CHARACTERIZATION OF GROUND-DWELLING ARTHROPOD ASSEMBLAGES IN NORTHERN BOBWHITE (*COLINUS VIRGINIANUS*) HABITAT.

By

SHANE FOYE

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IN NORTHERN

BOBWHITE (*COLINUS VIRGINIANUS*) HABITAT.

Thesis Approved:

Dr. Carmen Greenwood

Thesis Adviser

Dr. Phil Mulder

Committee Member

Dr. Tyson Ochsner

Committee Member

Dr. Kris Giles

Committee Member

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Abstract: Northern bobwhites (*Colinus virginianus*) have been in decline over the past 50 years. Although land management practices, and habitat loss and degradation are known contributors to bobwhite decline, it is less certain whether the availability of arthropod forage taxa contribute to decreases in bobwhite populations. Despite the fact that brooding hens and chicks rely heavily on arthropod forage taxa for protein, fats, water, and micronutrients, little research has been done characterizing ground-dwelling arthropod communities in terms of richness, abundance, size class, and evenness in areas occupied by quail. During the summers of 2012 and 2013, we investigated these community characteristics by collecting arthropods using pitfall traps placed in vegetation zones quail are known to occupy in the Beaver and Packsaddle Wildlife Management Areas (WMA) of western Oklahoma. Differences in arthropod relative abundance were quantified using a split plot arrangement in a randomized complete block design with repeated measures, where each transect was considered a block, each habitat type a main unit factor, and each size class a split unit factor, with an autoregressive period 1 covariance structure used to compare correlations within traps and across dates and planned contrasts used to compare simple effects of habitat type given size class and date. During 2012 in Beaver WMA, arthropod relative abundance was higher later in the summer. During 2013 in Beaver WMA, arthropod relative abundance was higher in the middle of the summer and during 2013 in Packsaddle WMA arthropod relative abundance was higher towards the end of the summer. In different zones and on different sampling dates, differences in arthropod relative abundance were detected when comparing arthropods of the same size class in different zones in both the Beaver and Packsaddle WMA. Although quail appear to have enough arthropod forage taxa available later in the season, there also appear to be time intervals in both Beaver and Packsaddle WMAs during the early part of the brooding season where arthropod forage taxa tend to be scarce relative to what is suggested to be sufficient in previous studies.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Introduction

Colinus virginianus (Galliformes: Odontophoridae), commonly known as the northern bobwhite, are native to the Midwestern United States, Mexico, and parts of the Caribbean. *C. virginianus* are ground-dwelling birds named for their “bob-white” mating call. Bobwhites are small, round-bodied gallinaceous birds 24 to 27 cm long (Roseberry 1984). *C. virginianus* males are indicated by a white band across the eye, with a white underbelly and reddish brown feathers on the upper body. Bobwhites currently occupy a range extending from Mexico to Wisconsin, from the Midwest to eastern United States (Giuliano et al. 1995, Lusk et al. 2001).

Bobwhite populations increased across this range throughout the late 1800’s and early 1900’s due to diversified land use practices such as clearing forests for small farm plots, open grazing of cattle, and rotational cropping (Lusk et al. 2001). Changes in land use practices, such as intensive grazing, restricted use of fire in timber forests, and joining patchwork fields into increasingly large tracts of land have contributed to steep declines in bobwhite populations over the past 50 years (Cain and Lien 1985). This decline is concerning because bobwhites are the most popular game birds in Indiana, Georgia, Missouri, and Oklahoma, with approximately 1.7 million registered bobwhite hunters nationally (White et al. 2005).

One factor implicated in the decline of bobwhites is a lack of suitable arthropod forage taxa (Doxon and Carroll 2010). Northern bobwhite chicks receive approximately 80- 95% of their calories from arthropods (Doxon and Carroll 2010). Brooding hens also rely heavily on arthropods to get enough protein and micronutrients to complete the brooding process (Doxon and Carroll 2010, McNaughton and Haymes 1975). Bobwhite gut content analyses confirm Orthoptera, Coleoptera, Hemiptera, Hymenoptera, and Aranea are typically the most common arthropods in quail diets (Harveson et al. 2004). This research primarily focuses on ground-dwelling arthropods from those groups that are found in grassland ecosystems in western Oklahoma.

Previous studies on bobwhite forage communities often analyze the communities at the ordinal level and record primarily biomass of collected arthropods (Doxon and Carroll 2010). This approach overlooks differences in terms of abundance, diversity, evenness, and richness in quail habitat that may affect the quality and availability of arthropod forage. Understanding the diversity and evenness of arthropod communities at the family level is relevant for a variety of different reasons.

Different arthropods are available to bobwhites at varying times of the year and at different life stages. Arthropods also tend to be distributed differently within the landscape based upon vegetation profiles, vertical structure and other biotic and abiotic factors. Total biomass or abundance of arthropods within a system may not necessarily reflect availability of suitable forage taxa or availability in the habitats frequented by quail chicks at the most critical time in their development. Most arthropods peak in abundance later in the summer, during the months of July and August (Vikram Reddy and Venkataiah 1990). Chrysomelidae are often abundant in the spring relative to other arthropods (Hammack et al. 2010). Nymphal stages of grasshoppers are often abundant relative to other arthropods in the early months of the summer (Copock 1962). Both of these taxa have been documented as preferred forage of quail chicks (Doxon and Carroll 2010).

Different arthropods contain different levels of nutrients, which may explain why bobwhites are known to eat a diverse assortment of arthropods (Doxon and Carroll 2010). All quail need certain nutrients such as Zinc, Iron, Calcium, fats, proteins, and carbohydrates in order to have fully functioning immune systems (Lochmiller et al. 1993). Quail must consume 1,200 kilocalories per 2.2kg of bodyweight when brooding, as well as higher quantities of potassium, calcium, magnesium, Vitamin B, and thiamin (McNaughton and Haymes 1975). Larval and adult arthropods provide different nutritional value in terms of calcium, magnesium, potassium, iron, fats, proteins, and water, which may explain why quail eat a variety of both immature and mature arthropods (Studier and Sevick 1992). Insects in the orders Lepidoptera and Coleoptera are often good sources of fats and proteins, while the family Formicidae is usually a good source of Zinc (Studier and Sevick 1992).

Literature suggests bobwhites prefer “bite sized” arthropods over larger ones (Campbell-Kissock et al. 1985). Most bobwhite chicks are only a few centimeters tall, so a bite-sized arthropod for a chick would have to be less than a centimeter in length (Campbell-Kissock et al. 1985). Few studies have taken arthropod size into consideration when determining suitability of arthropod forage communities for both chicks and hens.

In addition to providing nutritional benefits to quail, arthropods benefit them indirectly because by supporting many processes that promote quality quail habitat, including; pollination, decomposition, and altering plant communities by moving seeds and establishing relationships with plant species (Canner et al. 2012, Meurisse et al. 1999, Vergara and Badano 2009). Arthropods that provide ecological services are sorted into "functional groups" based on the type of service they provide.

Examples of functional groups common among ground-dwelling arthropods include fungivores, micropredators, macropredators, decomposers, and shredders (Meurisse et al. 1999). Fungivores perform the role of consuming fungi (Meurisse et al. 1999). Examples of fungivorous arthropods are springtails (Order: Collembola), many species of soil-dwelling mites (Orbatida and Cryptostigmata), many beetle taxa and a wide range of other invertebrates (Meurisse et al. 1999). Springtails have been associated with increased soil aggregate stability, suggesting that Springtails may promote soil health (Siddiky et al. 2012).

Increased aggregate stability may increase gas exchange within soils, reduce erosion, and contribute to the flow of nitrogen (Siddiky et al. 2012). Springtails are capable of consuming enough fungi to slow the rate of litter decomposition in grasslands, further suggesting springtails play an important role in grassland nutrient cycling (Eisenhauer et al. 2011). The health of the soil contributes to overall quail welfare by providing nutrition for the plants they consume and use as vegetative cover when nesting (Kim and An 2014). Vegetation supports the arthropod communities quail rely on for sustenance when they are brooding or developing as chicks (Bohan et al. 2005, Fay 2003). Fungivores are part of a larger functional grouping of decomposers, which includes shredders, bacterial grazers, and scavengers. These organisms play an important role in breaking down dead organic matter in a system and cycling nutrients.

Springtail abundances are highly dependent on available soil moisture (Greenwood et al. 2011). Rainfall events can trigger an abundance of springtails when they capitalize on fungal growth following rain events (Greenwood et al. 2011). Also, during rain events, the foraging and breeding activity of springtails greatly increases (Greenwood et al. 2011, Kim and An 2014, Pfander and Zettel 2004). Springtails resist summer desiccation by going dormant, and can also be brought out of dormancy when rainfall enables their body water content to rise above approximately 50% (Pfander and Zettel 2004). These traits are relevant to the study of bobwhite forage because they suggest springtails will be most available to chicks following rain events that punctuate extended periods of dryness. Although it is uncertain whether chicks consume springtails, many springtails provide food for other arthropods such as beetles that quail have been known to eat. The relationship of arthropod forage taxa to quail will be discussed in greater detail later in the literature review when arthropod communities present in quail habitat are described.

Due to the close relationship between quail and arthropods, this study will investigate whether the availability of arthropod forage communities may play a role in recent *C. virginianus* decline in Beaver and Packsaddle WMAs in Oklahoma. The two WMA's contain different vegetation zones, so arthropod communities will be compared in terms of relative abundance, diversity, richness, evenness, and homogeneity between the different zones over the course of the summer, with an emphasis placed on evaluating ground-dwelling arthropod forage taxa during times when quail chicks and hens feed most heavily on these taxa. This project will also examine arthropod relative abundance by size class, and the similarity of different arthropod communities in different zones will also be considered. The size classes used will be less than 2 mm in length, 2 mm to 5 mm in length, 5.1 mm to 10 mm in length, and 10.1 mm and above. We will also collaborate with botanists and ornithologists to gather more specific data about plants in the different vegetation zones and to determine which zones have the largest numbers of successful quail nests.

Northern Bobwhites

When not breeding, bobwhites live in small groups called coveys during the fall, summer, and spring. Multiple coveys come together in the winter and may disperse over the summer (Roseberry 1984). Bobwhites feed on insects and plants throughout the year depending on availability; however, bobwhite behavior varies based on the season.

Cold winter temperatures require bobwhites to huddle from January to approximately April. Despite this adaptive behavior, quail mortality is often highest during November and December, due in part to cold weather causing death by exposure or starvation. Surviving birds then form mating pairs in mid-April and construct nests by digging shallow indentations in the ground and lining the holes with grasses. Bobwhites typically seek out areas with forbs, tall grasses, and fescue to construct suitable nests, and rely on tall vegetation for concealment from nest predators. Nests are often within 75 feet of an open area for escape purposes. Typically 25% of nests are successful (Barnes et al. 1995).

Bobwhites breed from early April through September based on the climate; however, peak breeding activity throughout the United States is usually in June and July (Roseberry 1984). Bobwhites have recently been breeding only once per summer in Oklahoma, with peak breeding activity occurring during late April and early May (Roseberry 1984). They lay approximately 12 eggs that take 23 days to incubate, with possible re-nesting events if conditions related to plant cover and climate are appropriate (Roseberry 1984).

Quail brood from June to October, and show a preference for habitat with erect forbs and sparse leaf litter with enough bare ground for the chicks to move freely. Quail often prefer a habitat with more legumes, because increased legumes are associated with increased arthropod abundance. Ragweed (*Ambrosia* spp.), partridge pea (*Chamaecrista fasciculate*), and annual bush clovers (*Lespedeza* spp.) provide improved nutrition and support arthropods in Midwestern quail habitats compared to areas without these plants (Barnes et al. 1995).

Coveys will often fluctuate in size as the summer progresses. Birds will often group together shortly after breeding then disperse in the late summer and early fall, as part of a "fall shuffle" behavior. Optimal covey size includes approximately eleven birds, with smaller groups having lower group persistence and lower individual survival, and larger groups (15 – 22 birds) having lower masses per bird, lower than average individual survival, and increased movement (Williams et al. 2003). Coveys with approximately eleven birds forage more efficiently, and some anecdotal evidence suggests that they are better at avoiding avian predators (Williams et al. 2003).

When the final covey forms, it often includes young from multiple broods, and the covey will settle in a "headquarters" area, from which it will not move more than about a quarter mile as winter approaches (Roseberry 1984). This area needs to have shrubs, brambles, or small trees to protect the birds from extreme conditions. Quail prefer to roost on the ground, but will roost in trees if snow obscures too much of the ground for them to find suitable cover.

Despite the numerous and complicated facets that comprise quality quail habitat, a system of evaluating quail habitat quality has been devised called the Climate-Soil-Vegetation Type Interaction Model (Bidwell et al. 2013). This schematic enables land managers to determine whether habitat is suitable for quail so they can limit the resources spent on areas with "limited potential" and devote the majority of their resources to more promising areas. Sand sage grassland, Shinnery oak grassland, Mesquite grassland, Post oak/blackjack oak grassland, and other types of oak forests are known to be high potential quail nesting sites (Bidwell et al. 2013).

Although suitable vegetation, cover, and winter temperatures are important components of bobwhite habitat, abundant arthropod forage is also necessary to quail success. Arthropods serve as the food source for chicks and as an important dietary supplement for brooding hens. The relationship between bobwhites and arthropod forage taxa should therefore be elucidated to maximize the efficiency of conservation efforts.

Arthropod Forage Communities

The most abundant quail forage arthropods in grasslands are usually represented by the insect orders Coleoptera, Hymenoptera, Diptera, and Hemiptera (Fay 2003, Manske 2007). Ants are typically abundant in dry ecosystems and are therefore likely prey items for quail in dry habitats like Beaver and Packsaddle (Eisenhauer et al. 2010). Springtails are often the most abundant arthropods in grasslands, however some springtails go dormant during the hottest parts of the summer, therefore it is important to identify which springtails are located in quail habitat and at what times (Pfander and Zettel 2004). Since arthropod abundance is typically lowest early in the summer, and quail usually brood during that time, arthropods may be scarce when hens and chicks rely upon them most heavily for brooding and growth (Little et al. 2013).

Previous studies have been conducted in Texas to evaluate the possibility that female bobwhite reproductive activity would be different in areas with different arthropod biomass. A study by Harveson et al. (2004) investigated this possibility in the Rio Grande Plains and the

Gulf Coast Plains. The study determined that despite the Gulf Coast Plains having significantly more arthropods, there was no difference in the percentage of laying females between the two areas. The study suggested that areas with particularly low biomass (0.58 kg/ha) of arthropods might be unsuitable for quail, due to low reproductive activities of quail in these areas (Harveson et al. 2004). This study inferred that although high arthropod abundance may not be necessary for sustaining high quail populations, low abundance can negatively affect reproductive activities. This study also provides a parameter for evaluating whether an area has a deficient number of arthropods to sustain quail numbers.

One aspect of this study that could be further explored is the possibility of analyzing arthropod communities in different vegetation zones within a wildlife management area (Harveson et al. 2004). Literature shows that various arthropods are available in different plant communities, which suggests that diverse plant communities may offer different nutrients for quail (Rosa García et al. 2010, Vikram Reddy and Venkataiah 1990). A study conducted in India during the year 1990 suggests arthropods were more abundant in grassland vegetation zones with planted trees than in grasslands without any trees (Vikram Reddy and Venkataiah 1990). This study also showed that certain arthropods normally only found during certain parts of the year such as rainy seasons and warm seasons could be found year-round in zones with planted trees. The tree-planted communities had more ant genera than grassland zones without trees (Rosa García et al. 2010, Vikram Reddy and Venkataiah 1990). The trees that were planted were Eucalyptus varieties, and were planted in Indian grasslands that were mostly dominated by grasses, forbes, and small shrubs. This finding suggests that grassland areas with trees may be supportive of more arthropod taxa and a larger arthropod abundance; which is possibly relevant to quail conservation because quail occupy areas with and without trees in Oklahoma grasslands. The primary tree species in these grasslands are typically oaks (*Quercus* spp.).

Arthropod abundance and diversity can be different between zones with different numbers and types of oak trees (Baini et al. 2012). This possibility is significant to quail conservation in Oklahoma because Shinnery oak (*Quercus harvardii*) is a common tree in many quail habitats (Lusk et al. 2001). Ground beetles and centipedes showed increased richness, diversity, and equitability in areas recently reforested with different oak species compared to a native oak forest (Baini et al. 2012). Areas with younger oaks supported more arthropods, suggesting arthropod forage taxa may vary in areas where oak trees are relatively new (Baini et al. 2012).

Although zones with trees may have different arthropod abundances than zones without trees, other vegetation types can affect arthropod abundance. A study evaluating arthropod abundance and diversity in agricultural vegetation zones suggests that planting areas with wildflowers, grasses, or mixtures of the two can affect arthropod communities (Meek et al. 2002). Soldier beetles were more common in areas planted or sown with wildflowers (Meek et al. 2002). Ground beetles, spiders, and ants were more abundant in zones where grasses and flowers were taller and more diverse (Meek et al. 2002). It was suggested that spiders needed the taller plants to construct webs. These findings are relevant because ground beetles, spiders, ants and soldier beetles have all been shown to serve as preferred arthropod forage taxa of quail chicks (Doxon and Carroll 2010). Ladybird beetles were present in greater abundance in zones where flowering plants had been added (Meek et al. 2002). These results suggest grassland zones with wildflowers and native grasses may provide different arthropod forage for quail than areas without many wildflowers or grasses.

Arthropod diversity is important not only because it provides quail with different nutrients, but also because arthropod diversity supports plant communities that quail rely on for food and cover. Studies confirm that in grasslands there is a link between plant diversity and arthropod diversity (Eisenhauer et al. 2010). One such study showed that insecticide applications which killed below-soil arthropods reduced plant growth, despite the ability of the pesticides to kill herbivorous soil-dwelling insects (Eisenhauer et al. 2010). Over the course of the summer, diverse soil communities of springtails enabled greater decomposition of biomass, and are associated with increased plant height (Eisenhauer et al. 2010).

The aforementioned studies show that arthropod communities can be variable in zones with different vegetation communities, and that arthropods are generally supportive of quail habitat vegetation. Since quail habitat often includes different vegetation zones, it is possible quail may have different arthropod forage options available when they move throughout their range. Since the arthropod forage communities are important to chicks and brooding hens, it may be necessary to characterize arthropod communities in terms of abundance, richness, diversity, and evenness in these different zones, to determine if all the areas inside a wildlife management area contain quality arthropod forage options throughout a timeframe relevant to the birds.

Bobwhite land management tactics

Although natural quail habitat exists throughout the American Midwest from Texas to Wisconsin and east to the Atlantic seaboard, many conservation tactics must be used to maintain quail habitat. These tactics may be necessary to maintain suitable quail vegetation, but their impacts on arthropods are not always beneficial. A discussion of these conservation tools may be necessary to understand the stresses affecting arthropod forage community in bobwhite habitat.

Burning is a common tactic associated with *C. virginianus* habitat maintenance. It is performed in idle fields to thin leaf litter that might inhibit quail chick movement. Total arthropod abundance is negatively affected by burning under certain conditions, however Orthoptera have been shown to thrive in areas that have recently been burned (Little et al. 2013). Arthropod diversity can also be reduced by burning (Coleman and Rieske 2006). Other studies suggest arthropod biomass can increase in areas following a controlled burn (Greenberg and McGrane 1996). These contradictory statements can be reconciled by considering the tendency of grasses to rapidly recolonize an area after a controlled burn, which are typically suitable forage for grasshoppers, which are typically large arthropods, but not necessarily other smaller arthropods that may require leaf litter for overwintering purposes (Meurisse et al. 1999, Greenberg and McGrane 1996, Eisenhauer et al. 2011). If burns are necessary, they are usually recommended every two to three years and are often conducted in the fall (Roseberry 1984).

Another common management tactic is strip disking. Strip disking involves cutting vegetation-free paths multiple feet wide through quail habitat to increase their mobility (Roseberry 1984). It also serves to break up weed banks, stimulate germination of certain grasses, and reduce leaf litter (Roseberry 1984). Strip disking can be done either annually on a smaller scale or every two to three years on a larger scale. Strip disking should be done in the fall or winter (Roseberry 1984).

Grazing, mowing, and rower chopping are all ways to increase airflow through quail habitat and also open up space for quail to move about (Moorman et al. 2013). Grazing can maintain proper roosting cover, whereas mowing and rower chopping stop or delay plant community succession so they can support quail for longer periods of time (Moorman et al. 2013). Overgrazing can be detrimental because it may reduce available grasses and legumes for quail to eat. In addition, grazing can reduce arthropod diversity and abundance in grasslands, even if overgrazing has not occurred (Lussenhop 1976).

The aforementioned natural and agricultural land management practices are common throughout the United States. Oklahoma in particular exercises grazing regimes and also burning schedules in Beaver and Packsaddle WMAs. Beaver and Packsaddle are distinct areas in Oklahoma with notable differences in addition to certain similarities.

One method for improving available insect abundance in quail habitat is to plant rows of native wildflowers, forbs, and grasses in quail habitat. Bobwhites have been shown to forage more efficiently in artificially planted rows of wildflowers and legumes than in otherwise unmanaged areas (Moorman et al. 2013). According to a study conducted using imprinted quail in North Carolina during 2013, quail foraged at rates of approximately 0.04 to 0.2 grams/chick/30 min foraging interval with higher foraging rates in rows planted with wildflowers and native grasses and lower rates in mowed areas (Moorman et al. 2013). Bobwhites also select different prey based on the plants in the rows, because quail foraging in rows planted with wildflowers consumed more Lepidoptera larvae and quail in mowed rows or rows planted mostly with legumes consumed more Coleoptera (Moorman et al. 2013).

Arthropod abundance is not always too low to support quail populations. Arthropod communities ought to occasionally be sampled in order to determine if they are capable of supporting essential ecosystem services. A variety of different methods are available to sample arthropods in grasslands.

Sampling Techniques for Available for Arthropod Collection

The literature is replete with information regarding various methods and tools for collecting arthropods in quail habitat. The most common collection techniques include sweep netting, pitfall trapping, the use of drift fences, and blower-vacuum sampling. The different methods have unique strengths and weaknesses as they apply to characterizing arthropod communities in quail habitat.

Sweep netting has been used extensively for arthropod sampling in the types of ecosystems quail occupy (Meek et al. 2002, Nemec et al. 2014, Semere and Slater 2007). Sweep netting involves the use of a net to collect arthropods by swinging the net close to the ground and physically trapping any arthropods that jump into the net. Sweeping can be conducted along transects running through designated study zones in various patterns relevant to the dispersion pattern of the target host. While this methodology is useful for targeting arthropods living in the canopies of short plants, it is not useful for studying quail forage taxa because quail feed mostly on invertebrates that are on the ground. The canopies are too high for chicks.

Blower-vacuum sampling is a useful tool for accurately quantifying arthropods at ground level or slightly above the ground (Moorman et al. 2013). This method involves the use of a leaf blower or similar air-propelling device to collect arthropods by sucking them into a bag for identification. This method is partially deficient for the purposes of this study because it only collects arthropods during a narrow sampling time frame, usually during the day. Vacuums are usually operated for minutes at a time, and are applied over the course of transects multiple meters long (Moorman et al. 2013). Our study seeks to quantify arthropod abundance available to quail over the course of the summer, and therefore requires a collection technique that operates over a longer time period.

Pitfall traps are used to measure the activity density or relative abundance of ground-dwelling arthropods, with a bias towards increasingly active individuals. Pitfall traps consist of a collection cup, killing solution, and funnel cup, and are usually combined with a cover to prevent bycatch and a drift fence to divert arthropods into the collection cup (Braun et al. 2009). They can be left open for extended periods of time (Moorman et al. 2013).

The selection of a proper killing solution is essential to successful pitfall trapping. The killing solution can attract mammals or invertebrates, so specific alterations to its formulation must be made depending on mammalian activity in trapping areas (Pekár 2002). Formaldehyde killing solutions have the effect of repelling Opiliones, and killing solutions with detergents have the effect of repelling certain Staphylinidae members. Also, high temperatures can cause killing solutions to evaporate. One disadvantage of ethanol-based killing solutions is that they can attract flies; however, flies are not a major food source for quail so overestimating their activity densities is not a major concern for this study. Another disadvantage of the ethanol-based killing solutions is that they can significantly reduce biomass of the trapped arthropods if they are stored in preservation fluid (95% ethanol) for extended periods of time. Our study is not concerned with biomass calculations, so this disadvantage is not applicable. Based on the advantages and disadvantages of the various trapping methods, it appears that pitfall traps with ethanol-based killing solutions are the most effective sampling tool for this ground-dwelling arthropod community characterization project.

Briefly stated, the goal of this project is to determine the relative abundance, diversity, and community composition of ground-dwelling arthropod forage taxa communities in bobwhite habitats in western Oklahoma. This study will assist bobwhite conservation efforts by identifying whether certain areas have insufficient forage taxa to sustain bobwhite populations and will allow wildlife managers to determine whether quail nest at higher rates in arthropod-rich areas. More specific objectives will be described in the following chapter.

CHAPTER II

THE CHARACTERIZATION OF GROUND-DWELLING ARTHROPOD FORAGE TAXA IN *C. VIRGINIANUS* HABITAT

Introduction

Northern bobwhite have been in decline in Oklahoma since the late 1960's (Doxon and Carroll 2010, Campell-Kissock et al. 1985, Harveson et al. 2004). This trend is troubling to conservation biologists and sportsmen because bobwhites are popular game birds (Harveson et al. 2004). Although habitat loss and degradation are likely contributors to bobwhite decline, the goal of this project is to investigate a lack of suitable arthropod forage as another component in the decline of bobwhites in two western Oklahoma Wildlife Management Areas (WMA).

Northern bobwhite chicks receive most of their calories from arthropods, and primarily feed on "bite sized" ants, beetles, and assorted other arthropods (Harveson et al. 2004, Lusk et al. 2001). Hens increase protein intake during brooding, and require certain nutrients that are found primarily in arthropods to maintain their immune systems (Harveson et al. 2004, Lusk et al. 2001). Arthropods also support quail habitat by providing decomposition, soil aeration, and pollination services.

This study investigated ground-dwelling arthropod community composition in Beaver and Packsaddle WMA's in different vegetation zones within the context of a larger study which characterized relative quail density, nest site choice, and nest success. We analyzed ground-dwelling arthropod communities in different vegetation zones at the levels of relative abundance, taxa richness, evenness, homogeneity, similarity, and diversity with special emphasis placed on the size of collected arthropods. We hypothesized arthropods less than 2 mm would be most abundant compared to other size classes on each date and in each vegetation zone because the insects we expected to find in that size class were often the most abundant insects in grassland ecosystems. Springtails, ants, and mites fit into this category. Large arthropods found in grassland ecosystems, like ground beetles, mantids, and ant lions, tend to be more territorial and therefore less likely to be densely populated.

We also hypothesized that the ecotone zone would have the largest arthropod taxa richness, abundance, and evenness, due to the overlap of plant diversity found in upland and lowland zones. This ecotone offers resources from lowland and upland zones, and would have supported a wider variety of arthropods. We hypothesized quail would nest with greater frequency and success in habitats with greater arthropod relative abundance, richness, diversity, and evenness, because these habitats provided quail with more food, a greater variety of nutrients, and increased availability at different times of the summer. We hypothesized arthropods of all size classes would be most abundant in August in each WMA, during each year, because of previous studies showing this trend in grassland ecosystems. We expected evenness to drop as the summer went on because as the temperatures increase and water levels decrease, certain heat-sensitive arthropods will be less active. We expected the arthropod communities that are most similar in terms of taxa composition to be found in adjacent vegetation zones, because adjacent plant communities would presumably have similar plant species, which would support similar types of arthropods.

Beaver and Packsaddle Wildlife Management Areas

Beaver Wildlife Management Area (WMA), Beaver County, Oklahoma, is located in the panhandle of western Oklahoma. The park contains 7,162 hectares of total area bordering the Beaver River, and receives about 41.8 centimeters of annual rainfall. Beaver WMA has a vegetative gradient that runs through at least four distinct habitat types perpendicular from the river's edge to the upland sand dunes. The vegetation zones associated with each of these habitat types includes riparian, grassy lowland, ecotone, and shrubby upland zone. The upland in Beaver WMA is dominated by sagebrush (*Artemisia* spp.), Shinnery oak (*Quercus harvardii*), and buffalo grass (*Bouteloua dactyloides*). The grassy lowlands consist of sand plum (*Prunus augustifolia*) thickets, saltcedar and mixed grassland. The riparian zone consists of saltcedar (*Tamarix* spp), cottonwood (*Populus* spp.), hackberry (*Celtis* spp.), and American elm (*Ulmus americana*). The ecotone zone is a mixture of the vegetation found in both the lowland and the upland zones.

Hunters, cattle ranchers, and oil companies use Beaver and Packsaddle for rich animal, floral, and fossil fuel resources. Beaver WMA supports pheasant (*Phasianus colchicus*), quail (*C. virginianus*), turkey (*Meleagris gallopavo*), deer (*Odocoileus virginianus*), waterfowl, dove (*Columba* spp.), and furbearing animal hunting. Approximately 162 hectares of Beaver WMA are devoted to agricultural plots as part of a land lease program. Beaver WMA maintains habitats supportive of these animals by burning and grazing.

Packsaddle WMA, Ellis County, Oklahoma, is located in western Oklahoma, approximately 20 miles south of Arnett, Oklahoma. The park contains 7,955 hectares bordering the South Canadian River, and receives 55cm of rain per year. Packsaddle WMA has a topographic gradient that runs through four distinct vegetation zones perpendicular from the river's edge to the upland sand dunes. The vegetation zones associated with each of these habitat types includes riparian, lowland, ecotone, and upland zones. The riparian zone is located on the northern shore of the South Canadian River. Riparian zones have saltcedar, cottonwood, American elm, and assorted grasses. The lowland zones occur at the lowest points between two or more hills. Lowland zones are sandier, and contain mostly grasses. The ecotone zones are located on the slopes of hills. They contain big bluestem grasses (*Andropogon gerardii*) little bluestem grasses *(Schizachyrium scoparium)*, Indian grass (*Sorghastrum nutans*), side oats grama (*Bouteloua curtipendula*), numerous wildflowers, yucca (*Yucca* spp.), and cacti *Melocactus* spp.). Upland zones, located atop hills, contain mostly Shinnery oak, sagebrush, buffalograss, and sand plum. Unlike Beaver WMA, which has four consecutive bands of vegetation ranging from the riparian zone to the upland zone, the four habitat types are dispersed among small hills that begin directly adjacent to the riparian zone. Oil companies, cattle ranchers, and hunters use the area for its rich mineral, floral, and animal resources.

Methodology

Sampling Procedure

Arthropod sampling was conducted at Beaver WMA during the summers of 2012 and 2013 in the McFarland Unit and Packsaddle during the summer of 2013 in the Dunn Unit using pitfall traps combined with drift fences. Each pitfall trap consisted of an approximately 1.1m long and 0.2 m tall Aluminum sheet metal drift fence with a nine-ounce collection cup nested inside a 16-ounce cup on each end. The nine-ounce cups were charged with approximately 25 ml of killing solution (80% ethanol, 10% glycerol, 10% water) (Fig. 1). A cup modified into a funnel was nested in the smaller cup to prevent arthropods from jumping out of the collection cup. Pitfall traps were separated by ten meters. The coordinates of the PVC pipe were recorded by a Trimble Juno ST GPS device (Fig. 2 and Fig. 3).

In 2012, sampling took place in the Beaver WMA on May 13, June 8, June 27, July 18 and August 9. In 2013, sampling took place in the Beaver WMA on May 11, May 25, June 8, June 22, July 6, July 18, and August 8, and in the Packsaddle WMA on April 19, May 11, May 25, June 8, June 22, July 6, July 22, and August 8. Traps were installed along six transects across four vegetation zones. The zones investigated in Beaver were called riparian, lowland, ecotone, and upland zones due to the noticeably different vegetation communities in these areas. These zones are present in the Packsaddle WMA; however, the hilly terrain divides the zones, so they are not contiguous (Fig. 4). At each site, transect locations were chosen randomly from areas close to the available service roads that were not scheduled to be burned during sampling times and that contained all four vegetation zones.

Transects used for pitfall trap locations at the Beaver WMA were previously established by other members of the quail conservation effort when this component of the project began. They placed their traps in areas that were not scheduled to be burned, intensively grazed, mined for resources, or used for hunting or camping. Efforts were taken to ensure traps were not dangerously close to quail nests by collaborating with park officials to determine approximate locations of quail nesting sites. The same sites were used during both years of the study.

Traps at the Packsaddle WMA were installed by first obtaining a map of the area (Fig. 5) created by Jeremiah Zurenda and Scott Parry, a technician and biologist, respectively, who work at the WMA. The map helped us determine which areas of the park were scheduled to be burned or had been recently burned (2011 or later). Areas of high traffic, like the park headquarters area, were avoided. Areas with oil rigs were also avoided. Park officials were instrumental in telling us which areas were inhabited by large numbers of cattle, and these were also avoided. After eliminating problematic areas, placement locations for the transects were further refined by using the map to find service roads that could support truck and SUV traffic. Once proper roads were selected, the terrain nearby these roads was scouted by driving and looking for areas that contained all four vegetation zones within walking distance that were free of any oil wells or herds of cattle. Based on these criteria, transects were placed in the Dunn Unit of Packsaddle WMA.

Pitfall traps in both the Beaver and Packsaddle WMA's were installed in approximately the middle of the vegetation zones. This decision was based on a visual assessment of the area, to determine approximate boundaries of the often expansive vegetation zones. This decision was made to limit edge effects, and to increase the probability that arthropods caught by the traps had at least in the hours of the trapping session, been in the investigated vegetation zone. If traps were close to edges the insects were more likely to have moved in from other zones before being captured. In order to find the pitfall traps in the middle of vast expanses of land, white PVC pipe centroids were placed between pitfall traps, which were oriented with one trap due east of the pipe and one trap due west. Each trap was approximately ten meters away from the centroid to reduce the possibility that the centroid could impact trapping success.

The decision to establish transects in fixed locations was the result of considering a series of tradeoffs. Traps had to be placed in quail habitat in order to collect relevant data; however, placing the traps in close proximity to a quail nest could result in disturbing the hens and increasing the chances of nest abandonment, resulting in skewed nest success data. Therefore, when a suitable trap location was encountered, it was used throughout the course of the experiment.

Establishing permanent transects limited our study to only providing indications about a smaller portion of the park; however, moving the transects increased the chances of encountering quail nests, areas of high grazing, burning, or oil development sites. We chose to limit our pitfall trap transects to places that could provide reliable results throughout the course of the study.

After traps were installed and the killing solution added to cups, they were left open for 24 hours and emptied in the order they were filled. The cups were emptied into 50ml vials and stored in cardboard tube racks at room temperature until they were identified, with added 95% ethanol to reduce chances of molding. After the cups were emptied, they were covered with a lid and soil to prevent accidental trapping. If water was collected in the cups, arthropods were filtered out using sieves and filter paper upon return to the laboratory, and then stored in 95% ethanol to prevent fungus from growing inside the tubes.

Collected arthropods were returned to the lab and identified to either family level or the lowest possible taxonomic unit using dissecting microscopes, Borror and DeLong's Introduction to the Study of Insects 7th Edition, and dichotomous keys (Borror and DeLong 2004). Diptera and Hymenoptera were identified to order in accordance with precedent established in the literature, with the exception of Formicidae which were identified to family due to their importance as a quail food source relative to other Hymenoptera. Springtails were identified to order, with Hypogastruridae identified to family, due to their conspicuous abundances. Diptera and Hymenoptera (excluding ants due to their importance as a quail food source) were generally overestimated because they were likely attracted to ethanol in the killing solution, and were considered an artifact of the sampling procedure. They are probably less available to quail than this study suggests.

<u>Data analysis</u>

The abundance of each individual taxon from each pitfall trap was recorded, along with the size class of each individual encountered. Relative abundance of the individual taxa collected was considered to be a representative measure of ground-dwelling arthropod activity. Diversity was evaluated as richness (S), or number of taxa, and evenness (relative abundance of individuals among the taxa detected), and also by incorporating measures of richness and evenness using Simpson's index and Shannon's index (Ludwig and Reynolds 1988, Hill 1973). Evenness was calculated using a Modified Hill's ratio, or E5 value (Alatalo 1981). Peterson's Homogeneity Index (Bakus 1990) was used to determine homogeneity of arthropod communities within sites and similarities between sites. Sørensen's Quotient (Sørensen 1958) was used to evaluate similarities between plant communities, and was also calculated for arthropod communities so trends in similarity could be compared between plant and arthropod communities. The following formulas were used, and an explanation of each will follow below:

Simpson's index $\lambda=\sum_{i=1}^{S} n_i(n_i-1)/n(n-1)$

S

Shannon's index $\hat{H}' = -\sum_{i=1}[(n_i/n)\ln(n_i/n)]$

Hill's 1 = N1 = $e^{\hat{H}'}$
Hill's 2 = N2 = $1/\lambda$
Evenness = ln(N2)-1/ln(N1)-1
Peterson's Homogeneity Index = I = 1 – 0.5∑[ai – bi]
Sørensen's Quotient = 2[a∩b]/[a +b]
Number of taxa = S
Number of taxa in each sample = n
ai = number of individuals in taxonomic unit a
bi = number of individuals in taxonomic unit b
a = number of species in community a
b = number of species in community b

Formulas were designed to be used at the species level; however, time constraints prohibited identification past the family level. The values generated from these formulas therefore provide conservative estimates of the differences between communities. The experimental design used for this study was a split plot arrangement in a randomized complete block design with repeated measures. Each transect was considered a block, each habitat type was considered a main unit factor, and size class was a split unit factor. Correlations within traps and across dates were modeled with an autoregressive period 1 covariance structure. Simple effects of habitat type given size class and date were compared with planned contrasts.

Plant species were identified along each transect by Dr. Mark Fishbein of Oklahoma State University. Although no species-level data exists regarding plant communities in Packsaddle WMA, Dr. Mark Fishbein compiled data during the summer of 2012 and 2013 in Beaver WMA regarding plant species in riparian, lowland, ecotone, and upland vegetation zones. The 2012 sampling was conducted in June, whereas the 2013 sampling was conducted in August.

Dr. Fishbein produced an index of diversity that took into consideration dominant plant species in each zone. Dr. Fishbein placed quadrats randomly along the transects, identified plants within the quadrats to species, and scored each species according to a scale of 1-6. If the plant species covered 75% of the ground or more, it received a score of 1. If it covered between 50% and 74% it received a score of 2. Plant species that covered 20-49% of the area in a quadrat received a score of 3, plant species that covered 5-19% received a score of 4, 1-5% scored a 5, and less than 1% scored a 6. He sampled the same transects used for arthropod collection. Samples were collected in Beaver WMA on June 8, 2012 and August 8, 2013. Based on these data, we can get an approximate understanding of which plant species dominate each vegetation zone; however, we cannot determine the abundance of a given plant.

Since abundance values were not obtained for plant communities, efforts to compare arthropod forage taxa to plant species would have to be made with formulas that use presence and absence data. Sørensen's Quotient (SQ) (Sørensen 1958) was used for this purpose because SQ compares the similarity of two quadrat or transect samples in terms of taxonomic groups within each quadrat or transect when quantitative data regarding the number of individuals in each taxon is not available. SQ values for comparisons of two communities range from 0 to 1 with values close to 1 indicating similar communities and values close to 0 indicating dissimilar communities.

Peterson's Homogeneity Index (PHI) is a method of comparing how similar two communities are to one another that considers the abundance of each taxon in the community (Bakus 1990). PHI values range from 0 to 1 with values close to 1 demonstrating increased homogeneity and increased similarity. Communities that share many of the same taxonomic groups , with nearly equivalent numbers of individuals per group, receive high PHI values, close to 1. If two communities are compared that do not have the same taxa and have different relative abundances in each taxonomic group, the comparison of the two communities will generate a low score, close to 0. Since we collected quantitative data regarding the relative abundance of arthropods in both zones, PHI was used to compare arthropod communities in different zones. PHI can also determine how homogenous a community is by determining the proportions of the community that belong to each member. PHI estimates are more accurate when the sample size is large, the compared communities are similar in diversity, and there is only a small sampling error. Therefore, understanding diversity is necessary to evaluating a PHI value.

The Simpson's diversity index (SDI) is one method of measuring diversity by determining the probability that two entities taken at random from the dataset of interest represent the same type (Hill 1973). SDI generates small values in datasets of high diversity and large values in datasets of low diversity. Shannon's Index (H') is another method of measuring diversity that states the more different taxa there are, and the more equal their proportional abundances in the community of interest, the more difficult it is to correctly predict whether an individual will belong to a given taxon in the community (Ludwig and Reynolds 1988). If nearly all abundance is concentrated in one taxon, then H' approaches zero, and if all the taxa are equally abundant H' should be 1.

H' and SDI can be combined to provide information about the evenness of different communities. The Modified Hill's Ratio (Alatalo 1981) is perhaps the easiest to interpret evenness measurement, and it compares the number of abundant species to the number of very abundant species to determine how abundant species are compared to one another in a community (Alatalo 1981). If all species are equally abundant, the Modified Hill's Ratio should equal 1, and if all the individuals belong to one species, then it should be zero. Although there are multiple evenness equations, this ratio works well when diversity is expected to be low (Alatalo 1981). One advantage of the Modified Hill's ratio is the ability of the ratio to provide adequate evenness estimates when diversity is low and if one taxa has a large variability in abundance (Molinari 1989). This study likely underestimated diversity because we are investigating taxa at the family level, so the selection of the Modified Hill's ratio was appropriate.

Rainfall and temperature data was collected using the Oklahoma Mesonet. The station from Arnett, Ellis County, Oklahoma was used to infer rainfall in Packsaddle WMA, whereas the station in Beaver, Beaver County, Oklahoma was used to infer rainfall in Beaver WMA. The Arnett station is approximately 17 miles north of Packsaddle WMA, whereas the Beaver station is a few miles southeast of the Beaver WMA.

Results

In Beaver WMA, during 2012, the total arthropod relative abundance collected by all pitfall traps was 54,460 (Fig. 6). In Beaver WMA, during 2012, the size class with the largest relative abundance was from specimens in the less than 2 mm size category and the size class with the lowest relative abundance was from specimens larger than 10 mm (Fig. 6). In Beaver WMA, during 2012, the riparian zones had the largest relative abundance of arthropods and the upland zones had the lowest relative abundance of arthropods (Fig. 6). In Beaver WMA, during 2012, ecotone zones had a lower relative abundance than the riparian zones but a larger relative abundance than lowland zones (Fig. 6). In Beaver WMA, during 2012, the highest relative arthropod abundance was collected on August 9 and the lowest relative abundance was collected May 13 (Fig. 7).

More specific comparisons of arthropod relative abundance collected in Beaver WMA during 2012 reveal significant differences between arthropod abundance in size classes in different zones on various dates. In the riparian zones, on May 13, 2012 in Beaver WMA, arthropods collected from the 5.1 to 10 mm size class were significantly more abundant than arthropods collected from the less than 2 mm size class (Fig. 8a). In Beaver WMA, on May 13, 2012, arthropods less than 2 millimeters were significantly more abundant in ecotone zones than the riparian zones (Fig. 8b). On June 8, 2012 in the Beaver WMA, arthropods from the 5.1-10 mm size class were significantly more abundant than arthropods from the 10.1 mm or greater size class in riparian zones (Fig. 8c).

During 2012, 87 families were collected from Beaver WMA (Table 1). The ecotone zone had the most families, followed by lowland and upland zones and finally the riparian zones (Table 1). As the summer progressed, different trends regarding diversity, evenness, and taxa richness emerged (Table 1).

During 2012 in the Beaver WMA, riparian zones were most even on July 18 and least even on June 8 (Table 1). During the summer of 2012, the riparian zones had the highest richness on August 9 and the lowest taxa richness on May 13 (Table 1). During the summer of 2012, in riparian zones, there were few noticeable trends in Simpson’s diversity values or Shannon’s Index values; however, Shannon’s Index was lowest on August 9, and Simpson’s diversity was lowest July 18 (Table 1).

During 2012 in the Beaver WMA, lowland zones had the highest taxa richness on June 8 (Table 1). During 2012 in the Beaver WMA, evenness values and Simpson’s values for lowland zones did not vary by a large amount; however Shannon’s values were lowest towards the end of the summer (Table 1). During 2012 in Beaver WMA, Ecotone zones were most even on May 13; however, evenness did not fluctuate much over the course of the summer (Table 1). During 2012, in ecotone zones, Shannon's index values were lowest towards the end of the summer and Simpson's diversity values generally increased as time progressed (Table 1). Upland zones had the lowest taxa richness on May 13, and had stable taxa richness throughout the remainder of the summer. Upland zones showed few trends in evenness, richness, or diversity.

In Beaver WMA, during the summer of 2012, quail nested in upland and ecotone zones (Table 2). Despite the fact that 15 nests were created in upland zones, four were abandoned and only four managed to maintain eggs long enough to hatch. Only two nests were constructed in ecotone zones, but both were successful.

During 2013 in the Beaver WMA, the total relative abundance collected by all pitfall traps was 40,998 (Fig. 6). During 2013 in the Beaver WMA, riparian zones had the largest arthropod relative abundance and lowland zones had the lowest arthropod relative abundance (Fig. 6). In 2013, ecotone zones in Beaver WMA had more arthropods than lowland or upland zones, and upland zones had slightly higher relative abundance compared to lowland zones (Fig. 6).

In Beaver during 2013, the size class with the highest relative abundance consisted of arthropods less than 2 mm (Fig. 6). Arthropods 10.1mm or greater had the lowest relative abundance (Fig. 6). The 2.1 – 5 mm size class had a higher relative abundance in 2013 than in 2012, whereas the 5.1 – 10 mm size class had a similar relative abundance in both years (Fig. 6). In Beaver WMA during 2013 the highest arthropod relative abundance was collected June 8, and the lowest arthropod relative abundance was collected August 8 (Fig. 7).

On May 11, 2013, there was a significantly greater relative abundance of arthropods less than 2 mm in all zones than arthropods greater than 10mm (Fig. 9a). On May 11, 2013, arthropods less than 2mm in length were significantly more abundant in riparian zones than in other zones (Fig. 9b). On May 25, 2013, in Beaver WMA, arthropods between 2.1 and 5.0 mm had significantly higher relative abundances in riparian zones than they had in other zones (Fig. 9c).

On June 8, arthropods smaller than 2 mm in length were significantly more abundant than arthropods of all other size classes in all zones (Fig. 9d). Arthropods larger than 10 mm were the second most abundant arthropods in ecotone zones on June 8, and were significantly more abundant than arthropods 5.1-10 mm (Fig. 9d). On June 8, in ecotone zones, arthropods smaller than 2 mm were significantly less abundant than all other size classes (Fig. 9d).

On June 8, 2013, at the Beaver WMA, the ecotone zone had significantly more arthropods smaller than two millimeters in length than any other zone (Fig. 9e). The lowland zone had significantly fewer arthropods smaller than 2mm compared to any other zone (Fig. 9e). On June 8, with the exception of the smallest size classes, there were no other significant differences in terms of abundance in different zones when sorted by size classes.

In 2013, in the Beaver WMA, 73 arthropod forage taxa were collected (Table 1). The upland zone had the largest total number of arthropod families, followed by lowland, ecotone, and riparian zones (Table 1). Evenness, richness, and diversity values were slightly different within the various zones.

Riparian zones were least taxa rich May 25, 2013 and most taxa rich June 22, 2013 (Table 1). Within this same zone, evenness values did not change considerably in Beaver during 2013; however evenness was highest in riparian zones on August 8 and lowest on June 8 (Table 1). Simpson's diversity and Shannon's Index values showed little change in riparian zones. On

May 25, 2013, lowland zones had the highest taxa richness, and on July 20, 2013, these areas had the lowest taxa richness (Table 1). Lowland zones were most even July 6 and least even June 8. In the lowland zone, Shannon's and Simpson's values were not noticeably different over time. Ecotone and upland zones both had the lowest evenness values on June 8; however, there were no noticeable trends in richness or diversity.

During 2013, in the Beaver WMA, bobwhites made 18 nests in upland zones, six nests in ecotone zones, five nests in lowland zones, and two nests in riparian zones (Table 2). The riparian zone nests both failed, whereas three out of the five lowland nests and five out of the six ecotone nests succeeded (Table 2). Eight out of the 18 upland nests hatched, and one was abandoned (Table 2).

In 2013, the total relative abundance of arthropods collected from Packsaddle was 60,684 (Fig. 6). In 2013 at Packsaddle, the upland zone had the largest relative abundance of arthropods (Fig. 6). In 2013 at Packsaddle, riparian zones had the lowest relative abundance (Fig. 6). In Packsaddle WMA, during 2013, the size class with the largest relative abundance was comprised of arthropods less than 2 mm, and the size class with the lowest relative abundance was the largest size class (Fig. 6).

In Packsaddle WMA, during 2013, arthropods were most abundant on July 22 and least abundant early in the season (Fig. 7). Within the various zones, there were few significant differences in terms of relative abundance between arthropods in the different size classes; however, On July 22, upland zones had significantly more arthropods smaller than 2mm than other zones (Fig. 10a). On July 22, at the Packsaddle WMA, there were significantly more arthropods smaller than 2mm in upland, ecotone, and lowland zones than arthropods of other size classes (Fig. 10b).

A total of 105 arthropod forage taxa were collected from Packsaddle WMA (Table 1). The largest number of taxa were collected from upland zones, followed by lowland, ecotone, and riparian zones respectively (Table 1). On May 25, 2013 at Packsaddle WMA the riparian zones had the highest taxa richness. On June 8 and July 20, lowland zones had the highest and lowest arthropod richness respectively (Table 1). Ecotone and Upland zones had peak arthropod richness on May 25, with lower arthropod richness as the summer progressed (Table 1). Lowland and upland arthropod communities were both extremely even on April 19 and May 11, whereas ecotone zone arthropod communities had similar evenness throughout the summer. Riparian arthropod communities had peak evenness values on May 11 and June 22.

In the Beaver WMA, during both years, arthropod communities in the riparian zones were most similar to arthropod communities in lowland zones and most distinct from arthropod communities in upland zones (Table 3). Upland zone arthropod communities were most similar to ecotone zone arthropod forage communities, and lowland arthropod communities were more similar to ecotone communities than lowland arthropod communities (Table 3). The level of distinctiveness was not as pronounced between the arthropod communities as it was between the vegetation communities (Table 3).

During both years, in the Beaver WMA, springtails and ants were the most common arthropods in all zones on almost every collection event. In addition, during both years, Isopods were found primarily in riparian zones. Spiders were also found primarily in riparian zones. Grasshoppers were found primarily in lowland and ecotone zones.

In Beaver WMA, during the summer of 2012, riparian zones had 43 plant species, lowland zones had 64, ecotone zones had 56 species, and upland zones had 48 species. The dominant species in riparian zones included saltcedar (*Tamarix*) species, western wheatgrass (*Pascopyrum smithii*), alkali sacaton (*Sporobolus airoides*), and cheat grass (*Bromus tectorum*). The dominant plants in lowland zones were *P. smithii* and *S. airoides*, however there were a large number of species in this zone and none besides these species covered more than 19% of the ground. The upland zones had at least 75% of the area covered by fragrant sumac (*Rhus aromatic*) on multiple transects. Sagebrush (*Artemisia filifolia*) also covered 50% of the area on two transects in upland zones. Ecotone zones were quite similar to upland zones, with *Artemisia filifolia* being the dominant species on most transects. The 2013 sampling event in Beaver WMA had 55 riparian species, 77 lowland species, 61 ecotone species, and 41 upland species; however, dominant plant species were very similar in each zone compared to 2012.

In Packsaddle WMA, on April 19, 2013, the riparian arthropod communities were most similar to ecotone arthropod communities (Table 4). On July 6, 2013, riparian arthropod communities in Packsaddle WMA were also highly similar to lowland arthropod communities (Table 4). On May 25, 2013, and August 8, 2013, riparian arthropod communities and ecotone arthropod communities were extremely dissimilar (Table 4). In Packsaddle WMA, lowland arthropod communities and ecotone arthropod communities were consistently very similar except on August 8 (Table 4). On August 8, in Packsaddle WMA, ecotone arthropod communities and upland arthropod communities were very dissimilar; however, during the other sampling periods they were very similar.

Discussion

Studies conducted in North Carolina grasslands suggested that bobwhites will consume dozens of arthropods per hour when not breeding, and an average of 23 arthropod families per summer (Harveson et al. 2004, Palmer et al. 2001). Quail often consume greater numbers of arthropods when breeding, suggesting these numbers are conservative estimates. These studies suggest that all the vegetation zones in Beaver and Packsaddle WMA's harbor sufficiently taxa rich arthropod communities to support bobwhites. Another such study suggested bobwhite chicks have between three and nine arthropod taxa in their guts or crops at a given time (Doxon and Carroll 2011). As a result of this study, we believe arthropod forage taxa richness is likely not problematic in the Beaver or Packsaddle WMA's because far more than three families were found per sampling event in the 2.1-5 mm and 5.1-10 mm size classes.

These studies also suggest that there are specific zones at certain times of the summer that do not provide suitable forage for either bobwhite hens or chicks. During both years, the upland and lowland zones in Beaver WMA consistently had a small number of arthropods compared to the values quail would typically consume when brooding, especially during the month of May (Doxon and Carroll 2010, Palmer et al. 2001). We therefore expected these zones to have the smallest number of quail nests.

In both years, however, quail in Beaver WMA built more nests in upland zones despite the lack of arthropods in this region. That choice may suggest the cover provided by shrubs, tall grasses, and small trees, common in that region, may be of greater benefit to quail than available forage. The precocial nature of bobwhite chicks also enables the birds to leave the nest area fairly early after development, so the birds may move to arthropod rich regions to meet caloric needs (Palmer et al. 2001). Upland regions also had the highest number of abandoned nests in Beaver, and although many factors contribute to quail nest abandonment, it is possible lack of food in the region played a role (Doxon and Carroll 2010, Palmer et al. 2001).

During 2013, at the Packsaddle WMA, quail nested primarily in upland zones as well. Unlike the Beaver WMA, nest success in the upland zones of Packsaddle was fairly high relative to nests established in other Packsaddle zones. Also, multiple quail that built second nests moved into upland zones to establish their second, successful nests. The relatively high nest success in upland zones in Packsaddle may be supported in part by the higher relative abundance of arthropods in those zones. The fact that quail established many nests in Packsaddle WMA's ecotone zone may be explained by the high degree of similarity between the ecotone and upland zone in terms of plant species communities and also arthropod communities (Table 4).

Our efforts to characterize the arthropod communities in the different vegetation zones of the Beaver WMA revealed somewhat predictable trends during the 2012 season but unexpected results during the 2013 season. In 2012, the peak relative abundance values collected from Beaver WMA were predictable based on available literature regarding grassland arthropods that suggests it is common for large relative abundances to be encountered in late July and early August (Vikram Reddy and Venkataiah 1990). Some arthropods have multiple generations over the course of the summer, and as more generations elapse, more arthropods occur in that area.

The August 9, 2012 sampling event in Beaver WMA was noteworthy because on this date 31,502 arthropods of the family Hypogastruridae (Order: Collembola) were collected from pitfall traps. This number represents more than half of the total arthropods collected during the summer of 2012. Springtail relative abundance and activity are tied to the input of water to ecological systems, and it is likely rainfall patterns contributed to the massive springtail emergence on this date (Greenwood et al. 2011). The mechanism by which springtails respond to water inputs is related to the fact that many species of springtails in the family Hypogastruridae reduce their activity during hot, dry periods of time to conserve water (Holmstrup et al. 2007). Rain events elevate the body water concentrations of springtails past the point required to activate them. Many of these springtails subsequently feed on the fungal growth that occurs due to the increased availability of water (Meurisse et al. 1999).

Springtails themselves are unlikely sources of food for quail, because by that time the summer quail have advanced into the adult stage of their life cycle, and are feeding mostly on vegetation; however, during 2013, the Beaver WMA showed increased numbers of springtail predators, many of which are food for bobwhites. During 2013, members of the order Araneae were more than twice as abundant, and members of this order are preferred bobwhite prey (Doxon and Carroll, 2010). Studies confirm that springtails maintain elevated levels of spiders in agricultural systems, so it is possible springtails maintained elevated levels of spiders in quail habitat (Aquisti et al. 2003).

During 2013, the Beaver WMA had a high relative abundance of springtails on June 8. It was unexpected that more springtails were collected in the middle of the summer compared to the later months, especially considering the data from the previous year where arthropods were most abundant later in the season. According to the Oklahoma Mesonet, a rainfall event occurred prior to the June 8, 2013 collection date. Much like the rainfall event in August in Beaver WMA during 2012, the June 2013 rainfall event came after a prolonged period of dryness. Therefore it is possible that the same mechanism responsible for the massive springtail emergence in Beaver

WMA during 2012 is also responsible for the massive springtail emergence on June 8, 2013 in the Beaver WMA (Holmstrup et al. 2007).

During 2013 in the Packsaddle WMA, a large number of springtails were collected in upland zones after a major rainfall event late in July. The rainfall event and springtail emergence scenario was very similar to the events that occurred in Beaver WMA during 2012 and 2013; however, one major difference is during 2013 in the Packsaddle WMA, the springtail emergence happened in upland zones. In the Packsaddle WMA, Shinnery oak is very prevalent in upland zone, whereas in the Beaver WMA, it is present but less prevalent. Springtails are known to thrive in the leaf litter of oaks, so perhaps the presence of the Shinnery oak in Packsaddle WMA sustained their large numbers (Sadaka and Ponge 2003). It is thought that in Beaver WMA during 2012 and 2013 springtails emerged in large numbers in riparian zones because of the increased moisture those zones provide due to their close proximity to a river; however, this opportunity would not have been available to springtails during 2013 in Packsaddle WMA because the South Canadian River went dry early in the summer.

The high relative abundance of small arthropods other than springtails common during both 2012 and 2013 in both the Beaver and Packsaddle WMA's was typical of grassland communities in part because of the arthropods that comprised this size class (Vikram Reddy and Venkataiah 1990, and Siemann et al. 1999). In both the Beaver and Packsaddle WMA's, the most commonly encountered small arthropods besides springtails were ants, which are known to be preferred food sources for quail and are common in grasslands (Vikram Reddy and Venkataiah 1990, and Doxon and Carroll 2011).

In 2012 and 2013, in both the Beaver and Packsaddle WMA's, riparian zones had low diversity relative to other zones. This finding was unexpected because riparian diversity is often high relative to grassy lowland areas (Bateman et al. 2013, Durst et al. 2008, and Ellis et al. 2000). Invasive saltcedar (*Tamarix* spp.) is ubiquitous in Beaver and Packsaddle riparian zones, and has been linked to arthropod biodiversity decreases (Durst et al. 2008; Ellis et al. 2000).

In 2013, in the Beaver WMA, the arthropod taxa richness values in ecotone zones were unexpectedly low. Since the ecotone zone represents a continuum of lowland and upland zones, we anticipated that it would support the largest number of families. After reviewing plant species richness data provided by Dr. Mark Fishbein, the lowland zone actually had the highest plant species richness so it appears ecotone zones are not as supportive and diverse as we anticipated.

In 2013, ecotone zones in the Beaver WMA had the largest number of wildflower species compared to other zones. Examples of wildflower species in ecotone zones include nine-anther prairie clover (*Dalea enneandra*), wooley prairie clover (*Dalea lanata*), and silky prairie clover (*Dalea villosa*). A recent paper suggests that blooming wildflowers can increase the quality of a forage patch, causing arthropods like crab spiders (Thomisidae) to leave patches at slower rates (Robakiewicz 2009). This tendency would reduce arthropod activity in Beaver WMA during 2013, and therefore cause our pitfall traps, which measure activity density, to underestimate the number of arthropod taxa in ecotone zones. This suggestion is supported by the fact that in the Beaver WMA during 2013, diversity values in ecotone zones were lowest during late June, July, and early August, which are the same months the prairie clovers bloom (Doyle 2014).

During 2013 in Packsaddle WMA, camel crickets (Rhaphidiophoridae) and Jerusalem crickets (Stenopelmatidae) were more abundant in the lowland zones than they were in other zones. These arthropods are known to prefer the sandy soils common in the Packsaddle WMA's lowlands (Weisman 2005). They are not known to be bobwhite forage taxa, but were unique to those zones (Doxon and Carroll 2011). In the Packsaddle WMA, during 2013, over 90% of Isopods were found in the riparian zones, perhaps due to the abundant plant detritus visible in riparian zones.

During 2012 and 2013, few arthropods besides camel crickets, Jerusalem crickets, and Isopods were unique to any zone in either WMA. In Beaver WMA during both years, adjacent zones had the most similar plant and arthropod communities (Table 3). This finding is predictable because the zones in the Beaver WMA form a continuum, so there should be a consistent overlap between the zones in terms of plants and the arthropods they support. In 2013 in Packsaddle WMA, adjacent zones or nearby zones did not always have the most similar arthropod communities. For example, on May 25, riparian and upland zones were more similar than riparian and ecotone zones. This result is also somewhat expected because the numerous hills of the Packsaddle WMA divide the zones, preventing the continuum we see at the Beaver WMA.

During both years in both the Beaver and Packsaddle WMA's, evenness values did not follow any noticeable trends. Evenness values consistently indicated relatively high evenness compared to other grasslands in bobwhite habitat, so it is likely evenness is not problematic for bobwhites in either Beaver or Packsaddle WMA's (Doxon and Carroll 2010, Palmer et al. 2001, and Siemann et al. 1999). The only time evenness dropped to unusually low levels was following a massive springtail emergence that likely skewed the data.

Our study suggests that quail do not nest in areas with higher arthropod relative abundance values, but may avoid areas with extremely low arthropod relative abundance values. Future studies should investigate the possibility springtails help sustain arthropod forage taxa in these areas. Also, future studies should investigate whether burning or grazing negatively affect arthropod forage taxa in quail habitat.

CHAPTER III

SUMMARY

Northern bobwhite (*Colinus virginianus*) have been in decline over the past 50 years, which is concerning because the bird is a popular game species in Oklahoma. Although land management practices and habitat loss and degradation are known contributors to bobwhite decline, it is less certain whether the availability of arthropod forage taxa contribute to decreases in bobwhite populations (Williams et al. 2003). Despite the fact that chicks consume most of their calories from arthropod sources and rely on arthropod forage taxa for protein, fats, water, and micronutrients, little research has been done characterizing ground-dwelling arthropod communities in terms of richness, abundance, size class (length of arthropod from head to abdomen), and evenness in quail habitat (Doxon and Carroll 2010, Eisenhauer et al. 2011, Harveson et al. 2004).

Due to the close relationship between quail and arthropods, this study investigated whether arthropod forage communities may play a role in recent *C. virginianus* decline in Beaver and Packsaddle WMAs in Oklahoma. This project examined the relationship between bobwhite nesting success and relative arthropod abundance by size class, richness, diversity, and evenness in different vegetation zones occupied by bobwhites in Beaver and Packsaddle Wildlife Management Areas during multiple dates throughout the summers of 2012 and 2013.

Riparian, lowland, ecotone, and upland zones were compared in Beaver and Packsaddle. The size classes used were less than 2 mm in length, 2 mm to 5 mm in length, 5.1 mm to 10 mm in length, and 10.1 mm and greater. This project determined whether differences in arthropod abundance were significant between size classes and whether there were differences in abundance over time. We investigated whether taxa richness was sufficient in each vegetation zone, and whether there were significant differences between the relative abundances of arthropods in each size class in each zone on each sampling date. We also investigated whether there were significant differences between the relative abundance of arthropods in different zones within each size class. Data regarding quail nesting locations was compared to relative abundance values of arthropods to determine whether quail were successful nesting in arthropod-rich zones.

Relative abundance of the individual taxa collected was considered to be a representative measure of ground-dwelling arthropod activity. Diversity was evaluated as richness (S), or number of taxa, and evenness (relative abundance of individuals among the taxa detected), and also by incorporating measures of richness and evenness using five different diversity indices (Ludwig and Reynolds 1988): Simpson's index, Shannon's index, Hill's diversity numbers (1 and 2) (Hill 1973) and evenness (Alatalo 1989). Peterson's Homogeneity Index was used to determine homogeneity within sites and similarities between sites (Bakus 1990). Sørensen's Quotient was used to compare plant community diversity to arthropod community diversity (Sørensen 1958).

In the Beaver WMA in 2012, average arthropod relative abundance was highest in August. In the Beaver WMA during 2013, arthropod relative abundance was highest June 8. In the Packsaddle WMA, arthropod relative abundance was highest July 22. Riparian zones had the most arthropods in Beaver during both years, whereas in 2013 in the Packsaddle WMA upland zones had the highest relative abundance of arthropods. In both Beaver and Packsaddle WMA's during both years, peak relative abundance values are most likely explained by the timing of rain events that triggered large emergences of springtails (Holmstrup et al. 2007, Greenwood et al. 2011).

During both years both the Beaver and Packsaddle WMA's, riparian zones had low taxa richness relative to other zones. Low richness values may be explained by saltcedar infestations in riparian zones (Durst et al. 2008). In the Beaver WMA during 2012, ecotone zones had expectedly high taxa richness, but low taxa richness during 2013, perhaps because the high quality of vegetation patches in ecotone zones reduced the need of arthropods to actively forage (Robakiewicz 2009). In the Packsaddle WMA in 2013, upland zones were most taxa rich. In both WMA's during both years, evenness values did not change much.

In Beaver during 2012 and 2013, according to SQ values for the vegetation zones, adjacent zones had the most similar plant communities. In Beaver WMA during both seasons, SQ values indicate arthropod communities in adjacent zones were also most similar. In Packsaddle WMA during 2013, the arthropod communities of adjacent zones were not necessarily more similar than arthropod communities in distant zones. Bobwhites nested primarily in upland zones in Beaver and Packsaddle during both years. These zones have shrubs, short trees, and tall grasses that would provide excellent cover for nesting hens, perhaps requiring the birds to choose these sites for nesting grounds. The Packsaddle WMA sites had more successful nests and fewer abandoned nests, which were interesting considering upland zones in the Packsaddle WMA had more arthropods. Lowland zones in the Beaver and Packsaddle WMA's had relatively few nests and relatively few arthropods, suggesting there were insufficient numbers of arthropods or the necessary cover to support quail nests and chicks.

These results are relevant to bobwhite conservation because they suggest in both WMA's, certain vegetation zones may not support adequate numbers of arthropods for bobwhites early in the summer (Harveson et al. 2004, Palmer et al. 2001). These results also suggest that quail prefer the uplands regardless of available arthropod forage relative abundances, so those areas should be prioritized as quail refuge space. Furthermore, even though large quantities of small arthropods may not directly support quail forage, our study shows springtails may support more appropriately sized forage taxa for bobwhites in subsequent months. Land management practices that have minimal impact on springtail populations should be considered.

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APPENDICIES

Appendix A – Field Sites

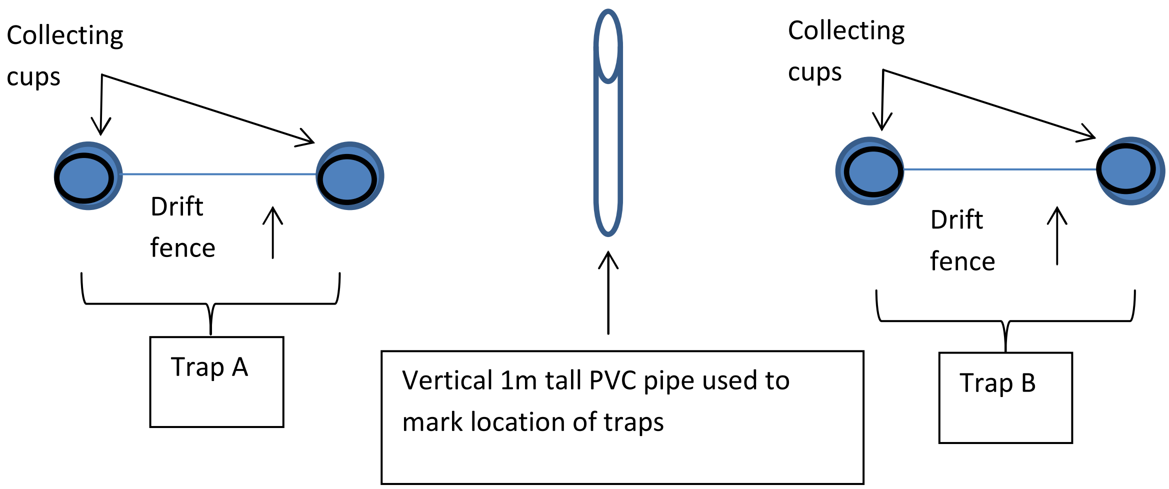


Fig. 1. Visual aid describing pitfall trap construction in Beaver and Packsaddle WMAs during 2012 and 2013.

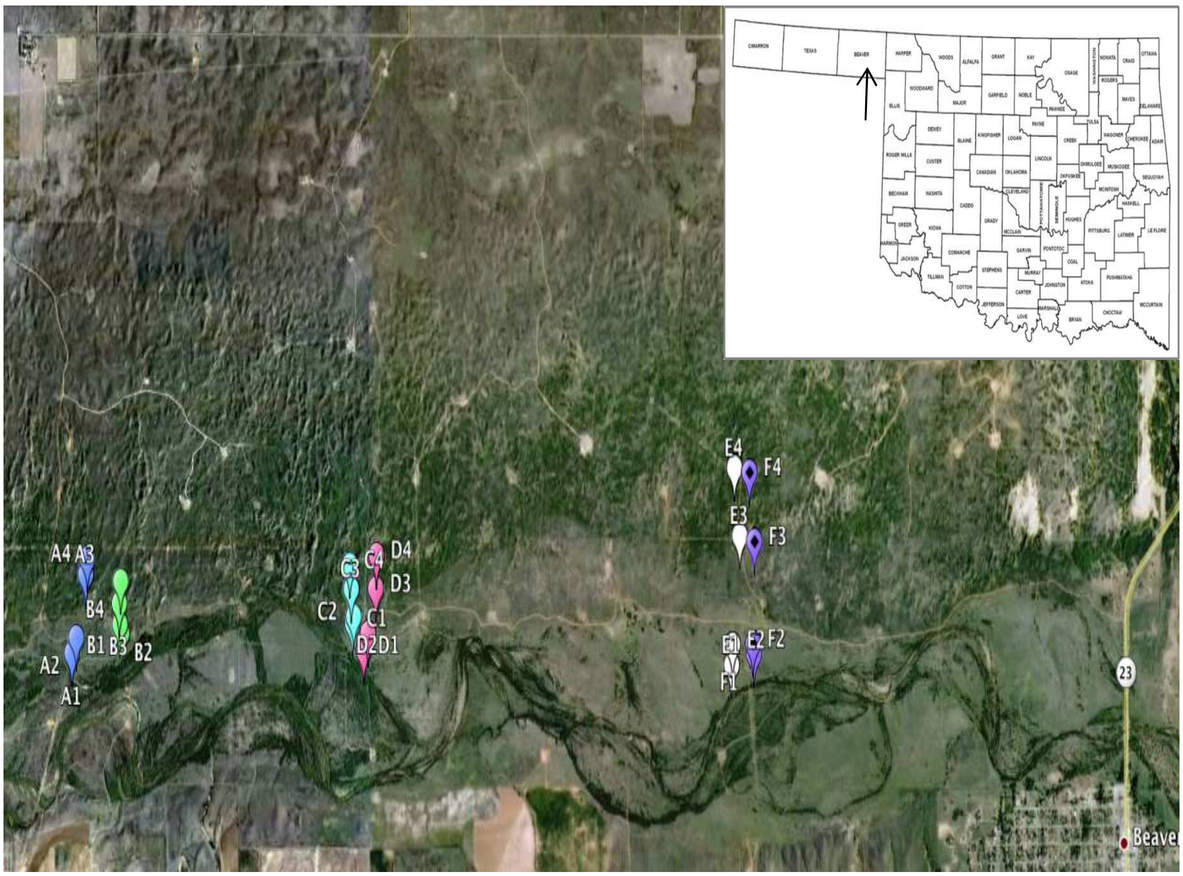


Fig. 2. Map of Beaver WMA with balloons denoting sampling locations and Oklahoma state map with arrow denoting Beaver County location. Numbers denote the vegetation zones, with 1 representing the riparian zone, 2 representing the lowland zone, 3 representing the ecotone zone, and 4 representing the upland zone. Letters A-F denote transects 1-6 respectively. Two pitfall traps were established at each of these 24 coordinates during the summers of 2012 and 2013.

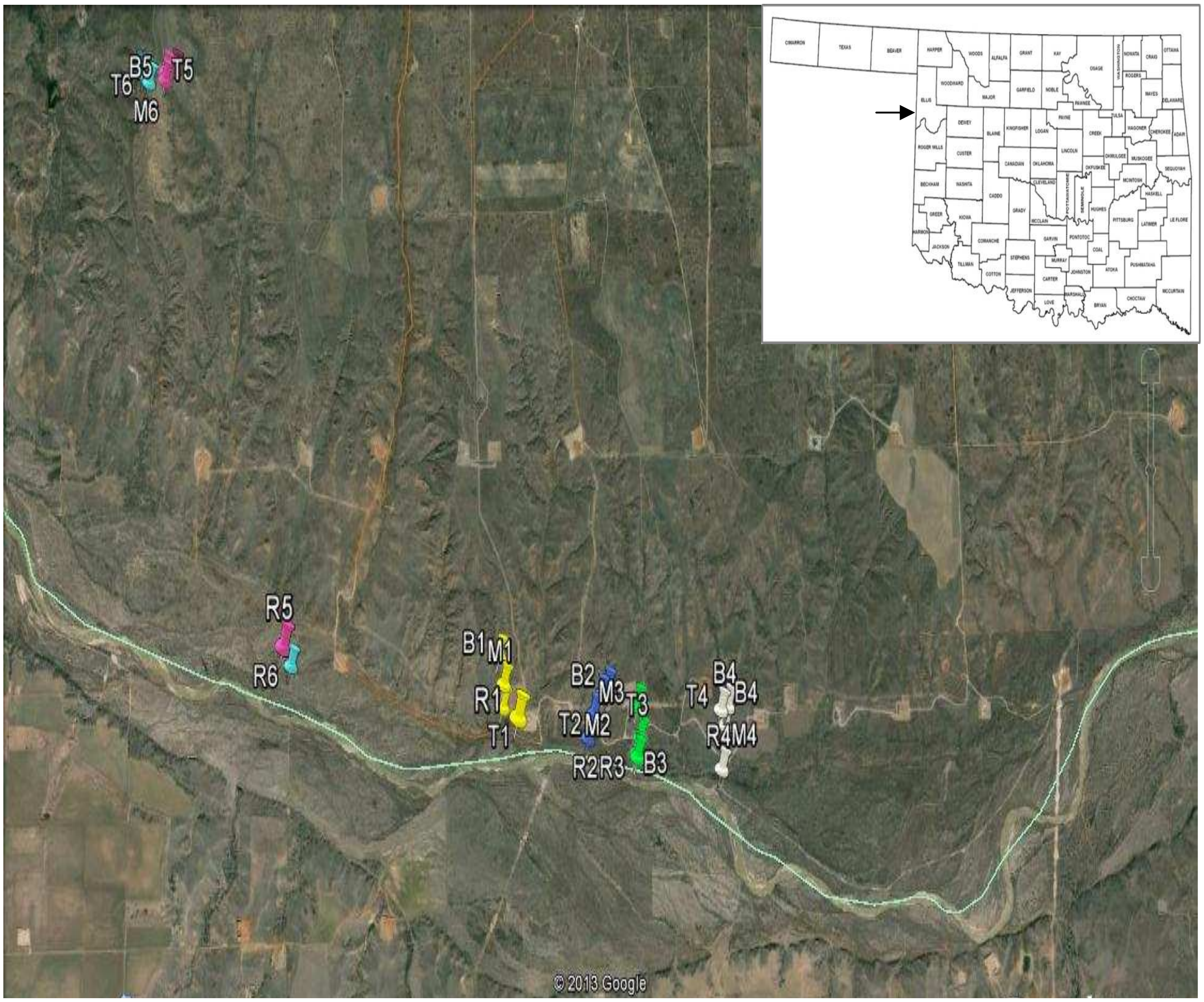


Fig. 3. Map showing Packsaddle WMA with map of Oklahoma and arrow showing Ellis County. Pins denote sampling sites. R= riparian zone, B= lowland zone, M= ecotone zone, and T= upland zone. The numbers denote the transects. Two pitfall traps were established at each coordinate during the summer of 2013.

Beaver Sampling Schematic					
upland 1a/1b	upland 2a/2b	upland 3a/3b	upland 4a/4b	upland 5a/5b	upland 6a/6b
ecotone 1a/1b	ecotone 2a/2b	ecotone 3a/3b	ecotone 4a/4b	ecotone 5a/5b	ecotone 6a/6b
lowland 1a/1b	lowland 2a/2b	lowland 3a/3b	lowland 4a/4b	lowland 5a/5b	lowland 6a/6b
riparian 1a/1b	riparian 2a/2b	riparian 3a/3b	riparian 4a/4b	riparian 5a/5b	riparian 6a/6b
Packsaddle Schematic					
upland 1a/1b	lowland 2a/2b	ecotone 3a/3b	lowland 4a/4b	upland 5a/5b	upland 6a/6b
ecotone 1a/1b	ecotone 2a/2b	upland 3a/3b	upland 4a/4b	ecotone 5a/5b	lowland 6a/6b
lowland 1a/1b	upland 2a/2b	lowland 3a/3b	ecotone 4a/4b	lowland 5a/5b	ecotone 6a/6b
riparian 1a/1b	riparian 2a/2b	riparian 3a/3b	riparian 4a/4b	riparian 5a/5b	riparian 6a/6b

Fig. 4. Sampling schematic for pitfall trap placement at Beaver and Packsaddle Wildlife Management Areas. Four vegetation zones (riparian, lowland, ecotone and upland) occurred in each of 6 transects randomly established at Beaver WMA and Packsaddle WMA. The numbers denote the transect (transects 1-6), whereas the letters next to the numbers indicate the identity of the trap (trap a or trap b).

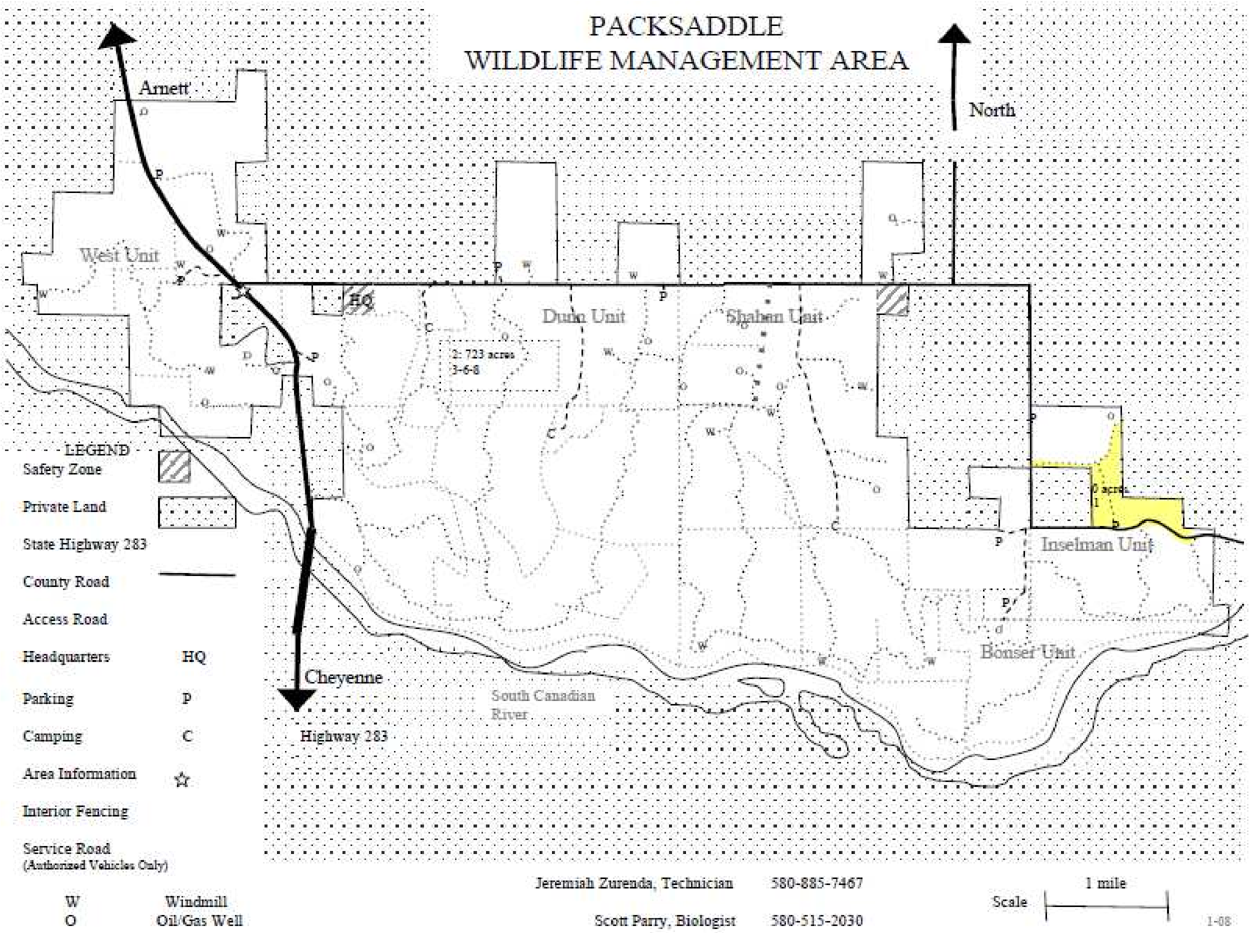


Fig. 5. Burn map of Packsaddle WMA from 2011. The Inselman unit was burned in 2011.

Appendix B- Tables

Table 1. Parameters of arthropod community composition: Arthropod community richness, diversity, and evenness are indicated, respectively, in the “Values” column for each vegetation zone and each sampling event during the summers of 2012 and 2013.

Beaver 2012 (87 taxa total)							
Zone	Date	Parameters	Values	Zone	Date	Parameters	Values
Riparian (53 total taxa)	13-May	Richness, □, H', E5	19, 0.81, 0.54, 0.319	Lowland (59 total taxa)	13-May	Richness, □, H', E5	26, 0.26, 1.88, 0.510
	8-Jun	Richness, □, H', E5	27, 0.29, 1.61, 0.081		8-Jun	Richness, □, H', E5	40, 0.30, 1.69, 0.513
	27-Jun	Richness, □, H', E5	32, 0.47, 1.29, 0.420		27-Jun	Richness, □, H', E5	32, 0.21, 2.11, 0.510
	18-Jul	Richness, □, H', E5	28, 0.24, 1.77, 0.662		18-Jul	Richness, □, H', E5	29, 0.36, 1.60, 0.451
	9-Aug	Richness, □, H', E5	35, 0.90, 0.29, 0.321		9-Aug	Richness, □, H', E5	33, 0.62, 0.85, 0.446
Zone	Date	Parameter	Value	Zone	Date	Parameter	Value
Ecotone (72 total taxa)	13-May	Richness, □, H', E5	29, 0.09, 2.70, 0.732	Upland (59 total taxa)	13-May	Richness, □, H', E5	22, 0.135, 2.42, 0.623
	8-Jun	Richness, □, H', E5	34, 0.30, 1.85, 0.441		8-Jun	Richness, □, H', E5	34, 0.18, 2.26, 0.537
	27-Jun	Richness, □, H', E5	31, 0.23, 2.21, 0.406		27-Jun	Richness, □, H', E5	34, 0.29, 1.83, 0.461
	18-Jul	Richness, □, H', E5	27, 0.33, 1.71, 0.449		18-Jul	Richness, □, H', E5	29, 0.179, 2.12, 0.622
	9-Aug	Richness, □, H', E5	30, 0.61, 0.88, 0.447		9-Aug	Richness, □, H', E5	34, 0.515, 1.20, 0.408
Beaver 2013 (73 taxa total)							
Zone	Date	Parameters	Values	Zone	Date	Parameters	Values
Riparian (47 total taxa)	11-May	Richness	32, 0.35, 1.59, 0.465	Lowland (59 total taxa)	11-May	Richness, □, H', E5	32, 0.13, 2.44, 0.675
	25-May	Richness	26, 0.36, 1.63, 0.441		25-May	Richness, □, H', E5	39, 0.15, 2.39, 0.548
	8-Jun	Richness	31, 0.49, 1.37, 0.155		8-Jun	Richness, □, H', E5	33, 0.31, 1.944, 0.376
	22-Jun	Richness	34, 0.155, 2.31, 0.593		22-Jun	Richness, □, H', E5	33, 0.33, 1.85, 0.378
	6-Jul	Richness	29, 0.27, 1.93, 0.459		6-Jul	Richness, □, H', E5	36 , 0.11, 2.54, 0.680

	20-Jul	Richness	29, 0.23, 2.03, 0.515		20-Jul	Richness, □, H', E5	26, 0.304, 1.82, 0.442
	8-Aug	Richness	32, 0.12, 2.50, 0.663		8-Aug	Richness, □, H', E5	30, 0.12, 2.50, 0.663
Ecotone (51 total taxa)	11-May	Richness	32, 0.14, 2.39, 0.614	Upland (62 total taxa)	11-May	Richness, □, H', E5	34, 0.15, 2.29, 0.611
	25-May	Richness	32, 0.81, 2.69, 0.830		25-May	Richness, □, H', E5	31, 0.09, 2.70, 0.695
	8-Jun	Richness	33, 0.70, 0.80, 0.136		8-Jun	Richness, □, H', E5	34, 0.52, 1.13, 0.158
	22-Jun	Richness	31, 0.155, 2.34, 0.577		22-Jun	Richness, □, H', E5	31, 0.11, 2.64 0.669
	6-Jul	Richness	26, 0.15, 2.31, 0.618		6-Jul	Richness, □, H', E5	29, 0.18, 2.24, 0.479
	20-Jul	Richness	29, 0.17, 2.18, 0.629		20-Jul	Richness, □, H', E5	27, 0.17, 2.25, 0.572
	8-Aug	Richness	28, 0.20, 1.97, 0.627		8-Aug	Richness, □, H', E5	33, 0.19, 2.12, 0.593
Packsaddle 2013 (105 taxa total)							
Zone	Date	Parameters	Values	Zone	Date	Parameters	Values
Riparian (64 total taxa)	19-Apr	Richness, □, H', E5	33, 0.18, 2.20, 0.579	Lowland (72 total taxa)	19-Apr	Richness, □, H', E5	33, 0.11, 2.62, 0.612
	11-May	Richness, □, H', E5	23, 0.17, 2.09, 0.685		11-May	Richness, □, H', E5	37, 0.11, 2.63, 0.655
	25-May	Richness, □, H', E5	34, 0.65, 1.01, 0.311		25-May	Richness, □, H', E5	42, 0.13, 2.65, 0.488
	8-Jun	Richness, □, H', E5	31, 0.35, 1.68, 0.430		8-Jun	Richness, □, H', E5	44, 0.19, 2.43, 0.403
	22-Jun	Richness, □, H', E5	28, 0.24, 1.81 0.624		22-Jun	Richness, □, H', E5	38, 0.30, 1.81, 0.459
	6-Jul	Richness, □, H', E5	32, 0.20, 2.07, 0.570		6-Jul	Richness, □, H', E5	32, 0.31, 1.71, 0.498
	20-Jul	Richness, □, H', E5	30, 0.29, 1.66, 0.565		20-Jul	Richness, □, H', E5	31, 0.75, 0.66, 0.364
	9-Aug	Richness, □, H', E5	25, 0.21, 1.96, 0.617		9-Aug	Richness, □, H', E5	34, 0.09, 2.76, 0.664
Zone	Date	Parameter	Value	Zone	Date	Parameter	Value
Ecotone (71 total taxa)	19-Apr	Richness, □, H', E5	33, 0.18, 2.38, 0.476	Upland (81 total taxa)	19-Apr	Richness, □, H', E5	31, 0.09, 2.75, 0.729
	11-May	Richness, □, H', E5	44, 0.13, 2.59,0.555		11-May	Richness, □, H', E5	42, 0.12, 2.44, 0.707
	25-May	Richness, □, H', E5	48, 0.18, 2.51, 0.407		25-May	Richness, □, H', E5	54, 0.12, 2.72, 0.541
	8-Jun	Richness, □, H', E5	42, 0.20, 2.33, 0.438		8-Jun	Richness, □, H', E5	47, 0.19, 2.37, 0.449
	22-Jun	Richness, □, H', E5	35, 0.41,1.52,0.408		22-Jun	Richness, □, H', E5	28, 0.25, 1.90, 0.526
	6-Jul	Richness, □, H', E5	28, 0.43, 1.30, 0.507		6-Jul	Richness, □, H', E5	34, 0.36, 1.57, 0.466
	20-Jul	Richness, □, H', E5	27, 0.77, 0.58, 0.377		20-Jul	Richness, □, H', E5	34, 0.78, 0.46, 0.506
	9-Aug	Richness, □, H', E5	31, 0.65, 0.82, 0.425		9-Aug	Richness, □, H', E5	29, 0.42, 1.56, 0.364

Table 2. Number of quail nests in each vegetation zone in each wildlife management area during each year. Nests neither abandoned nor hatched were destroyed, depredated, or had an unknown outcome.

Beaver 2012	Riparian	Lowland	Ecotone	Upland
Hatched	0	0	2	4
Abandoned	0	0	0	4
Total	0	0	2	15
Beaver 2013	Riparian	Lowland	Ecotone	Upland
Hatched	0	3	5	8
Abandoned	0	0	0	1
Total	2	5	6	18
Packsaddle 2013	Riparian	Lowland	Ecotone	Upland
Hatched nests	6	3	6	16
Abandoned nests	1	0	0	0
Total nests	8	7	16	23

Table 3. Sørensen's Quotients for plant and insect communities in Beaver WMA calculated with data from samples collected June 8, 2012 and August 8, 2013. Plant community values are above the x boxes, and arthropod values are below the x boxes (x indicates no comparison was made). Low values indicate communities are less similar and high values mean they are more similar.

Beaver WMA 2012 arthropod community comparisons	SQ values	Beaver WMA 2012 plant community comparisons	SQ values	
Riparian/lowland	0.746268657	Riparian/lowland	0.672268908	
Riparian/ecotone	0.655737705	Riparian/ecotone	0.563106796	
Riparian/upland	0.590163934	Riparian/upland	0.537634409	
Lowland/ecotone	0.756756757	Lowland/ecotone	0.538634409	
Lowland/upland	0.757756757	Lowland/upland	0.533333333	
Ecotone/upland	0.794117647	Ecotone/upland	0.84	
Beaver WMA 2013 arthropod community comparisons	SQ values	Beaver WMA 2013 plant community comparisons	SQ values	
Riparian/lowland	0.8125	Riparian/lowland	0.666666667	
Riparian/ecotone	0.78125	Riparian/ecotone	0.598290598	
Riparian/upland	0.738461538	Riparian/upland	0.448598131	
Lowland/ecotone	0.757575758	Lowland/ecotone	0.583941606	
Lowland/upland	0.71641791	Lowland/upland	0.456692913	
Ecotone/upland	0.835820896	Ecotone/upland	0.660714286	

Table 4. Peterson's Homogeneity Values for comparisons of arthropod community taxa similarity between different zones on each sampling date during the summer of 2013 in Packsaddle Wildlife Management Area. Low numbers (near 0) indicate zones with very different arthropod communities and high numbers (near 1) indicate very similar arthropod communities.

Packsaddle 2013					
April 19		May 11		May 25	
Zone Comparisons	Pc	Comparisons	Pc	Comparisons	Pc
Riparian/lowland	0.662561	Riparian/lowland	0.62903	Riparian/lowland	0.220852
Riparian/ecotone	0.741239	Riparian/ecotone	0.658988	Riparian/ecotone	0.190754
Riparian/upland	0.607937	Riparian/upland	0.599603	Riparian/upland	0.199532
Lowland/ecotone	0.751661	Lowland/ecotone	0.83503	Lowland/ecotone	0.80967
Lowland/upland	0.764598	Lowland/upland	0.777973	Lowland/upland	0.748542
Ecotone/upland	0.671523	Ecotone/upland	0.801738	Ecotone/upland	0.771363
June 8		June 22		July 6	
Zone Comparisons	Pc	Zone Comparisons	Pc	Zone Comparisons	Pc
Riparian/lowland	0.437818	Riparian/lowland	0.540925	Riparian/lowland	0.722102
Riparian/ecotone	0.399156	Riparian/ecotone	0.539033	Riparian/ecotone	0.677502
Riparian/upland	0.409518	Riparian/upland	0.542905	Riparian/upland	0.700425
Lowland/ecotone	0.86042	Lowland/ecotone	0.835956	Lowland/ecotone	0.79387
Lowland/upland	0.822928	Lowland/upland	0.843384	Lowland/upland	0.831061
Ecotone/upland	0.788738	Ecotone/upland	0.724501	Ecotone/upland	0.908619
July 22		August 8			
Zone Comparisons	Pc	Zone Comparisons	Pc		
Riparian/lowland	0.585524	Riparian/lowland	0.500392		

Riparian/ecotone	0.574996	Riparian/ecotone	0.186853		
Riparian/upland	0.544775	Riparian/upland	0.342703		
Lowland/ecotone	0.91732	Lowland/ecotone	0.112445		
Lowland/upland	0.951039	Lowland/upland	0.279753		
Ecotone/upland	0.954047	Ecotone/upland	0.264678		

Appendix C - Figures

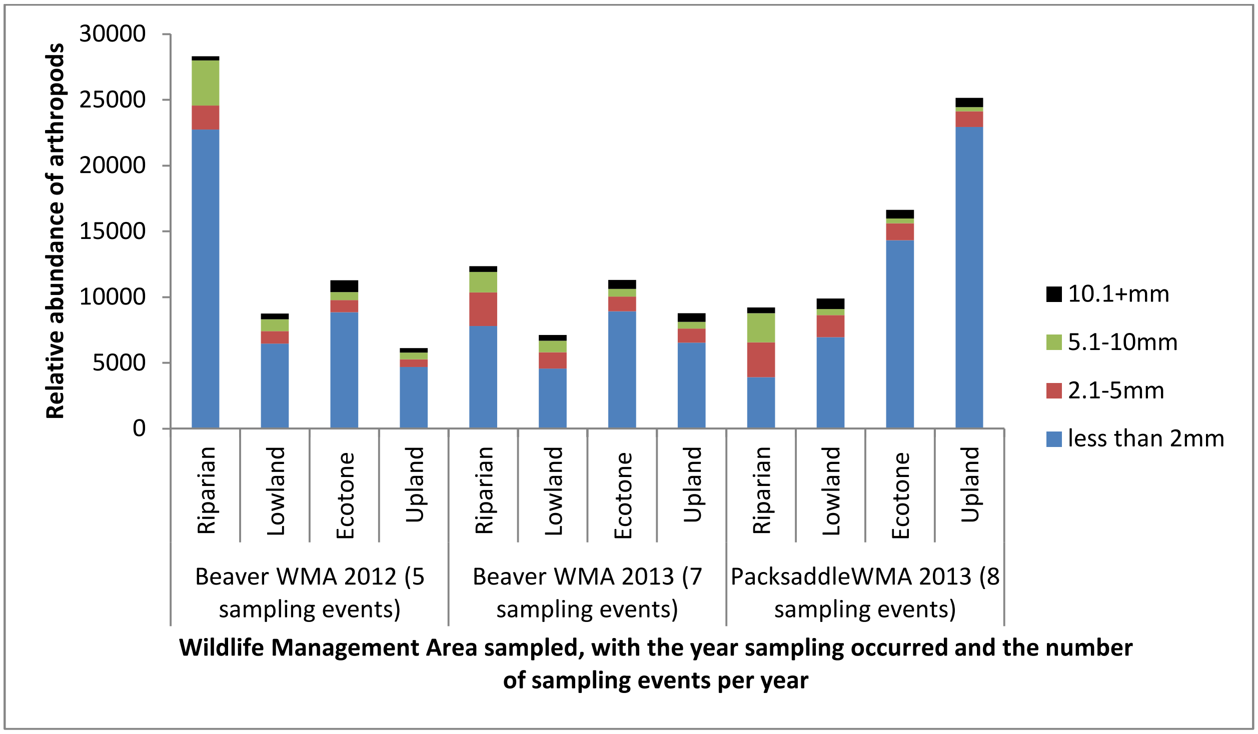


Fig. 6. Arthropod relative abundance by size class collected from pitfall traps (n=48 traps/ sampling date/WMA) during the summers of 2012 and 2013 in Beaver WMA and Packsaddle WMA.

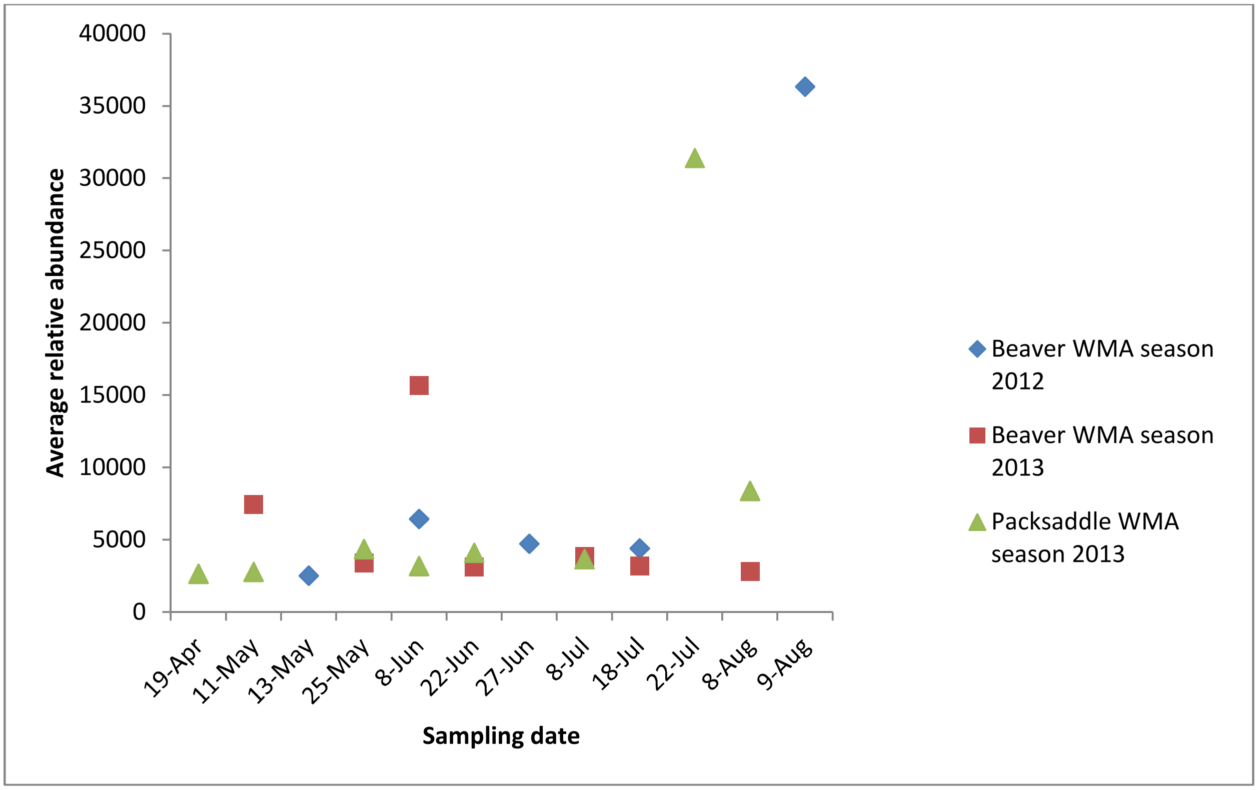
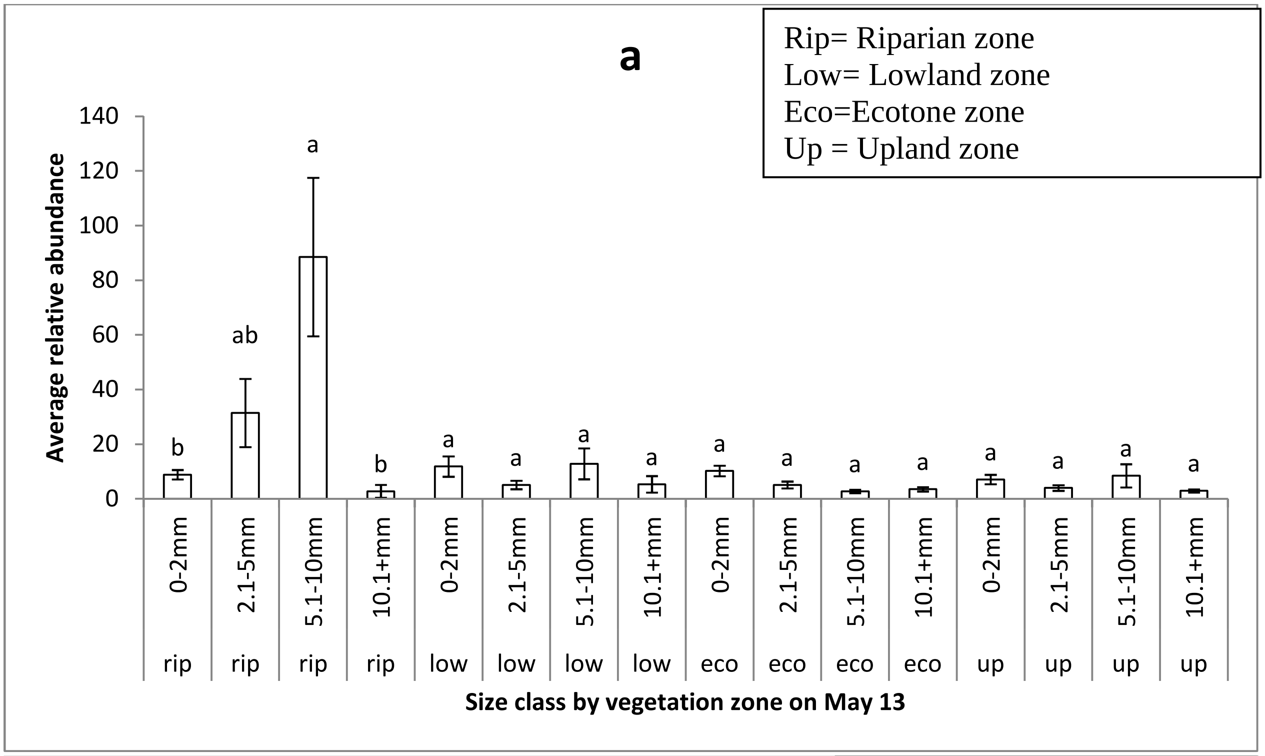
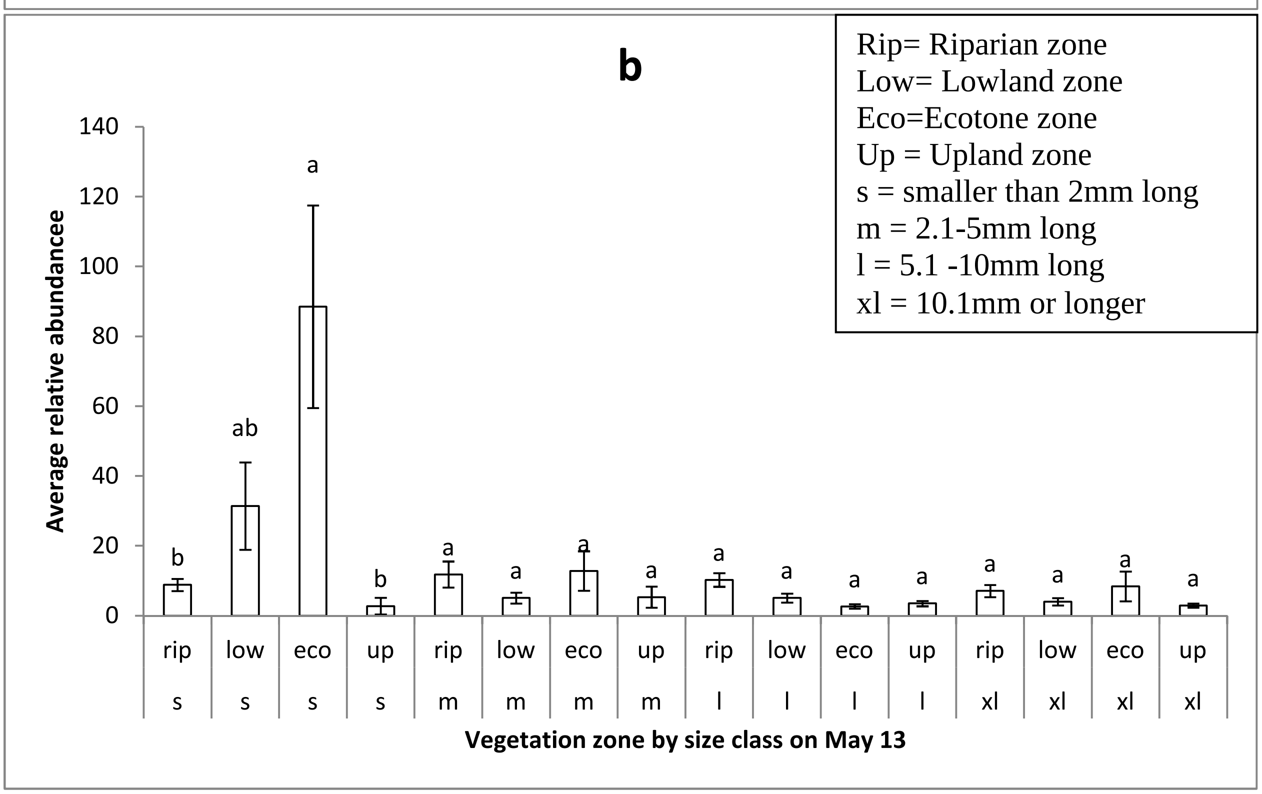


Fig. 7. Arthropod relative abundance collected from pitfall traps (n = 48 per sampling event) on sampling events that occurred over the summers of 2012 and 2013 in Beaver and Packsaddle Wildlife Management Areas.


a
Rip= Riparian zone
Low= Lowland zone
Eco=Ecotone zone
Up = Upland zone
Average relative abundance
140
120
100
80
60
40
20
0
b
ab
a
b
a
a
a
a
a
a
a
a
a
a
a
a
0-2mm
2.1-5mm
5.1-10mm
10.1+mm
rip
low
eco
up
Size class by vegetation zone on May 13


b
Rip= Riparian zone
Low= Lowland zone
Eco=Ecotone zone
Up = Upland zone
s = smaller than 2mm long
m = 2.1-5mm long
l = 5.1 -10mm long
xl = 10.1mm or longer
Average relative abundancee
140
120
100
80
60
40
20
0
b
ab
a
b
a
rip
low
eco
up
s
m
l
xl
Vegetation zone by size class on May 13

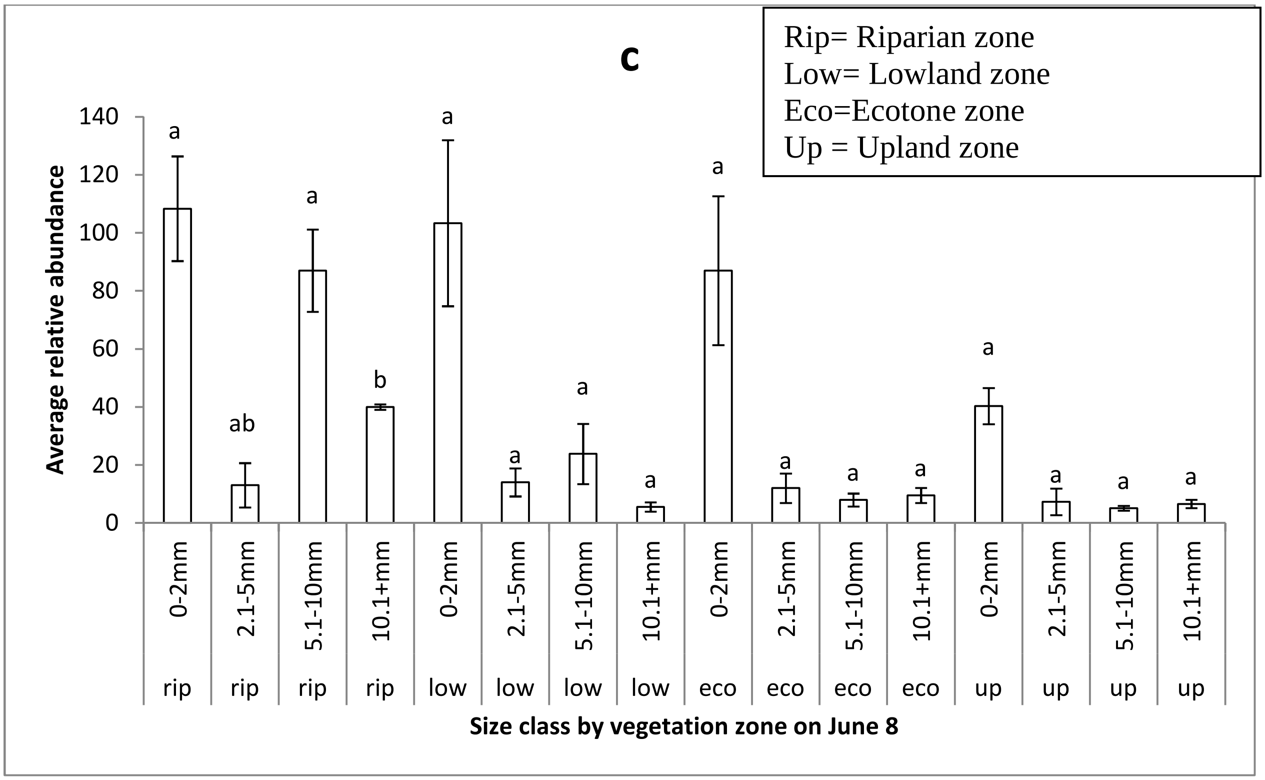
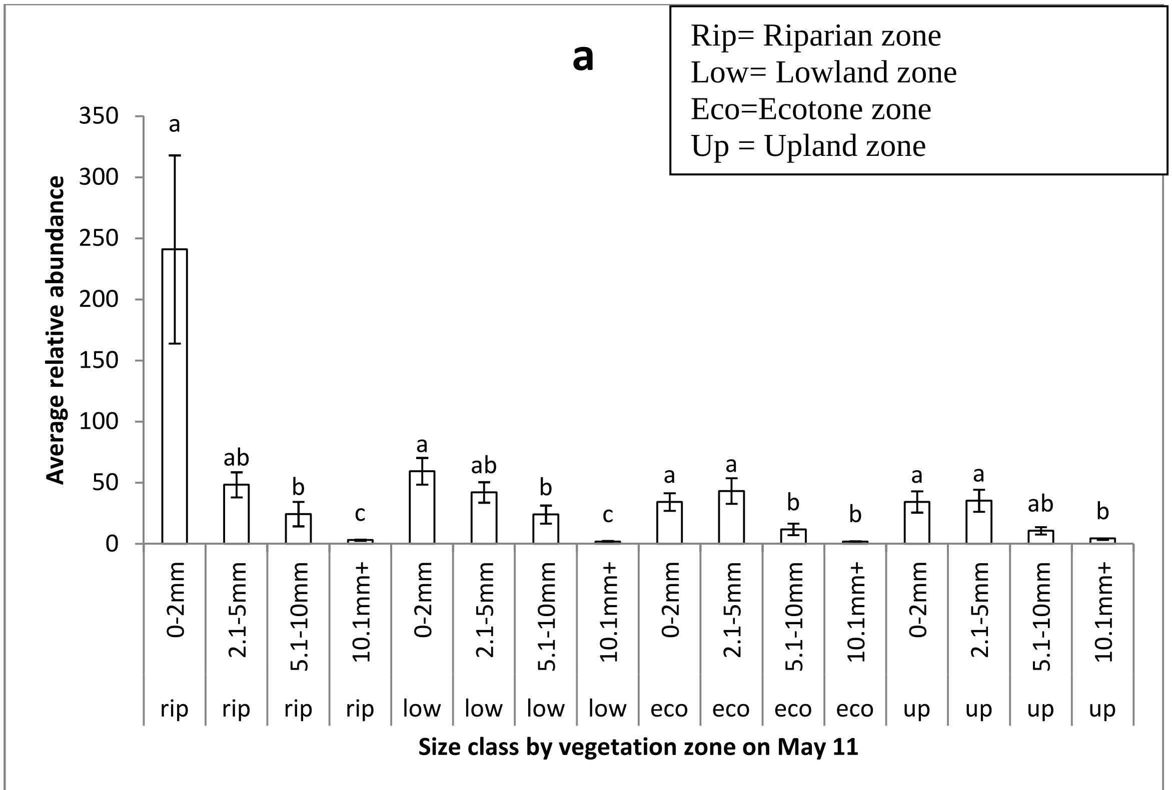
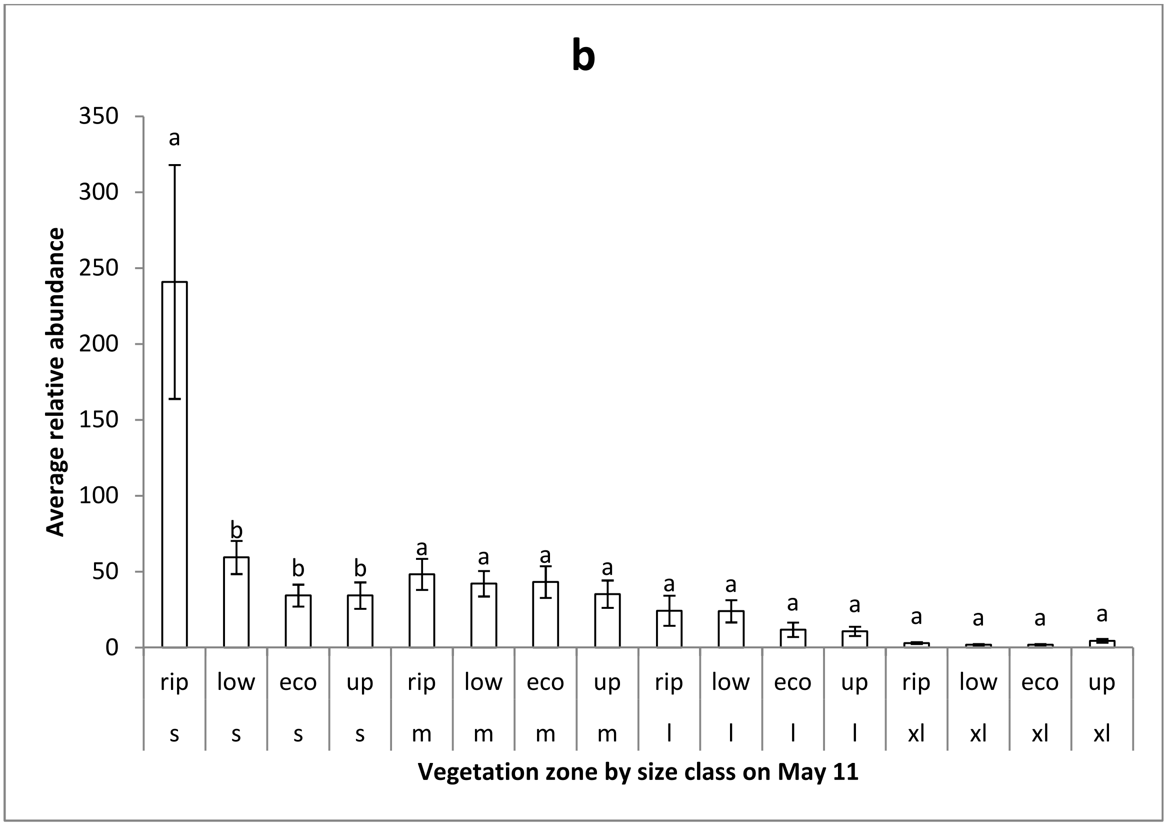
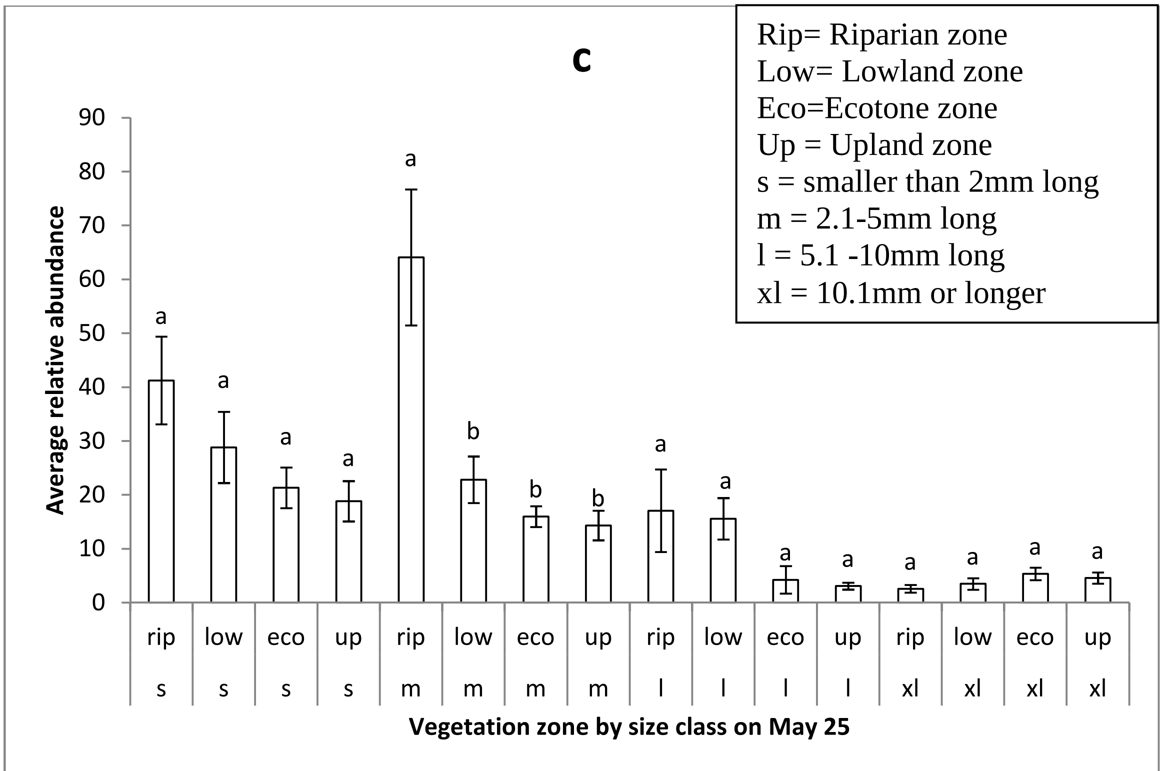


Fig 8a-c. Average relative arthropod abundance per pitfall trap on three dates collected from six transects across four vegetation zones sorted by length (n = 48 traps/sampling event total, 2 traps/transect/zone) collected during the summer of 2012 at Beaver WMA with standard error shown (p value <0.05 for significance). Averages with the same letters above them are not significantly different, and comparisons were only made in terms of abundance by size classes in a given zone or in terms of abundance by zone in a given size class.

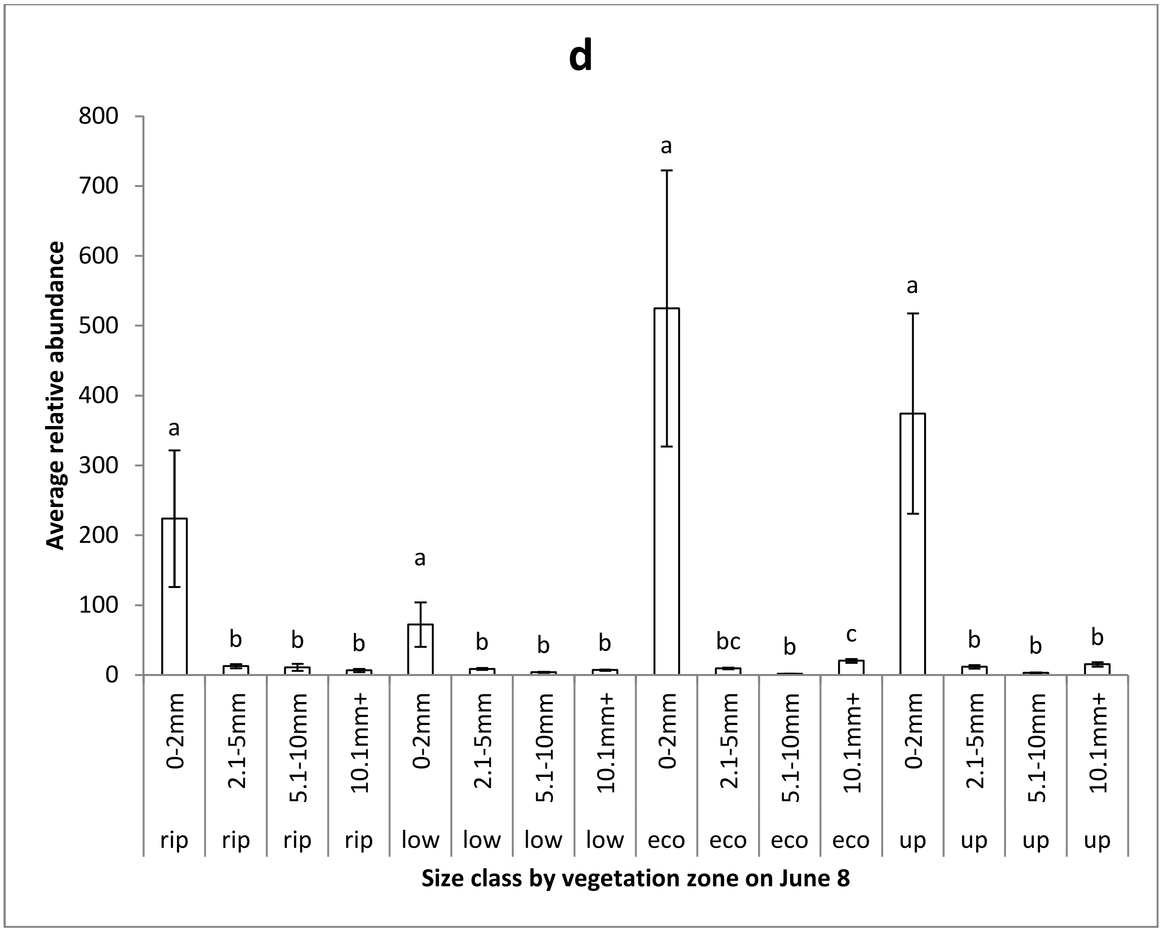


Rip= Riparian zone
Low= Lowland zone
Eco=Ecotone zone
Up = Upland zone
s = smaller than 2mm long
m = 2.1-5mm long
l = 5.1 -10mm long
xl = 10.1mm or longer


b
Average relative abundance
350
300
250
200
150
100
50
0
a
b
b
b
a
a
a
a
a
a
a
a
a
a
a
a
rip
low
eco
up
rip
low
eco
up
rip
low
eco
up
rip
low
eco
up
s
s
s
s
m
m
m
m
l
l
l
l
xl
xl
xl
xl
Vegetation zone by size class on May 11



Rip= Riparian zone
Low= Lowland zone
Eco=Ecotone zone
Up = Upland zone


d
Average relative abundance
800
700
600
500
400
300
200
100
0
a
b
b
b
a
b
b
b
a
bc
b
c
a
b
b
b
0-2mm
2.1-5mm
5.1-10mm
10.1mm+
0-2mm
2.1-5mm
5.1-10mm
10.1mm+
0-2mm
2.1-5mm
5.1-10mm
10.1mm+
0-2mm
2.1-5mm
5.1-10mm
10.1mm+
rip
rip
rip
rip
low
low
low
low
eco
eco
eco
eco
up
up
up
up
Size class by vegetation zone on June 8

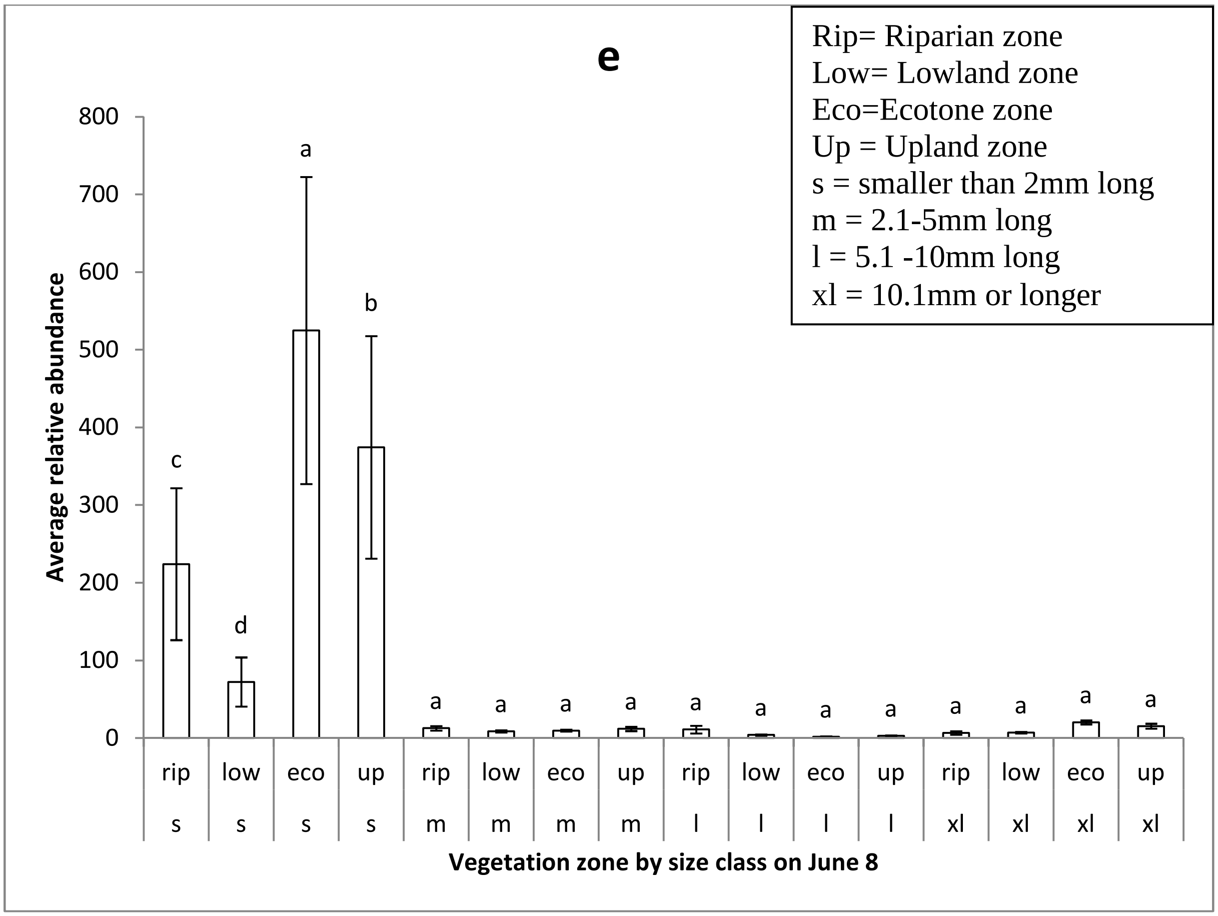
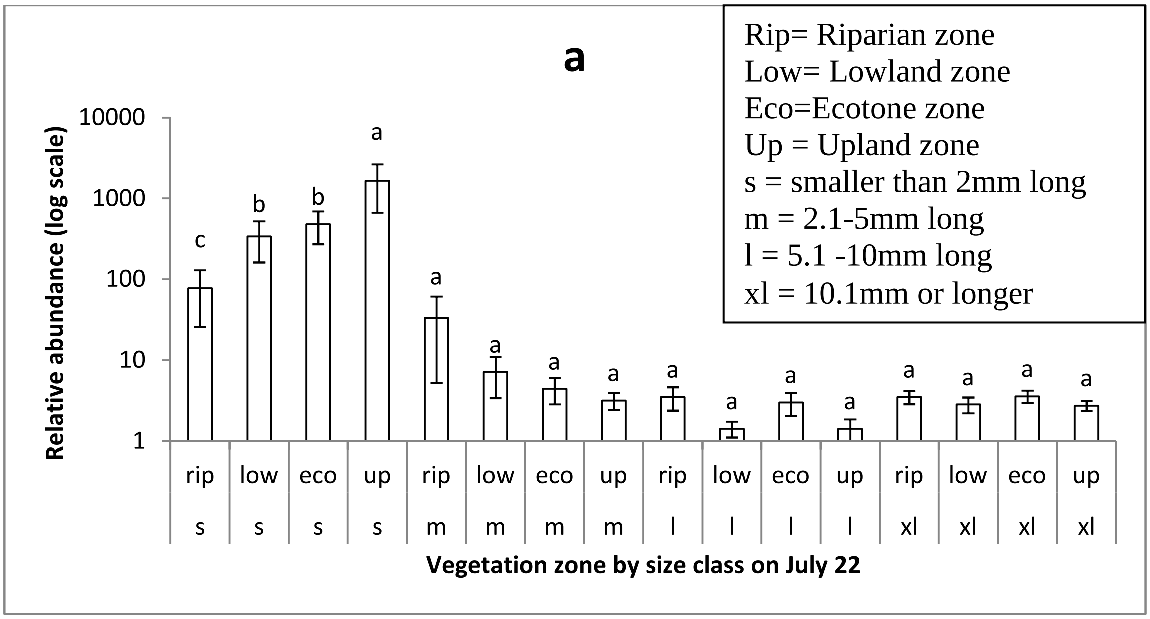


Fig 9a-e. Average relative arthropod abundance per pitfall trap on three dates collected from six transects across four vegetation zones sorted by length (n = 48 traps/sampling event total, 2 traps/transect/zone) collected during the summer of 2013 at Beaver WMA with standard error shown (p value <0.05 for significance). Averages with the same letters above them are not significantly different, and comparisons were only made in terms of abundance by size classes in a given zone or in terms of abundance by zone in a given size class.

.


a
Rip= Riparian zone
Low= Lowland zone
Eco=Ecotone zone
Up = Upland zone
s = smaller than 2mm long
m = 2.1-5mm long
l = 5.1 -10mm long
xl = 10.1mm or longer
Relative abundance (log scale)
10000
1000
100
10
1
c
b
b
a
a
a
a
a
a
a
a
a
a
a
a
a
rip
low
eco
up
rip
low
eco
up
rip
low
eco
up
rip
low
eco
up
s
s
s
s
m
m
m
m
l
l
l
l
xl
xl
xl
xl
Vegetation zone by size class on July 22

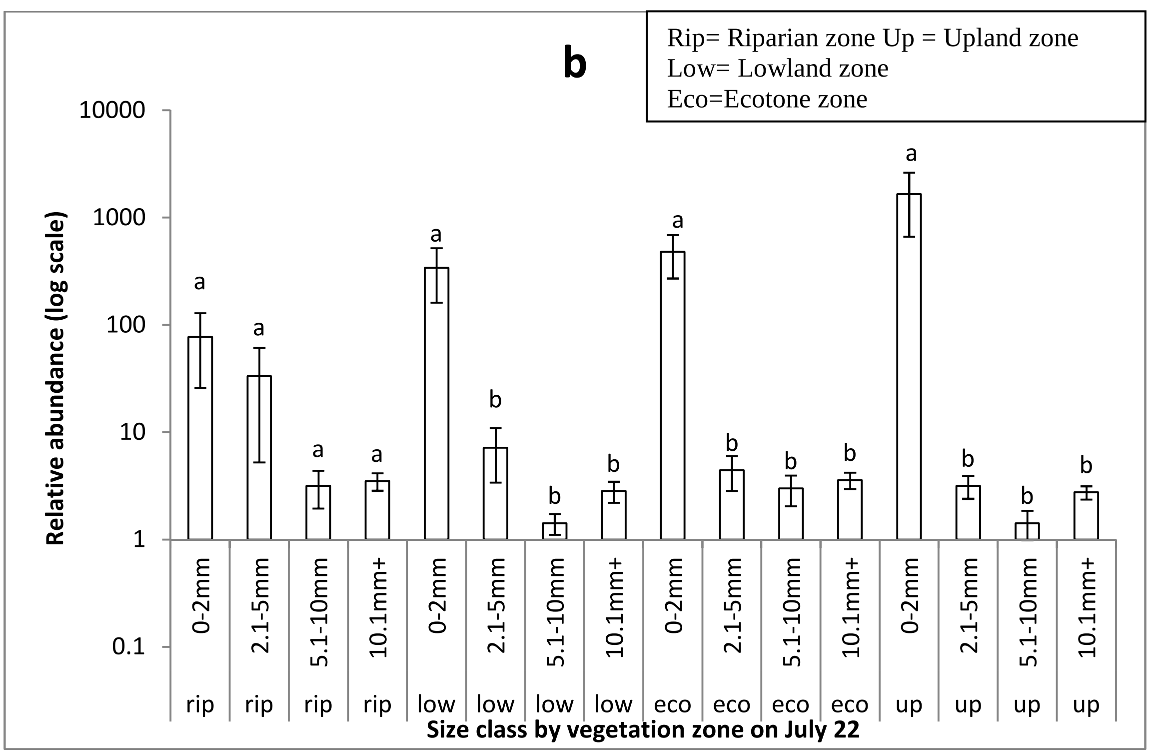

b
Rip= Riparian zone Up = Upland zone
Low= Lowland zone
Eco=Ecotone zone
Relative abundance (log scale)
10000
1000
100
10
1
0.1
a
a
a
a
a
b
b
b
a
b
b
b
a
b
b
b
0-2mm
2.1-5mm
5.1-10mm
10.1mm+
0-2mm
2.1-5mm
5.1-10mm
10.1mm+
0-2mm
2.1-5mm
5.1-10mm
10.1mm+
0-2mm
2.1-5mm
5.1-10mm
10.1mm+
rip
rip
rip
rip
low
low
low
low
eco
eco
eco
eco
up
up
up
up
Size class by vegetation zone on July 22

Fig. 10a-b. Average relative arthropod abundance per pitfall trap on three dates collected from six transects across four vegetation zones sorted by length (n = 48 traps/sampling event total, 2 traps/transect/zone) collected during the summer of 2013 at Packsaddle WMA with standard error shown (p value <0.05 for significance). Averages with the same letters above them are not significantly different, and comparisons were only made in terms of abundance by size classes in a given zone or in terms of abundance by zone in a given size class.

Appendix D- Unpublished Data

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     GETNAMES=YES;
     MIXED=NO;
     SCANTEXT=YES;
     USEDATE=YES;
     SCANTIME=YES;
        SHEET='First Day';


*VARIABLES USED: DATE COLLECTION TRAN ECOR TRAP SIZE PREY PRED NOTUSED XXX TOTAL;

DATA ONE2;
SET ONE;

SRPREY = SQRT(PREY);
SRPRED = SQRT(PRED);
SRTOT = SQRT(TOTAL);

PROC SORT;
BY TRANSECT DATE ECOR SIZE;

PROC MEANS NOPRINT MEAN;
BY TRANSECT DATE ECOR SIZE;
VAR PREY PRED TOTAL;
OUTPUT OUT=TWO MEAN=PREY PRED TOTAL;

PROC SORT DATA=TWO;
BY DATE ECOR SIZE;

PROC MEANS NOPRINT MEAN STDERR;
BY DATE ECOR SIZE;
VAR PREY PRED TOTAL;
OUTPUT OUT=THREE MEAN=MNPREY MNPRED MNTOTAL STDERR=SEPREY SEPRED SETOTAL;


PROC MIXED DATA=TWO;
CLASS DATE TRAN SIZE ECOR;
MODEL SRPREY = ECOR|SIZE|DATE/DDFM=KR;
RANDOM TRAN TRAN*ECOR TRAN*ECOR*SIZE;
REPEATED/SUBJECT=TRAN*ECOR*SIZE TYPE=AR(1);
LSMEANS ECOR*SIZE*DATE/SLICE=(SIZE*DATE) DIFF;
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BY DATE SIZE ECOR;

PROC PRINT NOOBS;
VAR DATE SIZE ECOR MNPREY SEPREY;


PROC MIXED DATA=TWO;
CLASS DATE TRAN SIZE ECOR;
MODEL SRPRED = ECOR|SIZE|DATE/DDFM=KR;
RANDOM TRAN TRAN*ECOR TRAN*ECOR*SIZE;
REPEATED/SUBJECT=TRAN*ECOR*SIZE TYPE=AR(1);
LSMEANS ECOR*SIZE*DATE/SLICE=(SIZE*DATE) DIFF;

PROC SORT DATA=THREE;
BY DATE SIZE ECOR;

PROC PRINT NOOBS;
VAR DATE SIZE ECOR MNPRED SEPRED;


PROC MIXED DATA=TWO;
CLASS DATE TRAN SIZE ECOR;
MODEL SRTOT = ECOR|SIZE|DATE/DDFM=KR;
RANDOM TRAN TRAN*ECOR TRAN*ECOR*SIZE;
REPEATED/SUBJECT=TRAN*ECOR*SIZE TYPE=AR(1);
LSMEANS ECOR*SIZE*DATE/SLICE=(SIZE*DATE) DIFF;

PROC SORT DATA=THREE;
BY DATE SIZE ECOR;

PROC PRINT NOOBS;
VAR DATE SIZE ECOR MNTOTAL SETOTAL;


PROC MIXED DATA=TWO;
CLASS DATE TRAN ECOR SIZE;
MODEL SRPREY = ECOR|SIZE|DATE/DDFM=KR;
RANDOM TRAN TRAN*ECOR TRAN*ECOR*SIZE;
REPEATED/SUBJECT=TRAN*ECOR*SIZE TYPE=AR(1);
LSMEANS ECOR*SIZE*DATE/SLICE=(ECOR*DATE) DIFF;

PROC SORT DATA=THREE;
BY DATE ECOR SIZE;

PROC PRINT NOOBS;
VAR DATE ECOR SIZE MNPREY SEPREY;


PROC MIXED DATA=TWO;
CLASS DATE TRAN ECOR SIZE;
MODEL SRPRED = ECOR|SIZE|DATE/DDFM=KR;
RANDOM TRAN TRAN*ECOR TRAN*ECOR*SIZE;
REPEATED/SUBJECT=TRAN*ECOR*SIZE TYPE=AR(1);
LSMEANS ECOR*SIZE*DATE/SLICE=(ECOR*DATE) DIFF;
```

```
PROC SORT DATA=THREE;
BY DATE ECOR SIZE;

PROC PRINT NOOBS;
VAR DATE ECOR SIZE MNPRED SEPRED;


PROC MIXED DATA=TWO;
CLASS DATE TRAN ECOR SIZE;
MODEL SRTOT = ECOR|SIZE|DATE/DDFM=KR;
RANDOM TRAN TRAN*ECOR TRAN*ECOR*SIZE;
REPEATED/SUBJECT=TRAN*ECOR*SIZE TYPE=AR(1);
LSMEANS ECOR*SIZE*DATE/SLICE=(ECOR*DATE) DIFF;

PROC SORT DATA=THREE;
BY DATE ECOR SIZE;

PROC PRINT NOOBS;
VAR DATE ECOR SIZE MNTOTAL SETOTAL;

RUN;
```

Figure 11. Statistical Analysis Software code and results for the analysis of Beaver and Packsaddle WMA arthropod relative abundance data.

Analysis performed separately for each location and year. This contains only Beaver analysis. Packsaddle is coming later. Total counts were transformed with a log function. Below are comparisons of ecoregion given date and size:

------------------------------ LOC=BEAVER YEAR=2012 --------------------------------

date	size	ecor	MNTOTAL		SETOTAL	PVALUE
1	a	a	8.83	a	1.740	0.9959
1	a	b	11.83	a	3.721	
1	a	c	10.25	a	1.939	
1	a	d	7.08	a	1.716	
1	b	a	31.42	a	12.516	0.5666
1	b	b	5.08	a	1.554	
1	b	c	5.08	a	1.276	
1	b	d	4.00	a	1.037	
1	c	a	88.50	a	28.999	0.0319
1	c	b	12.83	b	5.663	
1	c	c	2.67	b	0.644	
1	c	d	8.42	b	4.243	
1	d	a	2.75	a	2.390	0.9874
1	d	b	5.33	a	3.016	
1	d	c	3.50	a	0.774	
1	d	d	2.92	a	0.557	
2	a	a	108.33	a	18.042	0.5285
2	a	b	103.33	a	28.605	
2	a	c	87.00	a	25.650	
2	a	d	40.33	a	6.231	
2	b	a	31.33	a	7.641	0.7318
2	b	b	14.00	a	4.815	
2	b	c	12.00	a	5.078	

2	b	d	7.33	a	4.585	
2	c	a	71.50	a	14.174	0.1371
2	c	b	23.83	a	10.383	
2	c	c	7.92	a	2.261	
2	c	d	5.08	a	0.839	
2	d	a	3.67	a	0.932	0.9782
2	d	b	5.50	a	1.603	
2	d	c	9.50	a	2.592	
2	d	d	6.58	a	1.417	
3	a	a	46.75	a	7.138	0.7807
3	a	b	30.67	a	6.608	
3	a	c	41.33	a	6.799	
3	a	d	79.08	a	21.819	
3	b	a	43.75	a	19.128	0.4971
3	b	b	3.00	a	0.945	
3	b	c	3.67	a	1.150	
3	b	d	6.08	a	2.119	
3	c	a	68.00	a	16.317	0.2126
3	c	b	14.67	a	4.782	
3	c	c	6.50	a	0.917	
3	c	d	8.33	a	2.068	
3	d	a	11.25	a	5.657	0.9915
3	d	b	8.75	a	1.903	
3	d	c	13.92	a	3.213	
3	d	d	8.83	a	1.542	
4	a	a	91.50	a	43.504	0.9498
4	a	b	54.58	a	11.584	
4	a	c	62.58	a	14.936	
4	a	d	49.42	a	8.041	
4	b	a	18.42	a	8.079	0.9552
4	b	b	9.67	a	4.966	
4	b	c	5.58	a	2.347	
4	b	d	5.17	a	2.236	
4	c	a	22.67	a	7.737	0.8654
4	c	b	4.50	a	0.883	
4	c	c	15.67	a	4.184	
4	c	d	14.33	a	4.950	
4	d	a	2.92	a	0.379	0.9994
4	d	b	3.00	a	0.615	
4	d	c	4.17	a	0.983	
4	d	d	3.25	a	0.509	
5	a	a	1639.83	a	772.926	<.0001
5	a	b	338.42	c	174.619	
5	a	c	536.75	b	180.011	
5	a	d	215.67	c	85.3281	

5	b	a	27.417	a	4.2058	0.9274
5	b	b	47.500	a	17.1877	
5	b	c	50.417	a	16.9779	
5	b	d	24.667	a	5.1996	
5	c	a	34.667	a	9.1074	0.7704
5	c	b	18.250	a	7.8133	
5	c	c	16.833	a	7.5587	
5	c	d	6.667	a	2.0425	
5	d	a	4.750	a	0.6528	0.9184
5	d	b	14.333	a	11.8835	
5	d	c	45.333	a	41.9770	
5	d	d	7.083	a	1.4273	

------------------------------ LOC=BEAVER YEAR=2013 -------------------------------

date	size	ecor	MNTOTAL		SETOTAL	PVALUE
1	a	a	240.917	a	77.055	<.0001
1	a	b	59.417	b	10.938	
1	a	c	34.333	b	7.197	
1	a	d	34.333	b	8.684	
1	b	a	48.333	a	10.258	0.8965
1	b	b	42.083	a	8.374	
1	b	c	43.250	a	10.449	
1	b	d	35.250	a	9.040	
1	c	a	24.333	a	9.977	0.5836
1	c	b	24.000	a	7.374	
1	c	c	11.833	a	4.713	
1	c	d	10.750	a	3.025	
1	d	a	3.000	a	0.550	0.9590
1	d	b	1.917	a	0.468	
1	d	c	1.917	a	0.379	
1	d	d	4.500	a	1.165	
2	a	a	41.250	a	8.133	0.5217
2	a	b	28.833	a	6.607	
2	a	c	21.333	a	3.771	
2	a	d	18.833	a	3.745	
2	b	a	64.083	a	12.620	0.0115
2	b	b	22.833	b	4.320	
2	b	c	16.000	b	1.935	
2	b	d	14.333	b	2.737	
2	c	a	17.083	a	7.654	0.2590
2	c	b	15.583	a	3.844	

2	c	c	4.250	a	2.553	
2	c	d	3.083	a	0.633	
2	d	a	2.583	a	0.712	0.9511
2	d	b	3.500	a	1.070	
2	d	c	5.333	a	1.157	
2	d	d	4.583	a	1.055	
3	a	a	224.083	c	97.825	<.0001
3	a	b	72.250	d	31.708	
3	a	c	524.833	a	197.723	
3	a	d	374.333	b	143.330	
3	b	a	12.667	a	2.932	0.9852
3	b	b	8.750	a	1.420	
3	b	c	9.583	a	1.177	
3	b	d	11.833	a	2.657	
3	c	a	11.083	a	4.931	0.6505
3	c	b	4.000	a	0.769	
3	c	c	1.667	a	0.432	
3	c	d	2.917	a	0.743	
3	d	a	6.667	a	2.330	0.4069
3	d	b	7.083	a	0.941	
3	d	c	20.333	a	2.553	
3	d	d	15.4167	a	3.1967	
4	a	a	34.1667	ab	7.9027	0.0249
4	a	b	75.8333	a	22.3606	
4	a	c	29.0000	b	7.3783	
4	a	d	16.3333	b	4.1329	
4	b	a	25.6667	a	6.1501	0.2182
4	b	b	7.1667	a	1.3698	
4	b	c	6.7500	a	1.4674	
4	b	d	6.2500	a	1.1357	
4	c	a	9.0000	a	2.6170	0.9466
4	c	b	5.2500	a	0.9465	
4	c	c	3.8333	a	0.8513	
4	c	d	6.5000	a	2.2813	
4	d	a	5.2500	a	1.5082	0.7165
4	d	b	5.6667	a	0.9873	
4	d	c	11.6667	a	1.5731	
4	d	d	12.4167	a	2.4632	
5	a	a	39.2500	a	6.6857	0.8579
5	a	b	27.6667	a	7.1566	
5	a	c	28.9167	a	6.6258	
5	a	d	30.6667	a	6.5126	

5	b	a	36.3333	a	23.6112	0.2366
5	b	b	11.5833	a	3.1248	
5	b	c	6.1667	a	1.3075	
5	b	d	5.3333	a	1.6345	
5	c	a	59.2500	a	6.6630	0.0078
5	c	b	16.4167	b	2.8590	
5	c	c	15.9167	b	5.4348	
5	c	d	14.0000	b	4.4398	
5	d	a	7.7500	a	1.3034	0.9919
5	d	b	8.6667	a	1.3104	
5	d	c	8.1667	a	1.6322	
5	d	d	6.5000	a	1.4328	
6	a	a	51.9167	a	18.0427	0.5431
6	a	b	49.6667	a	11.6283	
6	a	c	57.7500	a	10.6871	
6	a	d	33.2500	a	8.9486	
6	b	a	12.5000	a	3.7487	0.8187
6	b	b	5.2500	a	1.6612	
6	b	c	4.5000	a	0.6908	
6	b	d	4.8333	a	1.2663	
6	c	a	6.6667	a	2.2372	0.9285
6	c	b	5.9167	a	1.3053	
6	c	c	9.5833	a	2.5892	
6	c	d	4.6667	a	1.4160	
6	d	a	4.7500	a	0.7191	0.9879
6	d	b	5.9167	a	0.9000	
6	d	c	5.3333	a	0.5125	
6	d	d	4.0833	a	0.8569	
7	a	a	19.5000	a	2.6213	0.2137
7	a	b	67.7500	a	28.8279	
7	a	c	49.4167	a	11.3354	
7	a	d	43.8333	a	9.6215	
7	b	a	11.3333	a	3.5704	0.9059
7	b	b	4.9167	a	1.2995	
7	b	c	5.0000	a	1.1997	
7	b	d	5.1667	a	0.9280	
7	c	a	2.9167	a	0.7226	0.8909
7	c	b	1.2500	a	0.4626	
7	c	c	1.3333	a	0.5685	
7	c	d	3.3333	a	0.8989	
7	d	a	5.9167	a	0.6793	0.9927
7	d	b	4.1667	a	0.7769	
7	d	c	4.9167	a	1.1041	

7	d	d	5.3333 a	1.0323	

Comparisons of size given date and ecoregion:

------------------------------ LOC=BEAVER YEAR=2012 -------------------------------

date	ecor	size	MNTOTAL	SETOTAL	PVALUE
1	a	a	8.83 b	1.740	0.0244
1	a	b	31.42 ab	12.516	
1	a	c	88.50 a	28.999	
1	a	d	2.75 b	2.390	
1	b	a	11.83 a	3.721	0.9567
1	b	b	5.08 a	1.554	
1	b	c	12.83 a	5.663	
1	b	d	5.33 a	3.016	
1	c	a	10.25 a	1.939	0.9464
1	c	b	5.08 a	1.276	
1	c	c	2.67 a	0.644	
1	c	d	3.50 a	0.774	
1	d	a	7.08 a	1.716	0.9812
1	d	b	4.00 a	1.037	
1	d	c	8.42 a	4.243	
1	d	d	2.92 a	0.557	
2	a	a	108.33 a	18.042	0.0149
2	a	b	31.33 ab	7.641	
2	a	c	71.50 a	14.174	
2	a	d	3.67 b	0.932	
2	b	a	103.33 a	28.605	0.0530
2	b	b	14.00 a	4.815	
2	b	c	23.83 a	10.383	
2	b	d	5.50 a	1.603	
2	c	a	87.00 a	25.650	0.0938
2	c	b	12.00 a	5.078	
2	c	c	7.92 a	2.261	
2	c	d	9.50 a	2.592	
2	d	a	40.33 a	6.231	0.3619
2	d	b	7.33 a	4.585	
2	d	c	5.08 a	0.839	
2	d	d	6.58 a	1.417	
3	a	a	46.75 a	7.138	0.3704
3	a	b	43.75 a	19.128	
3	a	c	68.00 a	16.317	
3	a	d	11.25 a	5.657	
3	b	a	30.67 a	6.608	0.6033

3	b	b	3.00	a	0.945	
3	b	c	14.67	a	4.782	
3	b	d	8.75	a	1.903	
3	c	a	41.33	a	6.799	0.3766
3	c	b	3.67	a	1.150	
3	c	c	6.50	a	0.917	
3	c	d	13.92	a	3.213	
3	d	a	79.08	a	21.819	0.1033
3	d	b	6.08	a	2.119	
3	d	c	8.33	a	2.068	
3	d	d	8.83	a	1.542	
4	a	a	91.50	a	43.504	0.1058
4	a	b	18.42	a	8.079	
4	a	c	22.67	a	7.737	
4	a	d	2.92	a	0.379	
4	b	a	54.58	a	11.584	0.1713
4	b	b	9.67	a	4.966	
4	b	c	4.50	a	0.883	
4	b	d	3.00	a	0.615	
4	c	a	62.58	a	14.936	0.1241
4	c	b	5.58	a	2.347	
4	c	c	15.67	a	4.184	
4	c	d	4.17	a	0.983	
4	d	a	49.42	a	8.041	0.2337
4	d	b	5.17	a	2.236	
4	d	c	14.33	a	4.950	
4	d	d	3.25	a	0.509	
5	a	a	1639.83	a	772.926	<.0001
5	a	b	27.42	b	4.206	
5	a	c	34.67	b	9.107	
5	a	d	4.750	b	0.653	
5	b	a	338.417	a	174.619	0.0013
5	b	b	47.500	b	17.188	
5	b	c	18.250	b	7.813	
5	b	d	14.333	b	11.883	
5	c	a	536.750	a	180.011	<.0001
5	c	b	50.417	b	16.978	
5	c	c	16.833	b	7.559	
5	c	d	45.333	b	41.977	
5	d	a	215.667	a	85.328	0.0010
5	d	b	24.667	b	5.200	
5	d	c	6.667	b	2.042	
5	d	d	7.083	b	1.427	

------------------------------ LOC=BEAVER YEAR=2013 -------------------------------

date	ecor	size	MNTOTAL		SETOTAL	PVALUE
1	a	a	240.917	a	77.055	<.0001
1	a	b	48.333	ab	10.258	
1	a	c	24.333	b	9.977	
1	a	d	3.000	c	0.550	
1	b	a	59.417	a	10.938	<.0001
1	b	b	42.083	ab	8.374	
1	b	c	24.000	b	7.374	
1	b	d	1.917	c	0.468	
1	c	a	34.333	a	7.197	0.0011
1	c	b	43.250	a	10.449	
1	c	c	11.833	b	4.713	
1	c	d	1.917	b	0.379	
1	d	a	34.333	a	8.684	0.0206
1	d	b	35.250	a	9.040	
1	d	c	10.750	ab	3.025	
1	d	d	4.500	b	1.165	
2	a	a	41.250	a	8.133	<.0001
2	a	b	64.083	a	12.620	
2	a	c	17.083	b	7.654	
2	a	d	2.583	b	0.712	
2	b	a	28.833	a	6.607	0.0758
2	b	b	22.833	a	4.320	
2	b	c	15.583	a	3.844	
2	b	d	3.500	a	1.070	
2	c	a	21.333	a	3.771	0.1396
2	c	b	16.000	a	1.935	
2	c	c	4.250	a	2.553	
2	c	d	5.333	a	1.157	
2	d	a	18.833	a	3.745	0.1931
2	d	b	14.333	a	2.737	
2	d	c	3.083	a	0.633	
2	d	d	4.583	a	1.055	
3	a	a	224.083	a	97.825	<.0001
3	a	b	12.667	b	2.932	
3	a	c	11.083	b	4.931	
3	a	d	6.667	b	2.330	
3	b	a	72.250	a	31.708	0.0002

3	b	b	8.750	b	1.420	
3	b	c	4.000	b	0.769	
3	b	d	7.083	b	0.941	
3	c	a	524.833	a	197.723	<.0001
3	c	b	9.583	bc	1.177	
3	c	c	1.667	c	0.432	
3	c	d	20.333	b	2.553	
3	d	a	374.333	a	143.330	<.0001
3	d	b	11.833	b	2.657	
3	d	c	2.917	b	0.743	
3	d	d	15.4167	b	3.1967	
4	a	a	34.1667	a	7.9027	0.0342
4	a	b	25.6667	ab	6.1501	
4	a	c	9.0000	b	2.6170	
4	a	d	5.2500	b	1.5082	
4	b	a	75.8333	a	22.3606	<.0001
4	b	b	7.1667	b	1.3698	
4	b	c	5.2500	b	0.9465	
4	b	d	5.6667	b	0.9873	
4	c	a	29.0000	a	7.3783	0.1259
4	c	b	6.7500	a	1.4674	
4	c	c	3.8333	a	0.8513	
4	c	d	11.6667	a	1.5731	
4	d	a	16.3333	a	4.1329	0.6509
4	d	b	6.2500	a	1.1357	
4	d	c	6.5000	a	2.2813	
4	d	d	12.4167	a	2.4632	
5	a	a	39.2500	ab	6.6857	0.0044
5	a	b	36.3333	bc	23.6112	
5	a	c	59.2500	a	6.6630	
5	a	d	7.7500	c	1.3034	
5	b	a	27.6667	a	7.1566	0.4637
5	b	b	11.5833	a	3.1248	
5	b	c	16.4167	a	2.8590	
5	b	d	8.6667	a	1.3104	
5	c	a	28.9167	a	6.6258	0.1745
5	c	b	6.1667	a	1.3075	
5	c	c	15.9167	a	5.4348	
5	c	d	8.1667	a	1.6322	
5	d	a	30.6667	a	6.5126	0.0876
5	d	b	5.3333	a	1.6345	
5	d	c	14.0000	a	4.4398	
5	d	d	6.5000	a	1.4328	
6	a	a	51.9167	a	18.0427	0.0048
6	a	b	12.5000	b	3.7487	

6	a	c	6.6667 b	2.2372	
6	a	d	4.7500 b	0.7191	
6	b	a	49.6667 a	11.6283	0.0012
6	b	b	5.2500 b	1.6612	
6	b	c	5.9167 b	1.3053	
6	b	d	5.9167 b	0.9000	
6	c	a	57.7500 a	10.6871	0.0002
6	c	b	4.5000 b	0.6908	
6	c	c	9.5833 b	2.5892	
6	c	d	5.3333 b	0.5125	
6	d	a	33.2500 a	8.9486	0.0283
6	d	b	4.8333 b	1.2663	
6	d	c	4.6667 b	1.4160	
6	d	d	4.0833 b	0.8569	
7	a	a	19.5000 a	2.6213	0.2633
7	a	b	11.3333 a	3.5704	
7	a	c	2.9167 a	0.7226	
7	a	d	5.9167 a	0.6793	
7	b	a	67.7500 a	28.8279	<.0001
7	b	b	4.9167 b	1.2995	
7	b	c	1.2500 b	0.4626	
7	b	d	4.1667 b	0.7769	
7	c	a	49.4167 a	11.3354	0.0002
7	c	b	5.0000 b	1.1997	
7	c	c	1.3333 b	0.5685	
7	c	d	4.9167 b	1.1041	
7	d	a	43.8333 a	9.6215	0.0023
7	d	b	5.1667 b	0.9280	
7	d	c	3.3333 b	0.8989	
7	d	d	5.3333 b	1.0323	

Packsaddle analysis: Comparing ecoregions given date and size:

------------------------------ LOC=PACKSA YEAR=2013 -------------------------------

date	size	ecor	MNTOTAL	SETOTAL	PVALUE
1	a	a	26.7500 a	6.6528	0.8521
1	a	b	27.1667 a	5.6780	
1	a	c	40.9167 a	6.6178	
1	a	d	20.4167 a	4.9244	
1	b	a	16.0000 a	3.1455	0.9889
1	b	b	15.8333 a	6.0137	
1	b	c	16.9167 a	4.2452	

1	b	d	10.3333	a	1.7681	
1	c	a	10.6667	a	3.6209	0.9846
1	c	b	6.1667	a	1.4916	
1	c	c	4.5833	a	1.0110	
1	c	d	6.3333	a	1.3046	
1	d	a	4.5000	a	1.3456	0.9895
1	d	b	6.9167	a	1.2819	
1	d	c	3.9167	a	0.7829	
1	d	d	4.2500	a	0.8360	
2	a	a	32.5000	a	7.2462	0.9980
2	a	b	35.0000	a	5.8245	
2	a	c	31.3333	a	6.7199	
2	a	d	34.2500	a	6.6676	
2	b	a	14.9167	a	3.9437	0.9361
2	b	b	23.8333	a	4.6218	
2	b	c	15.0833	a	2.0017	
2	b	d	12.4167	a	1.4167	
2	c	a	8.8333	a	3.6801	0.9373
2	c	b	3.9167	a	1.0621	
2	c	c	1.6667	a	0.4323	
2	c	d	3.0833	a	0.7226	
2	d	a	1.6667	a	0.3333	0.9468
2	d	b	7.9167	a	2.5240	
2	d	c	3.3333	a	0.5946	
2	d	d	3.4167	a	0.3362	
3	a	a	26.6667	a	5.3518	0.9818
3	a	b	21.6667	a	5.4597	
3	a	c	31.0000	a	10.2647	
3	a	d	29.5000	a	6.5488	
3	b	a	51.0833	a	23.5322	0.7767
3	b	b	18.0833	a	5.8250	
3	b	c	23.0000	a	5.0737	
3	b	d	26.2500	a	4.4264	
3	c	a	85.4167	a	33.4282	0.0188
3	c	b	7.3333	b	1.4890	
3	c	c	5.6667	b	1.2144	
3	c	d	4.4167	b	1.3732	
3	d	a	5.5000	a	1.4381	0.9716
3	d	b	10.0000	a	1.6143	
3	d	c	7.4167	a	1.5048	
3	d	d	11.2500	a	2.6231	
4	a	a	24.4167	a	5.1558	0.9996
4	a	b	24.6667	a	6.3691	
4	a	c	25.5833	a	6.6736	
4	a	d	22.5000	a	6.2383	

4	b	a	25.0000	a	6.5378	0.9364
4	b	b	17.0833	a	8.6423	
4	b	c	11.3333	a	3.7098	
4	b	d	18.7500	a	6.1732	
4	c	a	33.8333	a	11.0959	0.5321
4	c	b	7.4167	a	1.5248	
4	c	c	4.9167	a	0.7926	
4	c	d	3.5833	a	0.8021	
4	d	a	7.6667	a	1.1569	0.9518
4	d	b	15.3333	a	2.9241	
4	d	c	15.0833	a	2.6585	
4	d	d	14.2500	a	2.1747	
5	a	a	52.66	a	10.989	0.7589
5	a	b	56.00	a	17.303	
5	a	c	61.00	a	14.740	
5	a	d	29.42	a	5.499	
5	b	a	31.75	a	13.324	0.8853
5	b	b	16.92	a	6.675	
5	b	c	11.50	a	4.133	
5	b	d	12.75	a	5.513	
5	c	a	27.50	a	9.752	0.4065
5	c	b	4.83	a	1.381	
5	c	c	4.50	a	1.635	
5	c	d	2.33	a	0.980	
5	d	a	6.00	a	1.168	0.9927
5	d	b	8.92	a	1.505	
5	d	c	7.42	a	1.401	
5	d	d	9.58	a	1.971	
6	a	a	63.42	a	13.306	0.9033
6	a	b	54.00	a	21.044	
6	a	c	70.42	a	14.249	
6	a	d	49.42	a	8.619	
6	b	a	9.42	a	4.379	0.9767
6	b	b	11.83	a	4.455	
6	b	c	8.17	a	4.711	
6	b	d	5.17	a	2.242	
6	c	a	10.75	a	3.248	0.8369
6	c	b	3.00	a	0.663	
6	c	c	2.75	a	0.730	
6	c	d	1.67	a	0.810	
6	d	a	4.00	a	0.879	0.9914
6	d	b	5.25	a	0.922	

6	d	c	3.08 a	0.773	
6	d	d	4.00 a	0.739	
7	a	a	77.33 c	51.555	<.0001
7	a	b	340.42 b	179.028	
7	a	c	480.08 b	208.772	
7	a	d	1650.08 a	985.299	
7	b	a	33.33 a	28.093	0.7344
7	b	b	7.17 a	3.774	
7	b	c	4.42 a	1.579	
7	b	d	3.17 a	0.767	
7	c	a	3.17 a	1.224	0.9909
7	c	b	1.42 a	0.313	
7	c	c	3.00 a	0.953	
7	c	d	1.42 a	0.434	
7	d	a	3.50 a	0.645	0.9992
7	d	b	2.83 a	0.626	
7	d	c	3.58 a	0.621	
7	d	d	2.75 a	0.392	
8	a	a	22.00 bc	6.085	<.0001
8	a	b	12.67 c	1.453	
8	a	c	452.17 a	278.295	
8	a	d	75.67 b	22.565	
8	b	a	40.17 a	7.377	0.5189
8	b	b	23.83 a	3.539	
8	b	c	18.42 a	5.998	
8	b	d	10.50 a	4.623	
8	c	a	3.92 a	1.593	0.9996
8	c	b	2.67 a	0.772	
8	c	c	3.67 a	1.639	
8	c	d	4.33 a	1.755	
8	d	a	3.25 a	0.579	0.9521
8	d	b	9.08 a	1.979	
8	d	c	9.58 a	2.598	
8	d	d	7.50 a	2.109	

Comparing sizes given date and ecoregion:

------------------------------ LOC=PACKSA YEAR=2013 --------------------------------

date	ecor	size	MNTOTAL	SETOTAL	PVALUE
1	a	a	26.7500 a	6.6528	0.5867
1	a	b	16.0000 a	3.1455	
1	a	c	10.6667 a	3.6209	
1	a	d	4.5000 a	1.3456	

1	b	a	27.1667	a	5.6780	0.6117
1	b	b	15.8333	a	6.0137	
1	b	c	6.1667	a	1.4916	
1	b	d	6.9167	a	1.2819	
1	c	a	40.9167	a	6.6178	0.1842
1	c	b	16.9167	a	4.2452	
1	c	c	4.5833	a	1.0110	
1	c	d	3.9167	a	0.7829	
1	d	a	20.4167	a	4.9244	0.7481
1	d	b	10.3333	a	1.7681	
1	d	c	6.3333	a	1.3046	
1	d	d	4.2500	a	0.8360	
2	a	a	32.5000	a	7.2462	0.3019
2	a	b	14.9167	a	3.9437	
2	a	c	8.8333	a	3.6801	
2	a	d	1.6667	a	0.3333	
2	b	a	35.0000	a	5.8245	0.2653
2	b	b	23.8333	a	4.6218	
2	b	c	3.9167	a	1.0621	
2	b	d	7.9167	a	2.5240	
2	c	a	31.3333	a	6.7199	0.2095
2	c	b	15.0833	a	2.0017	
2	c	c	1.6667	a	0.4323	
2	c	d	3.3333	a	0.5946	
2	d	a	34.2500	a	6.6676	0.2454
2	d	b	12.4167	a	1.4167	
2	d	c	3.0833	a	0.7226	
2	d	d	3.4167	a	0.3362	
3	a	a	26.6667	a	5.3518	0.0603
3	a	b	51.0833	a	23.5322	
3	a	c	85.4167	a	33.4282	
3	a	d	5.5000	a	1.4381	
3	b	a	21.6667	a	5.4597	0.8440
3	b	b	18.0833	a	5.8250	
3	b	c	7.3333	a	1.4890	
3	b	d	10.0000	a	1.6143	
3	c	a	31.0000	a	10.2647	0.5072
3	c	b	23.0000	a	5.0737	
3	c	c	5.6667	a	1.2144	
3	c	d	7.4167	a	1.5048	
3	d	a	29.5000	a	6.5488	0.3720
3	d	b	26.2500	a	4.4264	
3	d	c	4.4167	a	1.3732	
3	d	d	11.2500	a	2.6231	
4	a	a	24.4167	a	5.1558	0.7264

4	a	b	25.0000	a	6.5378	
4	a	c	33.8333	a	11.0959	
4	a	d	7.6667	a	1.1569	
4	b	a	24.6667	a	6.3691	0.8348
4	b	b	17.0833	a	8.6423	
4	b	c	7.4167	a	1.5248	
4	b	d	15.3333	a	2.9241	
4	c	a	25.5833	a	6.6736	0.7429
4	c	b	11.3333	a	3.7098	
4	c	c	4.9167	a	0.7926	
4	c	d	15.0833	a	2.6585	
4	d	a	22.5000	a	6.2383	0.6055
4	d	b	18.7500	a	6.1732	
4	d	c	3.5833	a	0.8021	
4	d	d	14.2500	a	2.1747	
5	a	a	52.66	a	10.989	0.2156
5	a	b	31.75	a	13.323	
5	a	c	27.50	a	9.751	
5	a	d	6.00	a	1.168	
5	b	a	56.00	a	17.303	0.1478
5	b	b	16.92	a	6.675	
5	b	c	4.83	a	1.381	
5	b	d	8.92	a	1.505	
5	c	a	61.00	a	14.740	0.0528
5	c	b	11.50	a	4.133	
5	c	c	4.50	a	1.635	
5	c	d	7.42	a	1.401	
5	d	a	29.42	a	5.499	0.3397
5	d	b	12.75	a	5.513	
5	d	c	2.33	a	0.980	
5	d	d	9.58	a	1.971	
6	a	a	63.42	a	13.306	0.0396
6	a	b	9.42	b	4.379	
6	a	c	10.75	b	3.248	
6	a	d	4.00	b	0.879	
6	b	a	54.00	a	21.044	0.1356
6	b	b	11.83	a	4.455	
6	b	c	3.00	a	0.663	
6	b	d	5.25	a	0.922	
6	c	a	70.42	a	14.249	0.0115
6	c	b	8.17	b	4.711	
6	c	c	2.75	b	0.730	
6	c	d	3.08	b	0.773	

6	d	a	49.42 a	8.619	0.0433
6	d	b	5.17 b	2.242	
6	d	c	1.67 b	0.810	
6	d	d	4.00 b	0.739	
7	a	a	77.33 a	51.555	0.0508
7	a	b	33.33 a	28.093	
7	a	c	3.17 a	1.224	
7	a	d	3.50 a	0.645	
7	b	a	340.42 a	179.028	<.0001
7	b	b	7.17 b	3.774	
7	b	c	1.42 b	0.313	
7	b	d	2.83 b	0.626	
7	c	a	480.08 a	208.772	<.0001
7	c	b	4.42 b	1.579	
7	c	c	3.00 b	0.953	
7	c	d	3.58 b	0.621	
7	d	a	1650.08 a	985.299	<.0001
7	d	b	3.17 b	0.767	
7	d	c	1.42 b	0.434	
7	d	d	2.75 b	0.392	
8	a	a	22.00 a	6.085	0.1467
8	a	b	40.17 a	7.377	
8	a	c	3.92 a	1.593	
8	a	d	3.25 a	0.579	
8	b	a	12.67 a	1.453	0.5248
8	b	b	23.83 a	3.539	
8	b	c	2.67 a	0.772	
8	b	d	9.08 a	1.979	
8	c	a	452.17 a	278.295	<.0001
8	c	b	18.42 b	5.998	
8	c	c	3.67 b	1.639	
8	c	d	9.58 b	2.598	
8	d	a	75.67 a	22.565	0.0190
8	d	b	10.50 b	4.623	
8	d	c	4.33 b	1.755	
8	d	d	7.50 b	2.109	

Figure 12. Output of the SAS 9.2 code used to evaluate arthropod abundance data from the 2012 and 2013 seasons in Beaver and Packsaddle.

VITA

Shane Foye

Candidate for the Degree of

Master of Science

Thesis: CHARACTERIZATION OF GROUND-DWELLING ARTHROPOD ASSEMBLAGES IN NORTHERN BOBWHITE (*COLINUS VIRGINIANUS*) HABITAT.

Major Field: Entomology and Plant Pathology

Biographical:

Education:

Completed the requirements for the Master of Science in Entomology and Plant Pathology at Oklahoma State University, Stillwater, Oklahoma in July, 2014.

Completed the requirements for the Bachelor of Arts in Biology at Lafayette College, Easton, Pennsylvania in 2012.

Experience:

Completed an undergraduate Honors thesis in insect ecology at Lafayette College in 2012 regarding the effectiveness of *Gallerucella calmariensis* (Coleoptera: Chrysomelidae) on *Lythrum salicaria* in western Pennsylvania.

Professional Memberships:

Member of the Entomological Society of America since 2012.