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Phenology and Diversity of Arthropod Communities in Leaf Litter.

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Entomology

by

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University of Mary Washington
Bachelor of Science in Biology, 2008

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This thesis is approved for recommendation to the Graduate Council.

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ABSTRACT

Temperate deciduous forests produce a layer of leaf litter on the forest floor annually. This layer is dynamic, and both the composition and depth change throughout the year. The leaf litter layer is an important habitat to many arthropods since they utilize it for food, shelter from adverse environmental conditions, and protection from predators.

Two commonly encountered and diverse taxa found in the litter layer are the ground beetles (Coleoptera: Carabidae) and the ground spiders (Araneae: Gnaphosidae). Carabidae and Gnaphosidae were collected and identified on a monthly basis from April 2014 to March 2015 from the Ozark Mountains of Arkansas to measure temporal fluctuations of species diversity and abundance. A total of 480 Berlese samples and 208 pitfall trap samples were collected and processed from four sites across Northwest Arkansas including: Lake Wedington, Lake Wilson, and Withrow Springs 1&2. From those samples, 645 carabid individuals of 47 species were collected and 421 gnaphosid individuals of 15 species were collected.

Berlese samples from all four sites yielded a total of 194 carabid individuals of 29 species and 160 gnaphosid individuals of 10 species, whereas pitfall traps from two sites yielded 451 carabid individuals of 30 species and 261 gnaphosid individuals of 14 species. Statistical analyses detected no significant differences in number of individuals and species diversity of carabids and gnaphosids among sites, whereas species richness did differ among sites for carabids. Similarly, leaf litter depth had no significant effect on the number of individuals collected, species richness (with exception to Withrow 1), or species diversity of carabids and gnaphosids. Carabids were the most abundant and diverse during the spring and were the least abundant and diverse during the winter. Gnaphosids were the most abundant and diverse during the spring and were the least abundant in the fall and the least diverse in the winter.

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DEDICATION

To my grandmother, Marjorie Hamilton, who spent endless hours outside with me teaching me about plants and insects when I was a little girl.

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INTRODUCTION

The Interior Highlands of Northwest Arkansas are dominated by oak-hickory forests (Chapman et al. 2006). Oak-hickory is a type of temperate deciduous forest that drops leaves annually, which leads to a layer of leaf litter on the forest floor. Leaf litter depth and composition change throughout the year, with periodic addition of leaves coupled with leaves that are in various stages of decay (Fittkau and Klinge 1973). The leaf litter layer forms a habitat that is important to a variety of animal species, by providing food, shelter from adverse environmental conditions, and protection from predatory species.

Among organisms inhabiting the leaf litter layer of temperate deciduous forests, terrestrial arthropods are a dominant and diverse group. The ground beetles (Coleoptera: Carabidae) and the ground spiders (Araneae: Gnaphosidae) are two diverse taxa commonly encountered within the litter layer. Their phenology and diversity in the Ozark Mountains of Arkansas is unknown and thus is important to study.

This thesis is divided into two chapters: the first chapter broadly covers arthropod seasonality, physiological mechanisms, abiotic and biotic factors, leaf litter as a habitat, previous studies conducted on arthropod seasonality in leaf litter, and the biology and ecology of the taxa of focus – Carabidae and Gnaphosidae. The second chapter details a study that examined the phenology and diversity of Carabidae and Gnaphosidae in leaf litter over 12 months.

LITERATURE REVIEW

SEASONALITY

Seasonality or temporal variation impacts the diversity and abundance of arthropods present in a given area throughout the year, whether in the leaf litter or up in the canopy (Pineiro et al. 2002). It is a phenomenon that refers to periodic changes in the environment and the biological responses of organisms to those changes (Powell and Logan 2005). An organism's phenology is used to describe the seasonal progression of different biological stages or events (Powell and Logan 2005). Life history stages and events must occur at appropriate times to avoid being exposed to lethal temperatures or other harsh environmental conditions, to avoid predation by not having all individuals emerge at once, and to have appropriate timing of reproductive cycles (Powell and Logan 2005).

The beginning date, the mean date, the median date, and the duration of their presence are factors that are important in describing seasonality patterns of arthropods (Derron and Roth 1986, Scott and Epstein 1986, Brakefield 1987). A common distribution pattern found with arthropods is that over their seasonal appearance, there will be a peak near the center with lower numbers present at the beginning and end dates (Wolda 1988). Furthermore, one year of data is not sufficient enough to conclude that a peak present is seasonal, but can be used to describe their abundance and activity over the course of a year (Wolda 1988).

Seasonal patterns of arthropods are not the same throughout the world and vary between arthropods in temperate and tropical zones. A common trend observed is that with decreasing latitude insect activity starts earlier and lasts longer, whereas with increasing latitude insect activity is shorter lived and starts later (Wolda 1978, 1980, 1985; McElravy et al. 1987). In temperate areas that experience four seasons (i.e., spring, summer, fall and winter), there is a

seasonal progression of the appearance of different species (Scott and Epstein 1987). Varying temperatures and daylight hours are the driving forces behind seasonality in these areas and many insects become active during the spring and summer and enter an inactive state during the late fall and winter (Wolda 1988).

Species that are incapable of surviving colder environments in more northern latitudes may migrate south during the winter (Wolda 1988). For example, the Monarch butterfly makes an annual migration each year from Canada and the United States to Mexico where it overwinters. Other seasonal migrations of insects occur when they move between different habitats or overwintering sites to survive the winter (Oliver 1943, Fields and McMullen 1972, Shapiro 1974, Vepsalainen 1974).

In tropical areas, the variation in day length is greatly reduced. Similarly, temperature variation throughout the year is reduced and more pronounced temperature differences tend to occur over a 24-hour period (Denlinger 1986). Temperatures during the day and night are believed to be better indicators of seasonal patterns of insects in the tropics than the average monthly temperature (Denlinger 1986). Compared to temperate areas, the insect activity of tropical species tends to be longer, the overall number of species active during the year higher, and seasonal peaks are less well defined (Wolda 1988).

The driving forces behind insect seasonality in tropical areas is not caused by variation in day length or significant temperature changes, but rather by the fluctuating amount of moisture and food resources present in the environment (Denlinger 1986, Wolda 1988). Tropical areas generally experience two seasons, the rainy and dry with the rainy season typically alternating between one or two dry seasons annually. The rainy season brings an increase in plant growth, distribution of additional organic matter to the soil, increased tree fall, puddles created

throughout the habitat, and enhanced fungal growth and dispersal (Denlinger 1986). The dry season in tropical environments is also beneficial to many arthropods since this is when many tropical plants flower and bear fruit, which provides food resources to pollinators, frugivores, and seed predators (Denlinger 1986).

Due to the ever changing conditions in temperate and tropical areas, arthropods time their growth, development, and reproduction to occur when physical and biological conditions in the environment are most suitable to support them (Wolda 1988). When conditions become unfavorable to the organism, such as the weather turning cold or hot, a specific life history stage is used for overwintering or aestivation in order to enhance its survival (Tauber and Tauber 1976).

PHYSIOLOGICAL MECHANISMS

Because all regions of the world experience some degree of seasonal variation that affects growth, development, and reproduction, arthropods employ an array of physiological mechanisms to enable them to survive unfavorable conditions (Tauber and Tauber 1976).

Arthropods are poikilotherms, which means their internal temperature varies with environmental temperature (Block 1990). As a result, they have specific adaptations and strategies to prolong their survival in extreme cold and heat (Block 1990).

Arthropod adaptations to low temperatures involve specific morphological, behavioral, and physiological features (Somme 1989). Morphological adaptations include a smaller body, darker pigmentation, increased pubescence, wing reduction (brachyptery), or wing loss (aptery) (Block 1990). Behavioral adaptations consist of habitat selection, thermoregulation, and activity patterns to avoid harsh environmental conditions (Block 1990). Physiological adaptations

involve extension of the life cycle, univoltinism (one generation per year), increased metabolic rate, resistance to desiccation, and cold tolerance (Block 1990).

With the onset of winter and cooling temperatures, many arthropods go through a period of dormancy also known as diapause that enhances their survival and is characterized by specific morphological, behavioral, and physiological features (Tauber and Tauber 1976). Diapause involves developmental arrest, reduced oxygen consumption rates, and increased stress tolerance (Denlinger 1991, Denlinger et al. 2005). As temperature decreases, the temperature threshold for diapause development increases and diapause is actively maintained (Tauber and Tauber 1976).

Photoperiod and temperature are the two main factors that influence the start of diapause, its maintenance, and its termination (Tauber and Tauber 1976). As the seasons progress, there is a decrease in diapause depth, intensity, and the organisms response to diapause maintaining factors (Tauber and Tauber 1976). The rate of diapause development and its length varies within and between species and generally ends by mid-winter in temperate areas (Tauber and Tauber 1976).

When arthropods are exposed to below zero temperatures, they are at an increased risk of developing tissue damage and can suffer from two types of injury - chilling and freezing (Storey and Storey 1988). Chilling injury involves a negative effect on the physiological processes and one of the first symptoms is the inability to regulate ion balance, which impairs neuromuscular function and may lead to a chill coma (MacMillian and Sinclair 2011, Armstrong et al. 2012, MacMillian et al. 2012). With more extreme temperatures, arthropods can succumb to direct chilling, also referred to as cold shock injury, with membrane damage occurring as a result of the phase change from a liquid crystalline to a gel (Steponkus 1984, Lee 2010). Freezing injury is physical damage caused by ice crystal formation that can lead to fracturing of cell membranes

(Storey and Storey 1988, Tursman and Duman 1995). In order to prevent these types of injury, some arthropods may have freeze-avoidance or freeze-tolerance strategies (Block 1990).

Freeze-avoidance, also known as freeze-intolerance, is the most common strategy used by arthropods to prevent injury from subzero temperatures (Cannon and Block 1988, Block 1990). Cryoprotectants are produced that allow the arthropod to supercool and maintain body fluids in the liquid phase below their normal freezing point while also stabilizing membranes and proteins to prevent osmotic damage to cells (Block 1990, Yancey 2005, Klowden 2013).

Coleoptera and Lepidoptera that are freeze-avoiding species also produce antifreeze proteins (AFPs) that can lower the freezing point of water and inhibit ice formation in the gut and hemolymph (Klowden 2013).

Freeze-tolerance is a less common strategy utilized by arthropods to survive the extreme cold and is limited to higher insect orders such as Coleoptera, Diptera, Hymenoptera, and Lepidoptera (Block 1990, Sinclair et al. 2003). Ice-nucleating proteins are synthesized and raise the supercooling point of body fluids and promote the nucleation of ice in extracellular areas, so no damage will occur in intracellular areas (Block 1990, Klowden 2013). Carbohydrate cryoprotectants such as glycerol, sorbitol, and trehalose are also synthesized in freeze-tolerant insects for added protection (Klowden 2013).

In order to improve cold tolerance, insects are able to enhance it on a short-time scale known as rapid cold-hardening (RCH) and can occur from within minutes to hours at or around 0°C (Teets and Denlinger 2013). This mechanism allows both freeze-avoiding and freeze-tolerant species to survive sudden cold snaps and the falling temperatures from the day into the evening (Teets and Denlinger 2013). Therefore, it allows the survival of insects with unexpected temperature drops when they are not in a cold-hardy state (Teets and Denlinger 2013).

Compared to the variety of physiological mechanisms utilized by arthropods to deal with the cold, there are significantly fewer strategies to deal with heat stress. Heat shock causes denaturation or unfolding of proteins and enzymes, which leads to their accumulation in the body and a number of consequences such as increased permeability of membranes and ion leakage, which may then lead to desiccation (Korsloot et al. 2004). The accumulation of denatured proteins also triggers the synthesis of heat shock proteins (hsps) (Lindquist 1986). Heat shock proteins are the primary method arthropods cope with heat and there are several different families of heat shock proteins that are classified based on molecular weight; these include HSP110, HSP90, and HSP70 (Lindquist and Craig 1988, Klowden 2013). The proteins bind to unstable peptides in order to prevent improper interactions that alter their activity and help to repair protein damage (Klowden 2013). Their induction is rapid and the response is activated at different temperatures in different organisms (Lindquist and Craig 1988).

The physiological mechanisms employed by arthropods play a key role in their survival in temperate areas where freezing temperatures are experienced during the fall and winter months and when high temperatures are reached during the spring and summer months. In addition to physiological mechanisms, a number of abiotic and biotic factors also influence an organism's presence or absence throughout the year.

ABIOTIC AND BIOTIC FACTORS

Multiple abiotic and biotic factors influence the abundance, distribution, and diversity of arthropods found in the environment (Fried 1990, Burghouts 1992, Clouse 1999). Temperature is considered to be a major abiotic factor that affects arthropod seasonality, modifies species interactions, and influences what food sources are available (Wolda 1988, Cerda et al. 1997,

Morelissen and Harley 2007, O'Conner 2009). Temperature may also act as a physiological limit on the elevational distribution of taxa (Addo-Bediako et al. 2000 and Clarke and Gaston 2006). Many seasonal patterns have been modeled on the basis of temperature by determining the temperature threshold at which there is no insect activity occurring and the number of degrees-days (physiological time) above that threshold that are required for insect activity to commence (Brakefield 1987, Casagrande et al. 1987, Wolda 1988). In temperate areas, temperature is one of the environmental cues responsible for signaling to the organism that it is time to enter into diapause when it becomes cold or resume activities such as foraging, oviposition, and reproduction when temperatures begin warming (Wolda 1988).

Litter or soil moisture content is another abiotic factor that is important in the community organization of arthropods and the formation of uneven distributions (Usher 1970, 1975). In the tropics, litter moisture content has been found to be more variable during the dry season compared to the rainy season and may cause scattered distributions of arthropods (Levings and Windsor 1982). Areas where moisture is present in the leaf litter are considered refuges for desiccation-intolerant species and allow for continued reproduction and foraging activity (Levings and Windsor 1984).

Arthropods tend to decrease in abundance during the dry season, which may result from stress caused by food shortages and conditions being unsuitable for development due to lack of moisture in the organism's microenvironment (Denlinger 1980, Wolda 1988, Braithewaite 1991). Litter moisture content is positively associated with a number of taxa including: Hymenoptera, Coleoptera, Collembola, Hemiptera, Isopoda, and Diplopoda; conversely, litter moisture content has been found to be negatively associated with species of Psocodea, Gryllidae, Hemiptera, Araneae, and Opiliones (Levings and Windsor 1984).

Biotic factors are also important in determining the distribution and community structure of arthropods. The species composition of plants present in an area greatly influences what arthropod species inhabit a particular area for a number of reasons (Elfaki et al. 2013). Different arthropods favor different types of plant material; for example, some favor plants that contain higher nitrogen levels (Elfaki et al. 2013). If a change occurs in the environment that results in a shift of the dominant plant species, it will lead to a change in the composition of the leaf litter and the arthropod composition in that habitat (Anderson 1975, Olson 1994, Koivula et al. 1999).

Some arthropod species may also preferentially colonize litter with a specific physical structure (Hansen 1999). Bultman and Uetz (1982) found that the structural complexity of leaf litter greatly affected the abundance of spiders found on the forest floor and that the number of web-building spiders was lower in flat leaves compared to curly leaves. However, structural complexity was found to have minimal impact on spider species diversity and richness. Additionally, the three dimensional structure of deciduous litter provides multiple pathways that give spiders a better opportunity to avoid predators and competitors (Uetz 1979, Bultman and Uetz 1982).

In addition to the composition and physical structure of leaves, the depth of leaf litter is important in influencing the diversity and abundance of spiders and other arthropods (Uetz 1979, Bultman and Uetz 1982, 1984; Koivula et al. 1999). Bultman and Uetz (1982) found that litter depth was more influential in species composition and abundance in spiders than nutritional content or physical structure of leaves. Litter-dwelling spiders respond to vertical variation in litter structure and species richness often increases as litter depth increases (Anderson 1975, 1978; Bultman and Uetz 1982).

The variation in litter depth also influences litter moisture, temperature, complexity, and prey abundance (Bultman and Uetz 1982). According to Wardle (2006), forests that have a thicker layer of leaf litter and a higher diversity of plant species may have a greater diversity of arthropods. The leaf litter layer provides shelter against desiccation and adverse environmental conditions, which may explain the increased numbers of arthropods found in deeper leaf litter (Magura et al. 2005). On the other hand, a study done by Elfaki et al. (2013) in Tanzania found that litter depth did not have a significant influence on arthropod abundance.

Litter productivity is another factor that is influential in shaping the arthropod communities on the forest floor (McBrayer et al. 1977, Blair et al. 1994). Mature forests with a closed canopy are likely to support a more abundant and diverse fauna compared to forests in an early successional stage (McBrayer et al. 1977, Blair et al. 1994). However, natural canopy gaps formed through disturbance (e.g., tree fall), affect the distribution of arthropods through increased light, a warmer microclimate, decreased litter depth, and increased woody debris (Greenburg and Forrest 2003). Additional coarse woody debris present in the leaf litter attracts a higher density of arthropods because it provides them with shelter from predators and environmental conditions (Greenburg and Forrest 2003).

Prey and interspecific competition are also biotic factors that influence arthropod distribution and abundance within leaf litter (Niemela et al. 1996, Guillemain et al. 1997, Chen and Wise 1999). The abundance of prey items in a habitat is known to positively influence Carabidae (ground beetle) abundance leading to large aggregations of carabids in prey rich areas (Bryan and Wratten 1984, Loreau 1988, Niemela et al. 1996, Guillemain et al. 1997, Chen and Wise 1999).

LEAF LITTER

Leaf litter is composed of vegetative debris at various stages of decay and is an important habitat to many ground-dwelling arthropods since they utilize it for food and shelter (Fittkau and Klinge 1973). The composition and depth of leaf litter varies throughout the year, which affects the availability of nutrient resources to organisms belonging to a variety of feeding guilds (Fittkau and Klinge 1973, Boyce 2005, Hattenschwiler et al. 2005). Additionally, litter on the forest floor helps to regulate many functional processes in the ecosystem by acting to insulate the soil surface from temperature extremes, protecting the soil from erosion and raindrop impact, and increasing water infiltration rates (Gallardo et al. 1998).

Leaf litter is composed of three regions: the surface leaf litter layer, raw-humus layer, and humus layer (Kubiena 1953, Anderson 1975). The surface layer is characterized by leaves showing little or no sign of feeding, few species, and an unstable microclimate (Anderson 1975). The middle layer, the raw humus, is considered more structurally complex because it is beginning to break down; it is composed of fragmented leaves that show signs of feeding, supports a higher diversity of organisms, and offers a more stable microclimate (Anderson 1975). The bottom most layer, the humus, is at the highest stage of decomposition of all the litter layers and is characterized by homogenous plant material, little species diversity, and a very stable microclimate (Anderson 1975). Fewer species are found in the humus layer because the organic matter is compact and contains plant materials that cannot be broken down easily by decomposition (Anderson 1975).

Decomposition of leaf litter is controlled by many factors, the three most important being the physicochemical environment, litter quality, and the composition of the decomposer community (Berg et al. 1993, Couteaux et al. 1995, Cadish and Giller 1997). Temperature is an

important factor in determining the rate of litter decomposition in both temperate and tropical forests (Meentemeyer 1978, Anderson 1991, Hobbie 1996, Bothwell et al. 2014). As temperature increases, the decomposition rate of leaf litter has been found to increase (Mikola 1960). Moisture content of the soil and litter is also an important factor in governing the rate of decomposition since it can affect microbial activity and the movement and feeding of microarthropods such as mites and springtails (Mikola 1954, Hayes 1965, Witkamp 1966, Metz 1971, Usher 1970, 1971).

Litter quality is the main determinant for decomposition within a given climate and varies greatly among species of plants (Cadish and Giller 1997, Perez-Harguindeguy et al. 2000, Hattenschwiler 2005). Leaf litter species vary in the type and amount of nutrients present, along with compounds that may inhibit or stimulate decomposition (Hattenschwiler et al. 2005). Leaf toughness and the concentrations of nitrogen, lignin, and polyphenols are factors that affect the rate of decomposition by the amount of microbial activity and substrate utilization that take place (Berg et al. 1993, Cadish and Giller 1997, Perez-Harguindeguy et al. 2000). Leaves that decompose quickly typically have a high concentration of nitrogen and a low concentration of lignin and polyphenols (Haynes 1986). Conversely, leaves with a low concentration of nitrogen and a high concentration of lignin and polyphenols will take longer to break down (Swift et al. 1979, Hattenschwiler et al. 2005).

Leaf litter arthropods play an essential role in nutrient recycling by aiding in the incorporation of fragmented leaf litter into the soil, which helps to maintain soil fertility through the addition of nutrients such as nitrogen (Crossley and Hogland 1962, Elfaki et al. 2013). A succession of species is involved throughout the breakdown of leaves and commonly encountered groups within leaf litter include: Acari, Araneae, Chilopoda, Coleoptera,

Collembola, Diptera, Diplopoda, and Hymenoptera (Bultman and Uetz 1984, Lessard et al. 2011).

STUDIES ON INSECT SEASONALITY AND DIVERSITY IN LEAF LITTER

Insect seasonality in leaf litter has been studied in a variety of climates and habitats including box-ironbark forest (Taylor 2008), broadleaf-podocarp forest (Moeed and Meads 1986), desert (Santos et al. 1984), temperate deciduous forests (Anderson 1975, Gist and Crossley 1975, Uetz 1975, 1979; Dorris et al. 1995, Carlton and Robison 1998, Greenberg and Forrest 2003), riparian vegetation (Ellis et al. 2000), tropical rainforests (Levings 1983, Levings and Windsor 1985, Pearson and Derr 1986, Frith and Frith 1990), tropical evergreen forests (Lieberman and Dock 1982, Anu et al. 2009), and woodland savannahs (Bell 1985, Pinheiro et al. 2002). Studies on leaf litter arthropods are important because they help to illustrate the biodiversity found within forests or other systems and also help to indicate the health of an ecosystem by the identification of organisms serving as bioindicators (Nakamura et al. 2003).

World

Levings and Windsor (1985) analyzed the population fluctuations of various litter arthropod groups in a tropical deciduous forest on Barro Colorado Island, Republic of Panama over a 40-month period. Weekly samples of leaf litter were collected and divided into seasonal groupings based on litter moisture content from August 1975 until November 1978. Berlese extraction was used to remove the litter organisms and only the macroarthropods were analyzed and identified (Levings and Windsor 1985).

Leaf litter arthropod groups showed repeated seasonal patterns of increases and decreases and the fluctuations were partially correlated with environmental conditions (Levings

and Windsor 1985). The major arthropod groups showed three patterns of abundance that include: the dry season increase in Thysanoptera and Psocoptera, a wet season increase in Diplopoda, Chilopoda, Araneae, Opiliones, Pseudoscorpionida, Gryllidae, Hemiptera, Coleoptera larvae, and Formicidae larvae, and fluctuations with no relationship to seasonal changes in Isopoda and Amphipoda. The seasonal variation of arthropods in Panama was found to be somewhat similar to the changes in abundance found in temperate areas. There was an increase in arthropod abundance at the beginning of the wet season, which is comparable to the increases seen during the spring and summer in a temperate climate (Levings and Windsor 1985). During a dry season or a long wet season there was a reduction in abundance of arthropod communities similar to what is experienced in temperate areas during the winter (Andrewartha and Birch 1954, Varley et al. 1973, Price 1975).

Anderson (1975) carried out a study in a temperate area at Blean Woods National Nature Reserve in England and investigated the successional development of soil animal communities and decomposition of beech (*Fagus sylvatica*) and chestnut (*Castanea sativa*) leaves over a 20-month period. Litter bags were used of three different mesh sizes (7mm, 1mm, and 48 μ) in order to determine the weight loss from the leaf litter from the organisms present. Every 28 days from November 1968 to May 1970 the bags were collected, weighed, and the arthropods were extracted by washing the leaves (Anderson 1975).

Anderson (1975) found that there was no relationship between the weights of the litter and abundance of organisms within the samples and over time. There was an overall decreasing trend in litter mass as time passed and the beech litter decomposed significantly slower than the chestnut, but was colonized by a similar number of organisms. No prevalent seasonal patterns

were found in the fluctuations of the soil community with the exception of Harpacticoidea (copepod) and Diptera larvae (Anderson 1975).

United States

Compared to studies conducted abroad, more seasonal studies of arthropods have been completed in temperate forests in the United States (Uetz 1975, Greenberg and Forrest 2003). Uetz (1979) analyzed the relationship between litter depth and seasonal variation of the diversity and abundance of leaf litter spiders. For this study, Uetz created an artificial gradient of litter depth in a forest in Illinois and sampled it routinely for changes within the spider community and compared it to results of two other studies that also focused on the relationship between litter depth and diversity of Araneae. A 50 m x 100 m plot was selected for experimental manipulation of the leaf litter and was subdivided into 15 plots (100 m) that were arranged as 5-step gradients of litter depth with a pitfall trap located in the center of each plot. The experimental study took place from April through October 1973 in a heavily dominated oak forest at Hart Memorial Woods in Champaign, Illinois (Uetz 1979).

Uetz (1979) found that with increasing litter depth there was a decrease in the total number of Lycosidae and an increase in the total number of Clubionidae, Gnaphosidae, and Thomisidae, as well as significant increases in the number of species within Gnaphosidae and Thomisidae. Prey abundance and temperature variation were factors that accounted for the majority of the variation in species richness in the early-season while in the mid-season litter complexity and moisture fluctuations influenced it. Late-season species richness within the spider community was greatly influenced by temperature variation and litter complexity (Uetz 1979).

Unlike the previous study, Gist and Crossley (1975) used a combination of methods to examine the litter arthropod community in the Nantahala Mountains in the Southern Appalachians where forests were primarily composed of American chestnut (*Castanea dentata*), oaks (*Quercus* spp.), and hickories (*Carya* spp.). Pitfall traps, a sampling frame to collect leaf litter, and Berlese extraction were used to collect the leaf litter arthropods over four seasons. There were spring and fall peaks of different taxa and proposed that microarthropods were low in abundance during the summer because of larger arthropods foraging. Reduced activity of larger arthropods was experienced during the fall with senescence of the leaves and increased leaf fall and microarthropods reappeared due to the higher availability of food resources (Gist and Crossley 1975).

Arkansas

Currently, few seasonal studies of leaf litter arthropods have been conducted within deciduous forests in Arkansas (Dorris et al. 1995). Carlton and Robison (1998) carried out a survey on litter-dwelling Coleoptera in the Ouachita Mountains of Arkansas over a 12-month period between 1991 and 1992. The study area was composed of north-facing mesic oak-hickory forests and beech-maple riparian forests. Leaf litter collection and Berlese extraction were the primary methods used for collection of the litter arthropods at six different localities. Each site was sampled six to 12 times during the study at monthly or semimonthly intervals with a total of 102 Berlese samples collected. There were also 10 more localities that were sampled once throughout the study (Carlton and Robison 1998).

A total of 10,663 adult beetles were collected and identified to 46 families and 400 species (Carlton and Robison 1998). Staphylinidae was the most abundant family and was followed in number by Scydmaenidae, Curculionidae, and Carabidae. There were spring and fall

peaks in the Coleoptera with the greatest abundance occurring in March and October. On the other hand, January and June had the lowest amounts, probably due to diapausing adults in January and fluctuations in precipitation at the beginning of the summer (Carlton and Robison 1998).

TAXA OF FOCUS – CARABIDAE AND GNAPHOSIDAE

For this study, Carabidae (Coleoptera) and Gnaphosidae (Araneae) were both chosen as taxa to focus on for several key reasons. First, carabids and gnaphosids are commonly encountered within leaf litter. Second, both groups are highly diverse families (Lovei and Sunderland 1996, Platnick 2013). Third, seasonal fluctuations of Carabidae and Gnaphosidae have not yet been examined in the Ozark Mountains of Arkansas.

CARABIDAE

Carabidae, commonly known as ground beetles, is a diverse family of beetles with approximately 40,000 described species in 86 tribes (Lovei and Sunderland 1996). The carabids have worldwide distribution, and approximately 2,000 species are found in North America (Bell 1990, Lovei and Sunderland 1996). Although carabid species can vary greatly in size, they are characterized by having well-developed mandibles, large eyes, kidney shaped trochanters, long slender legs, striate elytra, and a set of punctures with tactile setae (Lovei and Sunderland 1996).

Fecundity within females ranges between five to several hundred eggs and eggs are laid singly, in a batch, over several batches in one season, or over several seasons within soil or crevices (Thiele 1977, Luff 1987). Carabids that live in more ephemeral habitats have been found to have higher numbers of eggs compared to ones that live in more stable environments

(Lovei and Sunderland 1996). Female carabids exhibit some parental care by guarding the eggs or caching seeds in the egg chamber for the larvae (Brandmayer et al. 1983, Horne 1990).

The larvae are campodeiform and undergo two or three stages before pupating in a pupal chamber in the soil (Crowson 1981, Lovei and Sunderland 1996). Carabid larvae of many species will go through diapause or aestivation (Lovei and Sunderland 1996). A general life history pattern of carabids is that they develop from eggs into adults in less than a year, reproduce once, and then die (Lovei and Sunderland 1996). However, many species from the tribes Agonini, Harpalini, Pterostichini, and Carabini live longer than one year (Thiele 1977).

Carabids can be categorized into diverse feeding guilds, including predators, omnivores, herbivores, and granivores (Thiele 1977, Luff 1987, Lovei and Sunderland 1996). Many carabids are predators that find their food by random search, sight, or chemical cues (Forsythe 1987, Chiverton 1988, de Ruiter et al. 1989, Wheeler 1989). The adults use their well-developed mandibles to kill and break apart their prey; some have mandibles specially developed to feed on certain organisms such as *Scaphinotus*, which are specialist snail predators (Pakarinen 1994, Lovei and Sunderland 1996).

Morphological defenses have evolved in response to different predator assemblages, such as amphibians, birds, mammals, and reptiles (Erwin 1985). Aposematic coloration along with Batesian or Mullerian mimicry is evident in some carabids such as tiger beetles (Lindroth 1971, Pearson 1988). Flightlessness has evolved multiple times in Carabidae and the fused elytra of flightless species provides additional protection from predators (Darlington 1943, Fiori 1974).

Ground beetles are both nocturnal and diurnal and this factor contributes to their size and coloration (Lovei and Sunderland 1996). Activity period is often reflected in size and coloration, as nocturnal species are larger and darkly colored while diurnal species are smaller

and more colorful and iridescent (Lovei and Sunderland 1996). Habitat type has been found to influence diel periodicity, with a greater proportion of forest species being nocturnal and a greater proportion of grassland species being diurnal (Greenslade 1963).

Temperature, photoperiod, and humidity have also been found to influence diel and seasonal activity of carabids (Thiele 1977, Jones 1979). Activity of carabids is usually highest during the fall and spring, which coincides with their reproductive period and lowest during the winter and/or summer when they are dormant (Makarov 1994, Lovei and Sunderland 1996). In temperate areas, temperature and photoperiod are the factors responsible for regulating carabid seasonality (Thiele 1977), while soil moisture and flooding regulate their seasonal activity in tropical regions (Paarman 1986).

Carabids are considered useful indicators of ecological changes in terrestrial communities because of their preference for certain microclimatic conditions and habitat features (Beaundry et al. 1997, Villa-Castillo and Wagner 2002, Rainio and Niemela 2003, McCravy and Willand 2005, Pearce and Venier 2006, Willand and McCravy 2006, Fuller et al. 2008). They have been used to assess for environmental pollution (Heliovaara and Vaisanen 1993), soil-nutrient status in forests (Szyszko 1983), and for the classification of habitats as protected (Luff et al. 1992, Pizzolotto 1994).

GNAPHOSIDAE

Gnaphosidae, commonly referred to as ground spiders, has 2,134 described species in 118 genera (Platnick 2013). The gnaphosids have a worldwide distribution, and approximately 250 species are found in North America (Guarisco and Kinman 1990, Ubick et al. 2005, Bennett et al. 2006).

At first glance, Gnaphosidae look somewhat similar to two other spider families, the Clubionidae and Corinnidae. However, they have several distinct characters that can easily separate them from these families. Gnaphosids most diagnostic characters include: posterior median eyes (PME) being irregularly shaped, depressed palpal endites, and cylindrical anterior spinnerets that are widely separated (Roth 1993). Other key diagnostic characters include: body size of 2-17 mm, body color brown to gray to black, eight eyes arranged in two straight rows, legs prograde and spined, and an elongate and moderately flattened abdomen that may have a chevron pattern, bands, or stripes (Ubick et al. 2005).

The life history of Gnaphosidae is not well known despite there being a number of publications on this family from across the world (Kamura 1993). It is likely that many gnaphosids have a one year life cycle and in areas where the warm season is short they may live for up to two years (Grimm 1985). Kamura (1993) examined the life history of *Zelotes asiaticus*, a common gnaphosid species found in Japan, by lab rearing and field investigation. Kamura (1993) found that this species has a two-year life cycle that follows the pattern of eggs being deposited by adult females from spring until early summer, spiderling emergence from the egg sacs in the summer, spiderling development from 2nd through 5th instars by the winter, juveniles that hibernate during their first year develop into penultimates by the summer, penultimates mature into adults by autumn, and the adults overwinter. Similar to carabids, female gnaphosids may also exhibit some parental care by guarding their egg sacs that are housed within a retreat or attached to a substrate (Ubick et al. 2005).

Gnaphosids are nocturnal hunting spiders that belong to the wandering spider guild (Uetz 1977). Spiders that belong to this guild are known to move through the litter and pounce on prey when it is seen, so they rely on their speed rather than webs to capture prey (Turnbull 1973,

Guarisco and Kinman 1990). Once Gnaphosids catch their prey, they hold onto it with their chelicerae, inject venom, and cling to the prey until the struggle stops (Turnbull 1973).

Gnaphosids are generalist predators that feed on an array of prey items including other Araneae and are considered an important component of the detrital food web in stabilizing invertebrate communities by feeding on abundant prey items (Brey Meyer 1966, Edgar 1969, Moulder and Reichle 1972, Riechert 1974, Ubick et al. 2005).

Both the microclimate and macroclimate influence the presence of Gnaphosidae throughout the year (Uetz 1991). Spider species diversity and richness have been found to increase midsummer and decrease as autumn approaches, so there is a significant correlation with prey abundance, but not with temperature, rainfall, or humidity (Uetz 1975). According to Uetz (1977), biotic factors may be more influential in limiting the distribution of spiders than the seasonal climate. The complexity and depth of leaf litter may affect wandering spiders by providing prey, decreasing temperature and moisture fluctuations, providing retreats during the day, and protection from predators (Uetz 1975).

Canopy closure, litter development, and the available prey affect spider species composition, but litter depth and complexity have been found to only affect spider abundance (Bultman and Uetz 1984, McIver et al. 1992). Gnaphosids have been found to occur more commonly in deeper and/or more complex leaf litter where they rest and hide in their silken retreats and within curled leaves (Uetz 1991). Their silken sacs not only serve as resting and hiding places, but also as shelter for overwintering and molting (Fitch 1963).

OBJECTIVES

The main objective of this thesis is to examine the phenology and diversity of Carabidae and Gnaphosidae in leaf litter over a 12-month period. From my research, I intend to answer these questions 1) How does diversity and abundance of carabids and gnaphosids differ as the seasons progressed? 2) How does diversity and abundance of carabids and gnaphosids differ as depth of the leaf litter varied? 3) How does diversity and abundance of carabids and gnaphosids vary across sites? This information will help to illustrate the amount of biodiversity found in leaf litter throughout the year in the Ozark Mountains of Arkansas and will also provide some information on carabid and gnaphosid phenology as both are not well known in this area.

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THE TEMPORAL VARIATION OF CARABIDAE (COLEOPTERA) AND GNAPHOSIDAE (ARANEAE) IN LEAF LITTER.

ABSTRACT

Temperate deciduous forests produce a layer of leaf litter on the forest floor annually. This layer is dynamic, and both the composition and depth change throughout the year. The leaf litter layer is an important habitat to many arthropods since they utilize it for food, shelter from adverse environmental conditions, and protection from predators.

Two commonly encountered and diverse taxa found in the litter layer are the ground beetles (Coleoptera: Carabidae) and the ground spiders (Araneae: Gnaphosidae). Carabidae and Gnaphosidae were collected and identified on a monthly basis from April 2014 to March 2015 from the Ozark Mountains of Arkansas to measure temporal fluctuations of species diversity and abundance. A total of 480 Berlese samples and 208 pitfall trap samples were collected and processed from four sites across Northwest Arkansas including: Lake Wedington, Lake Wilson, and Withrow Springs 1&2. From those samples, 645 carabid individuals of 47 species were collected and 421 gnaphosid individuals of 15 species were collected.

Berlese samples from all four sites yielded a total of 194 carabid individuals of 29 species and 160 gnaphosid individuals of 10 species, whereas pitfall traps from two sites yielded 451 carabid individuals of 30 species and 261 gnaphosid individuals of 14 species. Statistical analyses detected no significant differences in number of individuals and species diversity of carabids and gnaphosids among sites, whereas species richness did differ among sites for carabids. Similarly, leaf litter depth had no significant effect on the number of individuals collected, species richness (with exception to carabids at Withrow 1), or species diversity of carabids and gnaphosids. Carabids were the most abundant and diverse during the spring and

were the least abundant and diverse during the winter. Gnaphosids were the most abundant and diverse during the spring and were the least abundant in the fall and the least diverse in the winter.

INTRODUCTION

The south-central United States contains a mountainous region known as the Interior Highlands. The Highlands region is formed by the Ozark Mountains of northern and western Arkansas and southern Missouri, and the Ouachita Mountains of western Arkansas and eastern Oklahoma, and the region is dominated by oak-hickory forests. Bordered by mesic forests to the east and xeric grasslands to the west, the Interior Highlands region forms a unique area that is home to many endemic species and is considered a biodiversity hotspot (Mayden 1985, 1988; Frazer et al. 1991, Costa et al. 2008).

Temperate deciduous forests, such as oak-hickory, drop leaves annually, thus the forest floor accumulates a layer of leaf litter. This layer is dynamic, with periodic addition of leaves coupled with leaves that are in various stages of decay. The layer constitutes a habitat that is important to a variety of animal species, by providing food, shelter from adverse environmental conditions, and protection from predatory species.

Terrestrial arthropods are a dominant and diverse group inhabiting the leaf litter layer of temperate deciduous forests. Several factors of the leaf litter layer, such as plant species, litter depth, and the physical structure of the layer, have been shown to influence the composition of the terrestrial arthropod community (Uetz 1979, Bultman and Uetz 1982, 1984; Koivula et al. 1999, Elfaki et al. 2013). Two commonly encountered and diverse taxa found in the litter layer are the ground beetles (Coleoptera: Carabidae) and the ground spiders (Araneae: Gnaphosidae).

Carabidae constitute a diverse family of beetles with approximately 40,000 described species (Lovei and Sunderland 1996). Carabids have worldwide distribution and can be found in

every habitat (Erwin 1985). They can be categorized into diverse feeding guilds, including predators, herbivores, granivores, and omnivores (Thiele 1977, Luff 1987, Lovei and Sunderland 1996). In temperate regions, photoperiod and temperature are two main factors that contribute to carabid seasonality (Thiele 1977). Their activity is highest during the spring and fall when they are reproducing and lowest during the winter and summer when they are in an inactive state, such as diapause or aestivation (Makarov 1994, Lovei and Sunderland 1996). Leaf litter collection, Berlese extraction, and pitfall traps are common collection methods used to capture carabids (Lovei and Sunderland 1996, Carlton and Robison 1998).

Gnaphosidae is a diverse family of spiders with 2,134 described species in 118 genera (Platnick 2013). Gnaphosids have a worldwide distribution, and approximately 250 species are found in North America (Guarisco and Kinman 1990, Ubick et al. 2005, Bennett et al. 2006). Gnaphosids are all predators that capture prey by moving through the litter and pouncing on prey when it is seen (Guarisco and Kinman 1990). Because gnaphosids are all predatory, their presence in a habitat is influenced greatly by prey abundance, more than by climatic conditions (Uetz 1975). The temporal patterns of species diversity and species richness have been found to increase mid-summer and decrease as autumn approaches (Uetz 1975). Sampling and collecting gnaphosids in leaf litter has historically been done through litter collection, Berlese extraction, and pitfall trapping (Uetz 1975, 1977; Bultman and Uetz 1982, Dorris et al. 1995).

Terrestrial arthropods have been the focus of extensive survey and study of the richly biodiverse, deciduous forests of the Great Smoky Mountains (Carlton and Bayless 2007). However, despite the great potential of biodiversity of the Interior Highlands, the leaf litter of the deciduous forests of the Interior Highlands has received little attention through detailed study.

Carlton and Robison (1998) conducted a study on beetles in the leaf litter of the Ouachita Mountains of Arkansas from 1991-1992, and Dorris et al. (1995) studied the spiders of the leaf litter of the Ouachita Mountains. Similar studies of the seasonality of leaf litter arthropods in the Ozark Mountains of Arkansas have not been completed. In this study, I conducted a year-long sampling of the leaf litter in forests of the Ozark Mountains, focusing on the diversity, presence, and seasonality of carabid beetles and gnaphosid spiders.

MATERIALS AND METHODS

Study sites

Four Northwest Arkansas study sites at three locations in Washington and Madison Counties were used for this study, conducted from April 2014 until March 2015. Sites were located at Lake Wilson (Fayetteville city park, 109 ha) (35°59'53.39"N, 94°8'13.52"W), Lake Wedington (Ozark National Forest, 485,600 ha) (36°6'8.03"N, 94°23'29.94"W), and two different areas at Withrow Springs State Park (318 ha) (36°9'52.31"N, 93°43'21.31"W and 36°9'57.33"N, 93°43'26.57"W).

The dominant canopy tree species at Lake Wedington are black oak (*Quercus velutina*), post oak (*Q. stellata*), white oak (*Q. alba*), elm (*Ulmus spp.*), and mockernut hickory (*Carya tomentosa*), with the understory being composed of the same tree species and black cherry (*Prunus serotina*). At Lake Wilson, the dominant canopy tree species are mockernut hickory (*C. tomentosa*), northern red oak (*Q. rubra*), post oak (*Q. stellata*), and white oak (*Q. alba*), with the understory trees being mainly composed of black cherry (*P. serotina*), dogwood (*Cornus spp.*),

green ash (*Fraxinus pennsylvanica*), mockernut hickory (*C. tomentosa*), mulberry (*Morus spp.*), and white oak (*Q. alba*). The main canopy trees at Withrow Springs consist of American sycamore (*Platanus occidentalis*), hickory (*Carya spp.*), northern (*Q. rubra*) and southern (*Q. falcata*) red oak, and white oak (*Q. alba*), with the understory trees being primarily dogwood (*Cornus spp.*), red maple (*Acer rubrum*), and sassafras (*Sassafras albidum*). The two sites at Withrow Springs (hereafter Withrow 1 and Withrow 2) differed by being gently sloping with understory versus edged by a ravine and with little understory, respectively.

Leaf litter collection and Berlese extraction

Leaf litter collections occurred on a north-facing slope at each of the four locations. Collections at each site were made each month from April 2014 until March 2015 along 100-m transects from the same starting points at each site. Each month, at each site, the direction was randomly generated by rolling a die and each point on the die corresponded to a 30° angle measured from perpendicular to the right (i.e., 1 = 30°, 2 = 60°, 3 = 90°; 90° corresponded to straight ahead).

Ten samples were taken approximately 10 meters apart. At each 10-m mark, a square-meter frame was placed on the ground in a randomly generated spot that was determined by throwing a flag up into the air and placing the frame where it fell. Leaf litter depth was measured with a ruler for each sample by taking four measurements within the frame and then averaging those measurements. All leaf litter was removed from within the frame and processed in the field through a litter reducer (Paradox Company, Cracow, Poland), which had a metal screen with 10 mm x 10 mm openings to allow arthropods, small leaf fragments, and soil to fall into a 3.7-l storage bag. Each litter sample was kept in a separate 3.7-l storage bag. The 40 leaf

litter samples collected each month were placed individually in Berlese-Tullgren funnels for three to five days until the litter was thoroughly dry. All arthropods from the litter were collected in plastic cups of varying sizes, containing 70% ethanol. The samples were strained through a 63 μm sieve to remove the arthropods from the alcohol and soil. All arthropod specimens were preserved in 59.15 ml Whirl-Pak® bags that contained 70% ethanol and kept at room temperature for later processing.

Pitfall trap sampling

Pitfall trap collection occurred at only Lake Wilson and Lake Wedington. Pitfall traps had to be removed from both sites at Withrow Springs because the majority of them were found out of the ground at each monthly collection. At both sites, ten 0.95-l, round, plastic containers with a top diameter of 11.4 cm and a depth of 14 cm were placed on the same north-facing slopes where leaf litter was collected. The pitfall traps at Lake Wilson were arranged in a transect with the starting point adjacent to the litter sample starting point. The pitfall traps at the Lake Wedington site were arranged in a transect that was located approximately 200 meters upslope from the starting point of the leaf litter transect. Pitfall traps were spaced approximately five to 10 meters apart at each site.

Each container was covered by a plastic lid and three openings (8 cm wide x 2 cm tall, approximately equidistantly spaced around the perimeter of the container) were cut out on the sides of the containers. Containers were placed in the soil deep enough so the openings were level with the ground surface to allow arthropods to fall in. A 50:50 mixture of propylene glycol and water was added to each trap to a depth of 9 cm below the openings. Samples were processed at the field sites by pouring the liquid through a 63 μm sieve, and any collected

arthropods were removed and the liquid was discarded. The specimens were stored and preserved, for later sorting and identification, in 59.15 ml Whirl-Pak® bags that contained 70% ethanol and kept at room temperature. Pitfalls were left in place for approximately two weeks, and were collected on the same dates as the leaf litter samples, with one exception. The traps placed in mid-February 2015 were not collected until mid-March, due to inclement weather; thus, those traps were in place for nearly one month. The date associated with each sample reflected the date the trap was collected, meaning the sample contained arthropods collected from that month as well as up to two weeks earlier (in the previous month).

Identification

All specimens of the Carabidae were removed and pinned for identification, whereas all specimens of the Gnaphosidae were removed and stored in alcohol for identification. Carabids were identified to genus using Arnett and Thomas (2001), and further identified to species using keys in Freitag (1969) and Ciegler and Morse (2000). The specimens of Gnaphosidae were identified to genus level by using Ubick et al. (2005), and species level identification was made using a series of keys for each genus (Platnick 1975; Platnick and Shadab 1975, 1976, 1977, 1980a, 1980b, 1982, 1983).

Data analysis

Species richness was calculated using the formula of # species/month-site-method, and species diversity was represented by the Shannon-Wiener index, calculated using the formula of $H' = -\sum(p_i * \ln(p_i))$ (Shannon 1948). Data were analyzed using Excel 2013 and JMP Pro 11. Similar analyses were conducted for the carabids and gnaphosids and appropriate statistical

analyses were determined based on examination of the data. One-way ANOVAs were performed to examine Berlese data from all four sites over 12 months and included: number of individuals collected per month, species richness, species diversity, and litter depth. A Tukey-Kramer HSD test was used when significance was detected and allowed for the separation of means. Regression analyses were also used to examine Berlese data to determine if litter depth had a significant effect on the number of individuals collected per month, species richness and species diversity at each site. For all analyses, a significance level of 0.05 was used.

Pitfall trap catches at Wilson and Wedington were compared by using two-tailed t-tests to analyze the number of individuals captured per month, species richness, and species diversity.

RESULTS

Carabidae

A total of 645 individual carabids of 47 species was collected (Table 1). The 47 species from the four sites represented 15 tribes and 24 genera. The Wedington site produced 37 species and 214 individuals (52 were *Cyclotrachelus parasodalis*). The Wilson site yielded 16 species and 317 individuals (213 were *C. parasodalis*). Withrow 1 and 2 each produced 13 species, with a total of 56 and 58 individuals at the two sites, respectively. Fifteen species were represented by only one individual. At individual sites, 16 of the 37 species at Wedington had only one individual, whereas six of the 16 species at Wilson were represented by one individual. Of the 13 total species collected at each site at Withrow, eight species at Withrow 1 were represented by one individual and seven species at Withrow 2 also had only one individual.

Leaf litter samples processed through Berlese funnels (hereafter, Berlese) at all four sites yielded a total of 194 individuals of 29 species. Pitfall traps at two sites yielded 451 individuals of 30 species; of these, 195 individuals were *C. parasodalis*, collected in July. At the generic level, six genera were only collected in Berlese samples, eight genera were only found in pitfall samples and ten genera had species that were found in both trap types. Eighteen species were collected in only Berlese samples, 18 species were collected in only pitfall traps, and 11 species were collected by both methods. Across all sites and both sampling methods, the four most abundant carabid species collected included: *Cyclotrachelus parasodalis*, *Trichotichnus autumnalis*, *Notiophilus novemstriatus*, and *Pterostichus permundus* (Figures 1a, 1b, 2a, 2b).

Berlese samples

In the 12 monthly Berlese collections from the four sites, average numbers of carabid individuals ranged from 0.0 to 1.8 per sample (Figure 3). Twenty-one carabid species were collected at Wedington, versus eight species at Wilson and 13 species each at the two sites at Withrow Springs. No significant differences among the four sites were detected using ANOVA for the average number of individuals ($F=1.789$; $df=3,44$; $P=0.163$; Figure 4a) or species diversity ($F=0.736$; $df=3,44$; $P=0.536$; Figure 4b). However, species richness did differ among the sites ($F=2.994$; $df=3,44$; $P=0.041$; Figure 4c). A mean separation showed that the species richness at Wedington and Wilson was significantly different between the two sites.

Average monthly leaf litter depths ranged from a low of 1.35 cm at Withrow 2 to 7.03 cm at Wedington (Figure 5). Overall litter depth did not differ significantly among sites ($F=1.601$; $df=3,44$; $P=0.203$). Regression analyses showed no significant effect of the depth of leaf litter on the number of carabids at all four sites: Wedington ($F=0.036$; $df=1,10$; $P=0.853$; Figure 6a),

Wilson ($F=1.911$; $df=1,10$; $P=0.197$; Figure 6b), Withrow 1 ($F=0.968$, $df=1,10$; $P=0.348$; Figure 7a), and Withrow 2 ($F=0.974$; $df=1,10$; $P=0.347$; Figure 7b). Regression analyses showed no significant effect of the depth of leaf litter on species richness at three of the sites: Wedington ($F=0.245$; $df=1,10$; $P=0.631$; Figure 8a), Wilson ($F=2.399$; $df=1,10$; $P=0.152$; Figure 8b), and Withrow 2 ($F=2.398$; $df=1,10$; $P=0.153$; Figure 9a). However, litter depth significantly affected the species richness at Withrow 1 ($F=5.513$; $df=1,10$; $P=0.041$; Figure 9b) with the negative slope of the regression having a value of -0.144. For species diversity, regression analyses again showed no significant effect of leaf litter at Wedington ($F=0.066$; $df=1,10$; $P=0.802$), Wilson ($F=0.294$; $df=1,10$; $P=0.600$), Withrow 1 ($F=2.724$; $df=1,10$; $P=0.130$), and Withrow 2 ($F=0.045$; $df=1,10$; $P=0.837$).

Species accumulation curves were constructed to show the addition of species with subsequent monthly Berlese sampling from April until the following March (Figure 10). At three sites (Wilson, Wedington, and Withrow 1), new species were added with every monthly sample. In contrast, no new species were added at Withrow 2 after September.

Pitfall traps

Carabids were captured each month throughout the year in pitfall traps at both sites. At Wilson, 295 carabid individuals of 12 species were collected, whereas there were 156 individuals of 24 species captured at Wedington. Heavy rains in July flooded the traps, so results from July were excluded from analysis for both sites. Monthly averages of carabids caught per trap ranged from 0.1 to 5.0 at Wilson, versus a range of 0.25 to 3.3 at Wedington (Figure 11a). Analyses using two-tailed t-tests showed no significant differences between the two sites in the average numbers of carabid individuals per trap ($t=1.005$, $df=11$, $P=0.336$), species richness ($t=0.726$, $df=11$, $P=0.483$) or species diversity ($t=0.925$, $df=11$, $P=0.375$). Species accumulation curves

were constructed to show the addition of species with subsequent monthly pitfall sampling from April until the following March (Figure 11b). With the exception of two new species being collected at Wedington in February, no new species were accumulated at both sites after October.

Feeding guilds

The 47 carabid species collected by Berlese and pitfall sampling were assigned to either predator or omnivore feeding guilds (Table 2). Thirty-five species were categorized as predators and 12 species were categorized as omnivores. Trap catches for predator and omnivore guilds were compared at Wedington and Wilson, because the two sites had both Berlese and pitfall samples. The two sites yielded 14 species of predators found in Berlese samples and 23 species of predators found in pitfall samples; five of those species were found in both trap types. Of the 17 genera of predators, nine were found only in pitfall samples, four were only in Berlese samples, and four genera occurred in both trap types. Nine species were collected exclusively in Berlese samples, 18 were in pitfalls only, and five species occurred in both trap types. All four *Chlaenius* spp., two *Galerita* spp., and five *Cyclotrachelus* spp. were collected in pitfall traps. In contrast, all five *Lebia* spp. were collected only in Berlese samples at those sites.

The 11 species of omnivores at the Wilson and Wedington sites consisted of six genera. One genus (*Harpalus*) was found only in pitfalls, one genus (*Anisodactylus*) was found only in Berlese samples, and four genera were collected in both trap types. Further, four species were found only in Berlese samples, two only in pitfalls, and five species were found in both trap types.

Gnaphosidae

A total of 421 individual gnaphosids consisting of 11 genera and 15 species was collected (Table 3). The Wilson site yielded 15 species and 201 individuals, the Wedington site produced 12 species and 164 individuals. Five species and 33 individuals were collected at Withrow 1, whereas six species and 23 individuals were collected at Withrow 2. Two species were represented by only one individual and both were found at Wilson.

Berlese samples yielded 160 gnaphosids of 10 species from the four sites. Pitfall traps at two sites yielded 261 individuals of 14 species. At the generic level, one genus was collected only in Berlese samples, five genera were collected only in pitfall traps, and six genera had species that were found in both trap types. One species was collected only in Berlese samples, five species were collected only in pitfall traps, and nine species were collected with both methods. Across all sites and both sampling methods, the four most abundant gnaphosid species collected included: *Zelotes duplex*, *Talanites echinus*, *Drassyllus aprilinus*, and *Gnaphosa fontinalis* (Figures 12a, 12b, 13a, 13b).

Berlese samples

An average of 0.0 to 1.1 individual gnaphosids was collected in Berlese samples over 12 months from the four sites (Figure 14). Twelve species were collected at Wedington, 15 species were collected at Wilson, five species were collected at Withrow 1, and six species were collected at Withrow 2. No significant differences among the four sites were identified using ANOVA for the average number of individuals ($F=2.581$; $df=3,44$; $P=0.065$; Figure 15a), species richness ($F=2.716$; $df=3,44$; $P=0.056$; Figure 15b), and species diversity ($F=0.524$; $df=3,44$; $P=0.668$; Figure 15c).

Regression analyses showed no significant effect of the depth of leaf litter on average number of individual gnaphosids captured at the four sites: Wedington ($F=0.942$; $df=1,10$;

P=0.355; Figure 16a), Wilson (F=0.014; df=1,10; P=0.909; Figure 16b), Withrow 1 (F=0.175; df=1,10; P=0.684; Figure 17a), and Withrow 2 (F=0.920; df=1,10; P=0.360; Figure 17b).

Regression analyses showed no significant effect of the depth of leaf litter on species richness at each of the sites: Wedington (F=0.985; df=1,10; P=0.344; Figure 18a), Wilson (F=0.083; df=1,10; P=0.779; Figure 18b), Withrow 1 (F=0.033; df=1,10; P=0.859; Figure 19a), and Withrow 2 (F=2.189; df=1,10; P=0.170; Figure 19b). Regression analyses again showed no significant effect of the depth of leaf litter on species diversity of gnaphosids at all of the sites: Wedington (F=0.335; df=1,10; P=0.575), Wilson (F=0.645; df=1,10; P=0.441), Withrow 1 (F=1.175; df=1,10; P=0.304), and Withrow 2 (F=1.774; df=1,10; P=0.212).

Species accumulation curves were constructed to show the addition of species with subsequent monthly leaf litter sampling from April until the following March (Figure 20). At Wilson and Withrow 1, all species had been collected by July. No new species were added at Wedington after September and no new species were collected at Withrow 2 after November.

Pitfall traps

Gnaphosids were captured from April through November in pitfall traps at both sites. At Wilson, 155 gnaphosid individuals of 13 species were collected, whereas there were 106 individuals of 12 species captured at Wedington. Monthly averages of gnaphosids caught per trap ranged from 0.0 to 9.5 at Wilson, versus a range of 0.0 to 4.6 at Wedington (Figure 21a). Analyses using two-tailed t-tests showed no significant differences between the two sites in the average number of gnaphosid individuals ($t=0.736$; df=11; $P=0.477$), species richness ($t=0.609$; df=11; $P=0.555$) or species diversity ($t=0.037$; df=11; $P=0.971$). Species accumulation curves were constructed to show the addition of species with subsequent monthly pitfall sampling from

April until the following March (Figure 21b). No new species were added after August at Wedington and after November for Wilson.

DISCUSSION

The use of both Berlese sampling and pitfall trapping at Wedington and Wilson proved to be advantageous in capturing different species of carabids. Four species of omnivores were collected only in Berlese, two species of omnivores were collected only in pitfalls, and five species of omnivores were collected by both methods. Thirty-four individual omnivores were collected in Berlese and 24 omnivores were collected in pitfall traps at both sites. Similarly, the different trap types collected different predatory species at Wedington and Wilson. Nine predatory species were found only in Berlese samples, 18 predatory species were found only in pitfall traps, and five predatory species were collected in both trap types. At both sites with *Cyclotrachelus parasodalis* excluded, 46 predators were found in Berlese and 162 predators were found in pitfall traps. Because many species were collected only in one trap type, sampling consisting of only one trapping method would have yielded fewer species.

Pitfall traps are the most frequently used collection method for active predators, such as carabids (Lovei and Sunderland 1996), but design and installation can influence the species caught. If openings in the trap are not flush with the ground, small carabid species may be prevented from falling in the traps, thus be underrepresented in the collection. Similarly, if the height of the openings is too small, the trap can discriminate against larger species. Litter samples represent “snapshot” samples at one point in time, as opposed to the pitfall traps that are able to collect continuously over an extended period. Leaf litter samples need to be collected in

a manner that does not lose active and fast-moving species during the litter collection, possibly by placing a barrier outside of the frame before collecting litter samples.

C. parasodalis was the dominant species collected in pitfall traps at Wedington and Wilson, and all 265 *C. parasodalis* individuals were found in pitfall traps. The July sample contained 160 of the 213 individuals collected at Wilson and 35 of the 52 individuals collected at Wedington. These numbers were much greater than the number of individuals found the other months, which were fewer than 10 at each site, except in November when 22 were found at Wilson. Heavy rains in July (amounts not recorded) flooded the traps and diluted the propylene glycol, diminishing its ability to preserve collected arthropod specimens. The diluted fluid with decomposing individuals may have acted as an attractant for *C. parasodalis*. However, because this species is classified as predatory, it is also possible that the beetles were not attracted to decomposing arthropods, but to other species (e.g., carrion beetles [Coleoptera: Silphidae]) that responded to the decomposing specimens. If a dilute mixture of propylene glycol and water leads to decomposing arthropods, then it may be the most effective method for collecting *C. parasodalis*. Equally possible, *C. parasodalis* may have responded to heavy rains by being more active (perhaps prey species were more active or emerged with the rains) and, thus, were caught in greater numbers.

Pitfall traps appeared to be the most effective method in collecting gnaphosids, which are fast-moving predators that can move quickly through the litter and escape collection. Uetz (1977) abandoned leaf litter collection during his study due to many wandering spiders moving out of the sampling area, and he noted that pitfall trapping was the more accurate method to measure their diversity and abundance. At Wedington and Wilson, 261 gnaphosids were collected by pitfall traps and 104 individuals were collected in Berlese samples. Gnaphosids

were more commonly collected in leaf litter that contained woody debris or large rocks, possibly because the spiders could use these surfaces to attach their silken sacs during the day. Finding more gnaphosids near substrates was similar to the results of Ulyshen and Hanula (2009), who found that Araneae were significantly more abundant near logs. Although the numbers of species collected in pitfalls at the Wedington and Wilson sites (12 and 13, respectively) was apparently greater than the number collected in Berlese samples (7 and 10, respectively), no direct comparisons were made between trap types.

Much of the forest of Northwest Arkansas was logged approximately 100-150 years ago, causing disturbance to both the animal and plant communities. Similarly, each of the four collection sites in the study has had disturbance recently. The site where collections took place at Withrow Springs was logged in the 1940s and, in 2004, the area was used as a route for a water line to a nearby camping area. At Wedington, disturbance was experienced when the area directly across from the collection site was logged in 2014. Lake Wilson, Lake Wedington, and Withrow Springs are frequently used as recreational areas and experience disturbance from human foot traffic throughout the year. The effects of these disturbances are not known at the sites and could be tested in the future to see how disturbances affect the diversity and abundance of arthropod communities in leaf litter.

Although Lake Wilson is a city park and smaller in area (109 ha) than the other two locations, a fair number of diverse taxa were collected there. The 16 species of carabids and 317 individual carabids collected at the Lake Wilson site represented 34% of the species and 49% of the number of individuals collected in the study; however, 213 of those specimens were *C. parasodalis*. The Wilson site also yielded all 15 species of gnaphosids that were collected and 201 (48%) of the 421 individual gnaphosids. The site is dominated by many large canopy trees

and the park is located amid an expanse of large trees in an urban forest. The site diversity may be a result of the park being a remnant of an earlier forested habitat. The diversity of species collected at this site also points out the importance of its inclusion in sampling the arthropod diversity of the area—diversity is not exclusive to “natural” areas.

This study helped to demonstrate the importance of collecting at multiple sites over multiple months. Although there were no statistical differences among sites, some species were collected only at one site. One carabid species was found only at each of the two Withrow Springs sites, four carabid species and two gnaphosids were found only at Lake Wilson, whereas 19 carabid species were only collected at Lake Wedington. Although it may not be unexpected that the large (485,600 ha) site at Lake Wedington held the greatest number of species that were encountered only once, it was curious that four carabids and the two gnaphosids found only once were at the smallest (109 ha) site, Lake Wilson. Sampling for 12 months allowed for the capture of species that would not have been collected if the study took place just over several months.

Carabids were more abundant during the spring and fall, whereas gnaphosids were more abundant during the spring and summer months. Upon examination of the most abundant carabid and gnaphosid species collected, there were some prevalent patterns in their seasonal activity. *Cyclotrachelus parasodalis* was most abundant in the summer and fall months and *Pterostichus permundus* was collected throughout the spring, summer, and fall. *Notiophilus novemstriatus* and *Trichotichnus autumnalis* are carabid species that were active throughout the year. Similarly, the gnaphosid, *Drassyllus aprilinus*, was also collected throughout the year. The three other most commonly collected gnaphosid species, *Zelotes duplex*, *Talanites echinus*, and *Gnaphosa fontinalis* were most abundant during the spring and summer months.

These results provide the first glimpse of carabid and gnaphosid seasonality patterns and diversity in leaf litter in the Ozark Mountains of Arkansas. This study represents a small snapshot of the biodiversity of arthropod groups found in this region, and future studies may uncover endemic species and help explain seasonal patterns of other taxa in leaf litter that are important components of various ecosystem processes.

TABLES

Table 1. Numbers of species of Carabidae collected by Berlese or pitfall sampling at four sites (Lake Wedington, Lake Wilson, Withrow Springs 1&2) in Washington and Madison Counties, Arkansas, from April 2014 to March 2015.

Carabidae	Berlese collections				Pitfall collections	
Taxa	Wedington	Wilson	Withrow 1	Withrow 2	Wedington	Wilson
<i>Agonoleptus conjunctus</i>	1	0	1	0	0	0
<i>Agonum octopunctatum</i>	6	0	0	0	1	0
<i>Agonum punctiforme</i>	2	0	1	0	0	0
<i>Agonum</i> sp. 3	2	0	1	0	0	0
<i>Amara aenea</i>	0	0	0	0	2	0
<i>Amara musculus</i>	1	1	0	1	0	0
<i>Amara</i> sp. 3	2	0	0	1	1	0
<i>Amara</i> sp. 4	0	0	0	1	0	0
<i>Anisodactylus rusticus</i>	1	0	0	0	0	0
<i>Apenes sinuata</i>	5	2	2	1	1	0
<i>Bembidion rapidum</i>	0	0	0	0	1	0
<i>Calathus opaculus</i>	2	0	2	2	5	0
<i>Calosoma scrutator</i>	0	0	0	0	1	0
<i>Carabus sylvosus</i>	0	0	0	0	11	0
<i>Chlaenius aestivus</i>	0	0	0	0	0	1
<i>Chlaenius emarginatus</i>	0	0	0	0	1	0
<i>Chlaenius laticollis</i>	0	0	0	0	0	1
<i>Chlaenius platyderus</i>	0	0	0	0	0	3
<i>Cicindela sexguttata</i>	0	0	0	0	2	6
<i>Cyclotrachelus incisus</i>	0	0	0	3	11	0
<i>Cyclotrachelus parasodalis</i>	0	0	0	0	52	213
<i>Cyclotrachelus seximpressus</i>	0	0	1	1	15	0
<i>Cyclotrachelus sodalis</i>	0	0	0	0	7	0
<i>Cyclotrachelus whitcombi</i>	0	0	0	0	1	0
<i>Cymindis limbata</i>	0	0	3	1	0	0
<i>Cymindis platicollis</i>	1	0	0	0	0	0
<i>Dicaelus ambiguus</i>	0	0	0	0	1	1
<i>Dicaelus elongatus</i>	2	2	0	0	1	5
<i>Dicaelus sculptilis</i>	1	0	0	0	0	0
<i>Galerita atripes</i>	0	0	0	0	1	0

Table 1, Cont.

Carabidae	Berlese collections				Pitfall collections	
Taxa	Wedington	Wilson	Withrow 1	Withrow 2	Wedington	Wilson
<i>Galerita bicolor</i>	0	0	0	0	2	0
<i>Harpalus erythropus</i>	0	0	1	0	0	0
<i>Harpalus pensylvanicus</i>	0	0	0	0	1	0
<i>Lebia collaris</i>	2	1	0	0	0	0
<i>Lebia fuscata</i>	1	0	0	0	0	0
<i>Lebia grandis</i>	1	0	0	0	0	0
<i>Lebia solea</i>	4	0	0	0	0	0
<i>Lebia viridis</i>	0	1	1	0	0	0
<i>Notiophilus novemstriatus</i>	0	8	10	18	1	17
<i>Pterostichus permundus</i>	1	5	0	2	0	39
<i>Pterostichus punctiventris</i>	6	0	1	2	24	0
<i>Scaphinotus</i> sp.	0	0	0	0	0	2
<i>Scarites subterraneus</i>	0	0	0	0	0	6
<i>Synuchus impunctatus</i>	0	0	1	1	0	0
<i>Tachys columbiensis</i>	2	0	0	0	0	0
<i>Trichotichnus autumnalis</i>	14	2	31	24	12	1
<i>Trichotichnus fulgens</i>	1	0	0	0	1	0

Table 2. Species of Carabidae collected from Lake Wedington, Lake Wilson, and Withrow Springs, Washington and Madison Counties, Arkansas, from April 2014 to March 2015. Also shown are the tribe of each species, trapping method (Berlese or pitfall) of each species collected, and the appropriate feeding guild (O=omnivore, P=predator) of each species. Superscripts correspond to the references (below) used to assign species to guilds. Italicized letters indicate that information from a congeneric species was used for guild assignment.

Tribe	Species	Berlese	Pitfall
Bembidiini	<i>Bembidion rapidum</i> ⁴		P
Bembidiini	<i>Tachys columbiensis</i> ⁷	<i>P</i>	
Carabini	<i>Calosoma scrutator</i> ⁷		P
Carabini	<i>Carabus sylvosus</i> ⁹		P
Chlaeniini	<i>Chlaenius aestivus</i> ¹		P
Chlaeniini	<i>Chlaenius emarginatus</i> ^{1,4}		<i>P</i>
Chlaeniini	<i>Chlaenius laticollis</i> ^{1,4}		<i>P</i>
Chlaeniini	<i>Chlaenius platyderus</i> ⁴		P
Cicindelini	<i>Cicindela sexguttata</i> ¹⁵		P
Cychrini	<i>Scaphinotus</i> sp. ¹⁴		P
Galeritini	<i>Galerita atripes</i> ⁸		<i>P</i>
Galeritini	<i>Galerita bicolor</i> ⁸		P
Harpalini	<i>Agonoleptus conjunctus</i> ¹³	P	
Harpalini	<i>Anisodactylus rusticus</i> ^{7,12}	O	
Harpalini	<i>Harpalus erythropus</i> ¹³	P	
Harpalini	<i>Harpalus pensylvanicus</i> ^{7,12}		O
Harpalini	<i>Trichotichnus autumnalis</i> ^{1,10}	<i>O</i>	<i>O</i>
Harpalini	<i>Trichotichnus fulgens</i> ^{1,10}	<i>O</i>	<i>O</i>
Lebiini	<i>Apenes sinuata</i> ⁵	P	P
Lebiini	<i>Cymindis limbata</i> ³	<i>P</i>	
Lebiini	<i>Cymindis platicollis</i> ³	<i>P</i>	
Lebiini	<i>Lebia collaris</i> ^{4,6,16}	<i>P</i>	
Lebiini	<i>Lebia fuscata</i> ⁴	P	
Lebiini	<i>Lebia grandis</i> ¹⁶	P	
Lebiini	<i>Lebia solea</i> ^{4,6,16}	<i>P</i>	
Lebiini	<i>Lebia viridis</i> ⁶	P	
Licinini	<i>Dicaelus ambiguus</i> ^{4,7}		<i>P</i>
Licinini	<i>Dicaelus elongatus</i> ^{4,7}	P	P

Table 2, Cont.

Tribe	Species	Berlese	Pitfall
Licinini	<i>Dicaelus sculptilis</i> ^{4,7}	<i>P</i>	
Notiophilini	<i>Notiophilus novemstriatus</i> ⁷	<i>P</i>	<i>P</i>
Platynini	<i>Agonum octopunctatum</i> ¹¹	<i>O</i>	<i>O</i>
Platynini	<i>Agonum punctiforme</i> ^{7,12}	<i>O</i>	
Platynini	<i>Agonum</i> sp. 3 ^{7,11,12}	<i>O</i>	
Pterostichini	<i>Cyclotrachelus incisus</i> ^{4,12}	<i>P</i>	<i>P</i>
Pterostichini	<i>Cyclotrachelus parasodalis</i> ¹²		<i>P</i>
Pterostichini	<i>Cyclotrachelus seximpressus</i> ⁴	<i>P</i>	<i>P</i>
Pterostichini	<i>Cyclotrachelus sodalis</i> ⁴		<i>P</i>
Pterostichini	<i>Cyclotrachelus whitcombi</i> ^{4,12}		<i>P</i>
Pterostichini	<i>Pterostichus permundus</i> ²	<i>P</i>	<i>P</i>
Pterostichini	<i>Pterostichus punctiventris</i> ²	<i>P</i>	<i>P</i>
Scaritini	<i>Scarites subterraneus</i> ^{7,12}		<i>P</i>
Sphodrini	<i>Calathus opaculus</i> ⁷	<i>O</i>	<i>O</i>
Sphodrini	<i>Synuchus impunctatus</i> ⁴	<i>P</i>	
Zabrini	<i>Amara aenea</i> ^{7,12}		<i>O</i>
Zabrini	<i>Amara musculis</i> ¹³	<i>O</i>	
Zabrini	<i>Amara</i> sp. 3 ^{7,12,13}	<i>O</i>	<i>O</i>
Zabrini	<i>Amara</i> sp. 4 ^{7,12,13}	<i>O</i>	

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Table 3. Numbers of species of Gnaphosidae captured by Berlese or pitfall sampling at four sites (Lake Wilson, Lake Wedington, Withrow Springs 1&2) in Washington and Madison counties, Arkansas, from April 2014 to March 2015.

Gnaphosidae	Berlese Collections				Pitfall Collections	
Taxa	Wilson	Wedington	Withrow 1	Withrow 2	Wilson	Wedington
<i>Callilepis imbecilla</i>	2	0	0	0	16	1
<i>Cesonia bilineata</i>	1	0	0	0	21	3
<i>Drassodes</i> sp.	0	0	0	0	1	0
<i>Drassyllus aprilinus</i>	15	19	19	8	8	3
<i>Drassyllus covensis</i>	1	2	2	4	0	2
<i>Drassyllus dixinus</i>	0	0	0	0	1	1
<i>Gnaphosa fontinalis</i>	1	13	4	5	2	38
<i>Herpyllus ecclesiasticus</i>	0	0	0	0	1	1
<i>Litopyllus temporarius</i>	2	0	0	1	0	0
<i>Sergiolus capulatus</i>	0	0	0	0	3	1
<i>Sosticus insularis</i>	0	0	0	0	1	0
<i>Talanites echinus</i>	9	1	0	0	69	1
<i>Talanites exlineae</i>	1	17	0	0	1	7
<i>Zelotes duplex</i>	10	3	4	2	29	46
<i>Zelotes hentzi</i>	4	3	4	3	2	2

FIGURES

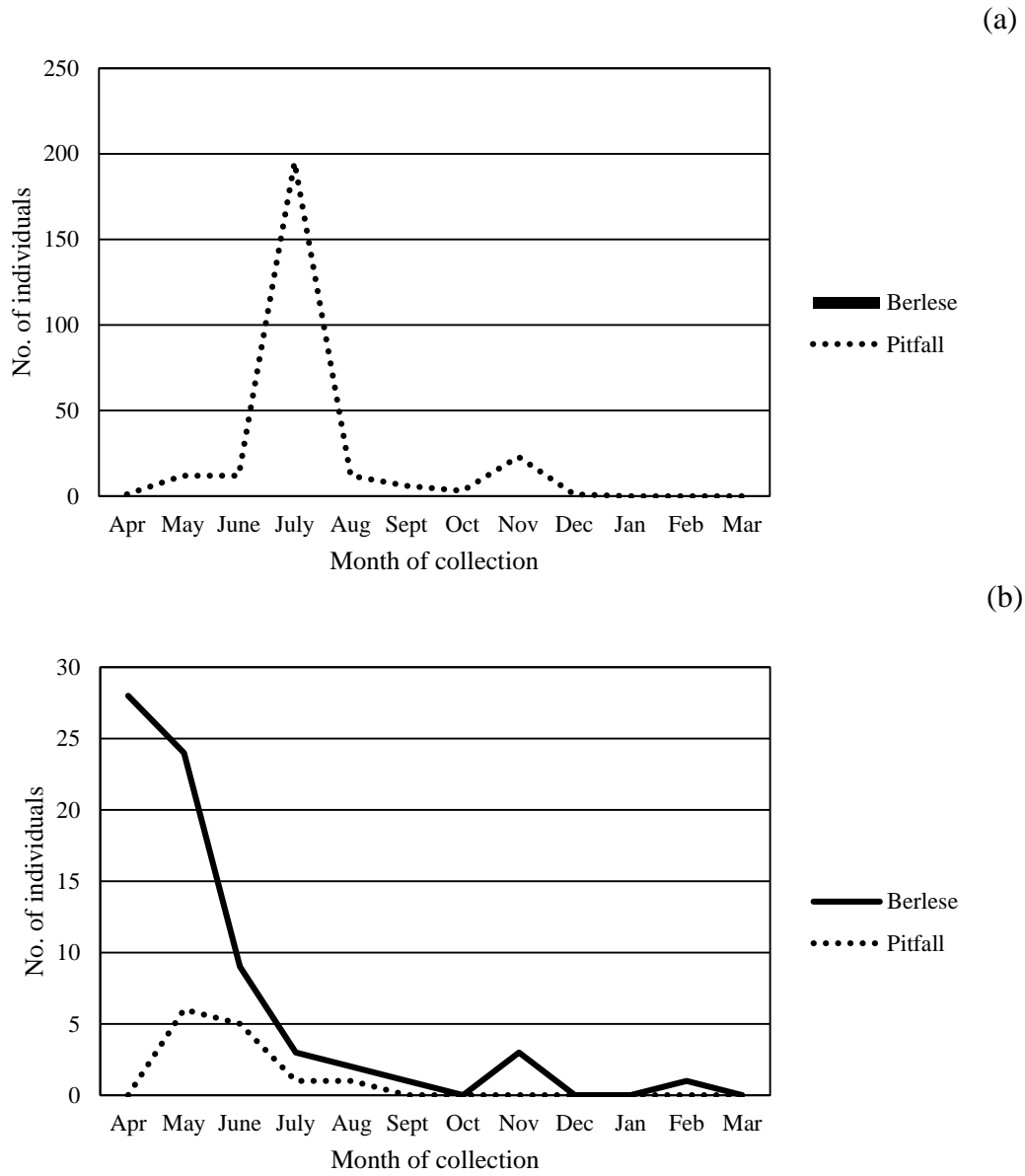
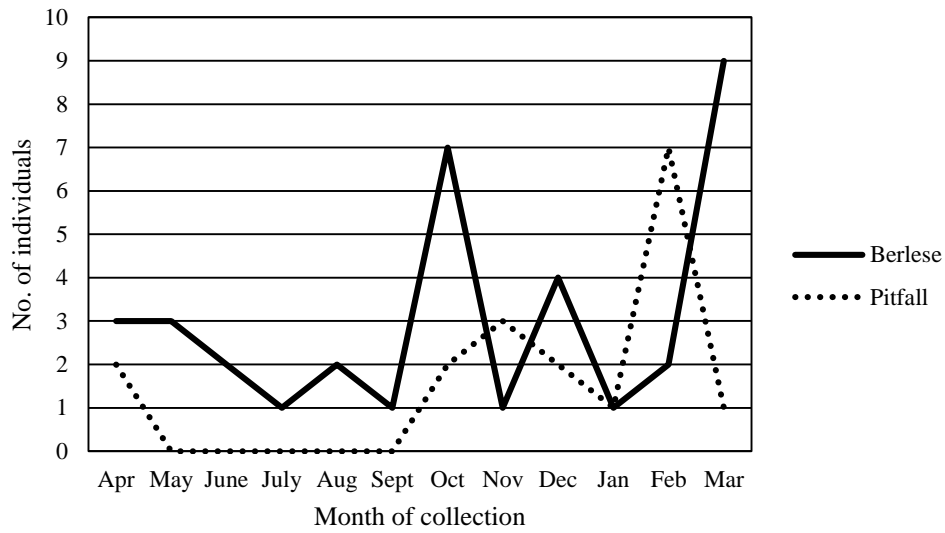


Figure 1. Numbers of individuals of *Cyclotrachelus parasodalis* (a) and *Trichotichnus autumnalis* (b) collected over 12 months across all sites in Berlese and pitfall trap samples.

(a)



(b)

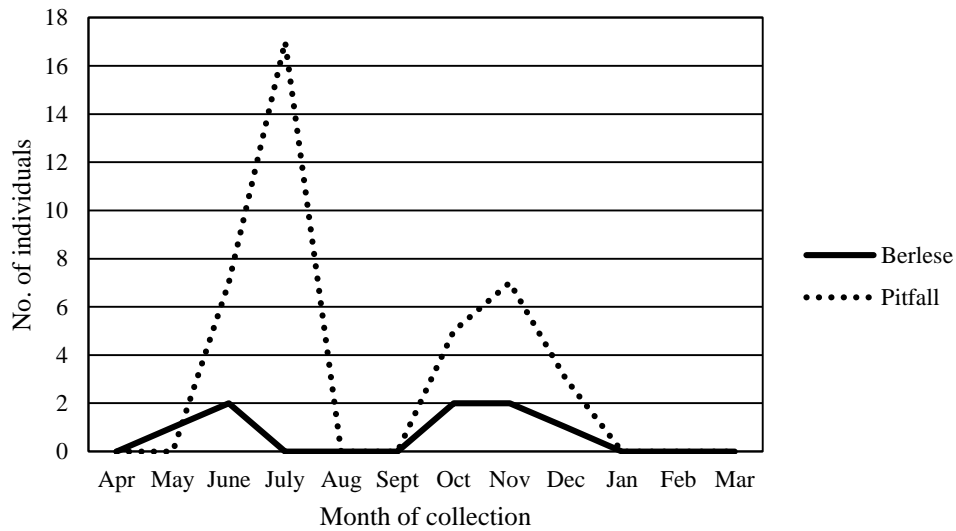


Figure 2. Numbers of individuals of *Notiophilus novemstriatus* (a) and *Pterostichus permundus* (b) collected over 12 months across all sites in Berlese and pitfall trap samples.

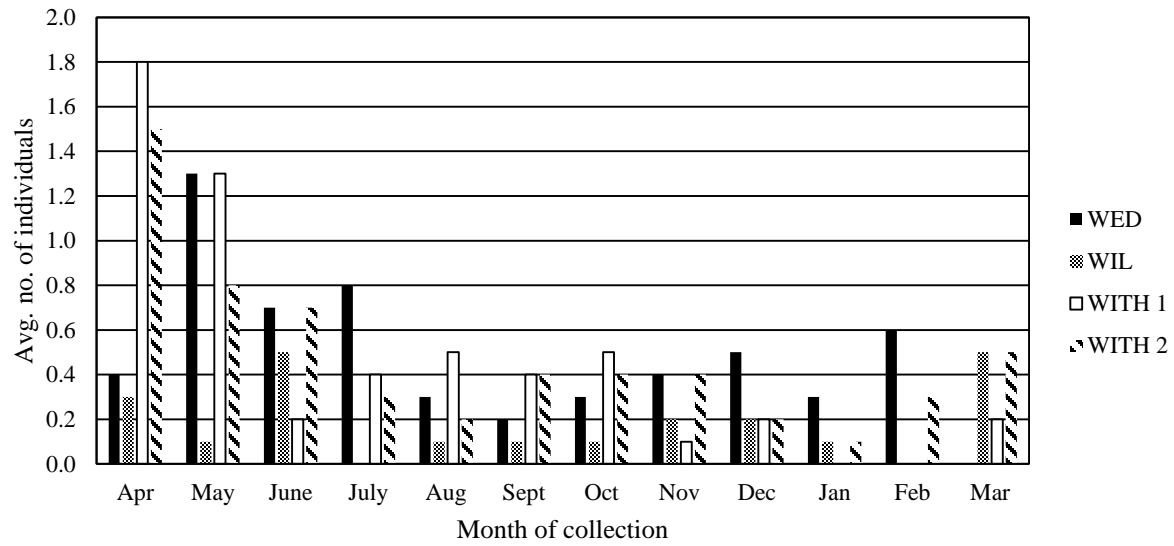
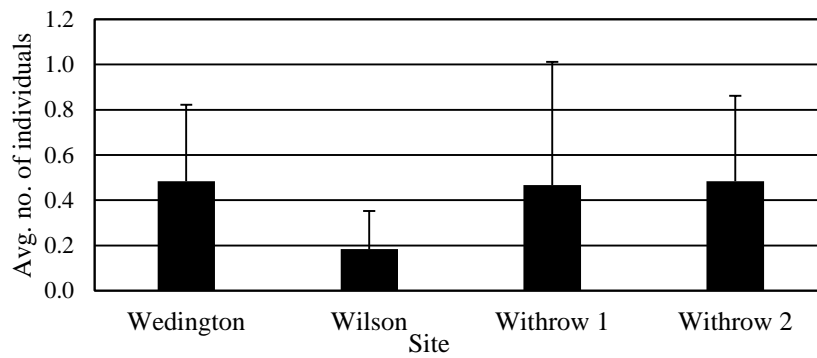
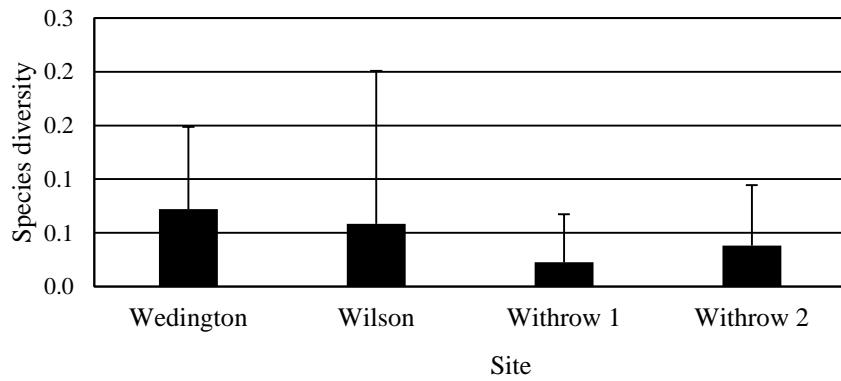


Figure 3. Average numbers of carabid individuals collected monthly in Berlese samples at Lake Wedington, Lake Wilson, and Withrow Springs 1&2, Washington and Madison Counties, Arkansas, in 2014-2015.

(a)



(b)



(c)

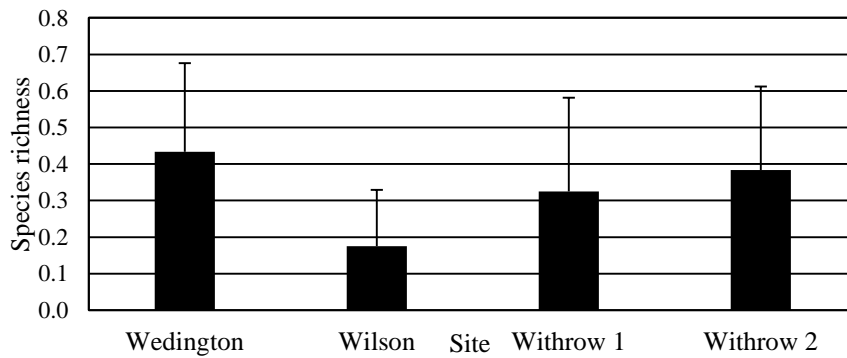


Figure 4. Average numbers of individual carabids (a), species diversity (b), and species richness (c) for Berlese samples collected at four sites in Washington and Madison counties Arkansas, from April 2014 to March 2015. Error bars above each of the means represent the standard deviation.

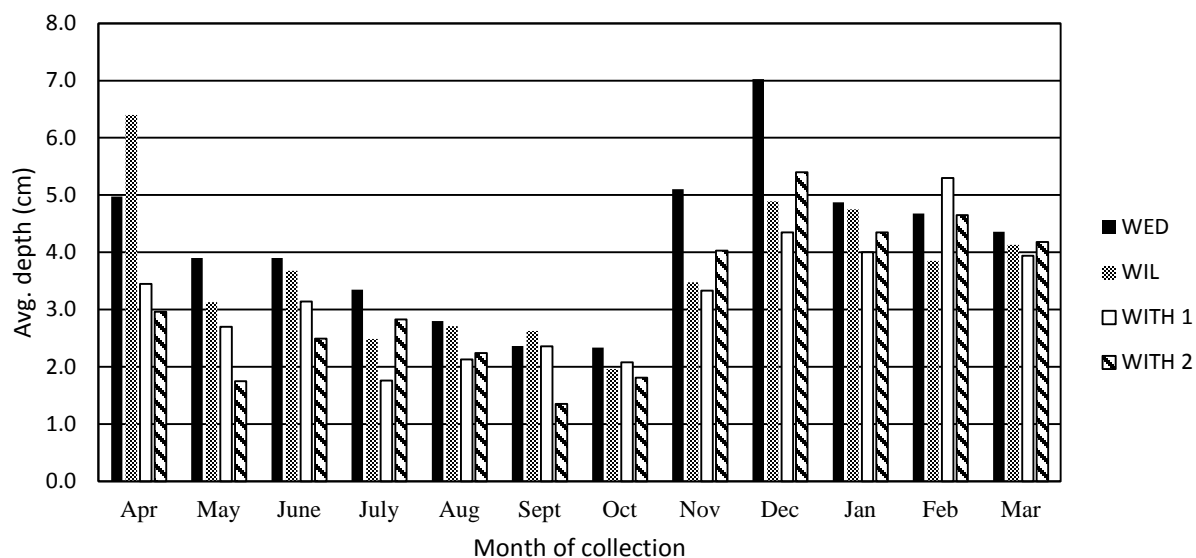
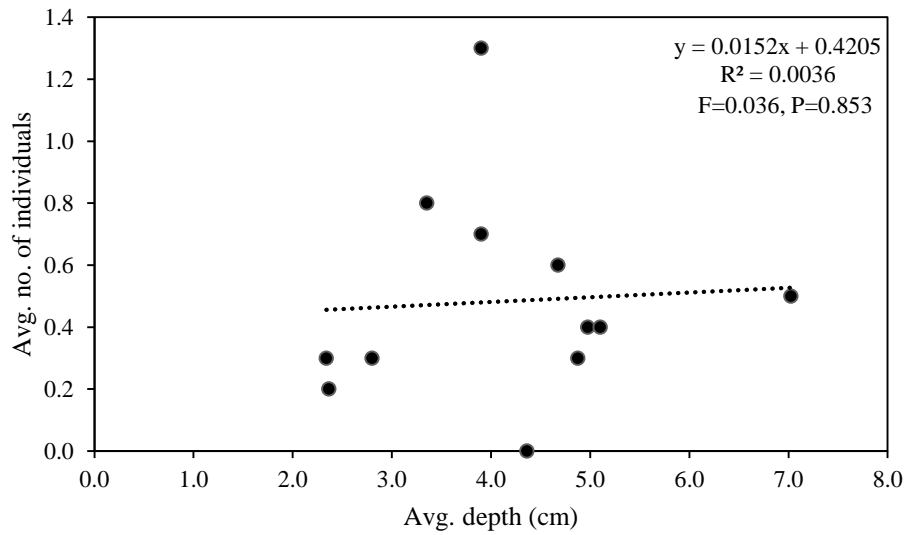


Figure 5. Average depth (cm) of leaf litter collected monthly at four sites in Washington and Madison Counties, Arkansas, from April 2014 to March 2015.

(a)



(b)

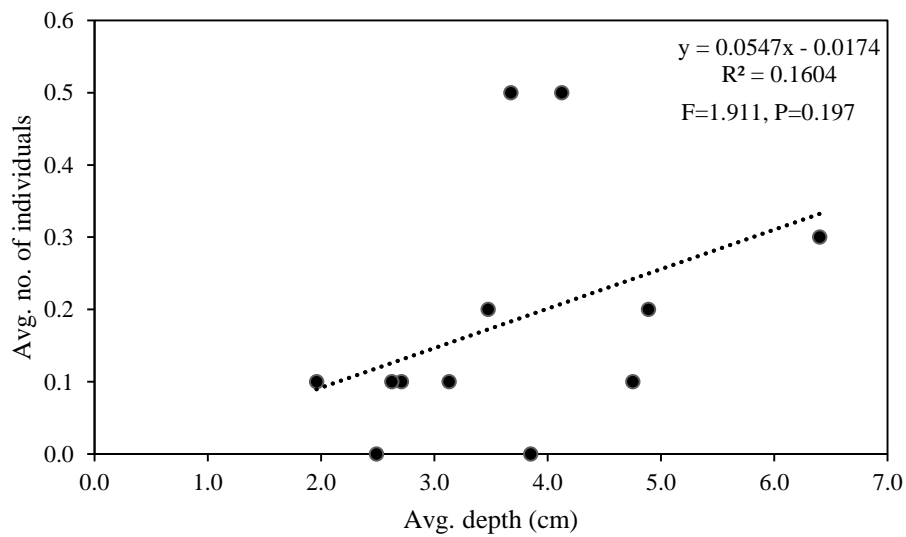
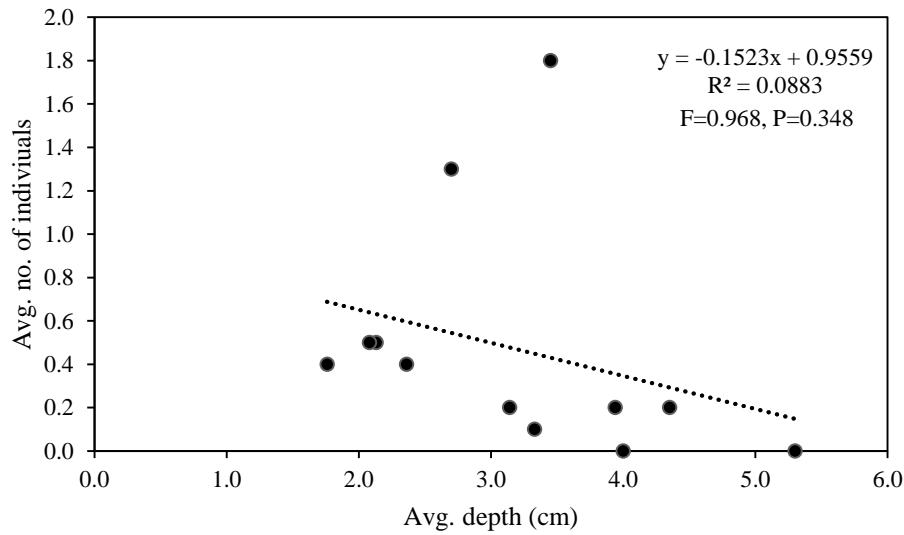


Figure 6. Average numbers of carabid individuals as influenced by depth (cm) of leaf litter. Collections were made monthly by Berlese sampling at Lake Wedington (a) and Lake Wilson (b), Washington County, Arkansas, from April 2014 to March 2015.

(a)



(b)

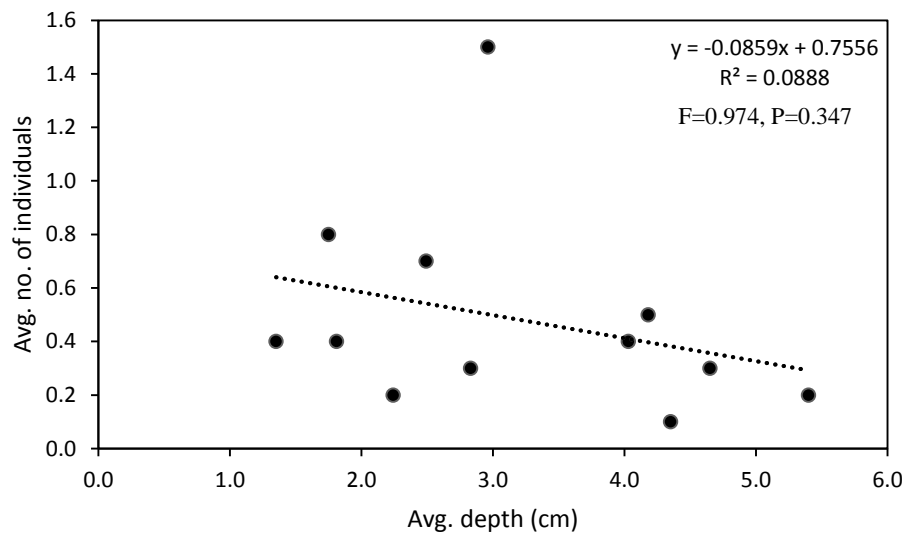
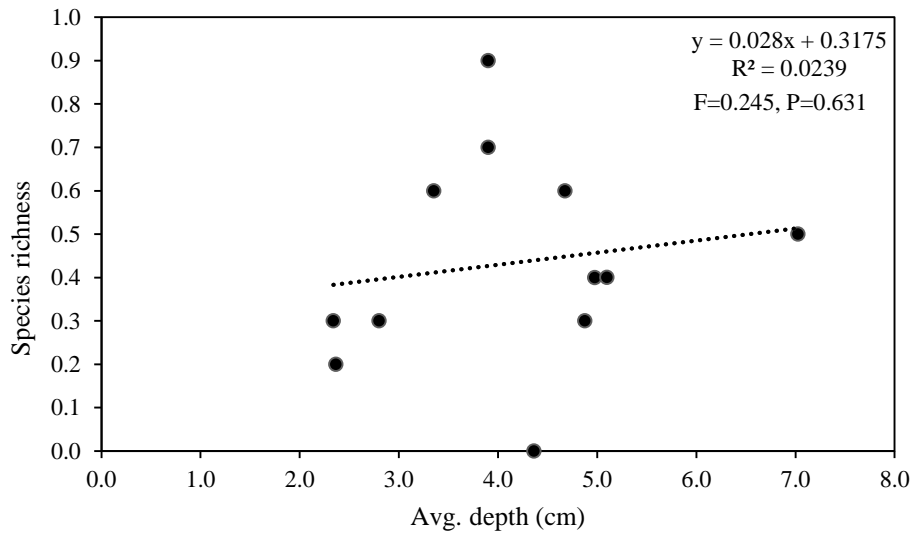


Figure 7. Average numbers of carabid individuals as influenced by depth (cm) of leaf litter. Collections were made monthly by Berlese sampling at Withrow 1 (a) and Withrow 2 (b), Washington County, Arkansas, from April 2014 to March 2015.

(a)



(b)

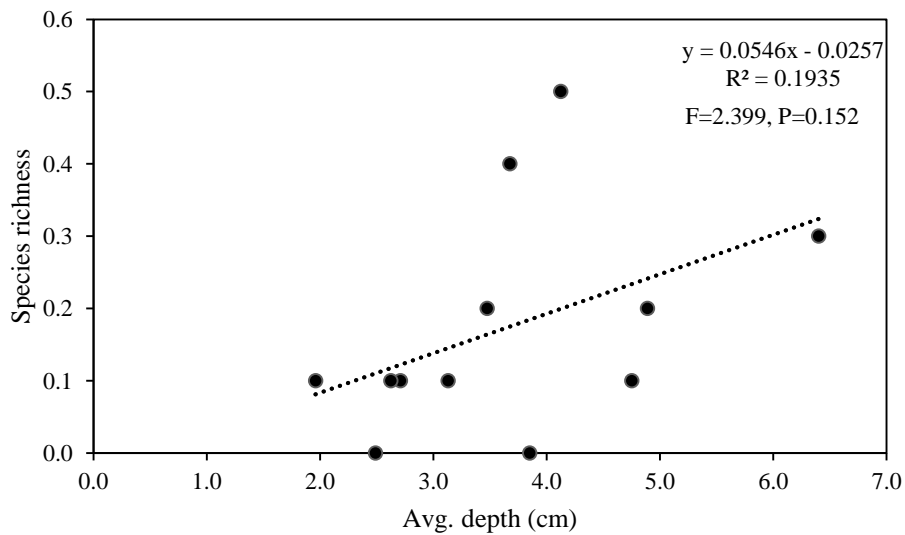
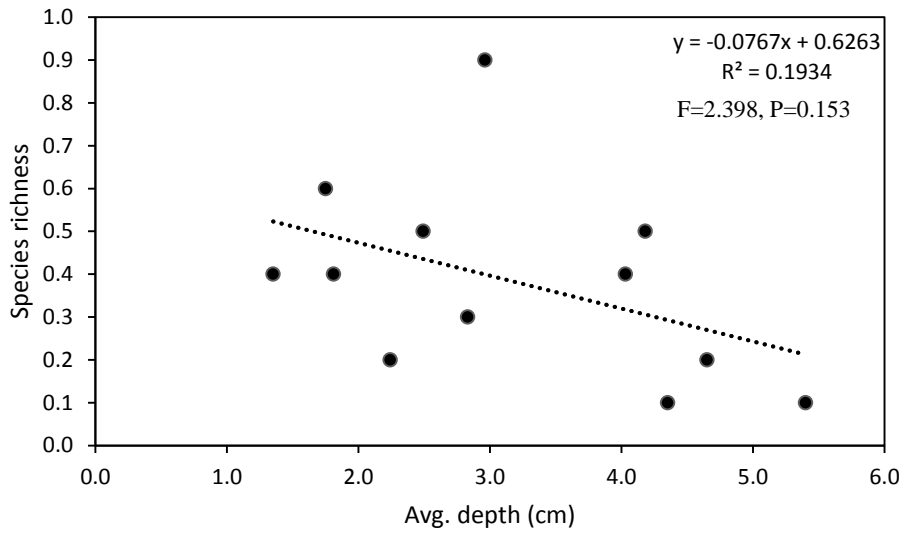


Figure 8. Species richness of carabid individuals as influenced by depth (cm) of leaf litter. Collections were made monthly by Berlese sampling at Lake Wedington (a) and Lake Wilson (b), Washington County, Arkansas, from April 2014 to March 2015.

(a)



(b)

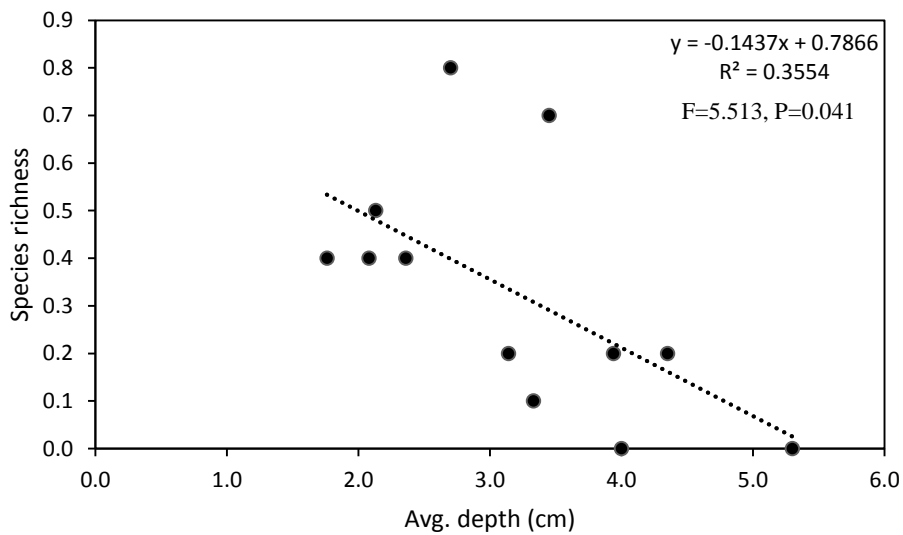


Figure 9. Species richness of carabid individuals as influenced by depth (cm) of leaf litter. Collections were made monthly by Berlese sampling at Withrow 2 (a) and Withrow 1 (b), Madison County, Arkansas, from April 2014 to March 2015.

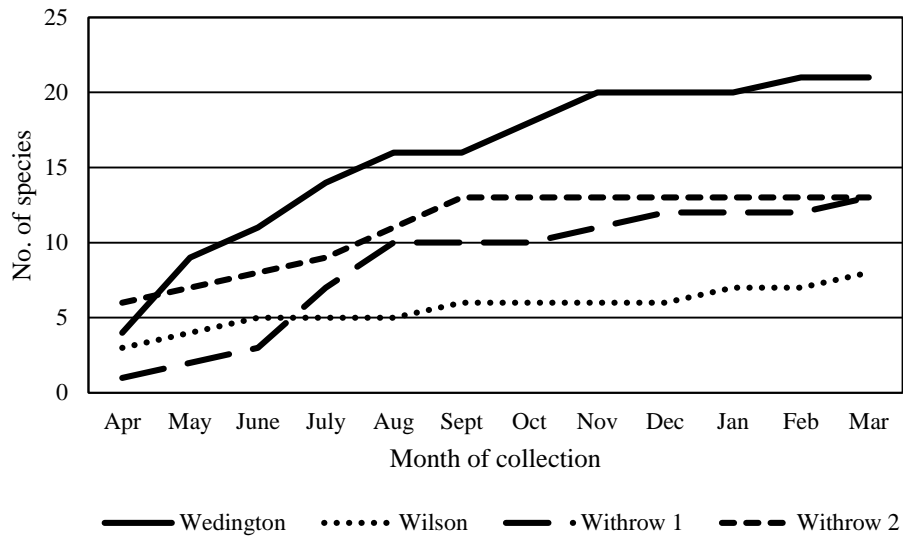
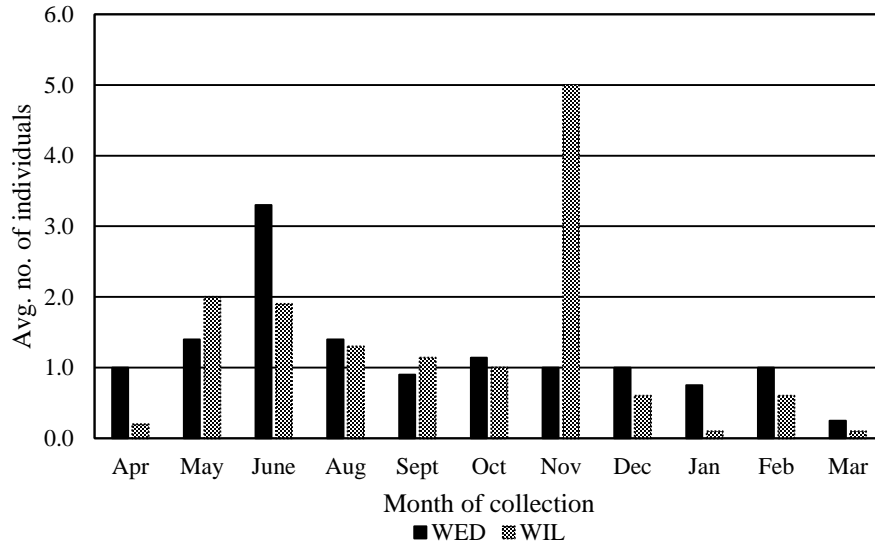


Figure 10. The numbers of carabid species accumulated monthly in Berlese samples at four sites (Lake Wedington, Lake Wilson, Withrow Springs 1&2) in Washington and Madison counties, Arkansas, from April 2014 to March 2015.

(a)



(b)

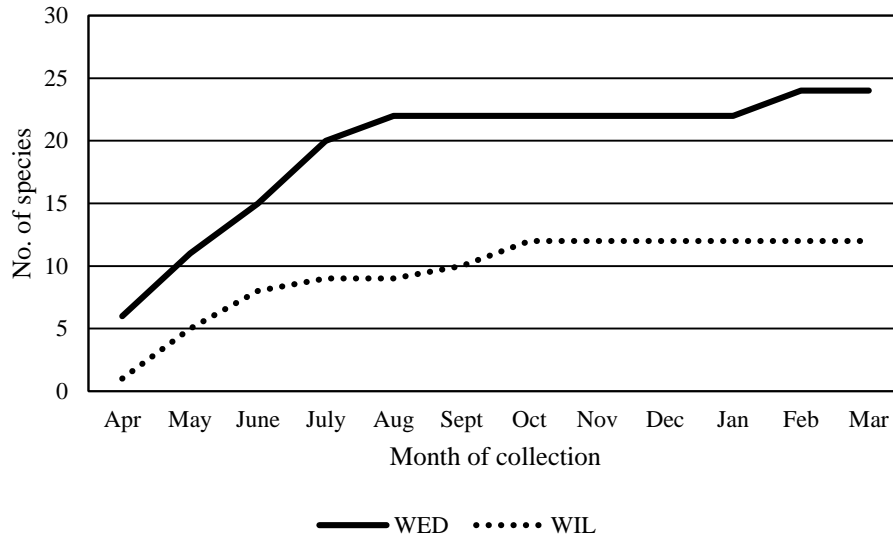
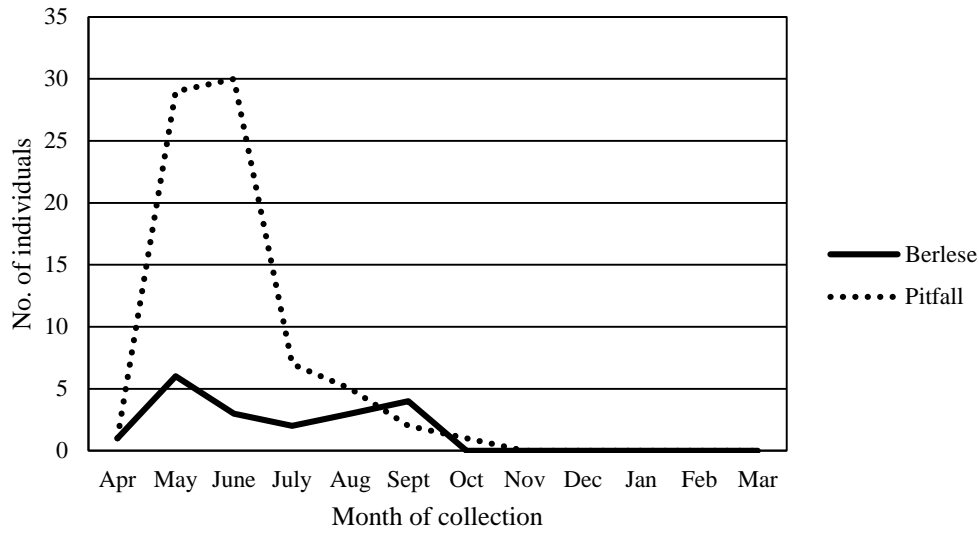


Figure 11. Average numbers of carabid individuals collected monthly in pitfall traps at Lake Wedington and Lake Wilson (a), Washington County, Arkansas, from April 2014 to March 2015. The numbers of carabid species accumulated monthly in pitfall traps at Lake Wedington and Lake Wilson (b) from 2014-2015.

(a)



(b)

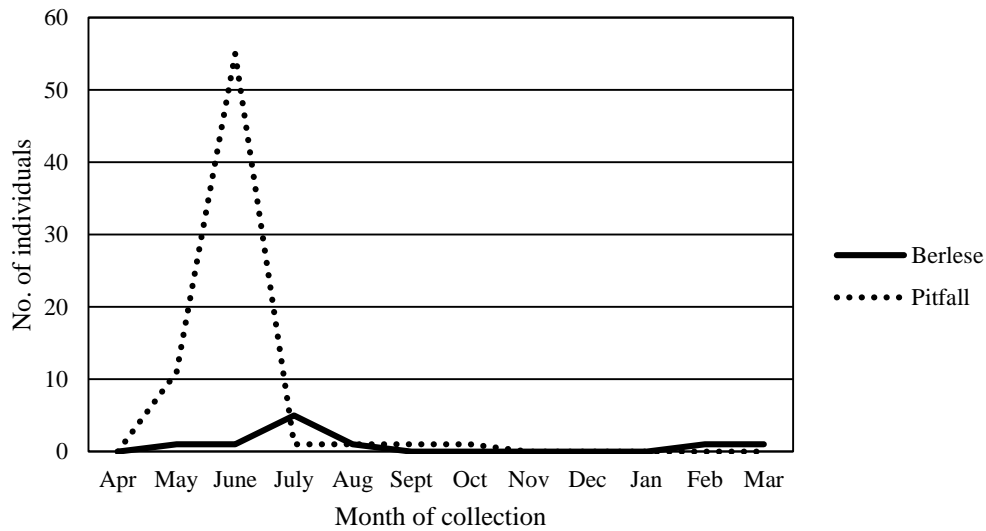
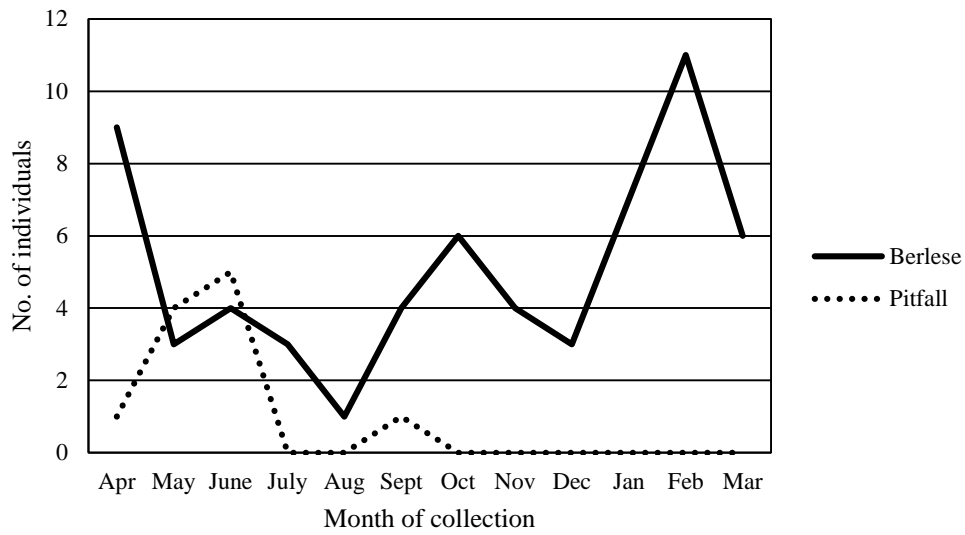


Figure 12. Numbers of individuals of *Zelotes duplex* (a) and *Talanites echinus* (b) collected over 12 months across all sites in Berlese and pitfall trap samples.

(a)



(b)

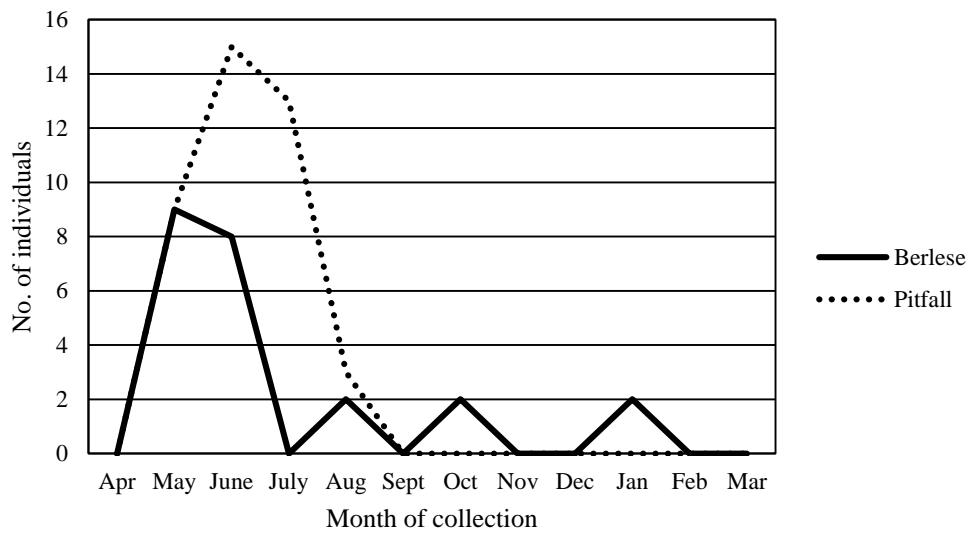


Figure 13. Numbers of individuals of *Drassyllus aprilinus* (a) and *Gnaphosa fontinalis* (b) collected over 12 months across all sites in Berlese and pitfall trap samples.

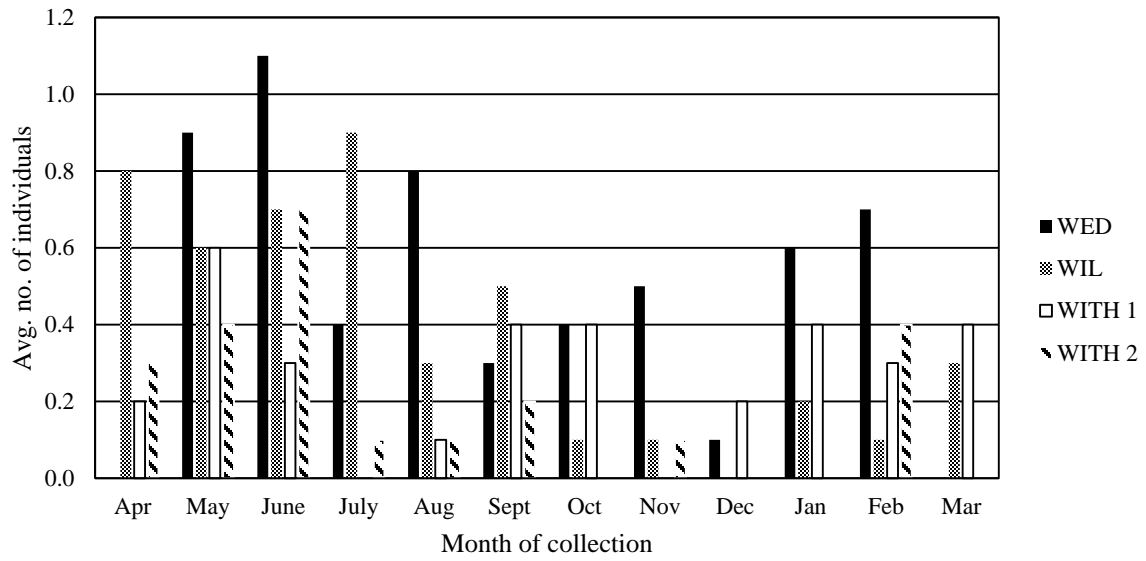
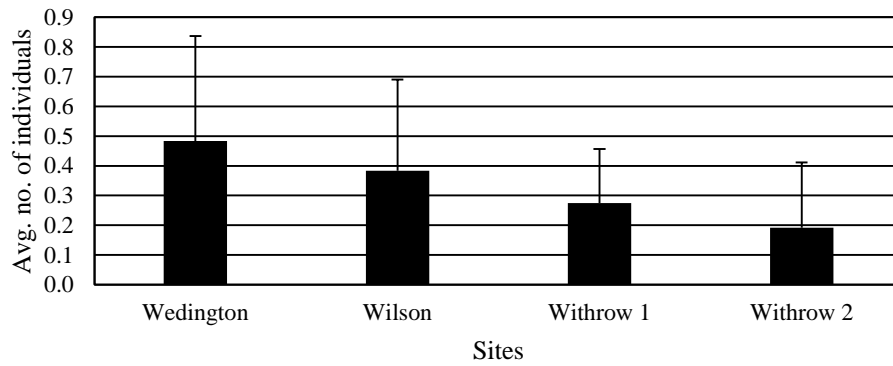


Figure 14. Average numbers of gnaphosid individuals collected monthly in Berlese samples at Lake Wedington, Lake Wilson, and Withrow Springs 1&2, Washington and Madison Counties, Arkansas, in 2014-2015.

(a)



(b)

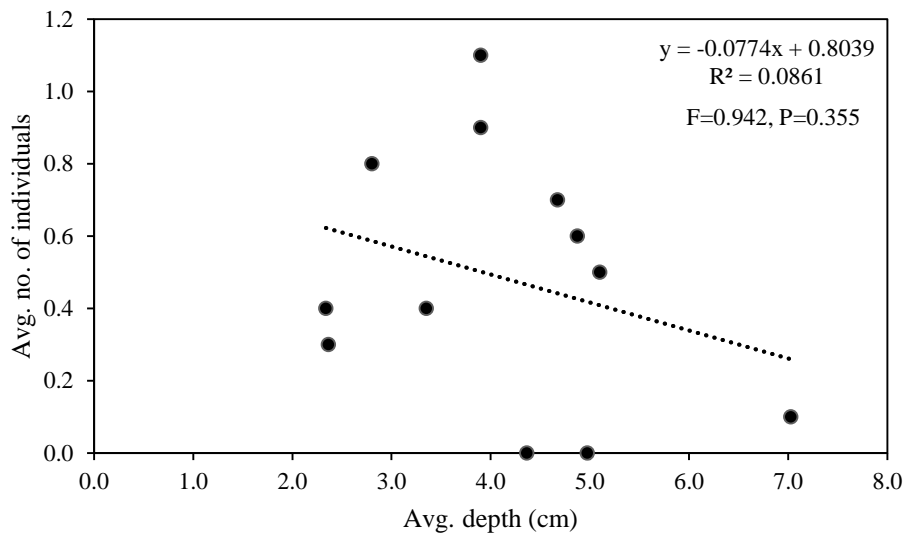


(c)



Figure 15. Average numbers of individual gnaphosids (a), species richness (b), and species diversity (c) for Berlese samples collected at four sites in Washington and Madison counties, Arkansas, from April 2014 to March 2015. Error bars above each of the means represent the standard deviation.

(a)



(b)

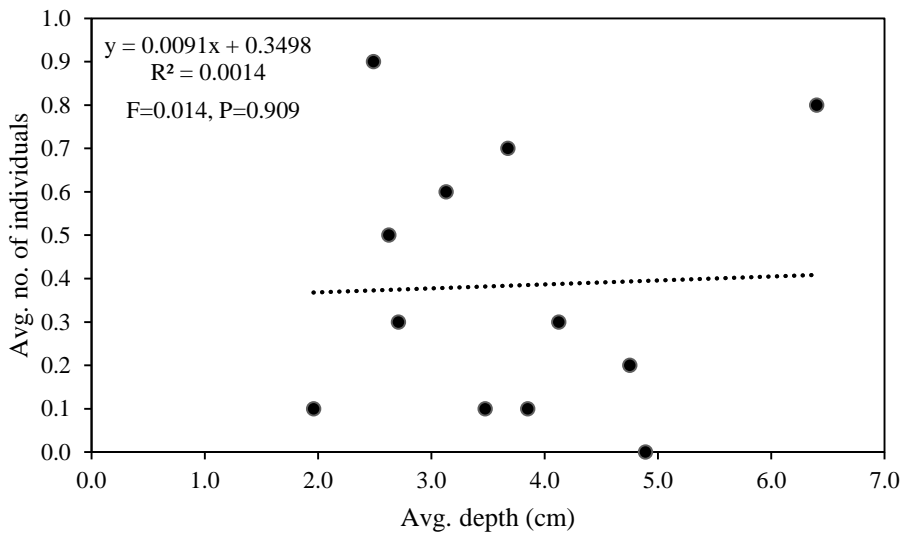


Figure 16. Average numbers of gnaphosid individuals as influenced by depth (cm) of leaf litter. Collections were made monthly by Berlese sampling at Lake Wedington (a) and Lake Wilson (b), Washington County, Arkansas, from April 2014 to March 2015.

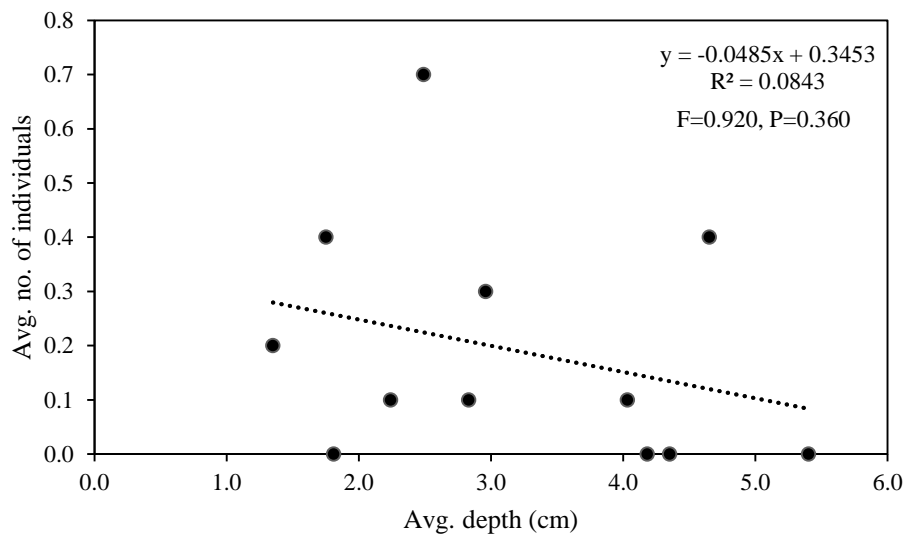
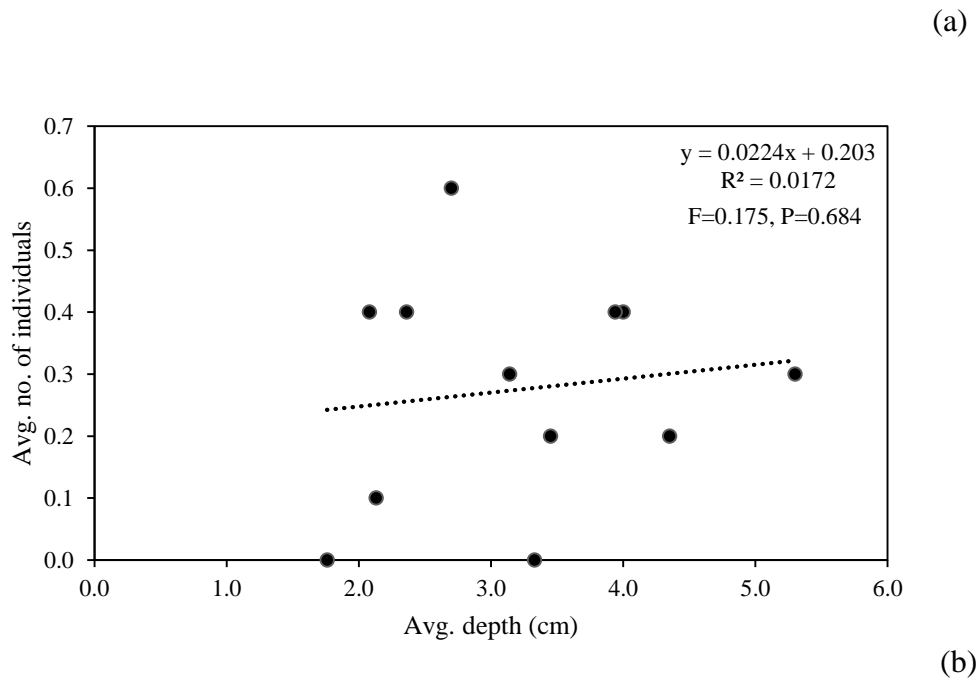


Figure 17. Average numbers of gnaphosid individuals as influenced by depth (cm) of leaf litter. Collections were made monthly by Berlese sampling at Withrow 1 (a) and Withrow 2 (b), Madison County, Arkansas, from April 2014 to March 2015.

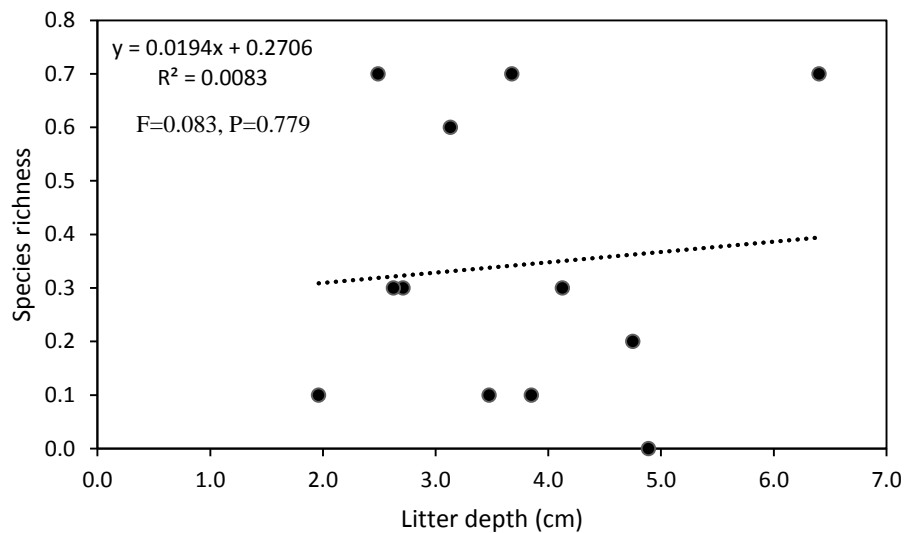
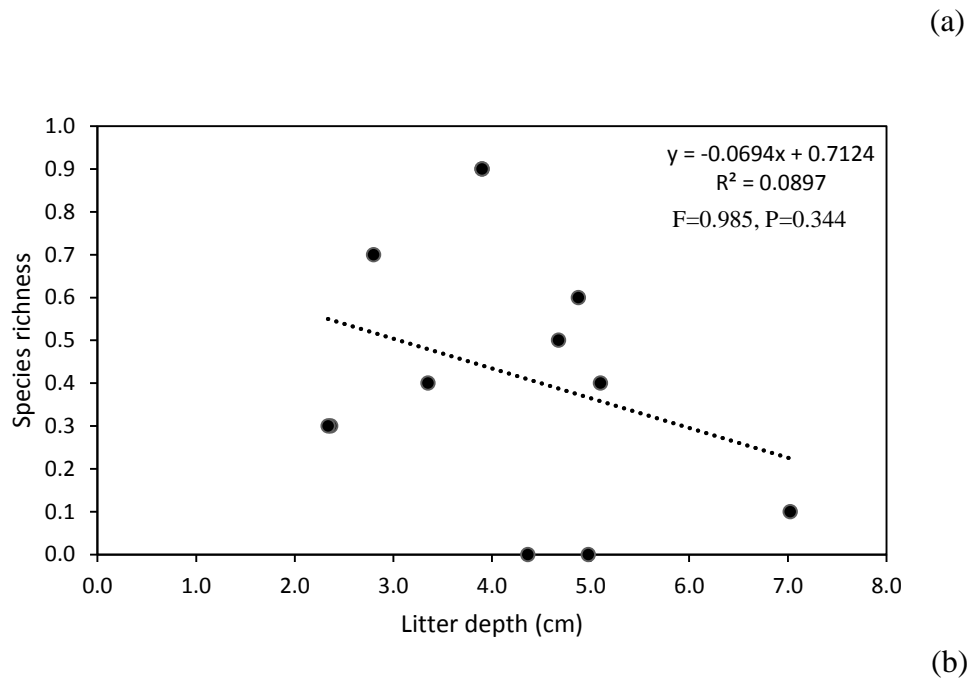
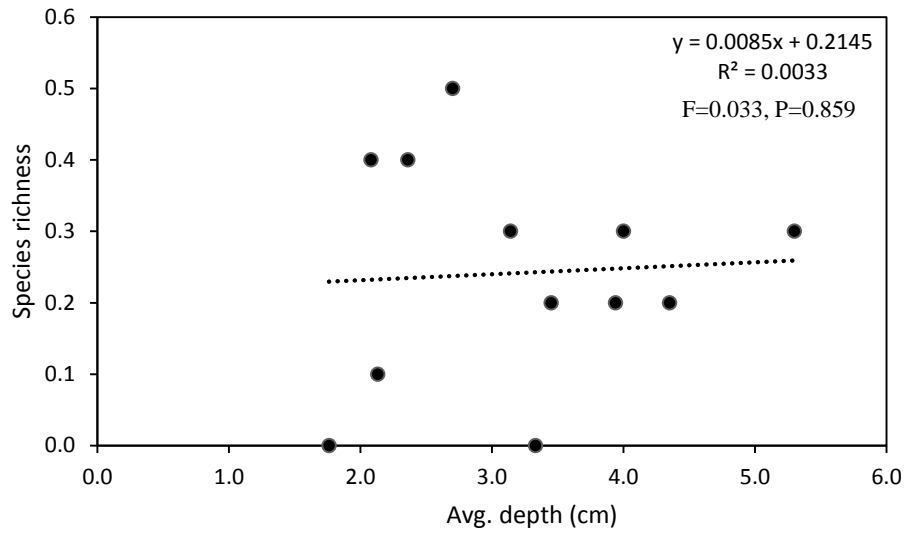


Figure 18. Species richness of gnaphosid individuals as influenced by depth (cm) of leaf litter. Collections were made monthly by Berlese sampling at Lake Wedington (a) and Lake Wilson (b), Washington County, Arkansas, from April 2014 to March 2015.

(a)



(b)

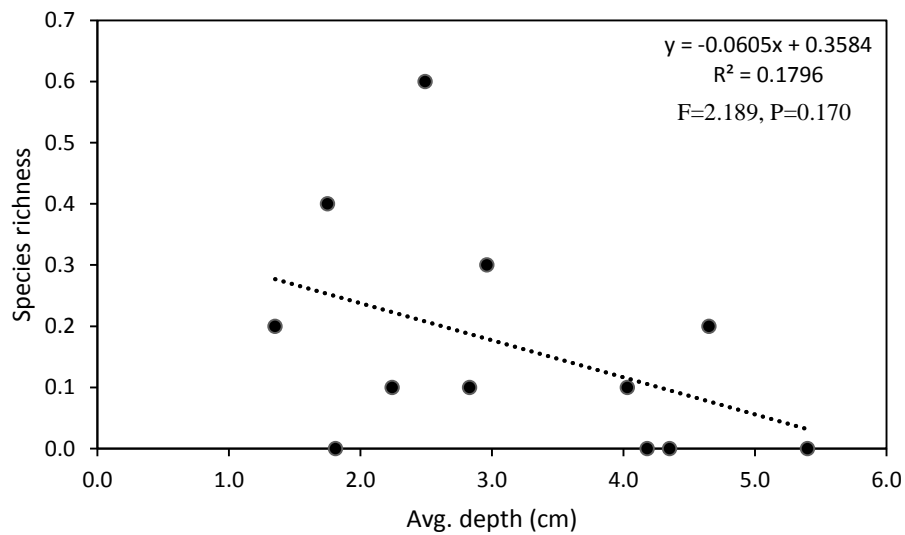


Figure 19. Species richness of gnaphosid individuals as influenced by depth (cm) of leaf litter. Collections were made monthly by Berlese sampling at Withrow 1 (a) and Withrow 2 (b), Madison County, Arkansas, from April 2014 to March 2015.

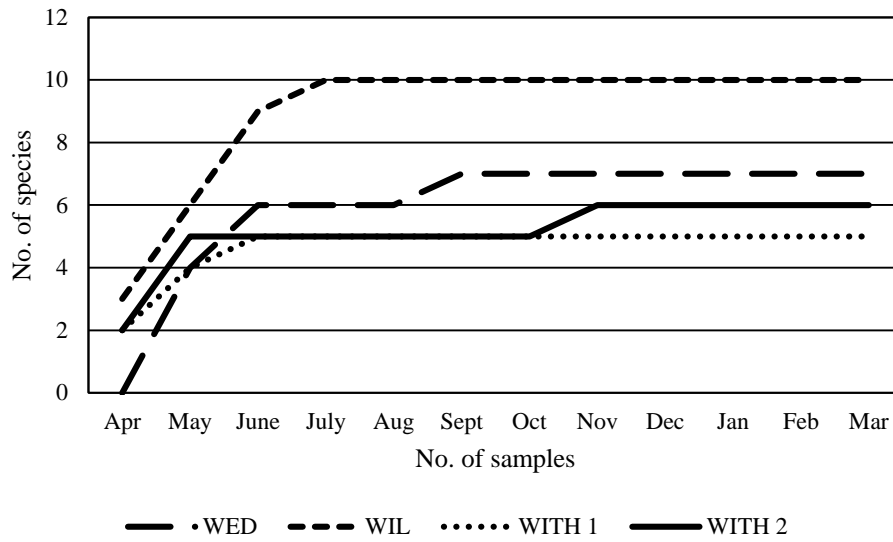
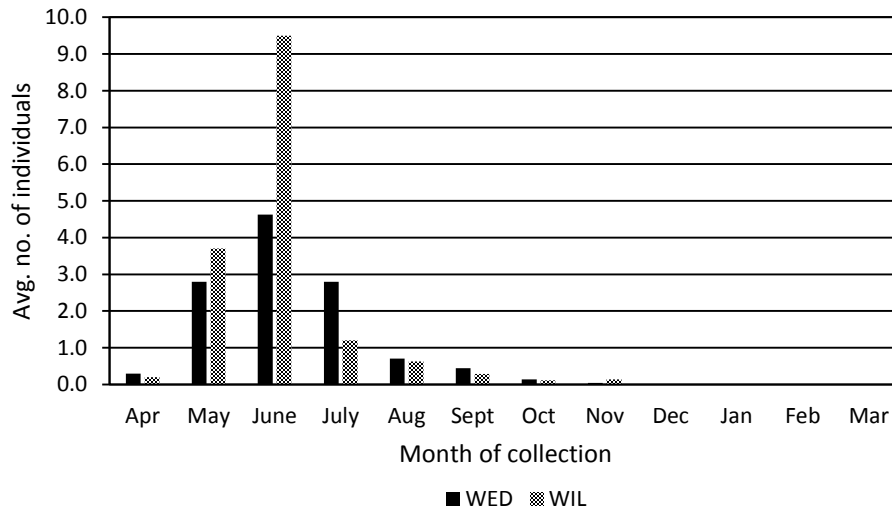


Figure 20. The numbers of gnaphosid species accumulated monthly in Berlese samples at four sites (Lake Wedington, Lake Wilson, Withrow Springs 1&2) in Washington and Madison counties, Arkansas, from April 2014 to March 2015.

(a)



(b)

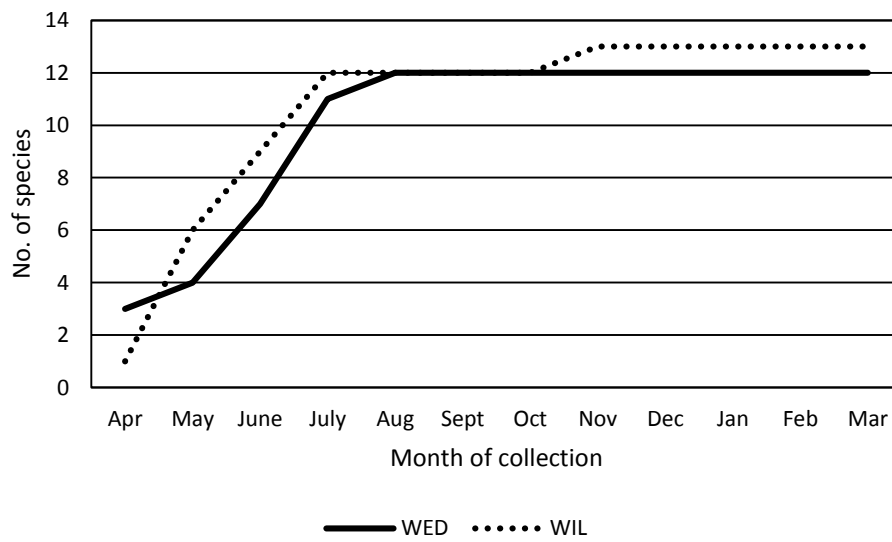


Figure 21. Average numbers of gnaphosid individuals collected monthly in pitfall traps at Lake Wedington and Lake Wilson (a), Washington County, Arkansas, from April 2014 to March 2015. Numbers of species accumulated in pitfall traps at Lake Wedington and Lake Wilson (b) from 2014-2015.

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CONCLUSION

Leaf litter in the deciduous forests of the Ozark Mountains of Arkansas was sampled for a year to examine the temporal variation of Carabidae and Gnaphosidae. Prior to this study, the presence, diversity, and abundance of these two groups were unknown in the area. Despite the amount of biodiversity found in this region, leaf litter has not been the focus of many detailed studies.

Through 12 months of collecting, carabids and gnaphosids were found to be highest in diversity and abundance during the spring. Although many species of both taxa were collected during the spring, some species of carabids were collected only during the fall and winter months including: *Scaphinotus* sp., *Lebia fuscata*, *Cymindis platicollis*, *Lebia viridis*, *Bembidion rapidum*, and *Lebia collaris*. My research has shown the effectiveness of using a variety of methods to capture leaf litter arthropods since some species were collected in only one trap type. This research has also demonstrated the importance of collecting at multiple sites over multiple months since some species were collected at only one site during one month.

To gain further insight into the seasonality patterns of litter arthropods in this region, studies should be conducted for more than one year. One year of data is not sufficient enough to conclude that a peak present is seasonal, but can only be used to describe abundance and activity over the course of a year (Wolda 1988). Ground temperature and moisture content of the leaf litter are additional factors that would be important to measure over 12 months when describing the phenology of leaf litter arthropods.

FUTURE RESEARCH

Two important factors that were not measured in this study were ground temperature and litter moisture content. Leaf litter depth was the only variable measured and the two other factors could have contributed to the presence or absence of carabids and gnaphosids throughout the year. Levings and Windsor (1984) found that there is a positive association between litter moisture content and Coleoptera abundance and a negative association between litter moisture content and Araneae abundance. Ground temperature and litter moisture content measurements should be taken for leaf litter collections each month. To obtain these measurements, a hygrothermograph can be used to measure the ground temperature and the moisture content can be obtained by collecting a sample of the top layer of soil, weighing it, drying it in an oven at 125° for one hour and then reweighing the sample to determine the percent moisture (Pearson and Derr 1986).

Only adults of carabids and gnaphosids were identified to species in this study and it would be beneficial to have data on the immatures to allow for a more complete picture of the seasonal variation of both taxa. Carabid larvae can be identified to species, whereas gnaphosid spiderlings may only be identified to genus level since fully developed genitalia are necessary for species level identification. However, certain species of immature gnaphosids can be accurately identified based on distinct body patterns (i.e., *Cesonia bilineata* and *Sergiolus capulatus*).

Many other families within Coleoptera and Araneae were prevalent in the leaf litter and pitfall trap samples and could be used for future seasonal studies dependent upon the questions being asked. Common beetle families found in the samples included: Chrysomelidae, Curculionidae, Nitidulidae, Scarabaeidae, Staphylinidae, and Tenebrionidae. Other common

spider families found in the samples included: Dictynidae, Linyphiidae, Lycosidae, Phrurolithidae, Salticidae, and Thomisidae.

In addition to other factors and groups requiring examination, changes to the field work would also need to occur for it to become more efficient and less labor intensive. Field collections for each month took approximately 12 hours with additional help. To shorten the time out in the field, changes would need to be made to the leaf litter and pitfall trap collection methods. A larger leaf litter reducer would need to be used that has a collection bag deeper than 1 m and openings in the wire sieve greater than 10 mm x 10 mm to allow for faster processing of deeper samples and to ensure larger arthropods are being collected. Litter depth should be measured outside of the sampling frame to lessen the amount of disturbance in the sample before collection and reduce the number of escapees. Pitfall trap collection could also be made more efficient by not straining the samples through a sieve out in the field, but rather transferring the samples into Whirl-Pak® bags large enough to contain them for later processing in the lab.

Six hundred and eighty-eight samples were collected over the duration of this study. These samples contain many more specimens that need to be identified to gain further insight of the diversity of arthropod species found within the oak-hickory forests of Northwest Arkansas. This study serves as a basis for future studies in assessing the diversity and abundance of leaf litter arthropods found within the Ozark Mountains.

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APPENDIX I. Species and numbers of carabid individuals collected by each method at each site.

Lake Wedington	Berlese	Pitfall	Total
<i>Agonoleptus conjunctus</i>	1	0	1
<i>Agonum octopunctatum</i>	6	1	7
<i>Agonum punctiforme</i>	2	0	2
<i>Agonum</i> sp. 3	2	0	2
<i>Amara aenea</i>	0	2	2
<i>Amara musculis</i>	1	0	1
<i>Amara</i> sp. 3	2	1	3
<i>Anisodactylus rusticus</i>	1	0	1
<i>Apenes sinuata</i>	5	1	6
<i>Bembidion rapidum</i>	0	1	1
<i>Calathus opaculus</i>	2	5	7
<i>Calosoma scrutator</i>	0	1	1
<i>Carabus sylvosus</i>	0	11	11
<i>Chlaenius emarginatus</i>	0	1	1
<i>Cicindela sexguttata</i>	0	2	2
<i>Cyclotrachelus incisus</i>	0	11	11
<i>Cyclotrachelus parasodalis</i>	0	52	52
<i>Cyclotrachelus seximpressus</i>	0	15	15
<i>Cyclotrachelus sodalis</i>	0	7	7
<i>Cyclotrachelus whitcombi</i>	0	1	1
<i>Cymindis platicollis</i>	1	0	1
<i>Dicaelus ambiguus</i>	0	1	1
<i>Dicaelus elongatus</i>	2	1	3
<i>Dicaelus sculptilis</i>	1	0	1
<i>Galerita atripes</i>	0	1	1
<i>Galerita bicolor</i>	0	2	2
<i>Harpalus pensylvanicus</i>	0	1	1
<i>Lebia collaris</i>	2	0	2
<i>Lebia fuscata</i>	1	0	1
<i>Lebia grandis</i>	1	0	1
<i>Lebia solea</i>	4	0	4

Lake Wedington Cont.	Berlese	Pitfall	Total
<i>Notiophilus novemstriatus</i>	0	1	1
<i>Pterostichus permundus</i>	1	0	1
<i>Pterostichus punctiventris</i>	6	24	30
<i>Tachys columbiensis</i>	2	0	2
<i>Trichotichnus autumnalis</i>	14	12	26
<i>Trichotichnus fulgens</i>	1	1	2
Grand Total	58	156	214

Lake Wilson	Berlese	Pitfall	Total
<i>Amara musculus</i>	1	0	1
<i>Apenes sinuata</i>	2	0	2
<i>Chlaenius aestivus</i>	0	1	1
<i>Chlaenius laticollis</i>	0	1	1
<i>Chlaenius platyderus</i>	0	3	3
<i>Cicindela sexguttata</i>	0	6	6
<i>Cyclotrachelus parasodalis</i>	0	213	213
<i>Dicaelus ambiguus</i>	0	1	1
<i>Dicaelus elongatus</i>	2	5	7
<i>Lebia collaris</i>	1	0	1
<i>Lebia viridis</i>	1	0	1
<i>Notiophilus novemstriatus</i>	8	17	25
<i>Pterostichus permundus</i>	5	39	44
<i>Scaphinotus</i> sp.	0	2	2
<i>Scarites subterraneus</i>	0	6	6
<i>Trichotichnus autumnalis</i>	2	1	3
Grand Total	22	295	317

Withrow Springs	Berlese	Berlese
Taxa	Site 1	Site 2
<i>Agonoleptus conjunctus</i>	1	0
<i>Agonum punctiforme</i>	1	0
<i>Agonum</i> sp. 3	1	0
<i>Amara musculis</i>	0	1
<i>Amara</i> sp. 3	0	1
<i>Amara</i> sp. 4	0	1
<i>Apenes sinuata</i>	2	1
<i>Calathus opaculus</i>	2	2
<i>Cyclotrachelus incisus</i>	0	3
<i>Cyclotrachelus seximpressus</i>	1	1
<i>Cymindis limbata</i>	3	1
<i>Harpalus erythropus</i>	1	0
<i>Lebia viridis</i>	1	0
<i>Notiophilus novemstriatus</i>	10	18
<i>Pterostichus permundus</i>	0	2
<i>Pterostichus punctiventris</i>	1	2
<i>Synuchus impunctatus</i>	1	1
<i>Trichotichnus autumnalis</i>	31	24
Grand Total	56	58

APPENDIX II. Data used for construction of the Carabidae accumulation curves for each site and method.

Wilson-Berlese	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
Total # individuals	3	1	5	0	1	1	1	2	2	1	0	5
Total # species	3	1	3	0	1	1	1	2	2	1	0	2
# species accumulated	3	1	1	0	0	1	0	0	0	1	0	1
Total # species accumulated	3	4	5	5	5	6	6	6	6	7	7	8

Wedington-Berlese	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
Total # individuals	4	13	7	8	3	2	3	4	5	3	6	0
Total # species	4	5	5	6	3	2	3	4	5	3	4	0
# species accumulated	4	5	2	3	2	0	2	2	0	0	1	0
Total # species accumulated	4	9	11	14	16	16	18	20	20	20	21	21

Withrow 1-Berlese	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
Total # individuals	18	13	2	4	5	4	5	1	2	0	0	2
Total # species	1	2	2	4	4	4	2	1	2	0	0	2
# species accumulated	1	1	1	4	3	0	0	1	1	0	0	1
Total # species accumulated	1	2	3	7	10	10	10	11	12	12	12	13

Withrow 2-Berlese	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
Total # individuals	15	8	7	3	2	4	4	4	2	1	3	5
Total # species	6	3	2	2	2	4	2	3	1	1	2	2
# species accumulated	6	1	1	1	2	2	0	0	0	0	0	0
Total # species accumulated	6	7	8	9	11	13	13	13	13	13	13	13

Wilson-Pitfall	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
Total # individuals	2	15	19	182	10	8	10	35	6	1	6	1
Total # species	1	4	6	6	3	3	3	5	3	1	1	1
# species accumulated	1	4	3	1	0	1	0	2	0	0	0	0
Total # species accumulated	1	5	8	9	9	10	10	12	12	12	12	12

Wedington-Pitfall	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
Total # individuals	10	14	26	52	10	8	8	4	7	6	9	2
Total # species	6	7	7	9	7	2	3	3	3	1	4	2
# species accumulated	6	5	4	5	2	0	0	0	0	0	2	0
Total # species accumulated	6	11	15	20	22	22	22	22	22	22	24	24

APPENDIX III. Data used for construction of the Gnaphosidae accumulation curves for each site and method.

Wilson-Berlese	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
Total # individuals	8	6	7	9	3	5	1	1	0	2	1	3
Total # species	3	6	5	4	3	2	1	1	0	1	1	2
# species accumulated	3	3	3	1	0	0	0	0	0	0	0	0
Total # species accumulated	3	6	9	10	10	10	10	10	10	10	10	10

Wedington-Berlese	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
Total # individuals	0	9	11	4	8	3	4	5	1	6	7	0
Total # species	0	4	5	2	3	2	2	2	1	4	2	0
# species accumulated	0	4	2	0	0	1	0	0	0	0	0	0
Total # species accumulated	0	4	6	6	6	7	7	7	7	7	7	7

Withrow 1-Berlese	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
Total # individuals	2	6	3	0	1	4	4	0	2	4	3	4
Total # species	2	4	3	0	1	3	2	0	1	2	1	1
# species accumulated	2	2	1	0	0	0	0	0	0	0	0	0
Total # species accumulated	2	4	5	5	5	5	5	5	5	5	5	5

Withrow 2-Berlese	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
Total # individuals	3	4	7	1	1	2	0	1	0	0	4	0
Total # species	2	4	3	1	1	2	0	1	0	0	1	0
# species accumulated	2	3	0	0	0	0	0	1	0	0	0	0
Total # species accumulated	2	5	5	5	5	5	5	6	6	6	6	6

Wilson-Pitfall	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
Total # individuals	2	37	95	12	5	2	1	1	0	0	0	0
Total # species	1	5	8	7	2	2	1	1	0	0	0	0
# species accumulated	1	5	3	3	0	0	0	1	0	0	0	0
Total # species accumulated	1	6	9	12	12	12	12	13	13	13	13	13

Wedington-Pitfall	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
Total # individuals	3	28	37	28	5	4	1	0	0	0	0	0
Total # species	3	3	6	8	3	3	1	0	0	0	0	0
# species accumulated	3	1	3	4	1	0	0	0	0	0	0	0
Total # species accumulated	3	4	7	11	12	12	12	12	12	12	12	12