EFFECT OF FIRE AND HABITAT INTERACTION ON ARTHROPOD FORAGE FOR NORTHERN BOBWHITE BROODS

By

Anna Elizabeth Butler

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EFFECT OF FIRE AND HABITAT INTERACTION ON ARTHROPOD FORAGE FOR NORTHERN BOBWHITE BROODS

Thesis Approved:

Dr. Shawn M. Wilder

Thesis Adviser

Dr. Craig A. Davis

Dr. Samuel D. Fuhlendorf

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Abstract:

Arthropods are abundant and diverse animals that dominate many terrestrial food webs and provide important ecosystem functions. Northern bobwhite (Galliformes, *Colinus virginianus*) chicks and reproducing hens require high quantities of arthropods in their diet during early chick development and female egg production. In western Oklahoma, shinnery oak shrubs (*Quercus havardii*) have hybridized with post oak (*Quercus stellata*) to create dense thickets of tall, woody vegetation, known as mottes. A gap exists in the current knowledge as to whether there are arthropods within mottes suitable for bobwhite forage. In one overall sampling design, I compared arthropod abundance and biomass along a gradient from mottes into open shrubland areas of different years since burn. Arthropods were collected in pitfall traps at four sampling locations in relation to mottes; in the center of mottes, and three plot location in open shrublands; 1m, 15m, and 50m away from the edge of the motte. There were three treatment levels for burning: one-year post burn (burned in dormant months of 2017), two-years post burn (burned in dormant months of 2016), and unburned (burned in dormant season of 2014 and prior). There was a difference in total arthropod abundance between the center of the motte and the open shrubland, with center plots having fewer total arthropods. For time since burn, the sum of all individuals across the entire study did not show significant differences however, when analyzed separately some individual arthropod orders showed differences between burn treatments. The findings of this study suggest that both fire and mottes can independently facilitate heterogeneity in arthropod communities, but they do not appear to interact with one another. The results of this study support the importance of maintaining heterogeneous landscapes to increase arthropod prey diversity, abundance, and biomass. We now know that mottes are a multifunctional aspect within bobwhites' range and that they provide food resources as well as protection. Prescribed fire does not seem to negatively affect the arthropod prey for bobwhites, nor does it detrimentally affect the arthropods inside mottes.

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CHAPTER I

EFFECTS OF FIRE AND MOTTES ON ARTHROPOD COMMUNITIES

Introduction

Disturbance is common in many ecosystems and can promote habitat heterogeneity and diversity by creating patches of ecological communities with different characteristics or at different successional stages (White & Jentsch, 2001). Management of habitats for human interests have reduced the occurrence of certain disturbances, such as wildfire, and have resulted in homogenization of habitats, such as clearing patches of forest to create large agricultural fields (Nowacki & Abrams, 2008). Efforts to restore habitats often focus on reintroducing disturbances and habitat heterogeneity (Bowman et al., 2016). Although, further data are needed on how disturbances like fire affect community level interactions especially in communities with multiple habitat types.

Arthropods are abundant and diverse animals that dominate many terrestrial food webs and provide important ecosystem functions. They have important roles as decomposers that facilitate nutrient cycling, as herbivores that can alter vegetation structure and composition, as pollinators, and as food for larger animals such as vertebrates. Yet, recent work has found that 41% of insect species are in decline and about one third of all insect species are threatened (Sánchez-Bayo & Wyckhuys, 2019), highlighting the vulnerability of invertebrates to climate change and other anthropogenic impacts (Deutsch et al., 2008; Gillespie et al., 2019; Hallmann et al., 2017; Lister & Garcia, 2018). Furthermore, the average airborne insect biomass has declined by 76% in just 27 years (Hallmann et al., 2017). Estimates suggest that arthropod biodiversity is decreasing at an annual rate of 2.5% of insect biomass worldwide (Sánchez-Bayo & Wyckhuys, 2019). Thus, arthropod declines are alarming given their importance for food web and ecosystem function.

In addition to declines in arthropods, there are also threats facing prairie habitat types, including many areas within the Great Plains region. Natural ecosystems across the contiguous United States have been dramatically altered (Noss et al., 1995). Since European settlement, the native prairies of North America have become an endangered biome (Peterson & Boyd, 2000; Noss et al., 1995). Direct loss due to landscape conversion to agriculture and rangeland are the primary cause of prairie decline (Fuhlendorf et al., 2017). Prairie quality also suffers from fragmentation, invasion of non-native plants, as well as pressure from overgrazing and fire (Sampson & Knopf, 1994). This large-scale conversion of native prairie to an agriculture-dominated landscape has been detrimental to many of the species reliant on this habitat (Brennan & Kuvlesky, 2005). Efforts to restore native prairie are primarily aimed at re-establishing the native plant community and natural disturbances, such as fire (Panzer & Schwartz, 1998).

The prairie of western Oklahoma is composed of mixed grass habitats where short-grass prairie and shinnery shrub occur. In this area, shinnery oak shrubs (*Quercus havardii*) have hybridized with post oak (*Quercus stellata*) to create dense thickets of tall, woody vegetation, known as mottes (Peterson & Boyd, 2000). Mottes are unique in this landscape because they form small patches of trees dispersed within the shrublands, which contributes to heterogeneity in the habitat. The vegetation structure provided by mottes can also provide thermal refugia to allow many taxa to escape high temperatures experienced in the relatively open shrubland habitat (Rakowski et al. 2019). For example, arthropods utilize behavioral thermoregulation, particularly thermal avoidance, where organisms stay away from extreme temperatures by seeking cooler locations within their habitat (Li & Wang, 2005; Robertson et al., 1996). This has also been observed in higher trophic levels, for example, bobwhite quail showed a fine-scale selection for mottes during peak daily temperatures (Carroll et al., 2015; Hovick et al., 2014). Behavioral thermoregulation often involves quickly moving among different microhabitats to allow their bodies to reach optimal temperatures (Caillon et al., 2014). Thus, arthropods found in open shrublands might differ from those inside a motte due to biotic restrictions. Hence, mottes may add to habitat heterogeneity by providing different habitat types to support species that primarily live in forest and shrubland, and also by providing thermal refugia to allow species that live in shrublands to tolerate extreme heat.

To stimulate habitat diversity, prescribed fire is often used as a management tool in prairie ecosystems in the Great Plains where patchy, discrete disturbances were the prominent driver of habitat heterogeneity in the past (Fuhlendorf & Engle, 2004). Patch burning at different intervals can reduce the abundance of woody vegetation and help to maintain diverse landscapes and arthropod communities (Engle et al., 2008). Since, the abundance of invertebrates can be strongly influenced by the diversity and productivity of the vegetation in shrubland ecosystems (Hairston et al., 1960; Pimentel, 1961), prescribed fire encourages arthropod communities through alterations of vegetative structure. When used as a natural disturbance, fire results in more heterogeneous landscapes with higher biological diversity, specifically with increased invertebrate biomass (Brennan et al., 2000; Fuhlendorf & Engle, 2004; Fuhlendorf et al., 2006; Glitzenstein et al., 2012; Hurst, 1972). To the best of my knowledge, no studies have looked at how fire affects mottes relative to shrubland habitats. The presence of mottes may also influence arthropods in the surrounding landscape and how they respond to prescribed burning. Understanding best management practices for arthropods will help maintain the ecosystem functions and services provided by arthropods. For example, managing for arthropods is an integral part of maintaining higher trophic levels including game species, both as a direct food source and pollinators of food plants.

The goal of this study was to examine how habitat type and fire interacted to affect the abundance and biomass of arthropods. To achieve this, I examined arthropod communities across a gradient of two habitat types (i.e., from open shrub lands leading into mottes), across patches of shrubland that were burned at different intervals in the Central Great Plains of Oklahoma. I hypothesized that the abundance and biomass of arthropod communities located inside a motte would be different from that in open shrubland areas due to vegetative features of habitat patches, as well as varying arthropod ecological niche requirements. Specifically, I predicted that mottes would contain greater abundance of detritivorous taxa due to increased leaf litter, while open shrubland locations would have comparatively greater amounts of herbivorous arthropods resulting from more grasses and forbs available. I also hypothesized that time since fire would affect the abundance and biomass of arthropods. I predicted that habitats more recently burned would have greater arthropod abundance and biomass due to the increased vegetative diversity following a burn. Understanding how mottes affect a landscape is an important step in assessing arthropod communities and their response to management practices.

Methods

Study Site

This study was conducted at Packsaddle Wildlife Management Area (hereafter Packsaddle WMA) in Ellis County, Oklahoma. It is a 6,475-ha mixed shrubland habitat with elevations ranging from 579 to 762 meters above mean sea level (Townsend et al., 2001). Soils in Packsaddle WMA consist of sandy Nobscot, Delwin and Eda, moderately sandy Hardeman-Likes-Devol and Eda-Carwile, and loamy Quinlan (Cole et al., 1966; Townsend et al., 2001; USDA-NRCS Official Soil Series Descriptions, 2000). Dominant species of grasses include sand bluestem (*Andropogon hallii*), little bluestem (*Schizachyrium scoparium*), indiangrass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), sand paspalum (*Paspalum stramineum*), blue grama (*Bouteloua gracilis*), hairy grama (*B. hirsuta*), and sand dropseed (*Sporobolus cryptandrus*) (Cole et al., 1966; Townsend et al., 2001). Common forbs in Packsaddle WMA include western ragweed (*Ambrosia psilostachaya*), croton (*Croton sp.),* and prairie sunflower (*Helianthus petiolaris*) (Cole et al., 1966; Townsend et al., 2001). Dominant woody vegetation includes shinnery oak (*Quercus harvardii*), sand sage (*Artemisia filifolia*), and sand plum (*Prunus angustifolia*) (Cole et al., 1966; Townsend et al., 2001). Pure shinnery oak shrubs rarely exceed one meter in height while mottes primarily comprised of hybrid, shinnery-post oak are often identified as a distinct “thicket” of uncharacteristically tall, tree-like shinnery (Peterson & Boyd, 2000). Therefore, mottes were identified as clumps of oak with heights averaging 2 meters or greater.

The managers at Packsaddle WMA use prescribed burns as frequently as possible along with low to moderate levels of grazing by cattle. Many areas within Packsaddle WMA are grazed by cattle during the growing season where stocking rates vary by site and time (Boyd & Bidwell, 2001). Within the boundaries of Packsaddle WMA, several units are burned every 2-3 years, weather permitting. During this study period, managers attempted to burn regions that have not been burned in more than one year.

Sampling Design

In one overall sampling design, I compared arthropod abundance and biomass along a gradient from mottes into open shrubland areas of different years since burn. There were three treatment levels for burning: one-year post burn (burned in dormant months of 2017), two-years post burn (burned in dormant months of 2016), and unburned (burned in dormant season of 2014 and prior).

Within Packsaddle WMA, shinnery-post oak mottes were identified in areas of known burn years using Google Earth (©Google, 2018). Soil types for each motte were obtained using Ecological Site Descriptions from the Natural Resource Conservation Service web soil survey application (Natural Resource Conservation Service, Web Soil Survey, 2018) and mottes were chosen within similar soil types. Mottes were then selected and verified in person as hybrid shinnery-post oak with predominately shinnery oak surrounding. The total sample size included 16 mottes with burn treatment sizes as follows; six mottes in unburned areas, five mottes in areas 2-years since burn, and five mottes in areas 1-year since burn.

Within each burn treatment, individual mottes served as a central point around which data were collected. Mottes were the unit of replication when testing for effects of burn year, and plot was the unit of replication for testing the effects of habitat type. To compare mottes to open shrubland, two transects were laid from the center of the motte and extended outward into the surrounding landscape in random directions (Figure 1). One meter squared sampling plots were placed along each transect in 4 locations: one plot was placed at the center of the motte, and 3 plots were in open shrubland habitat; 1m, 15m, and 50m away from the outside edge of the motte. Therefore, eight sampling plots were placed at each motte location. For each motte, data from the corresponding plot locations were averaged, such that for each motte there was one data point each for the center, 1, 15, and 50m plot locations. This allowed us to observe whether mottes contained different arthropod orders relative to shrubland and whether mottes have an effect on arthropods in the surrounding landscape.

Center plots were placed within the dense, shaded canopy of the motte. I attempted to ensure that center plots were at least 2 meters from the edge; however, some mottes were too small to allow this much space. In every sampling location, all center plots were at least 2 meters away from the 1m "open shrubland" plot and at least 2 meters away from the other, corresponding center plot.

Vegetation Measurements

Vegetation data were collected twice during the summer of 2018; once during May and again in July. Vegetation sampling included basic identification of woody shrub canopy cover and percent ground cover composition at each plot location. A line intercept method was used to quantify the canopy composition of woody shrubs, using a 20m transect that crossed over each sampling plot, which measured the horizontal linear length of each shrub that intercepts the line. Percent ground cover was determined with the use of a Daubenmire frame (20cm x 50 cm microplot marked in 10% classes) (Daubenmire 1959). Daubenmire cover classes were recorded at three points along the vegetation transect, at each end and in the center of the study plot. Ground cover was described as a range of six cover classes including 0-5%, 5-25%, 25-50%, 50-75%, 75-95%, and 95-100%. Cover classes were described in groups as follows; grass, forb, bare ground, litter, and rock.

Arthropod Collection

Arthropod sampling involved the use of pitfall traps, which occurred once per month in May through August 2018. Study sites were selected, transects placed, and pitfalls installed in April 2018. This allowed approximately one month between pitfall installation and sampling to prevent soil disturbance from affecting arthropod collection.

Each sampling plot contained five pitfall traps: one pitfall trap was placed at each corner of a $1m^2$ plot and one pitfall trap was placed in the center of the $1m^2$ plot (Figure 1). Pitfall traps were 473ml round, plastic cups with a completely white interior, 13.3cm deep, with a 5.7cm bottom diameter, and a 7.6cm top diameter. Pitfall traps were charged with 4oz (118.3ml) of killing solution and left active for 48 hours. The killing solution was composed of odorless and colorless propylene glycol (Pure USP, Food Grade Propylene Glycol, Momentum Fulfillment) diluted with water to 10% concentration and a few drops of clear, odorless dish soap (Seventh Generation, Inc.). This level of fluid was sufficient to submerge arthropods while avoiding the potential to for the cup to overflow following rain or for arthropods to escape.

After 48 hours, all five cups at each $1m^2$ plot were consolidated into one sample per center, 1m, 15m, and 50m plot location for a total of 8 samples per plot. Samples were removed from the field and transferred into 70% ethanol the same day. Pitfall samples remained stored in ethanol until identified and counted in the lab. After collection each month, traps were covered with a lid and left closed until the next month's sampling.

After all pitfall trap collection was complete, samples were brought to the lab at Oklahoma State University. To determine abundance, the contents of each sample were emptied into a petri dish and using a dissecting microscope, arthropods were identified to order, assigned to size classes, and counted. Size classes for measuring arthropod body length included <2mm, 2.1mm-5mm, 5.1mm-10mm, 10.1mm-15mm, and >15mm. To determine biomass, a subsample of several different size classes of each order were removed from pitfall samples. These individuals were dried at 60□ for 24 hours, weighed, and averaged to represent a dry weight for each size class of each order. In circumstances where there were too few individuals to provide a sufficient sample size, values from regression equations were used to generate an estimate for average dry weight following Rogers et al. (1976). Biomass measures were estimated with equations for at least one size class of Lepidoptera, Collembola, Blattodea, Neuroptera, Isopoda, Myriapoda, Psocoptera, and Thysanoptera. Dry mass was then calculated by multiplying the average arthropod abundance for each plot by the average dry mass of each order.

In some circumstances, arthropods could not be identified with complete confidence, often as a result of individuals being too damaged. These were classified as "Other". Additionally, some orders were encountered relatively infrequently and therefore do not represent a significant component of the arthropod community. Orders with an average percent composition of 1.0% or less were combined into the "Other" category. For abundance measures, these orders were: Lepidoptera, Blattodea, Neuroptera, Isopoda, Psocoptera, Thysanoptera, and the subphylum Myriapoda. When calculating the average percent biomass, I followed the same criteria; any order representing 1.0% or less of the total biomass of arthropods collected was summed into the "Other" category. For biomass measures of pitfall traps, these orders were: Neuroptera, Acari, Isopoda, Psocoptera, Thysanoptera, and the subphylum Myriapoda.

Data Analysis

Since each motte had two transects, the data from corresponding plots in each transect were averaged such that there was only one value per plot location (center, 1, 15, or 50m) per motte. However, one or more cups from these samples were lost or compromised as a result of weather conditions, damage from wildlife and livestock, or human error. Specifically, a prescribed burn in late July 2018 impacted one control treatment motte; therefore, the month of August is missing all eight pitfall samples from this motte. Of the 504 total pitfall samples, eight samples did not have all five pitfall traps included. In these cases, the entire sample was removed from analyses. Therefore, there are 8 values for pitfall samples that do not represent the average of two corresponding plots, but only one of the plot locations for that transect (e.g., instead of averaging both 50 m plots at a motte, the compromised 50m sample was excluded and the other 50m sample was used).

The data were then square root transformed to reduce the effect of highly abundant taxa while considering lesser represented orders as well. A square root transformation was used because it is more conservative than log transformation. The square root transformed abundance and biomass data were visualized using a multivariate ordination procedure, nonmetric multidimensional scaling (NMDS). This analysis was done using Bray-Curtis distances in program R using the vegan package (R package version 2.4-5, Oskanen et al., 2017). Ordination figures allowed the evaluation of differences among plot locations and burn years in arthropod assemblage space. Plot location and burn year were individually analyzed as separate variables affecting arthropod abundance and biomass in NMDS. Tests for significance were then determined using a non-parametric multivariate statistical test, permutational multivariate analysis of variance (PERMANOVA) using PRIMER software (version 7, Anderson et al., 2008). To determine the percent dissimilarity seen in the NMDS and PERMANOVA results, I performed a SIMPER analysis using the PRIMER software (version 7, Anderson et al., 2008). The SIMPER analysis identifies which taxa of arthropods primarily contributed to the differences in community composition between treatments. For this analysis, only orders that contributed to the top 70% of the total dissimilarity were considered.

Individual arthropod orders were analyzed with mixed model nested ANOVAs using the software program JMP (version 14, SAS Institute, 2018). These ANOVAs included motte nested with burn treatment as a random effect to include proper degrees of freedom for testing the burn treatment effect. The ANOVA models included burn year, distance from motte, and time separately in all interactions. Orders analyzed with ANOVAs for arthropod abundance were the top five most abundant: Collembola, Coleoptera, Hymenoptera, Acari, and Diptera. The orders with the top five highest biomass were analyzed with ANOVAs, including Orthoptera, Coleoptera, Blattodea, Hymenoptera, and Araneae. All abundance and biomass (mg) data were log(x+1) transformed for the ANOVA analysis because log transformed data better approximated a normal distribution relative to other transformations. Vegetation data were analyzed using ANOVA across individual habitat measures to determine differences across sampling plots using JMP (version 14, SAS Institute, 2018). Tukey's HSD post-hoc pairwise comparisons were performed in JMP (version 14, SAS Institute, 2018). Given the many statistical analyses used, I set the alpha value for evaluating significance of p-values to 0.005 to reduce the chance of type 1 errors due to multiple analyses.

Results

Sampling of 504 pitfall traps at 16 mottes over 4 months yielded 206,477 arthropods (Table 1) weighing a total of 196g dry mass (Table 2). This dataset included 15 taxonomic groups of arthropods plus one group of "Other" that included all other orders that represented less than 1.0% composition.

Abundance

For abundance, Collembola were the most numerous arthropods collected, representing 50% of all individuals (Table 3). Hymenoptera were the next most abundant, representing 30% of the total community. All other arthropod orders represented 5% or less of the total abundance.

There were significant effects of burn year and distance from motte on arthropod community abundance, using data on all months combined and for the individual months (Table 4). For burn year, arthropod communities in 1-year burn plots appeared different from those in the control and 2-years since burn in NMDS plots, especially in all months combined and the months of May and July (Figure 2, Figure 3). For distance from motte, there was a clear gradient in arthropod communities between the center and 50m plot location for all months combined and for each individual month (Figure 2, Figure 4).

SMIPER analyses, similarity percentages, break down the contribution of each order to the observed dissimilarity between samples for the PERMANOVA analyses. SIMPER results (Table 5) show that Collembola contributed the most (30% - 45%) to the dissimilarity in abundance between cross comparisons of each burn treatment. Hymenoptera contributed between 17% - 21% of the dissimilarity in abundance across all burn years. Taxa affecting less than 11% of the dissimilarities in burn treatments observed include Diptera, Acari, and Other. Differences in community abundance between plot locations were most explained by Collembola (45% - 47%). Hymenoptera accounted for 13% - 22% of the differences across all distances from motte. The remaining orders, Diptera, Acari, and Coleoptera, contributed less than 14% to the dissimilarities in abundance between plot locations.

I then analyzed the five most abundant arthropod orders using ANOVA. There were significant effects of distance from motte and time on total abundance of arthropods, summed across all four months (Table 6, Figure 5). There were no burn year by distance from motte interactions for any of the arthropod taxa. For Collembola, there were significant effects of burn year, distance from motte and time on abundance. Collembola were most abundant in the 1-year since burn treatment plots relative to the other two burn treatments and they were least abundant in the center plot compared to the other distances from motte (Figure 6). For Hymenoptera, there were significant effects of distance from motte and the interaction of burn year and month sampled on abundance (Table 6). Hymenoptera were least abundant in the plots in the center of a motte relative to the other plot locations (Figure 7). For Coleoptera, there were significant effects of distance from motte and time on abundance (Table 6). Coleopterans were most abundant in the center plot relative to other plot locations (Figure 8). For Acari and Diptera, there were only significant effects of time on abundance (Table 6, Figure 9, and Figure 10).

Biomass

For biomass, Orthoptera had the highest total biomass of individuals at 39%, followed by Collembola (24%), and Hymenoptera (12%) (Table 3). All other taxa represented 10% or less of the total biomass.

There were significant effects of burn year and distance from motte on arthropod community biomass, using data on all months combined and in the month of May (Table 7). For June, July, and August, there were significant effects of burn year, but not distance from motte (Table 7). For burn year, arthropod biomass in the 1-year since burn treatment appeared different from those in the 2-years since and control burns for all months combined and for May in NMDS plots (Figure 11, Figure 12). However, patterns of differences in arthropod communities were less clear among burn year treatments for June, July, and August (Figure 12). For distance from motte, there was a clear gradient in arthropod communities between the center and 50m plot locations for all months combined and for each individual month in NMDS plots (Figure 11, Figure 13).

Analysis of dissimilarities with SIMPER showed that multiple taxa contributed to the dissimilarities between biomass in both burn year and distance from motte. Blattodea contributed the greatest percent dissimilarity in biomass in relation to burn treatments (15% - 28%) while Orthoptera accounted for 17% - 24% (Table 8). Coleoptera also influenced dissimilarities in biomass between burn treatments, however this effect was only 11% - 17%. Other orders affecting burn year biomass were Hymenoptera, Araneae, and Collembola, contributing less than 13%. When comparing differences between distances from motte, Orthoptera contributed the greatest percent dissimilarity for each comparison (20% - 25%) (Table 8). Coleoptera biomass accounted for 14% - 17% of the differences between plots. Hymenoptera, Blattodea, Collembola, Araneae, and Lepidoptera contributed less than 13% of dissimilarities in biomass observed among plot locations.

Similar to the analysis of abundance, I analyzed the five arthropod taxa with the highest biomass. For overall biomass and the biomasses of Orthoptera, Coleoptera, and Araneae, the only significant effect was time (Table 9, Figure 14, Figure 15, and Figure 16). For Hymenoptera, there were significant effects of distance from a motte and the interaction between burn year and time (Table 9). The center plot had the lowest biomass of Hymenopterans relative of the other three distances from motte (Figure 18). For Blattodea, there were significant effects of burn year and time (Table 9). The biomass of Blattodea in the 1-year since burn was lower than the other two burn treatments (Figure 19).

Vegetation

For vegetation composition, the six habitat measurements were combined into two principal components. Principal component 1 had relatively high loading for shrub cover, bare ground and litter (Table 10). Principal component 2 had relatively high loading for grass cover and forb cover. For both principal components one and two, there were significant effects of distance from motte on vegetation structure (Table 11). For both principal component axes, the center plot location was different from the vegetation structure relative to the other three distances from motte (Figure 20, Figure 21). When analyzing the individual habitat components, there were significant effects of burn year for the percent grass composition and the percent forb composition (Table 12). Forb cover in the 1-year since burn treatment was significantly different from control burn forb composition (Table 13) Grass cover in 1-year since burn was significantly different from 2-years since burn, but neither were different from the control treatment. There were significant effects of distance from motte on shrub cover, grass cover, bare ground, and litter (Table 12). Shrub cover was only significantly different between the 1m and 15 m plot locations (Table 13). There was a significant difference in grass cover, bare ground, and litter in the center plots compared to all three of the open shrubland plots. Grass cover was the only variable that showed a significant effect of time. (Table 12).

Discussion

I tested the interacting effects of prescribed burning and distance from a motte on the abundance and biomass of the arthropod community. I hypothesized that mottes would contain different assemblages of arthropod groups relative to the surrounding open shrubland due to different thermal and vegetative features. My results supported my first hypothesis. I observed a difference in total arthropod abundance between the center of the motte and open shrubland, with center plots having fewer total arthropods. I also hypothesized that more recently burned areas would have greater arthropod abundance and biomass relative to older burns. This hypothesis was not supported for the sum of all individuals across the entire study however, when analyzed separately some individual orders followed this trend. Hence, the findings of this study suggest that both fire and mottes can independently facilitate heterogeneity in arthropod communities, but they do not appear to interact with one another.

Results of ordination analyses show a distinct gradient in arthropod communities across plot locations indicating that mottes have an impact on the surrounding landscape extending outwards. This would suggest that these are not just two distinct habitats for arthropods, but that there is a gradient along which mottes and shrublands interact. The analysis of Hymenoptera biomass supports these findings, where center plots had the lowest Hymenoptera biomass, which gradually increased moving outwards toward the 50m plots that had the greatest Hymenoptera biomass. This finding is supported by other research, for example, Blaum et al. (2009) found that invertebrates showed clear changes in species composition along a gradient of shrub cover density where the total arthropod abundance was lower in shrub-dominated habitat. Similarly, a study looking at habitat gradients observed that ant numbers were lowest in forest habitats in a landscape where the vegetation transitioned from grass-dominated to shrub-dominated to forest (Ferguson, 2001). Not all individual arthropod taxa showed the same pattern and some arthropods showed distinct differences in abundance inside versus outside of the motte. However, the NMDS suggests that the community, as a whole, shifts across the distances away from the motte. Hence, while mottes themselves can be relatively small features (11m - 42m diameter), their effects can extend outward into the shrubland and contribute to heterogeneity across the landscape. Future research should consider studying the interaction of mottes and surrounding habitats at finer scales to determine what arthropods are near the immediate edge of a motte and how far the effects of mottes extend into the shrubland.

One potential explanation for a gradient in arthropod communities with increasing distance from a motte is that some arthropods from the shrubland are using mottes as thermal refuge at certain times of day. Mottes are known to be important for thermoregulation of some vertebrates in shrublands, including bobwhite quail (Carroll et al., 2015; Guthery, 2000; Rakowski et al., 2019; Robinson, 1957). Arthropods, too, engage in behavioral thermoregulation including seeking shaded habitats, reducing activity, and digging in the ground. Less is known about whether arthropods would actively seek a different habitat patch for thermoregulation. For example, cicada killers (*Sphecius speciosus,* Hymenoptera) avoided bare ground during the heat of the day and were more abundant in areas with cooler ambient temperatures (Coelho, 2001).

Assuming some arthropod groups in Packsaddle WMA exhibit behavioral thermoregulation, I might expect them to stay within the motte or close enough to easily access temperatures that are relatively moderate. Arthropods may also be using mottes as a refuge from desiccation as the abundant leaf litter that accumulates in mottes may better retain humidity at the soil surface. Under this assumption, I would expect to see a gradient extending from a motte, such that arthropod groups less reliant on mottes occur further away and more shade-dependent taxa increasing in abundance closer to the motte's edge. Future work could test these potential explanations by sampling arthropods at different times of day at different distances from a motte to see if certain arthropod groups are more abundant inside of a motte during the hottest part of the day relative to cooler times of day.

Vegetation is an important factor that varies between mottes and shrubland and could be affecting the distribution of arthropods. A study by Wardhaugh et al. (2012), determined that the distribution of different beetle feeding guilds was not random, but highly correlated with preferred food resources. Ferguson (2001) found that neither predator nor detritivore arthropod abundances were directly correlated with feeding strategy because they were both increasing along a gradient of vegetative productivity. Given the landscape scale of my study and the large numbers of arthropods collected, identifying arthropod groups to order was too coarse to allow me to test if particular groups were more prevalent in certain areas. Within the Order classification, individual species are very diverse and therefore their diets and habitat requirements would be highly variable. A previous study in Australia also determined that identifying to order level may have failed to accurately detect fire effects or that results were primarily influenced by the most abundant taxa (Teasdale et al., 2013). Hence, more detailed study of the arthropod communities would be needed to test if the functional or feeding groups of arthropods differ between mottes and shrubland.

There was a significant difference in the community by burn year where much of this difference was driven by Collembola. I observed a greater arthropod abundance in 1-year since burn plots relative to the 2-years since burn and control burns later in the season. Collembola were consistently more abundant in 1-year since burn treatments in each of the four sampling periods. This is similar to other studies of microarthropod recovery that found that Collembola populations recovered in total abundance, after one year, to near pre-burn levels (Malmström et al., 2008). Groups of arthropods respond differently to fire depending on their life history traits including mobility, life stage, and feeding guild. A literature review of arthropod responses to fire suggests that arthropod communities do not simply respond negatively to fire, but that there is variation in communities on a species-by-species basis (Kral et al., 2017). Another study found that time since fire did not influence the overall species richness or diversity of arthropods, but when individual taxa were analyzed separately, the abundance varied greatly (Yekwayo et al., 2018). For example, a similar study in a longleaf pine ecosystem found that the orders Coleoptera and Hymenoptera did not show significant effects of time since fire, while Araneae and Orthoptera showed significant effects, where biomass of these two orders increased with time (Chitwood et al., 2017). Whereas, a study of post-fire effects in north-central Texas found that there was no effect of prescribed fire on dung beetle assemblages (Smith et al., 2019).

The intensity and severity of a prescribed burn will differentially impact arthropod taxa in an ecosystem. If a fire is relatively low intensity, litter dwelling arthropods are less likely to experience direct mortality, as the litter does not always combust completely, leaving some moisture and refuge in deeper litter while the top is only charred (Neary et al., 2005). For example, previous research on disturbance ecology found that arthropod abundance response to disturbance differed based on functional guilds (Kwon et al., 2013). Furthermore, they saw that as fire intensity increased the abundance of detritivores decreased, but the abundance of herbivores increased (Kwon et al., 2013). It is possible that prescribed burns in Packsaddle WMA have a relatively low fire intensity, which may allow the vegetation to recover quickly and may have limited the effect of burning on arthropod community composition.

It is necessary to maintain habitats that promote arthropod communities because of the important ecological roles they fulfill including decomposition, nutrient cycling, pollination, pest control, and serving as a major food source for higher tropic levels. Encouraging heterogeneous landscapes provides diverse vegetative characteristics and microhabitats that various arthropod taxa can utilize. I found that mottes have an effect on arthropods in the surrounding environment and are therefore important for supporting arthropod communities. Prescribe fire is a useful management tool that also contributes to variations in habitat structure and arthropod communities over space and time.

CHAPTER II

THE EFFECTS OF HABITAT TYPE AND PRESCRIBED FIRE ON POTENTIAL ARTHROPOD PREY FOR NORTHERN BOBWHITE

Introduction

In recent decades, Northern Bobwhite quail (Galliformes, *Colinus virginianus*) has experienced a decrease in population numbers. Their population was first recorded declining in the 1920s and has since continued to diminish (Brennan, 1991; Errington & Hamerstrom, 1936; Hernández et al., 2013; Stoddard, 1931). Although the rate of decline has reduced in recent years, bobwhite populations have not recovered as of 2014 according to the North American Breeding Bird Survey (Sauer et al., 2017). Populations have been decreasing the fastest in portions of the southern U.S., which have historically been known for high quality quail habitat and healthy bobwhite populations (Brennan, 1991; Rosene, 1969). The reduction in bobwhite numbers is largely attributed to habitat fragmentation and changes in land use practices in recent decades. There is also evidence that the increased use of pesticides and insecticides, intense grazing pressure, parasites, and invasive fire ants have a negative effect on bobwhite populations (Allen et al., 1995; Moore et al., 1988; Murray, 1958; Rosene, 1958; Rosene et al., 1962; Stoddard, 1931; Stoddard & Komarek, 1941). Clearly, there are a variety of factors that influence quail survival and biologists have been working to identify and resolve the potential sources of their decline. This has led to an urgent need to understand how quail are using their habitats and to identify management techniques that can encourage bobwhite population recovery.

In remaining quail habitats, management techniques are used to increase habitat quality. Prescribed fire can be used to manage shrubland habitats by stimulating forb growth, reducing woody biomass, and providing adequate bare ground (Harper, 2007). Fires improve habitat for bobwhite by encouraging germination of forbs that provide seeds for food and removing dense ground vegetation to facilitate movement and increase foraging (Buckner & Landers, 1979). When used as a natural disturbance, patch burning results in more heterogeneous landscapes with higher biological diversity (Fuhlendorf & Engle, 2004; Fuhlendorf et al., 2006) and promotes invertebrate biomass (Brennan et al., 2000; Guthery, 2000; Hurst, 1972). Maintaining diverse "patchwork mosaic" habitats promotes arthropod abundance and diversity, a primary food resource for bobwhite chicks and nesting females (Coppedge et al., 2008; Fuhlendorf & Engle, 2004). Habitats ideal for bobwhite brood foraging consist of open vegetation with bare ground for ease of movement, light litter which provides food resources and moisture, and access to nearby protective cover (Davis, 1964; Hiller et al., 2007; Richardson, 2006; Stoddard, 1931). It is important to understand how habitat management techniques affect arthropods because this will impact how management affects bobwhite populations.

In western Oklahoma, the prairie is composed of mixed grass habitats where mixed-grass prairie and shinnery shrub interact. In this area, shinnery oak shrubs (*Quercus havardii*) have hybridized with post oak (*Quercus stellata*) to create dense thickets of tall, woody vegetation, known as mottes (Peterson & Boyd, 2000). Mottes are unique in this landscape because they form small patches that are interspersed within open shrublands. These habitat patches provide variations in an otherwise relatively monotypic environment. Bobwhites use mottes for thermal refuge during periods of extreme heat, while open shrubland habitat is used for foraging (Carroll et al., 2015). Taller vegetation types, such as mottes, can have temperatures as much as 8.95°C cooler than the surrounding habitat (Johnson & Guthery, 1988; Rakowski et al., 2019). As a form of behavioral thermoregulation, bobwhites retreat to loaf in shaded locations during periods of extreme heat then return to open shrublands to forage (Carroll et al., 2015; Robinson, 1957). Mottes are especially important for chicks and juveniles, which are susceptible to overheating due to their small body size (Guthery, 2000). By increasing the heterogeneity of vegetation patches across a landscape, this increases the options for varying thermal conditions (Rakowski et al., 2019) thereby increasing the amount of useable habitat for bobwhites.

The diet of a Northern Bobwhite in western Oklahoma is an opportunistic mix, which consists primarily of forbs, nuts, seeds, and arthropods (Brennan, 1999). Bobwhites forage by scratching the ground and leaf litter, consuming what is seasonally available. In addition to plant-based foods, bobwhite rely on the arthropods as an important food source during the breeding season (Harveson et al., 2004). When insects are present, they are a preferred source of food for reproducing hens and juvenile quail. Reproducing hens have higher nutritional demands than other adults do because egg production requires protein, calcium, and phosphorus and insects help meet these needs (Hernández & Peterson, 2007). Insect foods typically dominate 94.1% of the diet for bobwhite chicks in the first two weeks after hatch and are crucial for chick development

(Butler et al., 2004; Doxon & Carroll, 2010; Eubanks & Dimmick, 1974; Harveson et al., 2004; Nestler et al., 1942). They are abundant sources of amino acids (Guthery, 2000) which bobwhite chicks need primarily for the development of feathers and flight muscles (Wenninger & Inouye, 2008). After approximately six weeks, bobwhite chicks begin feeding on seasonally available seeds and berries in addition to insects (Hurst, 1972).

The majority of arthropod species that bobwhites consume include: orders Araneae, Hemiptera, Hymenoptera, Lepidoptera, Orthoptera, and Coleoptera (Butler et al., 2004; Doxon & Carroll, 2010; Palmer et al., 2001). These groups will vary in where they are located within a habitat patch as a result of individual niche requirements since arthropod diversity is directly linked to plant community composition (Eisenhauer et al., 2010). Therefore, it is crucial to understand where various arthropods are present and whether developing quail have access to ample, high quality insect foods.

Although it is evident that mottes in western Oklahoma serve the important function of thermal refugia and protection from predators (Guthery et al., 2005), very little is known as to whether mottes could fulfill other needs for a bobwhite broods, specifically forage. The current consensus is that foraging primarily occurs in open areas (Brennan, 1999; Guthery, 2000). Hence, the assumption is that broods loafing in mottes are solely resting in a shaded environment. Under these circumstances, it follows that bobwhites are making a tradeoff between open areas where they forage and the thermal protection provided by mottes. However, a gap exists in the current knowledge as to whether there are arthropods within mottes suitable for bobwhite forage.

Mottes could increase arthropod availability and diversity because they increase plant diversity in a landscape. Since, the abundance of invertebrates can be strongly influenced by the diversity and productivity of the vegetation in shrubland ecosystems (Hairston et al., 1960; Pimentel, 1961), mottes could encourage arthropod communities by providing variations in vegetative structure. However, the spatial scale over which mottes affect arthropods remains unclear. In addition, mottes could influence the arthropod communities in the shrubland surrounding mottes if they support species that prefer a combination of forest and shrubland habitat or if mottes provide thermal refugia to arthropods, as they do for quail. If suitable arthropods inhabit mottes, bobwhite broods could maximize their time and energy by feeding in the shade during temperature extremes. Conversely, since fire removes leaf litter and woody vegetation, which are abundant in mottes, this alters the habitats utilized by arthropods and may differentially change arthropod communities available as bobwhite prey in mottes relative to open shrubland habitat. Thus, it is important to examine the interaction of mottes and fire and how the arthropod community responds. For this reason, understanding whether there are arthropods suitable for chick consumption within a motte across burn treatments will help illuminate if prescribed burning differentially affects arthropod prey abundance in mottes and shrubland habitat for bobwhites.

The broad goal of this study was to examine how habitat type (motte vs. open shrubland) and fire interacted to affect the abundance and biomass of arthropod prey for bobwhite chicks and adults. To achieve this, I examined arthropod communities between mottes and open shrubland habitat during the bobwhite nesting and brood rearing periods. In addition, I tested how time since burning affected the abundance and biomass of arthropods available for juvenile quail in mottes relative to open shrubland. I hypothesized that the arthropod community found inside a motte would be different from that in open areas due to the differences in habitat and vegetation features. I also predicted that potential prey for bobwhite chicks would have lower abundance and biomass inside mottes relative to open shrubland habitats. Further, I predicted that more recently burned areas would result in greater potential arthropods suitable for foraging bobwhite chicks.

Methods

Study Site

This study took place at Packsaddle Wildlife Management Area (hereafter Packsaddle WMA) in Ellis County, Oklahoma. It is a 6,475-ha mixed prairie habitat with elevations ranging from 579 to 762 above mean sea level (Townsend et al., 2001). This region in western Oklahoma, relative to much of the U.S, has historically been considered ideal quail habitat (Bidwell et al., 2013). Soils in Packsaddle WMA consist of sandy Nobscot, Delwin and Eda, moderately sandy Hardeman-Likes-Devol and Eda-Carwile, and loamy Quinlan (Cole et al., 1966; Townsend et al., 2001; USDA-NRCS Official Soil Series Descriptions, 2000). Dominant species of grasses include sand bluestem (*Andropogon hallii*), little bluestem (*Schizachyrium scoparium*), indiangrass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), sand paspalum (*Paspalum stramineum*), blue grama (*Bouteloua gracilis*), hairy grama (*B. hirsuta*), and sand dropseed (*Sporobolus cryptandrus*) (Cole et al., 1966; Townsend et al., 2001). Common forbs in Packsaddle WMA include western ragweed (*Ambrosia psilostachaya*), croton (*Croton sp.*), and prairie sunflower (*Helianthus petiolaris*) (Cole et al., 1966; Townsend et al., 2001). Dominant woody vegetation includes shinnery oak (*Quercus harvardii*), sand sage (*Artemisia filifolia*), and sand plum (*Prunus angustifolia*) (Cole et al., 1966; Townsend et al., 2001). Pure shinnery oak shrubs rarely exceed one meter in height while mottes primarily comprised of hybrid, shinnery-post oak are often identified as a distinct “thicket” of uncharacteristically tall, tree-like shinnery (Peterson & Boyd, 2000). Therefore, mottes were identified from the predominant shrubs as clumps of oak with heights averaging 2 meters or greater.

The managers at Packsaddle WMA use prescribed burns as frequently as possible to increase habitat heterogeneity. Many areas within Packsaddle WMA are also grazed by cattle during the growing season where stocking rates vary by site and time (Boyd & Bidwell, 2001). Within the boundaries of Packsaddle WMA, several units are burned every 2-3 years, weather permitting. During this study period, managers attempted to burn regions that have not been burned in more than one year.

Sampling Design

In one overall sampling design, I compared arthropod abundance and biomass across a gradient from mottes into open shrubland habitats of different years since burns. There were three treatment levels for burning: 1-year post burn (burned in dormant months of 2017), 2-years post burn (burned in dormant months of 2016), and unburned (burned in dormant season of 2014 and older).

Within Packsaddle WMA, shinnery-post oak mottes were identified in areas of known burn years using Google Earth (©Google, 2018). Soil types for each motte were obtained using Ecological Site Descriptions from the Natural Resource Conservation

Service web soil survey application (Natural Resource Conservation Service, Web Soil Survey) and mottes were chosen within similar soil types. Mottes were then selected and verified in person as hybrid shinnery-post oak with predominately shinnery oak surrounding. The total sample size included 16 mottes with burn treatment sizes as follows; 6 mottes in unburned areas, 5 mottes in areas 2-years since burn, and 5 mottes in areas 1-year since burn.

Within each burn treatment, individual mottes served as a central point around which data were collected. Mottes were the unit of replication when testing for effects of burn year, and plot location was the unit of replication for testing the effects of habitat type. To compare mottes to open shrubland areas, 2 transects were laid from the center of the motte and extended outward into the surrounding landscape in random directions (Figure 1). One meter squared sampling plots were placed along each transect in 4 locations: one plot was placed at the center of the motte, and 3 plots were in open habitat; 1m, 15m, and 50m away from the outside edge of the motte. Therefore, eight sampling plots were placed at each motte location. For the final dataset, data from the corresponding plot locations (e.g., both 50m plots from each transect) were averaged, such that there was only one data point each for the center, 1m, 15m, and 50m plot locations for each motte. This allowed us to observe whether mottes have an effect on arthropods in the surrounding landscape as well as the distribution of commonly consumed arthropod groups.

Center plots were placed within the dense, shaded canopy. I attempted to ensure that center plots were at least 2 meters from the edge; however, some mottes were too small to allow this much space. In every sampling location, all center plots were at least 2 meters away from the 1m “open shrubland” plot and at least 2 meters away from the other, corresponding center plot.

Vegetation Measurements

Vegetation data were collected twice during the summer of 2018; once during sampling in May and again in July. Habitat analysis included quantifying the horizontal components of the vegetative structure and cover at 12 height segments via a vegetative profile board (Nudds 1977). The Nudds board was adjusted for use in a predominantly sand shinnery community via methods described by Guthery et al. 1981. Horizontal vegetation structure was estimated twice for each plot in random directions.

Arthropod Collection

Arthropods were collected at each sampling location once a month from May through August (4 sampling periods) during the spring and summer of 2018. In western Oklahoma, bobwhite females typically lay eggs in late March and into early May. After all of the eggs are laid, the incubation period begins and will last between 22-24 days. Therefore, the first data collection occurred in the second half of May with the goal of seeing arthropods available for early broods hatching, hens that are incubating, and potential late nesting hens. In this region, the large majority of hatches should be completed by mid-July. Since insects are a vital food source for chicks in the first six weeks of life, any late-nesting hens or hens with failed initial nests could still potentially be brooding into the end of August.

Each site was sampled once a month for four months using pitfall traps (504 total pitfalls). Each sampling plot contained 5 pitfall traps: one pitfall trap was placed at each corner of a $1m^2$ plot and one pitfall trap was placed in the center of the $1m^2$ plot (Figure 1). Pitfall traps were 473ml round, plastic cups with a completely white interior, 13.3cm deep, with a 5.7cm bottom diameter, and a 7.6cm top diameter (WebstaurantStore.com). Pitfall traps were charged with killing solution and left active for 48 hours. The killing solution was composed of odorless and colorless propylene glycol (Pure USP, Food Grade Propylene Glycol, Momentum Fulfillment) diluted with water to 10% concentration and a few drops of clear, odorless dish soap (Seventh Generation, Inc.). Each pitfall trap was charged with 4 ounces (118.3ml) of killing solution. This level of fluid was sufficient to submerge arthropods while avoiding the potential to overflow following rain or for arthropods to escape.

After 48 hours, all five cups from each $1m^2$ plot were consolidated into one sample per canter, 1, 15, and 50m plot location for a total of eight samples per motte. Samples were removed from the field and transferred into 70% ethanol the same evening. Pitfall samples remained stored in ethanol until identified and measured in the lab. After collection each month, traps were covered with a lid and left closed until the next month's sampling.

Managers at Packsaddle WMA conducted a prescribed burn in late July, 2018 that affected one of my study mottes; therefore, the month of August is missing all pitfall samples for one control treatment motte. Of the 504 pitfall samples, eight samples did not have all five pitfall traps included. One or more cups from these samples were lost or compromised as a result of weather conditions, damage from wildlife and livestock, or human error. In these cases, the entire sample was removed from analyses. Therefore, there are 8 values for pitfall samples that do not represent the average of two corresponding plots, but only one of the plot locations for that transect (e.g., instead of averaging both 50 m plots at a motte, one was excluded and the other sample was used).

After all pitfall trap collection was complete, samples were brought to the lab at Oklahoma State University. The contents of each sample was emptied into a petri dish demarcated with a grid of $2mm^2$ squares. Using a dissecting microscope, arthropods were identified to order, counted, and measured by length into size classes. Size classes consisted of <2mm, 2.1mm-5mm, 5.1mm-10mm, 10.1mm-15mm, and >15mm following the methods from previous studies on bobwhite chicks (Foye et al., 2015).

To determine biomass, a subsample of each order, functional group, and respective size classes were removed from pitfall samples. These individuals were dried at 60°C for 24 hours, weighed, and averaged to represent a dry weight for each group. In circumstances where there were too few individuals to provide a sufficient sample size, values from regression equations were used to generate an estimate for average dry weight following Rogers et al. (1976). Biomass measures were estimated with equations for at least one size class of Lepidoptera, Collembola, Blattodea, Neuroptera, Isopoda, Myriapoda, Psocoptera, and Thysanoptera.

Data Analyses

Previous studies that performed crop analyses on bobwhite chicks and adults found that the arthropod orders most commonly consumed include Orthoptera, Coleoptera, Hemiptera, Araneae, Hymenoptera, and Lepidoptera (Butler et al., 2012;

Doxon & Carroll, 2010; Eubanks & Dimmick, 1974). Therefore, these six orders were the focus for these analyses. I also limited my study focus to specific functional groups that are relevant to bobwhite broods. Within the order Lepidoptera, both adults and the larvae were used to represent potential bobwhite foods. However, I did not include Lepidoptera larvae that had large quantities of urticating hairs, under the assumption that chicks would be sensitive to and therefore avoid these individuals. Hymenoptera was divided into two functional groups; Hymenopterans without wings and flying individuals. The arthropods found in the flightless category were primarily represented by ants and included flightless Mutillidae, commonly called “velvet ants”. All Hemipterans were identified into a single category and therefore representatives in this order include flightless individuals, such as Aphidoidea “aphids” and immature Cicadellidae “leaf hoppers”, as well as individuals with wings, including (but not limited to) adult Cicadellidae “leaf hoppers”, Pentatomidae “shield bugs”, and Reduviidae “assassin bugs”. The order Coleoptera was divided into adults and larvae; these were analyzed separately due to potential spatial differences in distribution based on varying habitat requirements.

Within the arthropod size classes measured, I narrowed my focus into two groups to differentiate between prey suitable for consumption by chicks versus adults. Data analyzed for chick forage were in the size classes 2.1-5mm and 5.1-10mm, which were summed. Arthropods measuring 2.1-5.0mm were considered the optimal size for chicks due to their small body size and small beak gape, but slightly larger arthropods can be consumed, especially by later stage chicks (Campbell-Kissock et al., 1985). Adult analyses were conducted using the arthropods 5.1-10mm and 10.1-15mm, which were summed. Arthropods measuring 5.1-10mm were considered optimal for adults, but they can also consume slightly larger prey (Foye et al., 2015).

Since each motte had two transects, the data from corresponding plots in each transect were averaged such that there was only one value per plot location (center, 1, 15, or 50m) per motte. However, one or more cups from these samples were lost or compromised as a result of weather conditions, damage from wildlife and livestock, or human error. Specifically, a prescribed burn in late July 2018 impacted one control treatment motte; therefore, the month of August is missing all eight pitfall samples from this motte. Of the 504 total pitfall samples, eight samples did not have all five pitfall traps included. In these cases, the entire sample was removed from analyses. Therefore, there are 8 values for pitfall samples that do not represent the average of two corresponding plots, but only one of the plot locations for that transect (e.g., instead of averaging both 50 m plots at a motte, the compromised 50m sample was excluded and the other 50m sample was used).

The data were then square root transformed to reduce the effect of highly abundant taxa while considering lesser represented orders as well. A square root transformation was used because it is more conservative than a log transformation. The square root transformed abundance data and biomass were visualized separately using a multivariate ordination procedure, nonmetric multidimensional scaling (NMDS). This analysis was done using Bray-Curtis distances in the program R using the vegan package (R package version 2.4-5, Oskanen et al., 2017). Ordination figures allowed for the evaluation of differences among plot locations, based on the separation or overlap among plots and burn years in arthropod assemblage space. Plot location and burn year were individually analyzed as separate variables affecting arthropod abundance and biomass in NMDS. Tests for significance were then determined using a non-parametric multivariate statistical test, permutational multivariate analysis of variance (PERMANOVA) using PRIMER software (version 7, Anderson et al., 2008). To determine the percent dissimilarity seen in the NMDS and PERMANOVA results, I performed a SIMPER analysis using the PRIMER software (version 7, Anderson et al., 2008). The SIMPER analysis identifies which taxa of arthropods primarily contributed to the differences in community composition between treatments. For this analysis, only the orders that contributed to the top 70% of the total dissimilarity were considered.

Individual arthropod orders were analyzed with separate mixed model, nested ANOVAs using the software program JMP (version 14, SAS Institute, 2018). These ANOVAs included motte nested within burn treatment as a random effect to include proper degrees of freedom for testing the burn treatment effect. The ANOVA models included burn year, distance from motte and time separately and in all interactions. The abundance and biomass (mg) data were log(x+1) transformed for the ANOVA analysis because log transformed data better approximated a normal distribution relative to other transformations. Only the taxa that comprised greater than 5% of the overall composition were analyzed with an ANOVA. Taxa analyzed for chicks for both abundance and biomass included Ants (Hymenoptera), Adult Coleoptera, and Araneae. Taxa analyzed for adults were as follows: Abundance included Adult Coleoptera, Ants (Hymenoptera), Flying Hymenoptera, Orthoptera, and Araneae; biomass included Adult Coleoptera, Ants (Hymenoptera), Orthoptera, and Araneae.

The 12 heights of vegetation data were combined into 2 principal components axes and these 2 axes were then analyzed using mixed model, nested ANOVA.

I set the alpha value for evaluating significance of p-values at 0.005 to reduce the chance of type 1 errors due to multiple analyses.

Results

Sampling of 504 pitfall traps at 16 mottes over 4 months yielded 68,081 arthropods weighing a total of 74g dry mass (Table 14, Table 15, Table 16, Table 17). This dataset, for both abundance and biomass, included 15 taxonomic groups plus one group of "Other" that included all other arthropods that represented less than 1.0% composition.

Abundance

For the potential prey of bobwhite chicks, the most abundant group was ants, which represented 75% of all individuals (Table 18). Adult Coleopterans were the next most abundant, representing 11%. All other arthropod groups represented 6% or less of the total abundance of potential chick prey. For adults, the most abundant group of potential prey was adult Coleoptera representing 42% of all individuals. The next most abundant groups were ants (22%), Orthoptera (13%), and Araneae (10%). All other arthropod groups represented 7% or less of the total abundance for potential adult prey.

For abundance of prey for both chicks and adults, there were significant effects of burn year and distance from motte using data on all months combined and for each individual month (Table 19, Table 20, and Figure 22). The only exception was that distance from motte was not significant for the prey of adults in August (Table 20). For burn year, despite significant PERMANOVA effects, there was no clear pattern of differences in community structure among the three burn treatments in NMDS for the prey of chicks and adults (Table 19, Table 20, Figure 23, and Figure 24). For distance from motte, there was a clear gradient in arthropod communities between the center and 50m plot locations for all months combined and each individual month (Figure 22, Figure 25, and Figure 26).

SMIPER analyses, similarity percentages, break down the contribution of each order to the observed dissimilarity between treatment groups. SIMPER results of chick prey show that ants contributed the most (40% - 53%) to the dissimilarity between the three burn treatments (Table 21). Adult Coleopterans contributed 9%-14% to the dissimilarity in arthropod abundance for chicks between burn years. Hemiptera, flying Hymenoptera, and Orthoptera each contributed less than 12% to differences in abundance across burn years. Dissimilarities in chick prey among distance from motte were most explained by ants, with contributions ranging from 39% to 52%. Adult Coleopterans contributed 12% - 14% across all plot locations. The remaining orders, Hemiptera, flying Hymenoptera, and Araneae, contributed less than 13% to differences in chick prey abundances between all distances from motte.

Abundance of adult prey showed similar results such that ants explained the greatest portion of dissimilarities across burn treatments (22% - 31%), while adult Coleoptera contributed 16% - 19% to dissimilarities between burn treatments (Table 22). Orthoptera contributed 17% - 14% between burn treatments. Flying Hymenoptera, Orthoptera, Araneae, and Hemiptera all contributed less than 14% to dissimilarities between the remaining burn year comparisons for adult prey abundance. For dissimilarities in prey abundance between plot locations, ants contributed the most (22% - 34%). The next biggest contributors were adult Coleopterans (16% - 24%) and flying Hymenoptera (10% - 15%). Orthoptera and Hemiptera contributed less than 12% to the dissimilarities of abundance between distances from motte for the potential prey of adult bobwhites.

ANOVA tested the effects of burn year, distance from motte, and time on the orders that comprised over 5% of the total arthropod abundance for chicks (ants, adult Coleopteran, Araneae) and adult bobwhites (Adult Coleoptera, ants, Orthoptera, Araneae, flying Hymenoptera) (Table 18). For total abundance of arthropod prey for chicks, there were significant effects of distance from motte and time (Table 23). Across all months, total abundance for chicks in center plots was less than the other three plots outside of the motte (Figure 27). For ant abundance for chick prey, there were significant effects of distance from motte and the interaction of burn year and time (Table 23). Ants were least abundant in the center plot relative to the other three plots outside of the motte across all four months (Figure 28). There were significant effects of distance from motte and time on adult Coleoptera for chicks (Table 23). Center plots had greater adult Coleopteran abundance than open shrubland plots in each individual month (Figure 29). For Araneae, the only significant effect was time (Table 23, Figure 30).

For adult prey total abundance, the only significant effect was time (Table 24, Figure 31). For the individual prey taxa, there was a significant effect of burn year on ants (Table 24). Ants had higher abundance in the one-year burn treatment for May and June compared to the other two burn treatments (Figure 32). For adult Coleoptera and

Araneae, the only significant effect was time (Table 24, Figure 33, and Figure 34), while Orthoptera and flying Hymenoptera had no significant effects for burn year or distance from motte for adult prey (Table 24, Figure 35, and Figure 36).

Biomass

For biomass of prey for chicks, there were significant effects of burn year and distance from motte using data on all months combined and for May and June (Table 25). Chick biomass in July was only affected by distance from motte, while in August it was only affected by burn year. For adults, there were significant effects for burn year and distance from motte in all months summed (Table 26). In June, July, and August, there were only significant effects of burn year. In May, there were only significant effects of distance from motte on adult biomass. For burn year, there was no clear pattern of differences in community structure among the three treatments in NMDS (Figure 37, Figure 38, Figure 39). For distance from motte, there was a clear gradient in biomass of arthropod communities between the center and 50m plot location for all months combined and each individual month (Figure 37, Figure 40, Figure 41).

SIMPER results of chick prey biomass show that ants (Hymenoptera) contributed between 26% and 34% to dissimilarities between burn treatments (Table 27). Whereas, adult Coleoptera contributed 20% - 28% of the dissimilarity between burn year comparisons. Taxa contributing less than 12% of the dissimilarities observed between burn treatments included Araneae and Orthoptera. For distance from a motte for potential prey of bobwhite chicks, ants contributed 27% - 35% of dissimilarities observed. Adult Coleopterans contributed the next greatest percent to all plot location dissimilarities (23%

- 28%). Orders contributing less than 14% to differences in chick prey biomass across plot locations were flying Hymenoptera, Araneae, and Orthoptera.

Orthoptera, adult Coleopterans, and ants affected dissimilarities in biomass of prey for adult bobwhite across burn treatments, with percent contributions ranging from 14% to 24% (Table 28). Dissimilarities of adult prey across burn years were also explained by Araneae, Adult Lepidoptera, and flying Hymenoptera with each contributing less than 13%. Differences observed between plot locations were mostly contributed by adult Coleopterans, ants, and Orthopterans (13% - 25%). Orders contributing less than 13% to dissimilarities in biomass of prey for adult bobwhites included flying Hymenoptera, Araneae, and Hemiptera.

I then analyzed the orders that comprised over 5% of the total arthropod biomass for both chicks (ants, adult Coleopteran, Araneae) and adults (Adult Coleoptera, Orthoptera, Araneae, ants) (Table 18). For total biomass of chick prey, the only significant effect was time (Table 29, Figure 42). For adult Coleoptera, distance from motte and time were significant (Table 29). Adult Coleoptera biomass was greater in the center plots in June and July relative to the other three plot locations (Figure 43). For ants, there were significant effects of distance from motte and the interaction of burn year and time (Table 29). For chicks, ants had lower biomass in the center plot relative to the plots outside a motte (Figure 44). Araneae only had significant effects of time (Table 29, Figure 45).

For total biomass of potential adult prey, there were significant effects of time and the interaction of burn year and time (Table 30, Figure 46). For ants, there were significant effects of burn year and the interaction of burn year and distance from motte

(Table 30). Ants in the 1-year since burn had greater biomass compared to the other two burn treatments in May and June (Figure 47). For adult Coleoptera and Araneae, there were only significant effects of time (Table 30, Figure 48, and Figure 49). For Orthoptera, the only significant effect was the interaction of distance from motte and time (Table 30, Figure 50).

Vegetation

Principal component 1 was primarily loaded on Nudds board segments 5 – 10, taller vegetation, while principal component 2 is more strongly related to segments 1 – 4, shorter vegetation (Table 31). For individual ANOVAs of the two principal components, there were only significant effects of burn year and distance from motte on principal component 2 (Table 32). Shorter vegetation was less dense in the control burn treatment compared to the other more recent burn years (Table 33, Figure 51) Shorter vegetation was also less dense in the center plot location relative to the open shrubland plots (Table 33, Figure 51).

Discussion

I studied the interacting effects of prescribed fire and mottes on potential arthropod prey for bobwhite chicks and adults. I hypothesized that the arthropod abundance and biomass found inside a motte would be less than the surrounding open shrubland. This hypothesis was supported for all of the abundance and biomass analyses for both bobwhite chicks and adults. I also hypothesized that more recently burned areas would have more arthropods compared to older burn treatments. Results of multivariate analyses supported my hypothesis with several significant analyses showing differences between burn years. My results suggest that both mottes and fire contribute to heterogeneity in arthropod prey communities for bobwhites.

Previous theories suggest that refuge use and foraging are mutually exclusive activities and that animals make tradeoffs between using refugia and foraging. Use of mottes as a refuge is important for bobwhites in western Oklahoma during the mid-day heat in the summer (Carroll et al., 2015; Guthery, 2000; Rakowski et al., 2019; Robinson, 1957). Yet, it is possible that bobwhites are not making a complete trade-off between using a refuge and foraging because there are suitable arthropod prey inside a motte. While seeking shade inside a motte, bobwhite broods have access to arthropods of optimal size classes for both hens and chicks. There are also abundant prey within 1-15m of the motte, which would provide additional resources relatively close to the shade of the motte. Yet, while prey are available inside of mottes prey quality may differ between habitat types. Coleoptera were more abundant inside a motte, however they would likely be relatively low quality prey due to high exoskeleton content. Whereas ants, a preferred food of bobwhites (Doxon & Carroll, 2010), were less abundant inside a motte compared to open areas. Hence, bobwhites may be making a partial tradeoff between refuge use and foraging. Mottes do have some prey, but these prey may be of lower quality than the preferred prey of bobwhites found more frequently in open shrublands.

My results suggest that both fire and mottes affect the food resources for bobwhites by impacting arthropod abundance and biomass, but they do not interact. Both burn year and plot location had an overall effect on arthropod communities, but distance from motte has a greater impact. It is important to remember that the two variables I studied influence habitat heterogeneity in different ways. Burning is a short-term disturbance that alters vegetative structure, while mottes are long-term sources of microhabitat diversity that interact within a landscape. These differences in impacts to habitat heterogeneity would therefore differentially affect the arthropod community.

There were significant effects of burn year on arthropod communities in the PERMANOVA and ANOVA analyses of some arthropod taxa. Yet, the NMDS plots did not show clear differences between arthropod communities between burn years. This is likely because the NMDS plots were only done with two axes and these axes may not explain all the variation in the arthropod communities. Also, SIMPER analyses suggested that the significant effects of burn year in the PERMANOVA analyses were primarily driven by ants and less so by other taxa. Hence, some of the community shifts due to burn year could be more simply explained as changes in ant abundance or biomass with burn year.

Results of ordination analyses show a distinct gradient in arthropod communities with distance from motte. This would suggest that mottes and shrublands are not just two distinct habitats, but that there is a gradient along which mottes and shrublands interact. This was evident in the total abundance for potential chick prey with the highest abundance at the 50m plots and decreasing until the lowest abundance in the center of a motte. This was also true for the individual analyses of ant abundance and biomass, where center plots had the lowest quantities of ants, which increased moving outwards where the 50m plots had the most ants. Although, not all individual taxa showed the same pattern of a gradient, as some taxa showed distinct differences inside versus outside of a motte. However, the NMDS suggests that the community, as a whole, shifts across the distances away from the motte. Hence, while mottes themselves can be relatively small features (11m -42m diameter), their effects can extend outward into the shrubland. More importantly, we can see that suitable prey are accessible for bobwhites in and around these patches.

Vegetation structure is the primary difference between a motte and open shrubland. Although there was variation between mottes, the center plot locations typically had greater litter depth, fewer forbs, and less grass cover. These differences would impact microhabitat features such as thermal extremes, shade, moisture, and food availability for arthropods. The lack of herbaceous ground cover inside a motte would reduce the quantity of herbivorous arthropods at center plot locations. Johnston and Holberton (2009) found that less-shaded forest microhabitats were important areas for increased food abundance for ground foraging birds because some arthropod groups were negatively associated with shade. This may also mean that arthropods inside a motte are less accessible to these ground-dwelling birds because much of the foliage, where herbivorous arthropods would feed, is higher in the canopy compared to grasses and low forbs in open areas.

Analyses of total abundance and biomass showed that there are numerous arthropods in Packsaddle WMA that meet the size requirements for bobwhites. Interestingly, chick prey abundance is most clearly affected by distance from motte. Mottes showed the lowest chick prey abundance compared to open shrublands. This may suggest that available foods are more prevalent away from the protection of a motte. Although this relationship was less clear for the total abundance of potential adult prey, this supports the consensus that open shrublands are the primary foraging locations for bobwhite broods (Brennan, 1999; Guthery, 2000). Analyses of total biomass for both adults and chicks showed that all treatments were similar across each sampling period. The similarity between adults and chicks is likely due to the overlap in size classes considered for each. However, what is clear is that there was a substantial amount of potential arthropod prey collected in these areas, regardless of treatment type.

Time since prescribed burn and the distance from a motte do not seem to change the overall arthropod community significantly. These treatments do however shift the arthropod community somewhat. The implications of this shift for bobwhites will depend on the relative nutritional quality of the different prey types available. The distribution of arthropod prey qualities in relation to bobwhite habitats is something that future research should explore. This may further illuminate the question of whether bobwhites are making a tradeoff between mottes and open shrublands, particularly if bobwhites are selecting foraging areas based on the quality of the prey present.

The results of my study support the importance of maintaining heterogeneous landscapes to increase arthropod prey diversity, abundance, and biomass. Providing a patchy landscape with diversity in vegetative structure, thermal conditions, and time since burn will promote arthropod communities, which are important prey for bobwhite chicks and reproducing females. Mottes are a multifunctional aspect within bobwhites' range and we now know that they provide food resources as well as protection. Prescribed fire does not seem to negatively affect the arthropod prey for bobwhites, nor does it detrimentally affect the arthropods inside mottes. Continuing the current tactics for habitat management should provide a diversity of arthropod foods for the bobwhite populations in Packsaddle WMA.

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APPENDICES
Appendix A

Table 1. Total abundance of arthropods collected in pitfall traps each month in Packsaddle WMA, Oklahoma during the summer of 2018.

	Month Sampled				
Arthropod Order	**May**	**June**	**July**	**August**	**Sum of Each Order**
Coleoptera	3412	1767	1076	1306	7561
Lepidoptera	106	56	83	79	324
Hymenoptera	14178	12801	16009	8360	51348
Collembola	8540	10545	72095	28674	119854
Orthoptera	668	394	910	788	2760
Blattodea	249	296	1280	444	2269
Neuroptera	36	16	18	12	82
Diptera	1321	761	4693	1229	8004
Araneae	1211	1044	771	834	3860
Acari	2796	1304	1878	821	6799
Isopoda	3	2	1	4	10
Hemiptera	907	347	440	534	2228
Myriapoda	35	5	6	1	47
Psocoptera	5	233	522	106	866
Thysanoptera	237	49	53	67	406
Other	9	16	22	12	59
Sum of Each Month	33713	29636	99857	43271	206477

Table 2. Total biomass (g) of arthropods collected in pitfall traps each month in Packsaddle WMA, Oklahoma during the summer of 2018.

	Month Sampled				
Arthropod Order	**May**	**June**	**July**	**August**	**Sum of Each Order**
Coleoptera	17.42	10.33	7.89	10.16	45.80
Lepidoptera	1.21	0.93	0.72	0.97	3.83
Hymenoptera	6.02	6.33	6.84	4.05	23.24
Collembola	0.70	0.39	2.56	2.00	5.65
Orthoptera	11.82	11.74	20.92	35.03	79.51
Blattodea	2.10	2.53	10.73	3.59	18.95
Neuroptera	0.08	0.07	0.03	0.02	0.20
Diptera	1.10	0.33	1.18	0.50	3.11
Araneae	4.17	3.72	1.98	2.31	12.18
Acari	0.31	0.15	0.20	0.09	0.75
Isopoda	0.01	0.00	0.00	0.01	0.02
Hemiptera	0.43	0.72	0.46	0.35	1.96
Myriapoda	0.21	0.02	0.05	0.01	0.29
Psocoptera	0.00	0.01	0.01	0.00	0.02
Thysanoptera	0.00	0.00	0.00	0.00	0.00
Other	0.06	0.11	0.18	0.12	0.47
Sum of Each Month	45.64	37.38	53.75	59.21	195.98

Table 3. Percent composition of all arthropod taxa collected in pitfall traps in Packsaddle WMA, Oklahoma, for both abundance and biomass, in four months during the summer of 2018.

	Percent Composition	
Arthropod Order	**Abundance**	**Biomass**
Coleoptera	5.04	24.41
Lepidoptera	0.19	2.03
Hymenoptera	30.15	12.42
Collembola	49.84	2.68
Orthoptera	1.51	38.85
Blattodea	1.01	9.34
Neuroptera	0.05	0.11
Diptera	3.51	1.58
Araneae	2.45	6.67
Acari	4.12	0.40
Isopoda	0.01	0.01
Hemiptera	1.38	1.08
Myriapoda	0.03	0.15
Psocoptera	0.39	0.01
Thysanoptera	0.27	0.00
Other	0.03	0.24
Total	100.00	100.00

Table 4. PERMANOVA results of abundance analyses in each month separately and with all four months combined. Bu = time since burn treatments (1-year, 2 years, and control), Pl = Pot location or distance from motte (Center, 1m, 15m, and 50m), BuxPl = interaction between burn and plot location, Res = residuals. Data were square root transformed. p-values <0.005 in bold. ** Term has one or more empty cells. Data were collected in Packsaddle WMA, Oklahoma during the summer of 2018.

Sampling Period	Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
May							
	Bu	2	2733.7	1366.9	7.46	**0.001**	997
	Pl	3	6194.3	2064.8	11.28	**0.001**	999
	BuxPl	6	650.62	108.44	0.59	0.953	998
	Res	52	9522.9	183.13			
	Total	63	19229				
June							
	Bu	2	2312.1	1156	4.06	**0.001**	999
	Pl	3	4152.2	1384.1	4.86	**0.001**	997
	BuxPl	6	1025.6	170.93	0.60	0.927	997
	Res	52	14797	284.56			
	Total	63	22254				
July							
	Bu	2	2739.7	1369.8	5.27	**0.001**	999
	Pl	3	5738.9	1913	7.36	**0.001**	997
	BuxPl	6	921.72	153.62	0.59	0.927	999
	Res	52	13524	260.07			
	Total	63	23124				
August							
	Bu	2	3117.1	1558.6	6.78	**0.001**	999
	Pl	4	4359	1089.7	4.74	**0.001**	999
	BuxPl**	6	656.74	109.46	0.48	0.991	998
	Res	47	10799	229.77			
	Total	59	19102				
All Months Summed							
	Bu	2	2559.4	1279.7	13.48	**0.001**	998
	Pl	3	4784.1	1594.7	16.79	**0.001**	998
	BuxPl	6	372.8	62.133	0.65	0.889	998
	Res	52	4938.4	94.97			
	Total	63	12779				

Table 5. Results of SIMPER analyses on arthropod abundance. SMIPER analyses, similarity percentages, break down the contribution of each order to the observed dissimilarity between samples for the PERMANOVA analyses. Total % explained shows the cumulative percentage of the average dissimilarity that is explained by all orders in each row. Data were square root transformed.

		Percent Contribution						
Comparison	**Average Dissimilarity**	**Collembola**	**Hymenoptera**	**Coleoptera**	**Acari**	**Diptera**	**Other**	**Total % Explained**
Control vs. 2 years since	12.99	30.4	16.71	-	9.32	10.91	8	75.34
Control vs. 1 year since	18.26	45.21	17.26	-	-	-	8.52	70.99
2 years since vs. 1 year since	17.04	43.51	21.42	-	-	-	7.09	72.02
Center vs. 1m	21.97	47.3	13.43	-	9.42	-	-	70.15
Center vs. 15m	22.24	45.3	17.85	-	7.33	-	-	70.48
1m vs. 15m	12.53	36.23	16.24	-	8.35	12.58	-	73.4
Center vs. 50m	25.11	45.87	20.75	-	6.45	-	-	73.07
1m vs. 50m	12.5	32.09	21.01	-	7.21	13.44	-	73.75
15m vs. 50m	12.08	35.71	21.55	6.62	-	9.12	-	73

Table 6. Summary of mixed model nested ANOVAs testing the effects of burn year and distance from motte on abundance of the five most abundant orders analyzed in each month separately and with all four months combined. Bu = time since burn treatments (1-year, 2 years, and control), Pl = Pot location or distance from motte (Center, 1m, 15m, and 50m), BuxPl = interaction between burn and plot location, Res = residuals. ANOVAs included motte nested within burn treatment as a random effect. Data were log(x+1) transformed. P-values <0.005 in bold. Data were collected at Packsaddle WMA, Oklahoma during the summer of 2018.

Taxa	Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Collembola						
	Burn Year	2	2	13.1	12.05	**0.001**
	Plot Location	1	1	227.2	29.43	**<.0001**
	Burn Year*Plot Location	2	2	227.2	0.32	0.726
	Time	1	1	229	97.79	**<.0001**
	Burn Year*Time	2	2	229	0.19	0.828
	Plot Location*Time	1	1	227.2	0.37	0.543
	Burn Year*Plot Location*Time	2	2	227.2	0.23	0.795
Hymenoptera						
	Burn Year	2	2	13	4.98	0.025
	Plot Location	1	1	227	41.93	**<.0001**
	Burn Year*Plot Location	2	2	227	0.65	0.524
	Time	1	1	228	7.30	0.007
	Burn Year*Time	2	2	228	6.93	**0.001**
	Plot Location*Time	1	1	227	2.02	0.157
	Burn Year*Plot Location*Time	2	2	227	0.35	0.707
Coleoptera						
	Burn Year	2	2	11.1	0.36	0.706
	Plot Location	1	1	224.9	14.38	**<0.001**
	Burn Year*Plot Location	2	2	224.9	0.28	0.753
	Time	1	1	227.3	93.92	**<.0001**
	Burn Year*Time	2	2	227.3	1.33	0.268
	Plot Location*Time	1	1	224.9	0.85	0.357
	Burn Year*Plot Location*Time	2	2	224.9	0.87	0.422
Acari						
	Burn Year	2	2	12.7	1.60	0.240
	Plot Location	1	1	227	2.17	0.143
	Burn Year*Plot Location	2	2	227	1.71	0.183
	Time	1	1	229.7	47.25	**<.0001**
	Burn Year*Time	2	2	229.7	6.70	**0.002**
	Plot Location*Time	1	1	227	1.24	0.267
	Burn Year*Plot Location*Time	2	2	227	1.05	0.350
Diptera						
	Burn Year	2	2	12.1	0.84	0.454
	Plot Location	1	1	226.1	6.69	0.010
	Burn Year*Plot Location	2	2	226.1	0.49	0.614
	Time	1	1	227.4	10.74	**0.001**
	Burn Year*Time	2	2	227.4	0.31	0.732
	Plot Location*Time	1	1	226.1	3.05	0.082
	Burn Year*Plot Location*Time	2	2	226.1	0.58	0.561
Total						
	Burn Year	2	2	157.7	1.40	0.250
	Plot Location	3	3	191.1	15.45	**<.0001**
	Burn Year*Plot Location	6	6	191.1	0.15	0.988
	Time	3	3	191.2	14.33	**<.0001**
	Burn Year*Time	6	6	191.2	1.37	0.227
	Plot Location*Time	9	9	191.1	1.02	0.427
	Burn Year*Plot Location*Time	18	18	191.1	0.69	0.821

Table 7. PERMANOVA results of biomass (g) of all arthropods collected in pitfall traps analyzed in each month separately and with all four months combined. Bu = time since burn treatments (1-year, 2 years, and control), Pl = Pot location or distance from motte (Center, 1m, 15m, and 50m), BuxPl = interaction between burn and plot location, Res = residuals. Data were square root transformed. p-values <0.005 in bold. ** Term has one or more empty cells. Data were collected at Packsaddle WMA, Oklahoma in the summer of 2018.

Sampling Period	Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
May							
	Bu	2	2737.1	1368.5	4.40	**0.001**	999
	Pl	3	4484.7	1494.9	4.81	**0.001**	999
	BuxPl	6	1031.1	171.84	0.55	0.98	999
	Res	52	16161	310.79			
	Total	63	24351				
June							
	Bu	2	4064.2	2032.1	5.16	**0.001**	999
	Pl	3	2257.5	752.5	1.91	0.018	997
	BuxPl	6	1565.1	260.85	0.66	0.921	998
	Res	52	20470	393.66			
	Total	63	28436				
July							
	Bu	2	5415.8	2707.9	6.79	**0.001**	998
	Pl	3	2143.1	714.37	1.79	0.03	999
	BuxPl	6	774.94	129.16	0.32	1	997
	Res	52	20735	398.76			
	Total	63	29054				
August							
	Bu	2	4621.8	2310.9	5.08	**0.001**	998
	Pl	4	3876.9	969.22	2.13	0.013	999
	BuxPl**	6	1207.4	201.24	0.44	0.994	998
	Res	47	21368	454.63			
	Total	59	31267				
All Months Summed							
	Bu	2	2886.6	1443.3	10.23	**0.001**	997
	Pl	3	1840.3	613.45	4.35	**0.001**	996
	BuxPl	6	275.05	45.841	0.32	1	996
	Res	52	7339.5	141.14			
	Total	63	12377				

Table 8. Results of SIMPER analyses on arthropod biomass (g). SMIPER analyses, similarity percentages, break down the contribution of each order to the observed dissimilarity between samples for the PERMANOVA analyses. Total % explained shows the cumulative percentage of the average dissimilarity that is explained by all orders in each row. Data were square root transformed.

		Percent Contribution							
Comparison	**Average Dissimilarity**	**Collembola**	**Hymenoptera**	**Coleoptera**	**Araneae**	**Orthoptera**	**Blattodea**	**Lepidoptera**	**Total % Explained**
Control vs. 2 years since	16.71	-	8.93	16.63	9.24	23.61	14.54	-	72.95
Control vs. 1 year since	21.01	8.54	9.58	11.26	-	16.55	28.27	-	74.2
2 years since vs. 1 year since	18.69	8.37	12.5	12.63	-	18.89	24.09	-	76.48
Center vs. 1m	18.93	9.59	11.94	16.83	-	24.11	10.73	-	73.2
Center vs. 15m	18.2	11.41	12.9	16.42	-	20.58	10.8		72.11
1m vs. 15m	15.22	9.71	10.08	14.22	-	24.32	11.47	8.74	78.54
Center vs. 50m	19.58	9.46	16.02	16.15	-	20.2	9.86	-	71.69
1m vs. 50m	15.73	-	11.01	15.12	-	25.2	10.37	8.55	70.25
15m vs. 50m	15.18	8.94	12.14	13.78	9.23	22.13	11.42	-	77.64

Table 9. Summary of mixed model nested ANOVAs testing the effects of burn year and distance from motte on biomass (mg) of the five largest orders. ANOVAs included motte nested within burn treatment as a random effect. Data were log(x+1) transformed. P-values <0.005 in bold. Data were collected in Packsaddle WMA, Oklahoma during the summer of 2018.

Taxa	Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Orthoptera						
	Burn Year	2	2	13	0.03	0.975
	Plot Location	1	1	227	3.11	0.079
	Burn Year*Plot Location	2	2	227	0.42	0.657
	Time	1	1	227.8	59.39	**<.0001**
	Burn Year*Time	2	2	227.8	1.11	0.331
	Plot Location*Time	1	1	227	4.27	0.040
	Burn Year*Plot Location*Time	2	2	227	0.41	0.667
Coleoptera						
	Burn Year	2	2	10.6	1.79	0.215
	Plot Location	1	1	224.5	5.19	0.024
	Burn Year*Plot Location	2	2	224.5	0.15	0.858
	Time	1	1	228.3	23.84	**<.0001**
	Burn Year*Time	2	2	228.3	2.90	0.057
	Plot Location*Time	1	1	224.5	1.40	0.238
	Burn Year*Plot Location*Time	2	2	224.5	0.35	0.707
Hymenoptera						
	Burn Year	2	2	13.1	4.36	0.036
	Plot Location	1	1	227.1	32.74	**<.0001**
	Burn Year*Plot Location	2	2	227.1	1.53	0.219
	Time	1	1	228.3	4.84	0.029
	Burn Year*Time	2	2	228.3	7.30	**0.001**
	Plot Location*Time	1	1	227.1	3.21	0.075
	Burn Year*Plot Location*Time	2	2	227.1	0.40	0.670
Blattodea						
	Burn Year	2	2	12.1	43.77	**<.0001**
	Plot Location	1	1	226.1	0.06	0.803
	Burn Year*Plot Location	2	2	226.1	1.73	0.179
	Time	1	1	227.5	20.68	**<.0001**
	Burn Year*Time	2	2	227.5	4.72	0.010
	Plot Location*Time	1	1	226.1	0.16	0.689
	Burn Year*Plot Location*Time	2	2	226.1	0.97	0.380
Araneae						
	Burn Year	2	2	13.1	3.49	0.061
	Plot Location	1	1	227.3	4.00	0.047
	Burn Year*Plot Location	2	2	227.3	0.35	0.705
	Time	1	1	229.7	28.18	**<.0001**
	Burn Year*Time	2	2	229.7	2.49	0.086
	Plot Location*Time	1	1	227.3	1.83	0.178
	Burn Year*Plot Location*Time	2	2	227.3	0.34	0.709
Total						
	Burn Year	2	2	13	0.18	0.836
	Plot Location	1	1	227.1	2.88	0.091
	Burn Year*Plot Location	2	2	227.1	0.69	0.502
	Time	1	1	227.9	15.06	**<.0001**
	Burn Year*Time	2	2	227.9	1.03	0.358
	Plot Location*Time	1	1	227.1	1.88	0.171
	Burn Year*Plot Location*Time	2	2	227.1	0.13	0.882

Table 10. PCA eigenvectors showing loading of vegetation measures on both principal components.

	Principal Components	
Vegetation Measure	**Prin 1**	**Prin 2**
Percent Shrub Canopy	-0.40851	-0.25383
Percent Grass	0.47695	-0.5195
Percent Forb	0.18698	0.77053
Percent Bare Ground	0.38271	0.22167
Percent Litter	-0.63905	0.11299
Percent Rock	0.12579	-0.10031

Table 11. Summary of mixed model nested ANOVAs on principal components on vegetation measurements. ANOVAs included motte nested within burn treatment as a random effect. P-values <0.005 in bold.

Principal Component	Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Prin 1						
	Burn Year	2	2	48.2	2.04	0.141
	Plot Location	3	3	219	11.46	**<.0001**
	Burn Year*Plot Location	6	6	219	0.61	0.723
	Time	1	1	219	2.38	0.125
	Burn Year*Time	2	2	219	0.25	0.777
	Plot Location*Time	3	3	219	0.20	0.899
	Burn Year*Plot Location*Time	6	6	219	0.52	0.791
Prin 2						
	Burn Year	2	2	113.6	3.93	0.022
	Plot Location	3	3	219	8.80	**<.0001**
	Burn Year*Plot Location	6	6	219	1.88	0.086
	Time	1	1	219	1.08	0.299
	Burn Year*Time	2	2	219	0.43	0.651
	Plot Location*Time	3	3	219	0.17	0.920
	Burn Year*Plot Location*Time	6	6	219	0.58	0.744

Table 12. Summary of mixed model nested ANOVAs on principal components on vegetation measurements. ANOVAs included motte nested within burn treatment as a random effect. Data were log (x+1) transformed. P-values <0.005 in bold.

Vegetation Measure	Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Percent Shrub Canopy						
	Burn Year	2	2	42.4	1.25	0.298
	Plot Location	3	3	219	6.30	**<0.001**
	Burn Year*Plot Location	6	6	219	0.81	0.565
	Time	1	1	219	0.04	0.834
	Burn Year*Time	2	2	219	1.97	0.143
	Plot Location*Time	3	3	219	0.06	0.979
	Burn Year*Plot Location*Time	6	6	219	0.61	0.720
Percent Grass Cover						
	Burn Year	2	2	78.6	7.91	**0.001**
	Plot Location	3	3	219	57.48	**<.0001**
	Burn Year*Plot Location	6	6	219	1.84	0.092
	Time	1	1	219	10.78	**0.001**
	Burn Year*Time	2	2	219	3.73	0.026
	Plot Location*Time	3	3	219	1.63	0.183
	Burn Year*Plot Location*Time	6	6	219	1.10	0.364
Percent Forb Cover						
	Burn Year	2	2	110.1	8.96	**<0.001**
	Plot Location	3	3	219	0.17	0.918
	Burn Year*Plot Location	6	6	219	2.90	0.010
	Time	1	1	219	0.41	0.524
	Burn Year*Time	2	2	219	0.06	0.944
	Plot Location*Time	3	3	219	0.36	0.781
	Burn Year*Plot Location*Time	6	6	219	0.94	0.469
Percent Bare Ground Cover						
	Burn Year	2	2	92.2	1.07	0.347
	Plot Location	3	3	219	9.75	**<.0001**
	Burn Year*Plot Location	6	6	219	1.55	0.163
	Time	1	1	219	0.84	0.360
	Burn Year*Time	2	2	219	1.11	0.333
	Plot Location*Time	3	3	219	0.43	0.728
	Burn Year*Plot Location*Time	6	6	219	0.87	0.514
Percent Litter Cover						
	Burn Year	2	2	85.8	1.07	0.347
	Plot Location	3	3	219	9.59	**<.0001**
	Burn Year*Plot Location	6	6	219	0.26	0.953
	Time	1	1	219	2.17	0.142
	Burn Year*Time	2	2	219	0.81	0.446
	Plot Location*Time	3	3	219	0.06	0.980
	Burn Year*Plot Location*Time	6	6	219	1.12	0.353
Percent Rock Cover						
	Burn Year	2	2	53	0.00	1.000
	Plot Location	3	3	219	2.22	0.086
	Burn Year*Plot Location	6	6	219	0.80	0.572
	Time	1	1	219	0.66	0.418
	Burn Year*Time	2	2	219	0.70	0.497
	Plot Location*Time	3	3	219	1.25	0.293
	Burn Year*Plot Location*Time	6	6	219	0.67	0.673

Table 13. Summary of SL means ± SE for individual mixed model nested ANOVAs of vegetation data. Differences in letters across rows indicate significant differences where $\alpha < 0.005$.

	Burn Year			**Plot Location**			
Vegetation Measure	**1 Year Since**	**2 Years Since**	**Control**	**Center**	**1m**	**15m**	**50m**
Percent Shrub Canopy	3.30 ± 0.32^{a}	3.99 ± 0.32^{a}	3.82 ± 0.29^{a}	3.71 ± 0.18^{ab}	3.45 ± 0.18^{b}	4.20 ± 0.18^{a}	3.99 ± 0.18^{ab}
Percent Grass Cover	1.72 ± 0.28^{a}	0.14 ± 0.28^{b}	1.09 ± 0.26^{ab}	0.98 ± 0.16^{b}	3.04 ± 0.16^{a}	3.02 ± 0.16^{a}	2.96 ± 0.16^{a}
Percent Forb Cover	2.08 ± 0.29^{a}	1.02 ± 0.29^{ab}	0.43 ± 0.26^{b}	1.18 ± 0.16^{a}	1.19 ± 0.16^{a}	1.06 ± 0.16^{a}	1.12 ± 0.16^{a}
Percent Bare Ground	1.60 ± 0.37^{a}	1.12 ± 0.37^{a}	0.87 ± 0.34^{a}	1.20 ± 0.21^{b}	2.37 ± 0.21^{a}	2.28 ± 0.21^{a}	2.30 ± 0.21^{a}
Percent Litter Cover	4.25 ± 0.14^{a}	4.51 ± 0.14^{a}	4.49 ± 0.13^{a}	4.42 ± 0.08^{a}	3.98 ± 0.08^{b}	3.99 ± 0.08^{b}	3.99 ± 0.08^{b}
Percent Rock	0.00 ± 0.04^{a}	0.00 ± 0.04^{a}	0.00 ± 0.04^{a}	0.00 ± 0.02^{a}	0.05 ± 0.02^{a}	0.02 ± 0.02^{a}	0.00 ± 0.02^{a}

Table 14. Total abundance of arthropods in size classes, optimal for chicks (2mm-10mm), collected in each month in Packsaddle WMA, Oklahoma during the summer of 2018.

	Month Sampled				
Arthropod Orders	**May**	**June**	**July**	**August**	**Sum of Each Order**
Adult Coleopteran	1537	736	198.5	474.5	2946
Coleoptera Larvae	38	46.5	53.5	34	172
Adult Lepidopteran	12	5	27	11.5	56
Lepidoptera Larvae	8	3.5	3	9.5	24
Ants (Hymenoptera)	5249.5	4721.5	6021.5	3115.5	19108
Flying (Hymenoptera)	132	259.5	171.5	159	722
Orthoptera	174.5	81	181	49.5	486
Araneae	541.5	448	271	212.5	1473
Hemiptera	231	98	117.5	164.5	611
Sum of Each Month	7923.5	6399.0	7044.5	4230.5	25597.5

Table 15. Total abundance of arthropods in size classes, optimal for adults (5mm-15mm), collected in pitfall traps each month in Packsaddle WMA, Oklahoma during the summer of 2018.

	Month Sampled				
Arthropod Orders	**May**	**June**	**July**	**August**	**Sum of Each Order**
Adult Coleopteran	1155	560.5	131.5	369.5	2216.5
Coleoptera Larvae	9.5	8	5	13	35.5
Adult Lepidopteran	13.5	15	5	19	52.5
Lepidoptera Larvae	5	3.5	3	0	11.5
Ants (Hymenoptera)	145.5	359	249	188.5	942
Flying (Hymenoptera)	67.5	96.5	77	72.5	313.5
Orthoptera	160.5	83	224	79	546.5
Araneae	146.5	204	68	72.5	491
Hemiptera	30	38.5	20.5	26.5	115.5
Sum of Each Month	1733	1368	783	840.5	4724.50

Table 16. Total biomass (g) of arthropods in size classes, optimal for chicks (2mm-10mm), collected in pitfall traps each month in Packsaddle WMA, Oklahoma during the summer of 2018.

	Month Sampled				
Arthropod Orders	**May**	**June**	**July**	**August**	**Sum of Each Order**
Adult Coleopteran	13.33	6.33	1.45	4.14	25.25
Coleoptera Larvae	0.02	0.02	0.02	0.02	0.08
Adult Lepidopteran	0.02	0.01	0.03	0.03	0.09
Lepidoptera Larvae	0.02	0.02	0.01	0.00	0.05
Ants (Hymenoptera)	4.24	4.50	5.10	2.82	16.66
Flying (Hymenoptera)	0.37	0.64	0.46	0.44	1.91
Orthoptera	0.82	0.49	0.75	0.33	2.39
Araneae	2.17	2.72	1.01	0.95	6.85
Hemiptera	0.30	0.15	0.15	0.23	0.83
Sum of Each Month	21.29	14.88	8.98	8.96	54.11

Table 17. Total biomass (g) of arthropods in size classes, optimal for adults (5mm-15mm), collected in pitfall traps each month in Packsaddle WMA, Oklahoma during the summer of 2018.

	Month Sampled				
Arthropod Orders	**May**	**June**	**July**	**August**	**Sum of Each Order**
Adult Coleopteran	13.40	7.03	2.23	4.62	27.28
Coleoptera Larvae	0.02	0.01	0.01	0.03	0.07
Adult Lepidopteran	0.47	0.59	0.08	0.54	1.68
Lepidoptera Larvae	0.03	0.02	0.02	0.00	0.07
Ants (Hymenoptera)	0.54	1.34	0.92	0.70	3.50
Flying (Hymenoptera)	0.50	0.64	0.55	0.48	2.17
Orthoptera	3.12	1.34	5.51	1.68	11.65
Araneae	2.25	2.93	1.10	1.28	7.56
Hemiptera	0.18	0.64	0.24	0.16	1.22
Sum of Each Month	20.51	14.54	10.66	9.49	55.20

Table 18. Percent composition of all arthropod taxa collected in pitfall traps for both abundance and biomass with size classes optimal for chicks (2mm-10mm) and adults (5mm-15mm) separated. Arthropods were collected in Packsaddle WMA, Oklahoma during the summer of 2018.

	Percent Composition			
Arthropod Order	**Abundance for Chicks**	**Biomass for Chicks**	**Abundance for Adults**	**Biomass for Adults**
Adult Coleopteran	11.23	41.86	42.09	45.81
Coleoptera Larvae	0.69	0.15	0.83	0.15
Adult Lepidopteran	0.22	0.21	1.19	3.19
Lepidoptera Larvae	0.11	0.09	0.23	0.14
Ants (Hymenoptera)	74.79	34.61	22.22	6.97
Flying (Hymenoptera)	2.98	4.02	7.35	4.28
Orthoptera	1.80	4.81	13.33	23.43
Araneae	5.68	12.59	10.17	13.73
Hemiptera	2.50	1.67	2.58	2.3
Total	100.00	100.00	100.00	100.00

Table 19. PERMANOVA results of abundance for potential prey of chicks collected in pitfall traps analyzed in each month separately and with all four months combined. Bu = time since burn treatments (1-year, 2 years, and control), Pl = Pot location or distance from motte (Center, 1m, 15m, and 50m), BuxPl = interaction between burn and plot location, Res = residuals. Data were square root transformed. p-values <0.005 in bold. ** Term has one or more empty cells. Data were collected at Packsaddle WMA, Oklahoma in the summer of 2018.

Sampling Period	**Source**	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**	**Unique perms**
May							
	Bu	2	2561	1280.5	5.00	**0.001**	999
	Pl	3	7698.3	2566.1	10.02	**0.001**	999
	BuxPl	6	1291.8	215.29	0.84	0.714	998
	Res	52	13320	256.16			
	Total	63	24910				
June							
	Bu	2	3051.2	1525.6	4.50	**0.001**	999
	Pl	3	4296.1	1432	4.22	**0.001**	999
	BuxPl	6	1870.5	311.74	0.92	0.589	997
	Res	52	17646	339.34			
	Total	63	26823				
July							
	Bu	2	1719	859.48	2.01	0.037	998
	Pl	3	3566.9	1189	2.78	**0.003**	998
	BuxPl	6	1132.9	188.82	0.44	0.99	996
	Res	52	22236	427.62			
	Total	63	28713				
August							
	Bu	2	4578.6	2289.3	4.07	**0.001**	999
	Pl	4	6786	1696.5	3.01	**0.002**	997
	BuxPl**	6	2180.8	363.46	0.65	0.919	999
	Res	47	26462	563.02			
	Total	59	40272				
All Months Summed							
	Bu	2	1940	969.99	6.02	**0.001**	999
	Pl	3	4712.6	1570.9	9.75	**0.001**	998
	BuxPl	6	605.62	100.94	0.63	0.921	998
	Res	52	8377.9	161.11			
	Total	63	15714				

Table 20. PERMANOVA results of abundance for potential prey of adults all arthropods collected in pitfall traps analyzed in each month separately and with all four months combined. Bu = time since burn treatments (1-year, 2 years, and control), Pl = Pot location or distance from motte (Center, 1m, 15m, and 50m), BuxPl = interaction between burn and plot location, Res = residuals. Data were square root transformed. p-values <0.005 in bold. ** Term has one or more empty cells. Data were collected at Packsaddle WMA, Oklahoma in the summer of 2018.

Sampling Period	Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
May							
	Bu	2	2332.5	1166.2	2.81	0.006	997
	Pl	3	5232.3	1744.1	4.20	**0.001**	999
	BuxPl	6	2318.5	386.41	0.93	0.576	999
	Res	52	21584	415.08			
	Total	63	31741				
June							
	Bu	2	6938	3469	4.99	**0.001**	997
	Pl	3	3643.1	1214.4	1.75	0.04	999
	BuxPl	6	3654.1	609.01	0.88	0.665	998
	Res	52	36117	694.56			
	Total	63	50616				
July							
	Bu	2	6643.1	3321.6	3.91	**0.001**	998
	Pl	3	6570.2	2190.1	2.57	**0.003**	999
	BuxPl	6	4933.9	822.32	0.97	0.517	997
	Res	52	44227	850.53			
	Total	63	62436				
August							
	Bu	2	9088.6	4544.3	4.39	**0.001**	998
	Pl	4	6926.5	1731.6	1.67	0.054	997
	BuxPl**	6	6155.5	1025.9	0.99	0.472	999
	Res	47	48649	1035.1			
	Total	59	71694				
All Months Summed							
	Bu	2	3084.2	1542.1	5.81	**0.001**	997
	Pl	3	2493.3	831.09	3.13	**0.001**	999
	BuxPl	6	2125.3	354.22	1.34	0.093	997
	Res	52	13797	265.33			
	Total	63	21651				

		Percent Contribution						
Comparison	**Average Dissimilarity**	**Adult Coleopteran**	**Ants (Hymenoptera)**	**Flying (Hymenoptera)**	**Orthoptera**	**Araneae**	**Hemiptera**	**Total % Explained**
Control vs. 2 years since	17.35	14.15	39.87	10.08	8	-	-	72.1
Control vs. 1 year since	17.87	12.11	44.4	8.45	-	-	11.76	76.72
2 years since vs. 1 year since	20.53	9.38	52.88	-	-	-	9.08	71.34
Center vs. 1m	21.89	13.25	40.59	-	-	10.12	12.24	76.2
Center vs. 15m	24.18	13.95	46.84	-	-	-	10.82	71.61
1m vs. 15m	15.05	12.85	39.05	10.23	-	-	9.67	71.8
Center vs. 50m	27.74	12.93	51.55	-	-	-	9.77	74.25
1m vs. 50m	16.95	11.54	44.61	11.24	-	-	8.75	76.14
15m vs. 50m	16.1	12.34	43.51	9.57	-	-	9.35	74.77

Table 21. Results of SIMPER analyses on arthropod abundance for potential prey of chicks. SMIPER analyses, similarity percentages, break down the contribution of each order to the observed dissimilarity between samples for the PERMANOVA analyses. Total % explained shows the cumulative percentage of the average dissimilarity that is explained by all orders in each row. Data were square root transformed.

Table 22. Results of SIMPER analyses on arthropod abundance for potential prey of adults. SMIPER analyses, similarity percentages, break down the contribution of each order to the observed dissimilarity between samples for the PERMANOVA analyses. Total % explained shows the cumulative percentage of the average dissimilarity that is explained by all orders in each row. Data were square root transformed.

				Percent Contribution				
Comparison	**Average Dissimilarity**	**Adult Coleopteran**	**Ants (Hymenoptera)**	**Flying (Hymenoptera)**	**Orthoptera**	**Araneae**	**Hemiptera**	**Total % Explained**
Control vs. 2 years since	25.73	18.82	29.25	11.21	13.72	-	-	98.73
Control vs. 1 year since	25.73	18.1	31.26	12.11	-	-	9.68	96.88
2 years since vs. 1 year since	22.92	16.34	22.16	13.43	16.83	9.74	-	101.42
Center vs. 1m	26.39	19.4	33.7	9.9	11.14	-	-	100.53
Center vs. 15m	24.54	23.59	21.93	11.26	10.99	-	11.16	103.47
1m vs. 15m	21.97	15.61	28.11	14.17	10.09	-	11.05	101
Center vs. 50m	26.77	23.39	25.73	11.43	-	-	10.94	98.26
1m vs. 50m	23.74	15.71	31.06	14.57	-	-	9.37	94.45
15m vs. 50m	20.95	19.35	25.15	14.65	-	-	11.5	91.6

Table 23. Summary of mixed model nested ANOVAs testing the effects of burn year and distance from motte on abundance of the orders that are >5% of potential prey for chicks. ANOVAs included motte nested within burn treatment as a random effect. Data were log(x+1) transformed. P-values <0.005 in bold.

Taxa	Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Ants (Hymenoptera)						
	Burn Year	2	2	13	4.58	0.031
	Plot Location	1	1	227	61.43	**<.0001**
	Burn Year*Plot Location	2	2	227	0.34	0.715
	Time	1	1	227.8	3.72	0.055
	Burn Year*Time	2	2	227.8	5.69	**0.004**
	Plot Location*Time	1	1	227	1.44	0.232
	Burn Year*Plot Location*Time	2	2	227	0.31	0.731
Adult Coleopteran						
	Burn Year	2	2	11.7	2.00	0.179
	Plot Location	1	1	225.7	13.11	**<0.001**
	Burn Year*Plot Location	2	2	225.7	0.03	0.968
	Time	1	1	227.9	131.19	**<.0001**
	Burn Year*Time	2	2	227.9	1.29	0.279
	Plot Location*Time	1	1	225.7	0.88	0.348
	Burn Year*Plot Location*Time	2	2	225.7	0.64	0.527
Araneae						
	Burn Year	2	2	13	0.34	0.719
	Plot Location	1	1	227.1	2.01	0.157
	Burn Year*Plot Location	2	2	227.1	0.17	0.841
	Time	1	1	229.1	61.11	**<.0001**
	Burn Year*Time	2	2	229.1	0.40	0.672
	Plot Location*Time	1	1	227.1	0.41	0.524
	Burn Year*Plot Location*Time	2	2	227.1	0.37	0.694
Total						
	Burn Year	2	2	95.4	0.45	0.636
	Plot Location	3	3	191.1	17.69	**<.0001**
	Burn Year*Plot Location	6	6	191.1	0.55	0.770
	Time	3	3	191.1	5.42	**0.001**
	Burn Year*Time	6	6	191.2	1.66	0.133
	Plot Location*Time	9	9	191.1	1.44	0.174
	Burn Year*Plot Location*Time	18	18	191.1	0.56	0.927

Table 24. Summary of mixed model nested ANOVAs testing the effects of burn year and distance from motte on abundance of the orders that are >5% of potential prey for adults. ANOVAs included motte nested within burn treatment as a random effect. Data were log(x+1) transformed. P-values <0.005 in bold.

Taxa	Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Adult Coleopteran						
	Burn Year	2	2	11.4	2.11	0.167
	Plot Location	1	1	225.3	6.65	0.011
	Burn Year*Plot Location	2	2	225.3	0.10	0.902
	Time	1	1	227.6	109.98	**<.0001**
	Burn Year*Time	2	2	227.7	1.71	0.182
	Plot Location*Time	1	1	225.3	1.31	0.253
	Burn Year*Plot Location*Time	2	2	225.3	0.45	0.639
Ants (Hymenoptera)						
	Burn Year	2	2	13	14.05	**0.001**
	Plot Location	1	1	227.1	6.13	0.014
	Burn Year*Plot Location	2	2	227.1	5.43	0.005
	Time	1	1	228.5	0.33	0.564
	Burn Year*Time	2	2	228.5	4.05	0.019
	Plot Location*Time	1	1	227.1	0.00	0.986
	Burn Year*Plot Location*Time	2	2	227.1	0.49	0.612
Orthoptera						
	Burn Year	2	2	12.4	4.54	0.033
	Plot Location	1	1	226.5	0.46	0.500
	Burn Year*Plot Location	2	2	226.5	0.21	0.807
	Time	1	1	227.8	6.08	0.014
	Burn Year*Time	2	2	227.8	5.03	0.007
	Plot Location*Time	1	1	226.5	7.61	0.006
	Burn Year*Plot Location*Time	2	2	226.5	0.64	0.529
Araneae						
	Burn Year	2	2	13.1	0.36	0.703
	Plot Location	1	1	227.2	0.03	0.857
	Burn Year*Plot Location	2	2	227.2	0.14	0.872
	Time	1	1	229.2	43.15	**<.0001**
	Burn Year*Time	2	2	229.2	1.61	0.202
	Plot Location*Time	1	1	227.2	0.53	0.467
	Burn Year*Plot Location*Time	2	2	227.2	0.44	0.646
Flying (Hymenoptera)						
	Burn Year	2	2	13	0.41	0.672
	Plot Location	1	1	227	2.73	0.100
	Burn Year*Plot Location	2	2	227	0.58	0.560
	Time	1	1	227.8	0.02	0.891
	Burn Year*Time	2	2	227.9	0.68	0.506
	Plot Location*Time	1	1	227	1.32	0.252
	Burn Year*Plot Location*Time	2	2	227	0.89	0.411
Total						
	Burn Year	2	2	193.5	0.42	0.657
	Plot Location	3	3	190.5	1.97	0.119
	Burn Year*Plot Location	6	6	190.5	0.11	0.995
	Time	3	3	190.7	4.87	**0.003**
	Burn Year*Time	6	6	190.7	1.32	0.249
	Plot Location*Time	9	9	190.5	1.62	0.113
	Burn Year*Plot Location*Time	18	18	190.5	0.39	0.988

Table 25. PERMANOVA results of biomass (g) for potential prey of chicks collected in pitfall traps analyzed in each month separately and with all four months combined. Bu = time since burn treatments (1-year, 2 years, and control), Pl = Pot location or distance from motte (Center, 1m, 15m, and 50m), BuxPl = interaction between burn and plot location, Res = residuals. Data were square root transformed. p-values <0.005 in bold. ** Term has one or more empty cells. Data were collected at Packsaddle WMA, Oklahoma in the summer of 2018.

Sampling Period	Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
May							
	Bu	2	1522.4	761.18	3.33	**0.003**	999
	Pl	3	3944.8	1314.9	5.75	**0.001**	997
	BuxPl	6	987.26	164.54	0.72	0.845	999
	Res	52	11884	228.54			
	Total	63	18374				
June							
	Bu	2	3466.8	1733.4	4.67	**0.001**	999
	Pl	3	3648.1	1216	3.28	**0.002**	996
	BuxPl	6	1450.1	241.69	0.65	0.899	999
	Res	52	19287	370.91			
	Total	63	27898				
July							
	Bu	2	2638.5	1319.3	2.95	0.005	998
	Pl	3	4981.9	1660.6	3.72	**0.001**	999
	BuxPl	6	1915	319.17	0.71	0.858	997
	Res	52	23238	446.88			
	Total	63	32703				
August							
	Bu	2	3992.8	1996.4	3.16	**0.002**	999
	Pl	4	5833.1	1458.3	2.31	0.011	998
	BuxPl**	6	3265.9	544.31	0.86	0.676	998
	Res	47	29680	631.48			
	Total	59	43020				
All Months Summed							
	Bu	2	1394.2	697.08	4.72	**0.001**	998
	Pl	3	2951.5	983.84	6.66	**0.001**	996
	BuxPl	6	602.93	100.49	0.68	0.864	997
	Res	52	7678.8	147.67			
	Total	63	12690				

Table 26. PERMANOVA results of biomass (g) for potential prey of adults collected in pitfall traps analyzed in each month separately and with all four months combined. Bu = time since burn treatments (1-year, 2 years, and control), Pl = Pot location or distance from motte (Center, 1m, 15m, and 50m), BuxPl = interaction between burn and plot location, Res = residuals. Data were square root transformed. p-values <0.005 in bold. ** Term has one or more empty cells. Data were collected at Packsaddle WMA, Oklahoma in the summer of 2018.

Sampling Period	Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
May							
	Bu	2	2398.7	1199.4	2.85	0.008	998
	Pl	3	5568	1856	4.40	**0.001**	996
	BuxPl	6	2235.9	372.65	0.88	0.595	998
	Res	52	21922	421.57			
	Total	63	32324				
June							
	Bu	2	6118.1	3059	4.16	**0.001**	998
	Pl	3	3391.4	1130.5	1.54	0.081	999
	BuxPl	6	3493.7	582.28	0.79	0.774	999
	Res	52	38232	735.23			
	Total	63	51407				
July							
	Bu	2	5888.6	2944.3	3.26	**0.003**	998
	Pl	3	5390.9	1797	1.99	0.023	998
	BuxPl	6	4819.7	803.28	0.89	0.609	999
	Res	52	46979	903.44			
	Total	63	63127				
August							
	Bu	2	6412.7	3206.3	2.93	**0.002**	997
	Pl	4	6195.9	1549	1.41	0.117	999
	BuxPl**	6	5862	977	0.89	0.614	999
	Res	47	51496	1095.7			
	Total	59	70828				
All Months Summed							
	Bu	2	2833.9	1417	5.52	**0.001**	998
	Pl	3	1859.4	619.8	2.41	**0.002**	999
	BuxPl	6	1640.9	273.49	1.06	0.379	997
	Res	52	13355	256.83			
	Total	63	19762				

Table 27. Results of SIMPER analyses on arthropod biomass (g) for potential prey of chicks. SMIPER analyses, similarity percentages, break down the contribution of each order to the observed dissimilarity between samples for the PERMANOVA analyses. Total % explained shows the cumulative percentage of the average dissimilarity that is explained by all orders in each row. Data were square root transformed.

			Percent Contribution				
Comparison	**Average Dissimilarity**	**Adult Coleopteran**	**Ants (Hymenoptera)**	**Flying (Hymenoptera)**	**Orthoptera**	**Araneae**	**Total % Explained**
Control vs. 2 years since	17.31	27.2	26.26	-	11.06	11.26	75.78
Control vs. 1 year since	16.74	25.75	27.25	-	10.21	11.45	74.66
2 years since vs. 1 year since	18.54	20	33.5	-	11.91	11.13	76.54
Center vs. 1m	19.99	25.53	30.29	-	9.66	11.18	76.66
Center vs. 15m	21.18	27.65	30.51		9.07	9.76	76.99
1m vs. 15m	15.03	23.72	26.9	11.98	-	11.57	74.17
Center vs. 50m	24.2	25.82	35.3	8.98	-	-	70.1
1m vs. 50m	16.07	23.12	28.48	13.37	-	10.87	75.84
15m vs. 50m	15.71	25.14	27.85	11.55	-	11.39	75.93

Table 28. Results of SIMPER analyses on arthropod biomass (g) for potential prey of adults. SMIPER analyses, similarity percentages, break down the contribution of each order to the observed dissimilarity between samples for the PERMANOVA analyses. Total % explained shows the cumulative percentage of the average dissimilarity that is explained by all orders in each row. Data were square root transformed.

		Percent Contribution							
Comparison	**Average Dissimilarity**	**Adult Coleopteran**	**Adult Lepidoptera**	**Ants (Hymenoptera)**	**Flying (Hymenoptera)**	**Orthoptera**	**Araneae**	**Hemiptera**	**Total % Explained**
Control vs. 2 years since	25.28	18.92	-	17.88	-	21.96	11.75	-	70.51
Control vs. 1 year since	24.5	19.98	-	19.68	10.86	14.65	10.54	-	75.71
2 years since vs. 1 year since	21.98	16.94	11.19	13.54	-	23.88	12.53	-	78.08
Center vs. 1m	24.77	21.57	-	21.99	-	17.76	10.87	-	72.19
Center vs. 15m	23.31	24.68	-	13.75	-	16.39	10.93	11.12	76.87
1m vs. 15m	20.99	18.12	-	17.68	12.1	15.19	-	11.55	74.64
Center vs. 50m	25.39	24.8	-	16.25	-	14.59	11.22	10.36	77.22
1m vs. 50m	22.26	17.3	-	20.1	12.48	13.35	11.75	-	74.98
15m vs. 50m	20.29	20.21	-	15.51	12.27	12.97	12.55	-	73.51

Table 29. Summary of mixed model nested ANOVAs testing the effects of burn year and distance from motte on biomass (mg) of the orders that are >5% of potential prey for chicks. ANOVAs included motte nested within burn treatment as a random effect. Data were log(x+1) transformed. P-values <0.005 in bold.

Taxa	Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Adult Coleopteran						
	Burn Year	2	2	11.7	3.07	0.085
	Plot Location	1	1	225.8	10.71	**0.001**
	Burn Year*Plot Location	2	2	225.8	0.08	0.928
	Time	1	1	228.5	96.57	**<.0001**
	Burn Year*Time	2	2	228.5	0.81	0.447
	Plot Location*Time	1	1	225.8	1.83	0.178
	Burn Year*Plot Location*Time	2	2	225.8	0.60	0.550
Ants (Hymenoptera)						
	Burn Year	2	2	13.1	6.03	0.014
	Plot Location	1	1	227.1	47.47	**<.0001**
	Burn Year*Plot Location	2	2	227.1	1.18	0.310
	Time	1	1	228.2	3.47	0.064
	Burn Year*Time	2	2	228.2	5.78	**0.004**
	Plot Location*Time	1	1	227.1	1.56	0.214
	Burn Year*Plot Location*Time	2	2	227.1	0.28	0.755
Araneae						
	Burn Year	2	2	13.2	0.10	0.902
	Plot Location	1	1	227.3	0.21	0.646
	Burn Year*Plot Location	2	2	227.3	0.28	0.753
	Time	1	1	229.4	57.77	**<.0001**
	Burn Year*Time	2	2	229.4	0.48	0.618
	Plot Location*Time	1	1	227.3	0.02	0.882
	Burn Year*Plot Location*Time	2	2	227.3	0.14	0.871
Total						
	Burn Year	2	2	13	2.00	0.175
	Plot Location	1	1	227	2.66	0.104
	Burn Year*Plot Location	2	2	227	1.99	0.139
	Time	1	1	227.9	162.03	**<.0001**
	Burn Year*Time	2	2	228	4.67	0.010
	Plot Location*Time	1	1	227	0.11	0.738
	Burn Year*Plot Location*Time	2	2	227	0.44	0.645

Table 30. Summary of mixed model nested ANOVAs testing the effects of burn year and distance from motte on biomass (mg) of the orders that are >5% of potential prey for adults. ANOVAs included motte nested within burn treatment as a random effect. Data were log(x+1) transformed. P-values <0.005 in bold.

Taxa	Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Adult Coleopteran						
	Burn Year	2	2	11.1	2.04	0.176
	Plot Location	1	1	225.1	6.54	0.011
	Burn Year*Plot Location	2	2	225.1	0.42	0.656
	Time	1	1	228.2	64.59	**<.0001**
	Burn Year*Time	2	2	228.2	0.97	0.382
	Plot Location*Time	1	1	225.1	0.92	0.338
	Burn Year*Plot Location*Time	2	2	225.1	0.19	0.831
Orthoptera						
	Burn Year	2	2	12.7	3.69	0.055
	Plot Location	1	1	226.7	0.51	0.475
	Burn Year*Plot Location	2	2	226.7	0.85	0.430
	Time	1	1	228	3.00	0.084
	Burn Year*Time	2	2	228	3.12	0.046
	Plot Location*Time	1	1	226.7	8.91	**0.003**
	Burn Year*Plot Location*Time	2	2	226.7	1.48	0.230
Araneae						
	Burn Year	2	2	13.1	0.56	0.582
	Plot Location	1	1	227.3	0.96	0.327
	Burn Year*Plot Location	2	2	227.3	0.22	0.801
	Time	1	1	229.1	23.31	**<.0001**
	Burn Year*Time	2	2	229.2	3.76	0.025
	Plot Location*Time	1	1	227.3	0.25	0.618
	Burn Year*Plot Location*Time	2	2	227.3	0.63	0.534
Ants (Hymenoptera)						
	Burn Year	2	2	13	12.39	**0.001**
	Plot Location	1	1	227.1	7.58	0.006
	Burn Year*Plot Location	2	2	227.1	5.90	**0.003**
	Time	1	1	228.4	1.63	0.203
	Burn Year*Time	2	2	228.4	5.27	0.006
	Plot Location*Time	1	1	227.1	0.01	0.927
	Burn Year*Plot Location*Time	2	2	227.1	0.20	0.823
Total						
	Burn Year	2	2	12.6	1.04	0.381
	Plot Location	1	1	226.7	1.38	0.242
	Burn Year*Plot Location	2	2	226.7	0.47	0.626
	Time	1	1	228.3	87.54	**<.0001**
	Burn Year*Time	2	2	228.3	5.90	**0.003**
	Plot Location*Time	1	1	226.7	2.31	0.130
	Burn Year*Plot Location*Time	2	2	226.7	0.25	0.777

Table 31. PCA eigenvectors showing loading of vegetation measures on both principal components. Nudd's segments were collected such that 1 was on the ground and 12 was 1.2 m above the ground. Visual obstruction data were collected in Packsaddle WMA, Oklahoma in May and July of 2018.

	Principal Components	
Nudd's Segments	**Prin 1**	**Prin 2**
1	0.13429	0.4052
2	0.163	0.41212
3	0.2356	0.37563
4	0.29016	0.29858
5	0.33035	0.19104
6	0.34413	0.10835
7	0.35474	-0.02812
8	0.3521	-0.11856
9	0.33134	-0.24208
10	0.3007	-0.29501
11	0.27544	-0.32598
12	0.24948	-0.34748

Table 32. Summary of mixed model nested ANOVAs on principal components on Nudd's board measurements. ANOVAs included motte nested within burn treatment as a random effect. P-values <0.005 in bold. Visual obstruction data were collected in Packsaddle WMA, Oklahoma in May and July of 2018.

Principal Components	**Source**	**Nparm**	**DFNum**	**DFDen**	**F Ratio**	**Prob > F**
Prin 1						
	Burn Year	2	2	53	0.96	0.390
	Plot Location	3	3	219	2.66	0.049
	Burn Year*Plot Location	6	6	219	1.20	0.310
	Time	1	1	219	0.03	0.871
	Burn Year*Time	2	2	219	0.64	0.528
	Plot Location*Time	3	3	219	0.92	0.430
	Burn Year*Plot Location*Time	6	6	219	0.59	0.739
Prin 2						
	Burn Year	2	2	89.7	6.07	**0.003**
	Plot Location	3	3	219	37.31	**<.0001**
	Burn Year*Plot Location	6	6	219	3.20	0.005
	Time	1	1	219	0.01	0.919
	Burn Year*Time	2	2	219	1.30	0.276
	Plot Location*Time	3	3	219	0.37	0.777
	Burn Year*Plot Location*Time	6	6	219	0.45	0.844

Table 33. Summary of standard least squares means ± SE for individual mixed model nested ANOVAs of Nudd's board vegetation data. Differences in letters across rows indicate significant differences where $\alpha < 0.005$. Visual obstruction data were collected in Packsaddle WMA, Oklahoma in May and July of 2018.

	Burn Year			**Plot Location**			
Principal Components	**1 Year Since**	**2 Years Since**	**Control**	**Center**	**1m**	**15m**	**50m**
Prin 1	0.50 ± 0.86^{a}	1.76 ± 0.86^{a}	0.23 ± 0.78^{a}	0.83 ± 0.48^{a}	-0.65 ± 0.48^{a}	-0.01 ± 0.48^{a}	0.14 ± 0.48^{a}
Prin 2	-0.79 ± 0.47^{a}	-1.79 ± 0.47^{ab}	-2.99 ± 0.43^{b}	-1.86 ± 0.26^{b}	0.17 ± 0.26^{a}	1.11 ± 0.26^{a}	1.07 ± 0.26^{a}

Appendix C

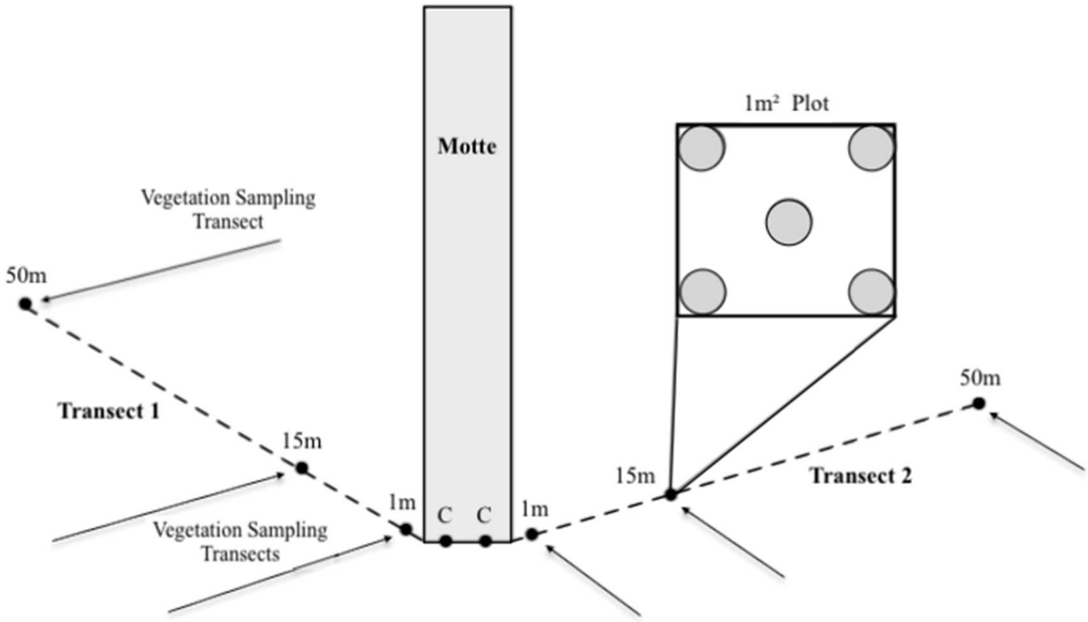


Figure 1. Visual depiction of sampling design and placement of pitfall traps at each motte in Packsaddle WMA, Oklahoma during the summer of 2018. "C" represents plots located in the center of a motte.

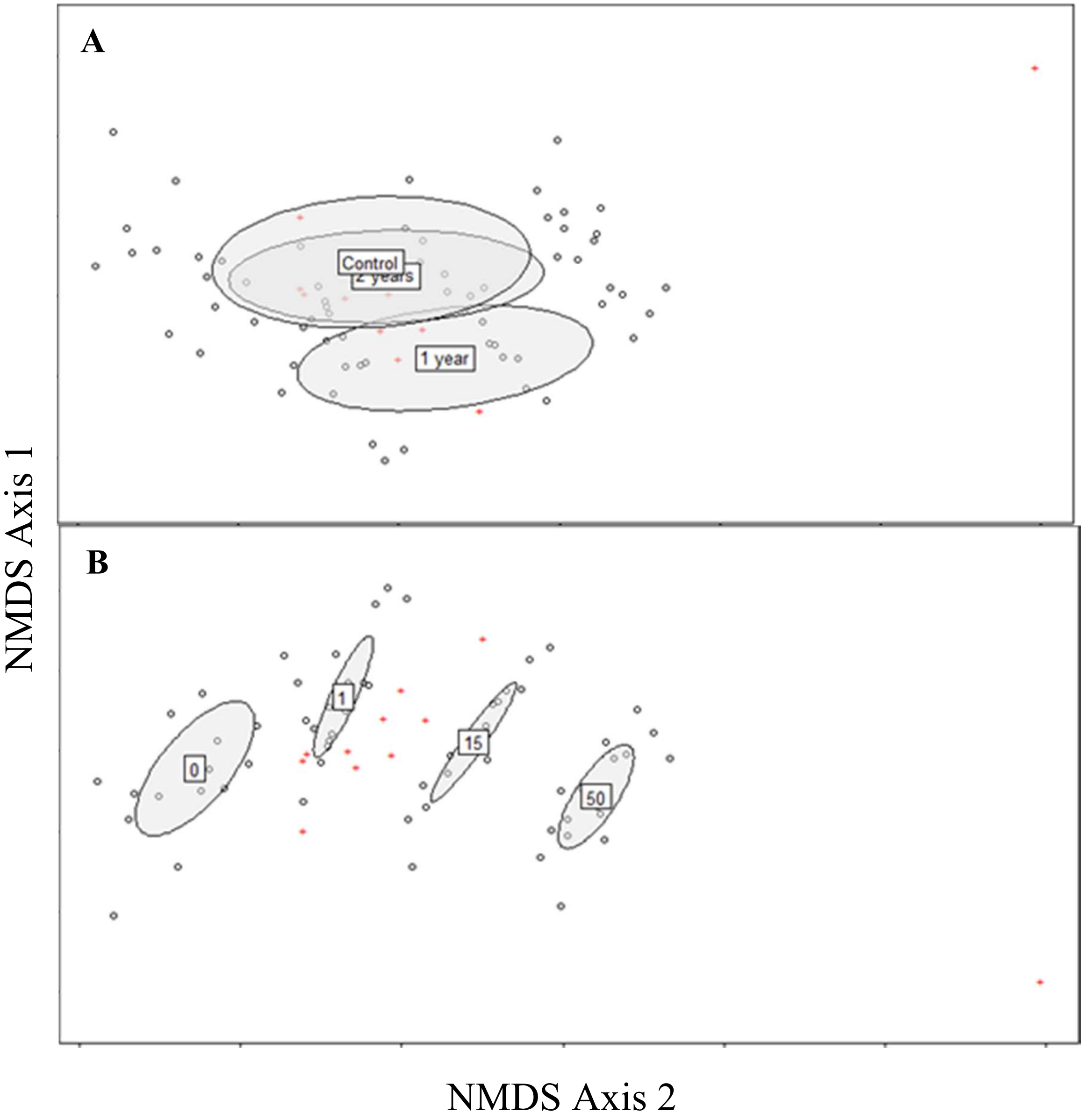


Figure 2. NMDS ordination plots of total arthropod abundance collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. A) depicts arthropod community orientation in relation to time since burn treatments, B) depicts arthropods in relation to distance from motte (m) with 0 representing center plots. Data were square root transformed.

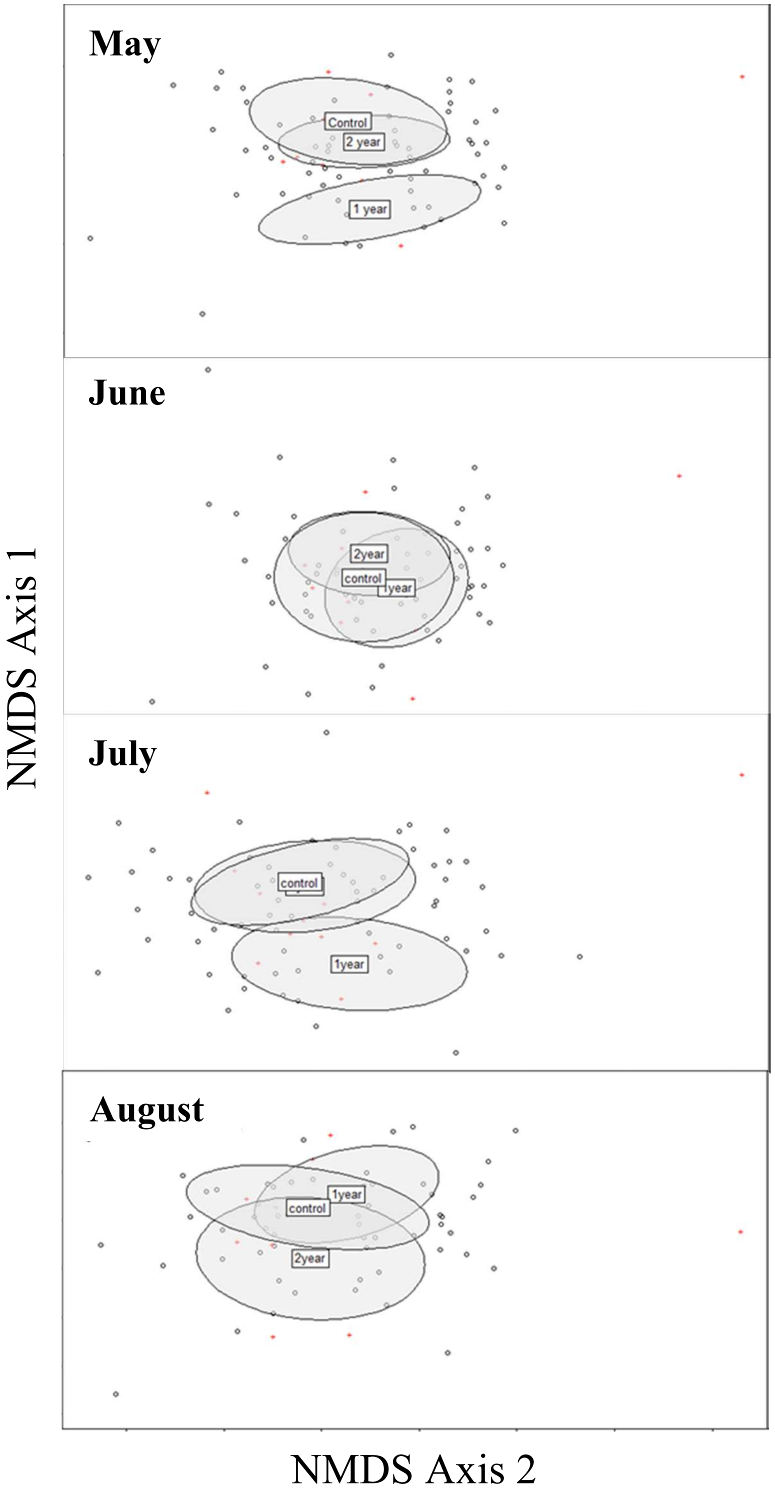


Figure 3. Abundance of arthropods in relation to time since burn treatments for each month collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. Data were square root transformed.

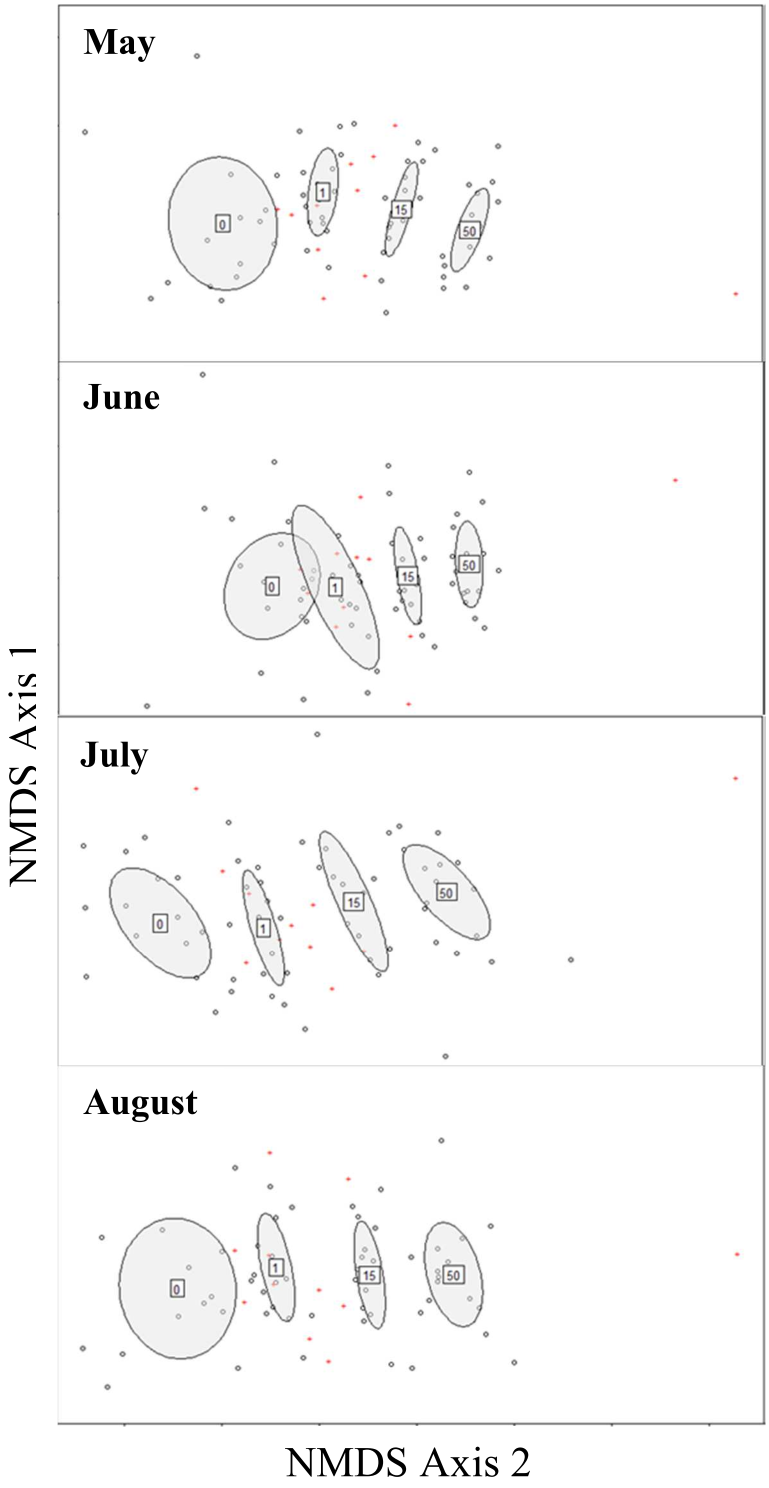


Figure 4. Abundance of arthropods collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018 in relation to distance from motte (m). Zero represents plots in the center of a motte. Data were square root transformed.

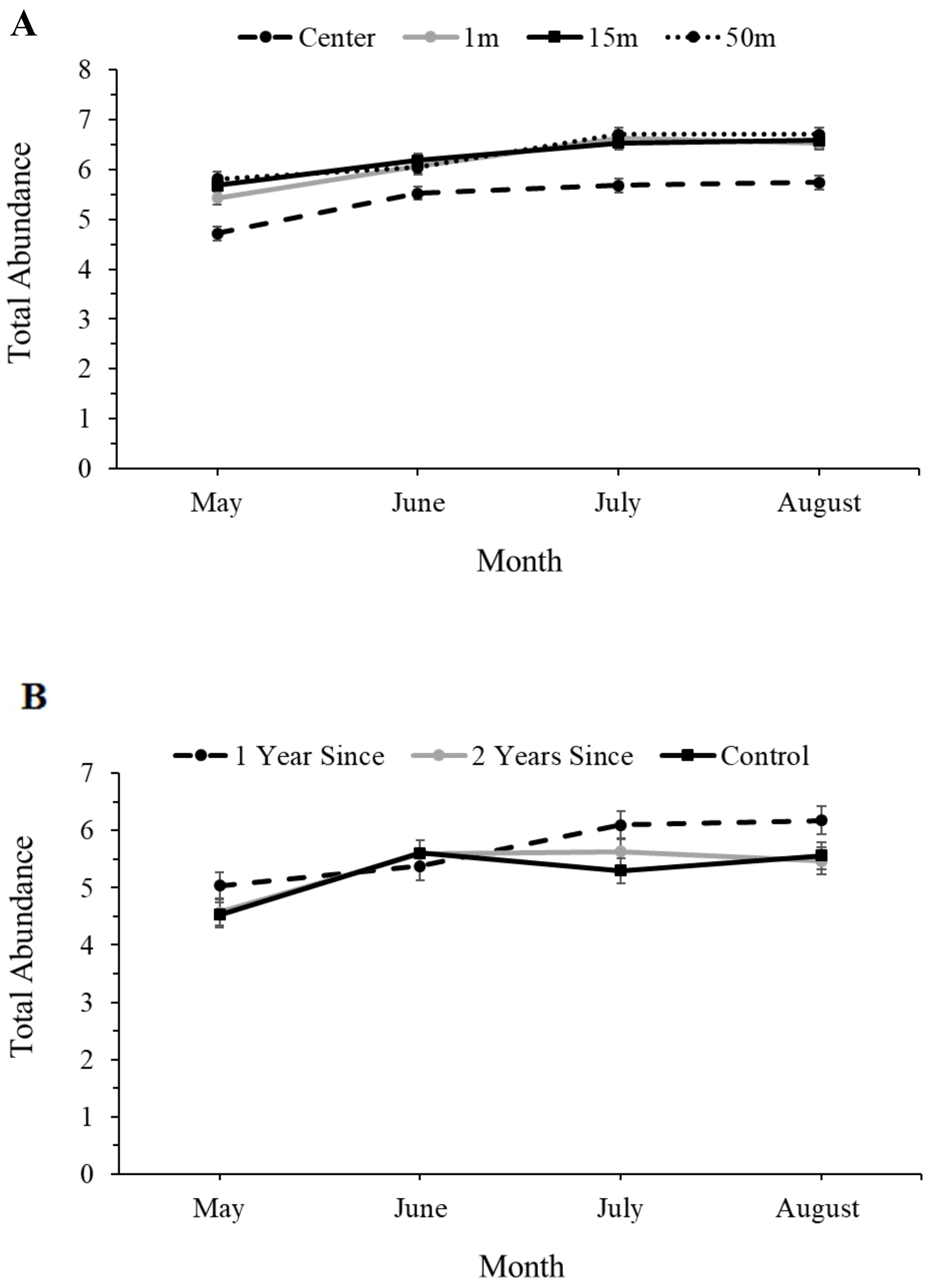


Figure 5. Least square means (± SE) for total abundance of arthropods in relation to A) distance from motte and B) time since prescribed burn for each month collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. Data were log(x+1) transformed.

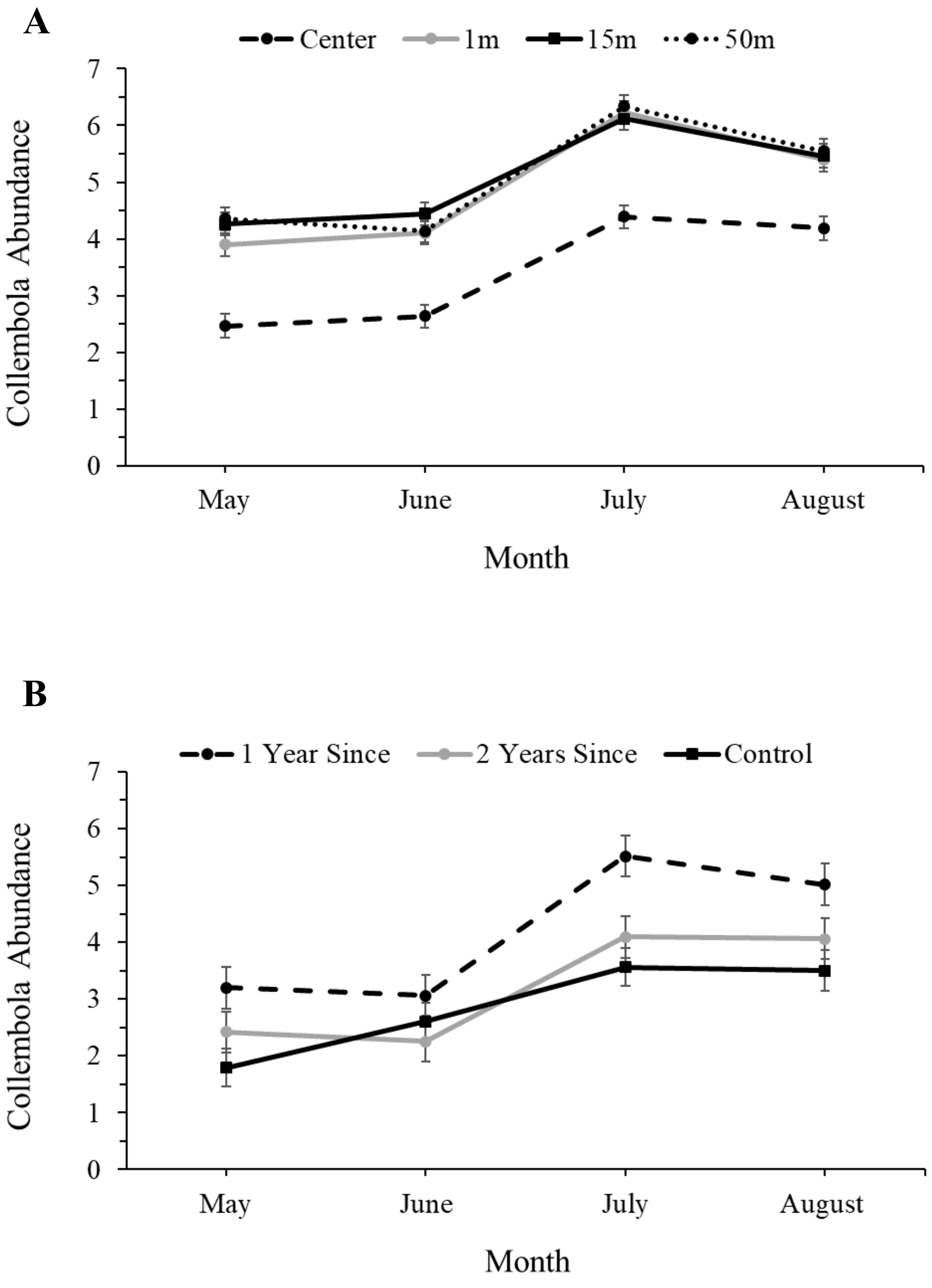


Figure 6. Least square means (± SE) for abundance of Collembola in relation to A) distance from motte and B) time since prescribed burn for each month collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. Data were log(x+1) transformed.

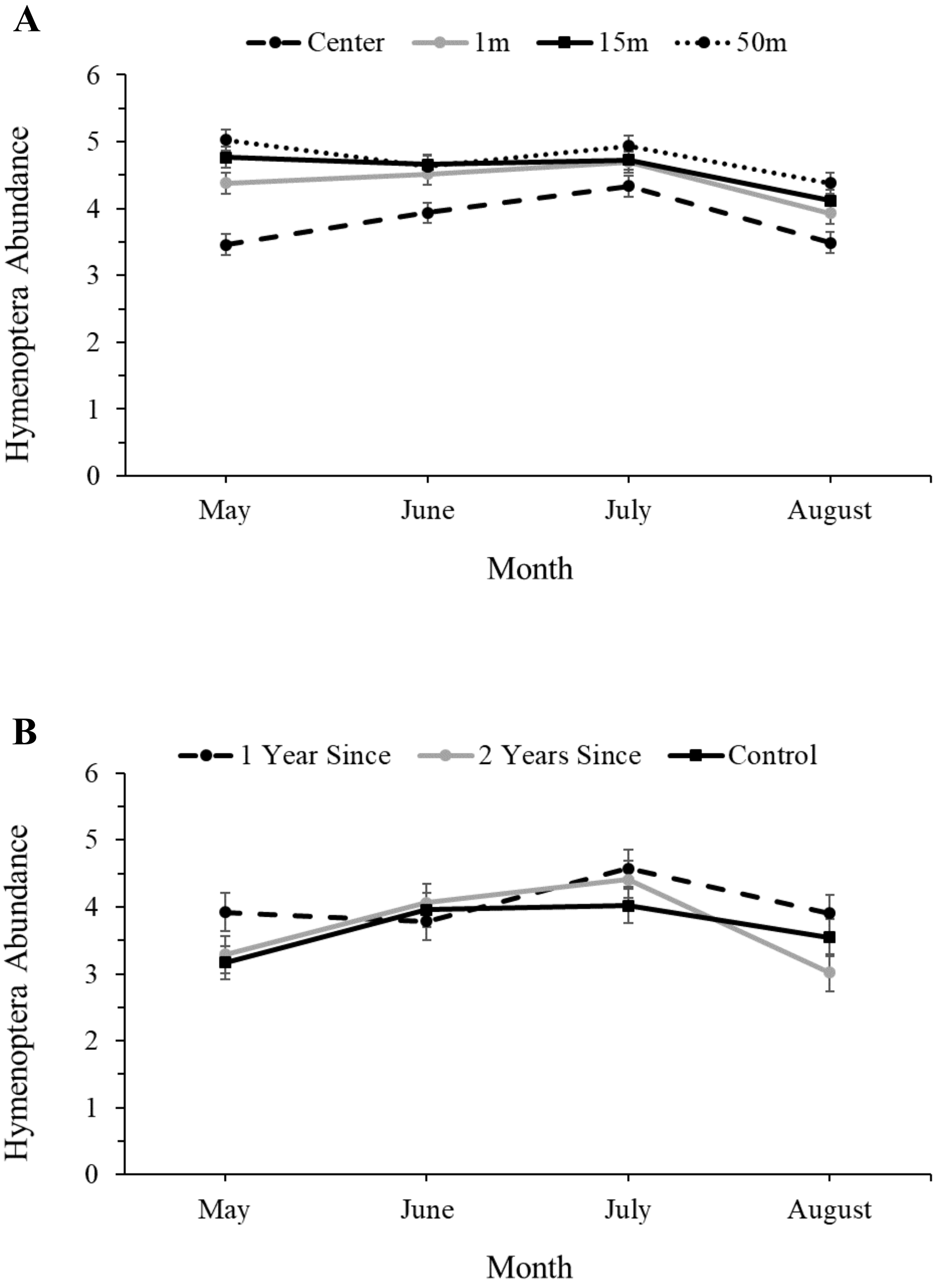


Figure 7. Least square means (± SE) for abundance of Hymenoptera in relation to A) distance from motte and B) time since prescribed burn for each month collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. Data were log(x+1) transformed.

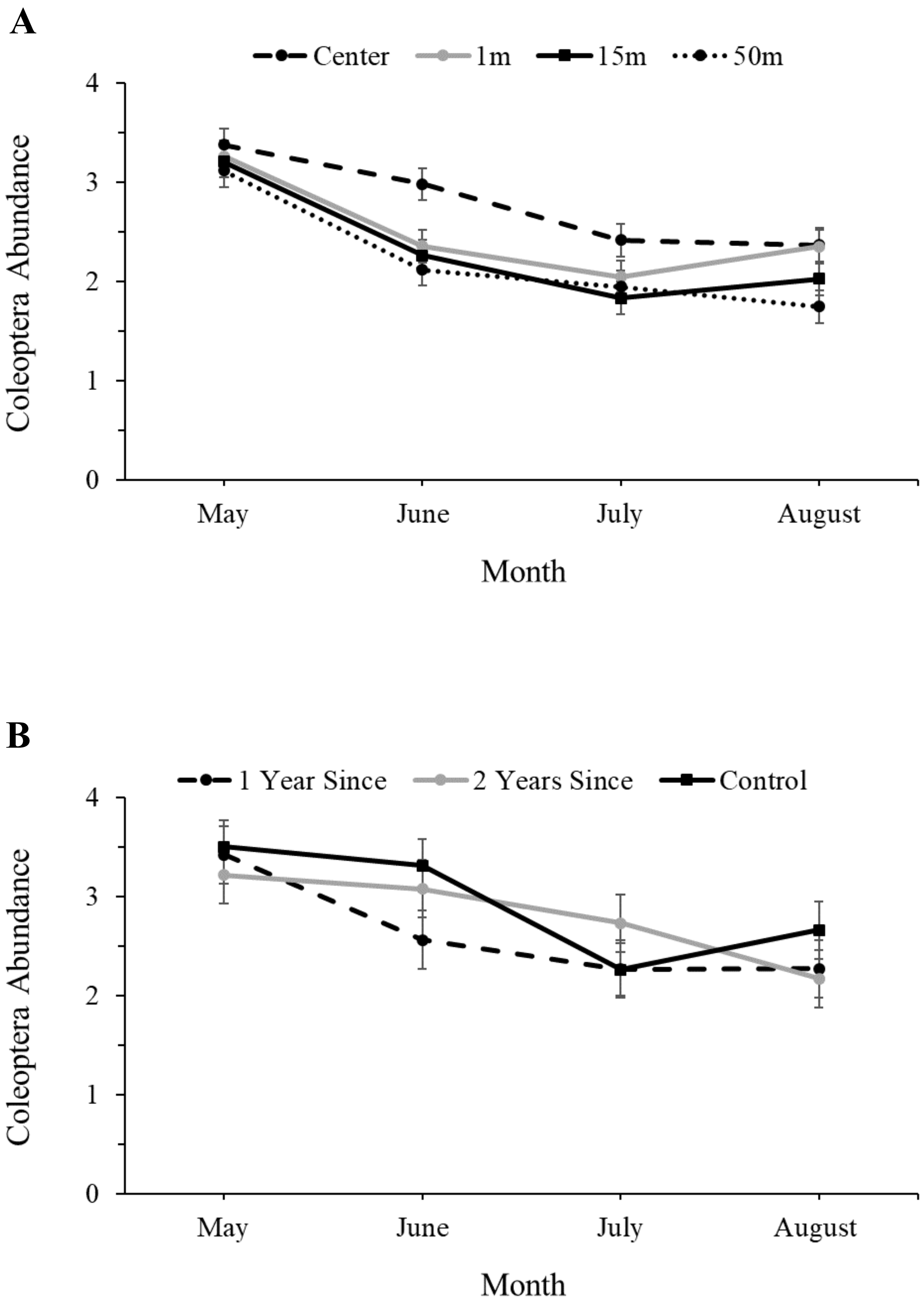


Figure 8. Least square means (± SE) for abundance of Coleoptera in relation to A) distance from motte and B) time since prescribed burn for each month collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. Data were log(x+1) transformed.

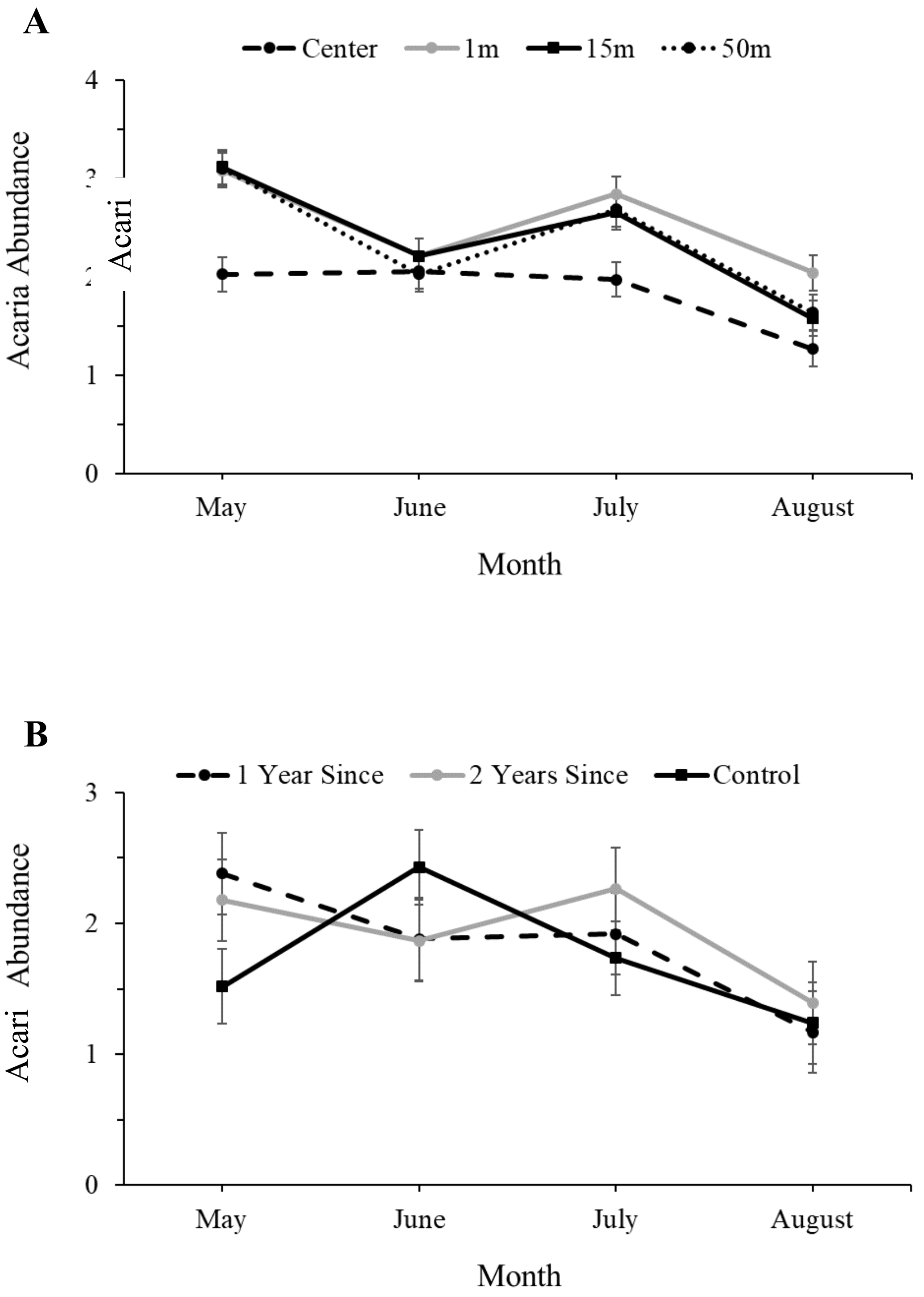
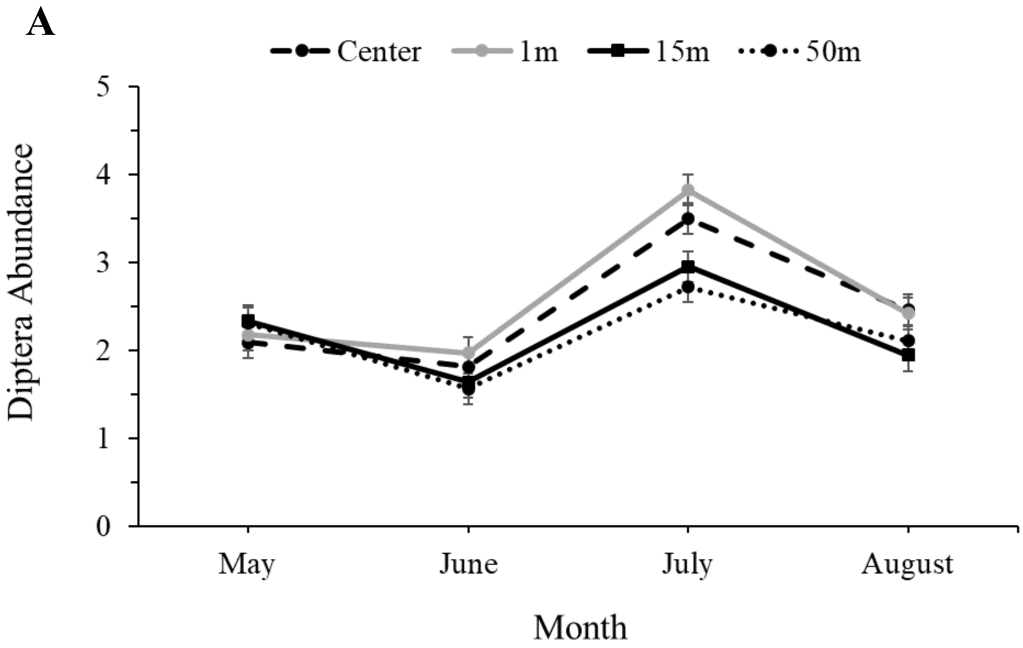


Figure 9. Least square means (± SE) for abundance of Acari in relation to A) distance from motte and B) time since prescribed burn for each month collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. Data were log(x+1) transformed.



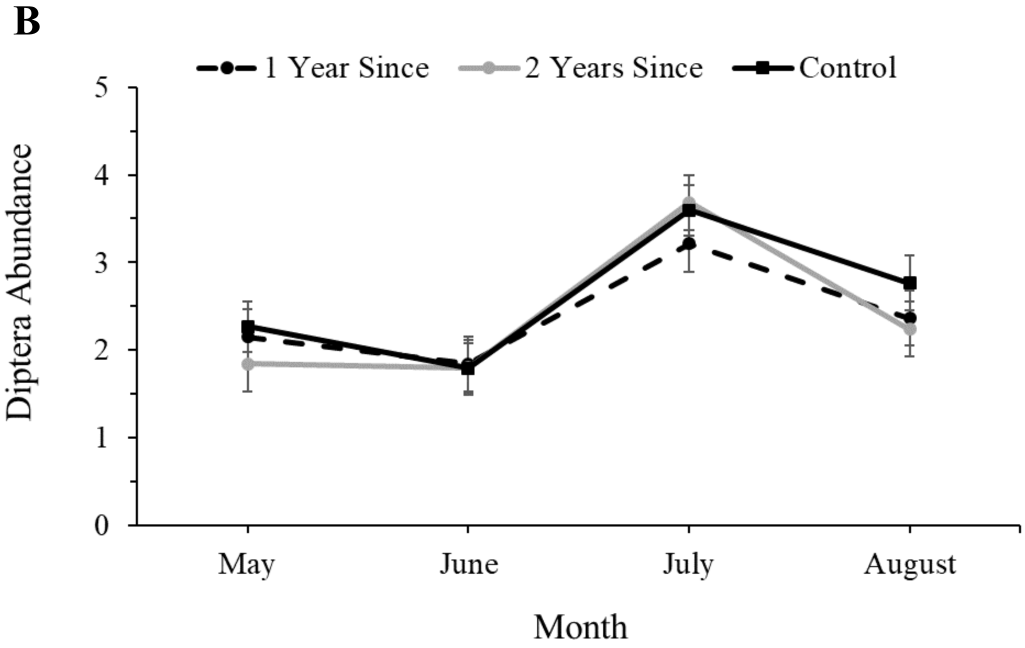


Figure 10. Least square means (± SE) for abundance of Diptera in relation to A) distance from motte and B) time since prescribed burn for each month collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. Data were log(x+1) transformed.

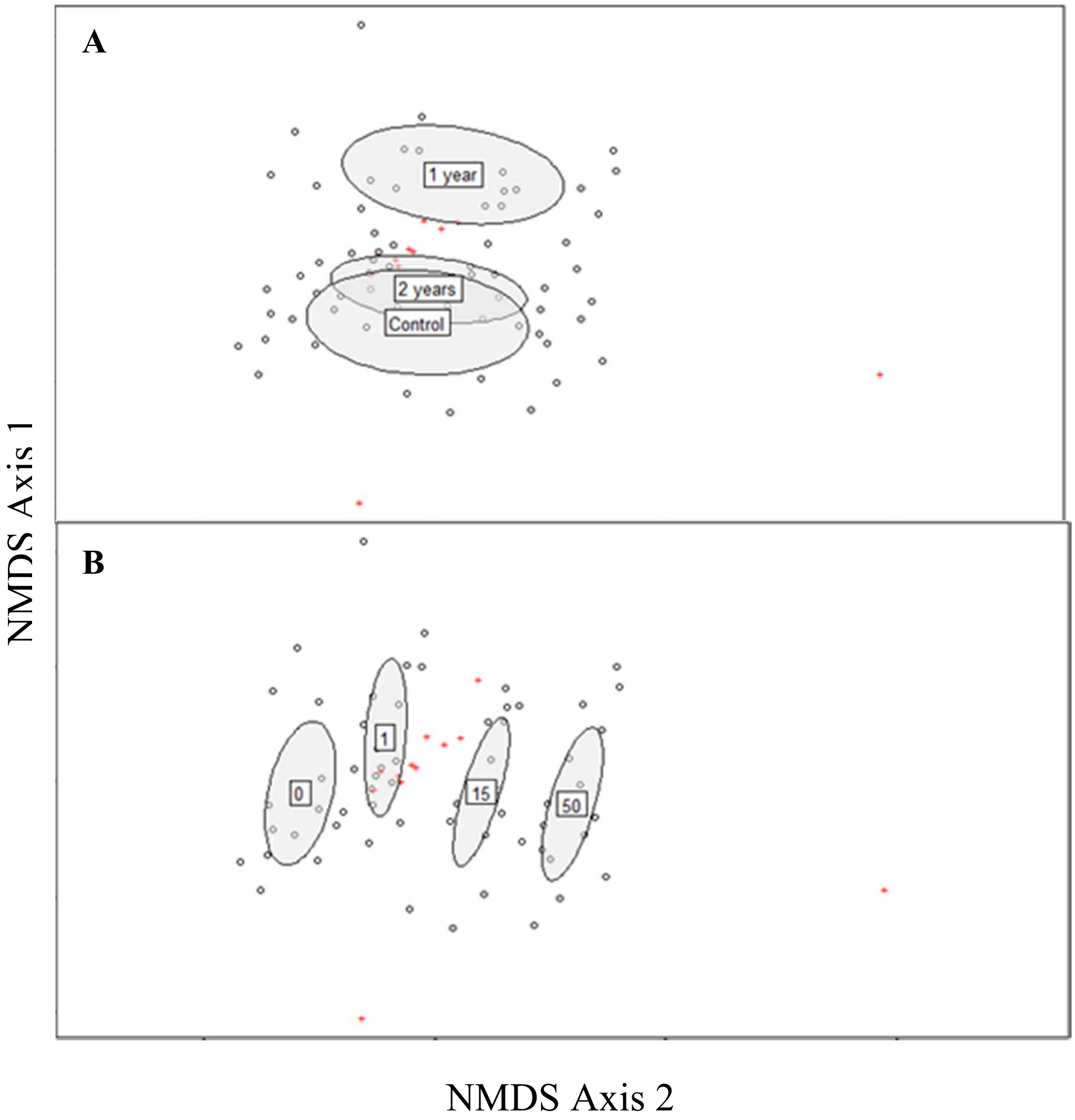


Figure 11. NMDS ordination plots of total arthropod biomass (g) collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. A) depicts arthropod community orientation in relation to time since burn treatments, B) depicts arthropods in relation to distance from motte (m) with 0 representing center plots. Data were square root transformed.

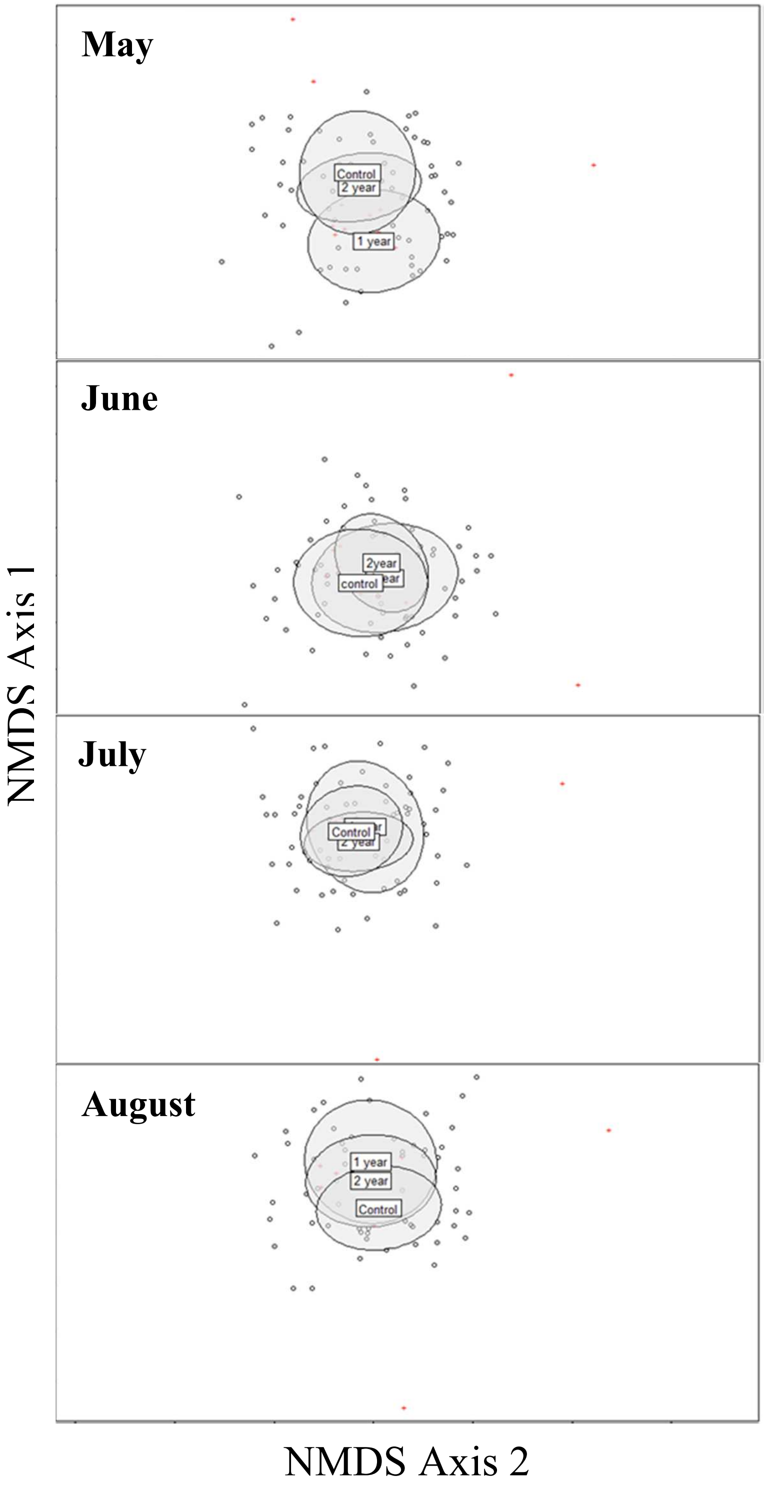


Figure 12. Biomass (g) of arthropods in relation to time since burn treatments for each month collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. Data were square root transformed.

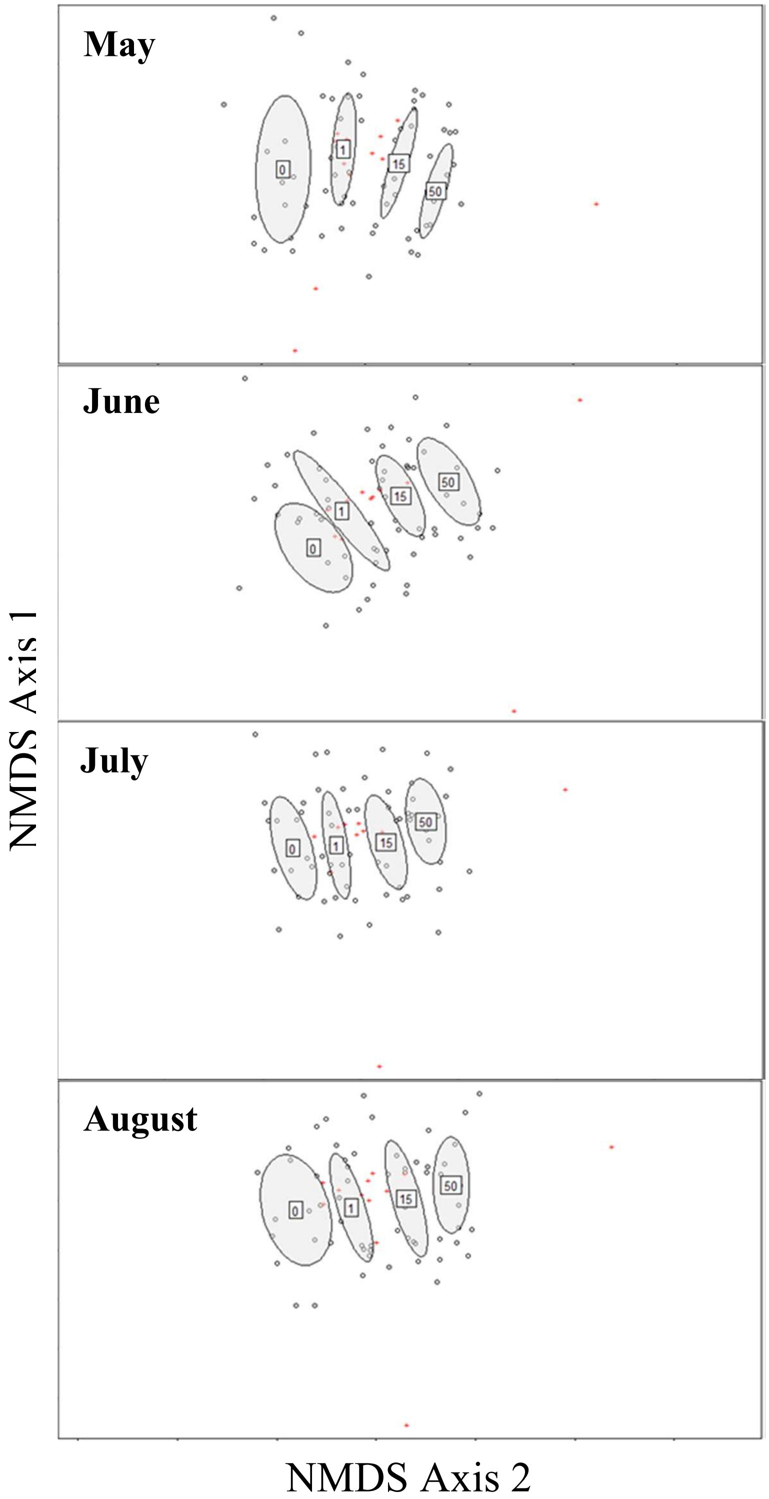


Figure 13. Biomass (g) of arthropods in relation to distance from motte (m) for each month collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. Zero represents plots in the center of a motte. Data were square root transformed.

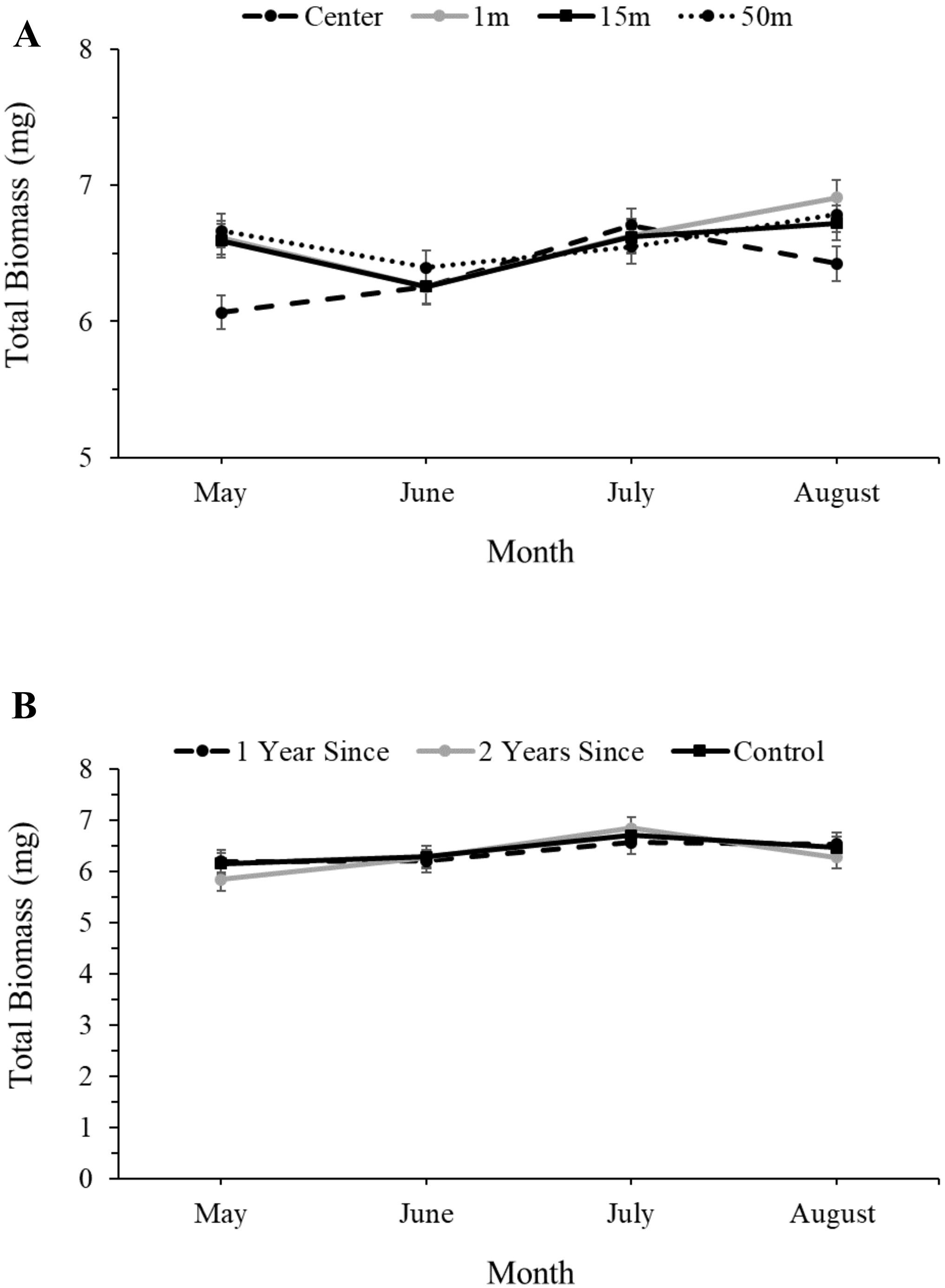


Figure 14. Least square means (±SE) for total biomass (mg) of arthropods in relation to A) distance from motte and B) time since prescribed burn for each month collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. Data were log(x+1) transformed.

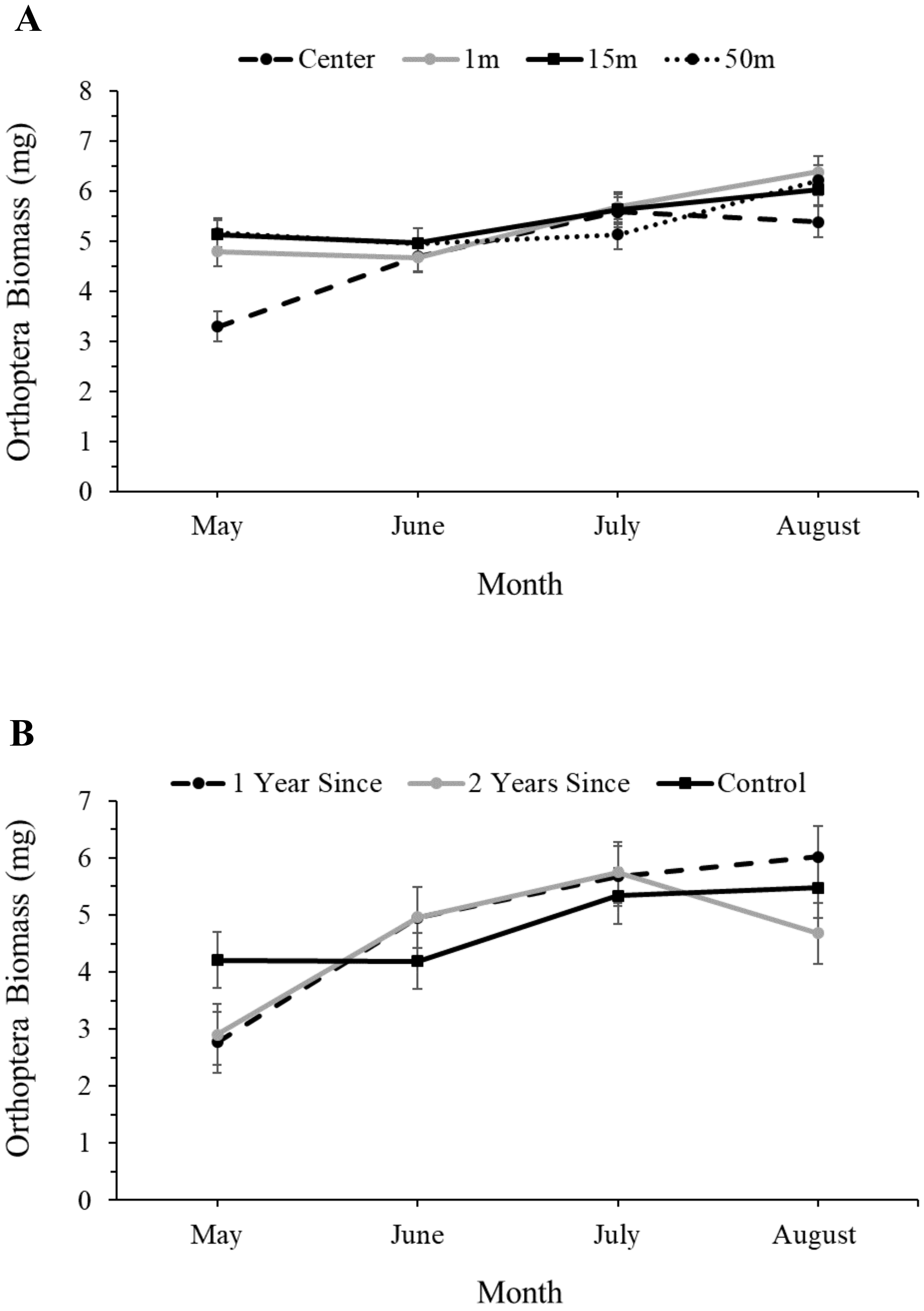
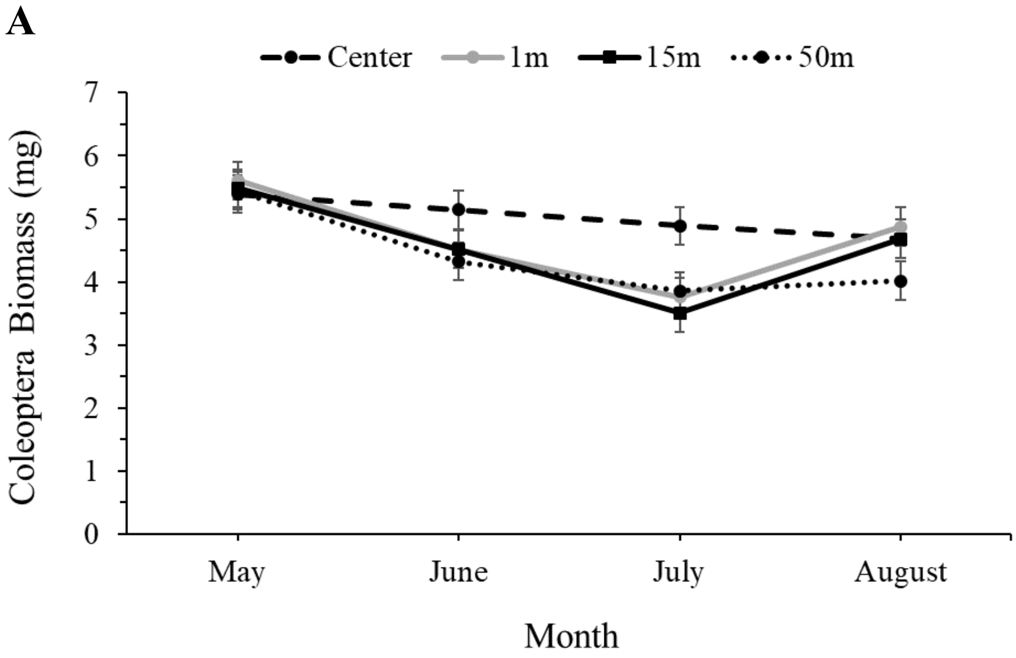


Figure 15. Least square means (±SE) for biomass (mg) of Orthoptera in relation to A) distance from motte and B) time since prescribed burn for each month collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. Data were log(x+1) transformed.



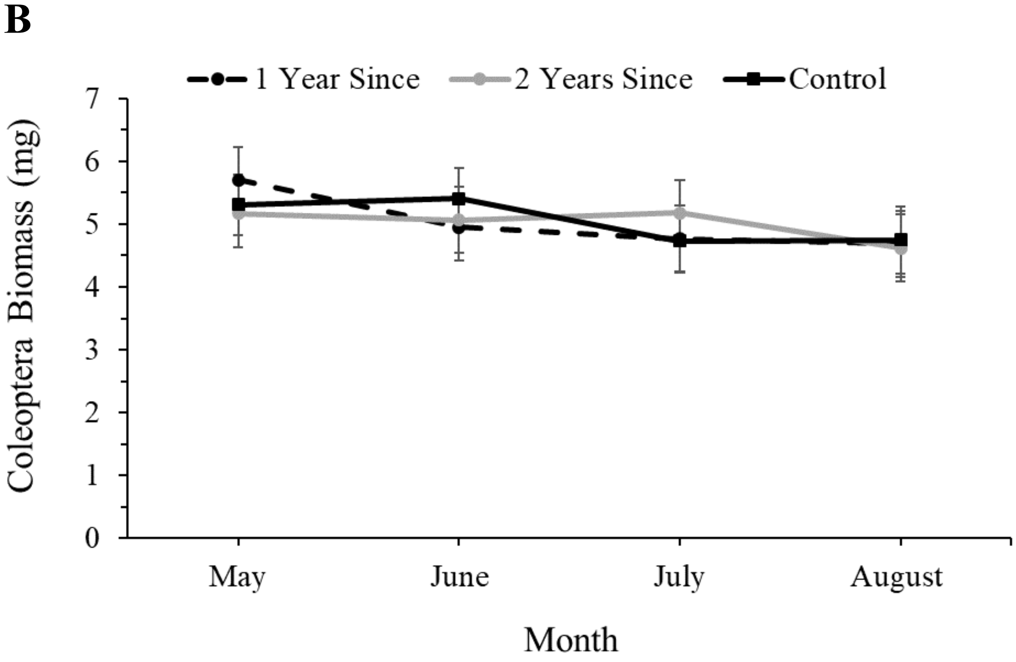


Figure 16. Least square means (±SE) for biomass (mg) of Coleoptera in relation to A) distance from motte and B) time since prescribed burn for each month collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. Data were log(x+1) transformed.

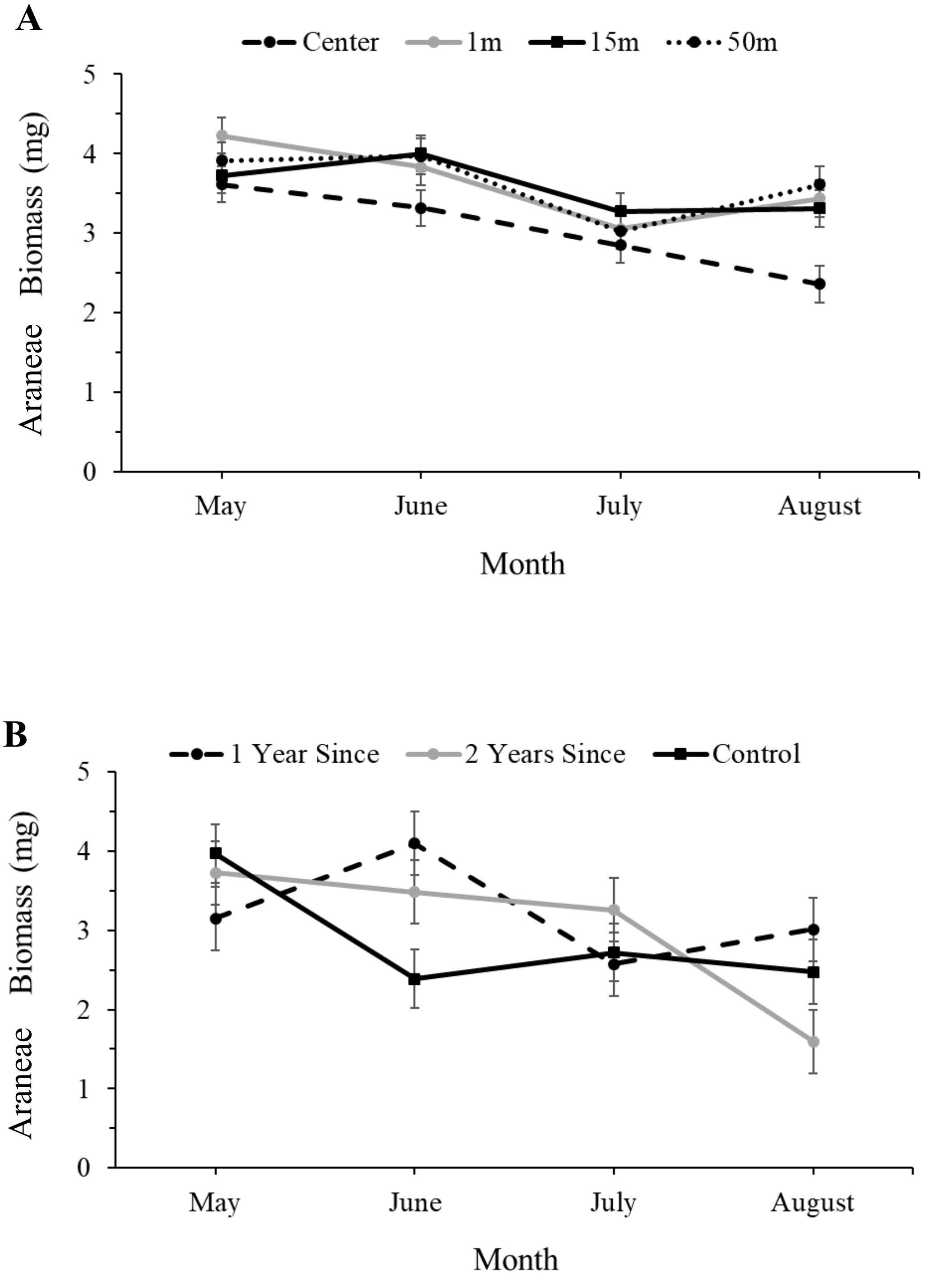


Figure 17. Least square means (±SE) for biomass (mg) of Araneae in relation to A) distance from motte and B) time since prescribed burn for each month collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. Data were log(x+1) transformed.

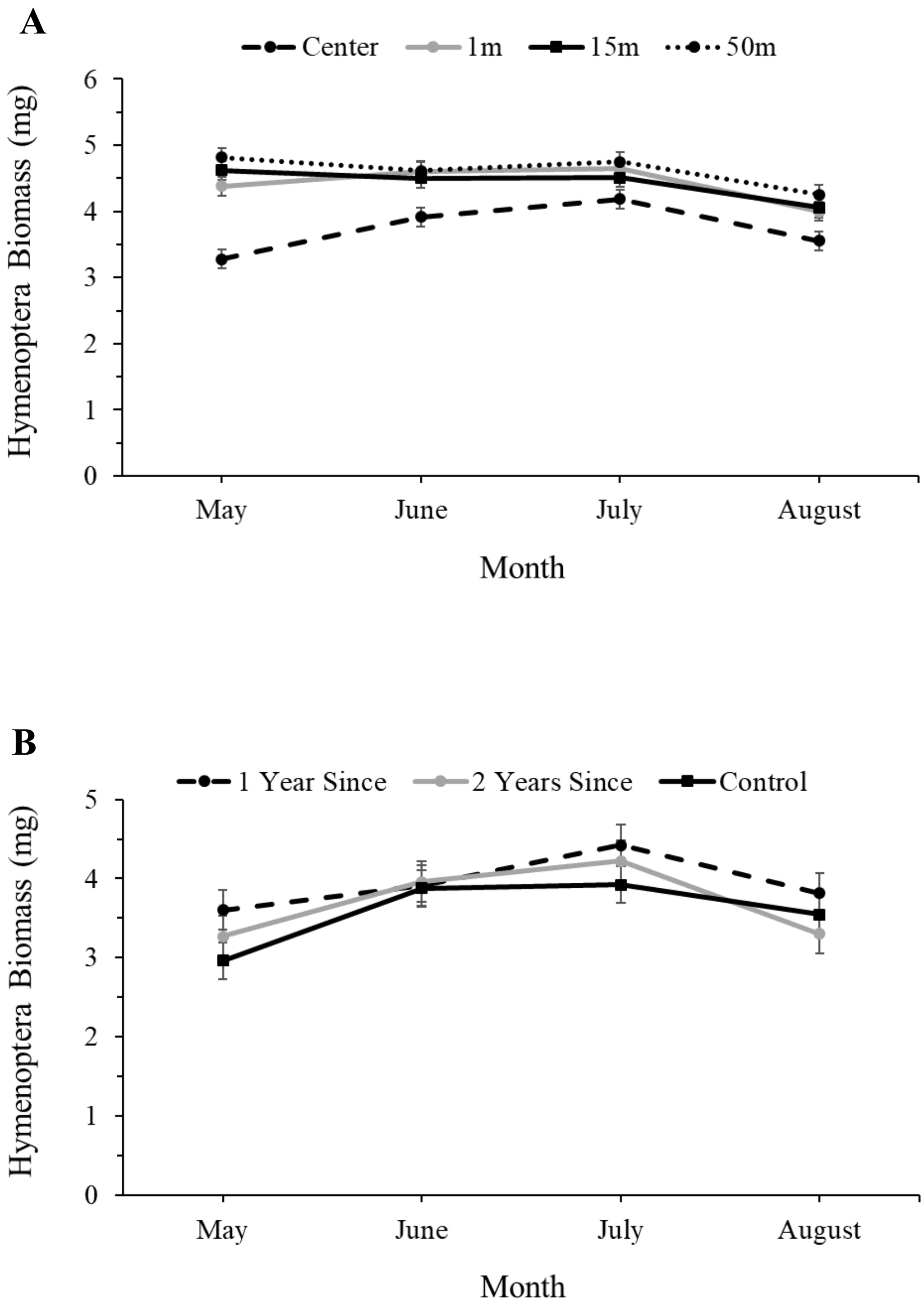


Figure 18. Least square means (±SE) for biomass (mg) of Hymenoptera in relation to A) distance from motte and B) time since prescribed burn for each month collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. Data were log(x+1) transformed.

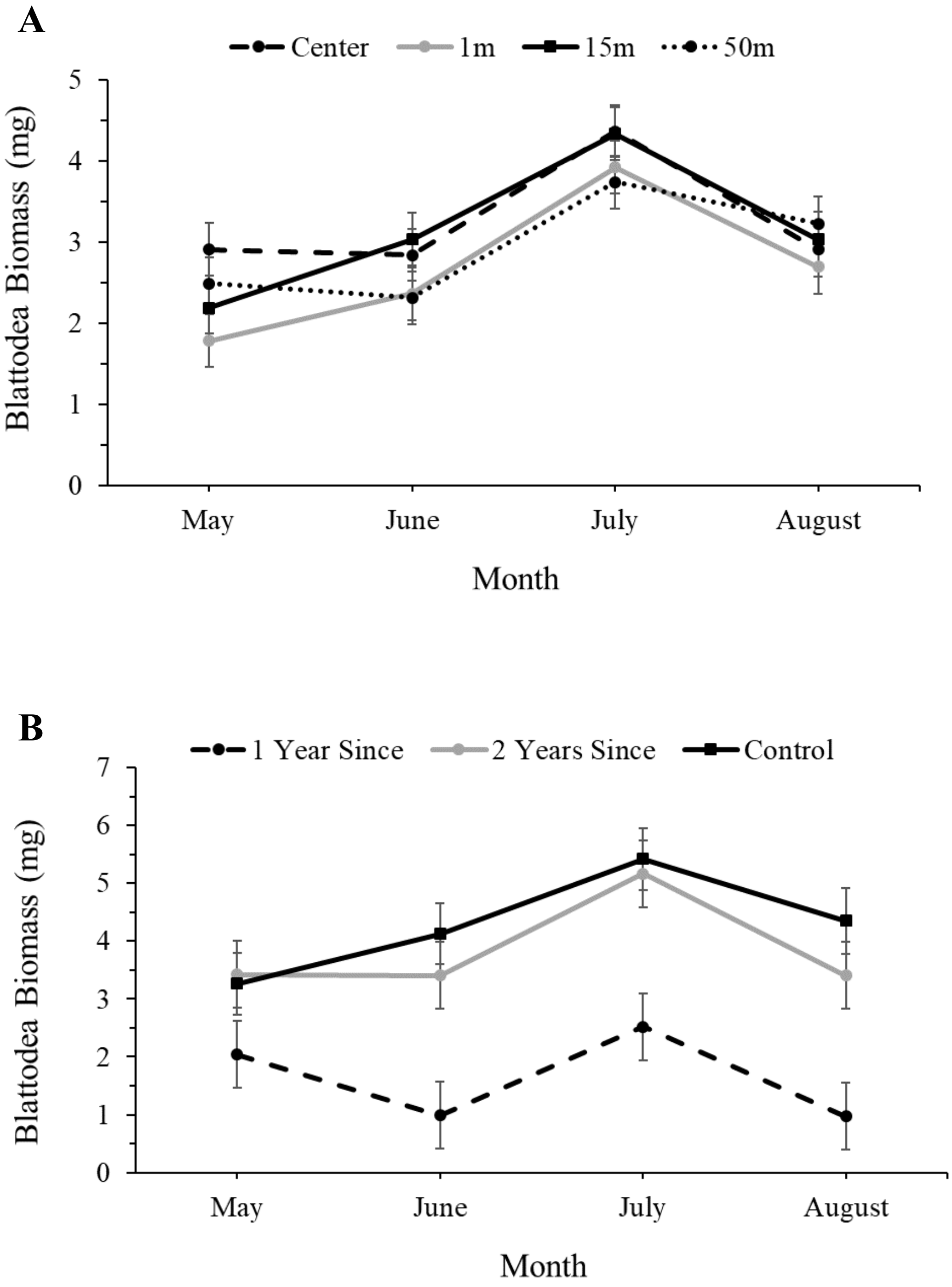


Figure 19. Least square means (±SE) for biomass (mg) of Blattodea in relation to A) distance from motte and B) time since prescribed burn for each month collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. Data were log(x+1) transformed.

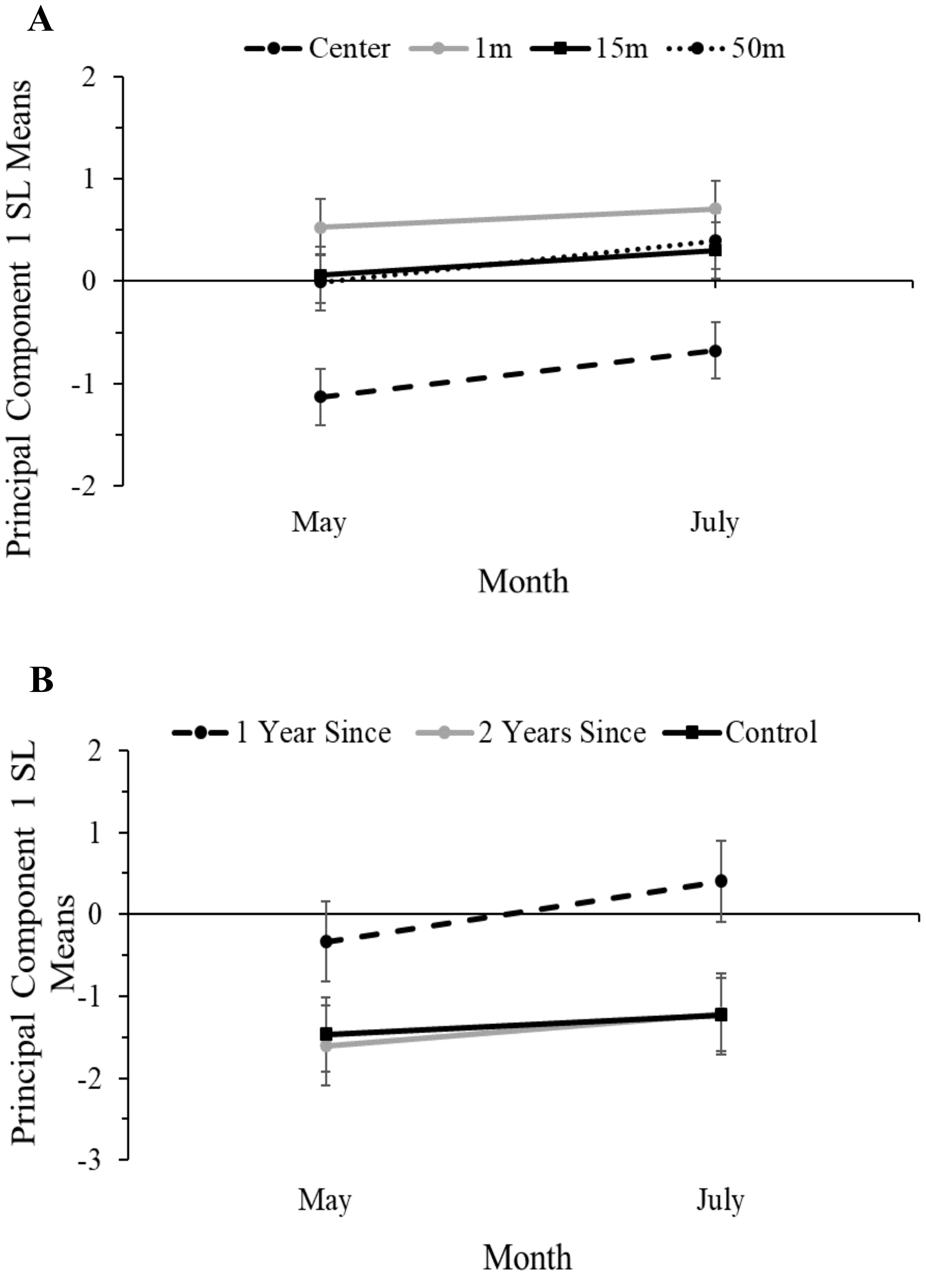


Figure 20. Least square means (±SE) for principal component 1 in relation to A) distance from motte and B) time since prescribed burn for each month in Packsaddle WMA, Oklahoma during the summer of 2018.

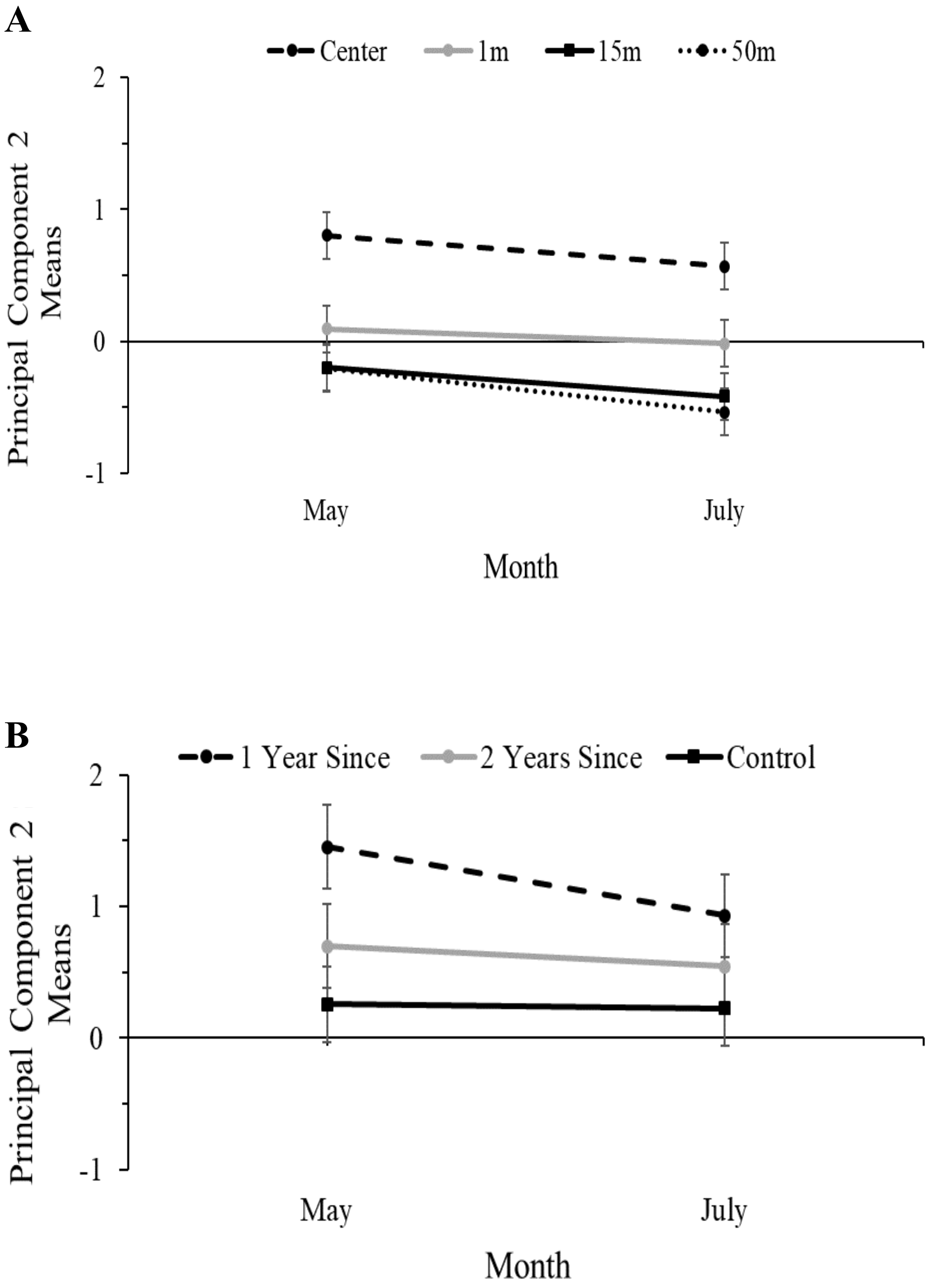


Figure 21. Least square means (±SE) for principal component 2 in relation to A) distance from motte and B) time since prescribed burn for each month in Packsaddle WMA, Oklahoma during the summer of 2018.

Appendix D

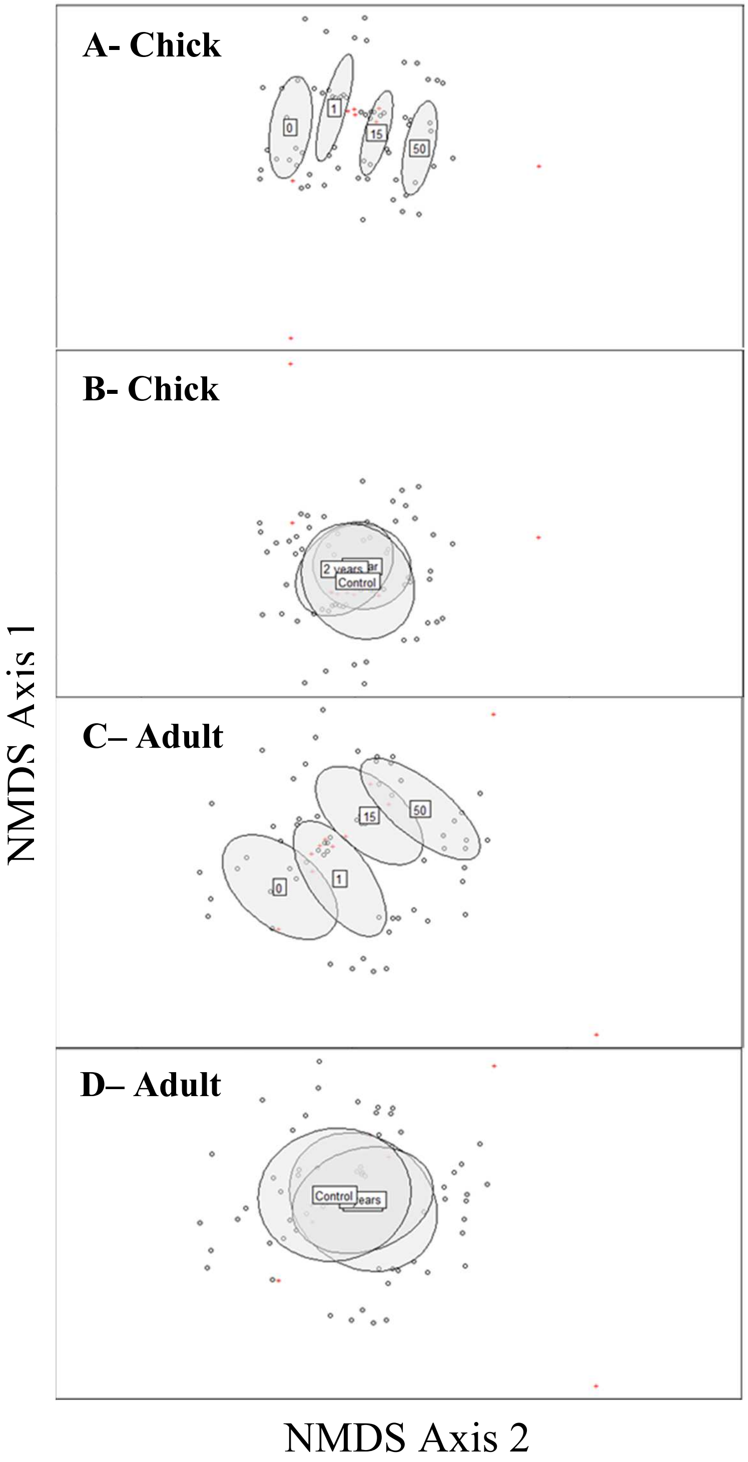


Figure 22. NMDS ordinations of arthropod abundance with all months combined: A) prey for chicks by distance from motte (m), B) prey for chicks by time since burn, C) prey for adults by distance from motte (m), D) prey for adults by time since burn. Zero represents plots in the center a motte. Data were square root transformed

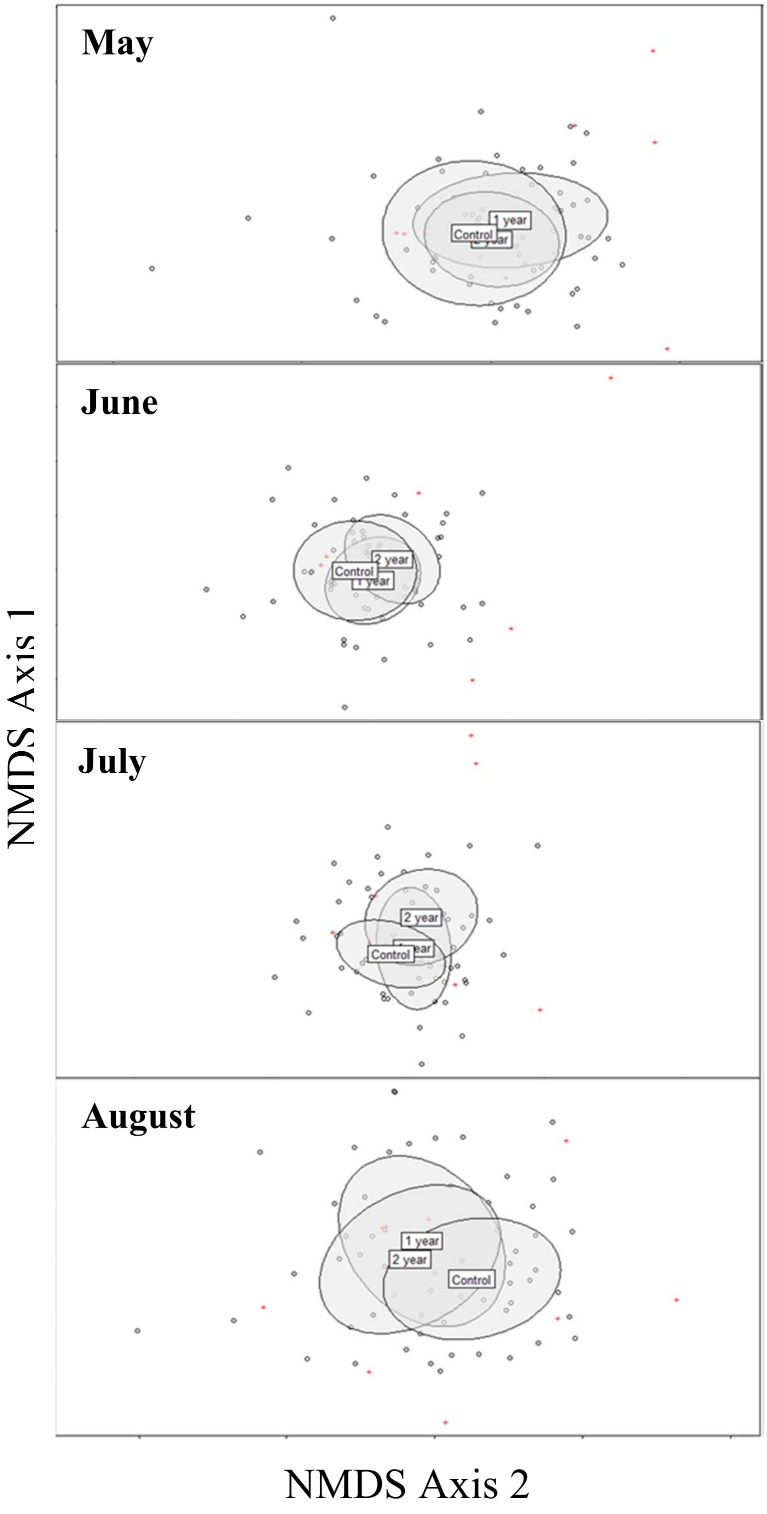


Figure 23. NMDS ordinations of abundance of arthropod prey for chicks in relation to time since burn for each month collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. Data were square root transformed.

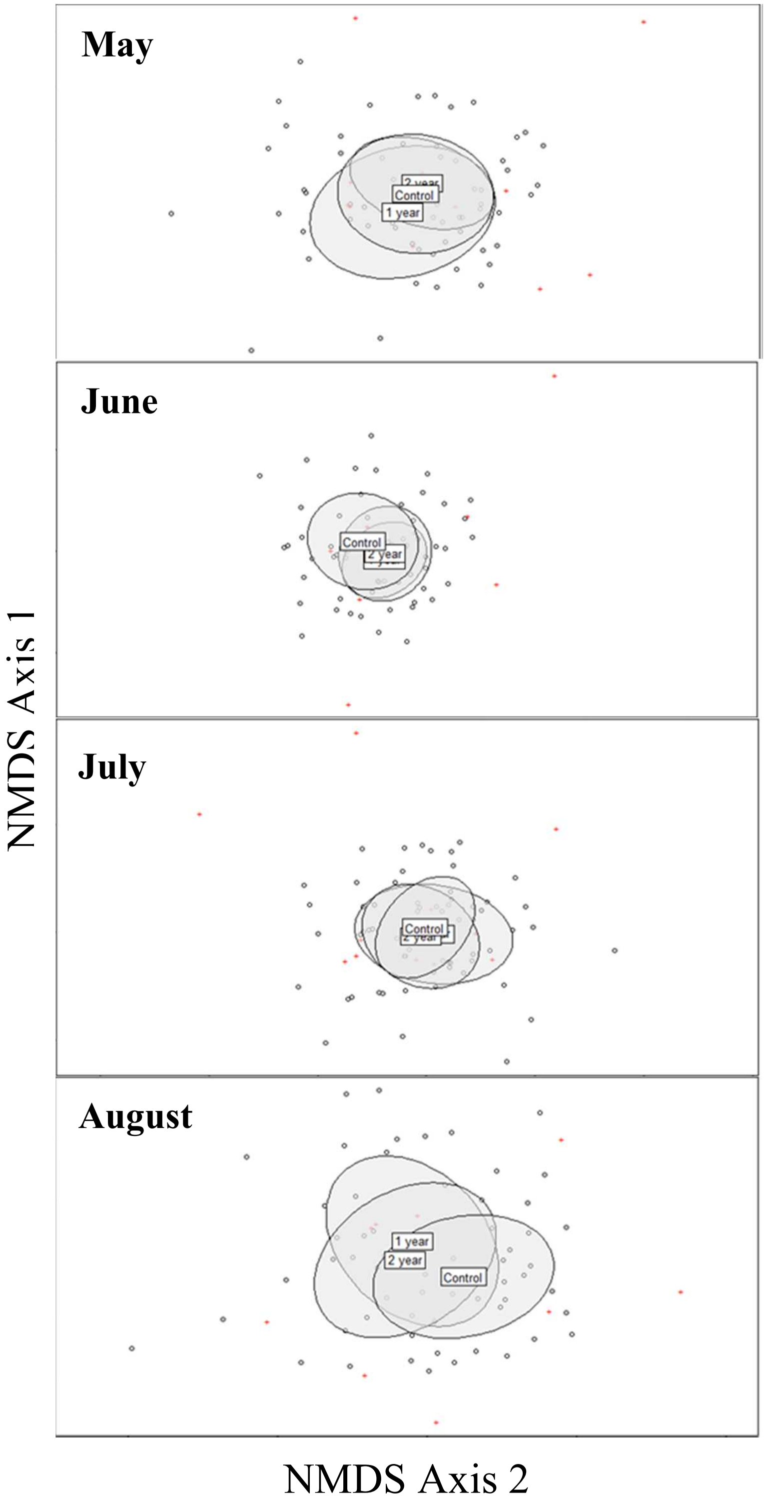


Figure 24. NMDS ordinations of abundance of arthropod prey for adults in relation to time since burn for each month collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. Data were square root transformed.

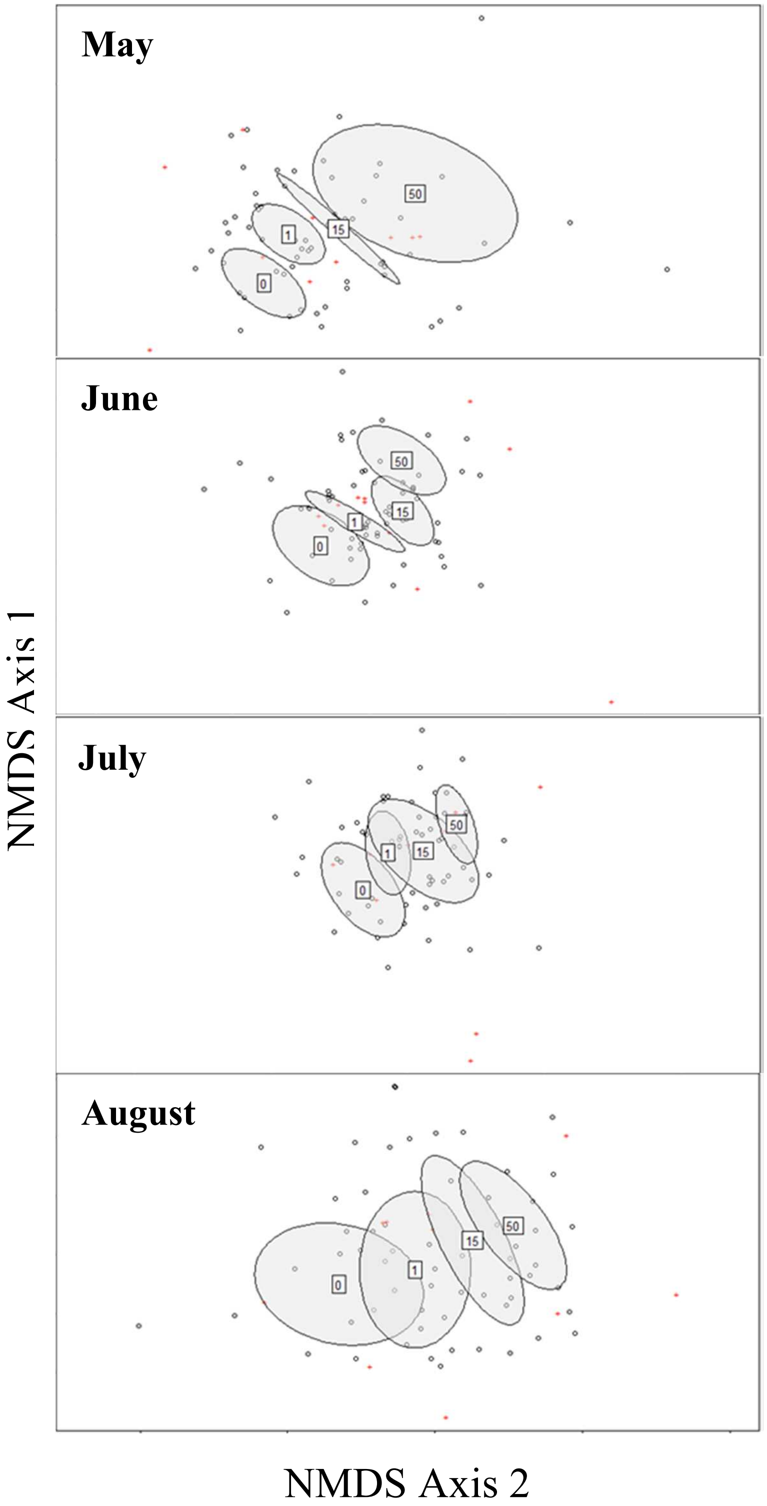


Figure 25. NMDS ordinations of abundance of arthropod prey for chicks in relation to distance from motte (m) collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. Zero represents plots in the center of a motte. Data were square root transformed.

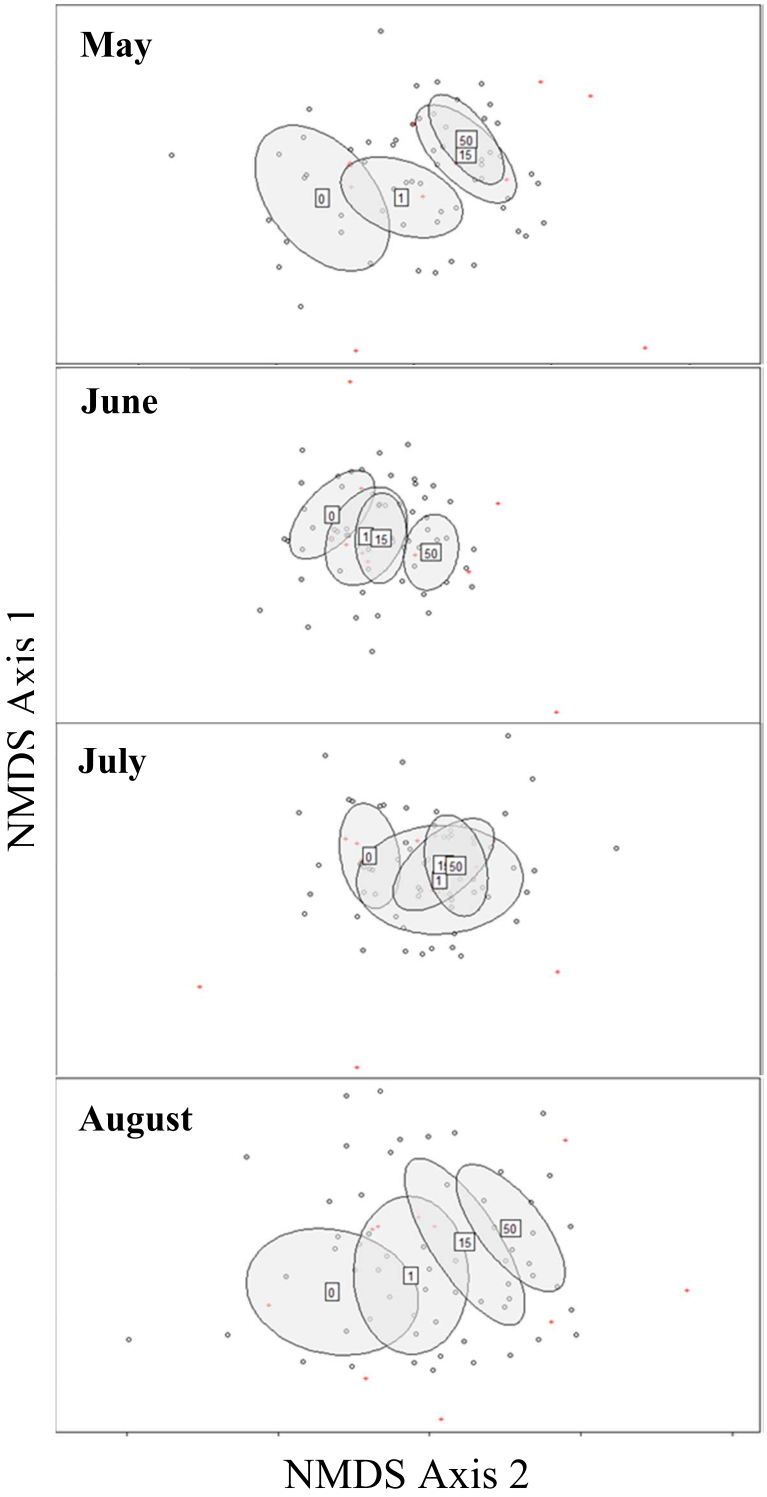


Figure 26. NMDS ordinations of abundance of arthropod prey for adults in relation to distance from motte (m) collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. Zero represents plots in the center of a motte. Data were square root transformed.

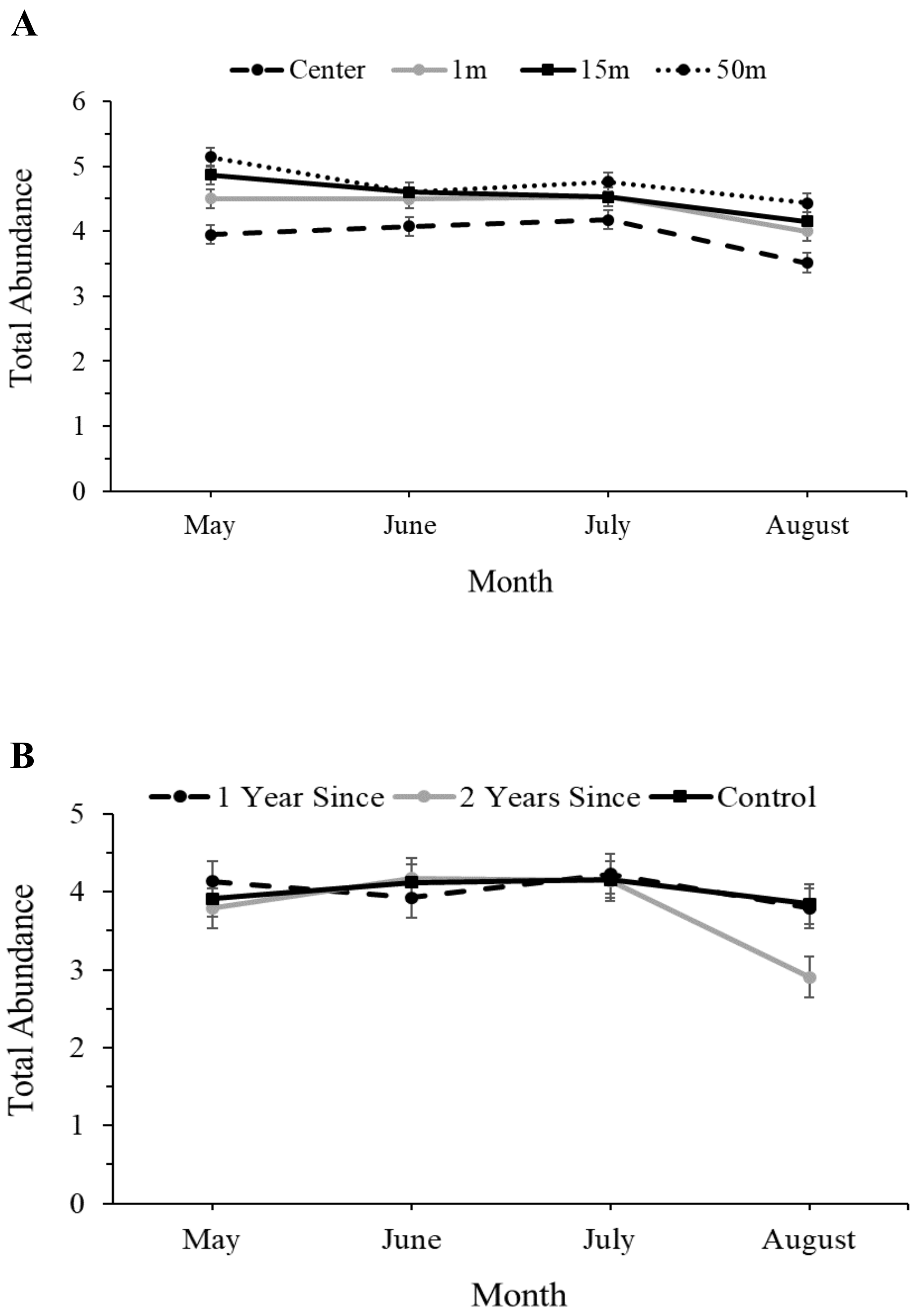
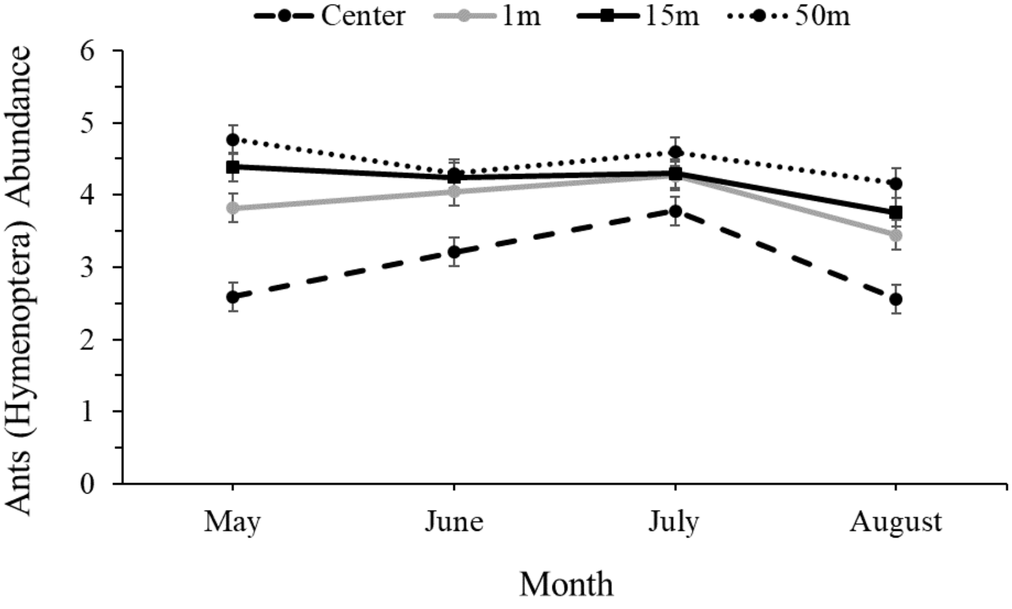


Figure 27. Least square means (± SE) for total abundance of arthropod prey for chicks in relation to A) distance from motte and B) time since prescribed burn for each month. Data were log(x+1) transformed. Arthropods were collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018.

A



B

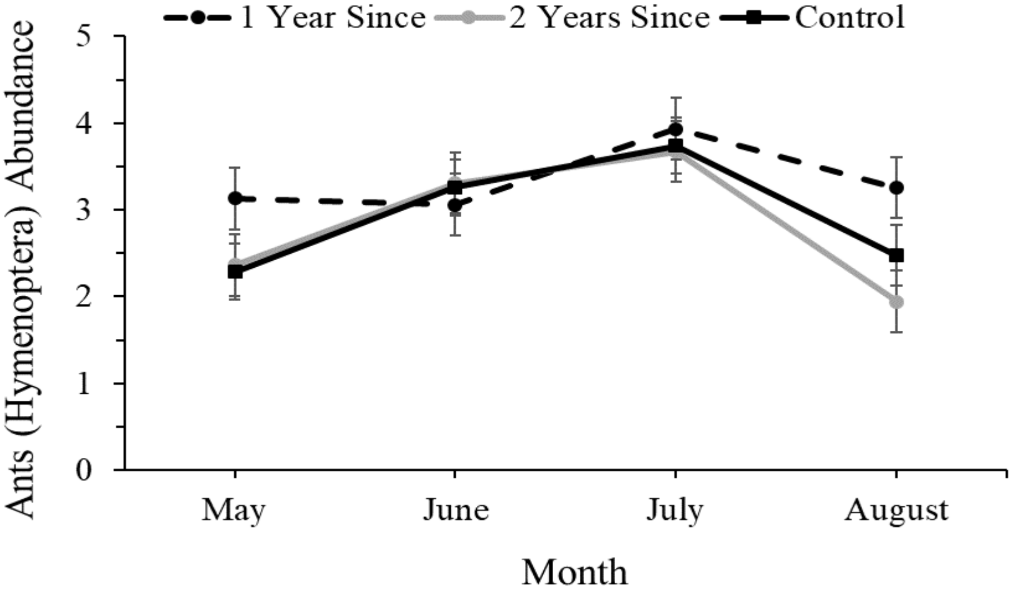


Figure 28. Least square means (± SE) for abundance of ants for chicks in relation to A) distance from motte and B) time since prescribed burn for each month. Data were log(x+1) transformed. Arthropods were collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018.

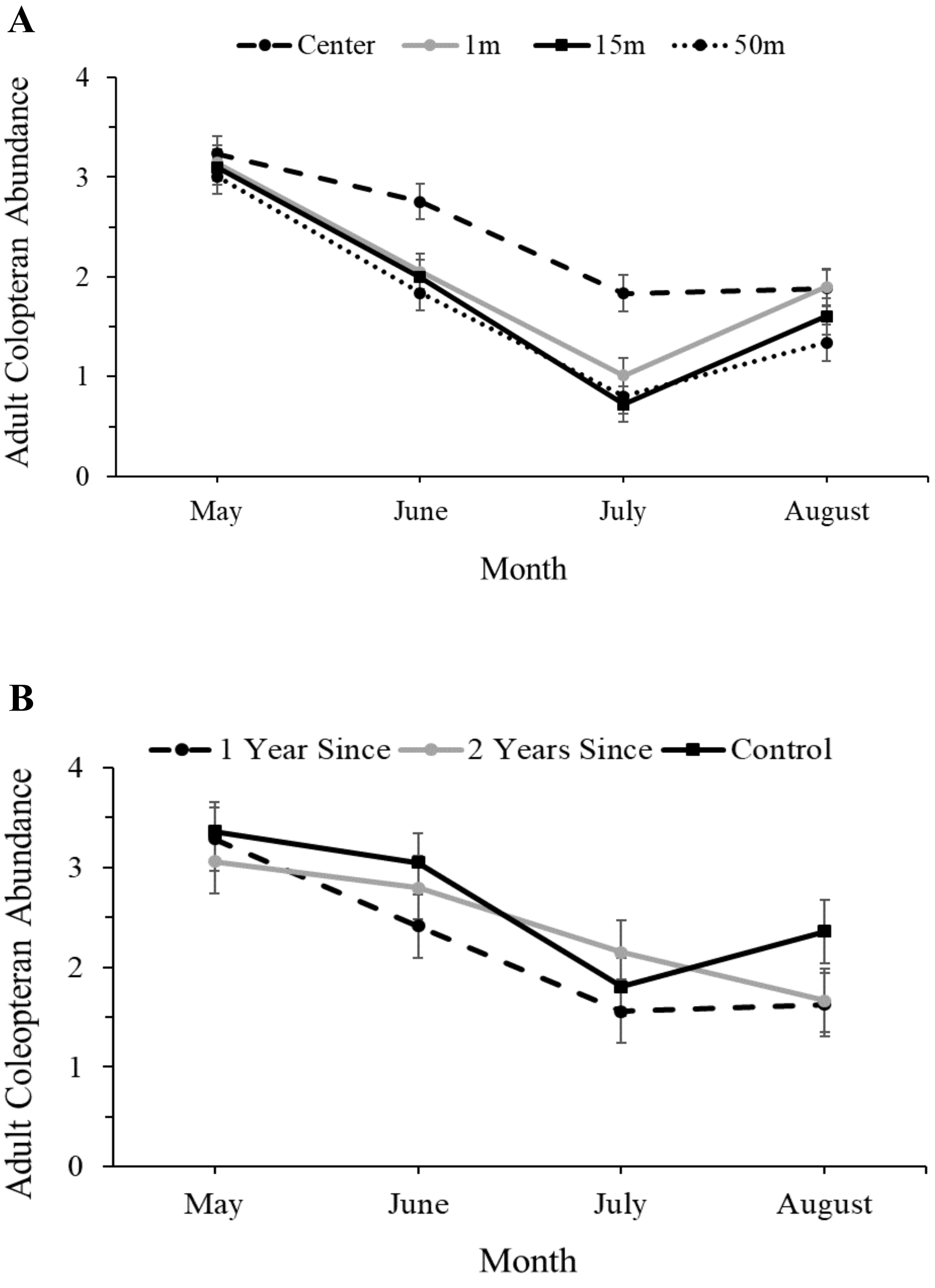
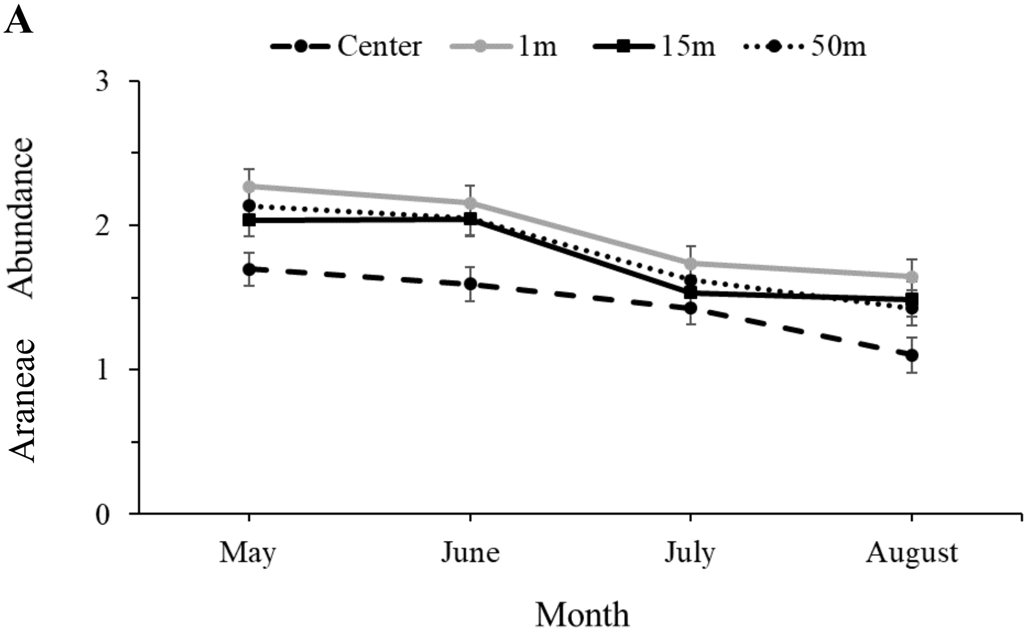


Figure 29. Least square means (± SE) for abundance of adult Coleopterans for chicks in relation to A) distance from motte and B) time since prescribed burn for each month. Data were log(x+1) transformed. Arthropods were collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018.



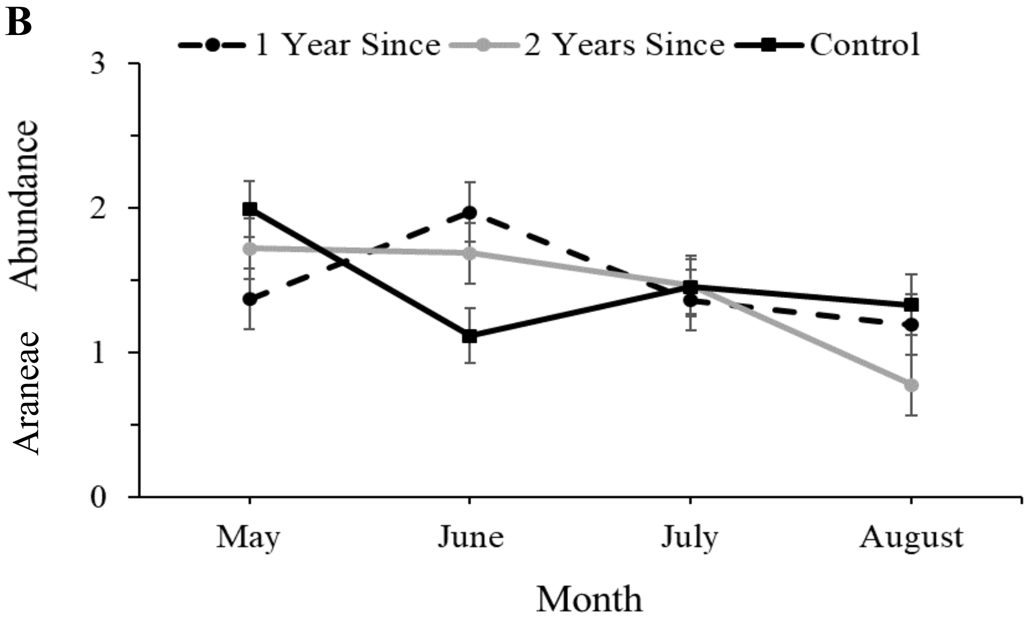
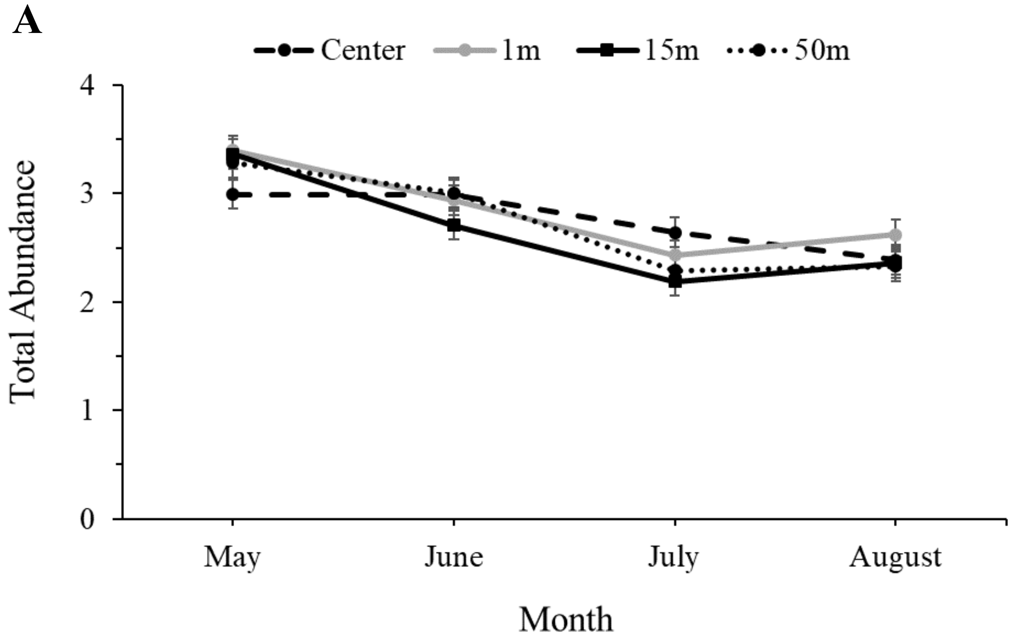


Figure 30. Least square means (± SE) for abundance of Araneae for chicks in relation to A) distance from motte and B) time since prescribed burn for each month. Data were log(x+1) transformed. Arthropods were collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018.



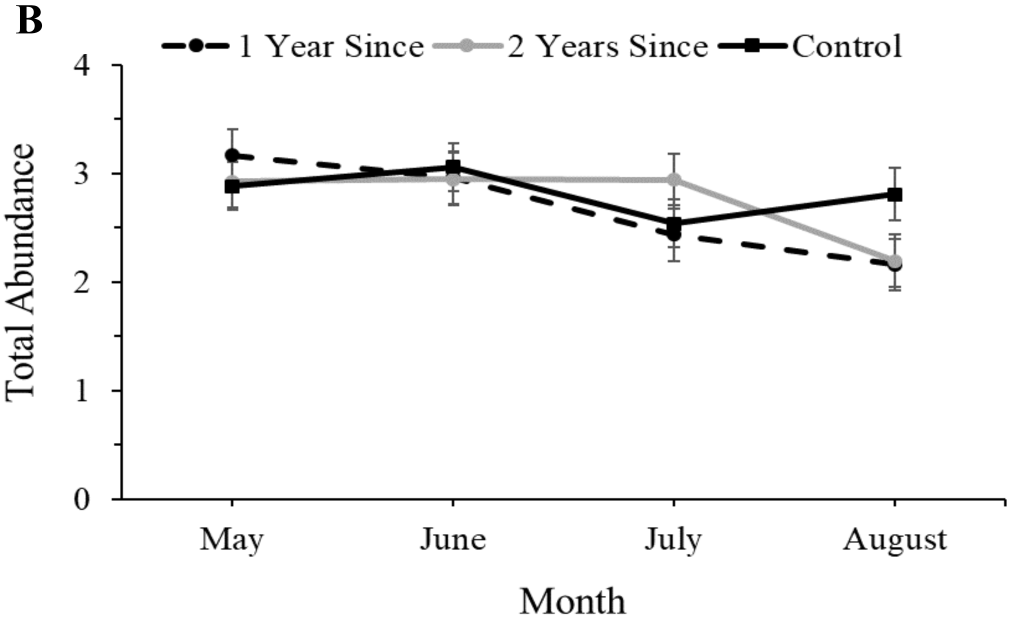


Figure 31. Least square means (± SE) for total abundance of arthropod prey for adults in relation to A) distance from motte and B) time since prescribed burn for each month. Data were log(x+1) transformed. Arthropods were collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018.

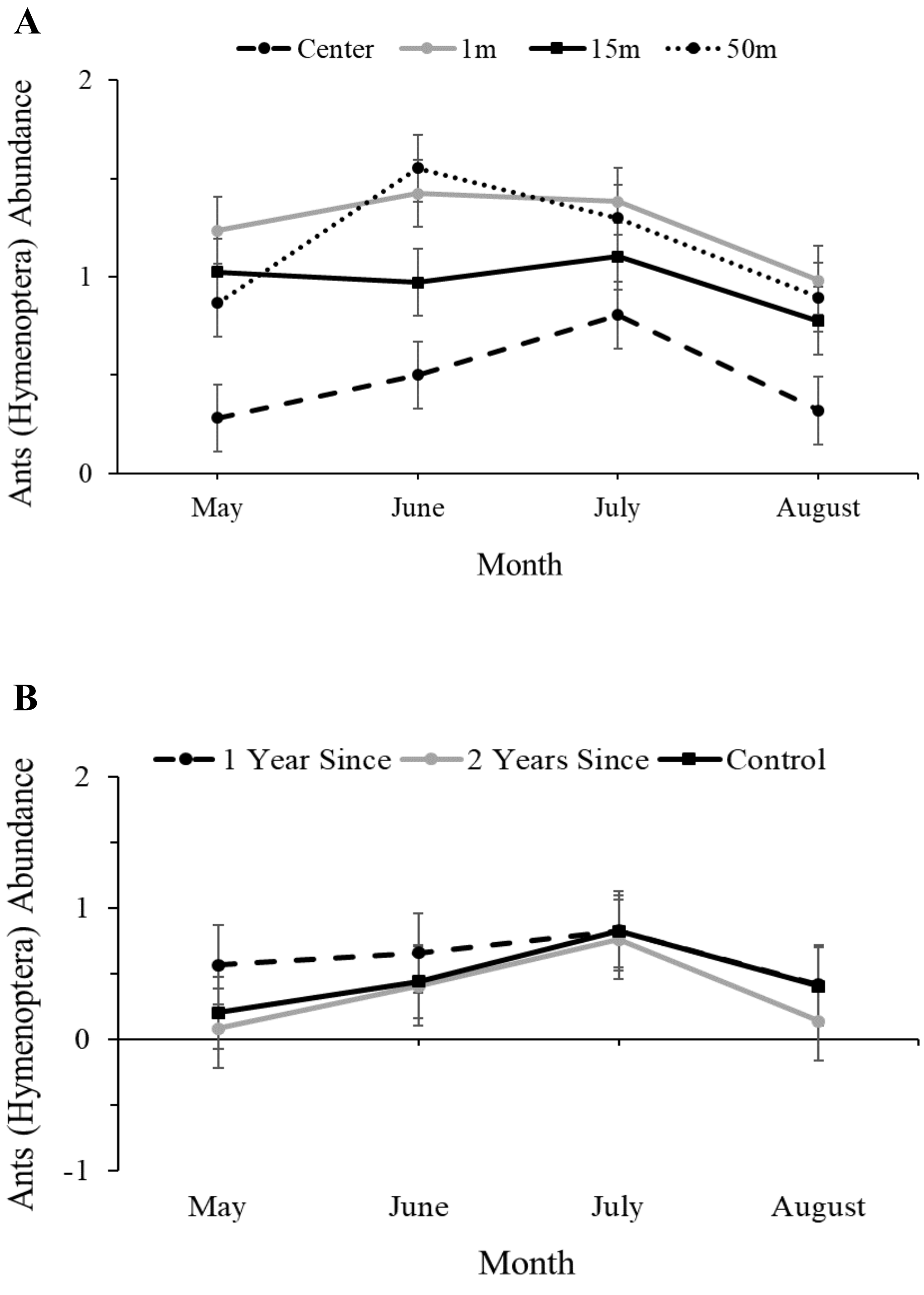


Figure 32. Least square means (± SE) for abundance of ants for adults in relation to A) distance from motte and B) time since prescribed burn for each month. Data were log(x+1) transformed. Arthropods were collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018.

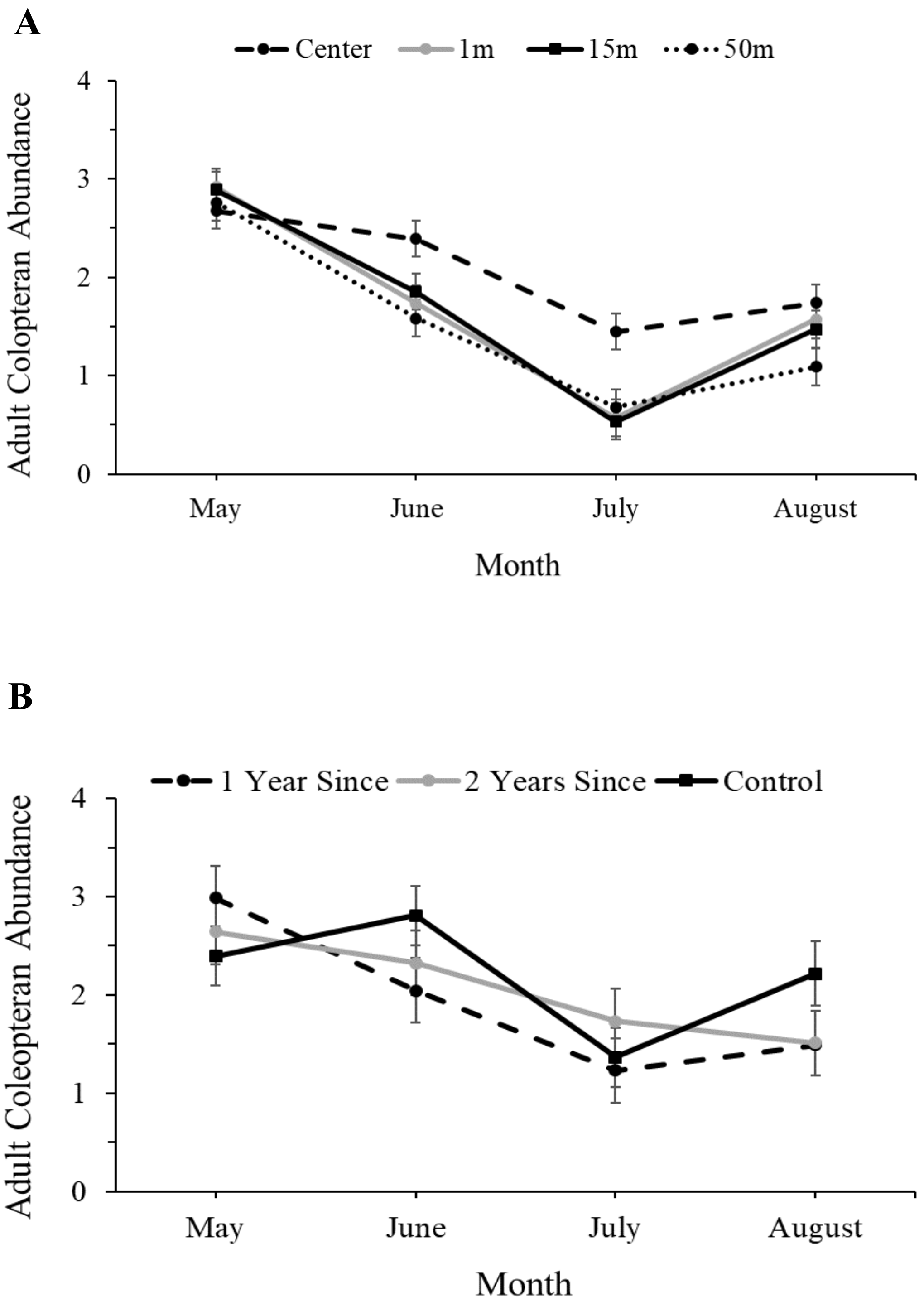


Figure 33. Least square means (± SE) for abundance of adult Coleopterans for adults in relation to A) distance from motte and B) time since prescribed burn for each month. Data were log(x+1) transformed. Arthropods were collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018.

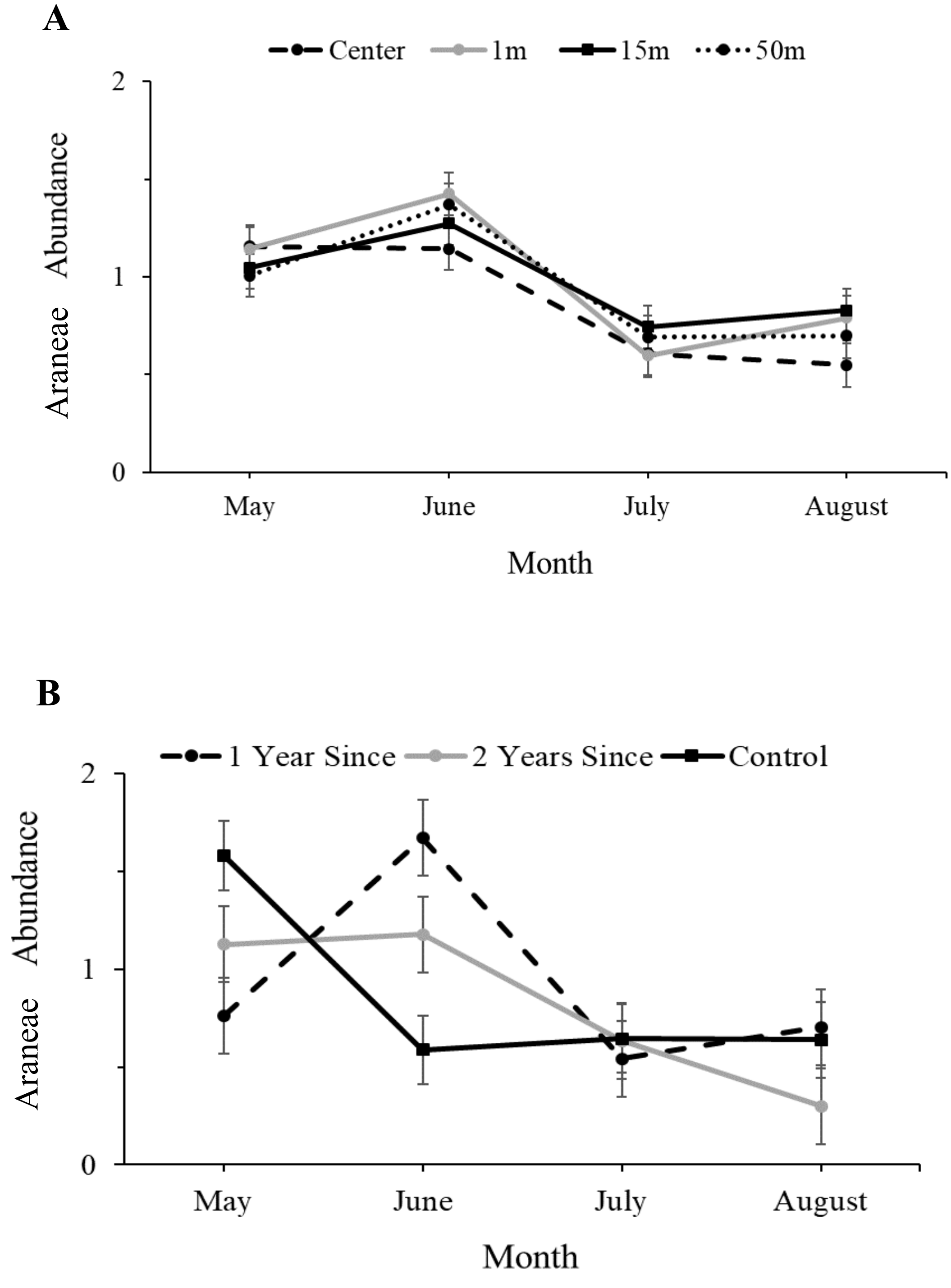
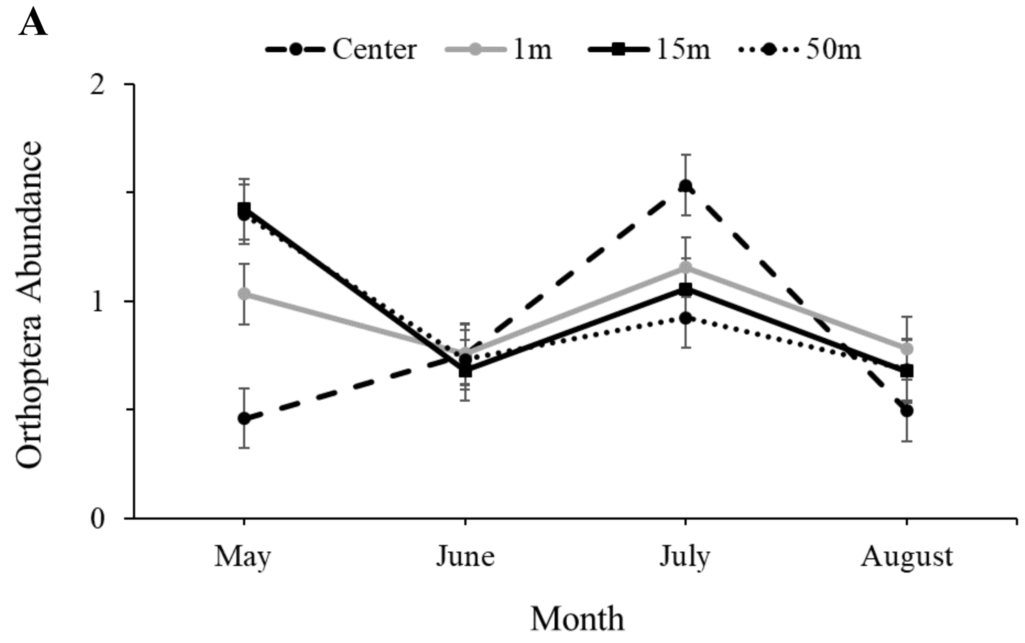


Figure 34. Least square means (± SE) for abundance of Araneae for adults in relation to A) distance from motte and B) time since prescribed burn for each month. Data were log(x+1) transformed. Arthropods were collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018.



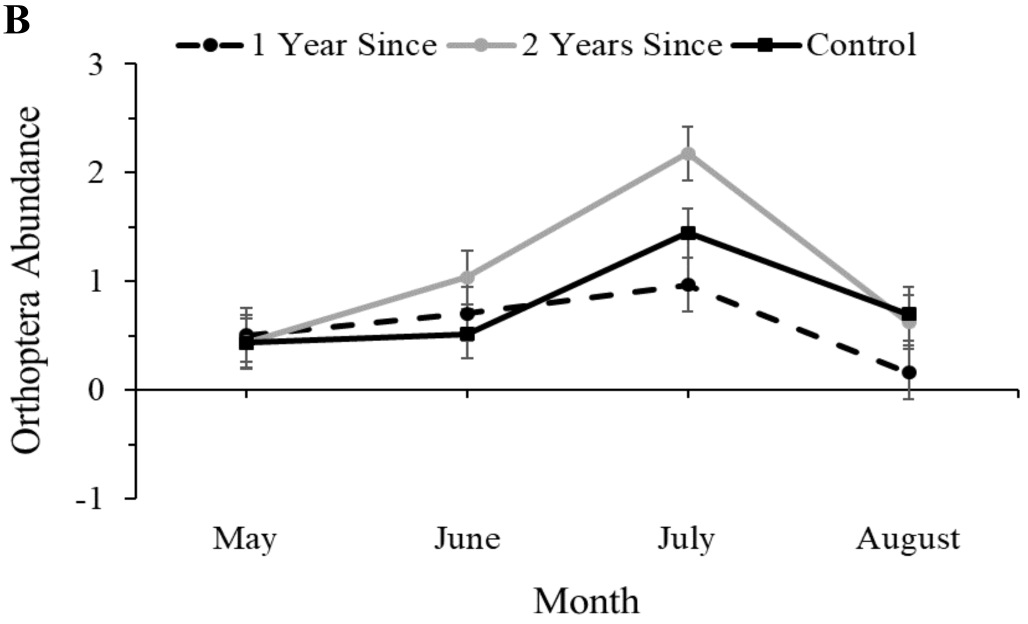
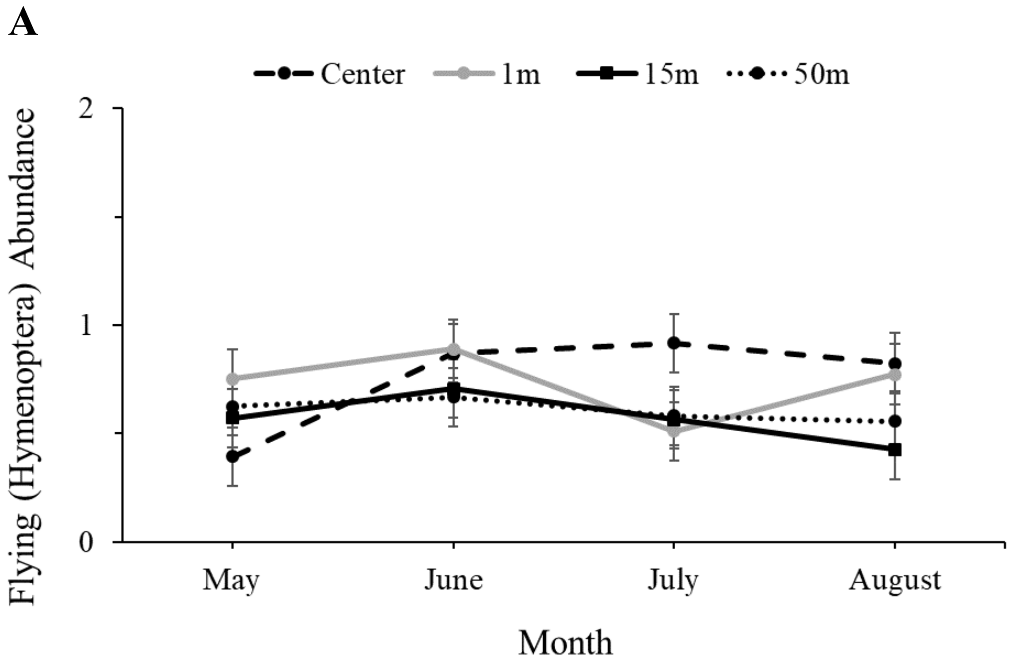


Figure 35. Least square means (± SE) for abundance of Orthoptera for adults in relation to A) distance from motte and B) time since prescribed burn for each month. Data were log(x+1) transformed. Arthropods were collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018.



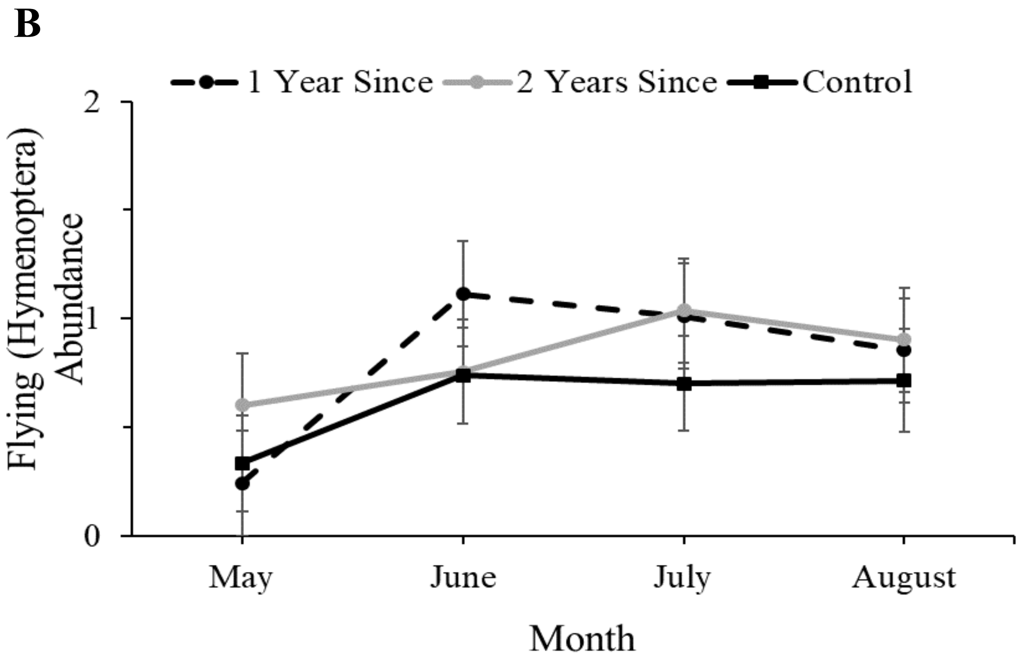


Figure 36. Least square means (± SE) for abundance of flying Hymenopterans for adults in relation to A) distance from motte and B) time since prescribed burn for each month. Data were log(x+1) transformed. Arthropods were collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018.

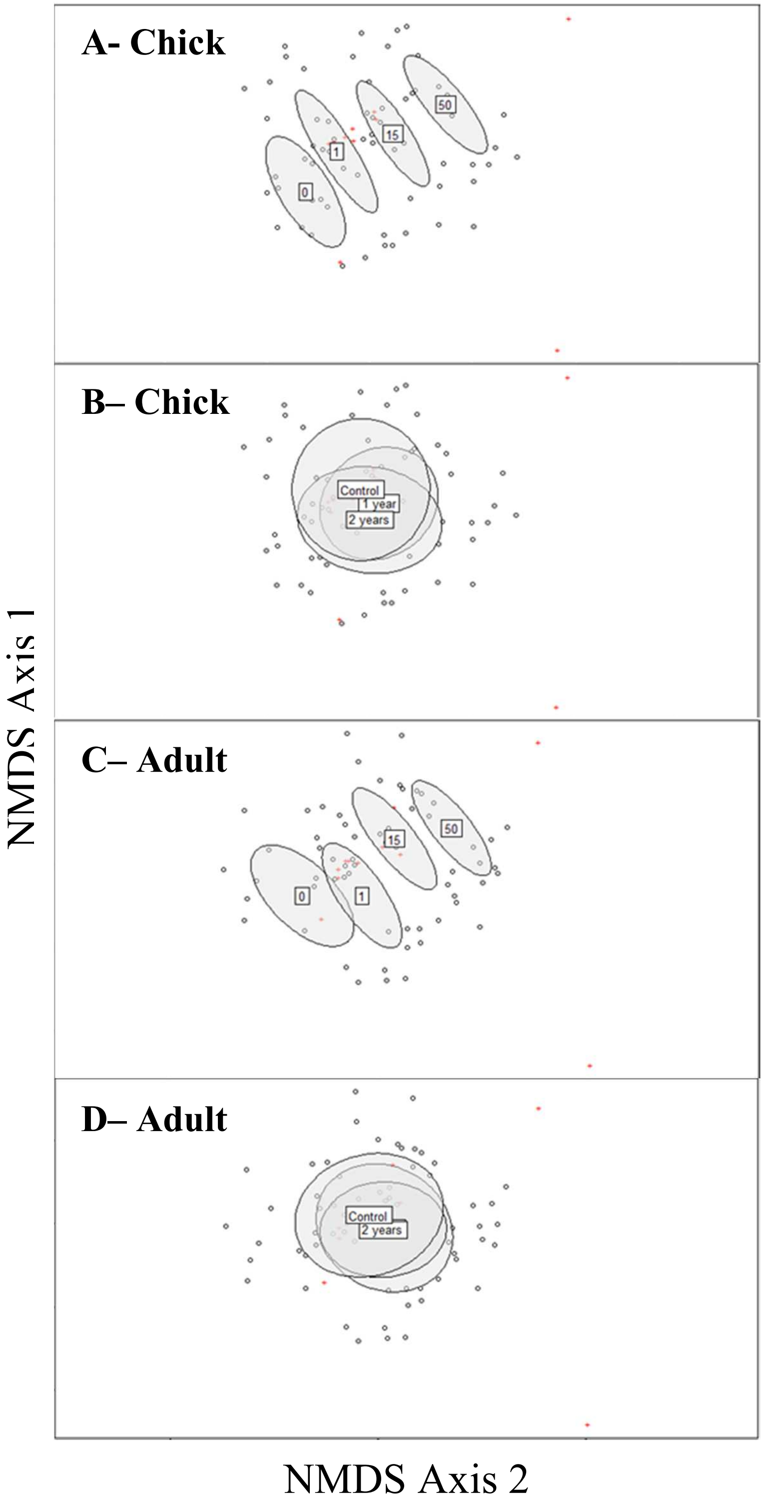


Figure 37. NMDS ordinations of arthropod biomass (g) with all months combined: A) prey for chicks in relation to distance from motte (m), B) prey for chicks in relation to time since burn, C) prey for adults in relation to distance from motte (m), D) prey for adults in relation to time since burn. Zero represents plots in the center a motte. Data were square root transformed.

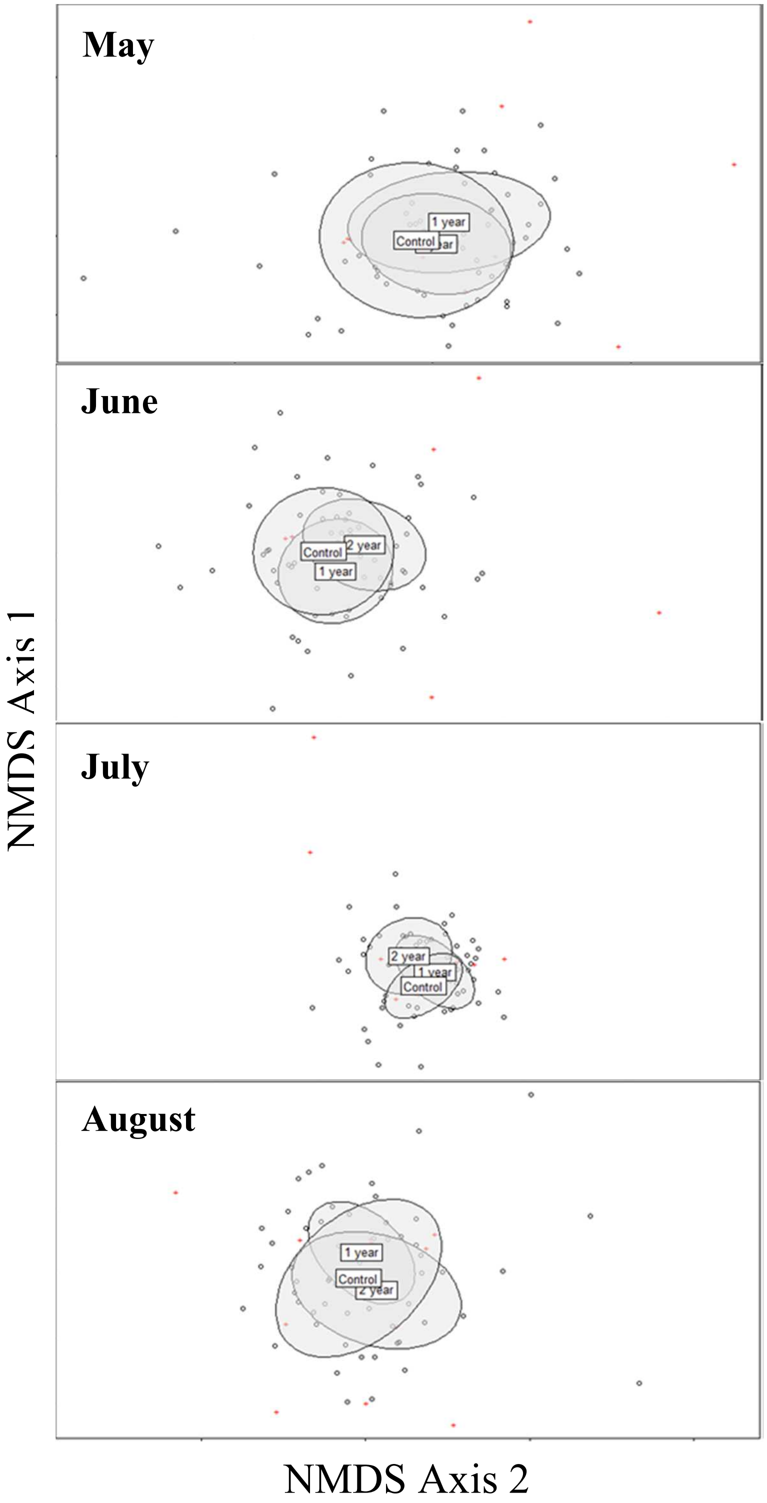


Figure 38. NMDS ordinations of biomass (g) of arthropod prey for chicks in relation to time since burn for each month collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. Data were square root transformed.

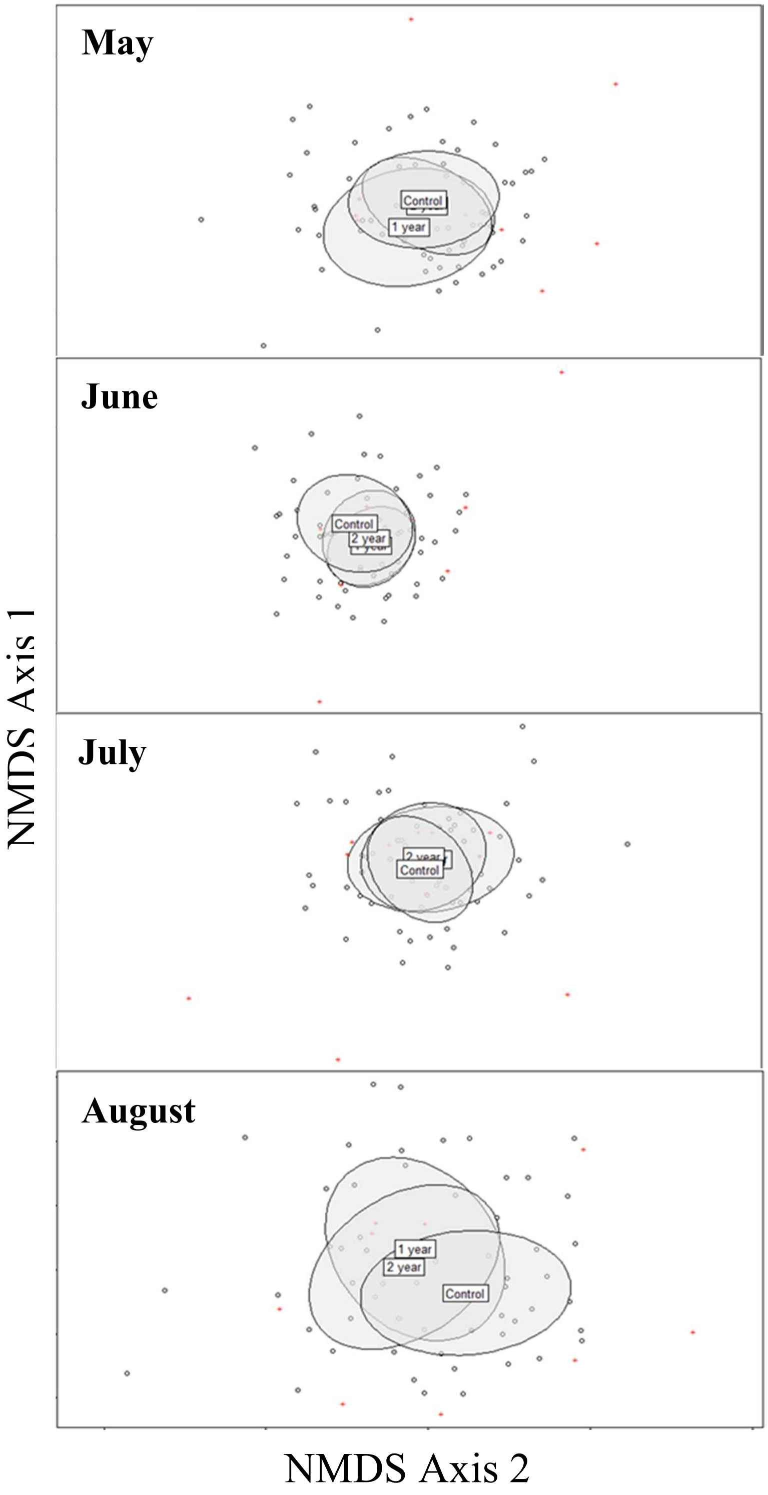


Figure 39. NMDS ordinations of biomass (g) of arthropod prey for adults in relation to time since burn for each month collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. Data were square root transformed.

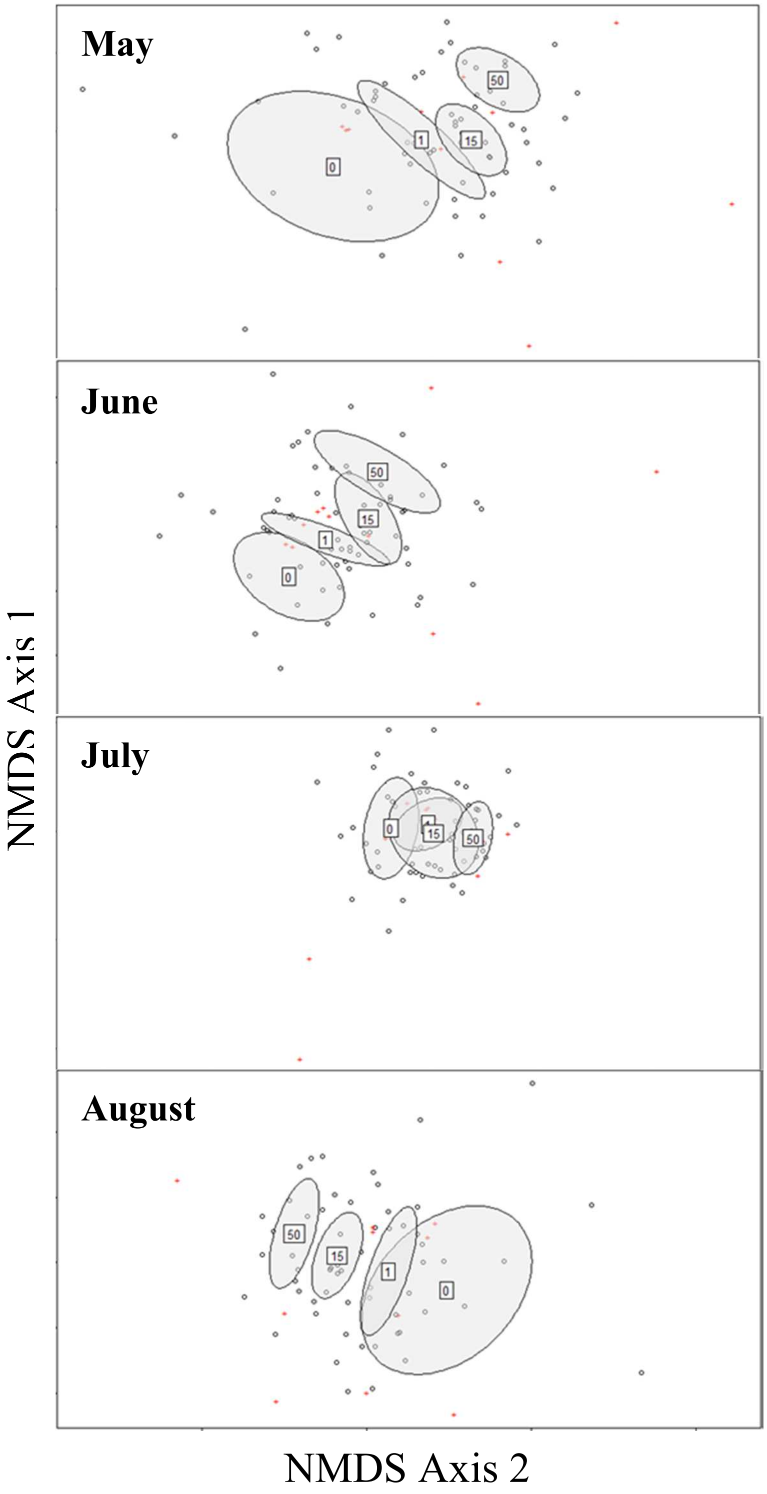


Figure 40. NMDS ordinations of biomass (g) of arthropod prey for chicks in relation to distance from motte (m) collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. Zero represents plots in the center of a motte. Data were square root transformed.

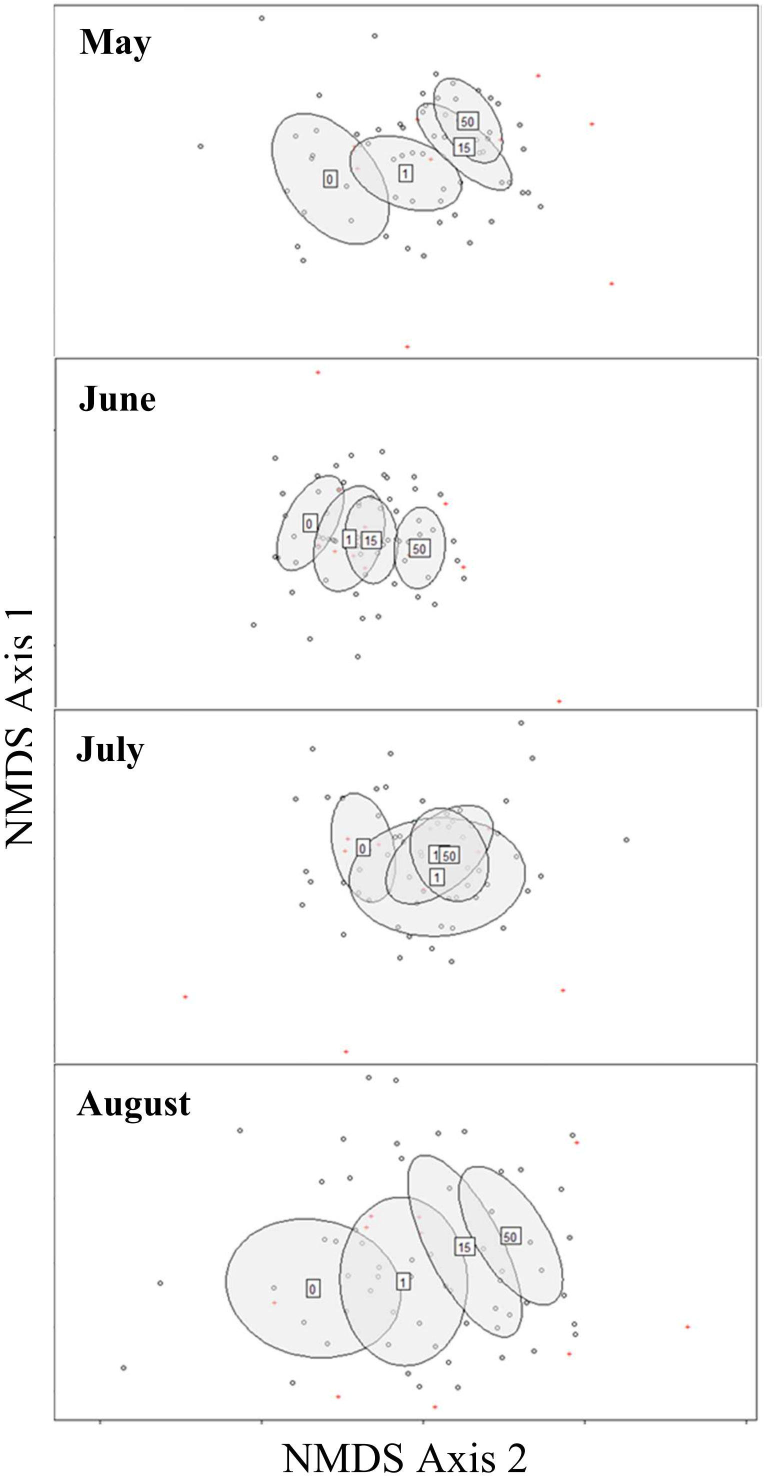


Figure 41. NMDS ordinations of biomass (g) of arthropod prey for adults in relation to distance from motte (m) collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018. Zero represents plots in the center of a motte. Data were square root transformed.

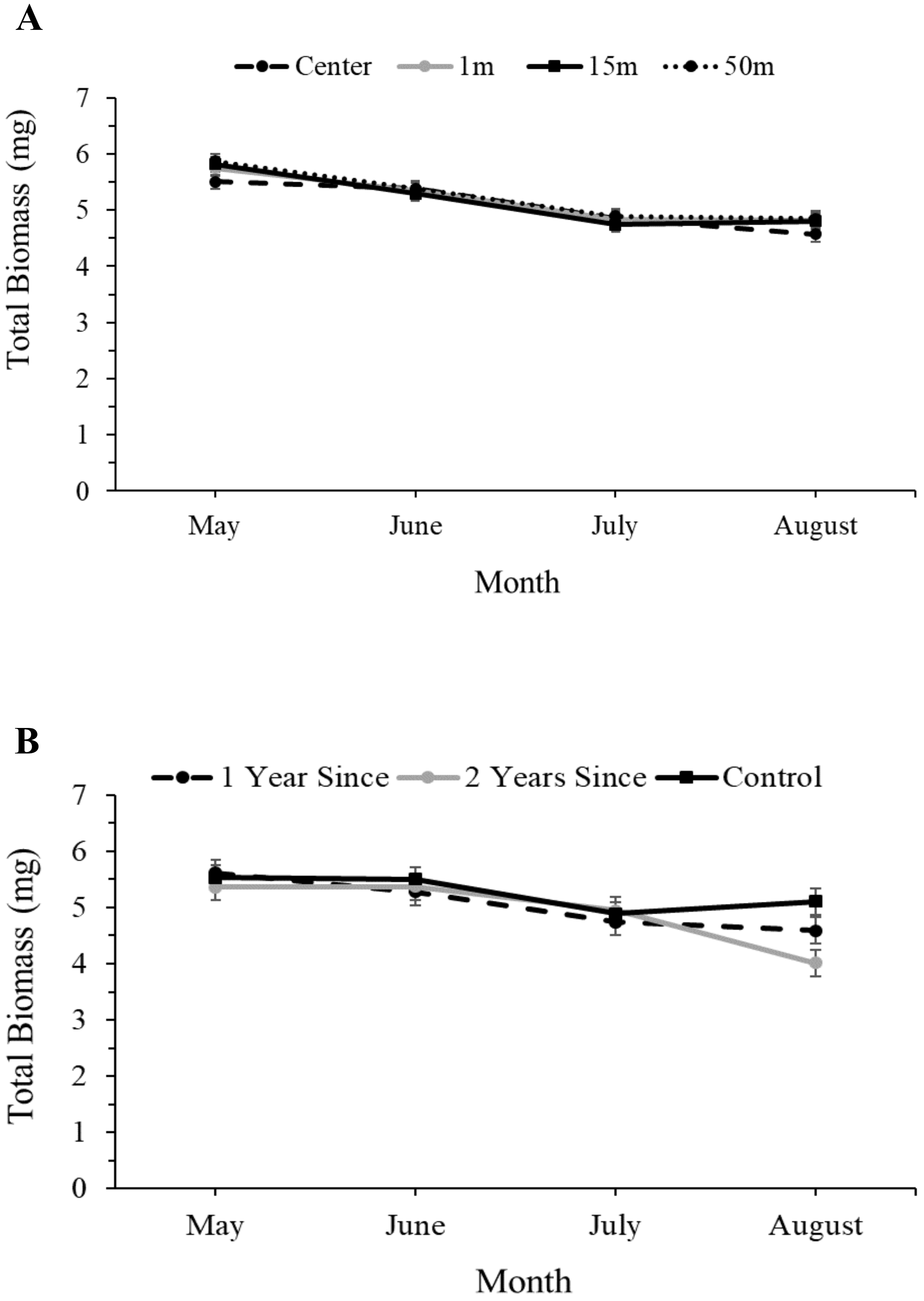


Figure 42. Least square means (± SE) for total biomass (mg) of arthropod prey for chicks collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018 in relation to A) distance from motte and B) time since prescribed burn for each month. Data were log(x+1) transformed.

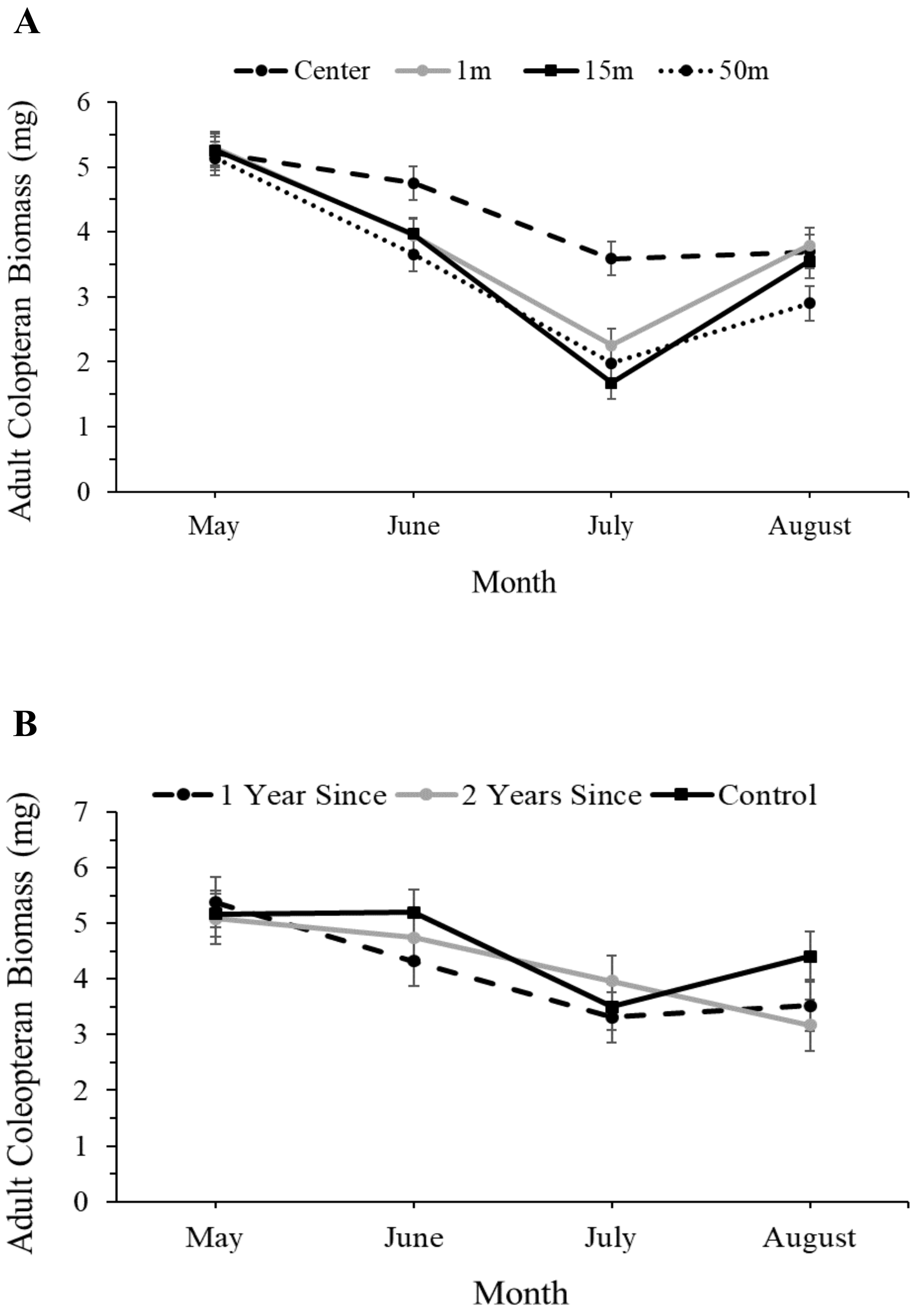


Figure 43. Least square means (± SE) for biomass (mg) of adult Coleopteran prey for chicks collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018 in relation to A) distance from motte and B) time since prescribed burn for each month. Data were log(x+1) transformed.

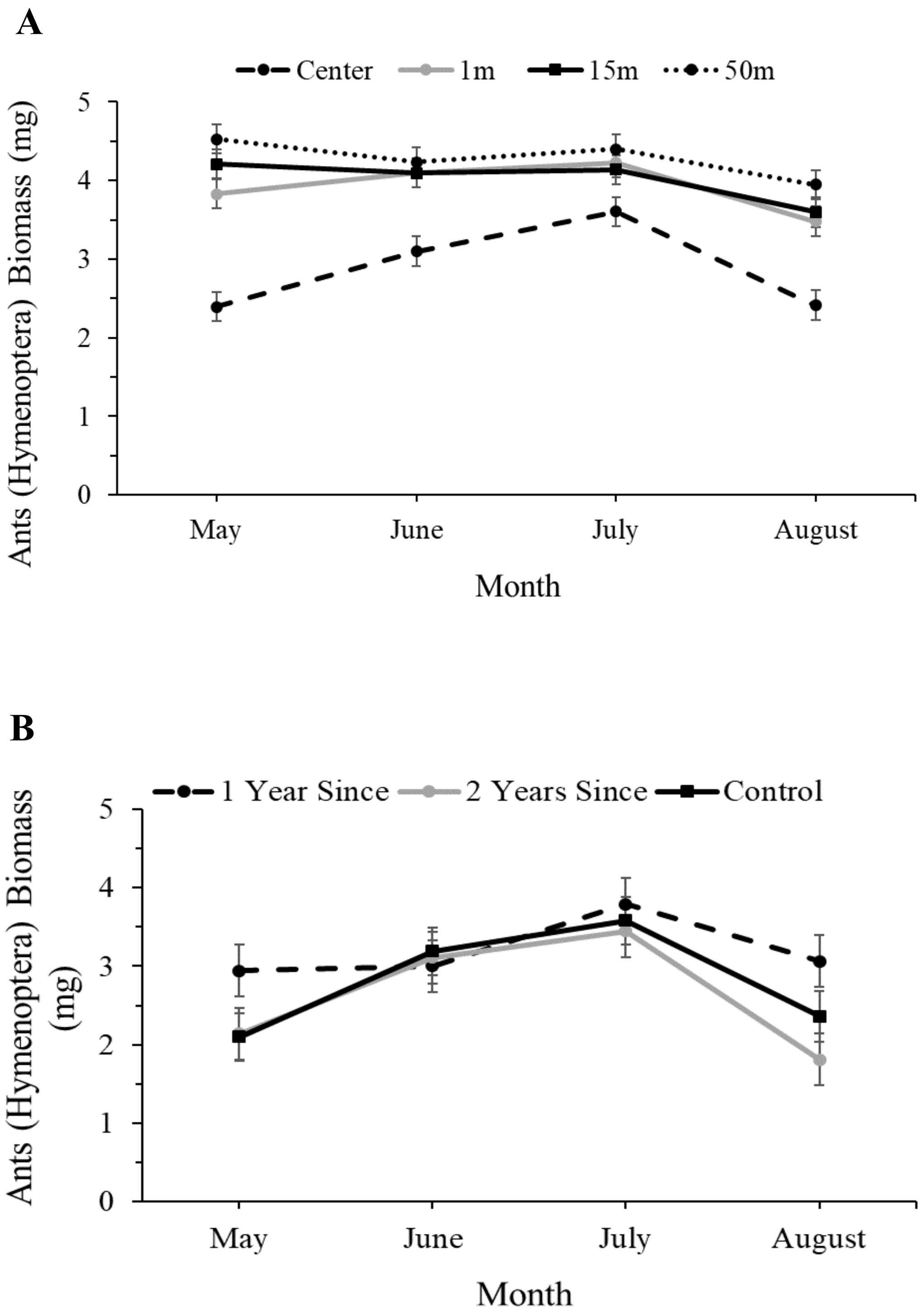
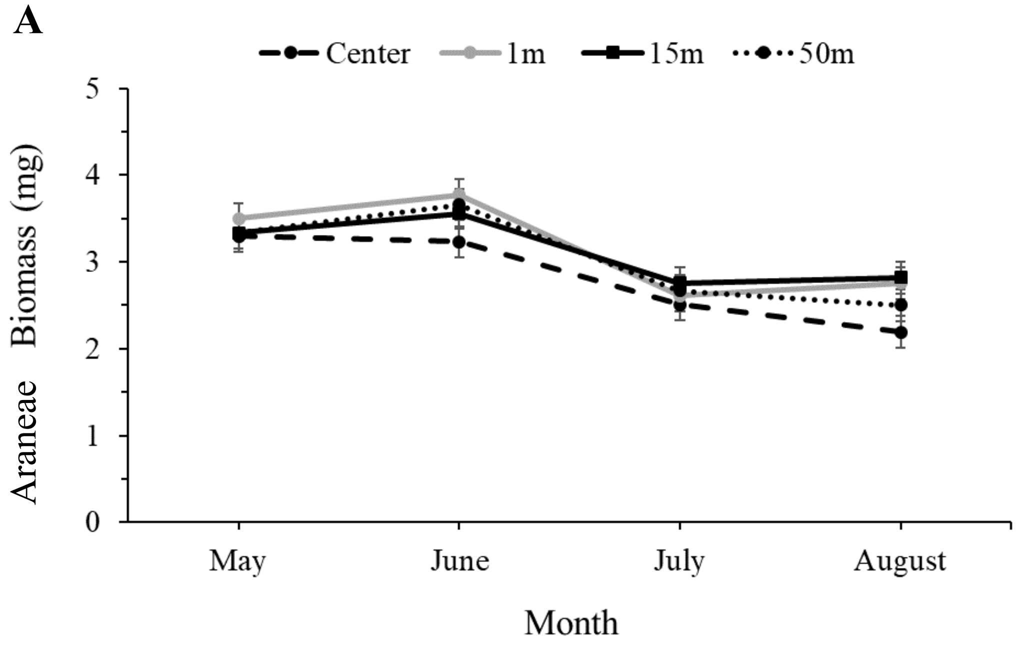


Figure 44. Least square means (± SE) for biomass (mg) of ant prey for chicks collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018 in relation to A) distance from motte and B) time since prescribed burn for each month. Data were log(x+1) transformed.



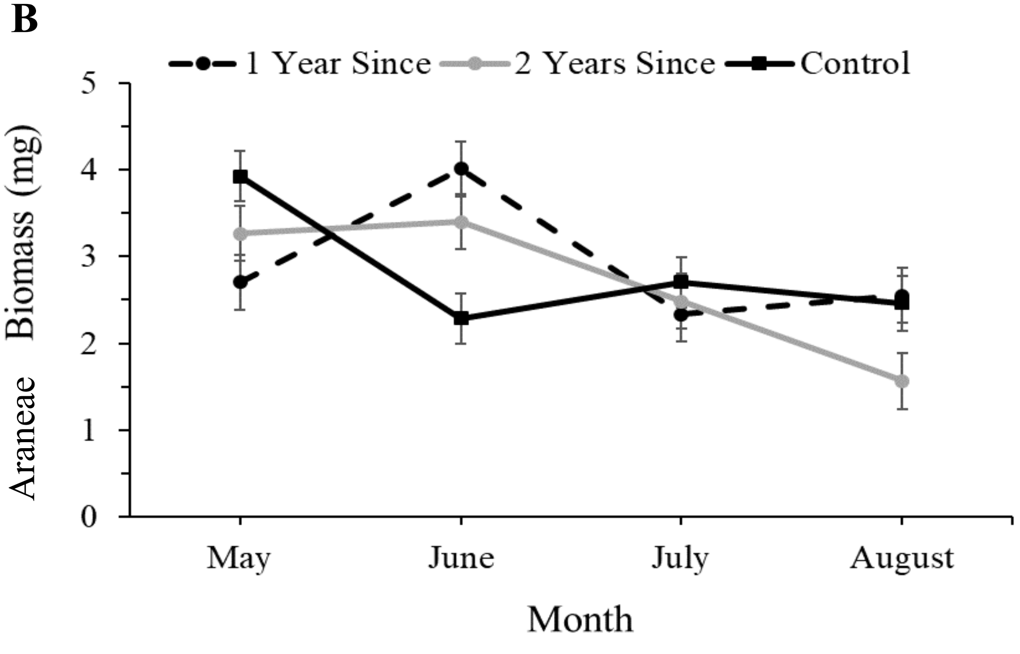
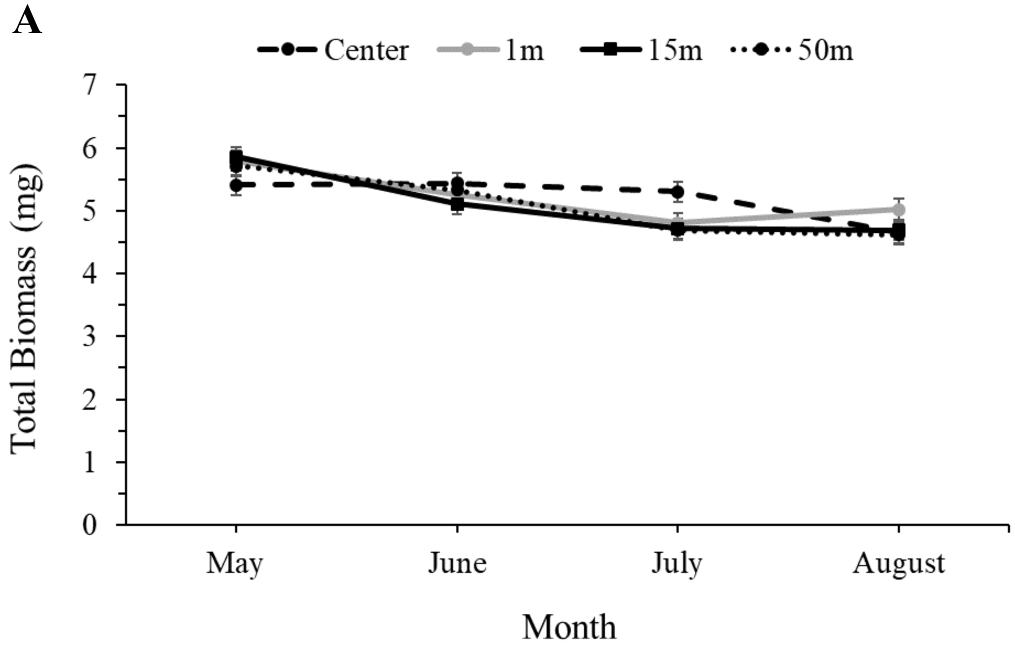


Figure 45. Least square means (± SE) for biomass (mg) of Araneae prey for chicks collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018 in relation to A) distance from motte and B) time since prescribed burn for each month. Data were log(x+1) transformed.



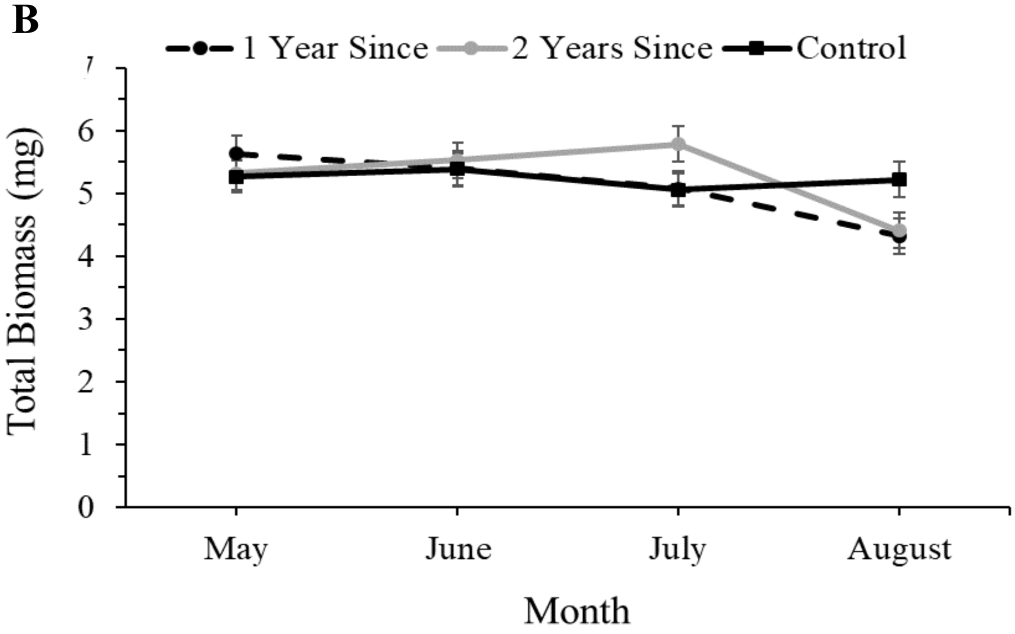


Figure 46. Least square means (± SE) for total biomass (mg) of arthropod prey for adults collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018 in relation to A) distance from motte and B) time since prescribed burn for each month. Data were log(x+1) transformed.

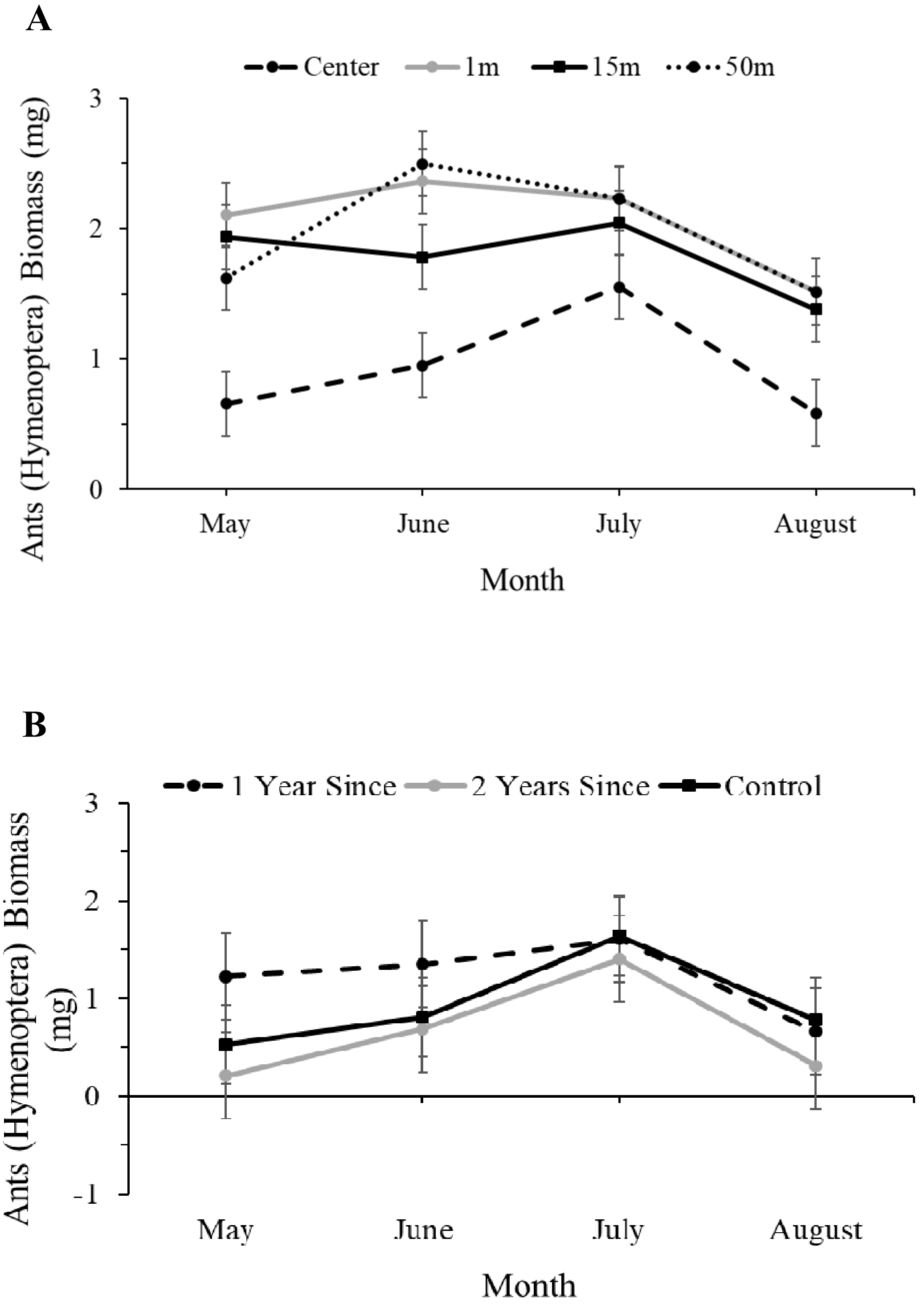


Figure 47. Least square means (± SE) for biomass (mg) of ant prey for adults collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018 in relation to A) distance from motte and B) time since prescribed burn for each month. Data were log(x+1) transformed.

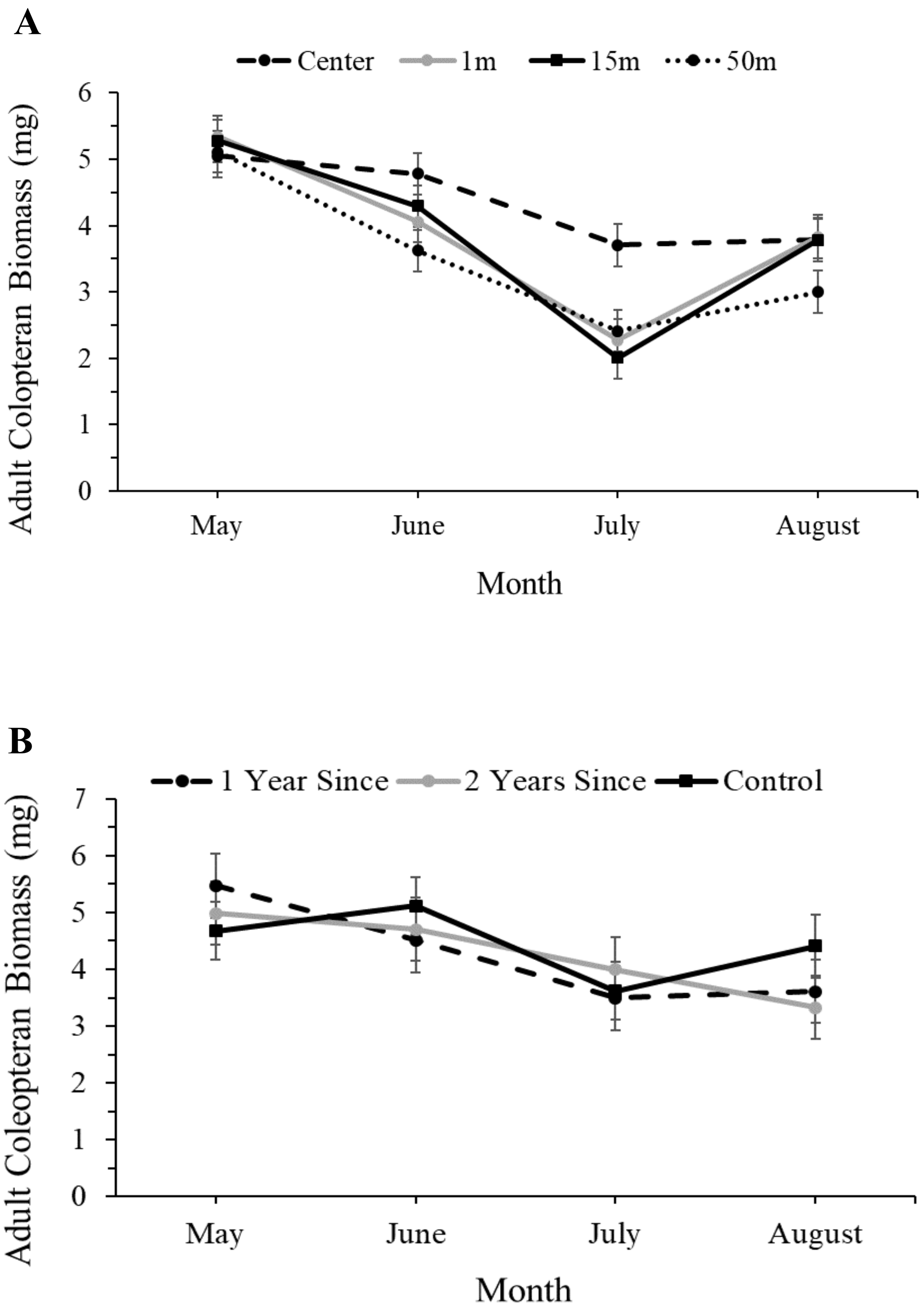


Figure 48. Least square means (± SE) for biomass (mg) of adult Coleopteran prey for adults collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018 in relation to A) distance from motte and B) time since prescribed burn for each month. Data were log(x+1) transformed.

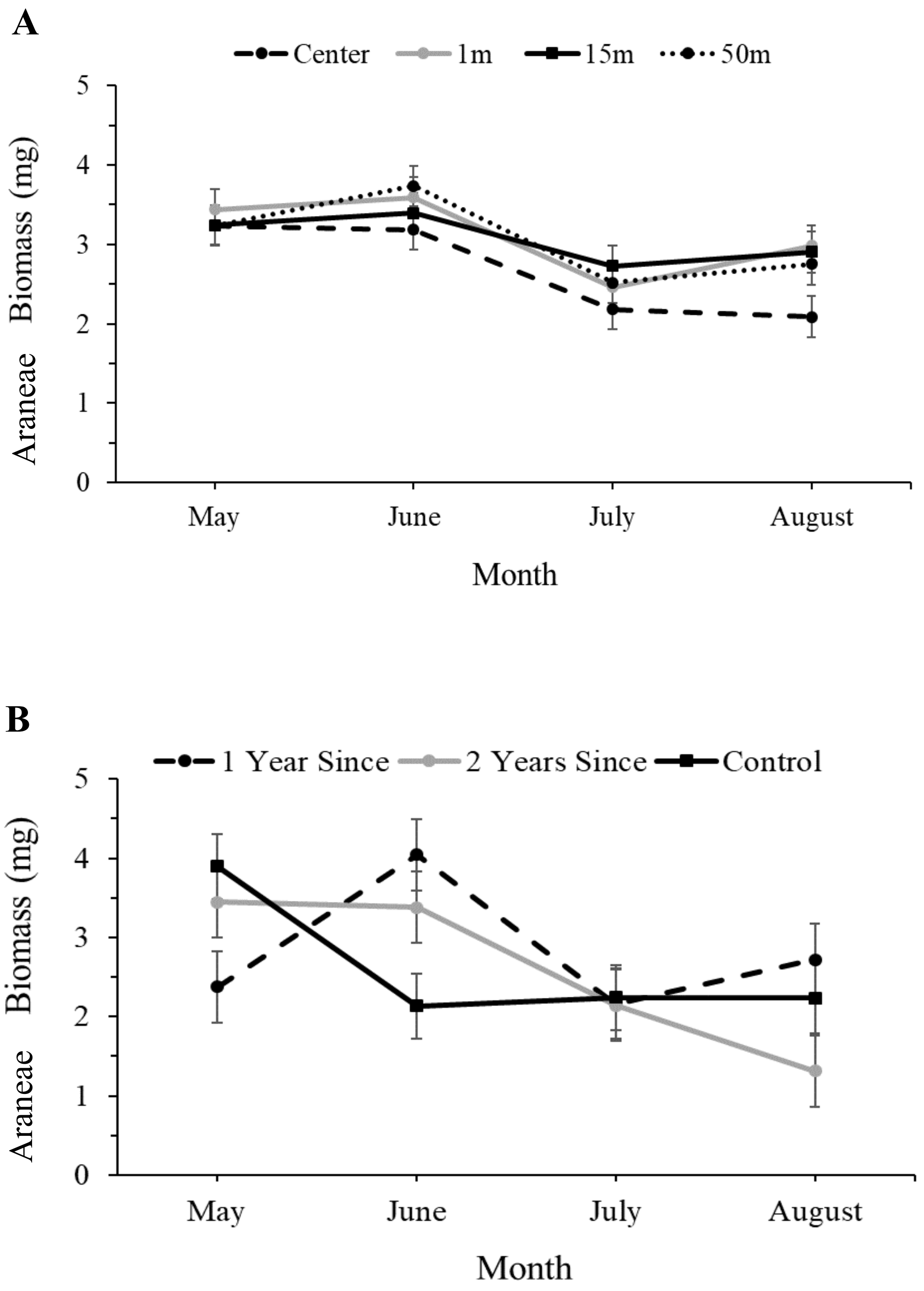


Figure 49. Least square means (± SE) for biomass (mg) of Araneae prey for adults collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018 in relation to A) distance from motte and B) time since prescribed burn for each month. Data were log(x+1) transformed.

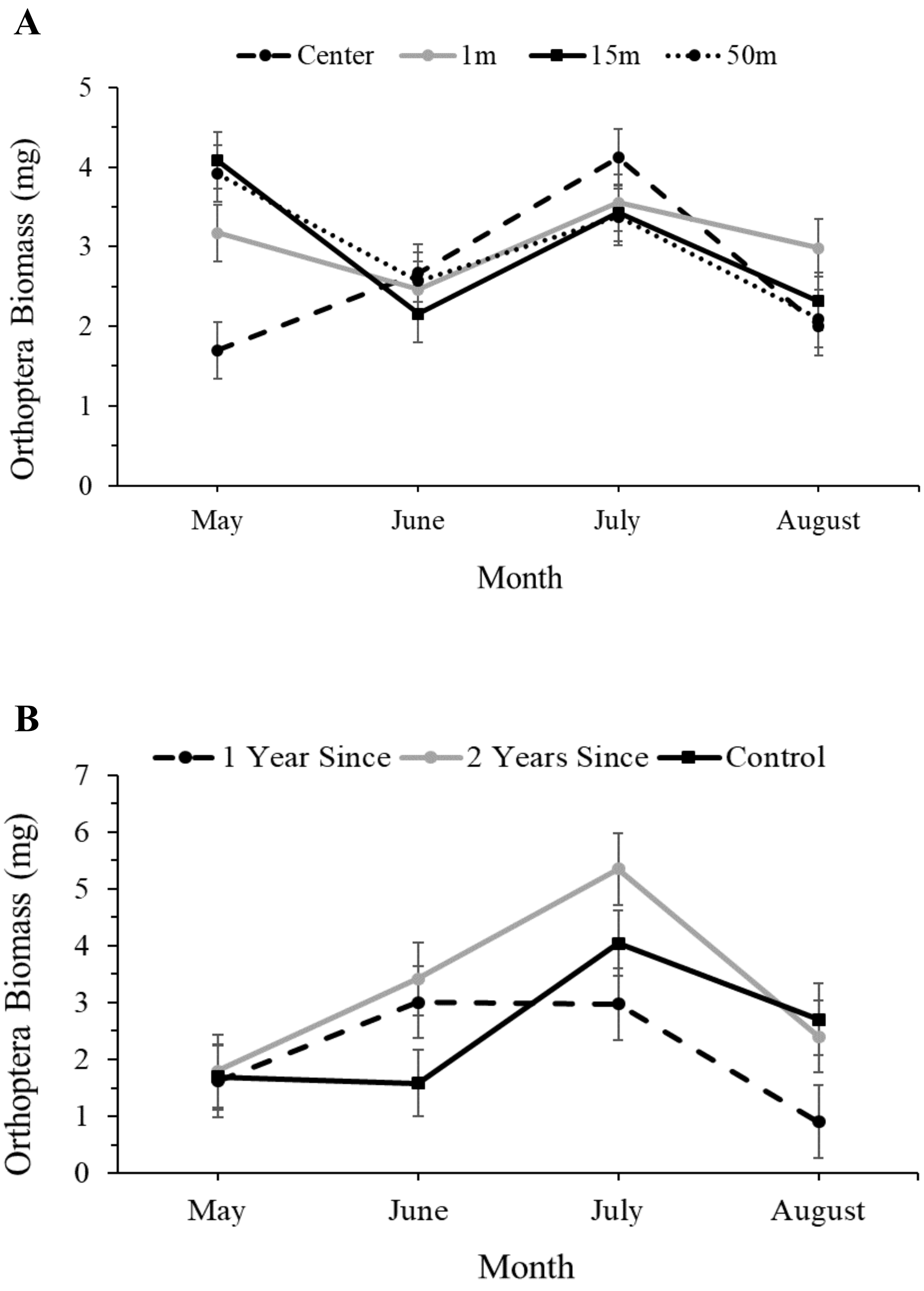


Figure 50. Least square means (± SE) for biomass (mg) of Orthopteran prey for adults collected in pitfall traps in Packsaddle WMA, Oklahoma during the summer of 2018 in relation to A) distance from motte and B) time since prescribed burn for each month. Data were log(x+1) transformed.

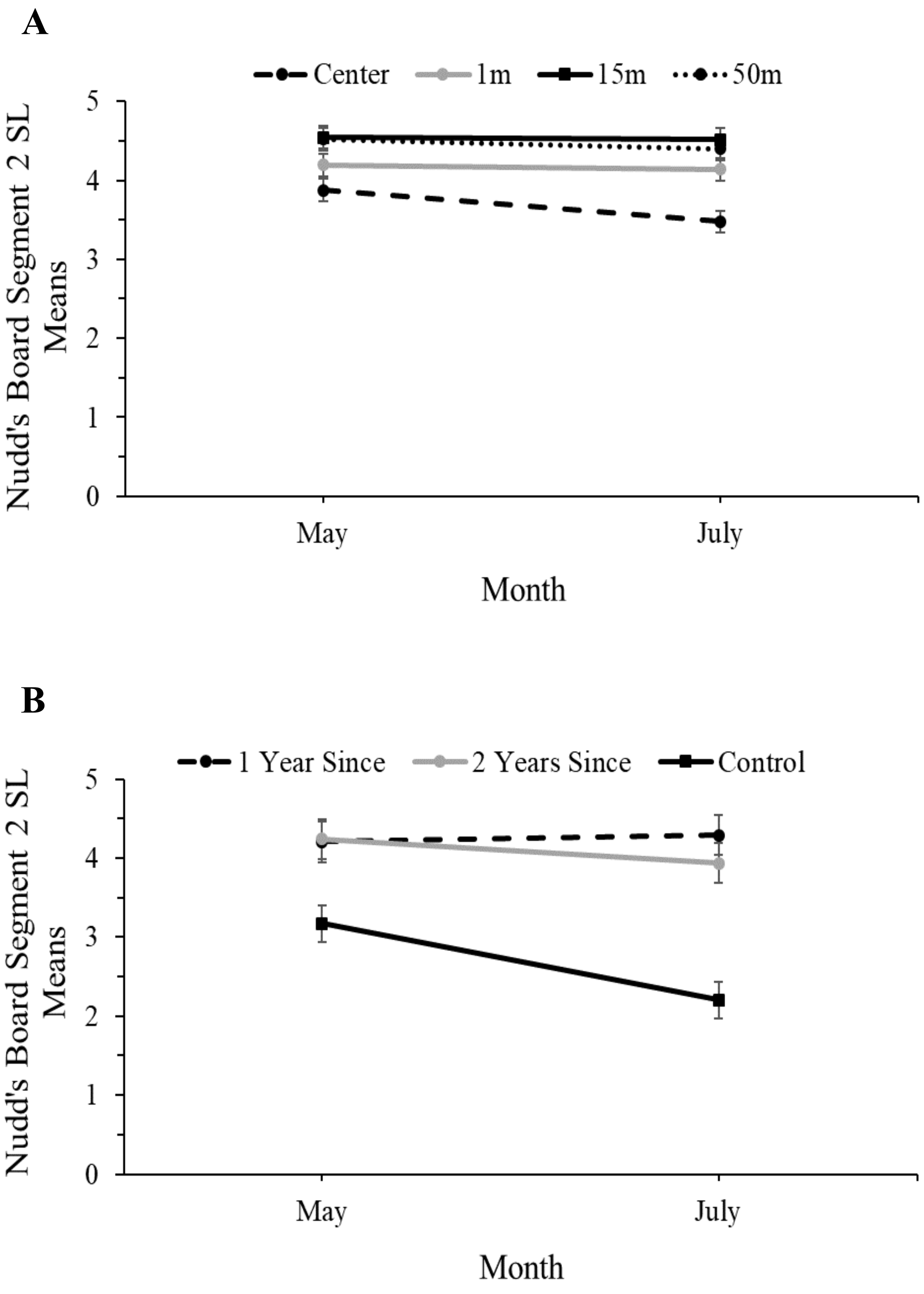


Figure 51. Least square means (±SE) for segment 2 of Nudd's board vegetation obstruction collected in May and July in Packsaddle WMA, Oklahoma during the summer of 2018 in relation to A) distance from motte and B) time since prescribed burn for each month.

VITA

Anna Elizabeth Butler

Candidate for the Degree of

Master of Science

Thesis: EFFECT OF FIRE AND HABITAT INTERACTION ON ARTHROPOD FORAGE FOR NORTHERN BOBWHITE BROODS

Major Field: Integrative Biology

Biographical:

Education:

Completed the requirements for the Master of Science in Integrative Biology at Oklahoma State University, Stillwater, Oklahoma in July 2019.

Completed the requirements for the Bachelor of Science in Biology at State University of New York at Potsdam, Potsdam, NY in 2012.

Completed the requirements for the Associates of Science in Liberal Arts and Sciences at Finger Lakes Community College, Canandaigua, NY in 2010.

Experience:

Seasonal Wildlife Technician-Colorado Parks and Wildlife from April 2016 to September 2016

Fish and Wildlife Biologist-Riveredge Environmental, LLC, Massena, NY from June 2015 to November 2015

Sea Turtle Research Assistant-Pacuare Beach Program, Costa Rica from February 2015 to May 2015

Snowy Plover and Least Tern Monitor-California State Parks, Oceano Dunes, CA from March 2014 to October 2014

Sea Turtle Research Assistant-San Miguel, Guanacaste, Costa Rica from October 2013 to December 2013

Fish and Wildlife Biologist-Riveredge Associates, LLC, Massena, NY from May 2012 to November 2013

Herpetological Research Intern-SUNY Potsdam Biology Department from May 2011 to June 2012