THERMAL ECOLOGY AND EFFECTS OF LAND USE ON WILD TURKEY

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Abstract: Wildlife are influenced by their surroundings and capable of making choices and selecting areas that provide habitat. We investigated habitat selection on several scales to determine what influences Rio Grande wild turkey (*Meleagris gallopavo intermedia*; hereafter wild turkey) space use and movement. On a fine scale we sought to describe the thermal landscape to determine how landscape features such as vegetation can be used to moderate thermal extremes. We captured and fitted 36 female wild turkey with GPS transmitters. We measured black bulb temperature (surrogate for operative temperature) and identified vegetation characteristics at wild turkey GPS locations and random landscape locations. We observed that the thermal landscape was highly heterogeneous with temperatures ranging up to 52 ^{o}C at a given ambient temperature. Vegetation type strongly influenced temperature across spatial scales, with taller vegetation types having mean temperatures up to 8.95 ^{o}C cooler than the remainder of the landscape. However, these cooler vegetation types were uncommon, only making up 8.2% of the landscape. Despite the rarity of tall vegetation, wild turkey showed strong selection for this vegetation type. Wild turkey also altered their movement in response to temperature. We found that on the hottest days ($\geq$35 ^{o}C), wild turkeys decreased movement by three fold during peak heating, while movement on cooler days (<30^{o}C) was consistent throughout the day until the final locations. Collectively, our data provide evidence that space use on different scales and movement can be influenced by the thermal environment. In addition, we also examined broad scale habitat selection in terms of land cover (vegetation) and land use (management practices and energy development). Oil/gas wells were avoided in both the breeding and non-breeding seasons, while high traffic roads were avoided and low traffic roads were selected for in the breeding season. However, forest vegetation was by far the most influential factor in space use of wild turkey throughout the year. Therefore, our data collectively indicate that vegetation type, especially forest vegetation is the primary driver of wild turkey space use in terms of the thermal environment and land cover use.

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CHAPTER I

THERMAL REFUGE DRIVES SPACE USE AND MOVEMENT PATERNS OF A GALLIFORM

Abstract

Temperature affects every organism on Earth and has been argued to be one of the most critical factors in influencing organisms' ecology and evolution. Most organisms are susceptible to landscape temperature ranges that exceed their thermal tolerance. As a result, the distribution of landscape features that mitigate thermal extremes affects daily movement and space use of organisms. We sought to determine how these landscape features can be used to moderate thermal extremes and how the thermal environment can influence space use and movement of organisms. Using Rio Grande wild turkey (*Meleagris gallopavo intermedia*) as a model species, we measured black bulb temperature (surrogate for operative temperature) and identified vegetation characteristics at wild turkey GPS locations and random landscape locations. We observed that the thermal landscape was highly heterogeneous with temperatures ranging up to 52 ^{o}C at a given ambient temperature. Maximum black bulb temperatures were >70^{o}C, yet temperatures as cool as 28.7^{o}C existed simultaneously on the landscape. Vegetation type strongly influenced temperature across spatial scales, with taller vegetation types forest [(tall woody vegetation >2m) and hybrid shinnery oak (*Quercus havardii x Quercus stellata*)] having mean temperatures up to 8.95 ^{o}C cooler than the remainder of the landscape. However, these cooler vegetation types were uncommon, only making up 8.2% of the landscape. Despite the rarity of forest vegetation, wild turkey showed strong selection for this vegetation type. This relationship was most apparent during the heat of the day with 74.9% of locations within 18m of forest vegetation. Not only did wild turkey alter space use across time relative to temperature variation, but they also altered movement. We found that on the hottest days (≥35 ^{o}C), wild turkeys decreased movement by three fold during peak heating, while movement on cooler days (<30^{o}C) was consistent throughout the day until the final locations. Collectively, our data provide evidence that space use on different scales and movement can be influenced by the thermal environment. Failure to account for thermal characteristics of landscapes and the effects on habitat selection can lead to erroneous conclusions and incomplete understanding of what constitutes habitat for a species.

Introduction

Temperature affects every organism on Earth and has been argued to be one of the most critical factors in influencing organisms' ecology and evolution (Brock 1967). Specifically, temperature influences animal physiology, distribution, home range, reproduction, and survival. Organisms experience and respond to their thermal environment on a scale comparable to their size and mobility (Heath 1965, Chelazzi and Calzolai 1986). Understanding how organisms respond to temperature variation across the landscape can provide important information Temperature is accepted to be a driver of ecological processes (Smith and Smith 2000, Begon et al. 2006) and so understanding how temperature variation across landscapes affects species space-use and patterns of movement will help better explain what constitutes as habitat.

Most organisms are susceptible to landscape temperature ranges that exceed their thermal tolerance (Gilchrist 1995; Williams and Tielman 2005). Endotherms can make physiological adjustments for greater heat dissipation (Calder 1974; Williams and Tieleman 2005) and rely on behavioral modifications such as reducing activity or seeking shade in tall woody vegetation (Wolf 2000). As a result, the distribution of landscape features that mitigate thermal extremes affect an organism’s daily movement and space use (Melin et al. 2014, Ageilletta 2009). Survival may even hinge on the availability of these thermally buffered landscape features, especially during extreme heat events where usable space on the landscape may drastically change or decrease (Suggitt et al. 2011, Tanner et al. 2016, Elmore et al. 2017). In particular, the microclimate, which includes physical factors such as ambient temperature, solar radiation, wind, and humidity directly around an organism, is critical for survival and space use (Porter and Gates 1969).

Identifying these features that provide thermal refuge is important for conservation and management and determining how much usable space is available on the landscape for an organism during times of extreme temperature. Equally as important is understanding when these thermal refuges are available as they may shift on varying temporal scales. For example, a species space use on the landscape is constrained during extreme climactic events compared to more moderate temperatures. Extreme cold and hot periods both constrain the amount of useable space on the landscape. However, there is a dissimilarity in the amount and location of useable space on the landscape indicating that vegetation types and structures are needed to buffer against different extreme temperature events (Tanner et al. 2016). Previous literature has often focused on annual means to determine thermal constraints on organisms (Dunbar et al. 2009). However, averaging organisms usable space on an annual or seasonal scale does not appropriately identify thermal refugia available on the landscape that may be necessary for survival during variable environmental conditions (Tanner et al. 2016). For most species, we do not understand how discrete environmental conditions may constrain space use and survival or how species respond to thermal variation at the landscape level. This limited understanding of thermal environments consequently limits our understanding of what constitutes habitat for a species.

Heterogeneity is widely recognized as a driver of biodiversity and ecosystem function (Weins 1997, Christensen 1997). It has primarily been associated with spatial and temporal variation of vegetation structure and composition, though other facets of landscape heterogeneity such as microclimate are essential yet understudied (Limb et al. 2009). The spatial and temporal variation of microclimate, created by heterogeneity of vegetation, can generate variable locations that differ dramatically spatially across landscapes providing organisms with thermal heterogeneity (Carroll et al. 2016, Hovick et al. 2014).This variation provides microclimates that both far exceed ambient temperatures and those that buffer against extreme ambient temperatures. For example, tall woody vegetation provides shade and is 10-12 °C cooler than open herbaceous vegetation which is often subjected to high levels of solar radiation (Carroll et al. 2016). The interactions between vegetation composition/structure and temperature strongly influence the characteristics of microsites (Saunders et al. 1998, Schut et al. 2014) and in turn, dictate which locations are useable to organisms during bouts of temperature extremes (Guthery 2000, Melin et al. 2014, Carroll et al. 2015). For example, tall woody vegetation has been shown to provide critical thermal refuge for both ectotherms (Attum et al. 2013, Burrow et al. 2001) and endotherms (Melin et al. 2014, Carroll et al. 2015a, 2015b, McKechnie at al. 2012). Understanding the scale at which individuals make behavioral adjustments, and movement decisions based on both temporal and spatial variation of the thermal environment is essential for conservation and management decisions (Porter et al. 2002, Wiens 1989, Jackson and Fahrig 2012).

Increases in annual global temperature as well as an increase in the frequency and intensity of extreme temperature events (IPCC 2014) are predicted to alter thermal patterns across landscapes (Opdam and Wascher 2004). Landscapes that already experience high heat and aridity are predicted to experience the greatest increases (Meehl and Tebaldi 2004). Temperature increases and thermal extremes have already been implicated in local extinctions (Sinervo et al. 2010), mass mortality events (Welbergen et al. 2008, Towie 2009, McKechnie et al. 2012), and reductions in long term survival

(Moses et al. 2011). While all organisms are influenced by their thermal environment (Brock 1967, Angilletta 2009), most avian species are particularly vulnerable to elevated temperatures because they are predominately active and above ground during the day (McKechnie and Wolf 2010, Wolf et al. 1996).

The Rio Grande wild turkey (Meleagris gallopavo intermedia) is a generalist gallinaceous species (Rioux et al. 2009) that can tolerate a wide range of vegetation types. Rio Grande wild turkey (hereafter, wild turkey) is native to Texas, Oklahoma, and Kansas in the Southern Great Plains of the United States where summer ambient temperatures often exceed 35°C (Arndt 2003) and tall woody vegetation can be sparse. Because Rio Grande wild turkey are birds that are active during the day, they are likely, susceptible to high ambient temperatures and levels of solar radiation. These characteristics make wild turkey an ideal species to investigate the influence of the thermal environment on an individual's movement and space use especially during periods of high heat. Our objectives were to 1) describe the thermal heterogeneity of a landscape and examine how wild turkey use the landscape to moderate extreme temperatures, and 2) to characterize the microclimates wild turkey use during peak heating. Therefore, we quantified both thermal and vegetation characteristics at wild turkey diurnal locations and random landscape points to identify how spatial variation in vegetation and temporal variation influence wild turkey behavior.

Methods

Study site

We studied the thermal ecology of wild turkey in western Oklahoma on Packsaddle Wildlife Management Area (WMA). The Oklahoma Department of Wildlife Conservation (ODWC) owns and manages the 7,956 ha property. The study site is predominately composed of mixed-grass prairie and sand shinnery oak (*Quercus havardii*). Other shrubs include sand sagebrush (*Artemisia filifolia*), sand plum (*Prunus angustifolia*) and aromatic sumac (*Rhus aromatica*) (DeMaso et al. 1997, Vermeire and Wester 2001). Common herbaceous plants include little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), sideoats grama (*Bouteloua curtipendula*), blue grama (*Bouteloua gracilis*), western ragweed (*Ambrosia psilostachya*), Texas croton (*Croton texensis*) and prairie sunflower *(Helianthus petiolaris*) (DeMaso et al. 1997, Peterson and Boyd 1998). Tall woody cover predominately consists of hybrid sand shinnery/post oak mottes (*Quercus havardii x Quercus stellata*), but also contains cottonwood (*Populus deltoides*), black locust *(Robinia pseudoacacia*), hackberry (*Celtis occindentalis*), and soap berry (*Sapindus drummondii*). From 1994 to 2017, the region received an average precipitation of 571.25 mm per year (Arnett Oklahoma Mesonet Site; Oklahoma Mesonet 2017). Summer temperatures in the area can reach 37.8 C on average for 15 or more days per year (Arndt 2003). The area includes sandy Nobscot, Nobscot-Brownsfield, and Pratt-Tivoli soils (DeMaso et al. 1997), has rolling hills and contains partially wooded draws/re-entrants.

Data Collection

We captured wild turkeys in the spring of 2016 and 2017 using modified walk-in funnel traps (Davis 1994). We fitted female wild turkeys with solar powered 70g backpack-style GPS transmitters that have ± 18 m error (Microwave Telemetry, Inc., Columbia, MD). Transmitters generally recorded 7 locations during the day (8:00, 10:00, 12:00, 14:00, 16:00, 18:00, and 20:00h) from 15 March to 15 September during each year.

To investigate the thermal environment across the landscape and assess potential thermal selection of wild turkey during the periods of potentially high thermal stress, we measured black bulb temperature during June-August of each year. Black bulbs are steel spheres (101.6 mm-diameters; 20 gauge thickness) painted flat black that contain a temperature probe suspended in the center of each sphere and connected to a HOBO U12 data logger (Onset Corporation, Bourn, Massachusetts, USA). Black bulb temperatures provide closer estimates of thermal conditions an organism is experiencing than does ambient temperature because they provide a proxy for operative temperature (Cambell and Norman 1998, Guthery et al. 2005). Operative temperature incorporates ambient temperature, solar radiation, and wind convection into a single metric (Dzialowski 2005). We attached three total spheres to each data logger, one at the center point (turkey location or random landscape location), and the other two distributed 6 m away in a random cardinal direction to form a thermal sampling array to characterize the thermal conditions at a given point. As the thermal environment can vary tremendously at very small spatial scales (Hovick et al. 2014), we used three spheres at each point to better capture the small scale variation at that point while also accounting for telemetry error. To measure the black bulb temperature of wild turkey locations, we deployed thermal sampling arrays on the day following telemetry download (typically within 3 days of data acquisition) only if similar temperature and solar radiation conditions were forecast. In this way, we were not assessing the precise thermal environment the wild turkey experienced, but modeling an index of thermal conditions at turkey and random locations across space and time to evaluate thermal variation, thermal selection, and drivers of temperature variation. Each day, a random wild turkey was chosen, with the constraint that an individual was not sampled more than once per week. We placed thermal arrays at all seven daytime GPS locations for each selected wild turkey. All arrays were placed at the respective telemetry locations before 08:00 and data were recorded every 15 minutes from 08:00 to 20:00h. In this way, we were able to collect temperature data during the entire diurnal period of GPS telemetry (8:00 – 20:00h).

To capture thermal variation of the landscape, we selected the four most common vegetation types on the study site (herbaceous, shinnery oak, hybrid shinnery oak, and forest). We then used a combination of data collected during the study and points used from a previous study conducted on Packsaddle WMA. We used or collected thermal data on each vegetation type by randomly choosing 30 pts per vegetation type (2012-2017) resulting in 120 vegetation points. Vegetation was delineated using Maximum Likelihood Supervised Classification method from 2 meter resolution satellite imagery. A total of 319 known vegetation polygons were used to train and create a map of vegetation types on the study area. Our four vegetation types accounted for 90.09% (50.97%, 30.40%, 6.43%, and 2.29% for herbaceous, shinnery oak, hybrid shinnery oak, and forest, respectively) of the total vegetation coverage on the landscape. We measured black bulb temperature at random landscape locations with the same black bulb array design as the wild turkey locations. At each random location, we deployed a data logger and three thermal spheres to take black bulb temperature every 15 minutes from 07:30 to 20:30h. To compare site-specific black bulb temperature measurements to ambient temperatures, we recorded ambient temperature every hour at an onsite meteorological station. Because the meteorological station recorded averaged hourly temperatures, we averaged the black bulb temperatures that were recorded every 15 min by hour as well so that we could compare ambient and black bulb temperatures on the same temporal scale. Hour 20 was omitted from the analysis since data was only collected until 20:30h, leaving only two 15 min intervals to be averaged instead of four.

To determine the frequency at which wild turkeys use vegetation types over the course of the day, we overlaid wild turkey GPS locations with our vegetation map and extracted vegetation values for each point. Observations in the field suggested that wild turkey were often selecting areas near trees or even single isolated trees. Therefore, to evaluate potential association with discrete vegetation classes, we additionally buffered the forest vegetation type and recalculated the frequency at which turkey use the forest class given our ± 18 m GPS error. The last GPS point (hour 20) was omitted from this analysis as well because its proximity when turkey use the roost, and we did not want to overestimate the frequency of forest use because of roosting behavior.

To examine daily movement patterns of wild turkey, we calculated the distance moved between two consecutive GPS locations (which spanned two hours) for all turkey telemetry locations. If a transmitter was unable to record a GPS point, we discarded that 2 hour time period. We then averaged the movement data into three categories, days that experienced maximum air temperatures ≥35°C, <35°C and days <30°C to evaluate the effect of temperature on wild turkey movement across the 2 hour time periods. Previous laboratory research suggests that wild turkey show signs of heat stress through panting, dropping wings, and extending neck and snood (fleshy protuberance above the beak) at ambient temperatures above 35 °C (Buchholz 1996). Therefore, we used this threshold to investigate possible differences in mean daily movement between days that experienced maximum air temperatures <30°C, <35 °C and ≥35 °C.

Results

We found that this heterogeneous landscape of mixed prairie intermixed with shrubs and trees has high thermal variability with differences in operative temperature ranging up to 52°C when ambient temperatures are >30°C (Fig 1). Within this heterogeneous thermal landscape, there were operative temperatures available that were cooler than ambient temperatures and also those that reached an excess of 70°C (Fig 1).

We additionally found that different vegetation types provided different ranges of operative temperature throughout the day with considerable disparity occurring during the midday when ambient temperatures and solar radiation levels are highest (Fig 2). Forest and hybrid shinnery oak vegetation types (the taller vegetation types) provided the most moderated temperatures throughout the day especially during peak heating (Fig 2). The forest vegetation type was the coolest of all vegetation types with black bulb temperatures averaging 3.65°C, 8.17°C, and 8.95°C cooler than hybrid shinnery oak, shinnery oak and herbaceous vegetation types, respectively, during the heat of the day (Table 1).

We found that the study site was primarily comprised of herbaceous (52.94%) and shinnery oak (28.79%) vegetation types (Fig 3). Only 8.22% of the landscape was comprised of taller vegetation types (1.99% forest and 6.23% hybrid shinnery oak). We found that wild turkey strongly selected for the forest cover type. Depending on the time of day, wild turkey selected for this vegetation type six and a half to eleven times more than what was available on the landscape (Fig 3). While this selection was apparent during all times of the day, it was especially strong during hours of peak heating (Fig 3). Hybrid shinnery oak was also selected more than expected by random chance (up to 1.7 times), but this selection was much less than selection for forest (Fig 3). We found that shinnery oak was used approximately in proportion to availability and wild turkey tended to avoid herbaceous vegetation at all times of the day (Fig 3). However, wild turkey tended to use herbaceous vegetation more during early morning and late afternoon. When an 18 m buffer was applied to the forest vegetation type to account for potential GPS error and associations with this cover type, the frequency of forest used and forest availability increased. We found that during peak heating, 74.91% of wild turkey locations were within 18 m of a forest edge or within the forest vegetation type while only 23.26% of the total landscape fell within this buffer (Fig 4).

During the early hours of the day, wild turkey locations were on average 35.88 m ± 1.37 from forest vegetation and 24.47 m ± 1.18 from hybrid shinnery oak (Fig 5). As ambient temperatures increased throughout the day, the proximity of wild turkey locations to these taller vegetation types decreased to an average distance of 22.67 m ± 1.11 for forest and 12.65 m ± 0.60 for hybrid shinnery oak (Fig 5). However, when mean distances were calculated for only days that experienced maximum air temperatures ≥35 °C, wild turkey mean distance to forest and hybrid shinnery oak decreased every hour. During peak heating, distance to forest decreased 5.24 m to 17.43 m ± 1.75 and distance to hybrid shinnery oak decreased 4.63 m to 8.01 m ± 0.50. Note that both of these distances are within the 18 m error of the telemetry data. Turkey distance to herbaceous vegetation and shinnery oak remained below 5.5 m throughout the day for all days and days ≥35 °C, however, approximately 82.7% of the study area was comprised of herbaceous vegetation and shinnery oak (Fig 5).

Wild turkey temporally altered their movement patterns over the course of the day on hotter days, but no difference in movement was detected on cooler days. Specifically, on days <30°C, wild turkey movement did not differ between consecutive locations throughout most of the day (only the final mean movement differed from peak heating movements). However, on days that included temperatures <35°C, wild turkey altered their movement patterns during midday when ambient temperatures and solar radiation levels were the highest. Wild turkey moved most in the early and late hours of the day and decreased their mean movement by 117 m during peak heating. Compared to days <30°C, wild turkey moved approximately 73 m less during the hottest time of the day. On days experiencing maximum temperatures ≥35 °C, wild turkey altered their movement patterns further during peak heating. During the hottest days, wild turkey mean movement was 234.16 m ± 6.69 during 8:00-10:00h and declined more than threefold to 74.34 m ± 3.31 during midday (12:00-14:00h). After peak heating, average movement increased. The difference in mean movement between days <30°C and days ≥35 °C during peak heating is 126.83 m (Fig 6).

Discussion

Heterogeneity in vegetation across the landscape provides a wide array of thermal options. When ambient temperatures and levels of solar radiation are high, organisms can mitigate the stress of thermal extremes by moving to or occupying cooler microclimates that may be influenced by vegetation types (e.g., tall vegetation that offers shade). The distribution of these thermal refuges across the landscape may dictate the amount of usable space available to organisms, which suggests that available habitat is variable depending on temperature and other environmental conditions (Tanner et al. 2016). During periods of high heat, the amount of usable space may be substantially reduced by the distribution of thermal refuges accessible to organisms (Tanner at el. 2016), due to vegetation height and type. However, if the landscape provides heterogeneity in vegetation types, organisms may be provided with sufficient locations that thermally buffer high temperatures (Figure 7). In some cases, the persistence of both endotherm (Guthery 2000) and ectotherm (Lagarde et al. 2012, Attum et al. 2013) populations may be contingent upon the presence of refugia during these high temperatures.

We observed that the thermal landscape was highly heterogeneous with temperatures ranging up to 52 ^{o}C at a given ambient temperature. Maximum black bulb temperatures were >70^{o}C, yet temperatures as cool as 28.7^{o}C existed simultaneously on the landscape providing potential thermal refugia for wild turkeys. Vegetation type strongly influenced temperature across spatial scales, with taller vegetation types (forest and hybrid shinnery oak) having mean temperatures up to 8.95 ^{o}C cooler than the remainder of the landscape. Yet, these cooler vegetation types were uncommon given that forest and hybrid shinnery oak make up only 1.99% and 6.23% of the landscape, respectively. Despite the rarity of forest vegetation, wild turkey showed strong selection for this vegetation type with 57.7 % of total locations found within 18m (corresponding to GPS telemetry error) of forest vegetation. This relationship was most apparent during the heat of the day with 74.9% of locations within 18m of forest vegetation. Not only did wild turkey alter space use across time relative to temperature variation, but they also altered movement. We found that on the hottest days (≥35 ^{o}C), wild turkeys decreased movement by three fold during peak heating, while on cooler days (<30^{o}C) movement was consistent throughout the day until the final locations. Collectively, our data provides evidence that space use and movement can be influenced by the thermal environment. We caution that failure to account for thermal characteristics of landscapes and the effects on habitat selection can lead to erroneous conclusions and incomplete understanding of what constitutes habitat for a species.

We found that the coolest vegetation types in our landscape moderated temperatures up to 8.95^{o}C compared to more open (herbaceous and shinnery oak) vegetation. Yet, the cooler forest vegetation made up a relatively small portion of the landscape (1.99%), which likely constrains the total useable space for some organisms during times of thermal extremes. While hybrid shinnery oak also provides cooler temperatures than shinnery oak and herbaceous vegetation, it was not as highly selected for. This was likely due to a combination of thermal and vegetation structure differences. Wild turkey rely on sight to avoid potential predators and prefer loafing in open understory (Baker 1979 and Baker et al. 1980).

Studying long-term temperature averages and climate over a landscape can be informative for broad-scale questions relevant to animal distributions, population fluctuations, and species persistence (Dunbar et al. 2009). However, small scale changes in temperature over the course of the day influences animal behavior and movement. Further, the availability of thermal refuge to organisms in times of thermal stress can have profound effects on habitat selection and in some cases even discrete stochastic weather events can affect animal survival (Tanner et al. 2016). Previous studies suggest that different species of reptile (Attum et al. 2013, Sears et al. 2011), birds (Carroll et al. 2015a, 2015b), and mammals (Melin et al. 2014), select for thermal buffering when temperatures begin to exceed their thermal tolerances. Our study also indicates that wild turkey similarly make space use decisions based on discrete vegetation types that are cooler than the majority of the landscape. These vegetation types provide thermal buffering against extreme ambient temperatures throughout the day. In addition to changes in behavior, a reduction in activity or movement is a common strategy for organisms to moderate heat loads (Wolf 2000). We found movement was reduced during peak heating. On days characterized by milder temperatures (<30 ^{o}C), wild turkey did not alter their movement from morning. On days with higher ambient temperatures (<35 ^{o}C and ≥35 ^{o}C), wild turkey decreased their midday movements by approximately 36% to 68% or an average of 100 m less than on days <30 ^{o}C. The variation in movement over hours of the day and between days indicates that temporal variation in temperature affects space use at multiple scales (Tanner et al. 2016).

Previous studies have found that organisms mitigate thermal extremes during significant life events. Exposure to high temperatures and solar radiation can affect nest success and selection for cooler nesting locations (Hovick et al. 2014). During early stages of growth, exposure to heat may directly cause chick mortality (Salzman 1982), or decrease foraging time which can lead to reduced growth or survival (Goldstein 1984, Cunningham et al. 2013). Extreme temperatures also change brood behavior and movement. For example, northern bobwhite (*Colinus virginianus*) were found to move their broods to tall vegetation and decrease movement which provided thermal cover and reduced the amount of energy expended (Carroll et al. 2015b). Our study provides evidence that organisms may need to mitigate thermal extremes on a daily basis when choosing loafing locations and not just significant life events such as nesting and brood rearing. Our data suggest that organisms actively choose to buffer against extreme temperatures by selecting cooler locations and reducing movement in discrete time intervals (<2 hours). While this finding is intuitive, very little empirical data exist documenting intra-daily behavior modifications relative to landscape thermal variation. Though active heat dissipation through adjustments in behavior, movement, and physiology is beneficial to organisms, it may incur costs such as increased demand for energy, reduced foraging efficiency, or reduced the rate of water intake (du Plessis et al. 2012). The increase in wild turkey movement that we documented from 18:00-20:00 hours on days ≥35 °C (Figure 6) may be a compensating mechanism to increase foraging opportunities that may have been restricted during midday due to extreme temperatures. Prioritizing foraging, movement, and cover selection decisions could be increasingly important on a daily basis with future predictions of increased temperatures and extreme thermal events (IPCC 2014)

Thermal landscapes are dynamic systems that vary spatially and temporally across different scales (Saunders et al. 1998). Our study suggests that the heterogeneity of a landscape provides a broad range of thermal options for organisms, especially during periods of high heat. The interaction of temperature and vegetation structure is a primary driver in the variation of microhabitats and affects organism behavior and space use. We found that discrete vegetation patches (tall woody vegetation) offered the most thermal refuge during midday and on days with relatively higher temperatures. In many landscapes, thermal refuge may be discrete both spatially and temporally. Temperature moderation may play a foundational role in organisms' selection of habitat. A reduction in thermal refuge would likely be detrimental to species that require thermal mitigation (Fig 7), offering fewer sites to moderate extreme temperature. Conservation practices should be directed towards maintaining structural heterogeneity to ensure a wide range of thermal choices are available on the landscape to support organisms and their thermal tolerances.

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Table 1. Range of ambient temperature T_{air} and black bulb temperature T_{bb} sampled from peak heating (12:00-16:00) in herbaceous, shinnery, hybrid shinnery, and forest vegetation types at the Packsaddle Wildlife Management Area, Oklahoma, USA during June-August (2012-2017).

Vegetation Type	T_{air} range (°C)	T_{air} mean (°C)	T_{bb} range (°C)	T_{bb} mean (±SE)
Herbaceous	25.85-39.36	34.31 ± (0.15)	25.58-64.10	49.08 (±0.44)[a]
Shinnery	25.85-41.01	34.27 ± (0.19)	22.35-67.29	48.30 (±0.52)[a]
Hybrid shinnery	26.51-41.87	35.56 ± (0.20)	27.48-72.43	43.78 (±0.59)[b]
Forest	26.51-38.51	34.51 ± (0.16)	25.68-64.50	40.13 (±0.51)[c]

Different superscript letters denote significant differences (Tukey's multiple comparisons, $p > 0.05$). Ambient temperature corresponds to days vegetation type was taken (n=1029)

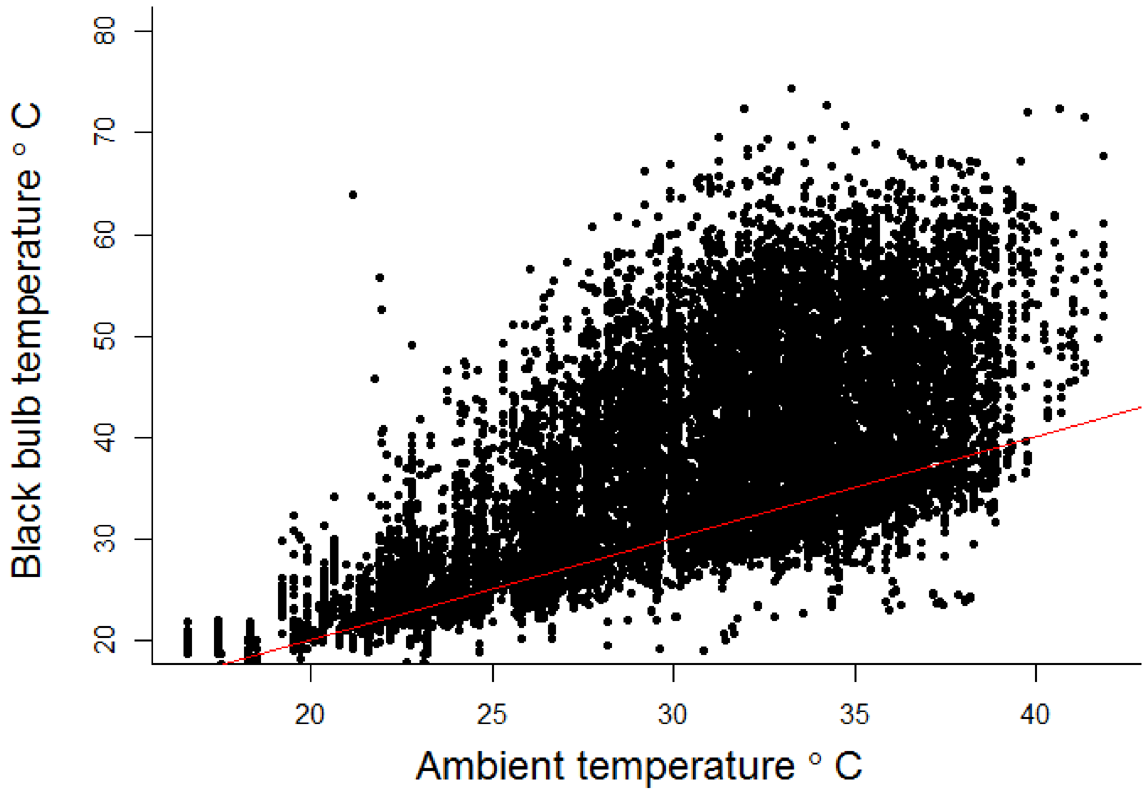

Figure 1. Relationship between black bulb temperature and ambient temperature recorded from 08:00 to 19:00h at Packsaddle Wildlife Management Area, Oklahoma, USA during June-August (2016-2017). The red line represents a 1:1 linear relationship. Data points below this line are areas of thermal refuge at a given ambient temperature (n=14,764).

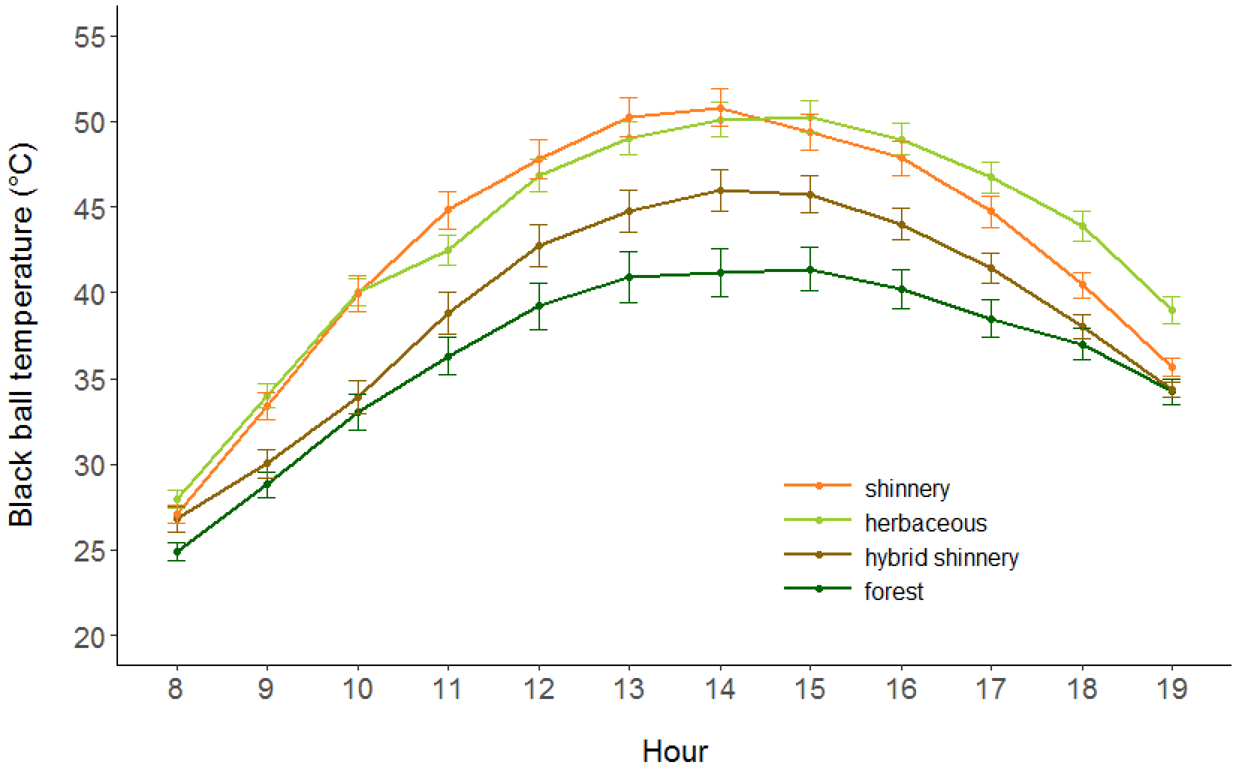

Figure 2. Variation in average back bulb temperatures (± SE) recorded in herbaceous, shinnery oak, hybrid shinnery oak, and forest vegetation types at different times of the day (8:00-19:00h) at Packsaddle Wildlife Management Area, Oklahoma, USA during June-August (2012-2017). Both hybrid shinnery oak and forest vegetation were significantly cooler than shinnery oak and herbaceous vegetation during peak mid-day heating. Forest was significantly cooler than hybrid shinnery oak during peak mid-day heating (n=2598).

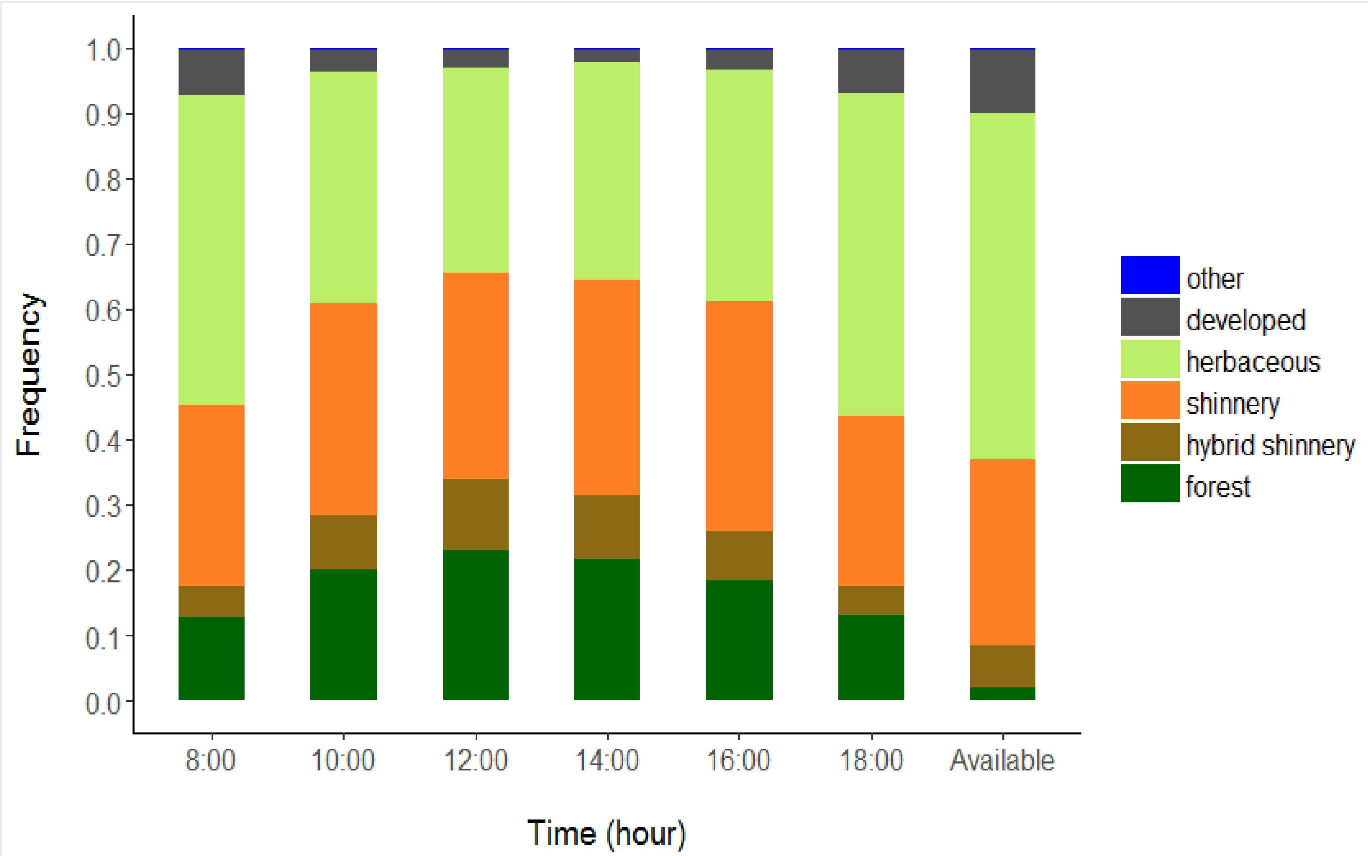

Figure 3. Frequency of wild turkey telemetry locations within each vegetation type at different times of the day (8:00-18:00) at Packsaddle Wildlife Management Area, Oklahoma, USA (2016-2017). The frequency at which each vegetation type was available across the landscape is represented in the right-most bar. Wild turkey selected for forest vegetation greater than expected at random and this selection was greatest during mid-day hours (n=12,623).

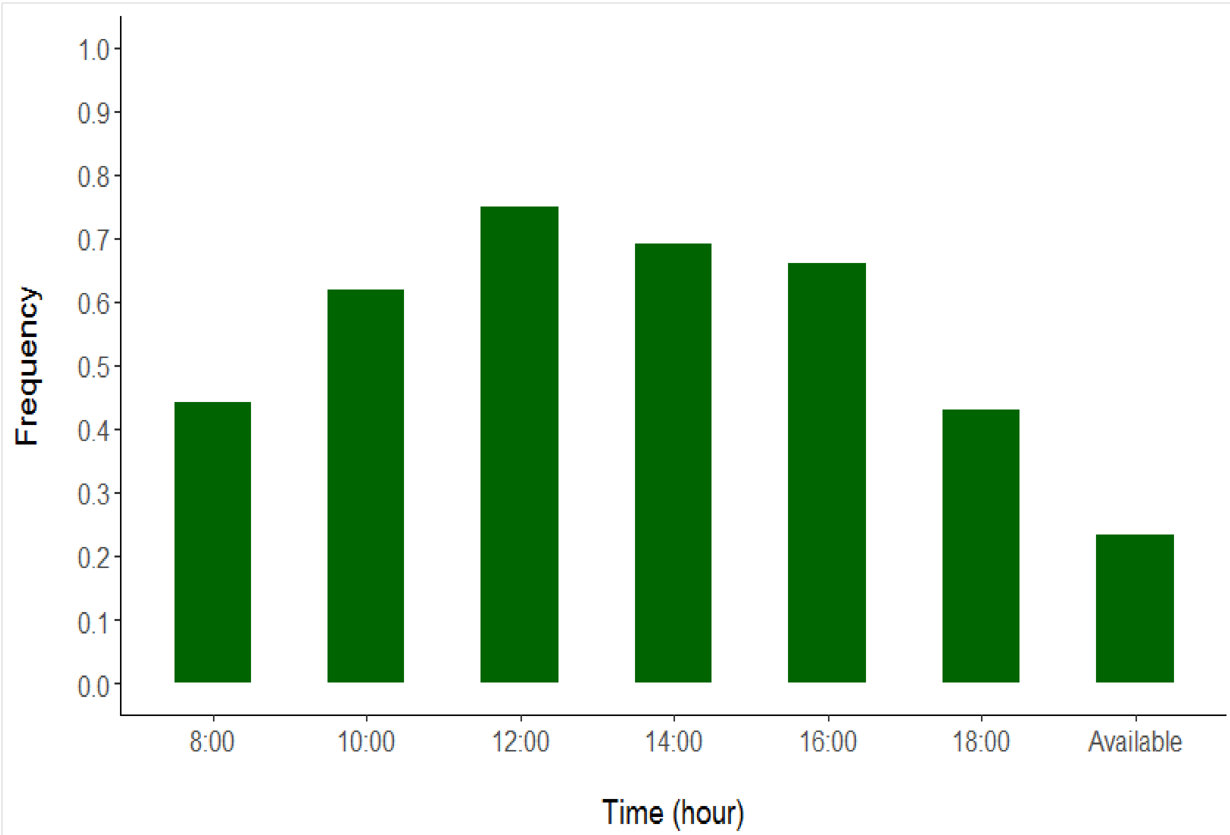

Figure 4. Frequency of wild turkey telemetry locations for each hour (8:00-18:00h) within 18 meters (m) of forest at Packsaddle Wildlife Management Area, Oklahoma, USA (2016-2017). The percent of the landscape that is within 18 m of the forest vegetation type is represented by the right-most bar. Wild turkey minimized the distance to a forest edge particularly at mid-day hours (n=3,393).

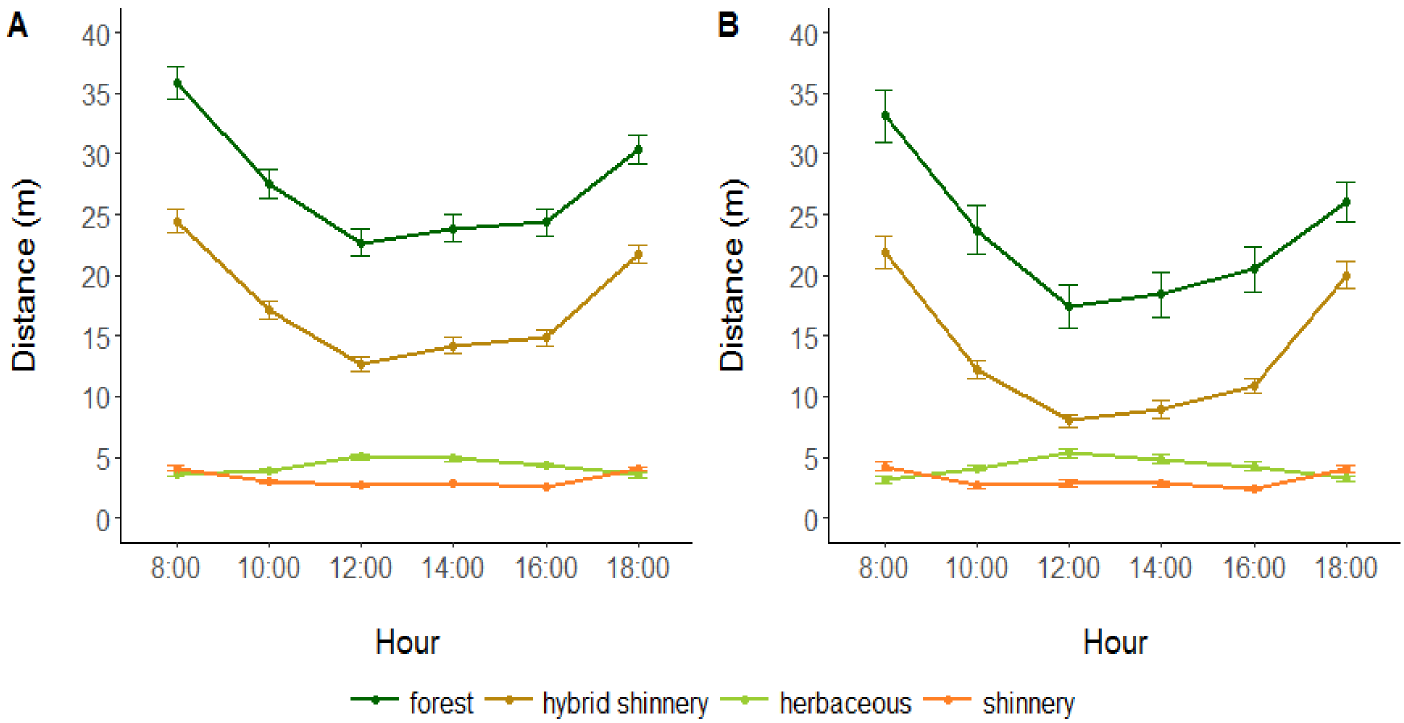

Figure 5. The average distance (± SE) wild turkey locations were from each vegetation type (herbaceous, shinnery, hybrid shinnery, and forest) during different times of the day (8:00 to 18:00h) for all days (A) (n=84) and on days ≥35 °C (B) (n=66) at Packsaddle Wildlife Management Area, Oklahoma, USA, 2016 - 2017. (Multiple pairwise comparisons, $p < 0.05$, significance corresponds to non-overlapping error bars).Wild turkey minimized distance to thermal refuge during peak heating of mid-day and this distance was less on days with higher temperatures.

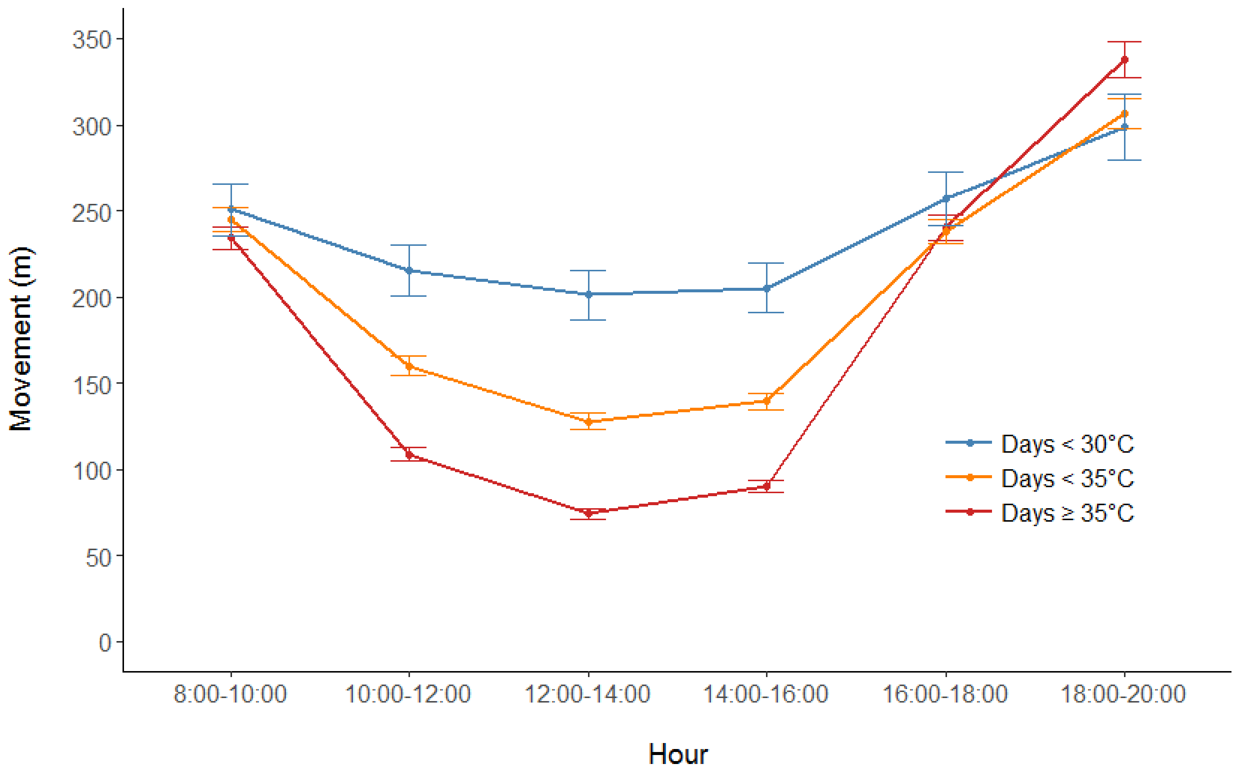

Figure 6. Variation in mean wild turkey movement (± SE) at different times of the day (8:00-20:00h) on days experiencing maximum air temperature < 30 ºC (blue) (n=21) on days where maximum temperatures were < 35 ºC (orange) (n=84) and days experiencing maximum air temperatures ≥35 ºC (red) (n=66) at Packsaddle Wildlife Management Area, Oklahoma, USA, 2016-2017 (Multiple pairwise comparisons, $p < 0.05$, significance corresponds to non-overlapping error bars). Wild turkey minimized their movements as mid-day temperatures increased.

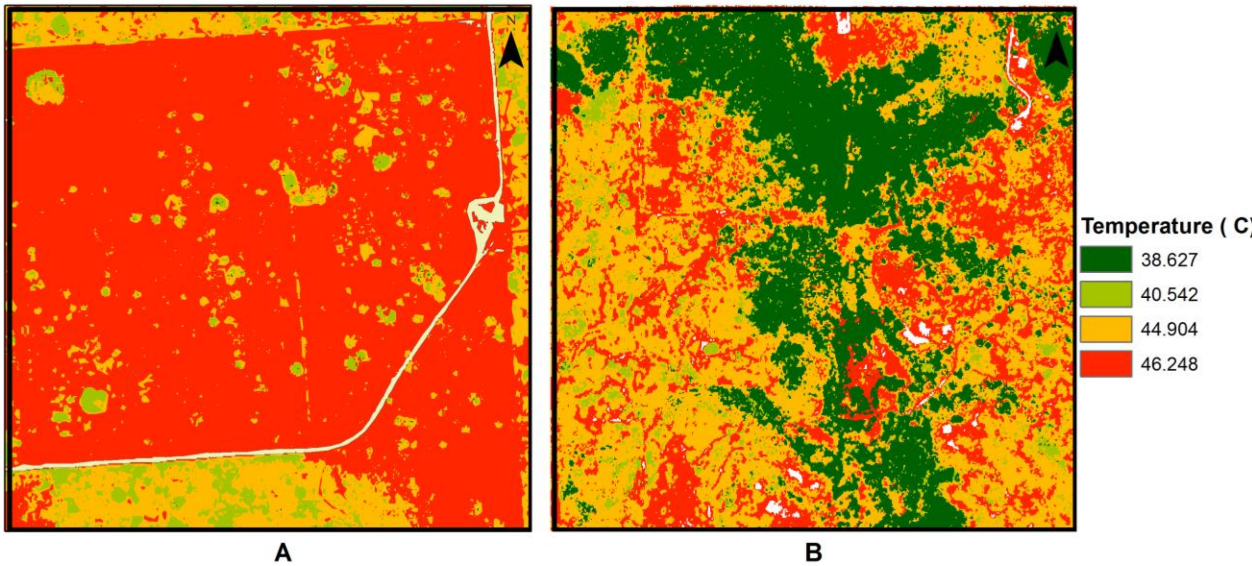

Figure 7. Spatial variation of available mean black bulb temperatures across a homogenous landscape (A) and a relatively heterogeneous landscape (B) during midday peak heating on Packsaddle Wildlife Management Area, Oklahoma, USA (2016-2017). Each panel is one square kilometer of the study site. The more homogenous landscape (A) offers fewer thermally buffered choices to wild turkey as seen by the large areas of red. This portion of the study site is characterized by mainly herbaceous vegetation. The relatively heterogeneous portion of the landscape (B) provides a wide array of thermal options due to patches of forest.

CHAPTER II

RESPONSE OF RIO GRANDE WILD TURKEY TO ENERGY DEVELOPMENT AND LAND COVER

Abstract

The use of unconventional oil and gas extraction is transforming millions of hectares of grasslands into more industrialized landscapes. As oil and gas demands continue to rise, wildlife may be subjected to unprecedented levels of energy infrastructure and associated fragmentation of landscapes. Within the context of avifauna, several studies have focused on the effects of energy development on resident ground nesting Galliforms and have come to varying conclusions. We attached GPS transmitters to 36 female Rio Grande wild turkey (*Meleagris gallapavo intermedia;* hereafter wild turkey) and monitored them from March 2016 to February 2018 to better understand management practices and energy development effect wild turkey space use. Wild turkey selected for the most recent time since fire category (0-6 months) during the breeding season. Oil/gas wells were avoided in both the breeding and non-breeding seasons, while high traffic roads were avoided and low traffic roads were selected for in the breeding season. However, forest vegetation was by far the most influential factor in space use of wild turkey throughout the year. Therefore, our data indicate that vegetation type is the primary driver of wild turkey space use but that anthropogenic features and activity do have an effect. Consideration of wild turkey should be taken into account when planning oil and gas development, particularly in landscapes where forest cover is limited as is often the case where Rio Grande wild turkey occur. Though wild turkey show limited avoidance of anthropogenic structures, they may not be as susceptible to energy development as reported for other Galliform species.

Introduction

The native grasslands of North America are experiencing dramatic declines in size and biodiversity and have become the most altered biome in North America. Since the 1830's, estimated declines in tallgrass, mixed grass, and short grass prairie range from 82-99%, 30-99%, and 20-85% respectively, throughout different regions across North America (Samson and Knopf 1994). These declines have resulted in extensive loss in wildlife habitat, biodiversity, and ecological function (Herkert et al. 2003; Hoekstra et al. 2005). The loss of native grasslands is mainly due to anthropogenic causes such as conversion for cropland and energy development. In the US, approximately 7,784,000 km^2 of land has been converted to cropland from 1850 to 1997 (Waisanen and Bliss 2002). Much of the cropland development peaked by the late 1960's (Waisanen and Bliss 2002), though approximately 1,600 km^2 of land is still converted to cropland each year (USDA 2013). With our energy demands predicted to increase, we continue to follow the trend of converting grasslands into industrialized landscapes.

The US and Canada currently produce the greatest amount of unconventional oil and gas energy globally (United States Energy Information Administration; Gadonneix et al. 2010). Unconventional oil and gas extraction uses horizontal drilling and/or hydraulic fracturing (Thompson et al. 2015). Energy demands have facilitated an average of 50,000 new wells per year in North America since 2000 (Allred et al. 2015). Though energy development and its accompanying infrastructure are not recent additions to North America landscapes (Braun et al. 2002), the amount of space, infrastructure, and maintenance for horizontal drilling and high-volume hydraulic fracturing is much greater than that of more traditional oil and gas extraction methods (Allred et al. 2015;

Brittingham et al. 2014). The use of this unconventional oil and gas extraction is transforming millions of hectares of grasslands into more fragmented landscapes. As predictions of oil and gas demands continue to rise, wildlife may be subjected to unprecedented levels of energy infrastructure and associated fragmentation of landscapes.

Effects of energy development on wildlife are complex and pervasive. Since unconventional extraction methods are a multistep process (Brittingham et al. 2014), oil and gas development can have both direct and indirect impacts on wildlife (Sawyer et al. 2006). The construction of unconventional oil and gas pads requires more area and infrastructure, which results in the direct removal of vegetation to create the well pads and creates fragmentation for some species of wildlife (Brittingham et al. 2014). Unconvential oil and gas well pads average 1.2-2.7 ha while conventional well pads average 1.08 ha in size (Brittingham et al. 2014; Clancy et al. 2017). In addition, oil and gas development increases noise and light pollution and increases human activity which can elicit behavioral changes such as shifts in movement patterns and space use of various wildlife species (Barber et al. 2010; Bayne et al. 2008; Blickley et al. 2012; Habib et al. 2007; Reijnen and Foppen 1995; Shannon et al. 2016; Swaddle et al. 2015).

Previous research in North America indicates energy development, particularly unconventional oil and gas, can have a negative impact on some wildlife species. The majority of these studies focused on ungulates, greater sage-grouse (*Centrocercus urophasianus*), and other bird species (Brittingham et al. 2014). Within the context of avifauna, many studies have focused on the effects of energy development on resident ground nesting Galliforms. Galliforms are typically ground-dwelling, ground nesting, and non-migratory, which may make them more susceptible to energy development than other bird species (Brennan et al. 2008; Hovick et al. 2014). A meta-analysis of oil and gas structures effects on grouse found that the greatest impact was on behavioral responses (such as changes in space use/avoidance) of grouse (Hovick et al. 2014). Additionally, there is evidence of decreased survival in grouse (Hovick et al. 2014) caused by oil and gas wells, while roads associated with energy structures may also elicit avoidance behavior (Hagen et al. 2011; Hovick et al. 2014; Pitman et al. 2005). In northern bobwhite (Colinus virginianus), risk of mortality has been shown to increase in proximity to primary roads (Tanner et al. 2016). However, oil and gas structures have a neutral effect on northern bobwhite space use and mortality (Dunkin et al. 2009; Tanner et al. 2016).

Little research has been conducted on wild turkey (Meleagris gallopavo) and energy development, although turkeys are thought to avoid roadways during the breeding season (Still Jr and Baumann Jr 1990) and development may cause the displacement of important roost trees (Beasom and Wilson 1992). Wild turkey have distinct separate breeding and nonbreeding home ranges. During the breeding season, wild turkey generally have larger home ranges and are engaged in mating, nesting, and brood rearing (Healy 1992). Breeding and non-breeding hens will separate from one another, and non-breeding hens will form small flocks. During the non-breeding season, wild turkey often travel many kilometers to concentrate into groups, creating large flocks (Butler et al. 2005; Cook 1973). During this time, wild turkey are more sedentary with smaller home ranges than the breeding season (Phillips 2004; Thomas et al. 1966). Additionally, previous research indicates that turkey preferentially select for different vegetation types and that vegetation is directly altered by fire (Beasom and Wilson 1992; Hulbert 1988).

Because these seasons and management practices can differ in location with differential habitat selection, we sought to investigate the effects of vegetation, time since fire, and energy development and associated infrastructure on wild turkey space use during the breeding and non-breeding season and to determine if wild turkey are more susceptible to energy infrastructure during different times of the year. Specifically, we evaluate the Rio Grande subspecies of wild turkey (*M. gallopavo intermedia*).

Methods

Study site

We studied the effects of energy infrastructure and management on wild turkey (hereafter turkey) space use in western Oklahoma, United States on Packsaddle Wildlife Management Area. The property is owned and managed by the Oklahoma Department of Wildlife Conservation (ODWC). The 7,956 ha property is predominately composed of mixed-grass prairie and sand shinnery oak (*Quercus havardii*). Shinnery oak is a clonal shrub, and is the dominant woody plant and forms extensive stands seldom reaches heights >1.5 m. Shinnery is codominant with many species of grasses and forbs. Common grasses and forbs include little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), sideoats grama (*Bouteloua curtipendula*), blue grama (*Bouteloua gracilis*), Texas croton (*Croton texensis*), western ragweed (*Ambrosia psilostachya*), and prairie sunflower (*Helianthus petiolaris*) (DeMaso et al. 1997; Peterson and Boyd 1998). Other shrubs include sand sagebrush (*Artemisia filifolia*), sand plum (*Prunus angustifolia*) and aromatic sumac (*Rhus aromatica*) (DeMaso et al. 1997; Vermeire and Wester 2001). Hybrid sand shinnery/post oak (*Quercus stellata*) mottes make up most of the taller (>2 m) woody cover. These hybrid shinnery have a distinct structure (particularly in the understory) than other tree species on the landscape. Other tree species present include cottonwood (*Populus deltoides*), black locust (*Robinia pseudoacacia*), hackberry (*Celtis occindentalis*), and soap berry (*Sapindus drummondii*).

Over the course of the study, the average temperature through the breeding season (March-October) ranged from 11.7-27.5 and 11.8-27.3 °C for 2016 and 2017, respectively. The long-term (1997-2017) average temperature for the region during this time is 20.85 °C. Annual precipitation for 2016 and 2017 was 53.82 and 69.24 cm, respectively. Long-term (1994-2017) annual precipitation is 57.23 cm (Arnett Oklahoma Mesonet Site; Oklahoma Mesonet 2017). The area includes sandy Nobscot, Nobscot-Brownsfield, and Pratt-Tivoli soils (DeMaso et al. 1997), has rolling hills and contains partially wooded draws. The primary management practices used on the study area are prescribed fire and grazing by domestic cattle (*Bos taurus*). Prescribed fire has consistently been used as a management technique since 2004, and most burns are conducted during the dormant season. In 2016, approximately 1,284 ha were burned during the dormant season, and 74 ha were burned during the growing season. In 2017, approximately 290 ha were burned during the dormant season. Stocking rate of livestock on the study area was uniformly applied at 1 steer per 7.3 ha from April 1 to August 15 of both years.

Capture and GPS Monitoring

We trapped turkey in March, May, and June of 2016 and 2017 using baited modified walk-in funnel traps (Davis 1994). We banded all captured turkey with leg bands (size 28; National Band and Tag, Newport, KY) and fitted 36 females with a solar-powered GPS transmitter (Microwave Telemetry, Inc., Columbia, MD). Transmitters had ± 18 m error, weighed 70 g, and were attached using a backpack style harness constructed of marine grade bungee cord. Transmitters recorded approximately 7 diurnal locations during the day (8:00, 10:00, 12:00, 14:00, 16:00, 18:00, and 20:00h) from 15 March to 15 September and 6 diurnal locations (9:00, 11:00, 13:00, 15:00, 17:00h) from 16 September to 14 March. We distinguished between breeding and non-breeding season individually for each bird due to variation in home range changes. The breeding period was approximately March to October depending on the individual. The non-breeding period was approximately October to April. We excluded GPS locations that occurred during movement between non-breeding and breeding home ranges.

Data analysis

We used an IKONOS multispectral imagery with 2-meter resolution obtained in July of 2016 to classify four major vegetation types relevant to turkey across the study area: herbaceous, shinnery, hybrid shinnery, and forest. We defined the forest vegetation class as any tree species other than hybrid shinnery that was >2 m. This could be a singular tree, or a grouping of trees as long as it was distinguishable from the satellite imagery. Hybrid shinnery was classified separately due to its distinct structure and because preliminary evidence suggested that wild turkey use it differently than other tree species. We digitized anthropogenic features such as oil and gas wells (N = 329) and roads (367.35 km) using the 2-meter imagery. Additionally, we identified all anthropogenic and natural fresh water sources on the study site. During the 2016 and

2017 breeding season, there were 66 water sources available distributed across the study area.

For the breeding season, we used variables that are either known or hypothesized to be important to turkey (vegetation type and distance to forest) and those that are related to anthropogenic features (oil/gas wells, roads, water sources, and time since fire [TSF]) for our analysis. Forest vegetation has been shown to be particularly important to wild turkey as they choose to associate with forest more than any other vegetation type because it provides roosting and loafing cover. Fire is a key management tool that changes vegetation structure and composition. Fire promotes new growth and increases the availability of food resources such grass, forbs, and legumes which can improve habitat for wild turkey (Yarrow et al. 1998). We chose to use four categories of time since fire: 0-6 months, 6-12 months, 12-24 months, and >24 months. After 24 months post-fire shinnery oak, the primary plant community on this study site, returns to its pre-burn state (Boyd and Bidwell 2002). We determined vegetation type and TSF by overlaying used and random points with the supervised vegetation classification and TSF layer in ArcMap 10.3 (ESRI). We calculated proximity-to variables for forest, oil/gas wells, roads (high traffic and low traffic), and water using the near tool in ArcMap. We determined road traffic by a series of 15 traffic counters deployed across the study area during the entirety of the study period. We defined high traffic roads as roads that received ≥250 axel hits per day and low traffic roads as those that received <250 hits per day. For the non-breeding season, we used only proximity-to variables (forest, oil/gas wells, roads). This is because most of the wild turkey moved off of the WMA onto adjacent private land during the nonbreeding season and we did not have the same high-resolution satellite imagery, traffic data, or TSF information.

We used resource selection functions to determine the effects of energy infrastructure on turkey during the breeding and non-breeding season. We chose a "used versus available" design using generalized linear mixed models (Boyce et al. 2002; Manly et al. 2002). We included individual as a random effect to control for the variation among turkey. Turkey GPS locations were randomly reduced from 5-7 locations per bird a day to 2 locations per bird a day to help account for pseudoreplication (Dzialak et al. 2012; Lautenbach et al. 2017). We defined availability as the resources within 200 m of each GPS location during the breeding season and 350 m during the non-breeding season. We chose 200 m and 350 m as they represented the average movement between two consecutive GPS locations during the breeding season and non-breeding seasons respectively (Holt et al. 2009; Johnson et al. 2006). We then created five random points within each buffer (Cooper and Millspaugh 1999) and calculated each of the variables [vegetation type, time since fire, and distance to forest, wells, roads (high and low traffic), and water] for all random points. We designated the GPS locations as used points while the random locations were available points.

We evaluated the continuous covariates for multicollinearity using the Pearson correlation coefficient at a threshold of 0.6 (LeBeau et al. 2017). None of the variables were correlated. We incorporated these seven variables into resource selection functions to create a series of a priori generalized linear mixed models for the breeding season and three variables for the non-breeding season to determine drivers of turkey space use by season. The a priori models were ranked using the corrected Akaike's Information

Criterion (Burnham and Anderson 1998). Vegetation and TSF were categorical variables, and the logistic regression required a reference class to be selected for each of the categorical variables. We used forest as the reference class for vegetation because previous research shows turkey have a high association with forest vegetation. For TSF, we used the shortest time after fire, 0-6 months post burn because of the potential for increased wild turkey food resources available shortly after a burn (Ghermandi et al. 2004; Komarek 1969). The results for the categorical variables can only be interpreted relative to the reference variables for each category, forest vegetation or 0-6 months post burn.

Results

We collected location data from 36 female wild turkey between March 15, 2016, and February 26, 2018. We used a total of 7,806 used and 38,999 available breeding locations and 2,173 used and 10,865 available non-breeding locations for analysis. Our study area was comprised of 52.94% herbaceous, 28.78% shinnery oak, 6.23% hybrid shinnery oak, 1.99% forest, and 9.70% developed cover types. During the breeding season, turkey were found most commonly found in herbaceous vegetation (n = 2,561) and shinnery oak (n = 2,492) and less commonly in forest (n = 1,825), hybrid shinnery (n = 610), and developed land (n=348). We were unable to determine vegetation type selection during the non-breeding season as most of the turkey moved off the study site into areas where we did not have access to imagery.

The a priori model that best fit the breeding season data was the global model as determined by AICc rankings. There was one competing model (Table 1), which excluded management practices (prescribed fire and water sources). However, the categorical variable TSF was a significant variable (Table 2) as the confidence intervals did not overlap zero, so we chose the global model as our top model that best described the data.

During the breeding season, turkey preferred forest to all other vegetation types (Figure 1) and selected forest eleven times more than what was available to them on the landscape (Figure 2). The coefficient estimate for distance to high traffic roads (0.09) and oil/gas wells (0.03) were positive, indicating that turkey were maximizing the distance to (avoidance) of areas near high traffic roads and oil/gas wells. However, these coefficients are near zero, indicating only weak avoidance. Distance to forest (-0.22) and distance to low traffic roads (-0.05) had negative coefficient estimates which indicates that turkey were minimizing the distance to (selection) areas that were closer to forest and low traffic roads. However, the estimate for low traffic roads is near zero. Only two categories of time since fire were significantly different from one another which was 0-6 months and >2 years TSF (Figure 3). Greater than two years post-fire had lower selection than other categories. Turkey selected for locations that had been burned within six months, but not significantly so. Distance to water had a negative coefficient (-0.02) though likely has little descriptive power in the model since the confidence intervals overlapped zero.

The model that best described the non-breeding season was one that included forest (which was the only vegetation type that could be included in the non-breeding season analysis) and oil/gas wells. The global model was a competing model but, had a larger AIC value (Table 2). The top model was more parsimonious than the other competing model, so it was the model used to describe turkey resource selection during the non-breeding season.

Similar to the breeding season, during the non-breeding season, the coefficient estimate for distance to forest was negative (-0.27), indicating that turkey were minimizing distance to forest. A threshold of use was found at approximately 400 m with probability of space use of turkey increasing steadily as the distanced approached zero. Specifically, the predicted probability for finding a turkey is ~18% less at 400 m away from forest vegetation than within forest vegetation (Figure 4). The coefficient estimate for distance to wells (0.10) was positive which indicated that wild turkey were maximizing distance to areas further away from oil/gas well sites. A threshold of approximately 500 m was found where the predicted probability of locating a turkey at an oil/gas well is ~7% and increases to ~12% 500 m away and levels of past that distance (Figure 5).

Discussion

We found that wild turkey space use was most strongly related to the forest vegetation type, and this relationship was apparent for both the breeding and non-breeding season. Specifically, during the breeding season, turkey were twice as likely to be in forest as available locations, and used forest 11 times more than what is present across the landscape (Figure 2). During the non-breeding season turkey were 17% more likely to be within forest than locations that are 400 m from forest. We also found that turkey had a weak avoidance of anthropogenic structures (oil/gas wells) and activity (high traffic roads). Finally, time since fire was found to affect space use of turkey, with turkeys showing a trend toward avoiding greater time since fire areas and favoring more recent burns, but there was tremendous variation in response, and the effect was weak.

Forest vegetation is important during the diurnal breeding season. Turkey demonstrated a high infinity for forest vegetation by choosing to use this vegetation type more often than what is available on the landscape during the majority of the day (Figure 2). Turkey locations had the strongest association with forest likely because turkey use trees for various reasons over the course of the day. Turkey are likely using forest vegetation during the heat of the day for its thermal buffering properties. As turkey require trees for roosting (Beasom and Wilson 1992), turkey locations early and late in the day are likely to be near forests because they have just flown down from or are preparing to fly up to the roost for the night. However, it should be noted that we used diurnal locations throughout the day to describe space use of turkey. Had we chosen to use only early morning or late evening locations, our selection patterns may have shown different results. Turkey would likely have more of an association with open herbaceous vegetation during periods of the day when they are feeding (Dickson 1990). Therefore, our results reflect a representation of the entire diurnal period rather than discrete portions of it and should be interpreted accordingly.

Fire is an important management practice for wild turkey because it has a direct effect on vegetation structure and composition. Turkey selected the most recent TSF class (0-6 months post-fire) compared to the longest TSF category (>24 months post-fire). Locations experiencing the shortest time since fire may offer turkey increased food availability by favoring forbs, insects, and new palatable grass growth (Yarrow et al. 1998). Additionally, fire opens up the understory increasing foraging efficiency which promotes turkey use (Holbrook 1974). After two years post-fire, the shinnery oak plant community has been shown to return to pre-burn conditions (Boyd and Bidwell 2002), which may not be as appealing as a recently burned locations for foraging turkey.

During the non-breeding season when turkey have congregated into large winter flocks that are relatively sedentary, they select for diurnal locations closer to forest. Large stands of trees are needed to provide roosting locations for the entire flock. Swearingin et al. (2010) found that stands used for winter roosts could be upwards of 5.8 ha. Forests may also provide additional food sources during the winter such as acorns and pecans (Glover 1948; Haroldson et al. 1998). Further, turkey may rely on forests to buffer the effects of wind and to reduce heat loss during storms (Haroldson et al. 1998). Since turkey decrease their home range size during the winter and forest provides important roosting locations, thermal cover, and foraging opportunity, turkey likely minimize their diurnal locations to forest, and our data supports this.

Our analysis suggests that anthropogenic infrastructure can have a negative impact on turkey space use. Turkey tended to minimize use of areas close to oil/gas wells and high traffic roads (>250 axels per day) during the breeding season. While the avoidance was not particularly strong, it could have implications for wild turkey populations at some threshold of development. Our results were generally consistent with research conducted on grouse species and Eastern wild turkey (Meleagris gallopavo silvestris). A number of grouse species are particularly sensitive to energy structures resulting in declines in survival, displacement, and avoidance regardless of life history stage (Blickley et al. 2012; Green et al. 2017; Grisham et al. 2014; Hess and Beck 2012; Hovick et al. 2014; Kirol et al. 2015). Oil and gas structures have been shown to have the greatest negative impact on displacement while the impact of roads is thought to be related to the level of traffic (Grisham et al. 2014; Hovick et al. 2014). Similarly, Eastern wild turkey were shown to avoid areas with high human activity (Wright and Speake 1976) and roads where traffic rates exceeded 70 vehicles per hour (McDougal et al. 1990). The avoidance of high-traffic roads by breeding birds is thought to be associated with higher levels of noise (Summers et al. 2011). During the breeding season, the noise associated with high traffic roads and wells may inhibit communication for attracting mates or hen-brood communication (Rheindt 2003). In addition, anthropogenic noise and movement may be distracting, making individuals more vulnerable to predation (Chan et al. 2010). We found that turkey also avoided wells during the non-breeding season. Well sites can be related to the direct loss in habitat such as winter roost sites (Jarnevich and Laubhan 2011; Pitman et al. 2005) and more indirect effects such as avoidance due to anthropogenic noise or disturbance. Another possible explanation for selecting locations away from oil/gas wells may be because turkey require large tree stands during the winter and these stands are usually located in riparian areas where it may be difficult or unsuitable to build well sites. In addition, turkey often rely on nearby crop fields such as wheat during the winter months for food sources. Landowners may negotiate the location of oil/gas wells off of their agricultural fields, potentially increasing the distance of well sites to turkey locations.

We found that turkey tended to select locations closer to low traffic roads during the breeding season. Selection for low-traffic roads by gallinaceous birds has been previously documented in northern bobwhite (Colinus virginianus) and ruffed grouse (Bonasa umbellus) (Dunkin et al. 2009; Schumacher 2002; Unger et al. 2015; Wellendorf et al. 2002). Dunkin et al. (2009) suggested that northern bobwhite use roads with low traffic volume as travel corridors while ruffed grouse may use roads for displaying, dusting, and foraging for invertebrates (Berner and Gysel 1969; Bump et al. 1947; Schumacher 2002). In other avian studies, low traffic roads were seen to have less of a negative effect than high traffic roads or no effect on bird abundance, occurrence, and species richness (Forman et al. 2002; Reijnen and Foppen 1995; Van der Zande et al. 1980). During the breeding season, roadsides may be used by males for displaying similar to grouse. Roadsides provide open areas for strutting where visibility is unobstructed to allow hens to see displaying gobblers (Beasom and Wilson 1992; Hurst and Dickson 1992; Lewis 1992). Turkey may also use roads for feeding on herbaceous vegetation, seeds, and arthropods (Beasom and Wilson 1992; Berner and Gysel 1969; Yarrow et al. 1998). However, during the non-breeding season, roads did not appear to have a significant effect on turkey. This could be due several factors. Foremost is that we did not have traffic count data for much of the non-breeding home ranges and therefore we only had one road class. If we were to expect a similar trend to appear in the non-breeding season as the breeding season, then turkey would show an avoidance for high traffic roads and a selection for low traffic roads. These trends may have canceled each other out. However, we estimate most of the roads in the non-breeding home ranges had low traffic volume. Another possibility is that turkey may not be using low traffic roads during the non-breeding season because males are not displaying and food sources such as insects and herbaceous vegetation are no longer readily available (Beasom and Wilson 1992; Meanley 1956).

In summary, our findings suggest that vegetation structure, primarily tree cover, is the major driver of Rio Grande wild turkey space throughout the year. During the breeding season, forest vegetation provides thermal refuge from high temperatures and solar radiation while also providing roosting locations. In the non-breeding season, forest provides roosting locations for large flocks, thermal refuge, and food resources in the form of hard mast. While anthropogenic structures did affect turkey space use, the effect was much less than was distance to forest. Though there are thresholds to the amount of anthropogenic disturbance turkey can tolerate, wild turkey are a generalist species (Rioux et al. 2009) that are capable of tolerating of a wide range of conditions (Dickson et al. 1978) and appear to be somewhat tolerant of anthropogenic development.

Despite this tolerance, future development, especially the establishment of new oil/gas wells has the potential to reduce habitat quality for wild turkey. It is estimated that a total of 4,315 to 6,590 vehicle visits are required to maintain one fracked gas pad, with the majority of these visits occurring during the initial fracking period (Goodman et al. 2016). These additional vehicles have the potential to convert low traffic roads, which turkey select for, to high traffic roads which turkey avoid. This avoidance could be due to increased levels of noise and collision hazards (Blickley et al. 2012; McClure et al. 2013; Summers et al. 2011). Additional oil/gas wells could directly reduce useable space and potentially eliminate forest and roosting locations, particularly in landscapes where forest cover is limited as is often the case where Rio Grande wild turkey occur. In our study area, only 1.99% of the landscape provides forest cover. Our study demonstrates the importance of forest vegetation and direct removal of forest cover due to road and well construction, or potential reductions in space use due to the proximity of human activity, could negatively impact turkey. Though wild turkey may not be as sensitive to energy development as some other Galliforms, consideration of Rio Grande wild turkey habitat (especially tree cover) should be taken into account when planning additional oil and gas development.

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Table 1. Resource selection candidate models for Rio Grande wild turkey space use during the breeding season (approximately March to October) on Packsaddle Wildlife Management Area in western Oklahoma, United States in 2016 and 2017.

Candidate Models	**K**	**AIC**	**∆AIC**
VEG + DFOR + DOGW + DLT + DHT + DWA + TSF	14	41171.0	0.0
VEG + DFOR + DOGW + DLT + DHT	10	41172.6	1.6
VEG + DFOR	7	41187.0	16.0
VEG + DFOR + TSF + DWA	11	41191.1	20.1
VEG	6	41361.2	190.2
DFOR	3	41670.8	499.8
Null Model	1	42197.7	1024.7
DHT + DLT	4	42198.9	1024.9
DHT + DLT + DOGW	5	42200.8	1029.8

VEG=vegetation, DFOR= distance to forest, DOGW= distance to oil/gas wells, DLT= distance to low traffic roads, DHT= distance to high traffic roads, DWA= distance to water, TSF= Time since fire

Table 2. Resource selection candidate models for Rio Grande wild turkey space use during the non-breeding season (October to April) on Packsaddle Wildlife Management Area in western Oklahoma, United States in 2016 -2018.

Candidate Models	**K**	**AIC**	**∆AIC**
DFOR + DOGW	4	11487.9	0.0
DFOR + DOGW + DRD	5	11489.9	1.9
DFOR	3	11495.1	7.2
DOGW	3	11748.3	260.3
DOGW + DRD	4	11749.9	261.9
Null Model	2	11752.8	264.9
DRD	3	11753.5	265.6

DFOR= distance to forest, DOGW= distance to oil/gas wells, DRD = distance to roads (no distinction between high and low traffic)

Table 3. Parameter estimates from the top model of resource selection analysis using generalized linear mixed models during the breeding season (March to October) for Rio Grande wild turkey at Packsaddle Wildlife Management Area in western Oklahoma, United States in 2016 and 2017. Covariates marked with an asterisk denote significance as the confidence interval did not include zero.

Covariate	**Parameter estimate**	**Lower 95% CI**	**Upper 95% CI**
Intercept*	-0.77	-0.97	-0.57
Vegetation (developed)*	-0.68	-0.82	-0.54
Vegetation (herbaceous)*	-0.87	-0.95	-0.79
Vegetation (hybrid shinnery)*	-0.39	-0.49	-0.28
Vegetation (shinnery)*	-0.72	-0.79	-0.64
Distance to low traffic roads*	-0.05	-0.08	-0.02
Distance to high traffic roads*	0.09	0.05	0.13
Distance to wells*	0.02	0.00	0.05
Distance to forest*	-0.22	-0.25	-0.19
Distance to water	-0.02	-0.06	0.00
Time since fire (6-12 mo)	-0.23	-0.49	0.02
Time since fire (12-24 mo)	-0.15	-0.36	0.06
Time since fire (>24 mo)*	-0.22	-0.42	-0.04

Table 4. Parameter estimates from the top model of resource selection analysis using generalized linear mixed models during the non-breeding season (October to April) for Rio Grande wild turkey at Packsaddle Wildlife Management Area in western Oklahoma, United States in 2016 and 2017. Covariates marked with an asterisk denote significance as the confidence interval did not include zero.

Covariate	Parameter estimate	Lower 95% CI	Upper 95% CI
Intercept*	-1.76	-2.17	-1.34
Forest*	-0.27	-0.30	-0.23
Wells*	0.10	0.03	0.16

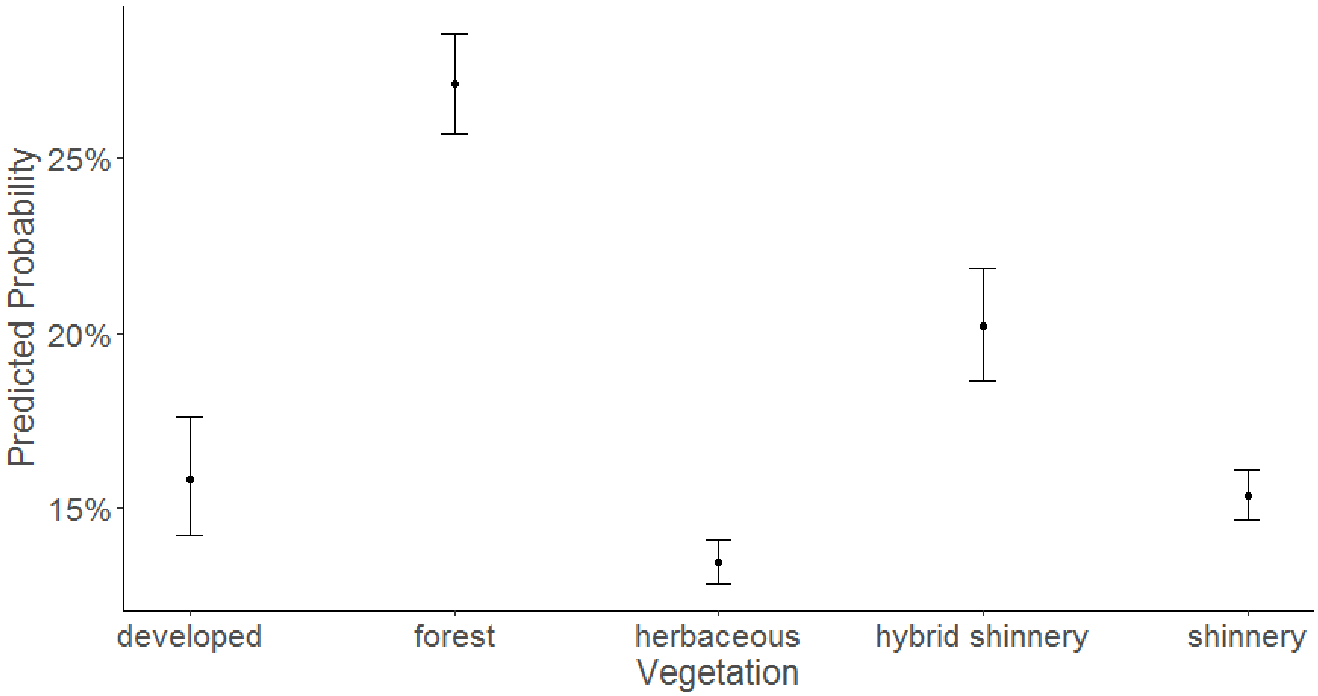

Figure 1. Predicted probabilities and 95% confidence intervals of Rio Grande wild turkey occurrence in different vegetation types during the breeding season (March to October) at Packsaddle Wildlife Management Area in western Oklahoma, United States in 2016 and 2017.

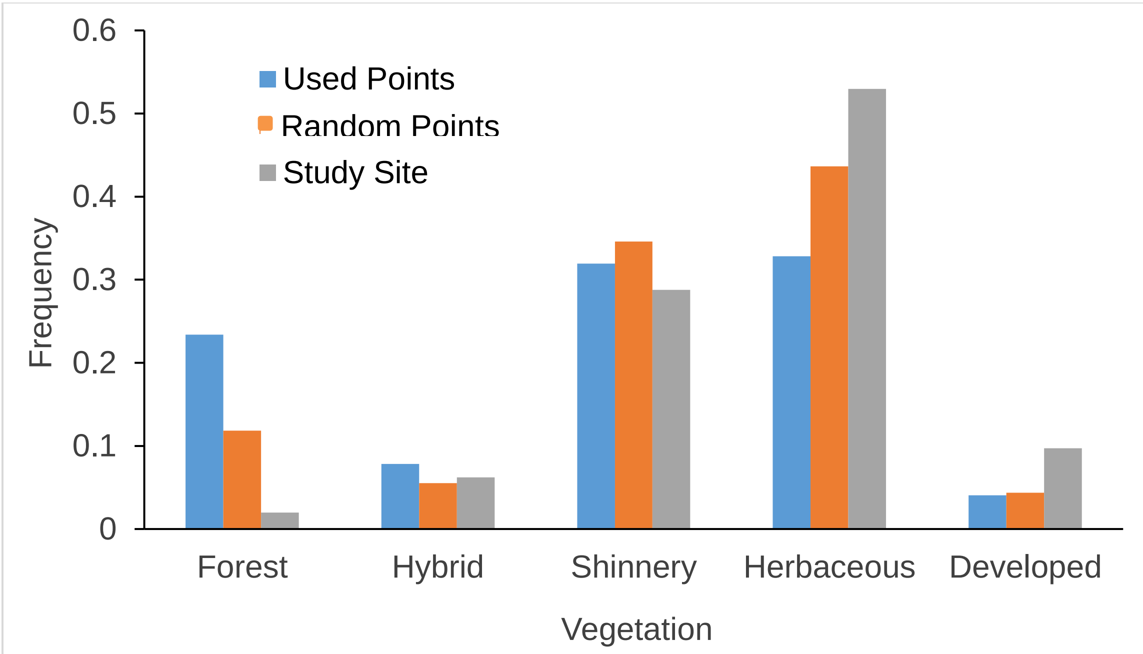

Figure 2. The frequency at which used points (Rio Grande wild turkey telemetry points) and random points occurred within different vegetation types during the breeding season (March to October) at Packsaddle Wildlife Management Area in western Oklahoma, United States in 2016 and 2017. The gray “Study Site” column represents the proportion of the study site that consists of each vegetation type.

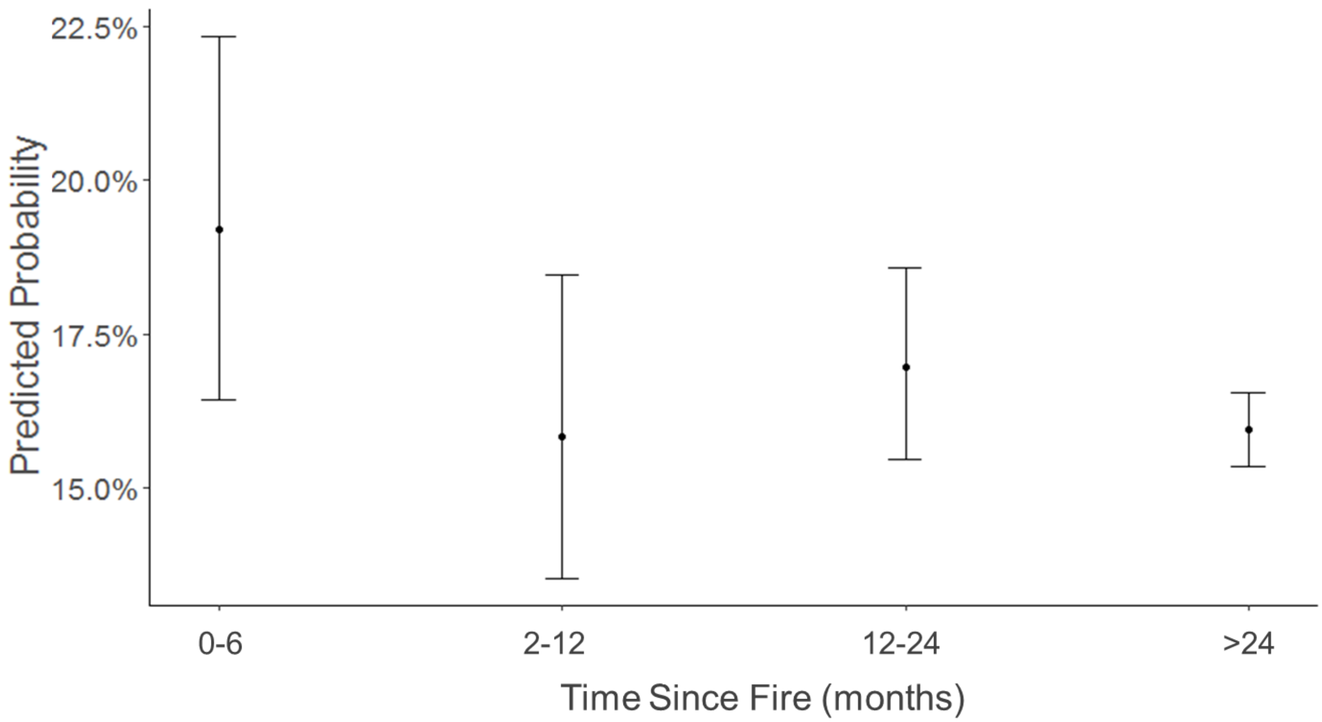

Figure 3. Predicted probabilities and 95% confidence interval of Rio Grande wild turkey occurrence in different time since fire categories during the breeding season (March to October) at Packsaddle Wildlife Management Area in western Oklahoma, United States in 2016 and 2017.

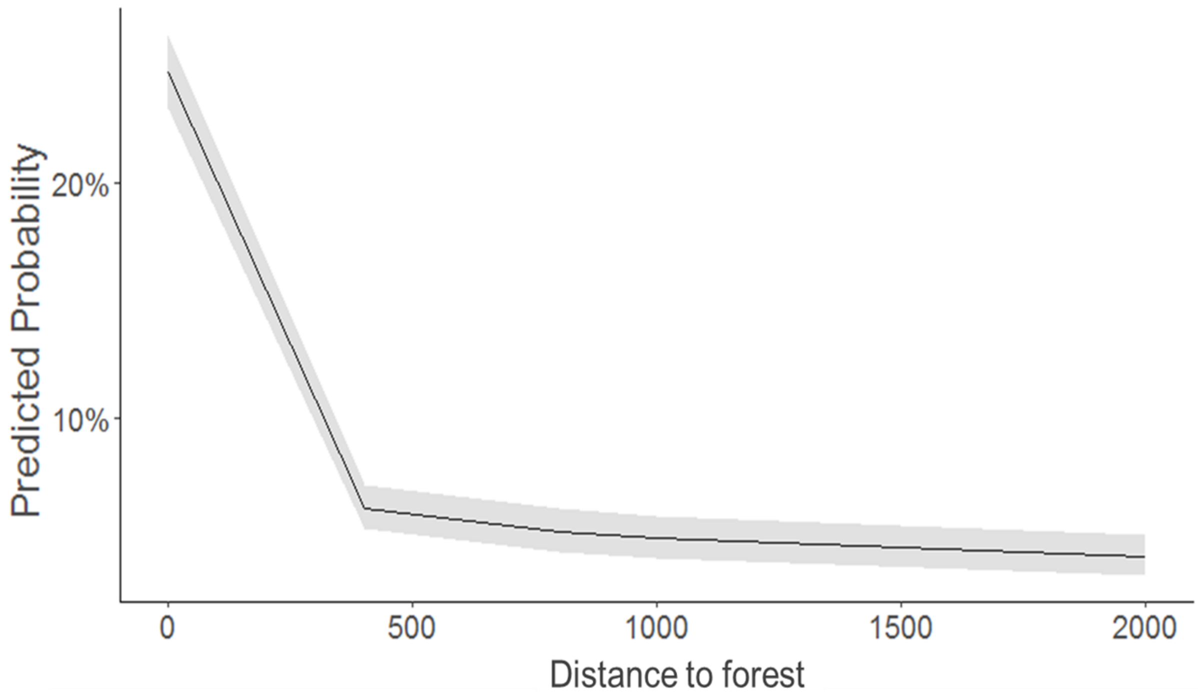

Figure 4. Predicted probabilities and 95% confidence intervals of Rio Grande wild turkey occurrence at different distances (m) to forest vegetation during the non-breeding season (October to April) at Packsaddle Wildlife Management Area in western Oklahoma, United States in 2016 and 2017. Highest probability of occurrence occurs closest to forest vegetation.

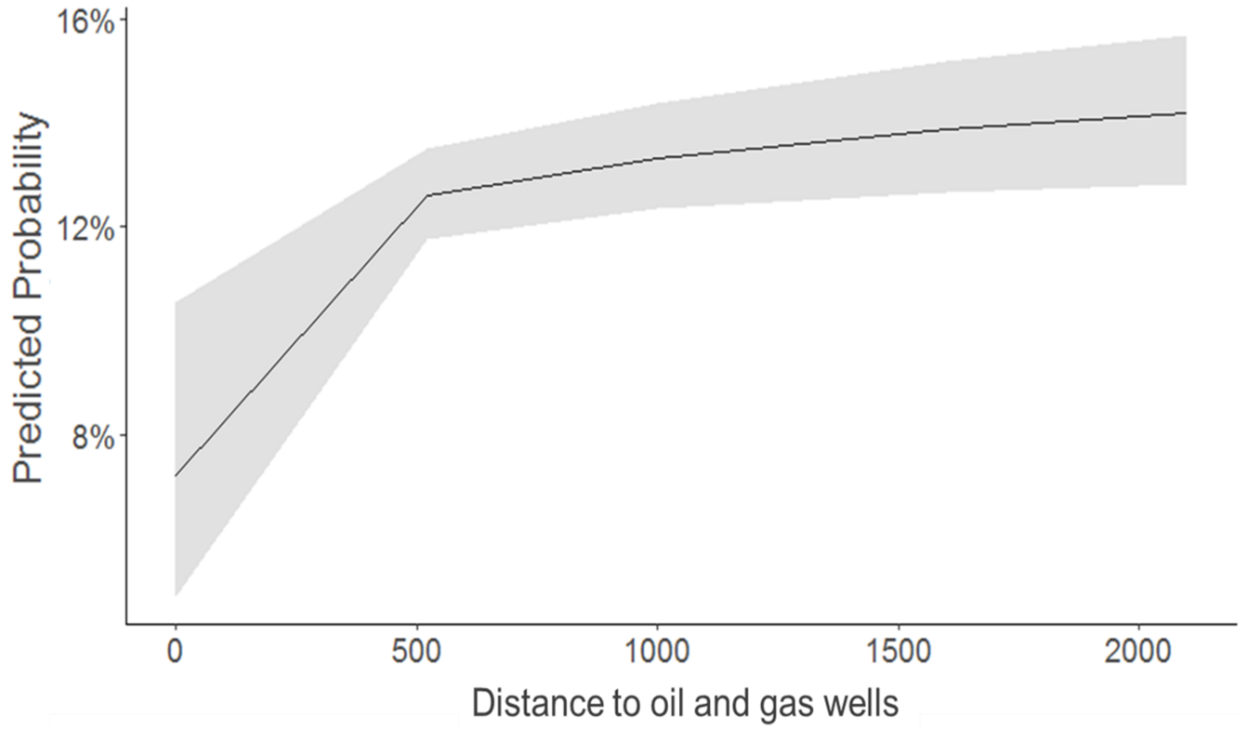

Figure 5. Predicted probabilities and 95% confidence intervals of Rio Grande wild turkey occurrence at different distances (m) to oil/gas wells during the non-breeding season (October to April) at Packsaddle Wildlife Management Area in western Oklahoma, United States in 2016 and 2017. The lowest probability of occurrence occurs closest to oil/gas wells.

VITA

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