

COMMUNITY COMPOSITION AND RESOURCE
PARTITIONING OF ANTS (HYMENOPTERA:
FORMICIDAE) IN WESTERN OKLAHOMA
GRASSLAND ECOSYSTEMS: A CRITICAL FORAGE
TAXON OF THE NORTHERN BOBWHITE (COLINUS
VIRGINIANUS)

By

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COMMUNITY COMPOSITION AND RESOURCE PARTITIONING OF ANTS
(HYMENOPTERA: FORMICIDAE) IN WESTERN OKLAHOMA GRASSLAND
ECOSYSTEMS: A CRITICAL FORAGE TAXON OF THE NORTHERN BOBWHITE
(*COLINUS VIRGINIANUS*)

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Abstract: Complementary sampling techniques were used to quantify the interspecific communities of ants in the Oklahoma panhandle. Six transects were established in the Beaver River Wildlife Management Area (BRWMA), that spanned four distinct vegetation zones (riparian, grassland, transitional, upland). Pitfall traps and baiting methods were used concurrently to collect over 30,000 specimens between both methods, representing 15 species. Differences were observed between sampling methods, bait types, and vegetation zones.

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CHAPTER I

REVIEW OF LITERATURE

Introduction:

Throughout the range of the northern bobwhite (*Colinus virginianus*), populations are undergoing a sustained and rapid decline. The United States Department of Agriculture (USDA) estimated that between 70% and 90% of the original population has been lost in some parts of its range, at the rate of 3% population loss per year (Link et al. 2008). In the American Great Plains region, the largest factor contributing to this decline is the widespread change in land use over the past several decades (Kleppinger 2007). These changes include, but are not limited to, the overall degradation of ideal bobwhite habitat, including loss of protective cover for nest sites, the removal of hedgerows, fencerows, and windbreaks from fields, the conversion of grasslands dominated by native species to grasslands dominated by introduced and invasive grasses, increased agrichemical use, increased grazing, increased fire suppression, the conversion of the wheat-fallow agricultural system to a continuous production system, the removal of timber and brush in open areas (Franks et al. 2007, Stillinger 1999), and urban and suburban development and expansion. Subsequently, it has been suggested that the conversion of the wheat-fallow agricultural regimen to continuous production, in conjunction with increased pesticide use in native grasslands, may have reduced total arthropod biomass. Arthropods are a critical component of the diet of developing and reproductive northern bobwhite chicks; a reduction of

insect biomass may contribute to the decline of this important game species (Doxon and Carroll 2010).

The northern bobwhite is a small, non-migratory, galliform (chicken-like) bird (Kleppinger 2007) which flies in short bursts. Its feet are highly adapted for scratching and most of its time is spent on the ground nesting or foraging. Because young northern bobwhites are not very mobile, their ability to harvest or catch arthropods limits what they are able to consume.

A northern bobwhite is most vulnerable during its earliest life stages. Between 12 and 50% of northern bobwhite eggs that are laid hatch (Kleppinger 2007). If the chick does hatch, mortality rates are high from predators including skunks (*Mephitis mephitis*), opossums (*Dipholphis virginiana*), grey foxes (*Urocyon nereoargenteus*), raccoons (*Procyon lotor*) and many species of raptorial birds. If additional pressure on bobwhite chick survival results from reduced (arthropod) forage availability, this protein deficit would likely have a negative effect on populations as a whole.

The diet of northern bobwhites consists of seeds, fruit, leaves, stems, and arthropods. Seeds and vegetation comprise up to 85% of an adult bird's diet; however, the same percentage of a juvenile's diet is made up of arthropods. Hatchlings consume protein-rich arthropods almost exclusively for at least their first 2 weeks after hatching (Stillinger 1999). The diet of adult females consists of approximately 20% arthropods during summer, while arthropods contribute only 5% to an adult male's diet (Stillinger 1999). Arthropod consumption is 3 to 12.5 times higher in laying females than males (Harveson et al. 2004). Females laying eggs consume 2.3 to 4 times the amount of arthropod nourishment as non-laying females (Harveson et al. 2004). Chicks that have insufficient arthropod protein during their developmental growth have reduced development rates, especially of feathers and muscular strength, which increases the duration to

fledging (Doxon and Carroll 2010). This longer time period before flight results in an increased window of time during which predation is unavoidable by flight and an increased risk of reduced body size during periods of decreased food availability, such as during the winter and spring months (Doxon and Carroll 2010; Nestler et al. 1942). According to Kleppinger (2007), spring has the lowest food availability and autumn has the greatest abundance. Therefore, body size must be adequate to allow the bobwhite to survive its first spring.

Ants (Formicidae) are consumed more frequently by bobwhite chicks than any other arthropod in grassland habitats, while Carabidae (ground beetles), Chrysomelidae (leaf beetles), Nabidae (damselflies), and Curculionidae (true weevils) are also predominant arthropod families for forage (Doxon and Carroll 2010). Ants are abundant in grassland ecosystems and because ants nest communally in eusocial colonies, make nests in the ground, generally do not fly, and occur in dense populations in close proximity to ground nesting bobwhite chicks, flightless young bobwhites discover a rich source of nutrition by locating a single colony. The semi-arid shortgrass prairie where this study was conducted endures long periods of high temperatures, very often above 38°C during the summer months. The ability of ants to forage and to remain more active in higher temperatures than many other animals also contributes to the availability of ants as a food source for bobwhites in this region.

Ants

Ants (Hymenoptera: Formicidae) are diverse in morphology and behavior. Chemicals and behaviors are used for communication and cooperation to provide for the needs of the entire colony. Amongst ant species, feeding habits are diverse; many species are generalists while others exhibit specialized feeding behaviors such as locating seeds, scavenging, raising aphids for honeydew, and even cultivating fungi as a food source. These differences allow ant colonies

to coexist in close proximity to other ant species by utilizing common resources at different times or in different ways. This is known as niche partitioning and allows for increased efficiency of resource utilization.

In addition to being important forage taxa, ants are abundant and critical to the grassland ecosystem for several other reasons, filling many important ecological niches and affecting the environment at a landscape level. The nesting and feeding behaviors of ants alters the chemistry of the soil around their nests by increasing organic matter, nitrogen, phosphorus (Wagner et al. 2004) and beneficial microbial biomass colonies (Whitford et al. 2012). Ants redistribute seeds and breakdown organic matter (Wagner et al. 2004). Despite their ecological significance, ants have been understudied in the grasslands of the Great Plains of North America and interactions between taxa are under documented. By examining naturally occurring vegetation gradient, which is typical of bobwhite habitat, conditions for both bobwhites and their prey can be observed. Moving seeds, aerating the soil by digging tunnels and creating pockets within the soil profile, and concentrating nutrients around the nest contribute to ecosystem heterogeneity not otherwise observed and as a result contribute to patchiness within the ecosystem (Bestelmeyer and Wiens 2003). These behaviors allow ants to be frequently used as a bioindicator species, especially for assessing information regarding ecological changes in response to disturbance (Hoffmann 2010).

Conspecific Interactions

While diversity in feeding strategies promotes resource-partitioning and co-existence between ant taxa, competition is also prevalent and widespread. Conspecific interactions significantly influence ant assemblages. Dominant species exclude subordinate species from several resource types in an area, forcing them out of habitats by prohibiting foraging and

keeping subordinate species from ideal nest sites (Baccaro et al. 2010, Savolainen and Vepsäläinen 1988). Habitat influences the degree to which interspecific dominance interactions influence individual species. Dominance behaviors have a lesser influence in undisturbed areas than in disturbed areas (Baccaro et al. 2010, Floren and Linsenmair 2000), presumably because resources are more limited in disturbed habitats.

The influence of interspecies competition on nest site selection is determined by both physical and chemical cues. Nest sites are sometimes a limiting resource for colonies in the presence of conspecifics. When colonies of different species are present in close proximity, nest sites are further apart than when competitive factors (conspecific colonies) are absent (Franks et al 2007). In addition to avoiding behavioral aggression from conspecifics, ants seeking a new nest site are also deterred by olfactory cues (boundary markers) left by colonies already utilizing a particular territory (Franks et al. 2007), preferring to have as much distance as possible between their own nest sites and those of aggressive colonies. Olfactory cues are deposited both as “trunk trails” which are chemical odors left behind to direct nest-mates from the nest to a food resource and as defensive odors deposited to warn other species of territorial boundaries. The eusocial structure of ant colonies, their reliance on chemical communication and complex behaviors make them unique among the arthropods. Sampling techniques for ants must also be uniquely designed to accurately reflect the diversity and interactive activities of these complex organisms and their “superorganism” colony behavior.

Niche Partitioning

Niche partitioning describes the divided utilization of resources by individuals or species which are in competition with one another, in such a way that each individual or group retains necessary access to those resources (food, water, nest sites, etc.). This sharing of resources

allows for coexistence between members of various species in a closer geographic area than would be otherwise possible.

Dominance interactions are a driving force in niche-partitioning of ants. The diversity and abundance of ant species in natural ecosystems indicates that utilization of required resources are divided, or partitioned, in order for various groups to coexist and thrive (Weeks et al. 2004, Cerdá et al. 1998). This division results in a reduction of competition and therefore fewer incidences of attack (physical and chemical) and can contribute to the improved fitness of each competing colony. Some of these resources include access to nest sites, seeds, carrion, and vegetation, both as food and as structure. Because of the competitive and territorial nature of ants and their extensive use of chemicals for defense, resources often cannot be utilized simultaneously and are therefore additionally partitioned by behavioral factors such as time of foraging, foraging location, behavioral or chemical defensive and offensive actions, temperatures in which to be active, food preferences, caste polymorphism and territoriality (Albrecht and Gotelli 2001, Weeks et al. 2004).

Temperature is a common parameter in partitioning foraging times in ant assemblages. Most ant species forage when temperatures are between 10-45°C (Hölldobler and Wilson 1990). Microhabitat and foraging schedules are frequently determined by temperature. Thermophilic species are active in the hottest environments or times of day and are often behaviorally subordinate, while opportunistic feeders and predatory species who take advantage of subdued prey are less active in extreme conditions (Bestelmeyer 1997, Harkness and Wehner 1977). In arid ecosystems, the more dominant species often exploit their ability to take advantage of the optimal, moderate temperatures and low stress conditions, while subordinate species must be more tolerant of extreme conditions in order to avoid conflicts between species (Cerdá et al.

1998, Baccaro et al. 2010, Bestelmeyer and Wiens 2003). In contrast to thermophilic species, few ant species are cold tolerant, or cryophilic, and foraging rarely extends below 0°C (Bestelmeyer 1997). During the warmest times of the year, diurnal niche partitioning has been observed in some species, who avoid the hottest times of day while others take advantage of reduced competition and utilize the warmest hours (Albreight and Gotelli 2001). Negative and positive correlations were identified between species and various temperature regimes, evidence for the separation of resource utilization for the avoidance of conspecifics (Albreight and Gotelli 2001). Temperature profiles also influence nest selection. In heat-limited ecosystems, more dominant colonies occupy the south facing side of a sloped ecosystem, while subordinate species are restricted to nesting in colder microhabitats, such as the north facing slope or areas of lower elevation (Brian 1952, Hölldobler and Wilson 1990). As a result, the behaviorally dominant species has a reproductive advantage driven by minimum temperature requirements for brood rearing and development (Hölldobler and Wilson 1990, Palladini et al. 2007).

Weather conditions alter dominance displays by certain species. Bestelmeyer (1997) found that dominance can be determined by cloud cover. Prey was overtaken from *Pheidole sp.* by *Forelius nigriventris* when clouds dispersed, but the dominance was returned to *Pheidole sp.* when clouds returned (Bestelmeyer 1997). In additionally, a bait study showed that when identical baits were placed in sunny locations and shaded locations, abundance was significantly higher on baits located in the sun and abundance followed the sunny baits as shade traveled through the day (Greenslade and Greenslade 1971).

A study of predatory ant species in an agroecosystem showed that competitive interactions among species played a major role in their success rate of food capture. Null model tests indicate that other factors are likely to contribute to this relationship. Two species

(*Camponotus compressus* and *C. paria*) showed reduced activity during ideal foraging times when more aggressive species (*Phiedole spp.*) were abundant. *Phiedole* was the only genus to capture Orthoptera prey in two contrasting agro-ecosystems (cauliflower and sponge gourd). This could indicate that another mechanism for division of resources is the division of food consumed by preferential feeding or the exclusion of a food group by a dominant species (Agarwal and Rastogi 2009).

Vegetation

Land use practices and other natural and anthropogenic mechanisms often have a dramatic effect on the vegetation in a location. Natural vegetation gradients exist in ecosystems as a result of topography and moisture availability. Grazing reduces ant species diversity in semi-arid and arid grasslands (Pihlgren et al. 2010). An increase in the amount of surface area covered by non-native plants increased the species richness of ant communities in Virginia, although the non-native plants were concentrated along a river, and other factors could contribute to this observation (Kjar 2005). Vegetative management practices affect ant communities in many ways. Mowing and removing hay have been shown to be one of the best management practices for arthropod conservation, increasing both species richness and abundance (Noordijk et al. 2010).

In a study of temperate grasslands, early phases of land use succession had more variation in community composition, as compared to later stages of succession where a more consistent community had less variation (Dauber and Wolters 2004). Successional stage likely influences competition similarly to ideal nest sites and slope orientation, with the most dominant species winning the best sites. The more dominant species has the advantage of obtaining and retaining ideal nest sites through successional stages.

Vegetation affects the community composition of ants. Vegetation zones were assessed and used to compare ant communities in this study. The four vegetation types examined in the Beaver River Wildlife Management Area (BRWMA) were the riparian zone (Zone 1), the grassland zone (Zone 2), the transitional zone (Zone 3) and the upland Zone (Zone 4). The riparian zone was dominated by invasive salt cedar (*Tamarix spp.*), the grassland zone was dominated by grasses and forbs, the transitional zone introduced shrubby vegetation and the upland zone (Zone 4) was characterized by sagebrush and *Yucca spp.* which could thrive in the dry, sandy environment. To evaluate those vegetation zones, a survey of plant species distribution was performed by botanists in each vegetative zone of the BRWMA. This survey indicated the diversity of plant species varied based on the predetermined vegetation zones in which ants were sampled. A mean species richness was calculated by vegetation zone across all six transects, using the same transects sampled for ant collection. The riparian zone had an average of 30.33 plant species, the grassland zone had an average of 42.83 species, the transitional zone had an average of 37.67 species and the upland zone had the lowest, with an average of 25.17 species. Each transect crossed through and contained permanent sampling sites in each vegetative zone (Fishbein unpublished data).

Environmental Conditions and Climate

The size of a colony's territory is dictated by the species, the size of individuals, environmental conditions, and available resources. When faced with limited resources, such as in arid or semi-arid environments, the distance ants will travel to acquire and transport prey is increased (Bestelmeyer and Wiens 2003). Territorial boundaries are communicated based on visual, auditory, and olfactory cues (Franks et al. 2007). There is a positive correlation between ant activity and humidity (Baccaro et al. 2010, Levings and Windsor 1982, Hahn and Wheeler

2002), which is supported by previous studies indicating an increased activity level of terrestrial arthropods with increased soil moisture (Levings and Windsor 1982). Subdued ant activity in drier soil is likely for the purpose of conservation of resources and to reduce the risk of desiccation (Baccaro et al. 2010). Ant nests frequently increase nutrient concentrations in the soil and increase heterogeneity of plant communities as compared with surrounding soils, but soil moisture is not significantly altered as a result of the presence of ant nest sites.

Temperature has been shown to play a role in nest site selection of ants in rain forest leaf litter ant communities. Although null model analyses indicate other factors are likely to alter nest choice more than temperature, the ten most dominant species in this study each preferred significantly different temperatures for their nest sites (Mezger and Pfeiffer 2010). Tropical ants cannot regulate nest temperature as well as temperate species can, so temperature of the nest site has widespread effects on the metabolism and development of the individuals in the colony (Mezger and Pfeiffer 2010).

Ants of Beaver County

All ant species belong to the family Formicidae and the order Hymenoptera. This family is subdivided into eleven subfamilies (Hölldobler and Wilson 1990) three of which, Formicinae, Dolichoderinae, and Myrmicinae, contain the fifteen species sampled during this study. The following will highlight the biology of these taxa.

Subfamily: Myrmicinae

Myrmicinae is the largest subfamily of ants, with 35 North American genera and over 150 genera worldwide (Fisher and Cover 2007). Myrmicinae is the only subfamily which uses starches extensively as a food source (Fisher and Cover 2007). *Pheidole* sp., *Monomorium*

minimum, *Pogonomyrmex barbatus*, *Solenopsis texana*, and *Crematogaster sp.* are the species recovered from the subfamily Myrmicinae.

Pheidole is a genus of polymorphic workers. Polymorphism in *Pheidole* causes complications in identification, as major workers are necessary for the morphological identification to species; the majority of workers captured at baits and in pitfall traps are minor workers. Colony sampling would have been beneficial for identification but was not possible for this study. About 100 North American species in the genus have been identified. Most species are omnivorous or predaceous (Fisher and Cover 2007), while many others consume predominately seeds (Young and Howell 1964). New species are frequently discovered (Fisher and Cover 2007) and major revision will likely occur in the near future.

Harvester ants in the genus *Pogonomyrmex* include 25 species within North America (Fisher and Cover 2007); however, sampling during this study recovered only one species, *P. barbatus*, in this genus. The preferential diet of *Pogonomyrmex spp.* consists primarily of seeds but insect carrion is also consumed (Fisher and Cover 2007; Young and Howell 1964). *Pogonomyrmex spp.* build large nests which have been shown to create patchiness in vegetation and increased nutrient concentrations as a result of the large quantity of seeds brought back to the nest by foragers (Bestelmeyer and Wiens 2003). *P. barbatus* is considered a crop pest in North America (Young and Howell 1964).

The genus *Solenopsis* is known for the voracious invasive *Solenopsis invicta*, the Red Invasive Fire Ant (often referred to as R.I.F.A.) however, the only representative species sampled during this study was *Solenopsis texana*. *S. texana* is a tiny yellow ant that is nearly transparent and is considered harmless. There are approximately 40 species of *Solenopsis spp.*

found in North America. Three groups make up this genus, and *S. texana* falls into the subgenus *Diplorhoptrum*, which are commonly called thief ants, who steal food and brood from neighboring colonies (Fisher and Cover 2007). Ants in the genus *Solenopsis* are often vegetation pests due to destruction caused by removal of seeds (Young and Howell 1964). Colonies of *S. texana* raise aphids for honeydew secretions which is an additional nutritional resource for this species (Young and Howell 1964).

Monomorium includes approximately 16 species in North America, including native and non-native species. Different species of *Monomorium* have various nesting habits, including within the soil, under rocks and bark and within rotting wood (Fisher and Cover 2007). In this study, only *M. minimum* was recovered. “The little black ant” is a generalist, and a particularly problematic urban pest in homes. It is identified morphologically by a bicarinate clypeus, its small size, and a distinctive body shape. *M. minimum* has a powerful stinger and interesting behaviors including playing dead or wagging its abdomen (called gaster flagging) to draw attention or protect itself from competition, helping it make up for its small size (Rice and Dunn 2014).

Crematogaster is a genus with around 30 North American species, including 5 Oklahoma species (Young and Howell 1964). *C. laeviuscula* was recovered during this study. The diverse feeding strategies of *Crematogaster* spp. include tending aphids for honeydew, and sometimes foraging for arthropod carcasses (Rice and Dunn 2014). Nest sites are diverse including soil, rotten wood, under rocks, as household pests and some species are arboreal (Fisher and Cover 2007, Rice and Dunn 2014).

Subfamily: Dolichoderinae

Dolichoderinae is a subfamily that contains four species recovered during this study, *Linepithema humile*, *Dorymyrmex flavus*, *Forelius pruinosus* and *Tapinoma sessile*. This subfamily has a unique anal gland which produces defensive chemicals with an unpleasant odor (Fisher and Cover 2007). This is a smaller subfamily, with only seven North American genera (Fisher and Cover 2007).

Linepithema humile is the only known North American species of *Linepithema*. This is an invasive species which is called “a miserable beast” by Fisher and Cover (2007). It tends aphids and coccids for their honeydew secretions, along with scavenging for other food types (Fisher and Cover 2007). *Tapinoma sessile* is a household pest (Fisher and Cover 2007), *T. sessile* has what is believed to be the greatest ecological tolerance and largest range of any species in North America (Fisher and Cover 2007). Like other Dolichoderinae, honeydew-secreting insects (aphids, coccids) are raised and eaten along with carrion (Young and Howell 1964).

Dorymyrmex includes approximately 20 species in North America, usually in arid environments. Feeding strategies are diverse and include scavenging, tending aphids (Young and Howell 1964), and gathering nectar (Fisher and Cover 2007). The taxonomy of this genus is in a state of confusion and is perceived by myrmecologists to be in a constant state of revision. *D. insanius* was located by this study.

Forelius contains only 5 or 6 species in North America and *F. pruinosus* was recovered during this study. Members of *Forelius* thrive in hot, open and xeric habitats. They have a particularly high tolerance for heat, allowing them to dominate southwestern deserts (Fisher and Cover 2007). Honeydew is consumed along with arthropod carrion and members of this genus

are excellent scavengers (Young and Howell 1964, Rice and Dunn 2014). *F. pruinosa* employs extensive use of chemicals to keep other species away from food sources and to caution nest-mates of danger. They also emit a sweet-smelling odor when crushed (Rice and Dunn 2014).

Subfamily: Formicinae

Formicinae is a large subfamily with many ecologically significant genera, including *Formica* and *Lasius* (Fisher and Cover 2007). Most *Formicinae* are generalists who consume mostly plant materials, but will consume other food types. *Formica pallidefulva*, *Lasius neoniger* and *Brachymyrmex depilis* were recovered during this study.

F. pallidefulva are omnivorous (Fisher and Cover 2007) and are known to nest in bunchgrasses. They are often enslaved by more dominant species (Young and Howell, 1964). *Lasius* is represented in this study by the cornfield ant, *L. neoniger*. Aphids raised on plant roots for honeydew secretions are used as a food source (Young and Howell 1964).

Paratrechina is a genus which contains many species of generalist scavengers (Fisher and Cover 2007). Of the 20 North American species, Only *P. bruessi* was recovered by study. A diversity of food types are consumed by this species. All species of *Paratrechina* will nest in soil, while some will also seek alternative nest sites (Fisher and Cover 2007).

Sampling Methods and Ant Abundance

Some of the sampling methods for ants include baiting, soil and litter sampling, chemical fogging of foliage, pitfall trapping, colony sampling, and a suite of other techniques. To study ant diversity comprehensively, it is generally necessary to use multiple sampling methods (Tista and Fiedler 2011). Microhabitat, ecosystem and climate all factor into determining the most appropriate combination of methods for a given study.

Leaf litter and Winkler traps are widely used ant collection methods, and involve sampling litter and later extracting living ants from these samples. This method is efficient and effective under appropriate conditions. These sampling methods are most efficient in forests and shrubby habitats. Grasslands and deserts do not have the appropriate substrate or loose litter accumulation for this method to be practical (Gotelli et al. 2012).

Pitfall traps, composed of a collection cup filled with a killing agent (commonly 80% ETOH) are often considered the most effective measure of ant activity in comparative studies. This type of trap usually delivers the highest species richness (Tista and Fieldler 2011). Pitfall traps are inexpensive, require minimal labor, and capture ants that forage at any time of day. This method eliminates the effects of competition and dominance because ants are killed immediately. This can be beneficial or detrimental to studies of ants, depending on the aims of the research. Using very small pitfall trap collection cups create a bias against larger ant species, which can skew capture rates (Abensperg-Traun and Steven 1995; Gotelli et al., 2012), but this is remedied by choosing an appropriate collection container. As compared to baiting, pitfall traps are superior in reflecting ant diversity (Wang et al. 2001). Drawbacks to this method include the inability to account for interspecific interactions and a potential for unintentional harvest of non-target arthropods and small vertebrates, such as amphibians, lizards and rodents. Care must be taken to make pitfall traps less attractive or too small for these organisms, or should be covered by something which would keep vertebrates out but allow insects to fall into the traps.

Colony sampling, also referred to as hand sampling, can provide valuable data on nest densities, colony counts, and distribution. Unfortunately, some severe drawbacks exist with hand sampling. Hand sampling consists of visually locating the opening of an ant colony and manually collecting and preserving several individuals (often 20 workers) from that particular nest.

Notably for this study, in microhabitats with thick undergrowth or a deep layer of dead plant matter it can be nearly impossible to visually identify the openings to an ant nest, especially for smaller nest openings. A higher than usual sampler bias occurs with different samplers exhibiting different nest-detection capabilities.

Using baits to attract ants to traps has been used for many years by myrmecologists (Gotelli et al., 2012). While baiting may not identify a significant increase in overall species richness counts in contrast to pitfall trap captures (Wang et al. 2001), bait sampling provides the opportunity to observe behavioral responses in ants, including food preference and dominance interactions. A bait becomes a resource to be defended and dominant species will exclude subordinate species from a bait (Gotelli et al. 2012), this can be both a benefit and a drawback for the use of this method, depending on the intention of the study. Certain studies have observed the destination of the bait rather than the individual which found it, collecting data regarding dominance, foraging range, microclimate, and more (Bestelmeyer and Wiens 2003). Tuna fish, sardines, dead insects, peanut butter, cookies, hotdogs, honey and other foods are often used as baits. These bait types have been evaluated and shown to be equivalent to natural food choices of ants, for example, previous research has indicated that ants behave similarly at tuna bait stations as they do with native fruits or arthropod carcasses. Using a combination of baits as a food choice introduces certain complications, but can be useful in observing preferences. A 2008 rain forest study compared bait choices (sugar, tuna, and oil), and observed no significant difference in either abundance or diversity of the ant community by bait type (Ward 2008).

Conclusion

Ants are important for northern bobwhites and alter grassland ecosystems in many ways. The study of their behavior, competitive interactions, resource utilization, and community

composition aids in the understanding of the grassland ecosystem as a whole and specifically for the conservation of northern bobwhites. When combining multiple methods of collection and by studying the vegetation gradient commonly observed throughout the Great Plains, we can investigate the community as a whole.

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CHAPTER II

ANT (HYMENTOPTERA: FORMICIDAE) DIVERSITY AND COMMUNITY COMPOSITION OF SEMIARID GRASSLANDS OF WESTERN OKLAHOMA THAT SERVE AS NESTING HABITAT FOR NORTHERN BOBWHITE (*COLINUS VIRGINIANUS*)

Abstract:

Communities of ants in Oklahoma grasslands were characterized using bait sampling techniques. Bait grids were established at twenty-four permanent sampling locations distributed along six transects. One sampling location was established in each of four distinct vegetation zones along each of the transects in the Beaver River Wildlife Management Area (BRWMA). The BRWMA is located in Beaver County, in the western panhandle region of Oklahoma. In total 23,475 specimens were collected using this method, representing 14 species. Eighty-five percent of the total abundance of ants in each vegetation zone was comprised of three or fewer dominant species and between nine and 11 subordinate species. Of the five bait types utilized (tuna, tuna mixed with honey, honey, and Keebler® Pecan Sandies®) Keebler® Pecan Sandies®

attracted a higher abundance of ants in three of the four vegetation zones studied, but did not attract higher species richness.

Introduction:

Ants (Hymenoptera: Formicidae) are diverse and plentiful in Oklahoma's semi-arid grasslands. Ants serve several ecological roles; they change ecological systems by altering resource distribution, relocating seeds, aerating soil (Wagner et al. 2004) and altering microbial communities (Whitford et al. 2012), in addition to their role as a critical forage taxon for a wide range of animals. Within this harsh, dry environment, the diversity of the ant community and the close distribution of colonies, both interspecific and intraspecific, suggest potential niche partitioning within the overall ant community. Common mechanisms of niche partitioning among ants include temperature in which a species will forage (Albrecht and Gotelli 2001), time of day it gathers food, the type of food it consumes, and the specific microhabitat it will forage, inhabit and defend. Ants' eusociality contributes to the territoriality and protectiveness of resources. This behavior sometimes causes subordinate species of ants to be forced into microhabitats with inferior resources, including nest sites.

One important ecological role of ants in grasslands is that of forage taxa for reproductive and juvenile northern bobwhite (*Colinus virginianus*) (Doxon and Carroll 2010). Northern bobwhite populations are currently in a state of rapid decline (Link et al. 2008). In addition to land use changes (Kleppinger 2007), availability of food resources, especially during the developing juvenile stage, may be a factor contributing to the decline. This characterization of arthropod taxa that serve as critical forage taxa for juvenile and nesting female northern bobwhites is part of a larger comprehensive study aimed at identifying potential factors contributing to northern bobwhite decline. Gaining a better understanding of the ant community

composition within the diverse habitats of the semi-arid shortgrass prairies will contribute to sustainable management practices for the conservation of northern bobwhites. Using bait stations that mimic specific resources provided us with a more comprehensive profile of ant community composition and allowed us to assess the efficacy of this trapping technique for different ant taxa, relative to standard pitfall trap sampling techniques in Oklahoma grasslands.

Methods and Study Sites:

Study Site: Beaver Wildlife Management Area

The Beaver River Wildlife Management Area (BRWMA) encompasses 7163 hectares of ecologically diverse land and is located in the panhandle region of western Oklahoma. The BRWMA is managed by the Oklahoma Department of Wildlife Conservation (ODWC) and is utilized for cattle grazing, hunting, and fossil fuel extraction. Management practices in the BRWMA include grazing, strip disking, strip mowing, and prescribed burning (Storer 2011). This land was set aside primarily to maintain wildlife habitat and to provide grazing lands with limited fencing and structures, dirt roads with limited traffic, and available water for grazing and wild animals in the form of a river, wells, and twenty windmill-powered pumps (Storer 2011) (Fig 2.1). When sufficient water is present, the Beaver River runs west to east at the southern edge of the BRWMA (Fig. 2.1). Severe droughts during summer months have impacted this region, leaving the river bed frequently dry. Hunting is the primary recreational activity on the BRWMA. Wild game includes pheasant (*Phasianus colchicus*), northern bobwhite (*Colinus virginianus*), white-tailed deer (*Odocoileus virginianus*), wild turkey (*Meleagris gallopavo*), cottontail rabbit (*Sylvilagus* spp.), coyotes (*Canis latrans*), bobcat (*Lynx rufus*), raccoons (*Procyon lotor*), doves, and a small population of waterfowl (Storer 2011).

Six transects were established from the riverbank and extended perpendicular from the river through four distinct vegetation zones: a riparian zone, grassland zone, transitional zone and upland zone. The length of each transect varied to ensure every vegetation zone was evaluated well into the zone so that it would not be affected by edge effects. Transect locations were chosen at random within terrain that included all four habitat types. The width of each habitat type along the length of each transect was dependent on natural topography. The riparian zone was dominated by saltcedar, an invasive *Tamarix sp.* which had grown in very thick groves along the river. The grassland zone consisted primarily of flat terrain dominated by native and non-native grasses with forbs intermittently dispersed throughout. The transitional zone was an ecotone between the grassland zone and the upland zone; it was characterized by increased elevation and vegetation was dominated by grasses, forbs and shrubs. The upland zone was atop vegetation stabilized sand dunes and was characterized by shrubs and woody plants. Each transect included four specific permanent sampling sites, one per vegetation zone, marked by a central stake made of flagged rebar sheathed in PVC pipe to serve as a permanent marker. This central stake was placed not less than 30 meters from the start of each predetermined vegetation zone. In addition, sampling sites were marked by portable Garmin GPS units to assist in the relocation of the sites. Transects were set in groups of two for accessibility and sampling efficiency, with paired transects approximately 0.5 kilometers apart. From west to east, transects were labeled alphabetically (Table 2.1).

Baits were carefully chosen to represent a diversity of naturally occurring resource categories. Providing various baits in close proximity to one another forced the ants to choose among the available baits, which enabled us to observe any evidence of resource preference. Diverse food choices were selected to mimic natural resources and to reveal preferences within

different ant taxa, but also to attract a variety of species in different functional groups. Tuna (canned in water) has been traditionally used to attract ants in field research. It is rich in protein, attractive to ants, inexpensive, and does not require refrigeration. Previous research has shown that ants behave the same way on a tuna bait as they do at an insect carcass, which is the most abundant protein-rich food an ant would naturally encounter (Bestelmeyer 1997). Honey has been traditionally used as bait for ant studies and was included to provide a naturally occurring sugar/carbohydrate bait choice. Honey was mixed with tuna as the third bait type, to combine the attractive qualities of the two bait types, and because it has been used in many other studies. Pecan Sandies® are shortbread cookies rich in protein, sugars, amino acids, and lipids and as a result of the nuts in the cookies, resemble a seed resource. They have been successfully used to attract ants in several studies in Oklahoma (Kaspari et al. 2000).

Methods

During each sampling event, a random azimuth was chosen and was used for all 24 sites during that sampling event and a marker was placed ten meters (in the direction of the selected azimuth) from the central stake of each sampling site. At each location, small (5 cm²) cards were baited with one of the four bait types, or left blank as a control. Approximately 1 teaspoon of bait was placed on a 5 cm² piece of white index card. Cards were placed in two rows with bait choices arranged 0.25 m apart; the two rows were 0.5 m apart to allow individuals a choice between the resources presented. Baits were positioned in the same order each time. Two cards of each bait type were left at each sample site, therefore ten samples were collected at each sample site (n=10), within each of the four habitat types on each of the six transects so each sampling event yielded a total of 240 samples (n=240).

Bait stations were left undisturbed for at least thirty minutes before hand collection. After thirty minutes each card with its bait and the ants present on the card were placed in a zip top bag and frozen until the contents were sorted and preserved in 80% ETOH. Two transects were sampled per day using this method and each sampling event required three field days; care was taken to have three consecutive collection days with analogous weather conditions. Three sampling events were completed each season, for a total of six events. Ants were identified using morphological characteristics and binomial keys. “The Field Guide to the Ants of North America” (Fisher and Cover 2007) and “Ants of Oklahoma” (Young and Howell, 1964) were the primary texts for identification. Experts in identification assisted in identification by confirming several voucher specimens using photographs taken through a dissecting microscope.

Once identified to species, data were quantified for ant species diversity and relative abundance. Diversity was measured by species richness at the sample site level and at individual baits. Relative abundance was calculated as the percentage of individual ants within each species as a percent of the total number of ants captured (total number of species/total of all species * 100) (absolute abundance).

Analysis

Analysis of variance procedures were used to determine the effects of the vegetation zone and bait type on the relative abundance of ant species. Insect counts were square root transformed to alleviate heterogeneity of variance issues. The experiment was performed with a split block arrangement in a randomized complete block design. Transect was used as the blocking factor, and vegetation zone and bait type were the factors of interest. The simple effects of bait given vegetation zone and vegetation zone given bait were assessed with planned

contrasts. SAS Version 9.3 (SAS Institute, Cary, NC 2011) was used in performing the analyses of variance. A 0.05 level of significance was used for all comparisons.

Results

In total, the number of individual ants analyzed was 23,475. Fourteen species were represented in various abundances (Fig. 2.2). Four species made up at least 85% of each vegetation zone, with the other 9 species accounting for between 6 and 15 percent of the total abundance (Fig. 2.3). *Monomorium minimum*, *Pheidole spp.*, *C. laevisucula*, and *D. flavus* combined made up at least 85% in every vegetation zone. Using these baiting methods 11 species were captured in the riparian zone. In the grassland zone 12 species were captured, in the transitional zone 9 species were captured, and in the upland zone 9 species were captured (Tab. 2.2). Figure 2.2 indicates the relative abundance of each ant species. The total abundance of ants that tuna, tuna mixed with honey, and honey each attracted was similar in each vegetation zone in which the bait was placed (Fig. 2.5). Pecan Sandies® attracted fewer ants in the riparian zone than it did in the other zones (Fig. 2.5). Honey attracted the fewest ants in each vegetation zone (Fig 2.5). All data displayed in this study were collected at the BRWMA in Beaver, Oklahoma along six transects (Tab. 2.1) during six three-day sampling events which occurred between June 2012 and July 2013. These events were each made up of 3 consecutive days, starting on 6/9/12, 7/1/12, 7/30/12, 5/9/13, 6/6/13, and 7/4/13.

Cards baited with Pecan Sandies® and cards baited with honey each captured 12 species, tuna mixed with honey attracted 13 species, and tuna by itself attracted 14 species (Tab. 2.3). Each bait type attracted a statistically similar total abundance of ants within each of the four vegetation zones studied, excluding the Pecan Sandies®, which attracted a higher abundance in

transitional and riparian zones (Fig. 2.4). Pecan Sandies® were slightly less attractive in upland zones and least attractive in grassland zones (Fig. 2.4).

Vegetation affects the community composition of ants, so vegetation zones were assessed and used to compare ant communities in this study. To evaluate those vegetation zones, a survey of plant species distribution was performed by botanists in each vegetation zone of the BRWMA. This survey validated the four vegetation zones with its finding that the diversity of plant species varied by the predetermined vegetation zones in which ants were sampled. An average species richness was calculated across transects, using the same transects established for ant collection. The riparian zone had an average of 30.33 plant species, the grassland zone had an average of 42.83 species, the transitional zone had an average of 37.67 species and the upland zone had the lowest, with an average of 25.17 species. Each transect crossed through and had sampling sites in each vegetative zone (Fishbein unpublished data).

A separate study was conducted concurrently to determine the success rates of northern bobwhites on the BRWMA. Northern bobwhites laid eggs in each vegetation zone, with the number of eggs laid increasing along the vegetation gradient. In the riparian zone 3 eggs were laid (0 hatched, hatching success rate: 0.0%), in the grassland zone 7 were laid (3 hatched, hatching success rate: 42.9%), in the transitional zone, 8 were laid (4 hatched, hatching success rate: 50.0%) and in the upland zone 43 were laid (24 hatched, hatching success rate: 55.8%) (Tanner unpublished data).

Differences in response were found based on bait types and vegetation zones when individual species were analyzed. Significantly more *M. minimum* individuals were captured on Pecan Sandies® than on any other bait type in the transitional zone (Fig 2.5a). In the grassland

and upland zones, no bait attracted a higher number of individuals (Fig 2.5a). In the riparian zone, Pecan Sandies® attracted a similar number of individuals as tuna, but was more effective than honey or tuna mixed with honey (Fig 2.5a). The number of individuals of the species *C. laeviuscula* captured was similar on every bait type in the riparian, grassland, and transitional zones, however tuna and tuna mixed with honey attracted a higher abundance in the upland zone (Fig 2.5b). *Dorymyrmex flavus* captures were unaffected by bait type in the riparian and upland zones. In the grassland zone, tuna mixed with honey attracted more individuals (Fig 2.5c) and no ants responded to Pecan Sandies®. In the transitional zone, honey and tuna mixed with honey attracted higher numbers of *D. flavus* (Fig. 2.5c). *Forelius pruinosus* showed no significant differences to the various baits in the transitional or upland vegetation zones. In the grassland zone, it exhibited a higher response to tuna mixed with honey than it did to Pecan Sandies®, but honey and tuna were similar to both tuna mixed with honey and Pecan Sandies® (Fig 2.5d).

Formica pallidefulva showed no significant differences on any bait types in the grassland, transitional or upland zones. In the grassland, it was particularly responsive to honey. *L. humile* showed no significant differences in response by bait type in any vegetation zone. *Pheidole spp.* was more responsive to Pecan Sandies® and tuna mixed with honey in the riparian, transitional and grassland zones, although in the grassland zone the tuna attracted a similar number of individuals as the tuna mixed with honey. In the upland zone, Pecan Sandies® attracted the most individuals (Fig. 2.5e). *Pogonomyrmex barbatus* showed no significant differences in relative abundance in the riparian, transitional or upland zones, more individuals were captured on Pecan Sandies® and tuna in the grassland zone. The response of *Solenopsis texana* showed no significant differences in relative abundance in grassland, transitional or upland zones. In the riparian zone, tuna attracted the most individuals. *Tapinoma sessile* showed

no differences in response in the grassland, transitional or upland zones; in the riparian zone, Pecan Sandies®, tuna mixed with honey and tuna attracted more individuals (Fig. 2.5f).

More individuals of *Lasius neoniger* were captured on tuna in the grassland zone, and tuna mixed with honey and tuna in the upland zone (Fig. 2.5g). Preferences were not observed in the riparian or transitional zones. *Brachymyrmex depilis* was captured significantly more on tuna baits in the riparian zone than on other baits in the riparian zone. *Nylanderia tericolla* was only captured in the upland zone. It was captured most frequently on the tuna mixed with honey and Pecan Sandies® baits. *Formica biophica* was only captured in the grassland zone. Honey captured the highest abundance.

Discussion

Bait types

Each bait type attracted a similar diversity of ants, 12 distinct species were attracted to each bait except honey, which attracted 11 species. Consistent with previous research, however, differences were seen in abundance between bait types (Pecan Sandies® attracted 10051 individuals, tuna mixed with honey attracted 5751, tuna attracted 5432 total species, and honey attracted 2308) (Tab. 2.3). The unbaited control recovered only 9 total individuals, representing 4 species. Pecan Sandies® attracted more ants than any other bait type in the riparian, transitional and upland zones (Fig. 2.4). In the grassland zone Pecan Sandies® attracted a similar abundance as tuna and tuna mixed with honey. This is consistent with other studies comparing baits, one of which found that of Pecan Sandies®, tuna and crickets, the Pecan Sandies® were always preferred or equally attractive as the other baits (Hunan and Gordon 1996). Carbohydrates, fats and proteins contribute to its quality as a bait source (Kaspari et. al. 2000). Moisture in the baits

themselves also may have been attractive to individuals since this region lacks moisture. Tuna, tuna mixed with honey and honey are moisture rich baits. This study was unable to assess whether moisture is a limiting resource in this environment. Temperature differences resulting from the shade versus exposed vegetation sites would also impact the duration it takes for baits to dry out and may have influenced the potency of olfactory cues dispersing from the baits. Previous research has shown that shade affects dominance interactions and preference for shaded or sunny baits (Greenslade and Greenslade 1971, Besterlmeyer 1997). This would be an interesting factor to consider for future research.

Honey has historically been used to study ants and a breadth of literature describes it as one of the most effective attractants, including comparative studies (Williams and Whelan 1992). In a study of 14 bait types, it was statistically similar to peanut butter, the bait which attracted the highest diversity (Williams and Whelan 1992). Our results contrast this, however, as we found that the fewest number of ants responded to honey baits. One observation that may have impacted this is that in our experiment, ants seemed to get stuck in the honey baits, which would reduce their ability to recruit nestmates back to the bait. This is likely to have reduced the abundance of ants at the baits. This finding may be supported by the results with tuna and tuna mixed with honey. Tuna baits recovered a similar total abundance as tuna mixed with honey which indicates that while not as many ants were caught on the honey, they were attracted to it when mixed with the tuna, which dramatically reduced their incidence of becoming stuck.

In the riparian zone, Pecan Sandies® were significantly more attractive than all other bait types. The effectiveness of Pecan Sandies® is a result of their concentrations of fats, carbohydrates and proteins, along with their high visibility on dark soil surfaces (Kaspari et al. 2000). In the grassland zone, tuna, tuna mixed with honey, and cookies were not significantly

different; however, tuna was significantly more attractive than honey. Tuna mixed with honey is used by other studies (Rojas et al. 2014), and was attractive to ants in this study, however, as it did not differ from plain tuna in this experiment, it could be omitted in future studies to reduce sampling and identification effort. In the transitional zone, Pecan Sandies® were significantly more attractive to ants, tuna and tuna mixed with honey were not different from one another, and honey attracted fewer ants. In the upland zone, cookies were not significantly different from tuna mixed with honey, but surprisingly, honey was significantly less attractive on its own. These interactions could lead to further studies to investigate which components of baits are most attractive, whether olfactory cues, moisture, visual cues, or particular nutritional aspects of the bait.

Species which lack behavioral flexibility are underrepresented in bait studies (Greenslade and Greenslade 1971). Preferences and willingness to consume baits are influenced by outside factors, as was shown by experiments which revealed that some species (example: *Myrmecia pyriformis*) are not attracted to certain baits in the field, however will feed on them in laboratory colonies (Greenslade and Greenslade 1971). This is likely a result of the availability of their naturally occurring food sources in the field and the reduced necessity to consume unfamiliar objects, as contrasted with laboratory studies in which the bait was the only available food for the colony. A concurrent pitfall trap study was conducted to observe the community without the competitive and bait preference factors.

On the bait samples, behavioral factors contribute to the numerical dominance of *M. minimum*, the most abundant species in each vegetation zone. *M. minimum* is a tiny species that recruits others to food sources with strong chemical cues (Adams and Traniello 1981). Additionally, the release of a poisonous chemical during vigorous gaster-flagging (the rapid

wagging of the abdomen in the air as a defensive warning behavior from their sting) deters other species from using that resource (Adams and Traniello 1981), as a result of this powerful chemical repellent. Bait studies allow us to observe the community as it is experienced on natural food sources, giving a view of what a quail might find on a dead grasshopper or other food source.

Vegetation Zones

Consistent with previous studies, in every vegetation zone, at least eighty-five percent of the total abundance of ants was comprised of three or fewer species (Fig. 2.3a). All four vegetation zones were dominated by *M. minimum*. This generalist species made up 57.4% of the total ant abundance in the riparian zone, 40.4% in the Grassland zone, 69.0% in the transitional zone, and 43.1% in the upland zone (Fig. 2.3a). In the riparian zone, *Phiedole spp.* was the second most abundant taxa making up 16.6% of the total abundance (Fig. 2.3a). *Crematogaster laeviuscula* was the third most abundant species comprising 13.9% (Fig. 2.3a). In the grassland zone, 32.3% of the total ants collected were *Phiedole spp.* and 12.0% were *D. flavus*. In the transitional zone, 92.5% of the total ants collected consisted of two species, *M. minimum* (69.0%) and *Phiedole spp.* (23.53%). Following *M. minimum* (43.14%), *C. laeviuscula* (27.13%) and *Phiedole spp.* (23.77%) were the most abundant species, making up 94.03% of the total abundance (Fig. 2.3a). This reflects similar results that indicate that a population's numbers are often from a small group of species, including a grassland study which showed that at least 80% of the total abundance of grassland sites was comprised of only three species (Boulton et al. 2005).

M. minimum was the most abundant species collected by this method, both overall and in each vegetation zone. *M. minimum* is a tiny species that deters conspecifics from its resources by

aggressively defending it. When approached by competition it starts gaster-flagging, or vigorously wagging its abdomen in the air as a warning. Its stinger then releases a poisonous chemical secreted by the Dufour Gland which irritates other ants and allows retention of the resource (Adams and Traniello 1981). Meat and insect carrion used as baits have been found to be defended and monopolized by dominant species (Greenslade and Greenslade 1971). These behaviors and chemical defenses which force conspecifics away from a bait enable the numerical dominance of the species at the baits which they arrive at first or can force others off the bait if they do not have more powerful defenses. It is not unusual for a small or very small ant to dominate an ant community, this was also found to be the case in a study by Rojas and Fragoso (1999) which divided desert sampling sites into grasslands and shrubs, likely similar to our transitional/upland (their shrubs) and grassland zones.

Another species that we located with an interesting ecology is the invasive Argentine ant (*L. humile*). *L. humile* was an extremely rare species on bait traps, making up less than 1% of the total ant community. This species has been shown to significantly reduce the success of native ants on bait traps and to displace native species from a bait in 60% of observances (Human and Gordon 1996). With the infrequency with which we observed them, along with that knowledge of their behavior and success, we understand that they are truly scarce in this region. We would have expected this species to have an advantage and therefore a higher percent of ants on the baits than their true proportion of the community because in addition to being more likely to win over and exclude native species from a bait, they also found and recruited nestmates to the bait more successfully than native species did (Human and Gordon 1996). The concurrent pitfall trap study showed it also made up <1% of the population measured in that way. If the populations were higher, we would expect to find a higher percentage based on the baits than on the pitfall

traps, in account of their ability to win baits. This invasive species is likely new to this region, or having a difficult time establishing here.

The species richness observed in this study was lower than expected based on other studies in arid and semi-arid habitats. It is possible that this method did not form a comprehensive list and other species may be located by using of additional methods. Additionally, *Phiedole spp.* could only be identified to the genus level as a result of the lack of major workers required for identification, however, based on morphological characteristics at least three species of minor workers appear to be present in this study.

In conclusion, many differences were observed between bait types, vegetation types, and species. The community of ants contributes to an important aspect of the diet of northern bobwhites, especially during reproduction and development. Ants were found to be abundant in each of the vegetation types in which northern bobwhites nest, however they were also less diverse than anticipated based on other research. Because northern bobwhites have not been observed to prefer certain types of ants over others, we can infer that the abundance is more important for food availability than is diversity.

	Riparian	Grassland	Transitional	Upland
A	14S 353538.76 E 4076757.88 N	14S 353583.67 E 4076859.85 N	14S 353693.64 E 4077268.57 N	14S 353709.62 E 4077433.65 N
B	14 S 354062.79 E 4076878.67 N	14 S 354030.34 E 4076928.88 N	14 S 354032.61 E 4077071.24 N	14 S 354048.23 E 4077216.64 N
C	14 S 356444.83 E 4076886.21 N	14 S 356462.11 E 4076948.35 N	14 S 356440.22 E 4077124.93 N	14 S 356425.83 E 4077281.84 N
D	14 S 356565.01 E 4076729.59 N	14 S 356612.96 E 4076837.40 N	14 S 356698.71 E 4077118.11 N	14 S 356708.93 E 4077339.48 N
E	14 S 360380.05 E 4076567.33 N	14 S 360394.28 E 4076693.30 N	14S 360474.37 E 4077413.84 N	14 S 360426.82 E 4077855.53 N
F	14 S 360614.89 E 4076628.89 N	14 S 360601.72 E 4076708.32 N	14 S 360626.71 E 4077366.13 N	14 S 360581.65 E 4077815.89 N

Table 2.1: Coordinates of the permanent sampling sites for each of the 6 transects established in the Beaver River Wildlife Management Area. Ants were collected in four vegetation types (riparian, grassland, transitional, upland) along each of these six transects in the Beaver River Wildlife Management Area in Beaver County, Oklahoma. Samples were collected

	Riparian	Grassland	Transitional	Upland	Total
<i>Monomorium minimum</i>	3697	1417	5593	2336	13043
<i>Crematogaster laeviuscula</i>	893	2	261	1469	2625
<i>Forelius pruinus</i>	241	87	25	0	353
<i>Formica pallidefulva</i>	1	19	0	1	21
<i>Formica biophilica</i>	0	27	0	0	27
<i>Linepithema humile</i>	5	1	10	0	16
<i>Pheidole spp.</i>	1069	1135	1909	1287	5400
<i>Pogonomyrmex barbatus</i>	0	14	8	0	22
<i>Solenopsis texana</i>	271	51	1	41	364
<i>Tapinoma sessile</i>	201	1	0	46	248
<i>Lasius neoniger</i>	1	184	118	121	424
<i>Brachymyrmex depilis</i>	11	0	0	0	11
<i>Nylanderia tericola</i>	0	0	0	17	17
<i>Dorymyrmex flavus</i>	64	618	185	113	980
Total	6454	3556	8110	5431	23551

Table 2.2: Total abundance of each taxon in four distinct vegetation zones. Ants were captured using honey, Pecan Sandies®, tuna, and tuna mixed with honey as baits. All data were collected in the Beaver River Wildlife Management Area in Beaver, Oklahoma during summers of 2012 and 2013 on 6/9/12, 7/1/12, 7/30/12, 5/9/13, 6/6/13 and 7/4/13.

	Blank	Pecan Sandies®	Honey	Tuna	Tuna with Honey	Total
<i>Monomorium minimum</i>	3	6160	1310	3278	2251	12999
<i>Crematogaster laeviuscula</i>	3	693	151	680	1098	2622
<i>Forelius pruinosus</i>	0	19	99	76	159	353
<i>Formica pallidefulva</i>	0	1	20	0	0	21
<i>Formica biophilica</i>	0	0	20	3	4	27
<i>Linepithema humile</i>	0	1	6	0	9	16
<i>Pheidole spp.</i>	2	3018	420	570	1390	5398
<i>Pogonomyrmex barbatus</i>	0	6	0	13	3	22
<i>Solenopsis texana</i>	0	40	2	271	51	364
<i>Tapinoma sessile</i>	0	89	17	86	56	248
<i>Lasius neoniger</i>	0	5	50	224	145	424
<i>Brachymyrmex depilis</i>	0	0	0	11	0	11
<i>Nylanderia tericola</i>	0	3	0	2	12	17
<i>Dorymyrmex flavus</i>	1	16	213	177	573	979
Total	9	10051	2308	5391	5751	

Table 2.3: Total abundance of each taxon collected on four bait types: honey, Pecan Sandies®, tuna, and tuna mixed with honey. All data were collected in the Beaver River Wildlife Management Area in Beaver, Oklahoma during summers of 2012 and 2013 on 6/9/12, 7/1/12, 7/30/12, 5/9/13, 6/6/13 and 7/4/13.

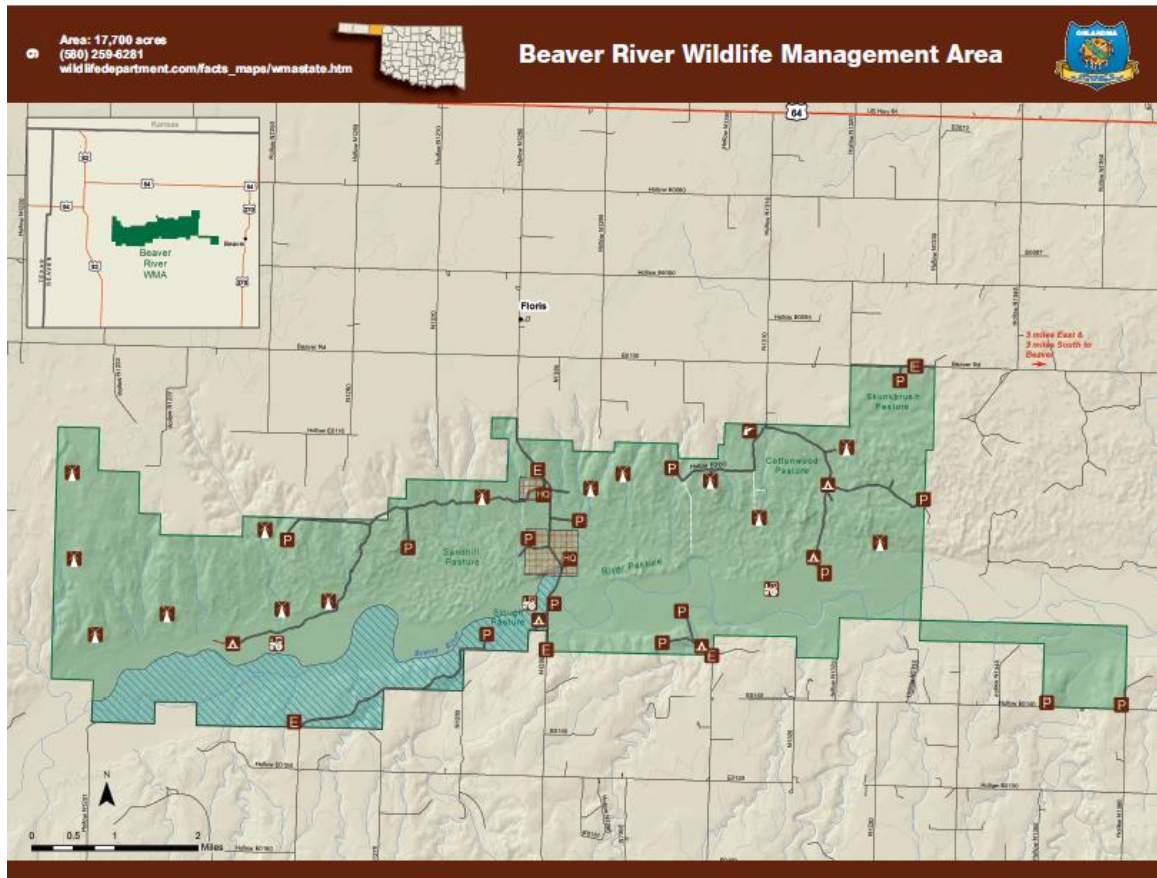


Fig. 2.1: Map of Beaver River Wildlife Management Area in Beaver County, Oklahoma. Map by Oklahoma Department of Wildlife Conservation (ODWC). All data were collected in this wildlife management area during summer of 2012 and 2013.

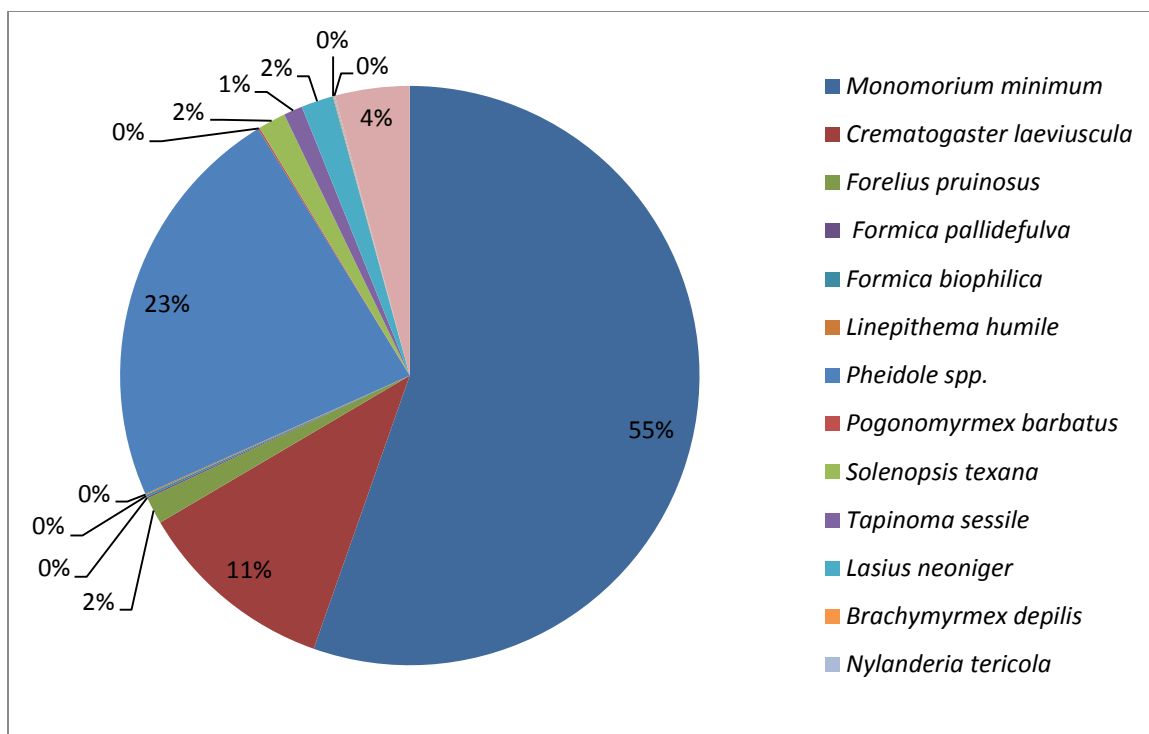


Fig. 2.2: Relative abundance of ants collected using baiting by species. Relative abundance of all ant species pooled from 4 bait types (tuna, tuna mixed with honey, honey, Pecan Sandies®) over 6 sampling events, (6/9/12, 7/1/12, 7/30/12, 5/9/13, 6/6/13, and 7/4/13), within 4 different habitat types (riparian, grassland, transitional, upland sand dune) during summer of 2012 and 2013 in Beaver, Oklahoma.

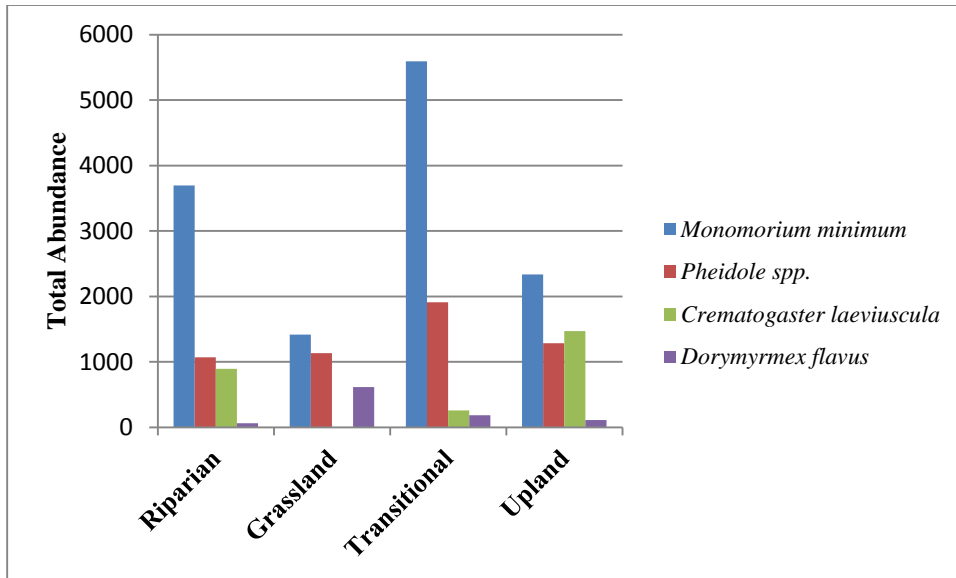


Figure 2.3: Most abundant ant taxa by vegetation zone. The four most abundant species comprised at least 85% of total abundance of the ants collected in each vegetation zone (riparian 87%, grassland 85%, transitional 92%, upland 94%). Numbers indicate abundance of each of the most common species. Abundances are summed from 6 sampling events, 6/9/12, 7/1/12, 7/30/12, 5/9/13, 6/6/13, and 7/4/13. All samples were collected on the Beaver River Wildlife Management Area.

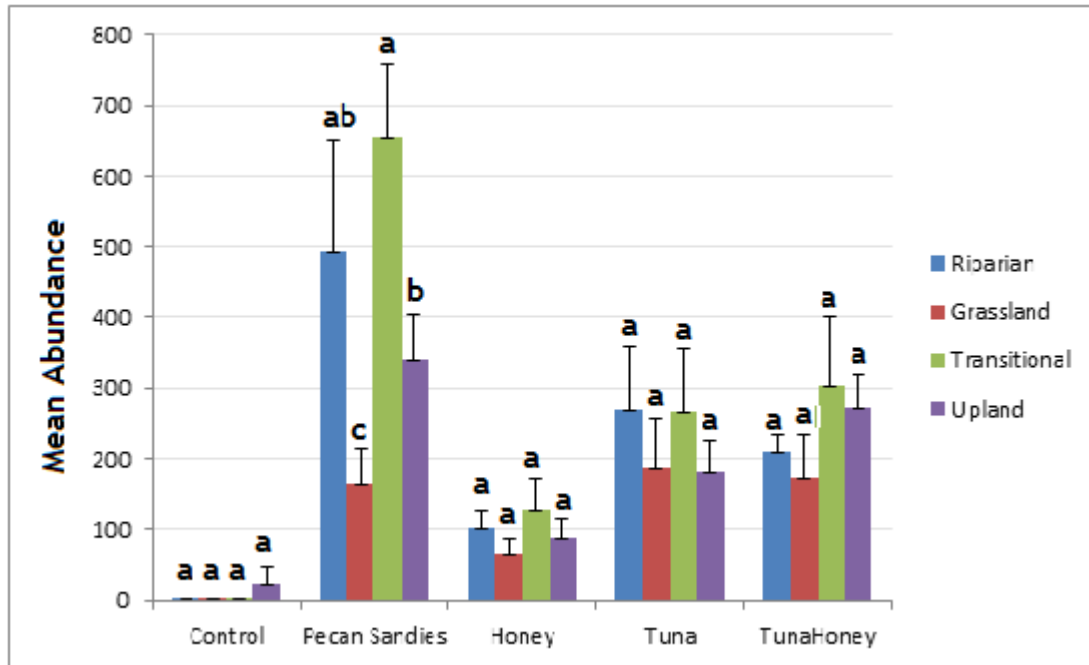


Figure 2.4: Mean abundance of ants on baits. Mean abundance of all species pooled in each vegetation zone by bait type. Data collected over 6 sampling events (6/9/12, 7/1/12, 7/30/12, 5/9/13, 6/6/13, and 7/4/13) in Beaver, Oklahoma during the summers of 2012 and 2013. Bars within groupings with the same letter are not significantly different ($p=0.05$).

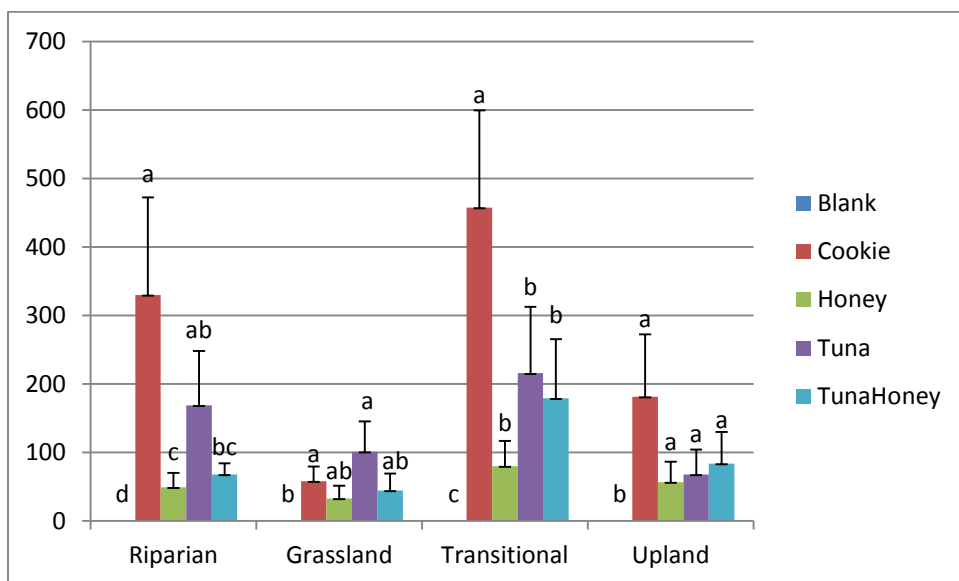


Fig 2.5a: Mean abundance of *Monomorium minimum* pooled by bait type on which it was collected. All data collected during 6 sampling events during summers of 2012 and 2013 (6/9/12, 7/1/12, 7/30/12, 5/9/13, 6/6/13, and 7/4/13) using Pecan Sandies®, honey, tuna, and tuna mixed with honey as bait choices. Data marked with the same letter within groups of bars are not statistically different ($p=0.05$).

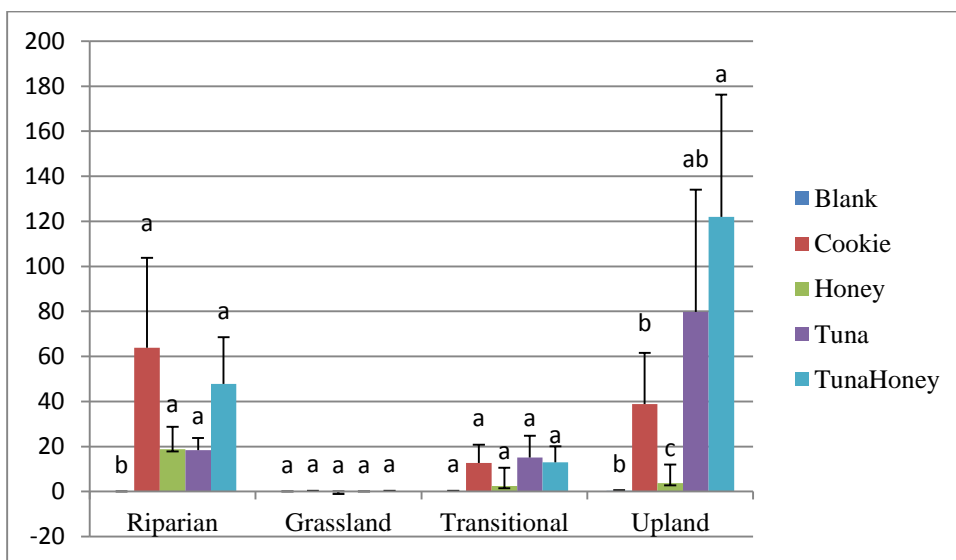


Fig 2.5b: Mean abundance of *Crematogaster laeviuscula* pooled by bait type on which it was collected. All data collected during 6 sampling events during summers of 2012 and 2013 (6/9/12, 7/1/12, 7/30/12, 5/9/13, 6/6/13, and 7/4/13) using Pecan Sandies®, honey, tuna, and tuna mixed with honey as bait choices. Data marked with the same letter within groups of bars are not statistically different ($p=0.05$).

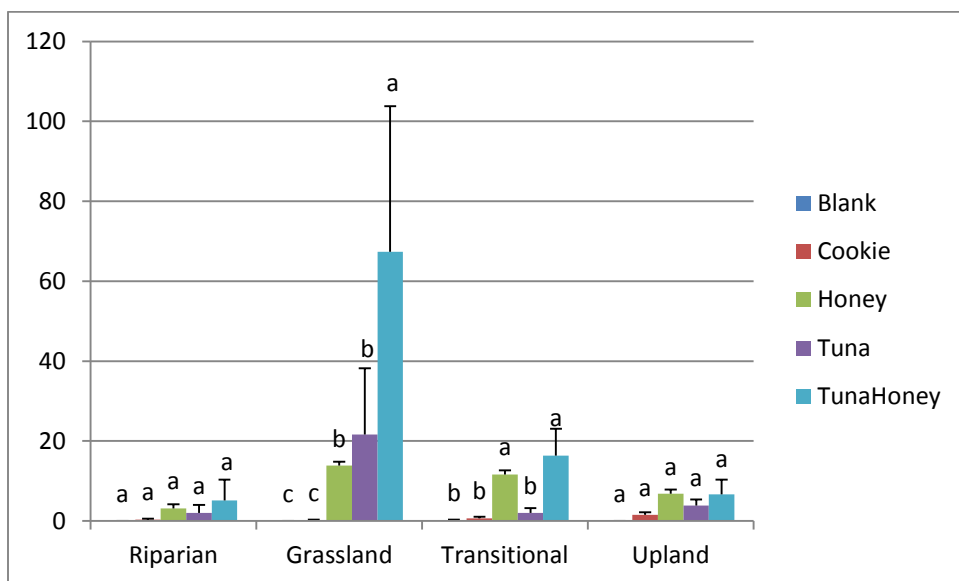


Fig 2.5c: Mean abundance of *Dorymyrmex flavus* pooled by bait type on which it was collected. All data collected during 6 sampling events during summers of 2012 and 2013 (6/9/12, 7/1/12, 7/30/12, 5/9/13, 6/6/13, and 7/4/13) using Pecan Sandies®, honey, tuna, and tuna mixed with honey as bait choices. Data marked with the same letter within groups of bars are not statistically different ($p=0.05$).

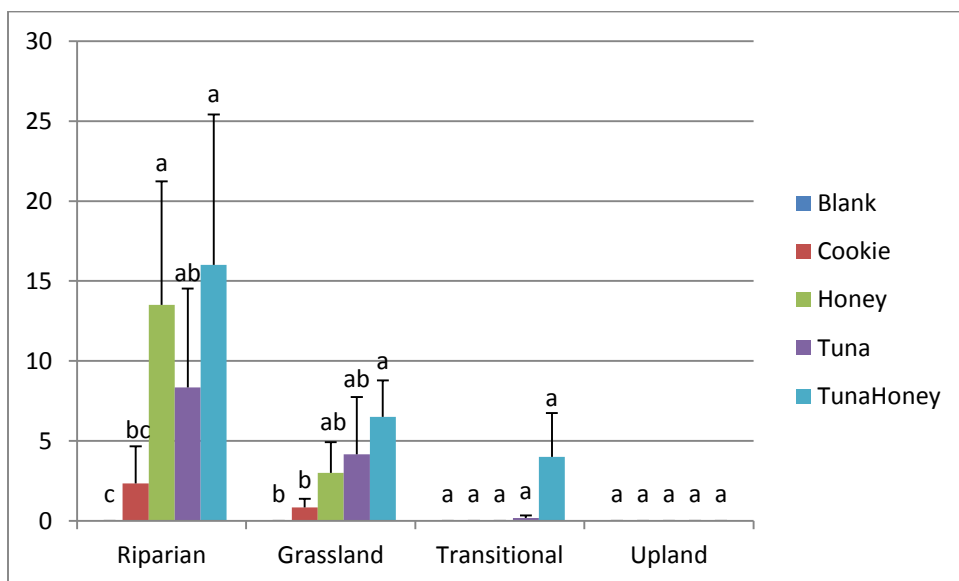


Fig 2.5d: Mean abundance of *Forelius pruinosus* pooled by bait type on which it was collected. All data collected during 6 sampling events during summers of 2012 and 2013 (6/9/12, 7/1/12, 7/30/12, 5/9/13, 6/6/13, and 7/4/13) using Pecan Sandies®, honey, tuna, and tuna mixed with honey as bait choices. Data marked with the same letter within groups of bars are not statistically different ($p=0.05$).

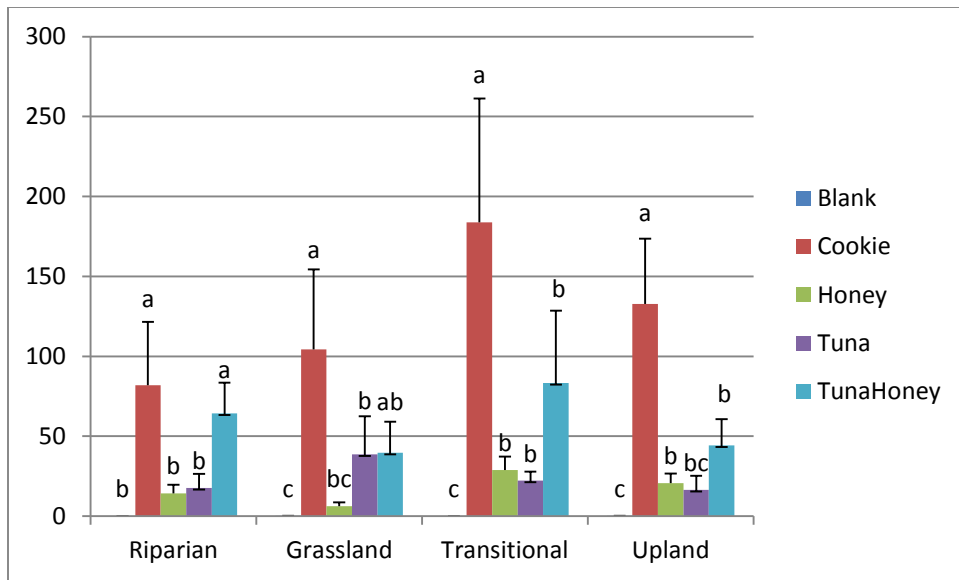


Fig 2.5g: Mean abundance of *Pheidole* spp. pooled by bait type on which it was collected. All data collected during 6 sampling events during summers of 2012 and 2013 (6/9/12, 7/1/12, 7/30/12, 5/9/13, 6/6/13, and 7/4/13) using Pecan Sandies®, honey, tuna, and tuna mixed with honey as bait choices. Data marked with the same letter within groups of bars are not statistically different ($p=0.05$).

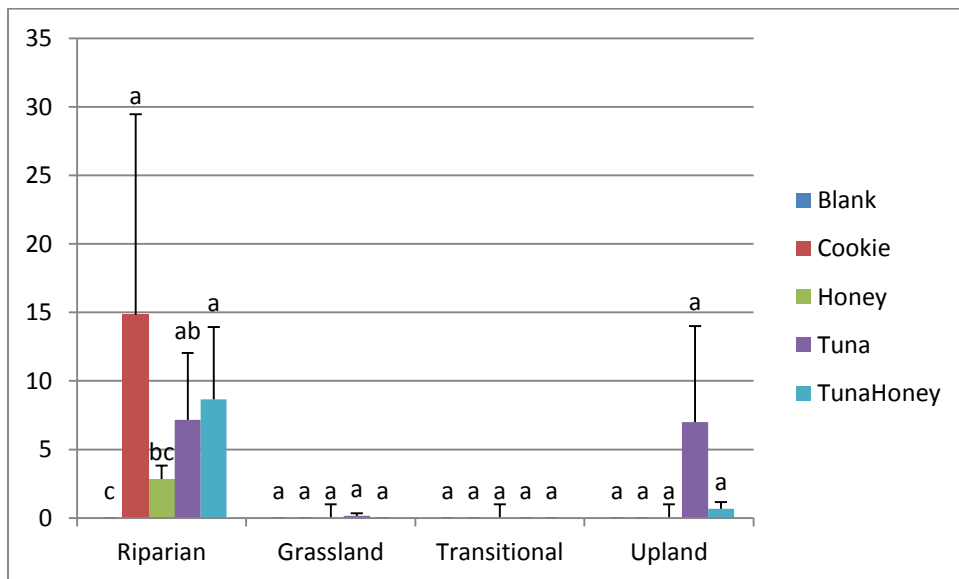


Fig 2.5j: Mean abundance of *Tapinoma sessile* pooled by bait type on which it was collected. All data collected during 6 sampling events during summers of 2012 and 2013 (6/9/12, 7/1/12, 7/30/12, 5/9/13, 6/6/13, and 7/4/13) using Pecan Sandies®, honey, tuna, and tuna mixed with honey as bait choices. Data marked with the same letter within groups of bars are not statistically different ($p=0.05$).

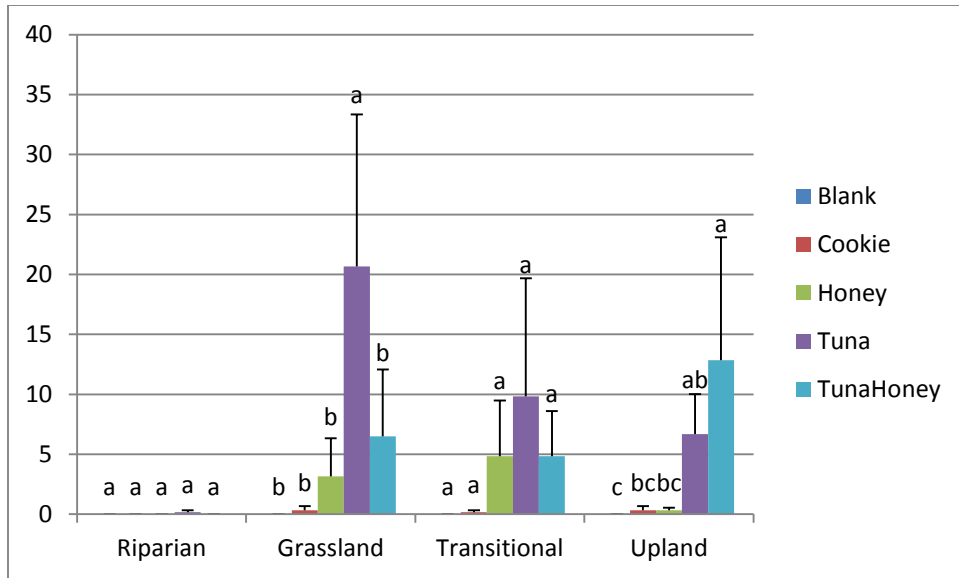


Fig 2.5k: Mean abundance of *Lasius neoniger* pooled by bait type on which it was collected. All data collected during 6 sampling events during summers of 2012 and 2013 (6/9/12, 7/1/12, 7/30/12, 5/9/13, 6/6/13, and 7/4/13) using Pecan Sandies®, honey, tuna, and tuna mixed with honey as bait choices. Data marked with the same letter within groups of bars are not statistically different ($p=0.05$).

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CHAPTER III

ANT DIVERSITY AND COMMUNITY COMPOSITION IN SEMIARID GRASSLANDS OF WESTERN OKLAHOMA THAT SERVE AS NESTING HABITAT FOR NORTHERN BOBWHITE (*Colinus virginianus*): CHARACTERIZATION BASED UPON PITFALL TRAP SAMPLING

Abstract

In the grasslands of Oklahoma, ants (Hymenoptera: Formicidae) are important forage taxa for northern bobwhites, and are abundant and diverse. Ant communities on the Beaver River Wildlife Management Area (BRWMA) were characterized using pitfall traps. Four vegetation zones were compared along each of six permanently established transects. Vegetation zones progressed perpendicularly from the riparian zone of the Beaver River through an area of mixed grasses, culminating in an upland shrub habitat atop sand dunes. Species richness ranged from 11-14 species in each of these zones. Fourteen species were recovered in the riparian and grassland zones, twelve were recovered in the transitional zone, and eleven were recovered in the upland zone. In total, 7326 individual specimens were collected using this method during 6 sampling events representing 15 total species. Five species comprised over 85% of the total abundance of ants and six species each contributed <1% to the total abundance.

Introduction

Ants (Hymenoptera: Formicidae) fill many roles in ecosystems. Their unique abilities to redistribute nutrients (Wagner et al. 2004), alter moisture distribution (Laundre, 1990), alter microbial communities (Whitford et al. 2012), aerate soil, consume dead and decomposing biological litter and provide a critical food resource for many higher organisms makes them an indispensable component of any terrestrial ecosystem. Northern bobwhites are particularly dependent on arthropod communities and previous studies have shown that Formicidae is the most commonly consumed arthropod family. (Doxon and Carroll 2010). Bobwhite populations are in a state of severe decline (Link et al. 2008) and this study of ant communities will allow us to assess the role of ant community composition as a potential contributing factor.

There are many methods of ant collection and previous studies of ant community composition have determined that pitfall traps are necessary to gain a comprehensive picture of community composition. Pitfall traps have been found to capture the highest species richness in ant sampling when compared to Winkler litter extraction, hand sampling, and colony sampling (Tista and Fiedler, 2011). A combination of sampling methods is recommended to ensure a thorough investigation of species distribution, particularly in consideration of the unique attributes of social insects and their habitat requirements (Tista and Fiedler, 2011). Competitive interactions including offensive and defensive behaviors and chemical attacks are especially important and cannot be readily observed in pitfall traps, as ants which are caught are immediately killed and do not interact with one another. For this reason a baiting study was done concurrently. Taxa recovered in the simultaneous bait study were similar to those recovered in pitfall traps,

however, as expected, some differences were observed. Pitfall traps recovered one additional species as compared to the baiting study (*Hypoponera opacior*). Pitfall traps can aid in the discovery of ant taxa that do not respond to baits. Additionally, our pitfall traps were open for 24 hours, collecting species that may forage at night, at alternate times of day, or in other unique conditions. The concurrent bait study collections took place only during the day.

Methods and Study Site

Study site:

This study was conducted on the Beaver River Wildlife Management Area (BRWMA) in the panhandle region of Oklahoma. The BRWMA is a 7163 hectare plot of land managed by the Oklahoma Department of Wildlife Conservation (ODWC) (Fig. 3.1). This land was set aside primarily to maintain wildlife habitat and to provide grazing lands; it contains limited fencing, few structures, and unpaved roads with restricted traffic. The Beaver River runs west to east at the southern edge of the BRWMA when sufficient water is present; however, during summer months severe droughts have impacted this region by leaving the river bed frequently dry. Water was available for cattle and wildlife in wells and twenty windmill-powered pumps (Storer, 2011). Land management practices included grazing, strip disking, strip mowing, and prescribed burns (Storer, 2011), however, all management practices were unpredictable and dependent on weather, wind, and availability of staff. The land was also utilized for hunting and fossil fuel extraction in addition to domesticated cattle grazing. Hunting for pheasant (*Phasianus colchicus*), northern bobwhite (*Colinus virginianus*), white-tail deer (*Odocoileus virginianus*), wild turkey (*Meleagris gallopavo*), cottontail rabbit (*Sylvilagus*

spp.), coyote (*Canis latrans*), bobcat (*Lynx rufus*), raccoon (*Procyon lotor*), mourning dove (*Zenaida macroura*), and a small population of waterfowl (Storer 2011) is the primary recreational activity on the BRWMA (Storer, 2011).

Methods

Six transects were established beginning at the riverbank and extending perpendicular from the river through four distinct vegetation zones: the riparian zone, grassland zone, transitional zone and upland zone. The length of vegetation zones and transects varied according to naturally occurring topography to ensure every vegetation zone was evaluated without edge effects. The riparian zone was dominated by saltcedar, an invasive *Tamarix sp.* which grew in very thick groves along the river bed. The grassland consisted primarily of native and non-native grasses with forbs intermittently dispersed throughout. The transitional zone was the area between the grassland and the upland sand dunes; it was characterized by increased elevation and contained grasses, forbs, and shrubs. The upland sand dune habitat was dominated by shrubs and woody plants. Each transect included four permanent sampling sites (Table 3.1), at least 30 meters from the start of each vegetation zone, to ensure edge effects would not alter results, and was marked by a central stake made of rebar. The central stake was also marked with GPS (Table 3.1) to ensure they could be relocated. Transects were set in groups of two for efficiency of sampling, with paired transects approximately 0.5 kilometers away from one another. Transects were labeled alphabetically from west to east.

This area is semi-arid with 21.5 inches of annual rainfall (Mesonet 2014) and very hot summer temperatures, frequently above 39°C, but it also experiences rather cool

winters. Common severe weather on the BRWMA includes thunderstorms, hail events, and tornados. The plant and animal taxa which are able to thrive in this environment must be able to withstand droughts as well as severe weather events. This area also carries a significant undergrowth of dead and old grasses which makes colony counts and similar methods to locate ant colonies impractical. This type of terrain is conducive to pitfall traps which are able to passively capture ants in this environment.

A pitfall trap was installed 10 meters to the east and west of each central stake. Each pitfall trap consisted of two 10 cm diameter plastic cups (16 ounce Solo® Brand drinking cup) fitted internally with a funnel. One collection cup was buried at ground level on either side of a 1.22 meter long aluminum drift fence. Each cup contained 80% ethanol to kill and preserve specimens and 20% glycerol to inhibit evaporation and desiccation of samples. Pitfall traps were open for one week and subsequently closed for 2 weeks; they were emptied every 48 hours during the open period. Ants which fell into these traps were counted and morphologically identified using “Ants of Oklahoma” (Young and Howell 1964) and “Ants of North America: A Guide to Genera” (Fisher and Cover 2007)

Analysis

Insect counts were analyzed using a randomized complete block design with repeated measures. In this model, the transect was the block factor and the vegetation zone was the main unit factor. By using the six sampling events as the repeated measure factor, we were able to model the correlations within transects and vegetation zones with an autoregressive covariance structure. SAS Version 9.3 (SAS Institute, Cary, NC 2011)

was used in performing the analysis. A 0.05 level of significance was used for all comparisons.

Results

Species richness decreased with distance from the riparian zone while total abundance increased. A total of 15 species were recovered (Tab. 3.2). In the riparian zone 14 species were recovered, in the grassland zone 13 species were recovered, in the transitional zone 12 species were recovered, and in the upland zone 11 species were recovered (Table 3.2). Across all sampling events, the riparian vegetation zone contained 18.50% (1355) of the total abundance collected, the grassland zone contained 22.1% (1619), the transitional zone contained 29.7% (2172), and the upland zone contained 29.8% (2180) (Tab. 3.2).

On June 18, 2012, May 13, 2013, and June 10, 2013, a similar number of individuals were captured in each of the four vegetation zones (Fig 3.2). On June 29, 2012, the highest abundance was captured in the transitional zone ($140.5 \pm \text{s.e. } 35.0169$), however the upland zone ($96.167 \pm \text{s.e. } 27.819$) and riparian ($79.000 \pm \text{s.e. } 20.5158$) zones were statistically similar. The only significant difference was between the transitional zone and the grassland zone ($60.883 \pm \text{s.e. } 25.0419$) and On July 24, 2012, total abundance was highest in the transitional zone ($95.167 \pm \text{s.e. } 16.672$), but it was statistically similar to that of the upland ($62.333 \pm \text{s.e. } 16.37$) and riparian zones ($28.167 \pm \text{s.e. } 7.5251$), (Fig. 3.3). Likewise, the grassland zone had the lowest abundance of ants during this sampling event ($69.667 \pm \text{s.e. } 24.9982$), but abundance was not significantly different than the grassland, upland, and riparian zones (Fig. 3.2). On July 8, 2013, the

upland vegetation zone had a significantly higher mean total abundance ($185 \pm \text{s.e. } 92.6$) than all other vegetation zones (riparian: $30.667 \pm \text{s.e. } 8.943$, grassland: $36.333 \pm \text{s.e. } 10.4902$, transitional: $52.167 \pm \text{s.e. } 17.4345$) (Fig. 3.2).

Consistent with other studies, four species made up 80% or more of all individuals caught in pitfall traps in each environment (Figure 3.4A). *Pheidole spp.* was the most abundant (33.88%), followed by *Monomorium minimum* (26.88%), *Dorymyrmex flavus* (12.64%), and *Crematogaster laeviuscula* (7.37%). As others have noted, the majority of individuals generally belong to a few dominant species, for example, Boulton et al. (2005) found that 3 species comprised 80% of the total abundance of ants in grassland zones of California. An additional 12 species, *Lasius neoniger*, *Pogonomyrmex barbatus*, *Solenopsis texana*, *Forelius pruinosus*, *Nylanderia terricola*, *Tapinoma sessile*, *Formica pallidefulva*, *Formica biophilica*, *Linepithema humile*, *Brachymyrmex depilis*, *Prenolepis imparis*, and *Hypoponera opacior* made up the remaining 20% of this ant community (Fig. 3.4b).

Different species of ants have different habitat requirements. Some species are generalists, able to inhabit diverse nest sites, while others have more specific requirements. *Pheidole spp.*, *Monomorium minimum*, *Dorymyrmex flavus*, *Crematogaster laeviuscula*, *Lasius neoniger*, *Solenopsis texana*, *Forelius pruinosus*, and *Brachymyrmex depilis* were captured in each vegetation zone represented in this study. *Pogonomyrmex barbatus* was captured in all but the riparian zone, *Prenolepis imparis* was only captured in the upland zone. *Hypoponera opacior*, *Formica biophilica* and *Formica pallidefulva* was captured in the riparian and grassland zones. *Tapinoma sessile*

and *Linepithema humile* were captured in all but the upland zone. *Nylanderia terricola* was found in all but the grassland zone (Tab. 3.2).

Pheidole spp. had the highest rate of capture (rate of capture is defined here as percentage of traps in which it was present), with individuals in 116 pitfall traps of 144 possible traps (n=144), *M. minimum* was captured in 111 traps, and *D. flavus* was located in 81 (Fig 3.5). In contrast, *Hypoponera opacior* was captured in only 3 traps (Fig. 3.5).

Discussion

The species richness of 15 is within the range of recovered species in other grassland experiments. Similar studies have reported between ten and 32 species in grassland ecosystems, yet many factors contribute to the species richness in a given habitat. A Chihuahuan Desert survey recovered 32 species (Rojas and Fragoso 2000), a state wide Nebraska study recovered 22 genera (Jurzenski et al. 2012), a California grassland study identified 20 species (Boulton et al. 2005), a Spanish grassland recovered 12 species (Luque and Lopez 2007), and a managed grassland in Germany recovered 10 species in 3 genera (Dauber and Wolters 2004). The species richness per sampling site is within the range observed by other researchers. Even Rojas and Fragoso, who found an astonishing 32 total species, discovered a *per site* richness of 11- 26 species (2000). We recovered 11-14 per vegetation zone, within their range. Competition within the ant community (Holldobler and Wilson 1990), disturbance (Dauber and Wolters 2004), management practices, appropriate nest sites, and availability of food and water can all influence ant communities. Reducing litter accumulation and nutrients, through grazing, is one management technique in semi-natural grassland ecosystems for preserving

biodiversity. While this is successful for biodiversity management in some taxa, removal of excess nutrients by grazing was not shown to affect ant species richness (Pihlgren et al. 2009). In respect to increasing ant diversity other methods of management will need to be explored.

While the total species richness based on vegetation zone was not explicitly analyzed, some observations can be made. The results from pitfall traps can be understood as a measurement of the ant's activity, or how often they are traveling through the area the area in which the trap is located. The number of ant species was lowest (11) at the upland site and increased by one in each vegetation zone, reaching 14 in the riparian zone. This is not surprising based on increased resources, such as available water, as we traveled down the vegetation gradient to the riparian zone.

The Nebraska study by Jurzenski et al. (2012) may have been most similar to ours in Oklahoma, but the vegetation types were different than ours and spanned the entire state of Nebraska. Thus, we found differences in our diversity. A statewide study of Oklahoma would be likely to have more similar results to the study by Jurzenski et al. both because of the scale of the project and the diversity of habitats we would be able to investigate.

In this study, species richness decreased as the distance from the riparian zone increased (riparian: 14, grassland 13, transitional 12, upland 11); however, total abundance did not follow the same trend. Thus, the community in the riparian zone had few individuals but higher species richness while the upland community had a greater total abundance and lower species richness. Factors which may influence this include

moisture, vegetation, and disturbance (Boulton et al. 2005 and Hoffmann 2010).

Environmental factors affect ant communities in many ways, Boulton found that soil attributes had a larger influence on ant communities than plant richness or plant biomass did (Boulton et al. 2005). While differences were observed between our vegetation zones (Fig. 3.3), more detailed soil surveys are recommended for future research. It was evident that the upland and transitional zones were predominantly sandy; however, riparian and grassland zones had a very different soil type with smaller particle sizes, probably rich in clay. Soil and vegetation type both have a greater influence on ant community composition than disturbance does (Hoffmann 2010).

The most abundant ant taxon collected using pitfall sampling (*Pheidole spp.*) differed from the most abundant ant taxon collected using bait sampling (*M. minimum*) concurrently (Chapter II). When using baits, recruitment behaviors, exclusionary competitive behaviors, time of foraging and behavioral interactions at a bait station can impact the total ant abundance, particularly with species such as *M. minimum*, which have powerful and effective chemical defensive and behavioral displays of dominance (Greenslade and Greenslade 1971).

Pitfall traps, however, remove these variables and provide a measure of how often individuals of a species travel through an area, because the individuals do not interact with one another and are killed immediately. This research is to be used alongside the results from the concurrent study utilizing baiting sampling. One species was located by this pitfall trap study which was not located in the concurrent baiting study. *Hypoponera opacior* is a small species which has an interesting ecology, producing two types of colonies, one type with ordinary reproductive morphs and the

other whose workers can lay eggs (Fisher and Cover 2007). This predatory species did not respond to our baits, and therefore would not have been recovered if these complementary methods had not been used. Using two collection methods resulted in differences in the scale of the surveys (duration of time traps left out, baited/unbaited, diurnal/nocturnal, etc.) and because these scales influence patterns of species richness, behavioral dominance and species composition (Anderson 1997), we use these methods as complementary means of gaining access to the larger picture. Pitfall traps contained alcohol and glycerol, which have been shown to neither attract nor repel ants (Greenslade and Greenslade 1971) although some other insect families are attracted to these kill agents. This previous research allows us to identify our pitfall traps as unbaited. Although imperfect, pitfall traps remain the predominant ant collection method in rangeland research (Hoffmann 2010). Other important benefits to pitfall traps are their efficiency in both cost and labor, further contributing to their usefulness.

It should also be noted that morphological identification to species of *Pheidole* required major workers, which were generally not harvested and therefore could not be identified to species. At least two distinct species were believed to be present, but we could not confirm. In addition to being the most abundant, *Pheidole spp.* also had the highest rate of capture (rate of capture is defined here as percentage of traps in which it was present), with individuals in 116 pitfall trap days of 144 possible traps (n=144) (81%), *M. minimum* was captured in 111 (77%) traps, and *D. flavus* was found in 81 traps (56% of all traps) (Fig 3.5).

Because northern bobwhites will consume any species of ants, and other arthropod, which it can locate, the higher abundance of ants in the upland zone is an

especially important contribution to their food supply, while the lower diversity is not detrimental. Northern bobwhites use the upland zone most often for nesting (Tanner unpublished data), so the abundance is ideally located as forage for northern bobwhites. Land management decisions for northern bobwhite should be mindful of their impact on arthropod populations, if a management practice increases conditions for nesting while neglecting this food source, chicks may not receive adequate protein during the critical first year.

	Riparian	Grassland	Transitional	Upland
A	14S 353538.76 E 4076757.88 N	14S 353583.67 E 4076859.85 N	14S 353693.64 E 4077268.57 N	14S 353709.62 E 4077433.65 N
B	14 S 354062.79 E 4076878.67 N	14 S 354030.34 E 4076928.88 N	14 S 354032.61 E 4077071.24 N	14 S 354048.23 E 4077216.64 N
C	14 S 356444.83 E 4076886.21 N	14 S 356462.11 E 4076948.35 N	14 S 356440.22 E 4077124.93 N	14 S 356425.83 E 4077281.84 N
D	14 S 356565.01 E 4076729.59 N	14 S 356612.96 E 4076837.40 N	14 S 356698.71 E 4077118.11 N	14 S 356708.93 E 4077339.48 N
E	14 S 360380.05 E 4076567.33 N	14 S 360394.28 E 4076693.30 N	14S 360474.37 E 4077413.84 N	14 S 360426.82 E 4077855.53 N
F	14 S 360614.89 E 4076628.89 N	14 S 360601.72 E 4076708.32 N	14 S 360626.71 E 4077366.13 N	14 S 360581.65 E 4077815.89 N

Tab. 3.1: Coordinates of the permanent sampling sites along each of the 6 transects established in the Beaver WMA. Ants were collected using pitfall traps at each sampling location. Four vegetation zones (riparian, grassland, transitional, upland) were sampled in each of the six transects in the Beaver River Wildlife Management Area in Beaver County, Oklahoma.

	Riparian	Grassland	Transitional	Upland	Total
<i>Pheidole spp.</i>	337	565	641	939	2482
<i>Monomorium minimum</i>	517	372	685	395	1969
<i>Dorymyrmex flavus</i>	89	300	347	190	926
<i>Crematogaster laeviuscula</i>	69	2	114	355	540
<i>Lasius neoniger</i>	148	50	86	75	359
<i>Pogonomyrmex barbatus</i>	0	173	101	34	308
<i>Solenopsis texana</i>	6	23	114	47	190
<i>Forelius pruinus</i>	48	78	40	9	175
<i>Nylanderia terricola</i>	2	0	28	115	145
<i>Tapinoma sessile</i>	103	10	1	0	114
<i>Brachymyrmex depilis</i>	7	6	14	18	45
<i>Formica biophilica</i>	6	27	0	0	33
<i>Formica pallidefulva</i>	16	11	0	0	27
<i>Prenolepis imparis</i>	0	0	0	3	3
<i>Linepithema humile</i>	6	1	1	0	8
<i>Hypoponera opacior</i>	1	0	0	3	4
Total	1355 (18.4%)	1619 (22.1%)	2172 (29.6%)	2180 (29.8%)	7326

Tab. 3.2: Total abundance of all ant taxa in four vegetation zones. Data pooled from 6 sampling events (6/8/12, 6/29/12, 7/24/12, 5/13/13, 6/10/13, and 7/8/13) on the Beaver River Management Area in Beaver County, Oklahoma. Vegetation zones are riparian, grassland, transitional, and upland, each vegetation zone was sampled on each of 6 transects, for a total of 24 sampling locations.

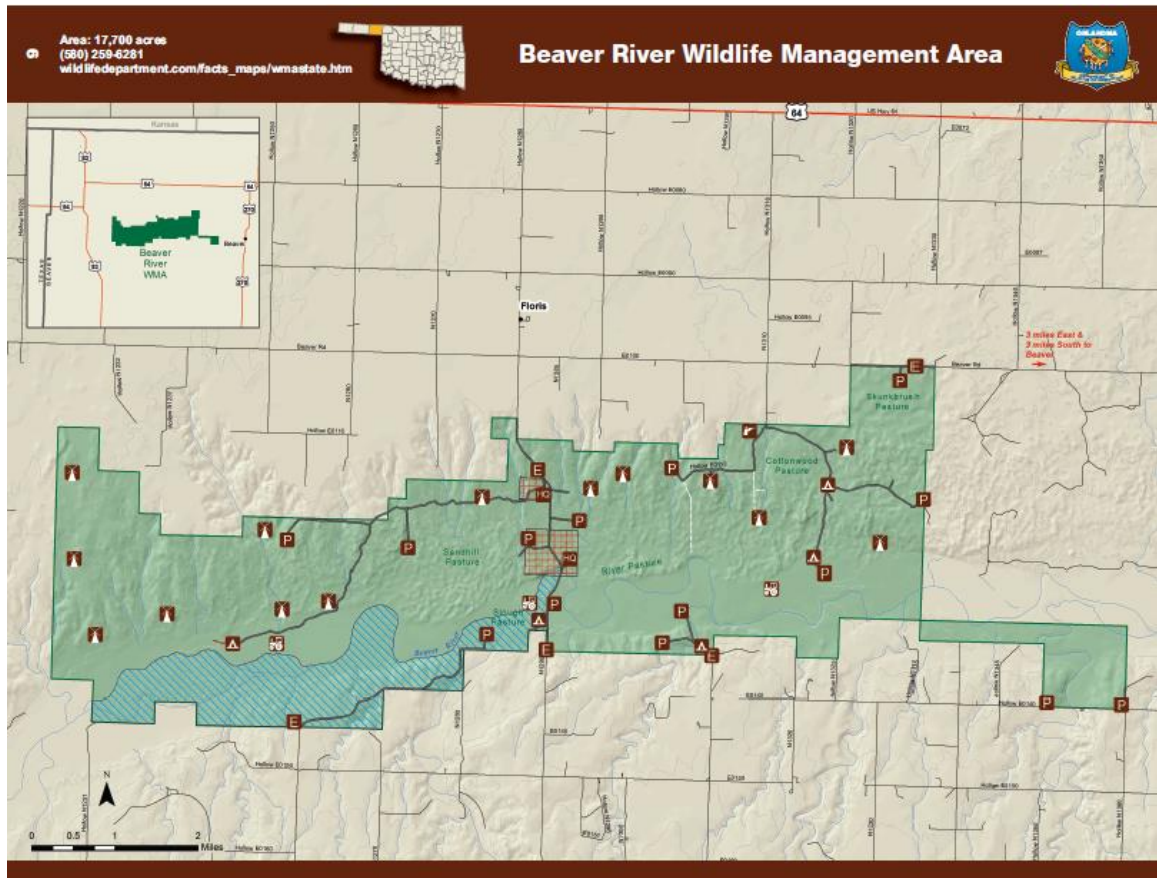


Fig. 3.1: Map of Beaver River Wildlife Management Area in Beaver County, Oklahoma. Map by Oklahoma Department of Wildlife Conservation (ODWC). This 17000 acre expanse is used for natural resource extraction, hunting, and grazing and is managed by the Oklahoma Department of Wildlife Conservation.

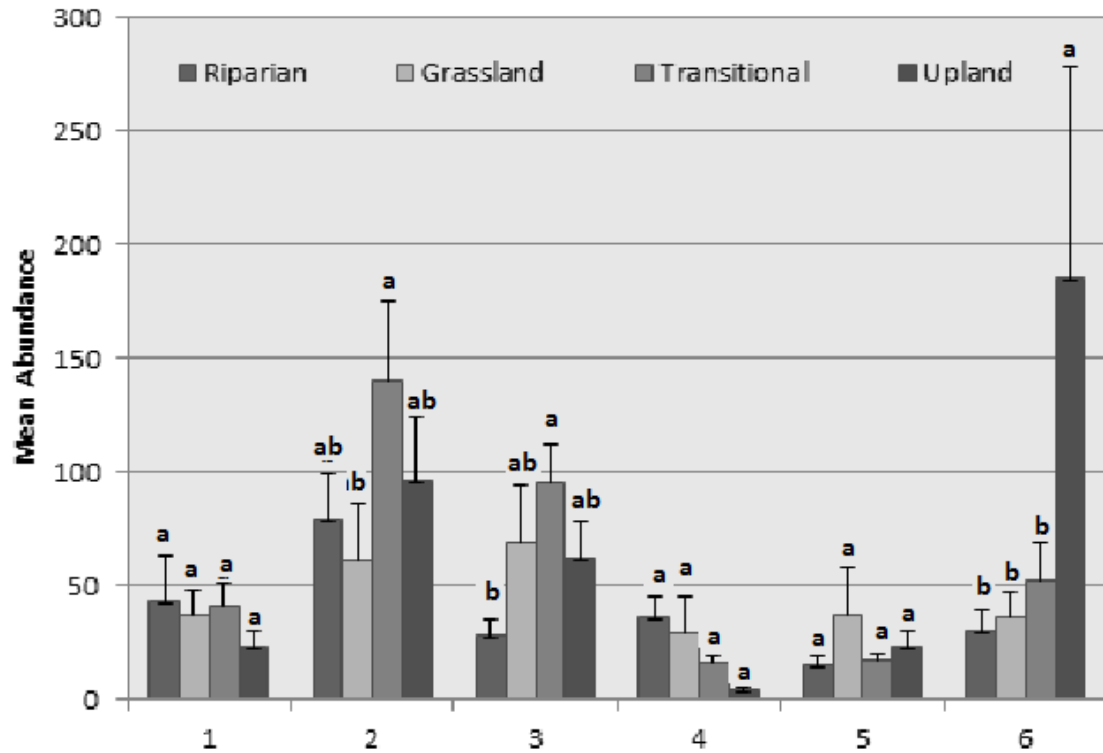


Figure 3.2: Mean abundance of all ant taxa collected over 6 sampling dates in 4 different vegetation zones at the Beaver WMA of western Oklahoma. Total abundance of all species from each sampling event are combined within the vegetation zones (riparian, grassland, transitional, upland) to indicate the total overall abundance. Numbers 1-6 indicate sampling event (1:6/8/12, 2:6/29/12, 3: 7/24/12, 4:5/13/13, 5:6/10/13, 6:7/8/13). Means that have the same letter, within each sampling event, are not significantly different, $p=0.05$.

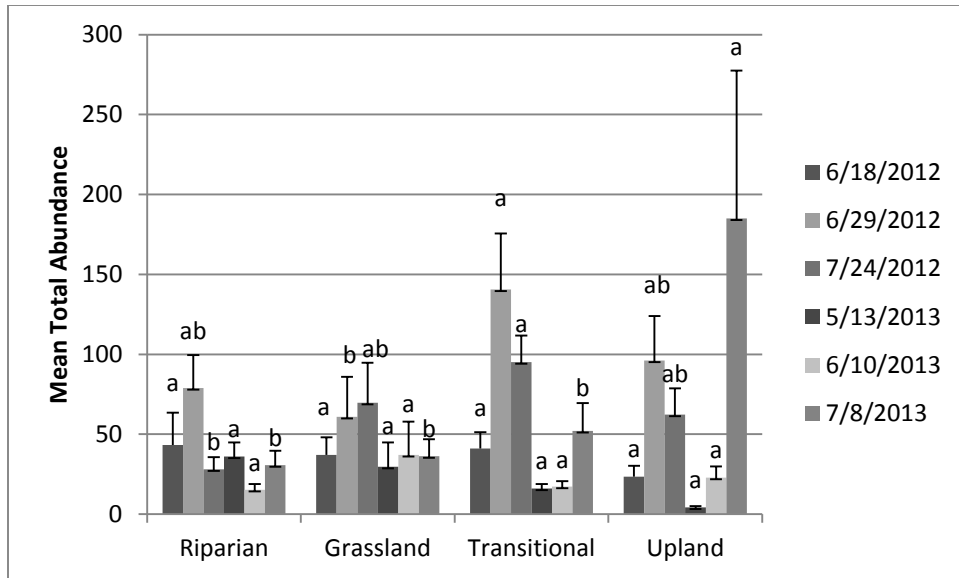


Fig. 3.3: Mean abundance of all ant taxa collected over 6 sampling dates in 4 different vegetation zones at the Beaver WMA of western Oklahoma. Total abundance of all species from each sampling event are displayed within the vegetation zones (riparian, grassland, transitional, upland) to indicate the total overall abundance. Sampling events, 6/8/12, 6/29/12, 7/24/12, 5/13/13, 6/10/13, 7/8/13, are shown by different colored columns. Means, in the same sampling event that are identified by the same letter are not significantly different, $p=0.05$.

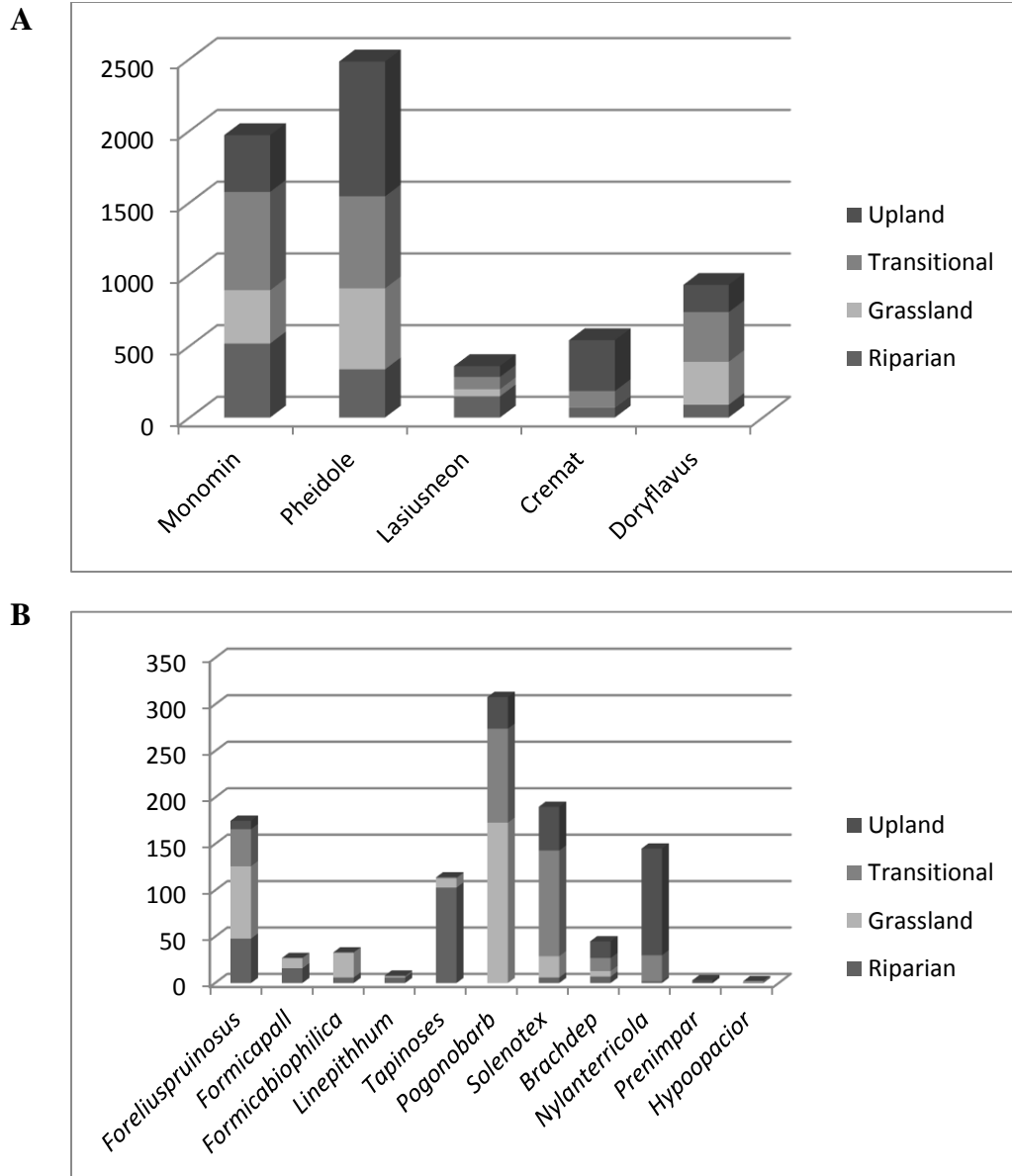


Figure 3.4: The total abundance of each ant species captured at Beaver River Wildlife Management Area in each vegetation zone (riparian, grassland, transitional, upland). A. indicates 5 most abundant species (*Monomorium minimum*, *Pheidole spp.*, *Lasius neoniger*, *Crematogaster laeviuscula*, *Dorymyrmex flavus*), making up a total of 85% of the total abundance. B. displays less abundant species. These 11 species (*Forelius pruinus*, *Formica pallidefulva*, *Formica biophilica*, *Linepithema humile*, *Tapinoma sessile*, *Pogonomyrmex barbatus*, *Solenopsis texana*, *Brachymyrmex depilis*, *Nylanderia terricola*, *Hypoponera opacior*, and *Prenolepis imparis*) combined make up 15% of the total abundance. Ants were collected in pitfall traps over 6 sampling events (1: 6/8/12, 2: 6/29/12, 3: 7/24/12, 4: 5/13/13, 5: 6/10/13, 6: 7/8/13).

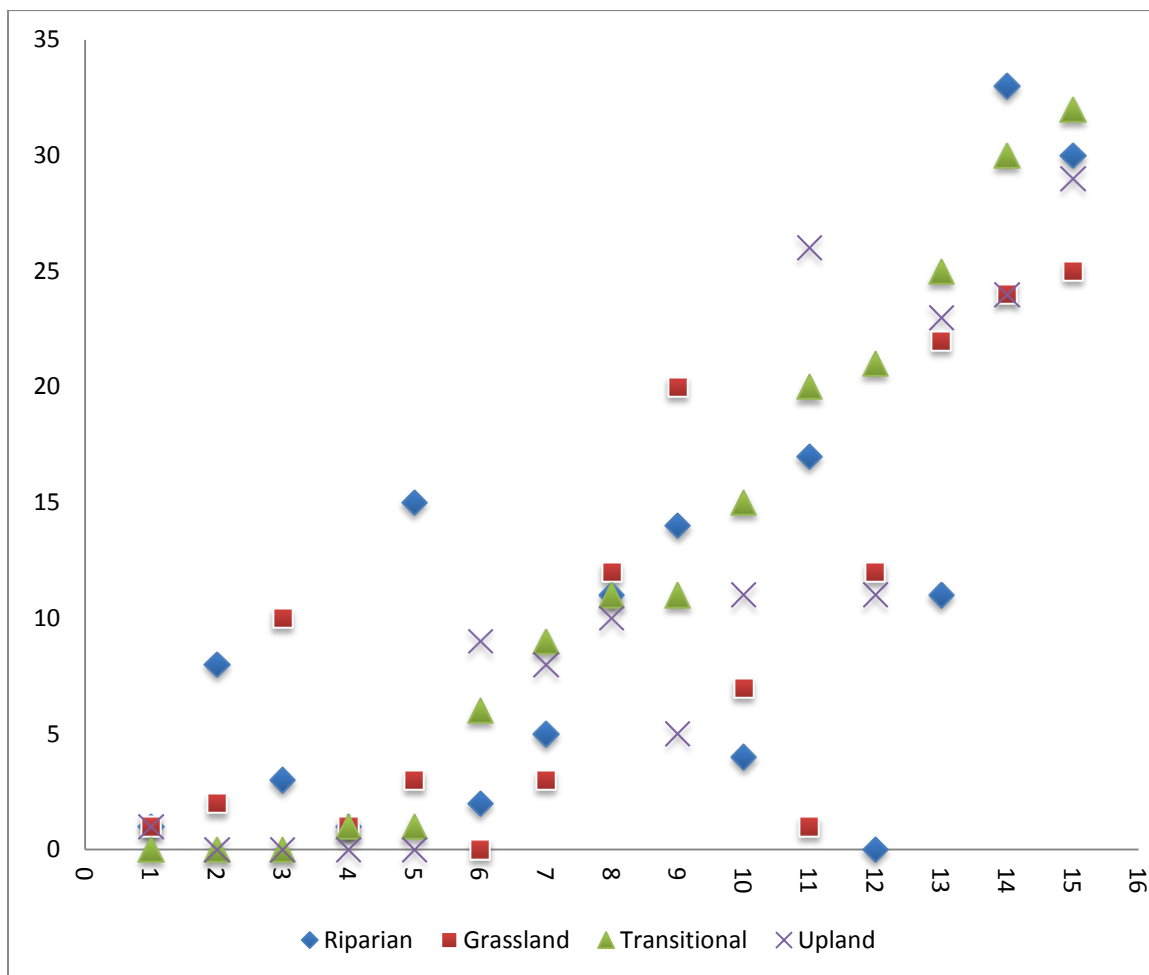


Fig. 3.5: Number of pitfall traps in which each species was observed by vegetation zone. Thirty-six total possible observations per zone ($n=36$ per zone) (6 sampling events, 6 transects) and $n=144$ total possible observations per species across all vegetation zones. All data collected in Beaver River Wildlife Management Area and pooled from 6 sampling dates (1:6/8/12, 2:6/29/12, 3: 7/24/12, 4:5/13/13, 5:6/10/13, 6:7/8/13). 1: *Hypoconera opacior*, 2: *Formica pallidefulva*, 3: *Formica biophilica*, 4: *Linepithema humile*, 5: *Tapinoma sessile*, 6: *Nylanderia terricola*, 7: *Brachymyrmex depilis* 8: *Lasius neoniger*, 9: *Forelius pruinosus*, 10: *Solenopsis texana*, 11: *Crematogaster laeviuscula*, 12: *Pogonomyrmex barbatus*, 13: *Dorymyrmex flavus*, 14: *Monomorium minimum*, 15: *Pheidole spp.*

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APPENDICES

APPENDIX A

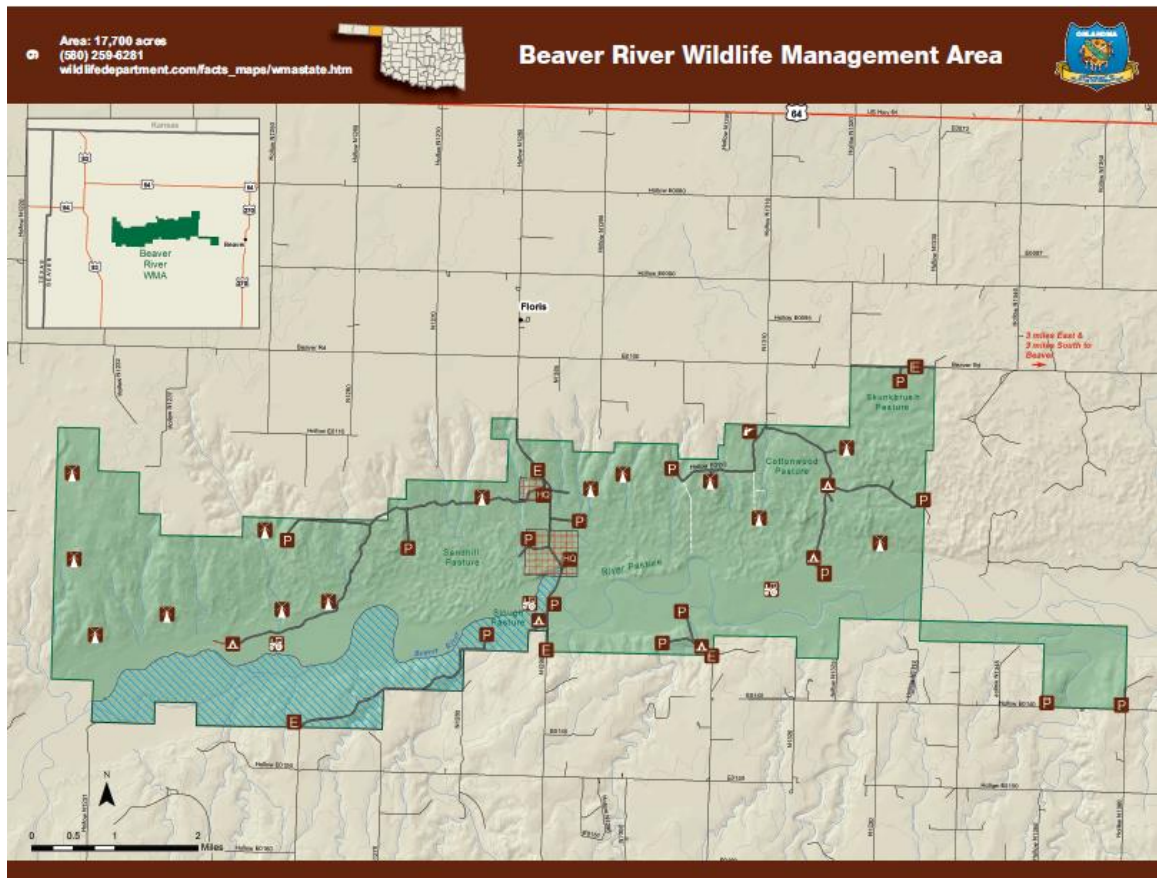


Fig. A1.1: Map of Beaver River Wildlife Management Area in Beaver Oklahoma (BRWMA). All data were collected within this conservation area. Land area managed by Oklahoma Department of Wildlife Conservation (ODWC). Map credit ODWC: www.wildlifedepartment.com/maps/Beaver%20River%20WMA.pdf

APPENDIX B

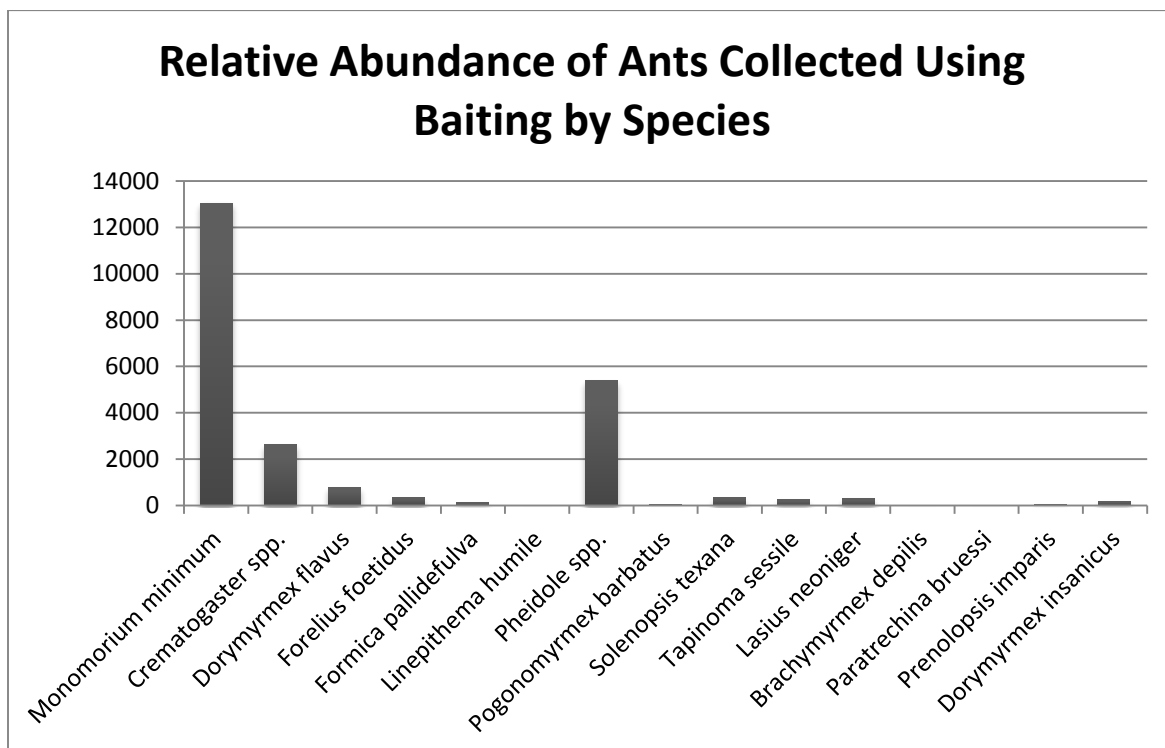


Fig. B: Total relative abundance of ant species collected over 6 sampling events on the Beaver River Wildlife Management Area during summer in 2012 and 2013. Ants were captured using honey, Pecan Sandies®, tuna, and tuna mixed with honey as baits. All data were collected in the Beaver River Wildlife Management Area in Beaver, Oklahoma during summers of 2012 and 2013 on 6/9/12, 7/1/12, 7/30/12, 5/9/13, 6/6/13 and 7/4/13.

APPENDIX C

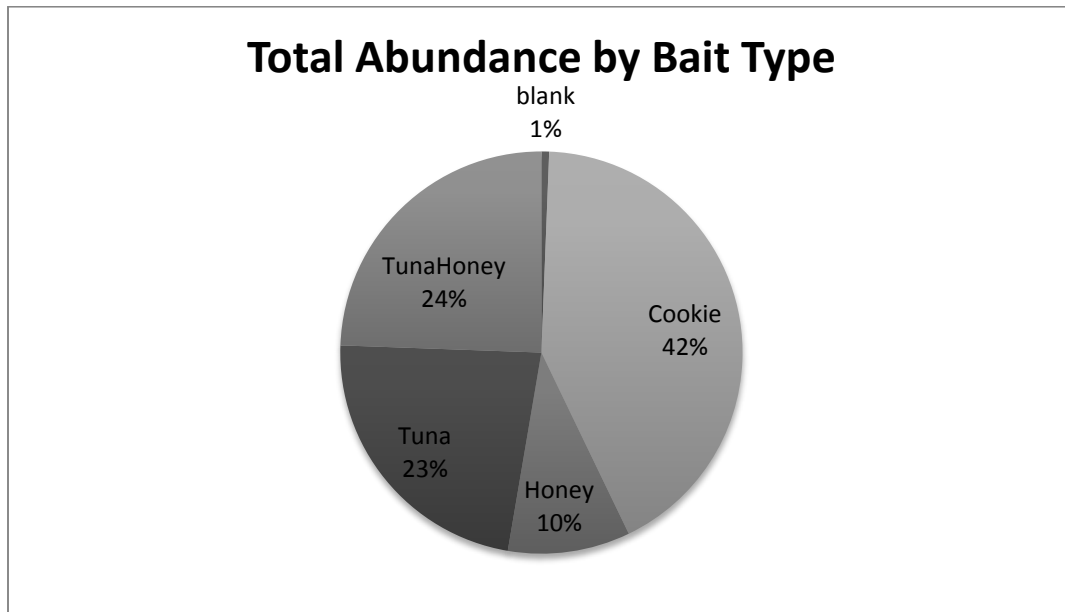


Fig. C: Total abundance of all ants in each bait type across all dates (6 sampling events). Ants were captured using honey, Pecan Sandies®, tuna, and tuna mixed with honey as baits. All data were collected in the Beaver River Wildlife Management Area in Beaver, Oklahoma during summers of 2012 and 2013 on 6/9/12, 7/1/12, 7/30/12, 5/9/13, 6/6/13 and 7/4/13.

APPENDIX D

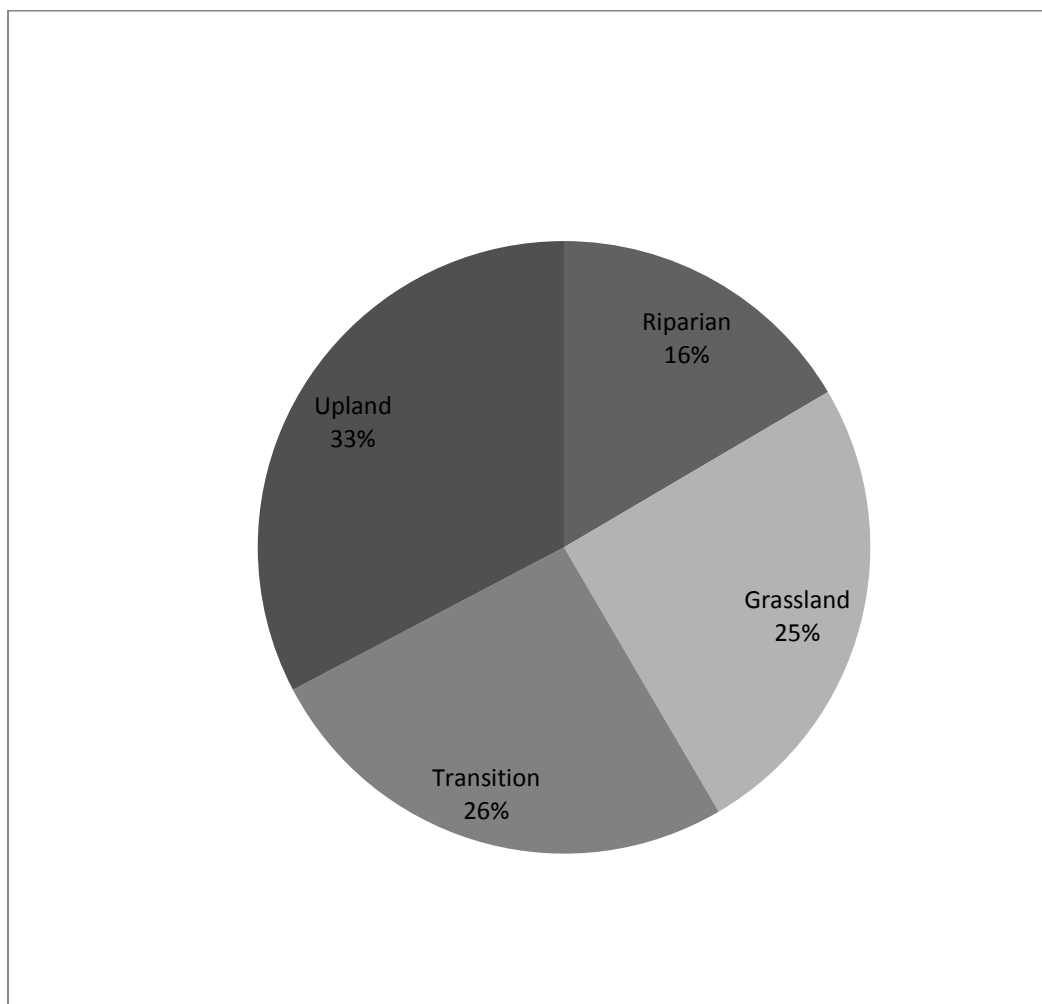


Fig. D: Relative abundance of all ant species in the vegetation zone they were captured in using pitfall trapping. All samples taken in Beaver River Wildlife Management Area in Beaver, Oklahoma. Samples collected over six sampling events during summers of 2012 and 2013(sampling events: 1:6/8/12, 2:6/29/12, 3: 7/24/12, 4:5/13/13, 5:6/10/13, 6:7/8/13).

APPENDIX E

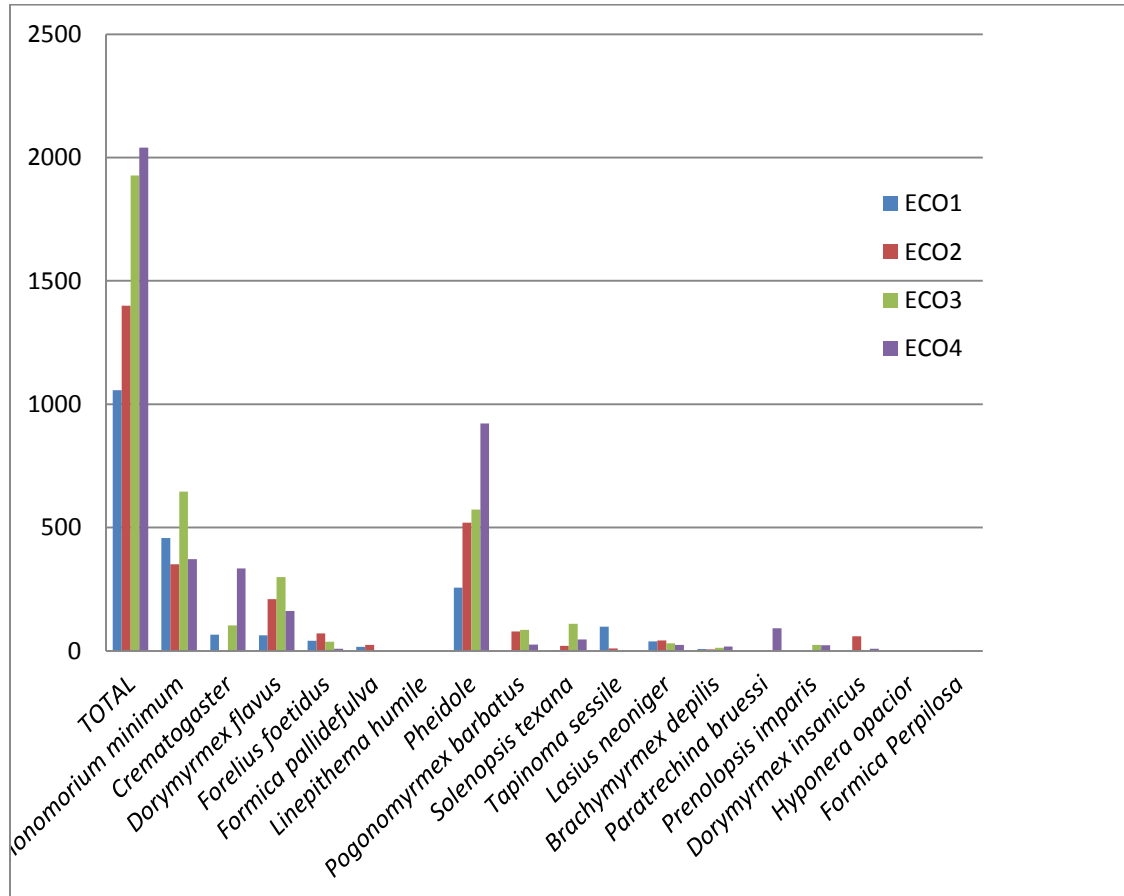


Fig. E: Ant abundance as captured in pitfall traps by vegetation type. All were captured along transects in Beaver, Oklahoma. ECO1 is a riparian zone, ECO2 is a grassland zone, ECO3 is a transitional zone and ECO4 is an upland sand dune zone. All data collected in Beaver River Wildlife Management Area and pooled from 6 sampling dates (1:6/8/12, 2:6/29/12, 3: 7/24/12, 4:5/13/13, 5:6/10/13, 6:7/8/13).

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