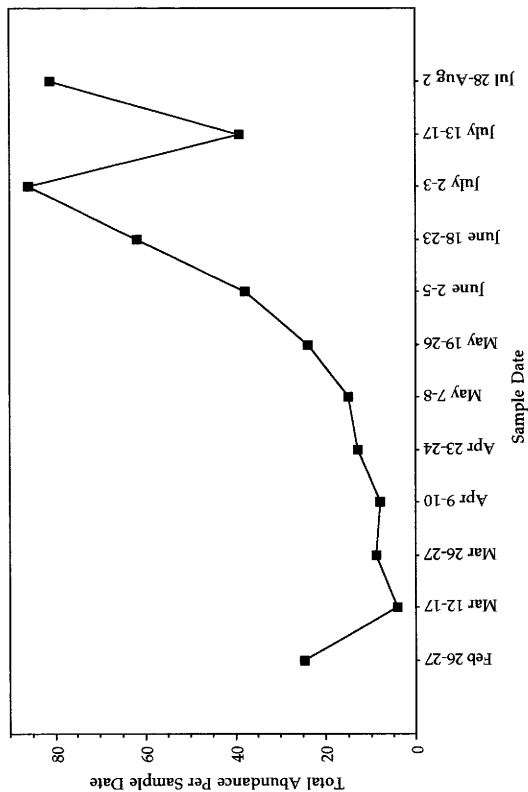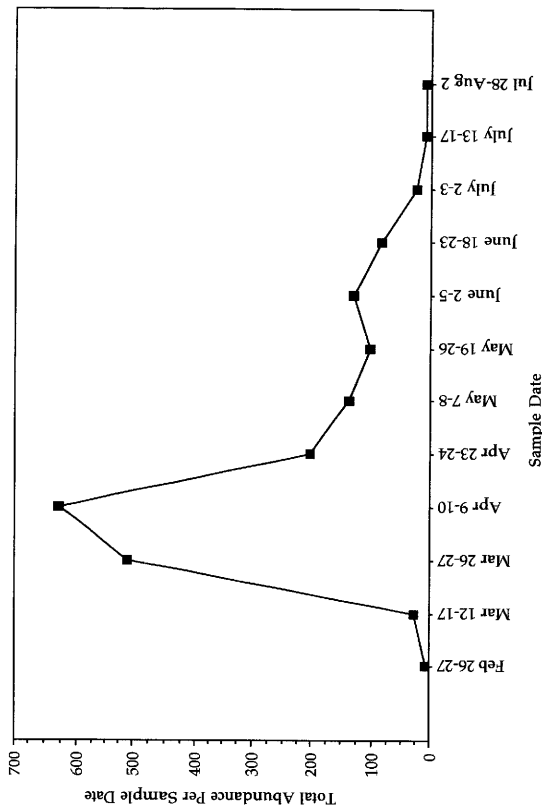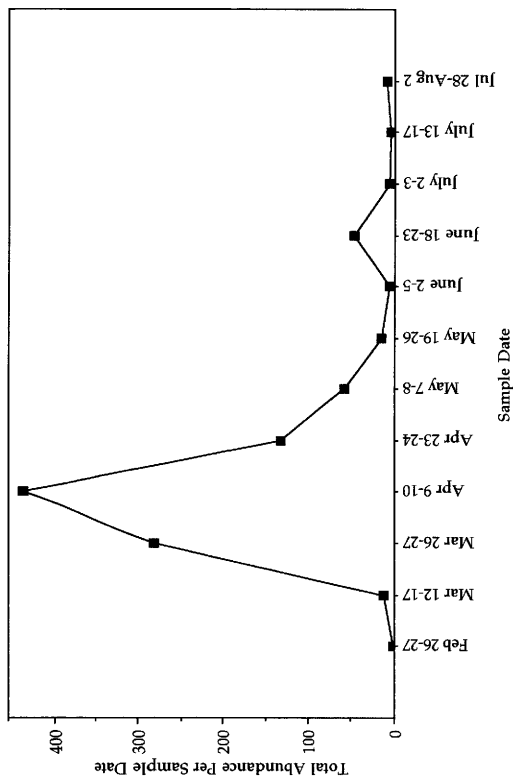
**Fig. 4.** Seasonal pattern for *Misumenops* spp. (Araneae: Thomisidae) at Long Hollow (1993-94) and Shellberg (1994). Data for first two dates from 1994 only.
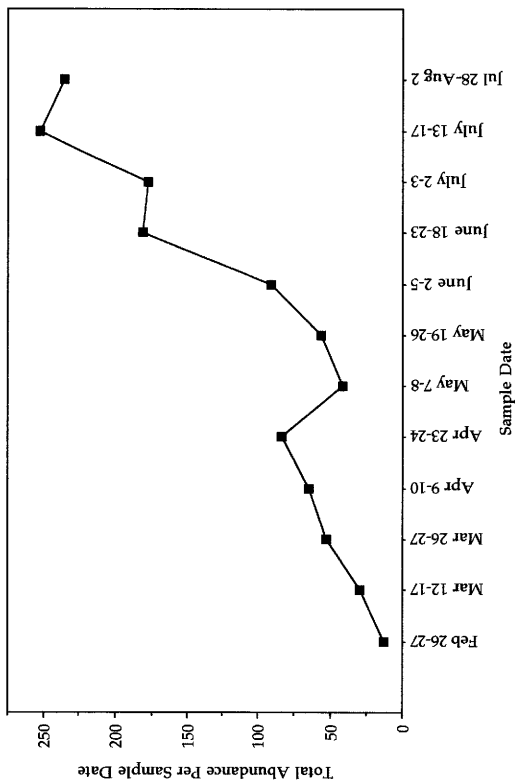
**Fig. 5.** Seasonal pattern of *Hibana* spp. (Araneae: Amyphaenidae) at Long Hollow (1993-94) and Shellberg (1994). Data for first two dates from 1994 only.
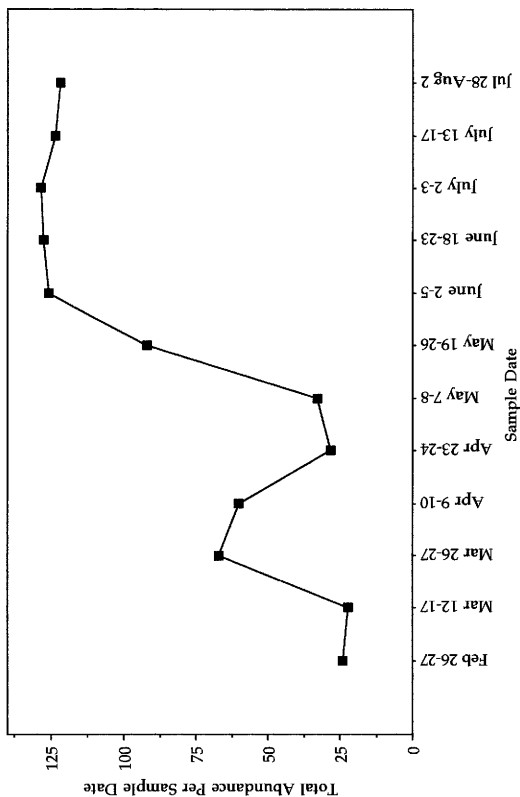
Fig. 6. Seasonal pattern of *Philodromus* spp. (Araneae: Philodromidae) at Long Hollow (1993-94) and Shellberg (1994). Data for first two dates from 1994 only.
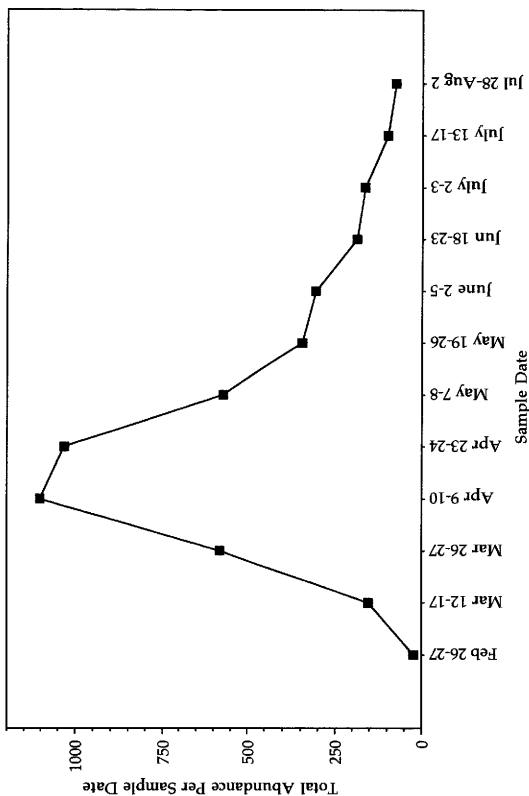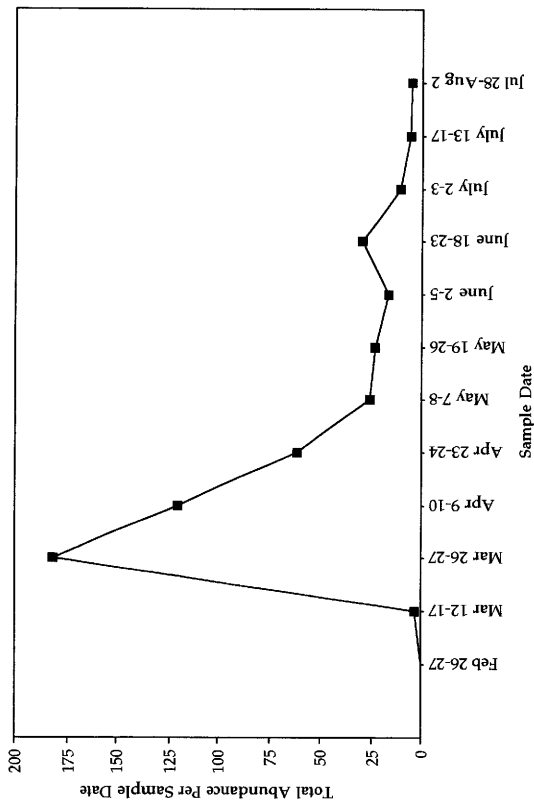
**Fig. 7.** Seasonal pattern of Coleoptera at Long Hollow (1993-94) and Shellberg (1994). Data for first two dates from 1994 only.
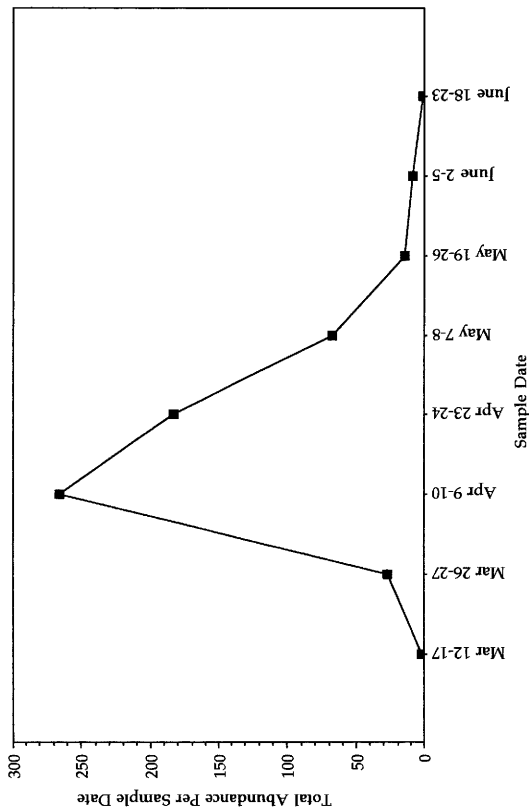
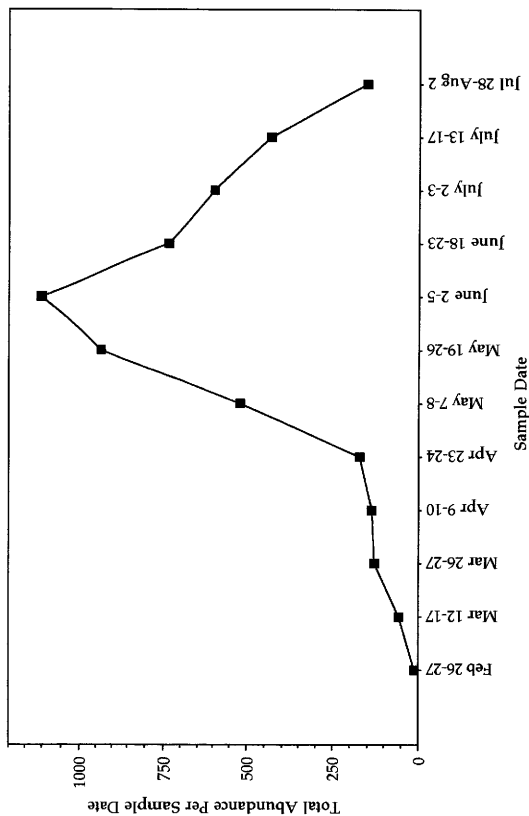**Fig. 8.** Seasonal pattern of *Xanthonia* sp. 1 (Coleoptera: Chrysomelidae) at Long Hollow (1993-94) and Shellberg (1994). Data for first two dates from 1994 only.
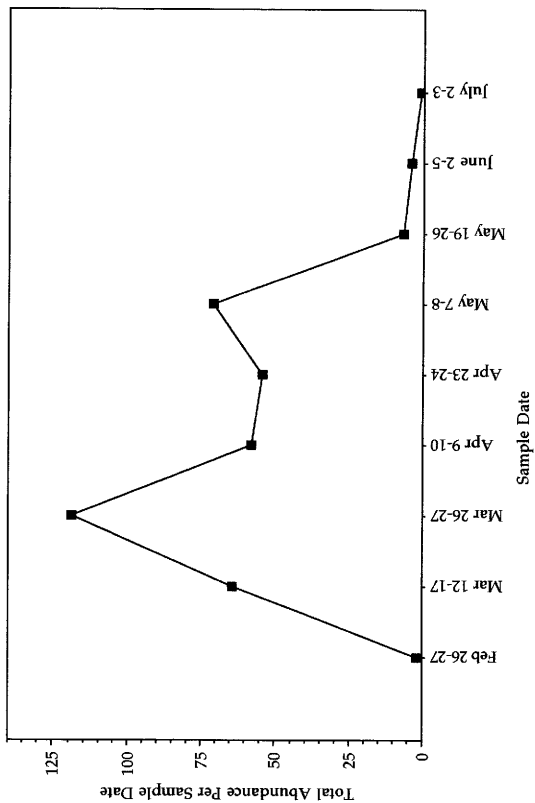
**Fig. 9.** Seasonal pattern of *Xanthonia* sp. 2 (Coleoptera: Chrysomelidae) at Long Hollow (1993-94) and Shellberg (1994). Data for first two dates from 1994 only.
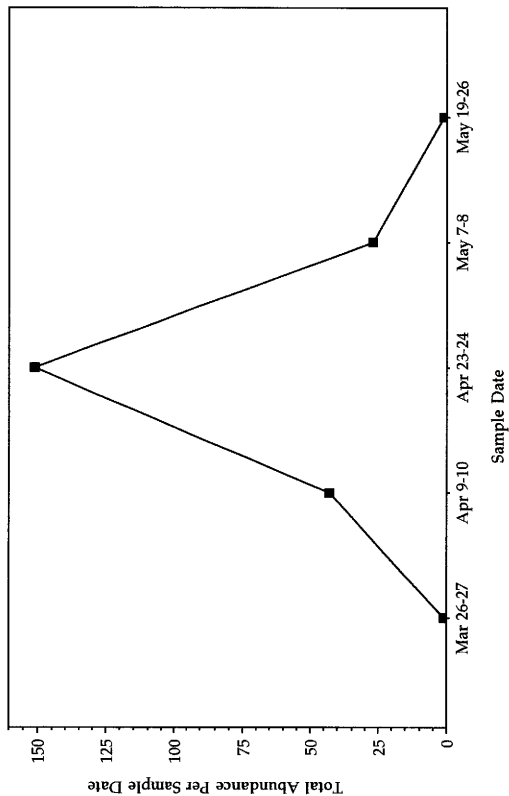
**Fig. 10.** Seasonal pattern of *Brachypnoea tristis* (Coleoptera: Chrysomelidae) at Long Hollow (1993-94) and Shellberg (1994).
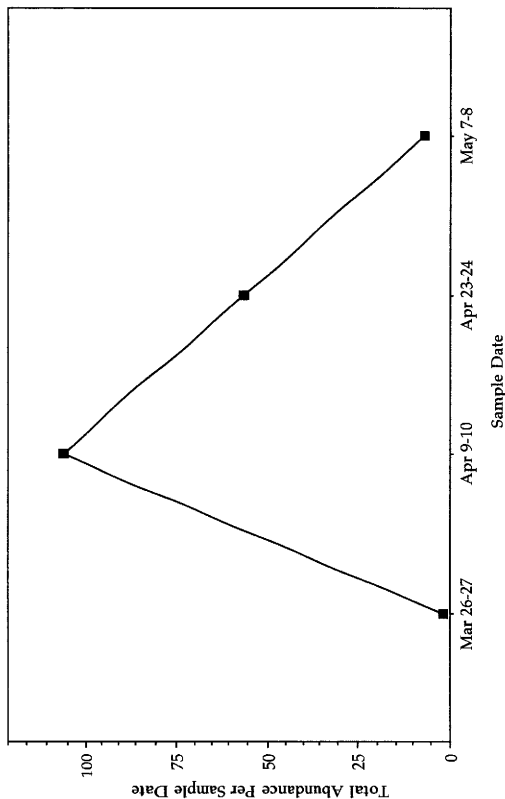
Fig. 11. Seasonal pattern of *Malthinis occipitalis* (Coleoptera: Cantharidae) at Long Hollow (1993-94) and Shellberg (1994).
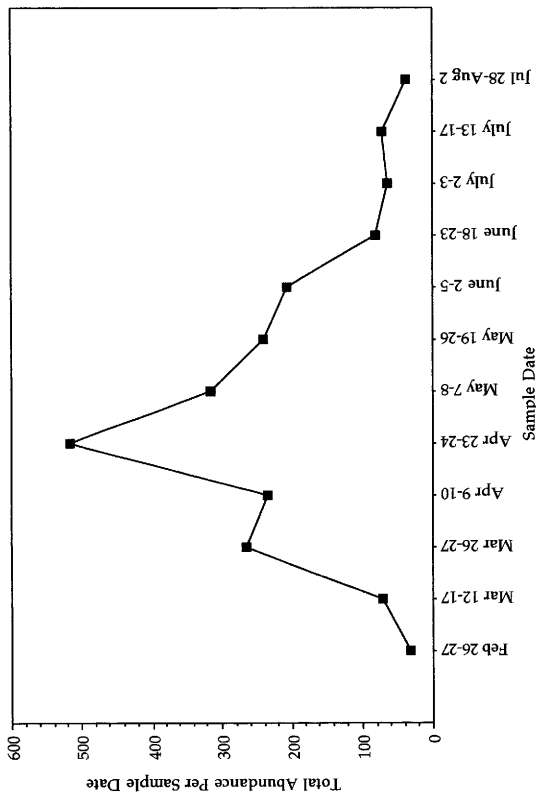
**Fig. 12.** Seasonal pattern of Hemiptera at Long Hollow (1993-94) and Shellberg (1994). Data for first two dates from 1994 only.
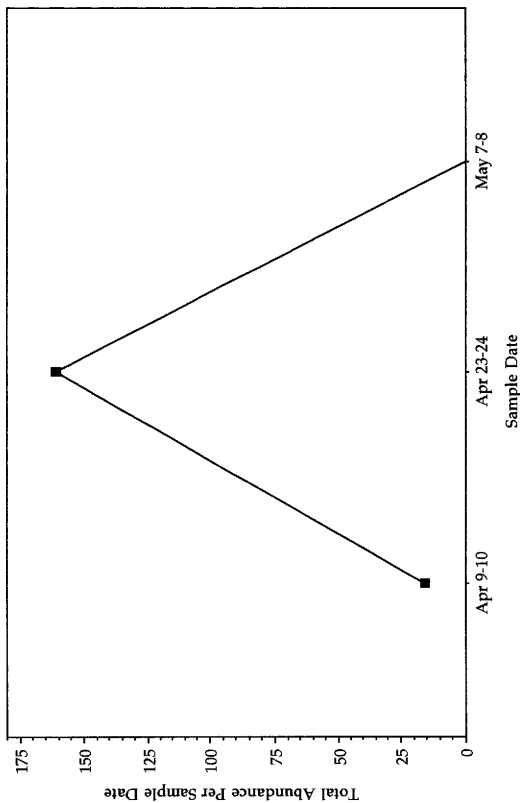
**Fig. 13.** Seasonal pattern of *Tropidosteptes quercicola* (Hemiptera: Miridae) at Long Hollow (1993-94) and Shellberg (1994).

83
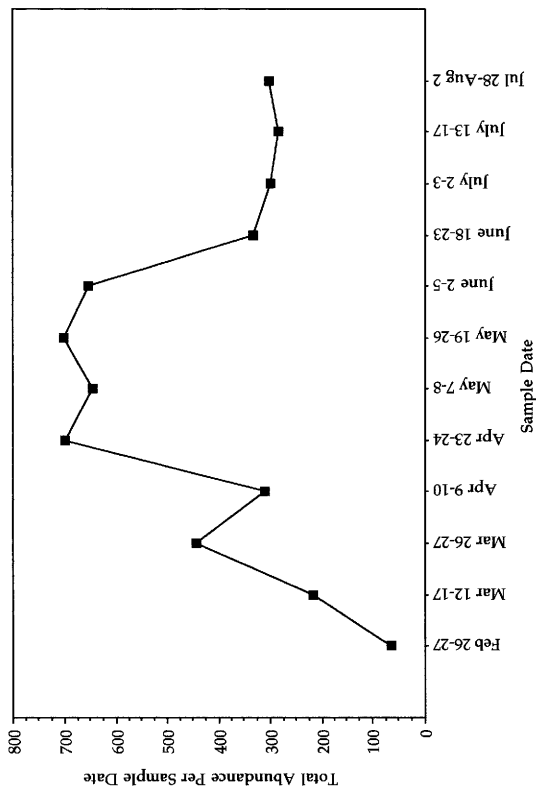


Fig. 14. Seasonal pattern of Homoptera at Long Hollow (1993-94) and Shellberg (1994). Data for first two dates from 1994 only.
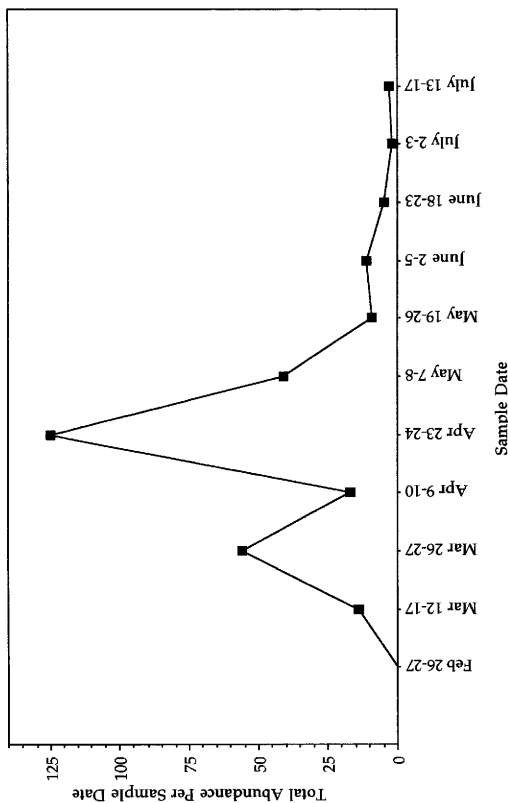
**Fig. 15.** Seasonal pattern of *Platycotis vittata* (Homoptera: Membracidae) at Long Hollow (1993-94) and Shellberg (1994). Data for first two dates from 1994 only.

**Fig. 16.** Seasonal pattern of Hymenoptera at Long Hollow (1993-94) and Shellberg (1994). Data for first two dates from 1994 only.

**Fig. 17.** Seasonal pattern of *Solenopsis invicta* (Hymenoptera: Formicidae) at Long Hollow (1993-94) and Shellberg (1994). Data for first two dates from 1994 only.
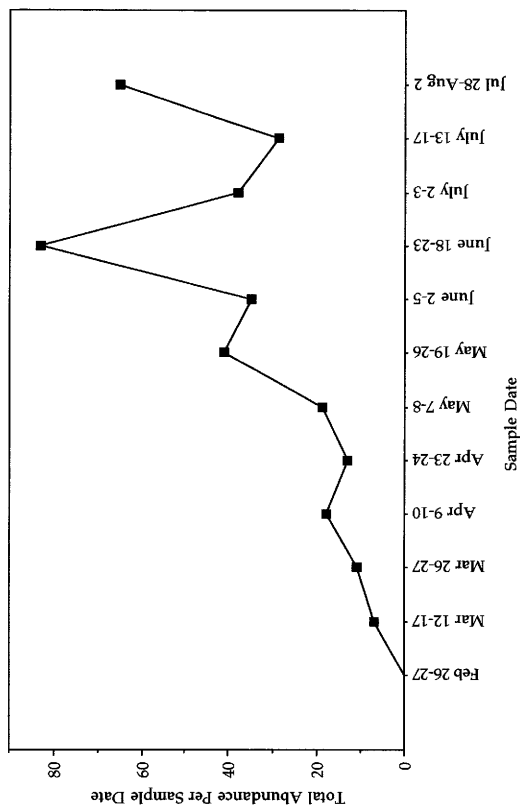
**Fig. 18.** Seasonal pattern of *Monomorium minimum* (Hymenoptera: Formicidae) at Long Hollow (1993-94) and Shellberg (1994). Data for first two dates from 1994 only.

**Fig. 19.** Seasonal pattern of Lepidoptera larvae at Long Hollow (1993-94) and Shellberg (1994). Data for first two dates from 1994 only.

**Fig. 20.** Seasonal pattern of Gelechiidae and Tortricidae (Lepidoptera, excluding *Cudoniger*) larvae at Long Hollow (1993-94) and Shellberg (1994). Data for first two dates from 1994 only.
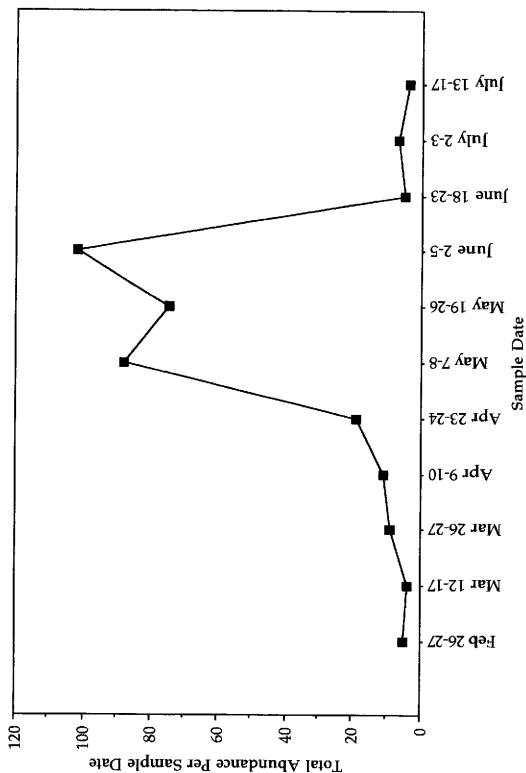
Fig. 21. Seasonal pattern of *Cudoniger houstonana* (Lepidoptera: Tortricidae) larvae at Long Hollow (1993-94) and Shellberg (1994). Data for first two dates from 1994 only.

**Fig. 22.** Seasonal pattern of Geometridae (Lepidoptera) Larvae at Long Hollow (1993-94) and Shellberg (1994). Data for first two dates from 1994 only.

**Fig. 23.** Seasonal pattern for Psocoptera at Long Hollow (1993-94) and Shellberg (1994). Data for first two dates from 1994 only.

Table 1. List of arthropod remains from 22 samples of Golden-cheeked
Warbler gizzards obtained from Warren Pulich.

| Arthropod Order | Number of recognizable individuals | Percent of Total |
|---|---|---|
| Lepidoptera larvae | 44 | 22 |
| Hymenoptera | 32 | 16 |
| Araneae | 29 | 14.5 |
| Coleoptera | 29 | 14.5 |
| Homoptera | 28 | 14 |
| Isoptera | 18 | 9 |
| Hemiptera (adults & eggs) | 12 | 6 |
| Diptera | 2 | 1 |
| Orthoptera | 1 | .5 |
| Trichoptera | 1 | .5 |
| Other insects | 4 | 2 |
| **Total** | **200** | **100%** |

# APPENDIX B

**Table 2.** Three-way ANOVA of all arthropods (excluding Thysanoptera) at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.

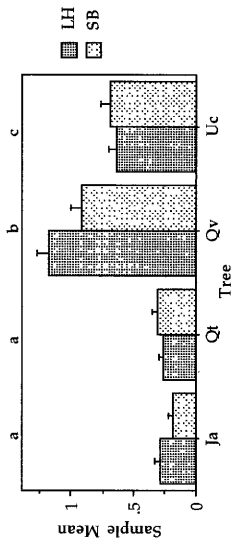| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Site | 1 | .637 | .637 | 7.238 | .0072 | 7.238 | .777 |
| Tree | 3 | 5.643 | 1.881 | 21.370 | <.0001 | 64.109 | 1.000 |
| Date | 11 | 54.996 | 5.000 | 56.802 | <.0001 | 624.824 | 1.000 |
| Site * Tree | 3 | .403 | .134 | 1.526 | .2059 | 4.577 | .394 |
| Site * Date | 11 | 4.684 | .426 | 4.838 | <.0001 | 53.215 | 1.000 |
| Tree * Date | 33 | 12.596 | .382 | 4.337 | <.0001 | 143.107 | 1.000 |
| Site * Tree * Date | 33 | 2.596 | .079 | .894 | .6418 | 29.495 | .868 |
| Residual | 1824 | 160.546 | .088 | | | | |
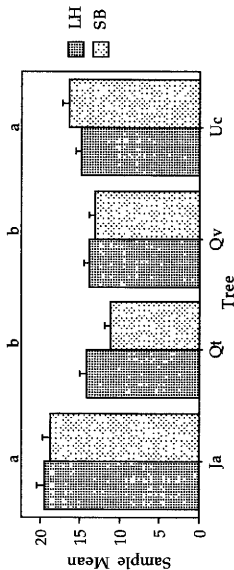


**Fig. 24.** Bar graph of Site by Tree for all Arthropods in 1994. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.
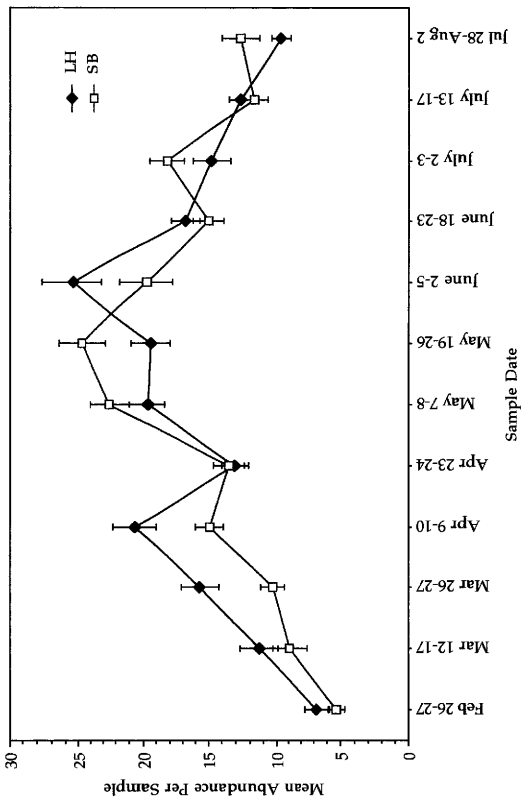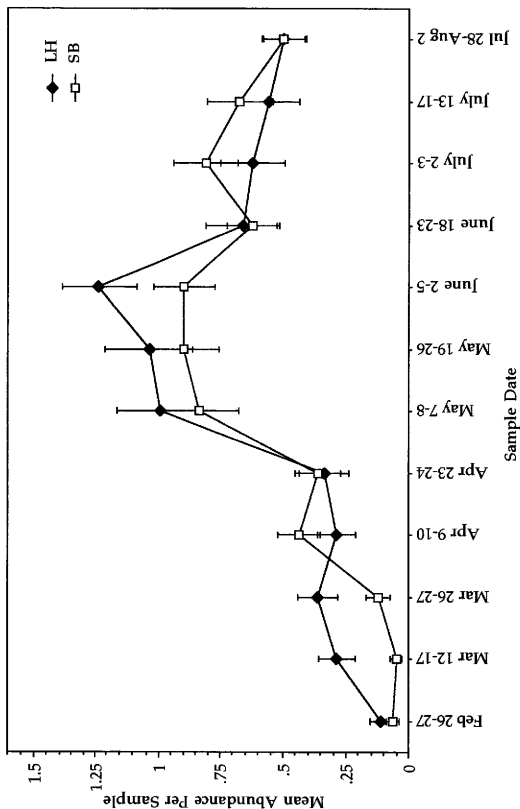
**Fig. 25.** Seasonal patterns for all Arthropods (excluding Thysanoptera) at Long Hollow and Shellberg in 1994. Vertical bars represent 1 SEM.

Table 3. Three-way ANOVA of Araneae at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.

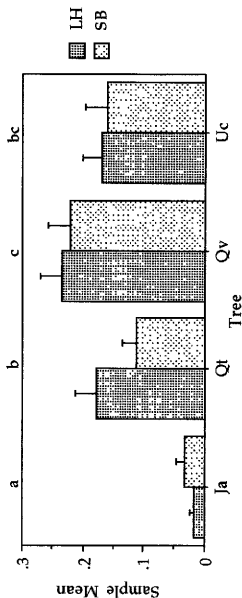| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Site | 1 | .234 | .234 | 2.952 | .0860 | 2.952 | .386 |
| Tree | 3 | 5.420 | 1.807 | 22.773 | <.0001 | 68.318 | 1.000 |
| Date | 11 | 47.822 | 4.347 | 54.802 | <.0001 | 602.819 | 1.000 |
| Site * Tree | 3 | .215 | .072 | .905 | .4378 | 2.715 | .243 |
| Site * Date | 11 | 1.996 | .181 | 2.287 | .0090 | 25.158 | .954 |
| Tree * Date | 33 | 10.295 | .312 | 3.933 | <.0001 | 129.775 | 1.000 |
| Site * Tree * Date | 33 | 2.098 | .064 | .801 | .7822 | 26.442 | .813 |
| Residual | 1824 | 144.700 | .079 | | | | |
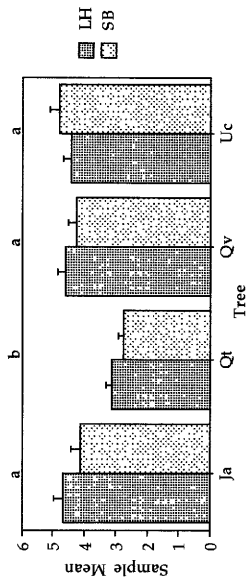


Fig. 26. Bar graph of Site by Tree for Araneae in 1994. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.
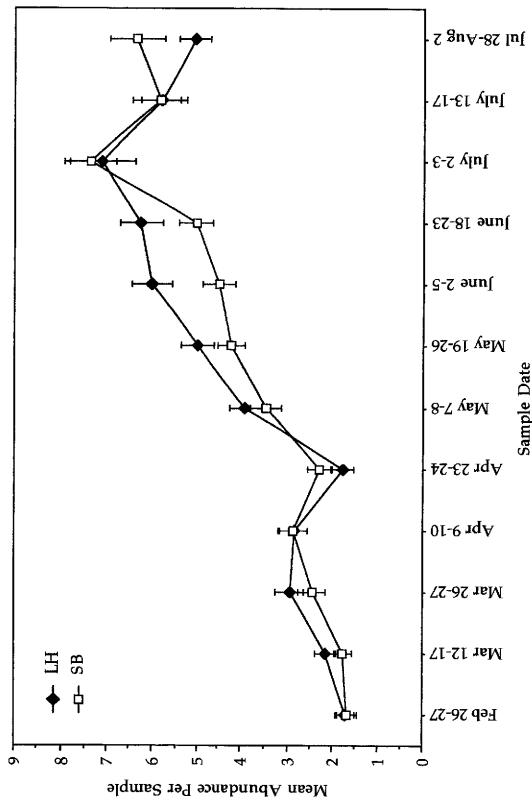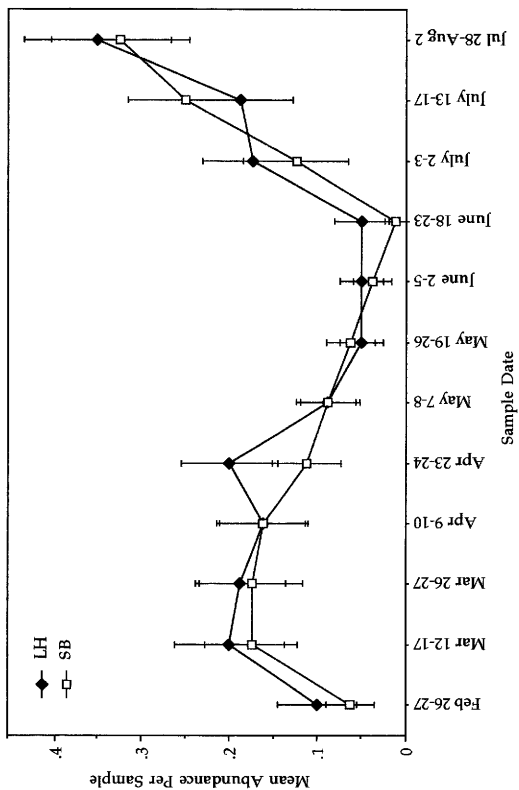
Fig. 27. Seasonal patterns of Araneae for Long Hollow and Shellberg in 1994. Vertical bars represent 1 SEM.

Table 4. Three-way ANOVA of *Misumenops* spp. (Araneae: Thomisidae) at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.

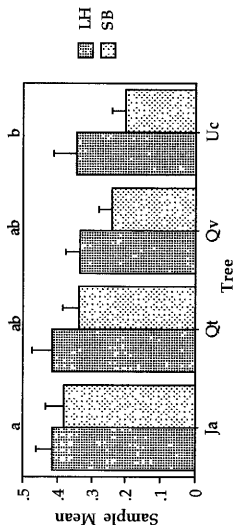| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Site | 1 | .034 | .034 | 1.082 | .2983 | 1.082 | .170 |
| Tree | 3 | 8.383 | 2.794 | 88.491 | <.0001 | 265.473 | 1.000 |
| Date | 11 | 8.518 | .774 | 24.523 | <.0001 | 269.750 | 1.000 |
| Site * Tree | 3 | .258 | .086 | 2.720 | .0431 | 8.159 | .659 |
| Site * Date | 11 | .631 | .057 | 1.817 | .0463 | 19.992 | .880 |
| Tree * Date | 33 | 6.330 | .192 | 6.075 | <.0001 | 200.473 | 1.000 |
| Site * Tree * Date | 33 | 1.073 | .033 | 1.030 | .4209 | 33.992 | .925 |
| Residual | 1824 | 57.597 | .032 | | | | |



Fig 28. Bar graph of Site by Tree for *Misumenops* spp. in 1994. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.
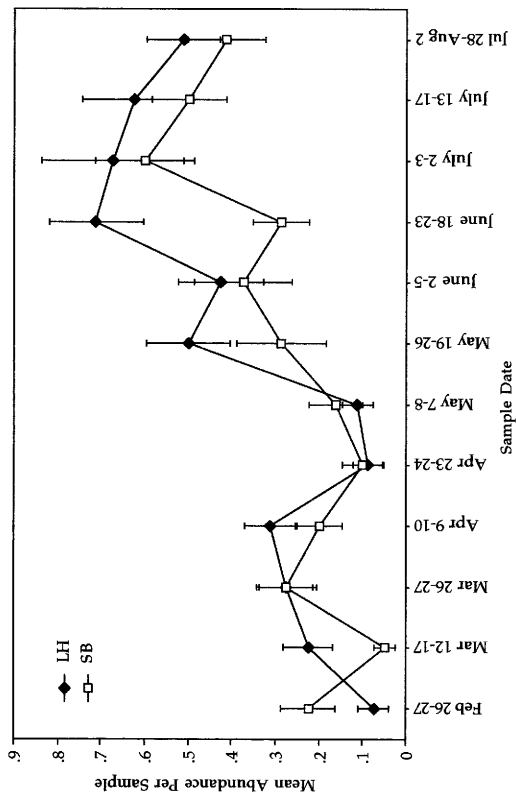
**Fig. 29.** Seasonal patterns of *Misumenops* spp. (Araneae: Thomisidae) at Long Hollow and Shellberg in 1994. Vertical bars represent 1 SEM.

Table 5. Three-way ANOVA of *Hibana* spp. (Araneae: Anyphaenidae) at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.

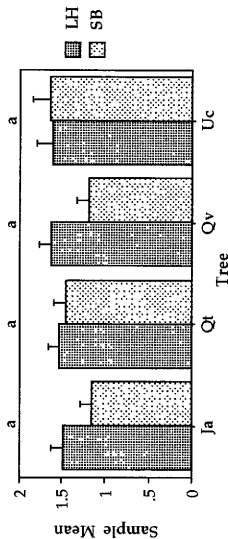| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Site | 1 | .012 | .012 | 1.005 | .3162 | 1.005 | .162 |
| Tree | 3 | .731 | .244 | 20.499 | <.0001 | 61.498 | 1.000 |
| Date | 11 | .862 | .078 | 6.600 | <.0001 | 72.595 | 1.000 |
| Site * Tree | 3 | .030 | .010 | .847 | .4682 | 2.540 | .229 |
| Site * Date | 11 | .045 | .004 | .347 | .9747 | 3.822 | .195 |
| Tree * Date | 33 | .818 | .025 | 2.087 | .0003 | 68.876 | 1.000 |
| Site * Tree * Date | 33 | .320 | .010 | .817 | .7594 | 26.976 | .824 |
| Residual | 1824 | 21.667 | .012 | | | | |



Fig. 30. Bar graph of Site by Tree for *Hibana* spp. in 1994. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.

Fig. 31. Seasonal patterns of *Hibana* spp. (Araneae: Anyphaenidae) at Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.

Table 6. Three-way ANOVA of *Philodromus* spp. (Aranae: Philodromidae) at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.

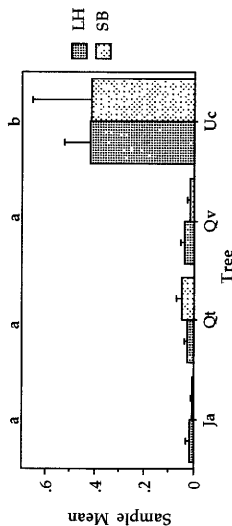| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Site | 1 | .227 | .227 | 9.015 | .0027 | 9.015 | .869 |
| Tree | 3 | .400 | .133 | 5.284 | .0013 | 15.853 | .943 |
| Date | 11 | 3.237 | .294 | 11.665 | <.0001 | 128.312 | 1.000 |
| Site * Tree | 3 | .015 | .005 | .194 | .9005 | .582 | .086 |
| Site * Date | 11 | .564 | .051 | 2.034 | .0222 | 22.369 | .921 |
| Tree * Date | 33 | 1.492 | .045 | 1.792 | .0039 | 59.133 | .999 |
| Site * Tree * Date | 33 | .879 | .027 | 1.056 | .3821 | 34.841 | .933 |
| Residual | 1824 | 46.013 | .025 | | | | |



Fig. 32. Bar graph of Site by Tree for *Philodromus* spp. in 1994. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.
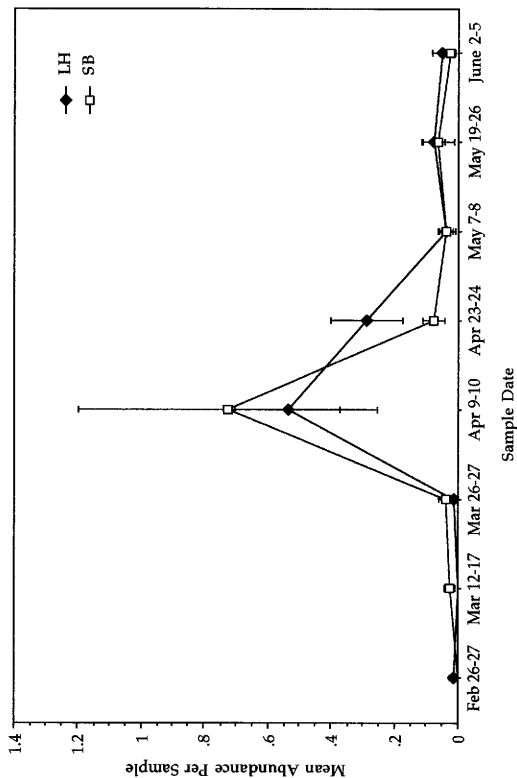
104



Fig. 33. Seasonal patterns of *Philodromus* spp. (Araneae: Philodromidae) at Long Hollow and Shellberg in 1994. Vertical bars represent 1 SEM.

Table 7. Three-way ANOVA of Coleoptera at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.

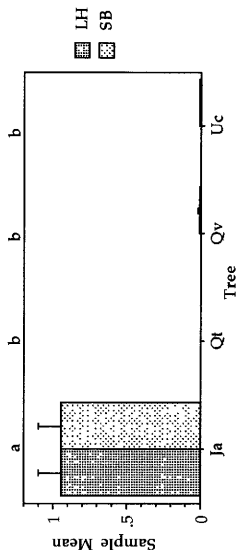| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Site | 1 | .863 | .863 | 14.632 | .0001 | 14.632 | .982 |
| Tree | 3 | .255 | .085 | 1.440 | .2294 | 4.319 | .373 |
| Date | 11 | 53.547 | 4.868 | 82.498 | <.0001 | 907.476 | 1.000 |
| Site * Tree | 3 | .539 | .180 | 3.043 | .0279 | 9.128 | .717 |
| Site * Date | 11 | 1.686 | .153 | 2.597 | .0028 | 28.571 | .977 |
| Tree * Date | 33 | 7.392 | .224 | 3.796 | <.0001 | 125.281 | 1.000 |
| Site * Tree * Date | 33 | 2.749 | .083 | 1.412 | .0610 | 46.583 | .989 |
| Residual | 1824 | 107.628 | .059 | | | | |



Fig. 34. Bar graph of Site by Tree for Coleoptera in 1994. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.
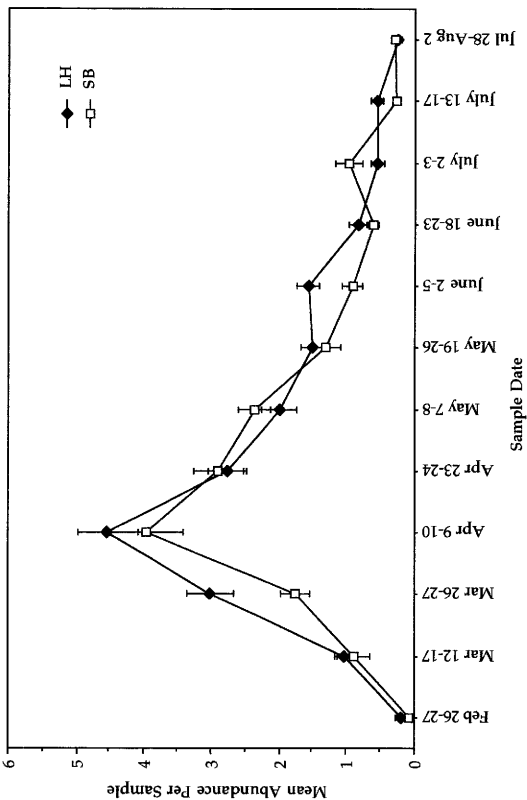
Fig. 35. Seasonal patterns of Coleoptera at Long Hollow and Shellberg in 1994. Vertical bars represent 1 SEM.

Table 8. Three-way ANOVA of *Xanthonia* sp. 1 (Coleoptera: Chrysomelidae) at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.

| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Site | 1 | .018 | .018 | 2.011 | .1564 | 2.011 | .277 |
| Tree | 3 | .874 | .291 | 31.965 | <.0001 | 95.896 | 1.000 |
| Date | 7 | .918 | .131 | 14.397 | <.0001 | 100.780 | 1.000 |
| Site * Tree | 3 | .050 | .017 | 1.823 | .1410 | 5.470 | .466 |
| Site * Date | 7 | .069 | .010 | 1.085 | .3704 | 7.595 | .468 |
| Tree * Date | 21 | 1.927 | .092 | 10.069 | <.0001 | 211.449 | 1.000 |
| Site * Tree * Date | 21 | .245 | .012 | 1.281 | .1771 | 26.900 | .902 |
| Residual | 1216 | 11.080 | .009 | | | | |



Fig. 36. Bar graph of Site by Tree for *Xanthonia* sp. 1 in 1994. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.
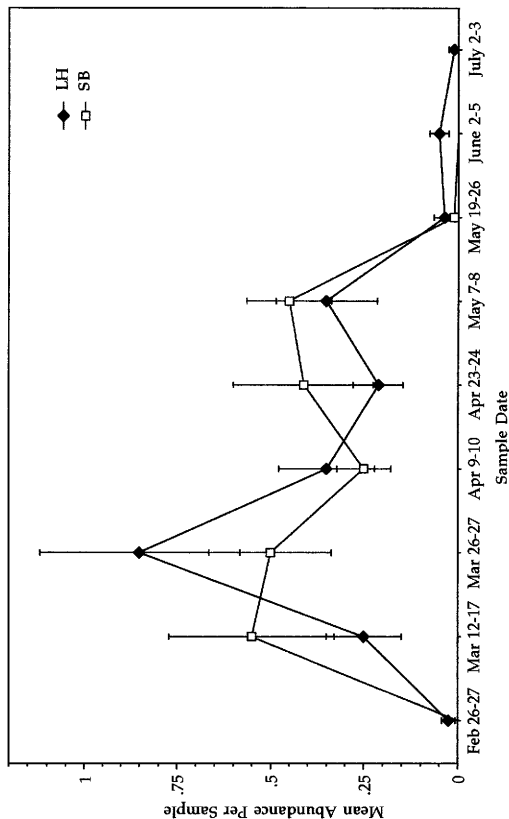
**Fig. 37.** Seasonal pattern of *Xanthonis* sp. 1 (Coleoptera: Chrysomelidae) for Long Hollow and Shellberg in 1994. Vertical bars represent 1 SEM.

Table 9. Three-way ANOVA of *Xanthonia* sp. 2 ( Coleoptera: Chrysomelidae) at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.

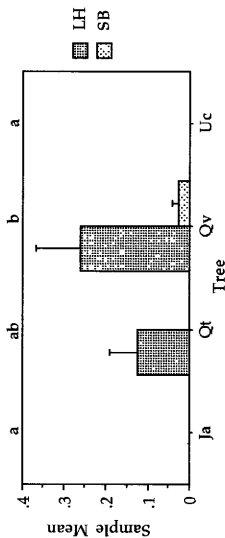| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Site | 1 | .001 | .001 | .077 | .7808 | .077 | .059 |
| Tree | 3 | 8.095 | 2.698 | 194.035 | <.0001 | 582.104 | 1.000 |
| Date | 8 | 1.982 | .248 | 17.813 | <.0001 | 142.502 | 1.000 |
| Site * Tree | 3 | .001 | 1.690E-4 | .012 | .9982 | .036 | .052 |
| Site * Date | 8 | .147 | .018 | 1.324 | .2270 | 10.592 | .611 |
| Tree * Date | 24 | 5.916 | .247 | 17.728 | <.0001 | 425.461 | 1.000 |
| Site * Tree * Date | 24 | .407 | .017 | 1.219 | .2132 | 29.262 | .914 |
| Residual | 1368 | 19.023 | .014 | | | | |



Fig. 38. Bar graph of Site by Tree for *Xanthonia* sp. 2 in 1994. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.
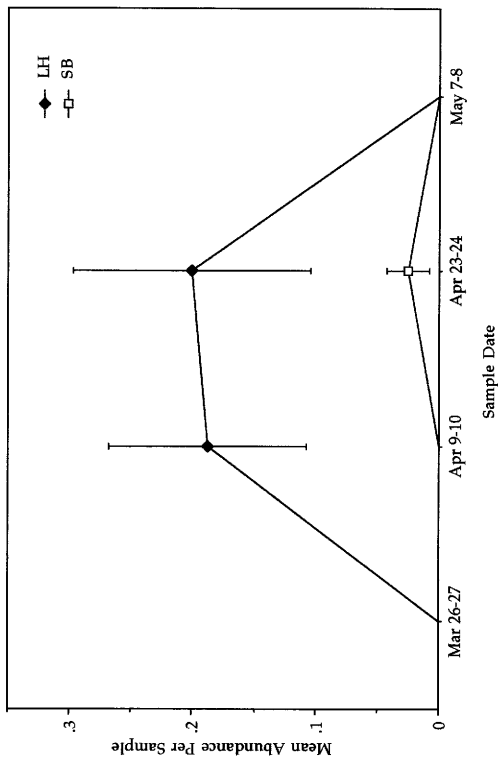
**Fig. 39.** Seasonal patterns of *Xanthonia* sp. 2 (Coleoptera: Chrysomelidae) at Long Hollow and Shellberg in 1994. Vertical bars represent 1 SEM.

Table 10. Three-way ANOVA of Hemiptera at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.

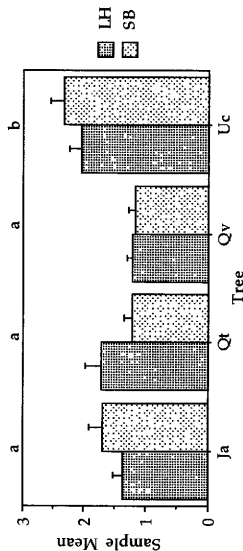| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Site | 1 | .592 | .592 | 14.570 | .0001 | 14.570 | .982 |
| Tree | 3 | 3.769 | 1.256 | 30.942 | <.0001 | 92.827 | 1.000 |
| Date | 11 | 12.165 | 1.106 | 27.236 | <.0001 | 299.591 | 1.000 |
| Site * Tree | 3 | .366 | .122 | 3.008 | .0292 | 9.025 | .711 |
| Site * Date | 11 | 1.020 | .093 | 2.284 | .0091 | 25.121 | .954 |
| Tree * Date | 33 | 4.840 | .147 | 3.612 | <.0001 | 119.192 | 1.000 |
| Site * Tree * Date | 33 | 2.239 | .068 | 1.671 | .0100 | 55.142 | .998 |
| Residual | 1824 | 74.064 | .041 | | | | |
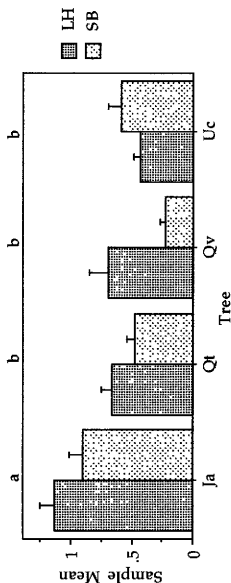


Fig. 40. Bar graph of Site by Tree for Hemiptera in 1994. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.
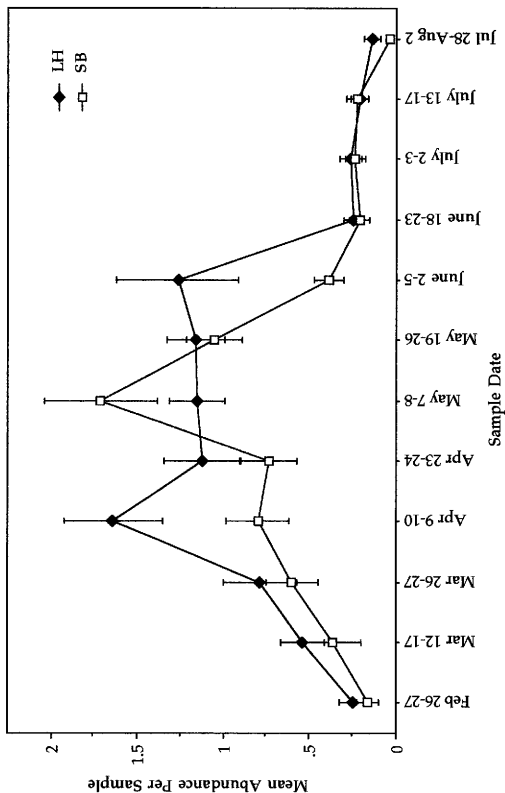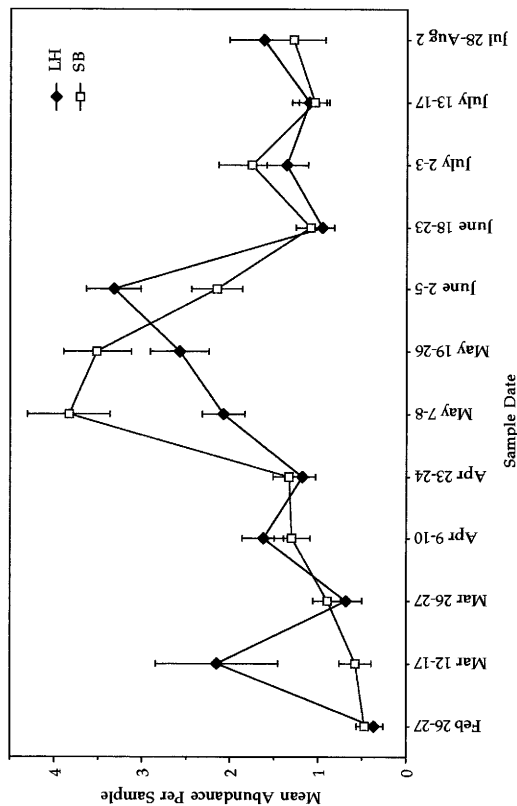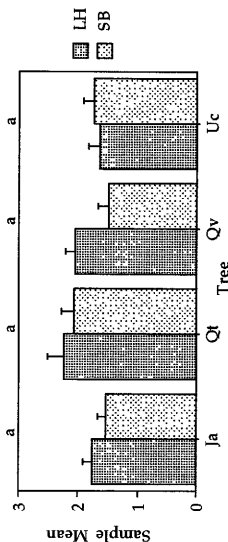
**Fig. 41.** Seasonal patterns of Hemiptera at Long Hollow and Shellberg in 1994. Vertical bars represent 1 SEM.

Table 11. Three-way ANOVA of *Tropidosteptes quercicola* (Hemiptera: Miridae) at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.

| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Site | 1 | .050 | .050 | 10.110 | .0015 | 10.110 | .907 |
| Tree | 3 | .096 | .032 | 6.496 | .0002 | 19.487 | .979 |
| Date | 3 | .074 | .025 | 5.020 | .0019 | 15.059 | .928 |
| Site * Tree | 3 | .057 | .019 | 3.843 | .0096 | 11.528 | .828 |
| Site * Date | 3 | .051 | .017 | 3.462 | .0161 | 10.385 | .779 |
| Tree * Date | 9 | .236 | .026 | 5.291 | <.0001 | 47.620 | 1.000 |
| Site * Tree * Date | 9 | .135 | .015 | 3.030 | .0015 | 27.270 | .979 |
| Residual | 608 | 3.007 | .005 | | | | |



Fig. 42. Bar graph of Site by Tree for *T. quercicola* in 1994. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.

**Fig. 43.** Seasonal patterns of *Tropidosteptes quercicola* (Hemiptera: Miridae) at Long Hollow and Shellberg in 1994. Vertical bars represent 1 SEM.

Table 12. Three-way ANOVA of Homoptera at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.

| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Site | 1 | .001 | .001 | .022 | .8830 | .022 | .052 |
| Tree | 3 | 3.040 | 1.013 | 14.633 | <.0001 | 43.899 | 1.000 |
| Date | 11 | 28.351 | 2.577 | 37.220 | <.0001 | 409.422 | 1.000 |
| Site * Tree | 3 | .234 | .078 | 1.124 | .3380 | 3.372 | .296 |
| Site * Date | 11 | 3.590 | .326 | 4.713 | <.0001 | 51.841 | 1.000 |
| Tree * Date | 33 | 18.878 | .572 | 8.261 | <.0001 | 272.618 | 1.000 |
| Site * Tree * Date | 33 | 2.754 | .083 | 1.205 | .1967 | 39.774 | .967 |
| Residual | 1824 | 126.305 | .069 | | | | |



Fig. 44. Bar graph of Site by Tree for Homoptera in 1994. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.
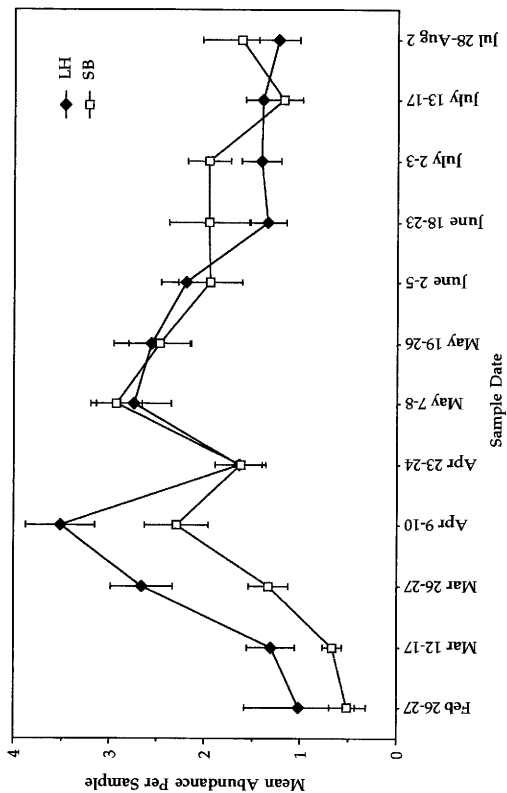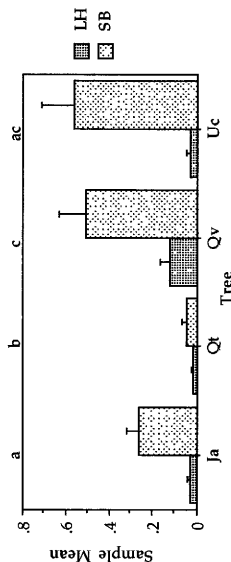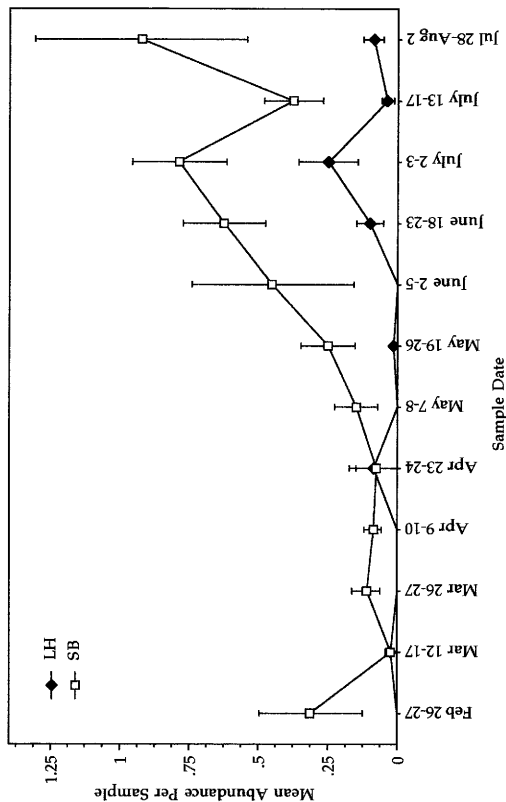
Fig. 45. Seasonal patterns of Homoptera at Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.

Table 13. Three-way ANOVA of Hymenoptera at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.

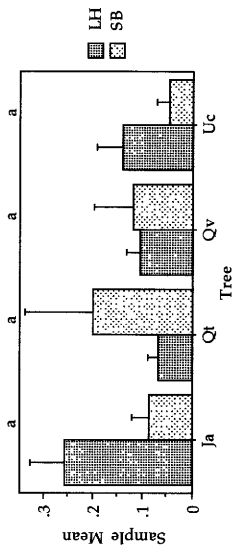| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Site | 1 | .479 | .479 | 5.868 | .0155 | 5.868 | .678 |
| Tree | 3 | .603 | .201 | 2.463 | .0608 | 7.389 | .608 |
| Date | 11 | 19.512 | 1.774 | 21.730 | <.0001 | 239.035 | 1.000 |
| Site * Tree | 3 | .725 | .242 | 2.959 | .0313 | 8.876 | .702 |
| Site * Date | 11 | 3.010 | .274 | 3.352 | .0001 | 36.877 | .997 |
| Tree * Date | 33 | 7.119 | .216 | 2.643 | <.0001 | 87.212 | 1.000 |
| Site * Tree * Date | 33 | 3.698 | .112 | 1.373 | .0776 | 45.305 | .986 |
| Residual | 1824 | 148.891 | .082 | | | | |



Fig. 46. Bar graph of Site by Tree for Hymenoptera in 1994. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.
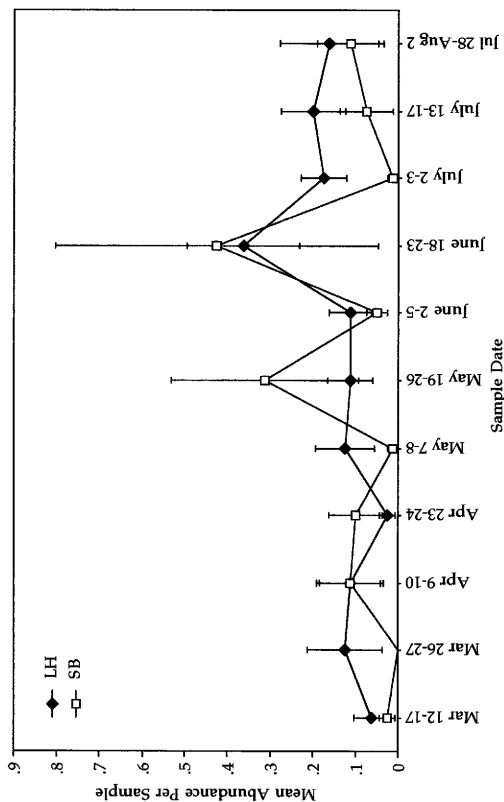
118



**Fig. 47.** Seasonal patterns of Hymenoptera at Long Hollow and Shellberg in 1994. Vertical bars represent 1 SEM.

Table 14. Three-way ANOVA of *Solenopsis invicta* (Hymenoptera: Formicidae) at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.

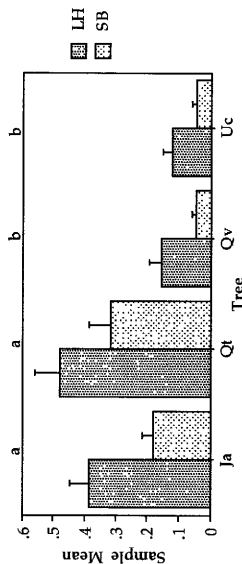| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Site | 1 | 1.241 | 1.241 | 73.209 | <.0001 | 73.209 | 1.000 |
| Tree | 3 | .634 | .211 | 12.467 | <.0001 | 37.402 | 1.000 |
| Date | 11 | 1.688 | .153 | 9.056 | <.0001 | 99.612 | 1.000 |
| Site * Tree | 3 | .339 | .113 | 6.659 | .0002 | 19.978 | .983 |
| Site * Date | 11 | .596 | .054 | 3.199 | .0003 | 35.194 | .995 |
| Tree * Date | 33 | 1.426 | .043 | 2.549 | <.0001 | 84.122 | 1.000 |
| Site * Tree * Date | 33 | 1.134 | .034 | 2.028 | .0005 | 66.932 | 1.000 |
| Residual | 1824 | 30.909 | .017 | | | | |



Fig. 48. Bar graph of Site by Tree for *S. invicta* in 1994. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.

120



Fig. 49. Seasonal patterns of *Solenopsis invicta* (Hymenoptera: Formicidae) at Long Hollow and Shellberg in1994. Error bars represent 1 SEM.

Table 15. Three-way ANOVA of *Monomorium minimum* (Hymenoptera: Formicidae) at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.

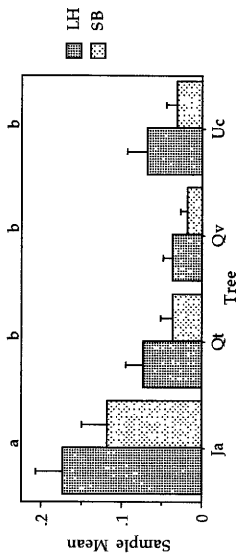| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Site | 1 | .106 | .106 | 8.535 | .0035 | 8.535 | .848 |
| Tree | 3 | .069 | .023 | 1.861 | .1342 | 5.584 | .475 |
| Date | 10 | .228 | .023 | 1.833 | .0506 | 18.327 | .857 |
| Site * Tree | 3 | .062 | .021 | 1.651 | .1757 | 4.953 | .425 |
| Site * Date | 10 | .173 | .017 | 1.389 | .1793 | 13.888 | .715 |
| Tree * Date | 30 | .598 | .020 | 1.601 | .0210 | 48.038 | .993 |
| Site * Tree * Date | 30 | .281 | .009 | .752 | .8317 | 22.554 | .745 |
| Residual | 1672 | 20.809 | .012 | | | | |



Fig. 50. Bar graph of Site by Tree for *M. minimum* in 1994. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.

122



Fig. 51. Seasonal patterns of *Monomorium minimum* (Hymenoptera: Formicidae) at Long Hollow and Shellberg in 1994. Vertical bars represent 1 SEM.

Table 16. Three-way ANOVA for Lepidoptera larvae at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.

|  | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Site | 1 | .478 | .478 | 30.184 | <.0001 | 30.184 | 1.000 |
| Tree | 3 | 1.254 | .418 | 26.413 | <.0001 | 79.239 | 1.000 |
| Date | 11 | 4.373 | .398 | 25.112 | <.0001 | 276.230 | 1.000 |
| Site * Tree | 3 | .053 | .018 | 1.126 | .3372 | 3.378 | .297 |
| Site * Date | 11 | .477 | .043 | 2.742 | .0016 | 30.163 | .984 |
| Tree * Date | 33 | 3.107 | .094 | 5.948 | <.0001 | 196.285 | 1.000 |
| Site * Tree * Date | 33 | 1.448 | .044 | 2.772 | <.0001 | 91.478 | 1.000 |
| Residual | 1824 | 28.875 | .016 |  |  |  |  |



Fig. 52. Bar graph of Site by Tree for Lepidoptera larvae in 1994. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.
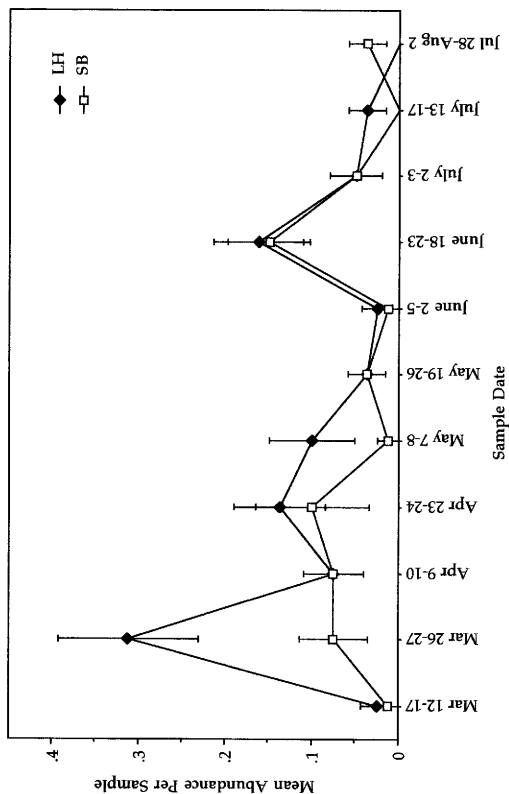
124
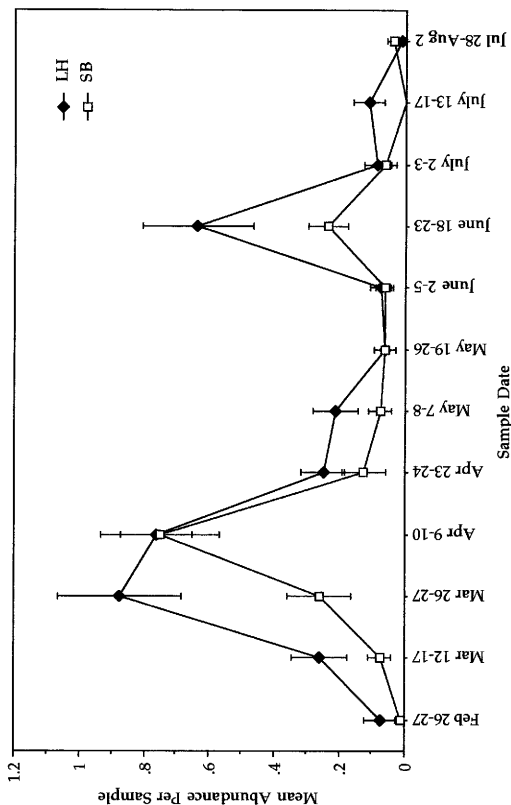


Fig. 53. Seasonal patterns for Lepidoptera larvae at Long Hollow and Shellberg in 1994. Vertical bars represent 1 SEM.

Table 17. Three-way ANOVA of Geometridae (Lepidoptera) larvae at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.

| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Site | 1 | .040 | .040 | 6.477 | .0110 | 6.477 | .725 |
| Tree | 3 | .238 | .079 | 12.974 | <.0001 | 38.923 | 1.000 |
| Date | 10 | .382 | .038 | 6.236 | <.0001 | 62.356 | 1.000 |
| Site * Tree | 3 | .006 | .002 | .318 | .8123 | .954 | .111 |
| Site * Date | 10 | .136 | .014 | 2.223 | .0144 | 22.234 | .929 |
| Tree * Date | 30 | .634 | .021 | 3.449 | <.0001 | 103.485 | 1.000 |
| Site * Tree * Date | 30 | .129 | .004 | .703 | .8834 | 21.098 | .705 |
| Residual | 1672 | 10.239 | .006 | | | | |



Fig. 54. Bar graph of Site by Tree for Geometridae larvae in 1994. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.
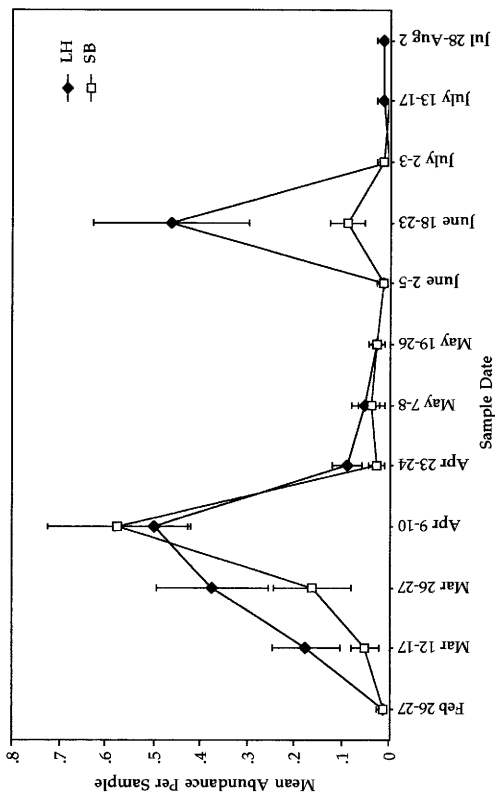
126



Fig. 55. Seasonal patterns of Geometridae (Lepidoptera) larvae for Long Hollow and Shellberg in 1994. Vertical bars represent 1 SEM.

Table 18. Three-way ANOVA of Gelechiidae and Tortricidae (Lepidoptera, excluding *Cudoniger*) larvae at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.

| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Site | 1 | .099 | .099 | 12.296 | .0005 | 12.296 | .957 |
| Tree | 3 | .971 | .324 | 40.241 | <.0001 | 120.723 | 1.000 |
| Date | 11 | 2.468 | .224 | 27.910 | <.0001 | 307.008 | 1.000 |
| Site * Tree | 3 | .050 | .017 | 2.071 | .1021 | 6.212 | .523 |
| Site * Date | 11 | .172 | .016 | 1.950 | .0296 | 21.453 | .907 |
| Tree * Date | 33 | 2.243 | .068 | 8.452 | <.0001 | 278.906 | 1.000 |
| Site * Tree * Date | 33 | 1.187 | .036 | 4.474 | <.0001 | 147.631 | 1.000 |
| Residual | 1824 | 14.666 | .008 | | | | |
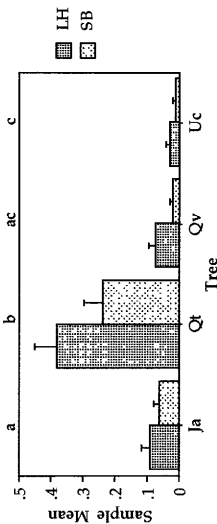


Fig. 56. Bar graph for Site by Tree of Gelechiidae and Tortricidae (Lepidoptera, excluding *Cudoniger*) larvae in 1994. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.

**Fig. 57.** Seasonal patterns of Gelechiidae and Tortricidae (Lepidoptera, excluding *Cudoniger houstonana*) larvae for Long Hollow and Shellberg in 1994. Vertical bars represent 1 SEM.

**APPENDIX C**

Table 19. Three-way ANOVA of all arthropods (excluding Thysanoptera) at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.

| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Height | 2 | 8.126 | 4.063 | 51.414 | <.0001 | 102.829 | 1.000 |
| Tree | 3 | 2.027 | .676 | 8.549 | <.0001 | 25.647 | .997 |
| Date | 11 | 34.828 | 3.166 | 40.066 | <.0001 | 440.730 | 1.000 |
| Height * Tree | 6 | .749 | .125 | 1.580 | .1496 | 9.480 | .608 |
| Height * Date | 22 | 4.008 | .182 | 2.305 | .0006 | 50.713 | .999 |
| Tree * Date | 33 | 7.634 | .231 | 2.927 | <.0001 | 96.598 | 1.000 |
| Height * Tree * Date | 66 | 6.306 | .096 | 1.209 | .1276 | 79.798 | .999 |
| Residual | 1009 | 79.735 | .079 | | | | |
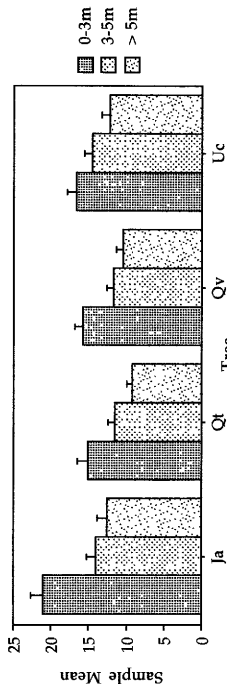


Fig. 58. Bar graph of Height by Tree for all arthropods at Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.
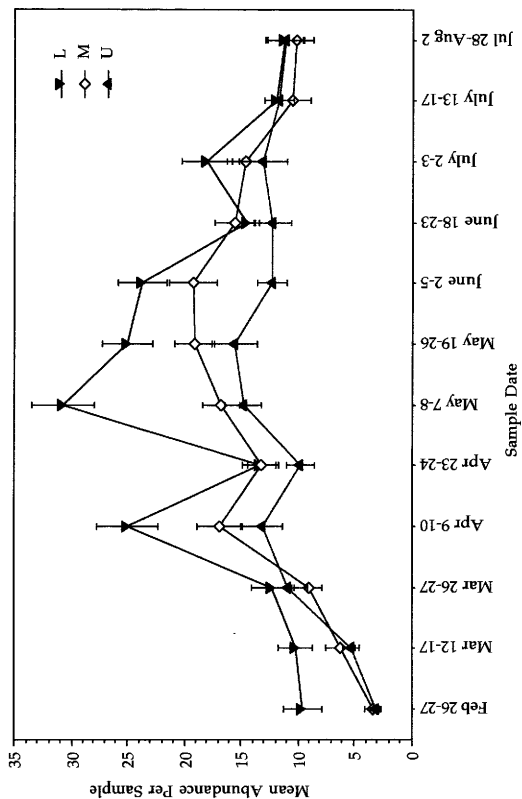
**Fig. 59.** Seasonal patterns by height class for all arthropods (excluding Thysanoptera) at Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.

132
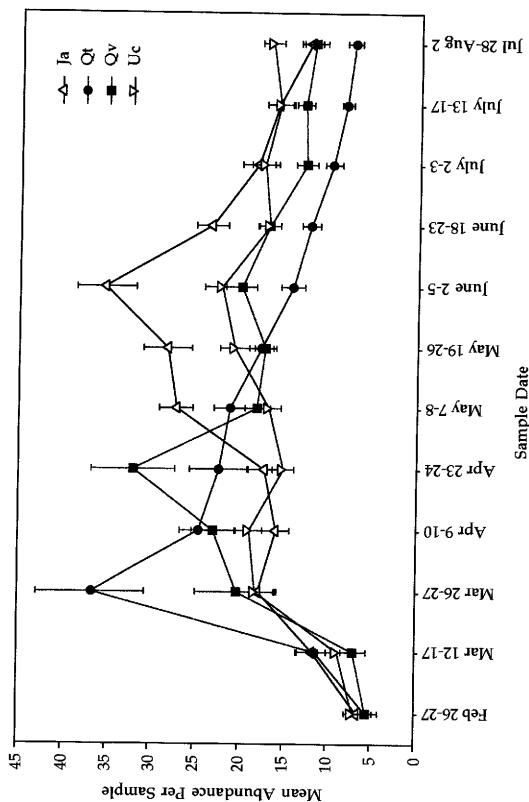


**Fig. 60.** Seasonal patterns by tree species of all Arthropods (excluding Thysanoptera) at Long Hollow (1993-94) and Shellberg (1994). Vertical bars represent 1 SEM.

Table 20. Three-way ANOVA for Araneae at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.

| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Height | 2 | 3.984 | 1.992 | 26.174 | <.0001 | 52.349 | 1.000 |
| Tree | 3 | 4.176 | 1.392 | 18.287 | <.0001 | 54.862 | 1.000 |
| Date | 11 | 26.679 | 2.425 | 31.866 | <.0001 | 350.522 | 1.000 |
| Height * Tree | 6 | .916 | .153 | 2.006 | .0622 | 12.038 | .736 |
| Height * Date | 22 | 3.000 | .136 | 1.792 | .0139 | 39.416 | .986 |
| Tree * Date | 33 | 6.234 | .189 | 2.482 | <.0001 | 81.902 | 1.000 |
| Height * Tree * Date | 66 | 5.416 | .082 | 1.078 | .3171 | 71.162 | .997 |
| Residual | 1008 | 76.720 | .076 | | | | |
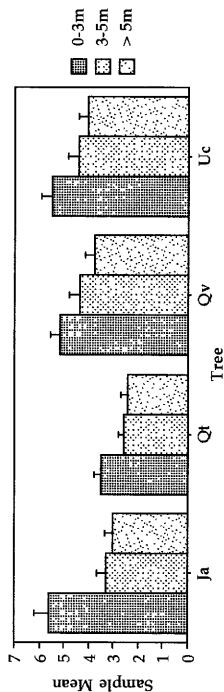


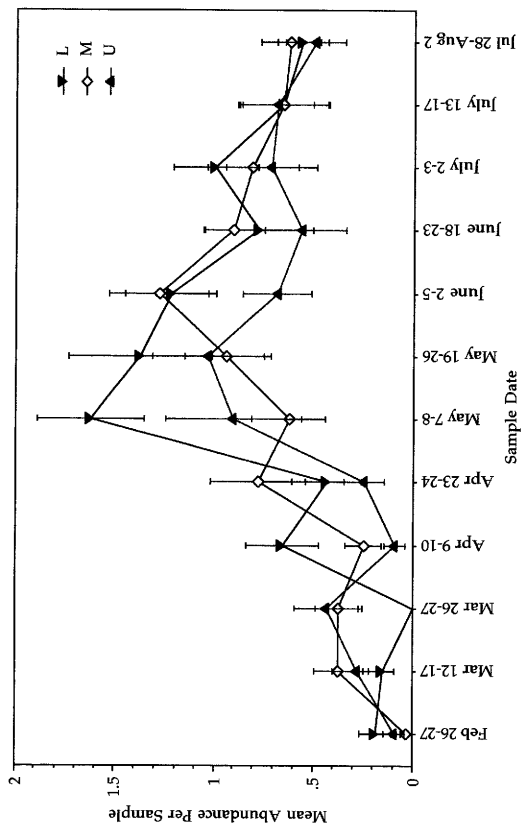Fig. 61. Bar graph of Height by Tree for Araneae at Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.

134
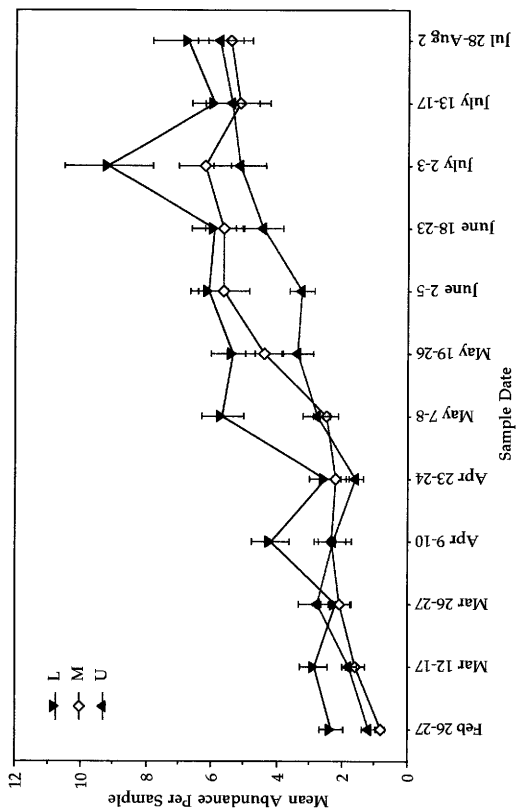


Fig. 62. Seasonal patterns by height class for Araneae at sites Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.
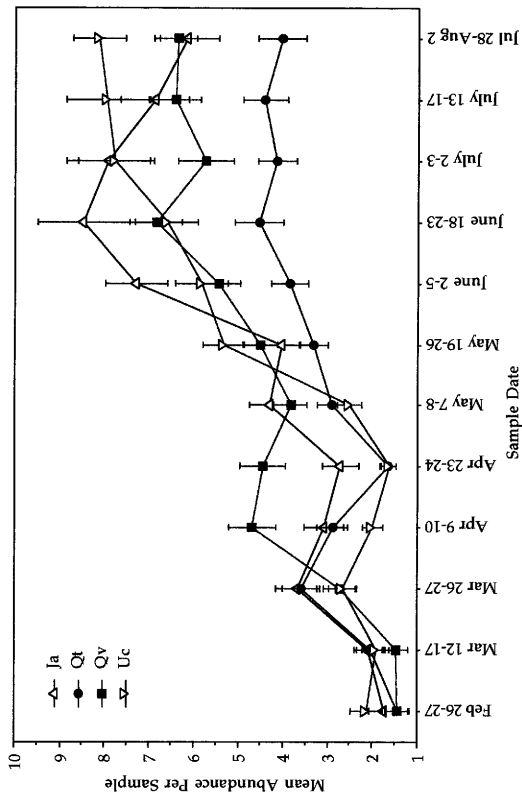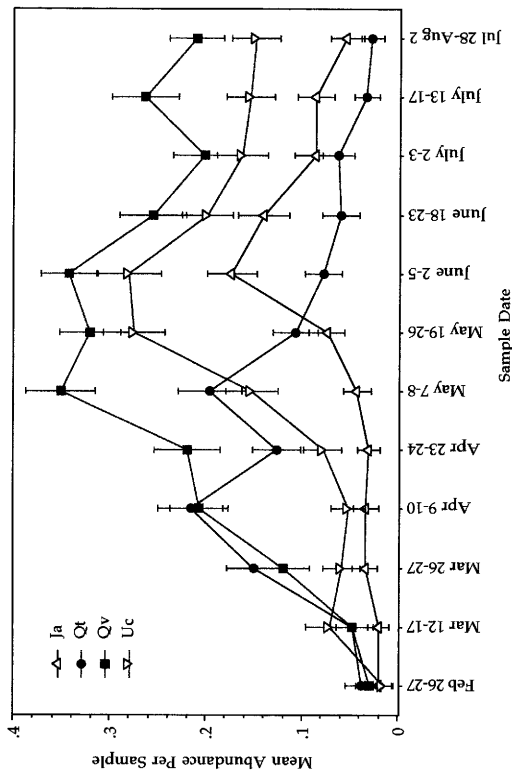
**Fig. 63.** Seasonal patterns by tree species for Araneae at Long Hollow (1993-94) and Shellberg (1994). Vertical bars represent 1 SEM.

Table 21. Three-way ANOVA of *Misumenops* spp. (Araneae: Thomisidae) at Long Hollow and Shellberg in 1994. Data transformed by (llog(x+1) before analysis.

| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Height | 2 | .377 | .188 | 5.438 | .0045 | 10.876 | .859 |
| Tree | 3 | 6.206 | 2.069 | 59.742 | <.0001 | 179.225 | 1.000 |
| Date | 11 | 5.235 | .476 | 13.746 | <.0001 | 151.203 | 1.000 |
| Height * Tree | 6 | .129 | .021 | .619 | .7156 | 3.712 | .246 |
| Height * Date | 22 | 1.789 | .081 | 2.349 | .0004 | 51.677 | .999 |
| Tree * Date | 33 | 4.205 | .127 | 3.680 | <.0001 | 121.442 | 1.000 |
| Height * Tree * Date | 66 | 2.268 | .034 | .993 | .4957 | 65.506 | .993 |
| Residual | 1008 | 34.902 | .035 | | | | |
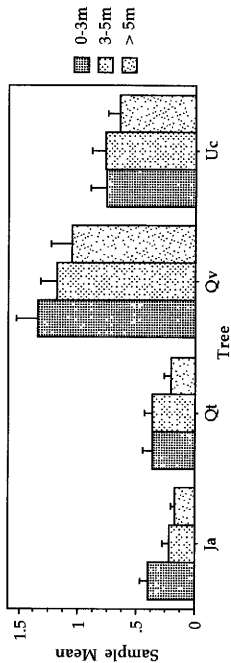


Fig. 64. Bar graph of Height by Tree for *Misumenops* spp. (Araneae: Thomisidae) at Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.
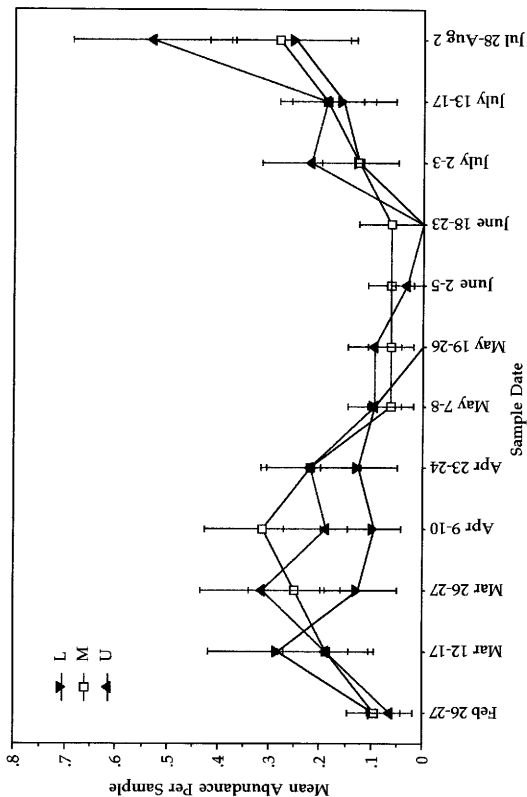
Fig. 65. Seasonal pattern by height class for *Misumenops* spp. (Araneae: Thomisidae) at sites Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.
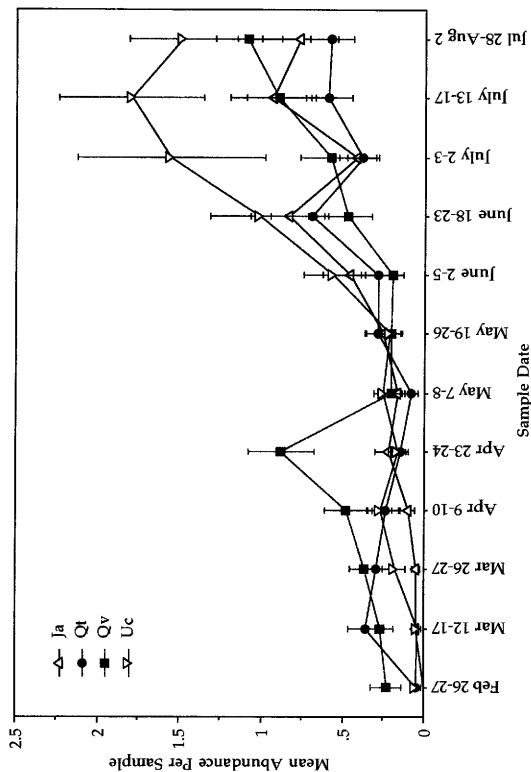
138



Fig. 66. Seasonal patterns by tree species of *Misumenops* spp. (Araneae: Thomisidae) at Long Hollow (1993-94) and Shellberg (1994). Vertical bars represent 1 SEM.

Table 22. Three-way ANOVA for *Hibana* spp. (Araneae: Anyphaenidae) at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.

| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Height | 2 | .066 | .033 | 2.590 | .0755 | 5.179 | .506 |
| Tree | 3 | .417 | .139 | 10.909 | <.0001 | 32.726 | 1.000 |
| Date | 11 | .632 | .057 | 4.509 | <.0001 | 49.596 | 1.000 |
| Height * Tree | 6 | .126 | .021 | 1.645 | .1314 | 9.871 | .629 |
| Height * Date | 22 | .181 | .008 | .646 | .8922 | 14.215 | .546 |
| Tree * Date | 33 | .649 | .020 | 1.541 | .0269 | 50.867 | .994 |
| Height * Tree * Date | 66 | .678 | .010 | .805 | .8676 | 53.140 | .965 |
| Residual | 1008 | 12.853 | .013 | | | | |
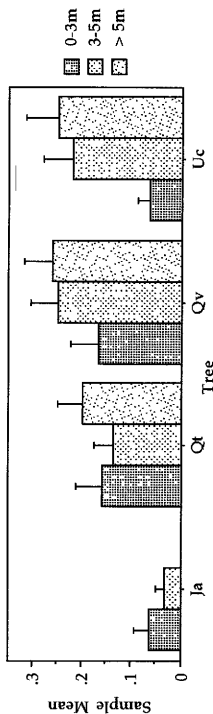


Fig. 67. Bar graph of Height by Tree for *Hibana* spp. (Araneae: Anyphaenidae) at Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.

**Fig. 68.** Seasonal patterns by height class for *Hibana* spp. (Araneae: Anyphaenidae) at Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.

141



Fig. 69. Seasonal patterns by tree species of *Hibana* spp. (Araneae: Anyphaenidae) at Long Hollow (1993-94) and Shellberg (1994). Vertical bars represent 1 SEM.

Table 23. Three-way ANOVA for Coleoptera at Long Hollow and Shellberg in 1994. Data transformed by (log(x+1) before analysis.

| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Height | 2 | .142 | .071 | 1.123 | .3256 | 2.247 | .239 |
| Tree | 3 | .255 | .085 | 1.339 | .2602 | 4.018 | .348 |
| Date | 11 | 31.917 | 2.902 | 45.791 | <.0001 | 503.702 | 1.000 |
| Height * Tree | 6 | .614 | .102 | 1.615 | .1396 | 9.689 | .619 |
| Height * Date | 22 | 1.489 | .068 | 1.068 | .3763 | 23.498 | .832 |
| Tree * Date | 33 | 6.095 | .185 | 2.915 | <.0001 | 96.183 | 1.000 |
| Height * Tree * Date | 66 | 4.967 | .075 | 1.188 | .1507 | 78.390 | .999 |
| Residual | 1008 | 63.872 | .063 | | | | |
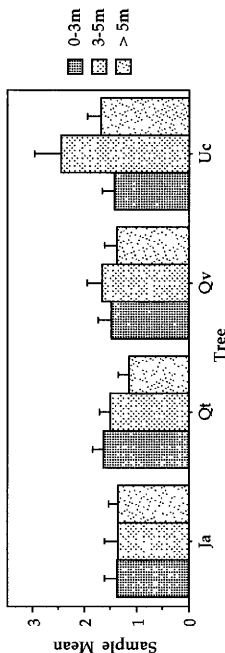


Fig. 70. Bar graph of Height by Tree for Coleoptera at Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.
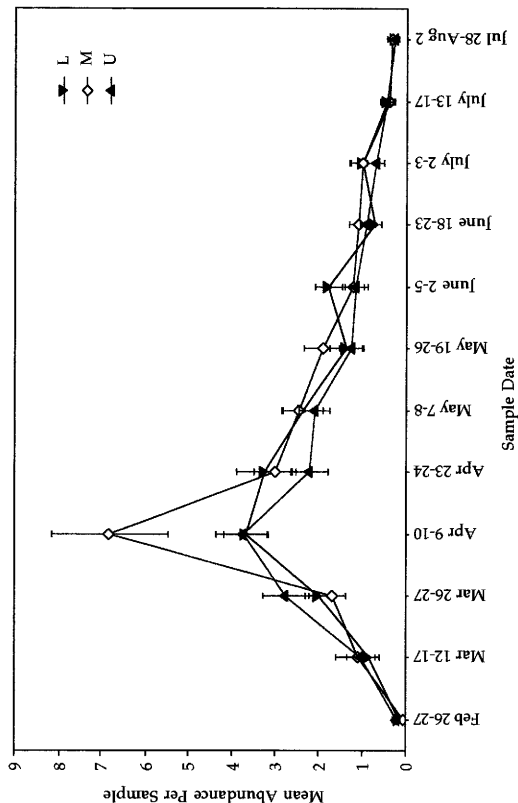
Fig. 71. Seasonal pattern by height class for Coleoptera at Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.
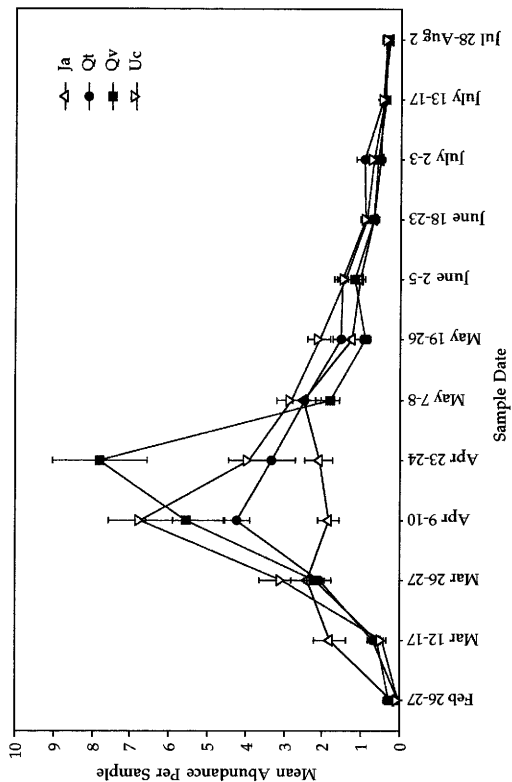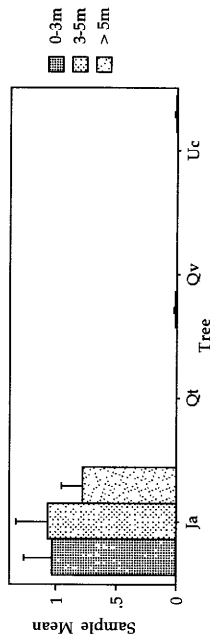
144



**Fig. 72.** Seasonal patterns by tree species of Coleoptera at Long Hollow (1993-94) and Shellberg (1994). Vertical bars represent 1 SEM.

Table 24. Three-way ANOVA for *Xanthonia* sp. 2 (Coleoptera: Chrysomelidae) at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.

| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Height | 2 | .019 | .010 | .631 | .5323 | 1.262 | .151 |
| Tree | 3 | 5.103 | 1.701 | 110.994 | <.0001 | 332.983 | 1.000 |
| Date | 8 | 1.119 | .140 | 9.126 | <.0001 | 73.005 | 1.000 |
| Height * Tree | 6 | .064 | .011 | .693 | .6557 | 4.155 | .273 |
| Height * Date | 16 | .095 | .006 | .388 | .9854 | 6.202 | .261 |
| Tree * Date | 24 | 3.400 | .142 | 9.244 | <.0001 | 221.863 | 1.000 |
| Height * Tree * Date | 48 | .361 | .008 | .491 | .9986 | 23.547 | .634 |
| Residual | 756 | 11.586 | .015 | | | | |



Fig. 73. Bar graph of Height by Tree for *Xanthonia* sp. 2 (Coleoptera: Chrysomelidae) at Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.
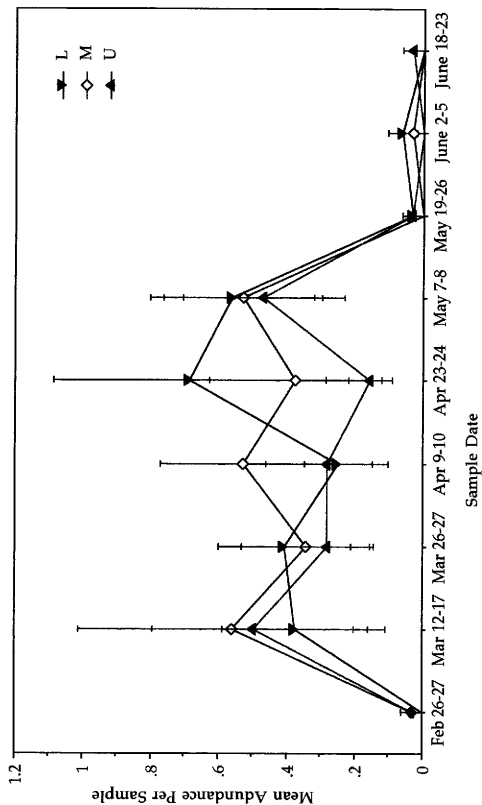
Fig. 74. Seasonal patterns by height class for *Xanthonia* sp. 2 (Coleoptera: Chrysomelidae) at Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.
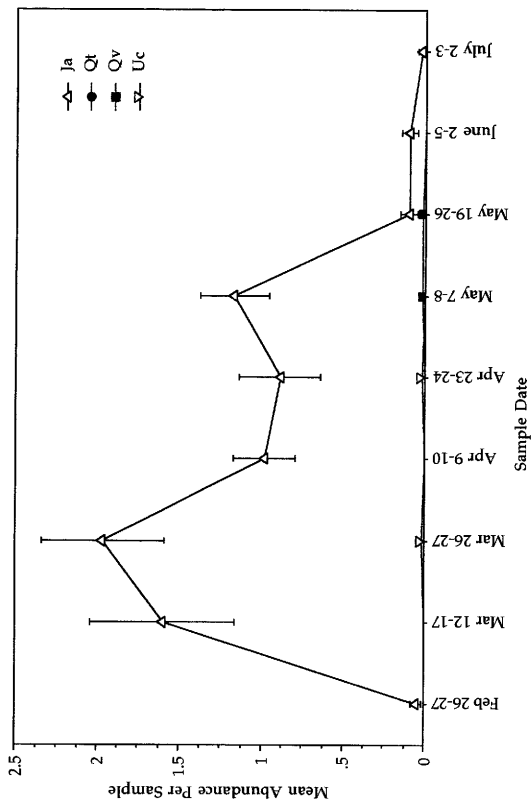
**Fig. 75.** Seasonal patterns by tree species of *Xanthonia* sp. 2 (Coleoptera: Chrysomelidae) at Long Hollow (1993-94) and Shellberg (1994). Vertical bars represent 1 SEM.

Table 25. Three-way ANOVA for Hemiptera at Long Hollow and Shellberg in 1994. Data transformed by (log(x+1) before analysis.

| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Height | 2 | .186 | .093 | 2.704 | .0674 | 5.408 | .525 |
| Tree | 3 | .897 | .299 | 8.684 | <.0001 | 26.051 | .998 |
| Date | 11 | 6.029 | .548 | 15.920 | <.0001 | 175.122 | 1.000 |
| Height * Tree | 6 | .520 | .087 | 2.517 | .0201 | 15.105 | .848 |
| Height * Date | 22 | 1.716 | .078 | 2.266 | .0008 | 49.853 | .998 |
| Tree * Date | 33 | 3.044 | .092 | 2.679 | <.0001 | 88.419 | 1.000 |
| Height * Tree * Date | 66 | 2.400 | .036 | 1.056 | .3598 | 69.711 | .996 |
| Residual | 1008 | 34.701 | .034 | | | | |
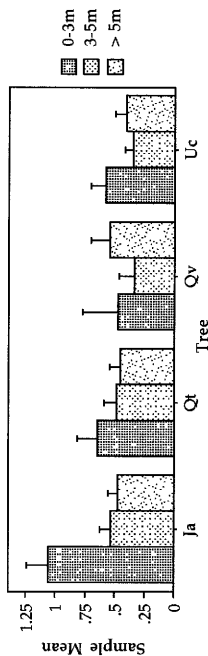


Fig. 76. Bar graph of Height by Tree for Hemiptera at Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.
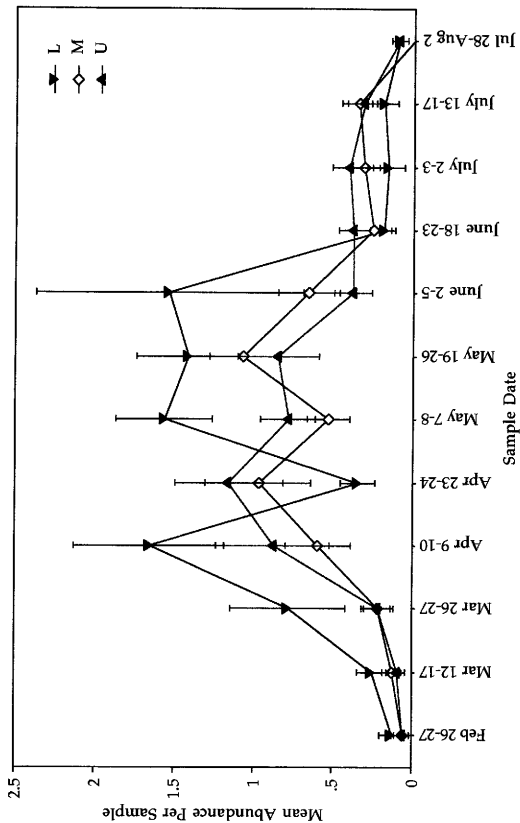
Fig. 77. Seasonal patterns by height class for Hemiptera at Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.
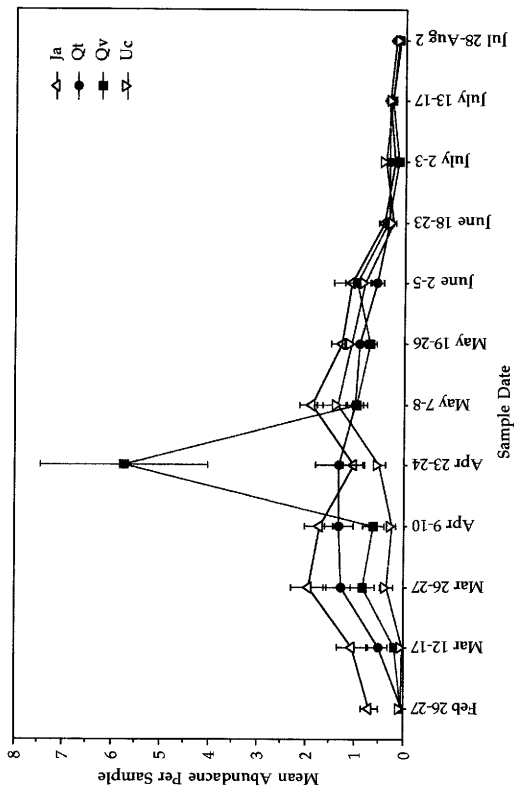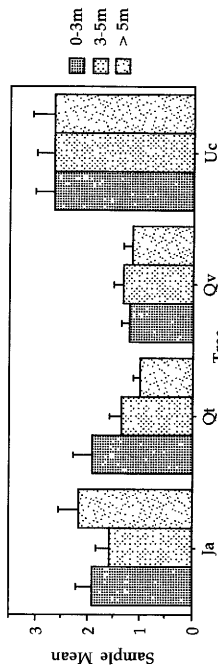
Fig. 78. Seasonal patterns by tree species of Hemiptera at Long Hollow (1993-94) and Shellberg (1994). Vertical bars represent 1 SEM.

Table 26. Three-way ANOVA for Homoptera at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.

| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Height | 2 | .103 | .051 | .752 | .4716 | 1.504 | .172 |
| Tree | 3 | 3.835 | 1.278 | 18.733 | <.0001 | 56.198 | 1.000 |
| Date | 11 | 22.246 | 2.022 | 29.638 | <.0001 | 326.013 | 1.000 |
| Height * Tree | 6 | .404 | .067 | .988 | .4322 | 5.925 | .389 |
| Height * Date | 22 | 3.668 | .167 | 2.444 | .0002 | 53.760 | .999 |
| Tree * Date | 33 | 12.936 | .392 | 5.745 | <.0001 | 189.576 | 1.000 |
| Height * Tree * Date | 66 | 4.788 | .073 | 1.063 | .3460 | 70.169 | .996 |
| Residual | 1008 | 68.781 | .068 | | | | |



Fig. 79. Bar graph of Height by Tree for Homoptera at Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.
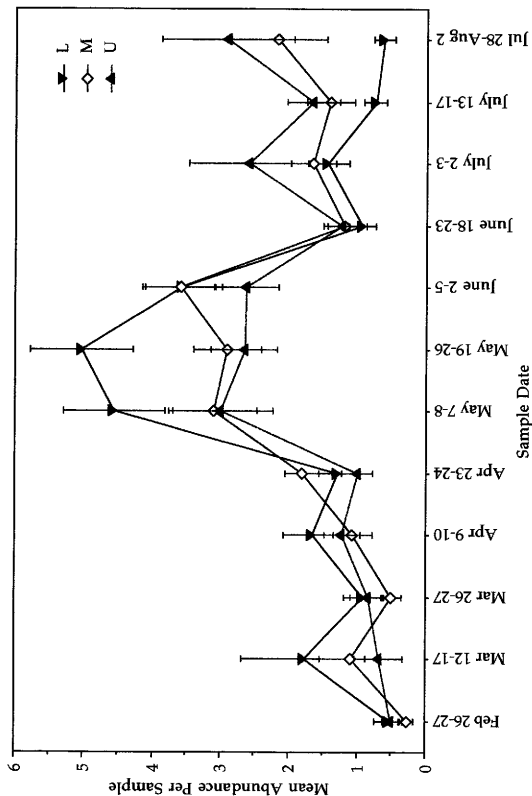
Fig. 80. Seasonal patterns by height class for Homoptera at sites Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.
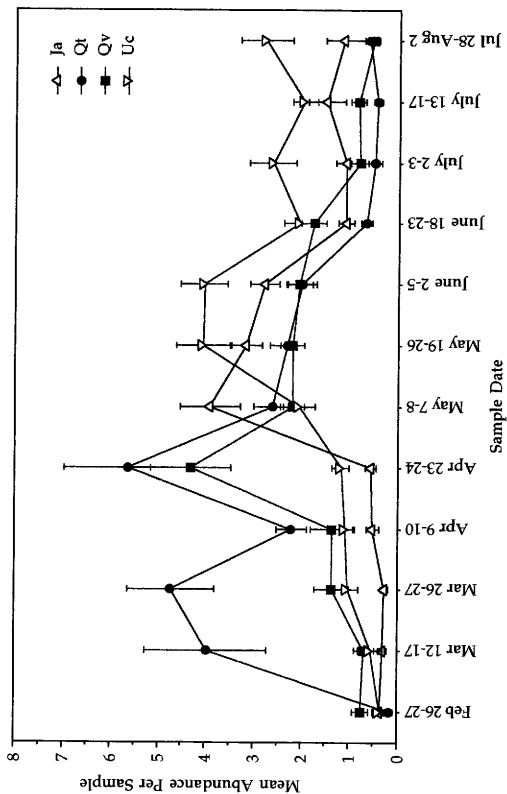
**Fig. 81.** Seasonal patterns by tree species of Homoptera at Long Hollow (1993-94) and Shellberg (1994). Vertical bars represent 1 SEM.

Table 27. Three-way ANOVA for Hymenoptera at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.

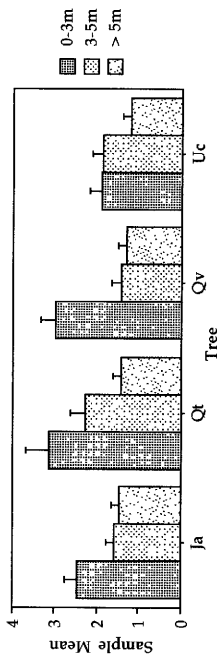| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Height | 2 | 4.662 | 2.331 | 29.629 | <.0001 | 59.258 | 1.000 |
| Tree | 3 | .539 | .180 | 2.282 | .0776 | 6.847 | .569 |
| Date | 11 | 14.818 | 1.347 | 17.122 | <.0001 | 188.346 | 1.000 |
| Height * Tree | 6 | .966 | .161 | 2.045 | .0572 | 12.273 | .746 |
| Height * Date | 22 | 2.045 | .093 | 1.181 | .2553 | 25.992 | .879 |
| Tree * Date | 33 | 5.118 | .155 | 1.971 | .0010 | 65.050 | 1.000 |
| Height * Tree * Date | 66 | 3.946 | .060 | .760 | .9213 | 50.161 | .952 |
| Residual | 1009 | 79.380 | .079 | | | | |



Fig. 82. Bar graph of Hymenoptera at Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.
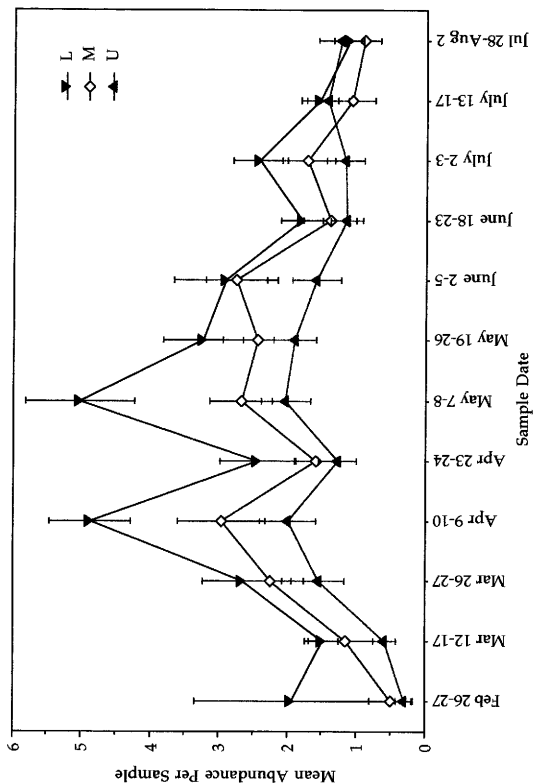
155



Fig. 83. Seasonal patterns by height class for Hymenoptera at sites Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.
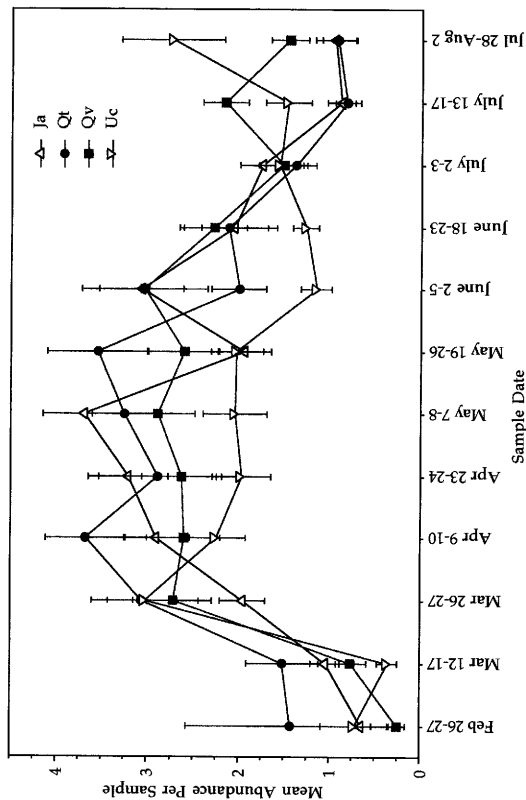
Fig. 84. Seasonal patterns by tree species of Hymenoptera at Long Hollow (1993-94) and Shellberg (1994). Vertical bars represent 1 SEM.

Table 28. Three-way ANOVA for *Solenopsis invicta* (Hymenoptera: Formicidae) at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.

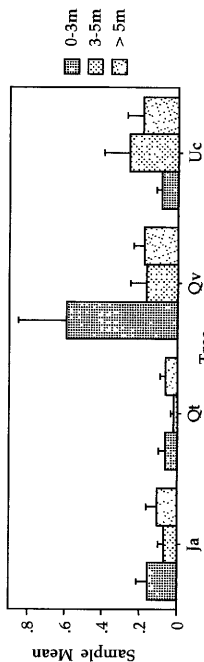| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Height | 2 | .054 | .027 | 1.811 | .1640 | 3.623 | .366 |
| Tree | 3 | .274 | .091 | 6.083 | .0004 | 18.250 | .971 |
| Date | 11 | .918 | .083 | 5.571 | <.0001 | 61.279 | 1.000 |
| Height * Tree | 6 | .160 | .027 | 1.782 | .0995 | 10.694 | .672 |
| Height * Date | 22 | .379 | .017 | 1.149 | .2874 | 25.269 | .867 |
| Tree * Date | 33 | .731 | .022 | 1.478 | .0412 | 48.778 | .992 |
| Height * Tree * Date | 66 | .880 | .013 | .890 | .7206 | 58.736 | .982 |
| Residual | 1008 | 15.107 | .015 | | | | |



**Fig. 85.** Bar graph of Height by Tree for *Solenopsis invicta* (Hymenoptera: Formicidae) at Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.
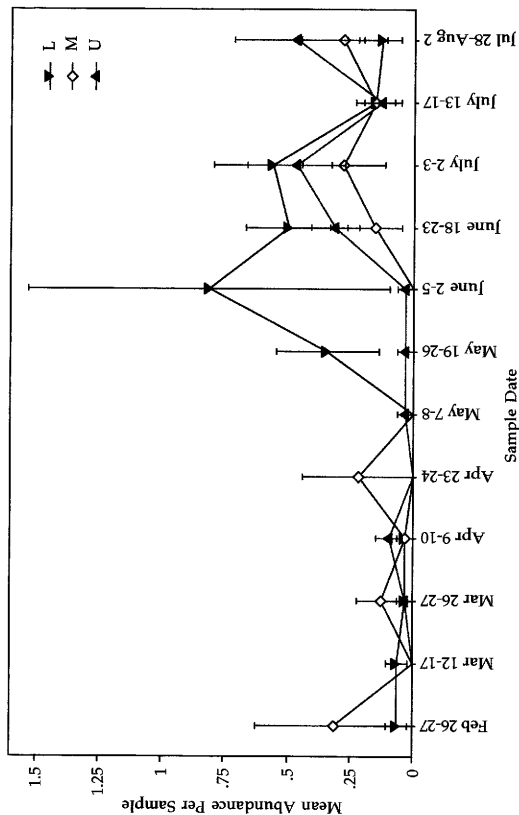
Fig. 86. Seasonal patterns by height class for *Solenopsis invicta* (Hymenoptera: Formicidae) at Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.
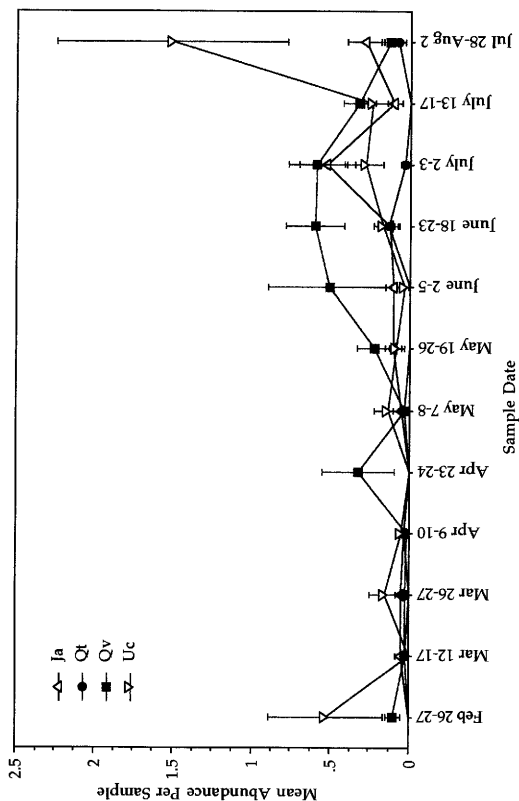
159



Fig. 87. Seasonal patterns by tree species of *Solenopsis invicta* (Hymenoptera: Formicidae) at Long Hollow (1993-94) and Shellberg (1994). Vertical bars represent 1 SEM.

Table 29. Three-way ANOVA for Lepidoptera larvae at Long Hollow and Shellberg in 1994. Data transformed by (log(x+1) before analysis.

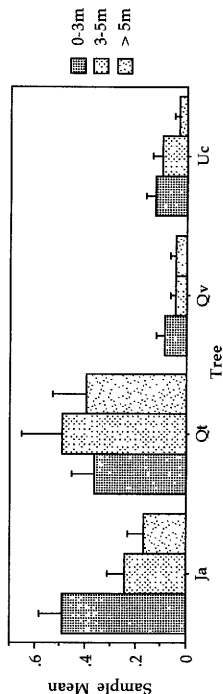| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Height | 2 | .196 | .098 | 6.089 | .0024 | 12.179 | .900 |
| Tree | 3 | .921 | .307 | 19.079 | <.0001 | 57.236 | 1.000 |
| Date | 11 | 2.580 | .235 | 14.572 | <.0001 | 160.293 | 1.000 |
| Height * Tree | 6 | .167 | .028 | 1.730 | .1108 | 10.379 | .656 |
| Height * Date | 22 | .486 | .022 | 1.374 | .1167 | 30.225 | .935 |
| Tree * Date | 33 | 2.420 | .073 | 4.557 | <.0001 | 150.365 | 1.000 |
| Height * Tree * Date | 66 | .923 | .014 | .869 | .7621 | 57.345 | .979 |
| Residual | 1008 | 16.222 | .016 | | | | |



Fig. 88. Bar graph of Height by Tree for Lepidoptera larvae at Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.
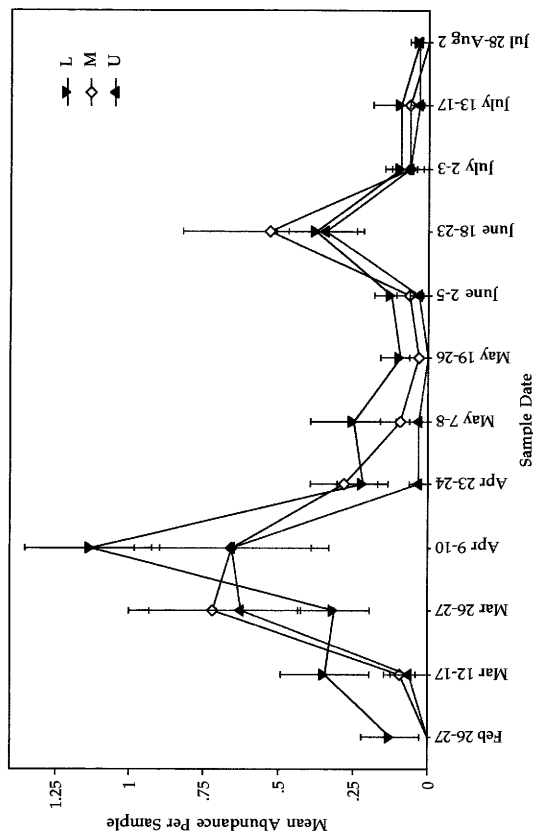
Fig. 89. Seasonal patterns by height class for Lepidoptera larvae at Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.
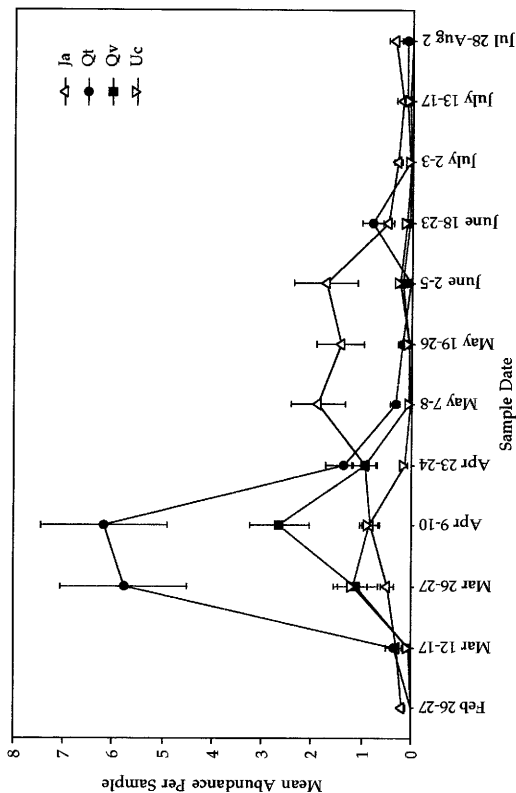
**Fig. 90.** Seasonal patterns by tree species of Lepidoptera larvae at Long Hollow (1993-94) and Shellberg (1994). Vertical bars represent 1 SEM.

**Table 30. Three-way ANOVA for Geometridae larvae (Lepidoptera) at Long Hollow and Shellberg in 1994. Data transformed by log(x+1) before analysis.**

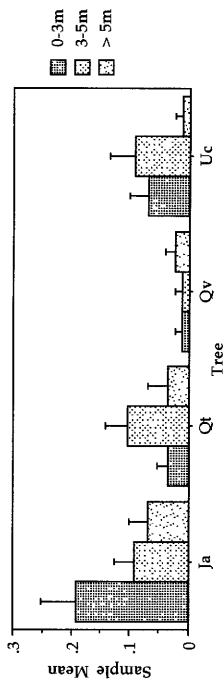|  | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Height | 2 | .030 | .015 | 2.871 | .0571 | 5.742 | .553 |
| Tree | 3 | .101 | .034 | 6.379 | .0003 | 19.136 | .978 |
| Date | 10 | .248 | .025 | 4.694 | <.0001 | 46.939 | 1.000 |
| Height * Tree | 6 | .059 | .010 | 1.869 | .0832 | 11.214 | .698 |
| Height * Date | 20 | .152 | .008 | 1.439 | .0954 | 28.788 | .930 |
| Tree * Date | 30 | .459 | .015 | 2.901 | <.0001 | 87.017 | 1.000 |
| Height * Tree * Date | 60 | .367 | .006 | 1.160 | .1948 | 69.613 | .997 |
| Residual | 924 | 4.873 | .005 |  |  |  |  |



Fig. 91. Bar graph of Height by Tree Geometridae larvae (Lepidoptera) at Long Hollow and Shellberg in 1994. Error bars represent 1 SEM.

**APPENDIX D**

`

Table 31. Three-way ANOVA of all Arthropods at Long Hollow in 1993 and 1994. Data transformed by log(x+1) before analysis.

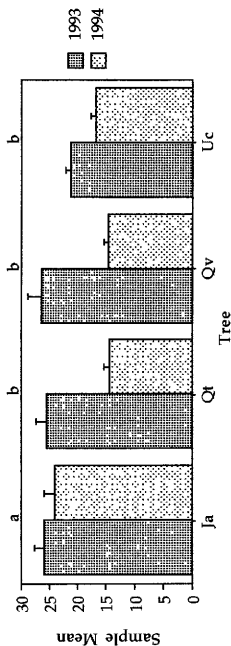| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Year | 1 | 5.455 | 5.455 | 73.160 | <.0001 | 73.160 | 1.000 |
| Tree | 3 | 1.651 | .550 | 7.379 | <.0001 | 22.136 | .991 |
| Date | 9 | 7.885 | .876 | 11.750 | <.0001 | 105.746 | 1.000 |
| Year * Tree | 3 | .732 | .244 | 3.274 | .0206 | 9.822 | .752 |
| Year * Date | 9 | 3.383 | .376 | 5.041 | <.0001 | 45.369 | 1.000 |
| Tree * Date | 27 | 10.543 | .390 | 5.237 | <.0001 | 141.394 | 1.000 |
| Year * Tree * Date | 27 | 3.765 | .139 | 1.870 | .0048 | 50.493 | .997 |
| Residual | 884 | 65.914 | .075 | | | | |



Fig. 92. Bar graph of Year by Tree for all Arthropods at Long Hollow. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.
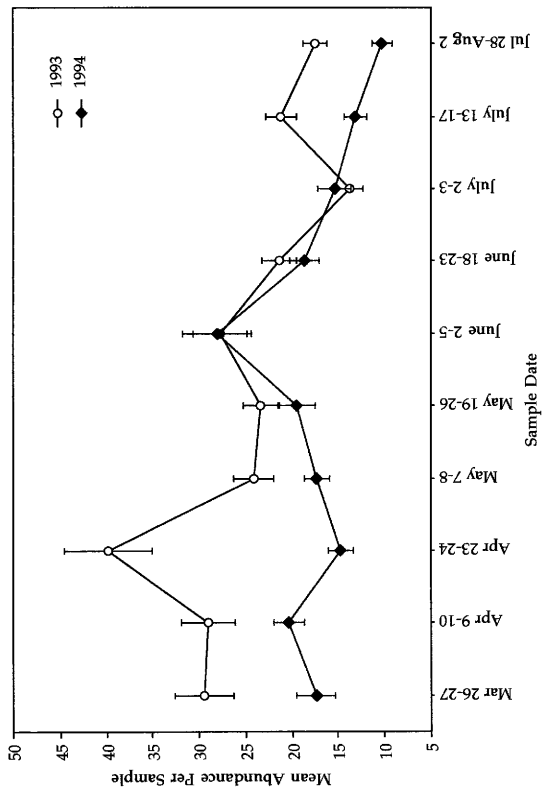
166



Fig. 93. Seasonal patterns of all Arthropods at Long Hollow by year. Error bars represent 1 SEM.

Table 32. Three-way ANOVA of Araneae at Long Hollow in 1993 and 1994. Data transformed by log(x+1) before analysis.

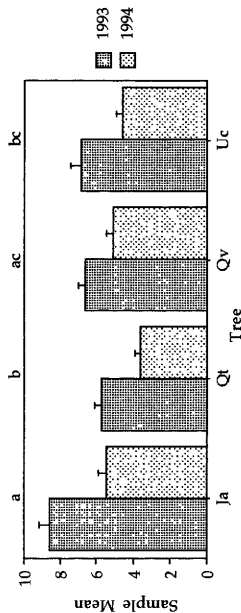| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Year | 1 | 4.821 | 4.821 | 64.635 | <.0001 | 64.635 | 1.000 |
| Tree | 3 | 2.447 | .816 | 10.936 | <.0001 | 32.809 | 1.000 |
| Date | 9 | 16.671 | 1.852 | 24.836 | <.0001 | 223.528 | 1.000 |
| Year * Tree | 3 | .467 | .156 | 2.088 | .1002 | 6.265 | .526 |
| Year * Date | 9 | 2.916 | .324 | 4.344 | <.0001 | 39.099 | .999 |
| Tree * Date | 27 | 5.842 | .216 | 2.901 | <.0001 | 78.330 | 1.000 |
| Year * Tree * Date | 27 | 3.566 | .132 | 1.771 | .0094 | 47.813 | .995 |
| Residual | 880 | 65.633 | .075 | | | | |



Fig. 94. Bar graph of Year by Tree for Araneae at Long Hollow. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.
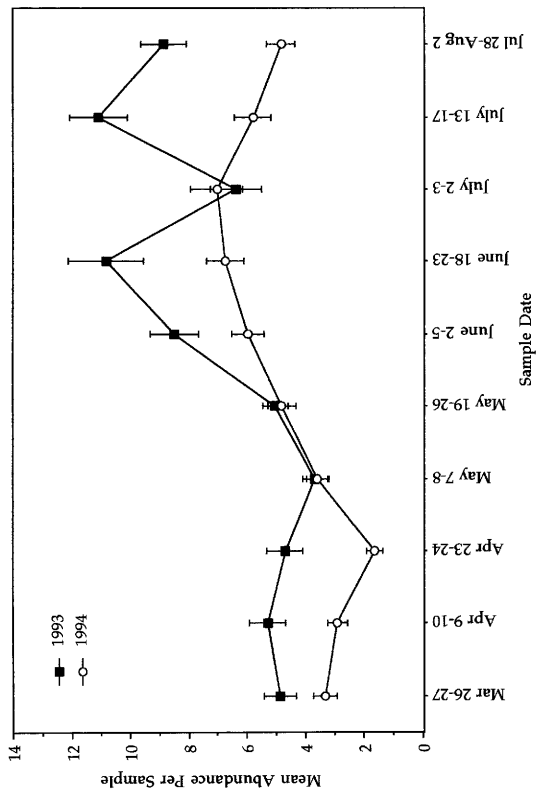
168



Fig. 95. Seasonal pattern of Araneae at Long Hollow in 1993 and 1994. Error bars represent 1 SEM.

**Table 33. Three-way ANOVA of *Hibana* spp. (Araneae: Anyphaenidae) at Long Hollow in 1993 and 1994. Data transformed by log(x+1) before analysis.**

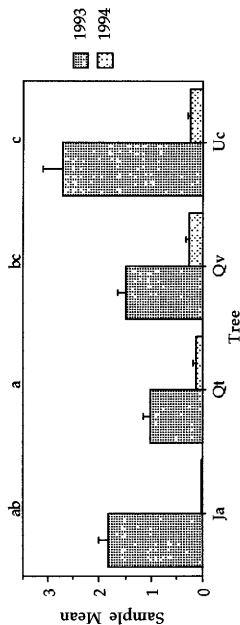|                   | DF  | Sum of Squares | Mean Square | F-Value | P-Value | Lambda  | Power |
|-------------------|-----|----------------|-------------|---------|---------|---------|-------|
| Year              | 1   | 16.448         | 16.448      | 442.702 | <.0001  | 442.702 | 1.000 |
| Tree              | 3   | 1.314          | .438        | 11.784  | <.0001  | 35.352  | 1.000 |
| Date              | 9   | 7.560          | .840        | 22.608  | <.0001  | 203.474 | 1.000 |
| Year * Tree       | 3   | 1.086          | .362        | 9.740   | <.0001  | 29.220  | .999  |
| Year * Date       | 9   | 6.804          | .756        | 20.349  | <.0001  | 183.139 | 1.000 |
| Tree * Date       | 27  | 3.346          | .124        | 3.336   | <.0001  | 90.068  | 1.000 |
| Year * Tree * Date| 27  | 2.942          | .109        | 2.933   | <.0001  | 79.192  | 1.000 |
| Residual          | 880 | 32.696         | .037        |         |         |         |       |



Fig. 96. Bar graph of Year by Tree for *Hibana* spp. at Long Hollow. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.
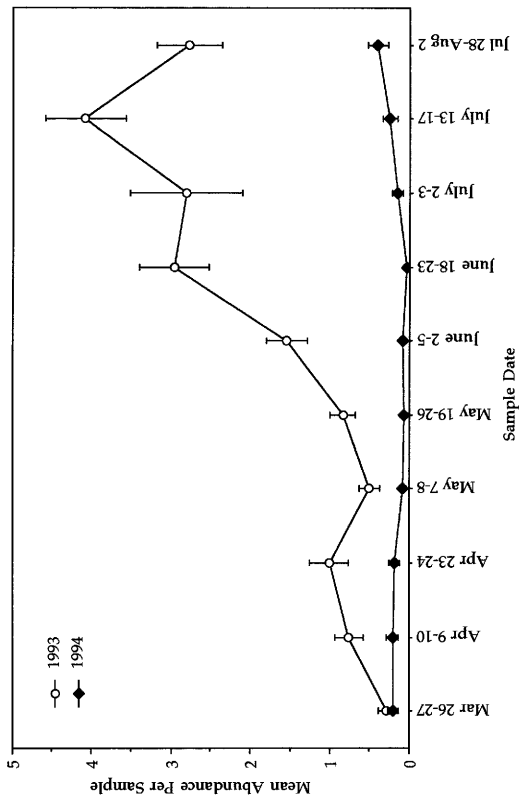
**Fig. 97.** Seasonal pattern of *Hibana* spp. (Araneae: Anyphaenidae) at Long Hollow for 1993 and 1994. Error bars represent 1 SEM.

Table 34. Three-way ANOVA for *Misumenops* spp. (Araneae: Thomisidae) at Long Hollow. Data transformed by log(x+1) before analysis.

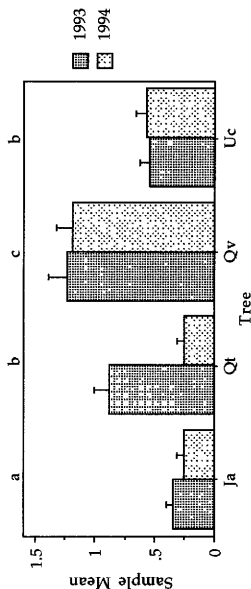| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Year | 1 | .343 | .343 | 9.542 | .0021 | 9.542 | .889 |
| Tree | 3 | 4.291 | 1.430 | 39.740 | <.0001 | 119.219 | 1.000 |
| Date | 9 | 1.846 | .205 | 5.698 | <.0001 | 51.284 | 1.000 |
| Year * Tree | 3 | .642 | .214 | 5.948 | .0005 | 17.844 | .967 |
| Year * Date | 9 | 1.555 | .173 | 4.802 | <.0001 | 43.215 | 1.000 |
| Tree * Date | 27 | 3.024 | .112 | 3.112 | <.0001 | 84.037 | 1.000 |
| Year * Tree * Date | 27 | 2.674 | .099 | 2.752 | <.0001 | 74.299 | 1.000 |
| Residual | 880 | 31.670 | .036 | | | | |



Fig. 98. Bar graph of Year by Tree for *Misumenops* spp. at Long Hollow. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.
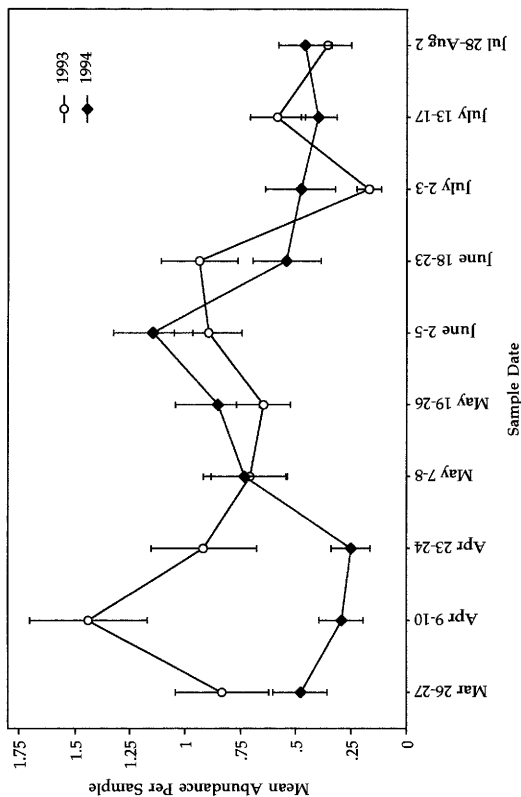
172



**Fig. 99.** Seasonal patterns of *Misumenops* spp. (Araneae: Thomisidae) at Long Hollow. Error bars represent 1 SEM.

Table 35. Three-way ANOVA of *Philodromus* spp. (Araneae: Philodromidae) at Long Hollow in 1993 and 1994. Data transformed by log(x+1) before analysis.

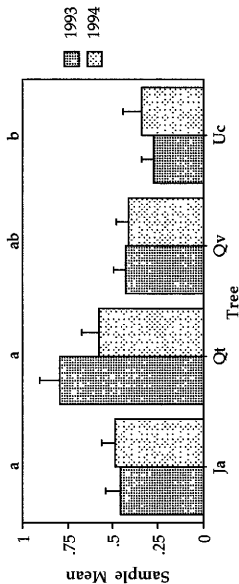| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Year | 1 | .013 | .013 | .386 | .5347 | .386 | .093 |
| Tree | 3 | .872 | .291 | 8.564 | <.0001 | 25.691 | .997 |
| Date | 9 | 1.816 | .202 | 5.947 | <.0001 | 53.526 | 1.000 |
| Year * Tree | 3 | .134 | .045 | 1.316 | .2677 | 3.949 | .343 |
| Year * Date | 9 | .170 | .019 | .556 | .8332 | 5.007 | .276 |
| Tree * Date | 27 | 1.358 | .050 | 1.482 | .0547 | 40.027 | .979 |
| Year * Tree * Date | 27 | .772 | .029 | .842 | .6972 | 22.743 | .768 |
| Residual | 880 | 29.861 | .034 | | | | |



Fig. 100. Bar graph of Year by Tree for *Philodromus* spp. at Long Hollow. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.

Table 36. Three-way ANOVA of Coleoptera at Long Hollow in 1993 and 1994. Data transformed by log(x+1) before analysis.

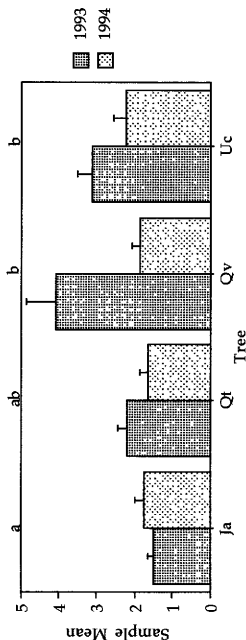| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Year | 1 | 1.067 | 1.067 | 15.819 | <.0001 | 15.819 | .989 |
| Tree | 3 | 1.176 | .392 | 5.812 | .0006 | 17.437 | .963 |
| Date | 9 | 36.842 | 4.094 | 60.694 | <.0001 | 546.243 | 1.000 |
| Year * Tree | 3 | .243 | .081 | 1.199 | .3089 | 3.598 | .314 |
| Year * Date | 9 | 1.861 | .207 | 3.066 | .0013 | 27.590 | .981 |
| Tree * Date | 27 | 6.589 | .244 | 3.618 | <.0001 | 97.691 | 1.000 |
| Year * Tree * Date | 27 | 3.176 | .118 | 1.744 | .0112 | 47.094 | .994 |
| Residual | 880 | 59.352 | .067 | | | | |



Fig. 101. Bar graph of Year by Tree for Coleoptera at Long Hollow. Tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.
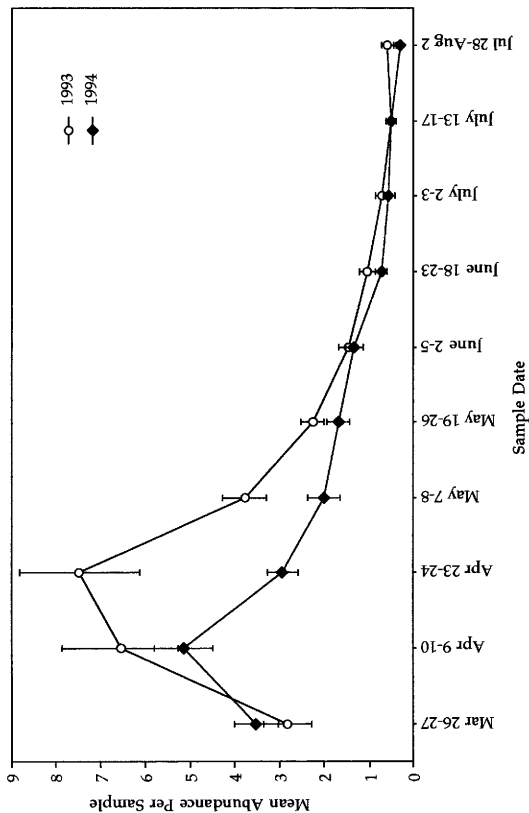
Fig. 102. Seasonal patterns of Coleoptera at Long Hollow in 1993 and 1994. Error bars represent 1 SEM.

Table 37. Three-way ANOVA for Hemiptera at Long Hollow in 1993 and 1994. Data transformed by log(x+1) before analysis.

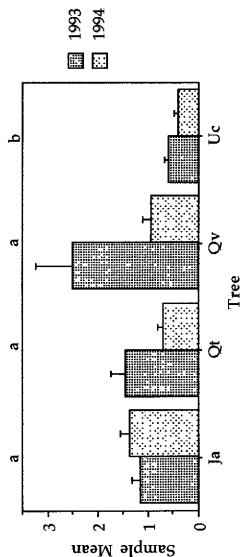| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Year | 1 | .679 | .679 | 11.890 | .0006 | 11.890 | .950 |
| Tree | 3 | 2.280 | .760 | 13.316 | <.0001 | 39.948 | 1.000 |
| Date | 9 | 7.496 | .833 | 14.591 | <.0001 | 131.316 | 1.000 |
| Year * Tree | 3 | .638 | .213 | 3.724 | .0112 | 11.173 | .815 |
| Year * Date | 9 | 1.804 | .200 | 3.512 | .0003 | 31.612 | .993 |
| Tree * Date | 27 | 6.257 | .232 | 4.060 | <.0001 | 109.624 | 1.000 |
| Year * Tree * Date | 27 | 3.397 | .126 | 2.204 | .0004 | 59.508 | 1.000 |
| Residual | 880 | 50.231 | .057 | | | | |



Fig. 103. Bar graph of Year by Tree for Hemiptera at Long Hollow. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.
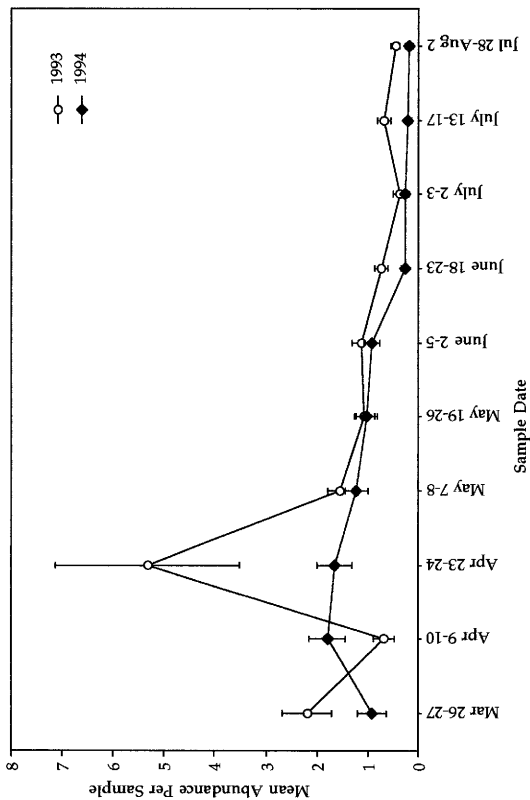
Fig. 104. Seasonal patterns of Hemiptera by year at Long Hollow. Error bars represent 1 SEM.

Table 38. Three-way ANOVA for Homoptera at Long Hollow in 1993 and 1994. Data transformed by log(x+1) before analysis.

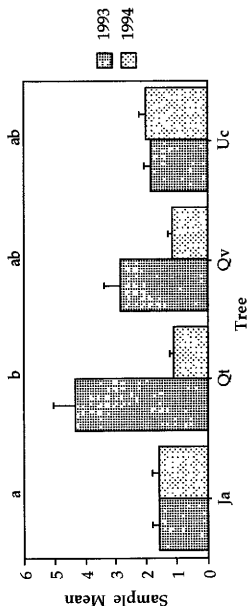| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Year | 1 | 1.812 | 1.812 | 22.841 | <.0001 | 22.841 | 1.000 |
| Tree | 3 | 1.090 | .363 | 4.583 | .0034 | 13.749 | .899 |
| Date | 9 | 8.280 | .920 | 11.600 | <.0001 | 104.404 | 1.000 |
| Year * Tree | 3 | 2.721 | .907 | 11.434 | <.0001 | 34.302 | 1.000 |
| Year * Date | 9 | 5.438 | .604 | 7.618 | <.0001 | 68.563 | 1.000 |
| Tree * Date | 27 | 14.934 | .553 | 6.974 | <.0001 | 188.292 | 1.000 |
| Year * Tree * Date | 27 | 6.207 | .230 | 2.899 | <.0001 | 78.260 | 1.000 |
| Residual | 880 | 69.794 | .079 | | | | |



Fig. 105. Bar graph of Year by Tree for Homoptera at Long Hollow. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.
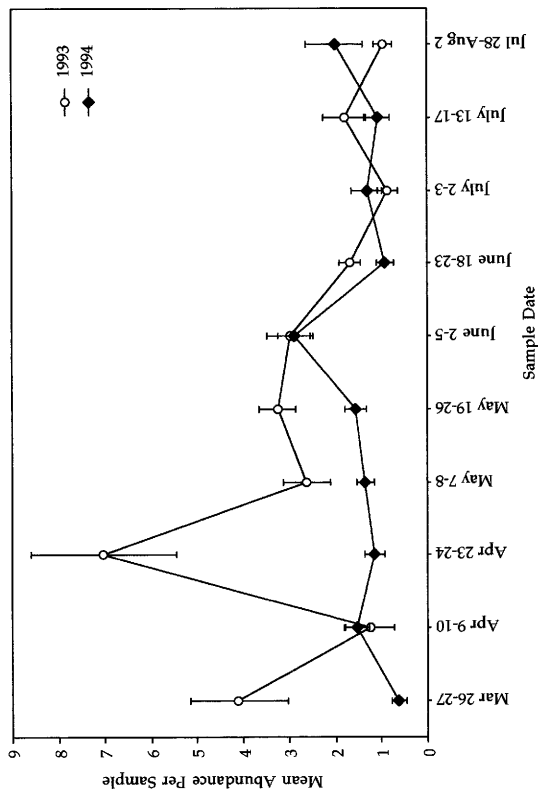
Fig. 106. Seasonal patterns by year of Homoptera at Long Hollow. Error bars represent 1 SEM.

Table 39. Three-way ANOVA for Lepidoptera larvae at Long Hollow in 1993 and 1994. Data transformed by log(x+1) before analysis.

| | DF | Sum of Squares | Mean Square | F-Value | P-Value | Lambda | Power |
|---|---|---|---|---|---|---|---|
| Year | 1 | 10.544 | 10.544 | 294.582 | <.0001 | 294.582 | 1.000 |
| Tree | 3 | 4.281 | 1.427 | 39.868 | <.0001 | 119.603 | 1.000 |
| Date | 9 | 19.941 | 2.216 | 61.901 | <.0001 | 557.111 | 1.000 |
| Year * Tree | 3 | 1.149 | .383 | 10.702 | <.0001 | 32.105 | 1.000 |
| Year * Date | 9 | 8.823 | .980 | 27.387 | <.0001 | 246.487 | 1.000 |
| Tree * Date | 27 | 15.546 | .576 | 16.086 | <.0001 | 434.324 | 1.000 |
| Year * Tree * Date | 27 | 11.765 | .436 | 12.174 | <.0001 | 328.685 | 1.000 |
| Residual | 880 | 31.498 | .036 | | | | |
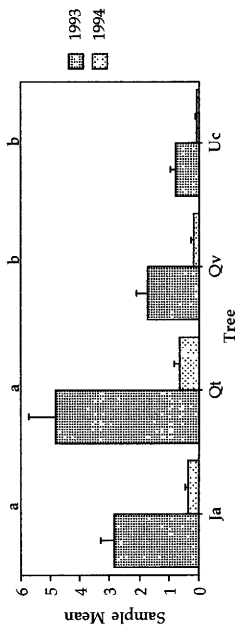


Fig. 107. Bar graph of Year by Tree for Lepidoptera larvae at Long Hollow. Combined tree means with same lowercase letter above fig. are not significantly different. Error bars represent 1 SEM.
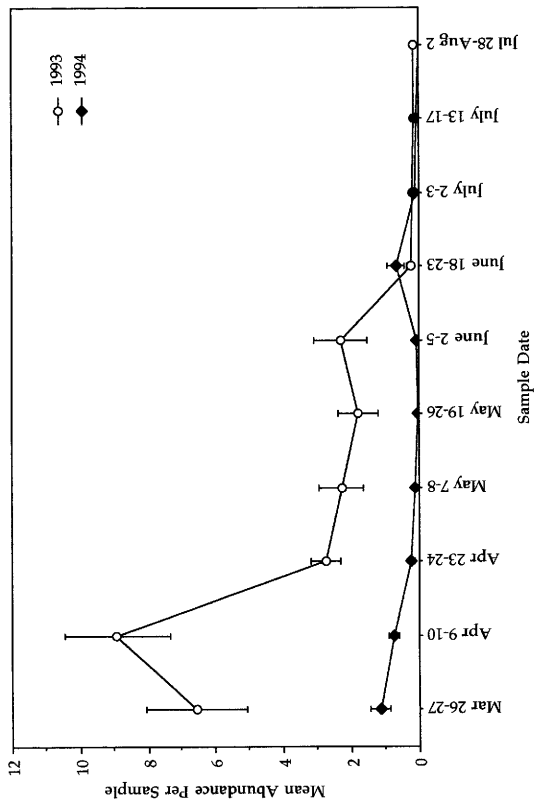
Fig. 108. Seasonal patterns by year of Lepidoptera larvae at Long Hollow. Error bars represent 1 SEM.

# VITA

Michael Andrew Quinn was born in Shreveport, Louisiana on December 6, 1962, the son of Allan S. and Mary Helen Quinn. With his parents' encouragement, he developed an interest in natural history at an early age.

Mike finished high school at Kirby Hall School in Austin, Texas in 1980. He graduated from Texas A&M University, in College Station with a B.S. in Wildlife and Fisheries Sciences, Science Option in May, 1993.

Mike is committed to conservation and public outreach. He worked on several bird studies including the Kirtland's Warbler in Michigan and the Black-capped Vireo in Texas and Oklahoma.

Mike can be contacted c/o 7739 Kiva Drive, Austin, Texas 78749-2919, USA.