COYOTES (*CANIS LATRANS*) RESPONSE TO ANTHROPOGENIC PRESSURES ON A HETEROGENEOUS LANDSCAPE

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Abstract:

Due to the extirpation of many large, native carnivores the coyote has become one of the most widespread and successful predators in North America. They are now considered apex predators in many ecosystems. For this reason, it is important to understand how they respond to natural and anthropogenic disturbances. For this study, ten coyotes were captured, fitted with GPS collars, and monitored for 18 months. By using GIS data from The Nature Conservancy and GPS data from the collars we were able to assess how coyote temporal activities and resource selection were affected by energy development and prescribed fires in the Tallgrass Prairie Preserve (TPP). Based on our data, it is clear coyotes strongly avoided anthropogenic structures on the landscape, but were only weakly affected by prescribed fires, and vegetation type. The coyotes on the nature preserve are also primarily nocturnal, which could be an indicator of temporal activity shifts due to anthropogenic pressures. Our data suggests that the behavior of this coyote population mirrors other studies that have evaluated behavior in relation to human presence. Coyotes represent an emerging shift in top predator species in prairie ecosystems; it is crucial to examine these species in order to understand the changes in behavioral ecology and how these changes affect the ecosystem in novel ways.

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CHAPTER I

RESPONSE OF COYOTES (*CANIS LATRANS*) TO ENERGY DEVELOPMENT ON A SHIFTING MOSAIC LANDSCAPE

ABSTRACT

Due to the extirpation of many large, native carnivores the coyote has become one of the most widespread and successful predators in North America. For this reason, it is important to understand how they respond to both natural and anthropogenic disturbances. The tallgrass prairie is a highly endangered and fragmented habitat types with less than 2% remaining; the TPP is one of the largest, contiguous remnants of this native ecosystem. Resource selection was used to determine how individuals (3^{rd} order) and the population (2nd order) utilized the landscape. By combining GIS data with GPS data from the collars we assessed how coyote's space use is affected by energy development and prescribed fires. Coyotes aid in regulating other faunal communities in many ecosystems throughout North America. This knowledge can enhance future conservation efforts such as the reintroduction of native prairie species and ecosystem resilience. To have a more complete understanding of the tallgrass ecosystem it is important to include information on the current apex predator.

INTRODUCTION

As the human population continues to increase, so will our demands for natural resources that supply energy, food, and water. With the expansion of agriculture over the past century and the subsequent energy developments, the landscape is increasingly fragmented. The increase in oil production has caused a negative impact on many ecosystem services such as carbon sequestration, water filtration, net primary productivity and wildlife habitat (Naugle 2011). It is estimated that about 3 million ha of land area in the United States are now occupied by energy development structures that were installed from 2000-2012 (Allred et al. 2015). Energy and agricultural development can lead to animal displacement, altered home ranges, and an increase in nutritional and psychological stress (Naugle 2011, Northrup & Wittemyer 2013). These influences can then lead to population declines. Within fragmented landscapes, wildlife are still subject to natural biotic and abiotic factors that influence their behavior even though the broader context of the landscape has changed. It is imperative to understand how animals respond to natural pattern-driving processes, such as fire, but in the context of anthropogenic changes that are occurring at broader spatial scales.

Due to large-scale habitat loss and predator control efforts, large predator populations have declined, allowing for an increase in abundance and distribution of mesopredators, such as the coyote (Canis latrans) (Prugh et al. 2009, Gehrt et al. 2010). Their increase in distribution throughout North America can be attributed to a high reproductive potential, opportunistic food habits, and ability to adapt to a variety of conditions (Bekoff & Wells 1986). In the absence of other large carnivores, coyotes aid in controlling microherbivore and other mesopredator communities and are the dominant and top predator in many modern ecosystems (Litvaitis & Shaw 1980, Henke & Bryant 1999, Crimmins et al. 2012).

One location in which coyotes are now considered the top predator is the tallgrass prairie region of North America. This area was once estimated to be 66 million ha and stretched from Canada to central Texas prior to European settlement (Samson & Knopf 1994). Current estimates of the remaining area are less than 3% (Deluca & Zabinski 2011). This decline is due primarily to conversion to other land uses such as crops and urban/suburban sprawl compounded by ecological changes facilitated by fire suppression and the associated woody plant encroachment (Samson & Knopf 1994). The tallgrass prairie was historically influenced by fire that enhanced the inherent heterogeneity and promoted biodiversity (Fuhlendorf & Engle 2001). Many wildlife species require a fire regime that promotes a heterogeneous landscape (Hovick et al. 2015). Previous research has documented that small mammals (Clark & Kaufman 1990, Fuhlendorf et al. 2010), large herbivores (such as American bison [Bison bison])(Schuler et al. 2006, Allred et al. 2011a), plants, and birds (Coppedge et al. 2008, Hovick et al. 2014) respond to patterns that are generated by variable fire regimes in tallgrass prairie. Studies hypothesize that animals that prefer recently burned areas do so for the new palatable growth, ease of movement, and better access to resources (Allred et al. 2011a, Hovick et al. 2014). While species that prefer old growth possibly prefer dense vegetation because it provides protection from predators and abiotic factors (Fuhlendorf et al. 2010). Although the effects of fire on other wildlife is well studied (Fuhlendorf et al. 2009, Hovick et al 2015), the effects on mesopredators are less understood (Cunningham et al. 2006). It is possible their response to fire would mimic their primary prey response (Mills &

Knowlton 1991, Keim et al. 2011), or they could avoid recently burned areas due to lack of cover for hunting (Eby et al. 2013).

The tallgrass prairie region is also experiencing an increase in energy development that has caused a decrease in ecosystem services and additional habitat loss (Allred et al. 2015). Grasslands are particularly vulnerable to fragmentation from energy development because of their correlation to sedimentary basins that hold hydrocarbon deposits (Naugle 2011). Studies that have evaluated these anthropogenic pressures document that wildlife will alter their behavior to avoid anthropogenic structures (Carpenter et al. 2010, Lendrum et al. 2012). The negative effects of oil development on agricultural land and vegetation is well documented, but there is limited knowledge on how drilling directly affects predators (Naugle 2011, Allred et al. 2015). However, there is evidence to suggest that in rural and suburban environments, coyotes will avoid any anthropogenic structures on the landscape (Grinder & Krausman 2001, Tigas et al. 2002, Riley et al. 2003, Atwood et al. 2004, Gehrt et al. 2009, Gese et al. 2012, Lesmeister et al. 2015).

The general objective of this study was to determine the effects of energy development on coyote space use in the context of a heterogeneous landscape. We used Global Positon System (GPS) locations of coyotes, to study their resource selection within the tallgrass prairie. Resource selection functions (RSF) were calculated at two scales, 2^{nd}, and 3^{rd} order selection (Johnson 1980) to determine strength and direction that landscape variables have on coyote selection. Additionally, resource selection will be examined using Ivlev's electivity indices, which model use vs availability within a variable (Allred et al. 2011b). It is possible coyotes will disproportionately utilize the landscape based on: energy development, prescribed fires, or vegetation structure.

METHODS

Study Area

This study took place at the Tallgrass Prairie Preserve (hereafter TPP) near Pawhuska, Oklahoma in Osage County, located between 36.73° and 36.9°N latitude, and 96.32° and 96.49°W longitude (Palmer 2007). The TPP includes15,700 ha and is owned and managed by The Nature Conservancy. The preserve is located in the southern end of the Flint Hills region and is the largest preserved tract of tallgrass prairie remaining in North America (Hamilton 2007). The goal of the TPP is to protect biological diversity and landscape heterogeneity (Payne & Caire 1999, Hamilton 2007). The management includes: maintaining a fire regime that promotes heterogeneity, controlling and removing invasive species, and sustaining and reintroducing species that were historically abundant in the area (Hamilton 2007). The TPP is managed as an example of the shifting mosaic driven by random fire and bison grazing similar to historic conditions across landscapes across the Great Plains. One-third of the preserve (approximately 6,000 -8,000 hectares) is burned each year in different seasons. Thirty-eight native mammalian species occur on the TPP, and an additional 17 species are known to occur close (approx. 200 km) to the boundaries of the TPP, and could ultimately be found there (Payne et al. 2001). The TPP is approximately 90 percent grassland and 10 percent forest, and bison (*Bison bison*) graze on roughly 10,000 hectare of preserve. Crosstimbers is the dominant forest type on the east side of the preserve consisting mostly of post oak (*Quercus stellate*) and blackjack oak (*Q. marilandica*) (Hamilton 2007). The preserve encompasses almost the entire watershed of Sand Creek, and the elevation ranges between 253m and 366m (Palmer 2007). Oil well sites occur on the TPP and are managed through the Bureau of Indian Affairs. The area has recently experienced increased energy development that has resulted in additional roads, power lines, vehicle traffic, site development, and human activity. The TPP serves as an excellent laboratory to test ecological questions.

Coyote Capture

We captured coyotes beginning January 2015 using foothold devices that met animal welfare performance criteria outlined in the Wildlife Techniques Manual (Silvy 2012), Oklahoma State Hunting and Trapping Regulations, The Guidelines of the American Society of Mammologists for the Use of Wild Mammals in Research (Sikes & Gannon 2011), and the Oklahoma State University Institutional Animal Care and Use Committee protocol (AG-14-24). We used spring loaded leg hold traps with an offset jaw (MB-550-RC 2-coiled) to minimize injury. The offset jaws close quicker and coyotes are less likely to pull out of them, making the traps more efficient and injuries less likely. We placed traps in locations that showed signs of coyote activity (e.g. scat, tracks, and kill sites), and near areas that coyotes frequented (e.g. ponds, trails, fence lines). We baited the traps with a commercially available coyote gland lure and coyote urine. We set approximately 10 traps, 4 nights per week. We checked all trapes twice per day (at dawn and in the evening). Additionally, we monitored weather and trapping did not occur if extreme weather conditions were predicted, such as snow, lightening, or high temperatures. We continued trapping until 10 coyotes were caught and collared (May 2015).

After a coyote was trapped, anesthesia was administered with a Pneu-Dart "Blo-jector" blow pipe and "type P" disposable darts. The anesthesia used was xylazine at a concentration of 100ml/mg and dosage of 1mg/kg in conjunction with ketamine hydrochloride at a concentration of 100ml/mg and a dosage of 10mg/kg (Plumb 2011, Boitani & Powell 2012). Ketamine and xylazine have proven to be effective in anesthetizing canids and maintaining researcher and animal safety (Silvy 2012). After the coyote was anesthetized, the researcher approached the coyote slowly and inspected it to confirm it was thoroughly sedated. The researcher checked their blink and pinnal reflex before removing the animal from the trap. If the coyote's paw had been injured in by the trap a betadine antiseptic solution was applied to the foot. An ophthalmic eye solution was applied to the eyes and then they were covered with a bandana to prevent debris from injuring their eyes during procedures Respiration, temperature, and heart rate were monitored (Kreeger & Seal 1986) every ten minutes throughout the process. Respiration was monitored visually, temperature was monitored using an anal thermometer, and heart rate was monitored using the femoral artery. Each coyote was placed in a burlap sack and approximate weight was taken using a spring scale, then fitted with a Lotek G5C 275D Pinnacle Lite Iridium Satellite Collar GPS tracking collar. At the conclusion of the procedures, the coyote was injected with yohimbine at 0.15 mg/kg intramuscularly as an antagonist to xylazine approximately 40 minutes after initial sedation (Silvy 2012). The coyote was monitored from a safe distance (>3 meters) until it seemed to be fully recovered and left the area.

The GPS transmitters were programed to record a location every hour and to transmit the data every day for the first two weeks. Initially there were 24 locations a day, but after the first two weeks the collar settings were adjusted so that a location was taken every 2 hours and transmitted the data every 2 days (12 locations a day). After 18 months, the electronic timer signaled a small explosive to release the collars.

Resource Selection

Relationships between coyote locations and landscape features were determined by using a resource selection function that yields values proportional to the probability of use of a resource unit (Boyce et al. 2002). By determining which areas are selected more often than others provides fundamental information about coyote habitat use (Manly et al. 2004). We identified 5 variables that could potentially determine resource selection in coyotes: distance to primary roads, distance to oil structures, density of oil structures, time since most recent fire, and vegetation type (grassland or forest) (Table 1). We chose these variables based on previous literature that evaluated anthropogenic and fire effects on native fauna (Clark & Kaufman 1990, Coppedge et al. 2008, Fuhlendorf et al. 2010, Allred et al. 2011a, Hovick et al. 2014, Hovick et al. 2015). Oil structure data, road data, and fire history came from GIS layers acquired from The Nature Conservancy and TPP. We ground trothed oil structure locations and found a total of 509; including pump jacks (electric, combustion, & down hole submersible) and tank batteries (Appendix 1). Road layers had previously been driven with a handheld GPS unit and were edited to only include primary roads, because secondary roads were correlated with oil wells. Primary roads were paved or maintained gravel roads that were > 2 meters wide (Appendix 1). Fire layers acquired from The Nature Conservancy had also been acquired from driving the boundaries of the burned area with a handheld GPS unit at the time of the fire. We determined the presence or absence of trees from the Oklahoma Department of Wildlife

Conservation 10m resolution ArcMap layer. In other studies, presence or absence of trees has proven to be a determining factor in coyote resource selection (Schrecengost et al. 2009, Boisjoly et al. 2010, Hinton et al. 2015).

Habitat selection can occur at many scales, so the sampling scale can influence the strength of habitat associations (Boyce 2006). For example, large spatial scales are necessary to evaluate habitat selection by mule deer (*Odocoileus hemionus)* (Kie et al. 2002), while muskoxen (Ovibos moschatus) select the same resources across scales due to landscape homogeneity in the arctic (Schaefer & Messier 1995). However, heterogeneity of the landscape can occur at different scales, and many studies that evaluated resource selection have found that the scale can alter the resource selection of an animal (Jiang et al. 2009, Decesare et al. 2012). We analyzed resource selection at two scales. 2nd order resource selection represents broad scale population preferences within the landscape and area available, and will from here on be called design II selection (Johnson 1980, Manly et al. 2004). 3rd order resource selection represents a finer scale approach; accounting for individual preference within each home range, and will be called design III selection hereafter (Johnson 1980, Manly et al. 2004). Design II incorporates transient and residential coyotes in the study area, while design III RSFs only utilize individuals with a home range and compare use vs availability within that home range, instead of the study area.

For design II resource selection, a minimum convex polygon (MCP) was placed around all GPS locations for the population (Appendix 2). We utilized a MCP instead of a kernel density so that exploratory points were also included. A MCP represents what area is theoretically known to the population. We then applied an equal number of random points within the MCP to represent area available to this population of coyotes. We built additive models utilizing various combinations of variables, and we analyzed data using a general linear model (GLM). Akaike information criterion (AICc), was used to correct for a small sample size, was then used to determine the best model within the candidate set of models given the data. A list of all models used in the analysis can be found in Appendix 3.

For design III resource selection, we applied a (MCP) around individual, resident coyotes GPS locations (Appendix 3). A MCP was used for this analysis because it represents known area available to individuals, but also preference within the area. A kernel density estimator (KDE) was not used because it eliminates exploratory points. We then applied an equal number of random points (as the individual) within each individual MCP to represent area available. We rescaled continuous variables so that each variable had a mean that was equal to 0 and a standard deviation equal to 1. We then built additive models utilizing different combinations of variables, and we analyzed data using a generalized linear mixed model (GLMM). We used an AICc to determine the best model within the candidate set of models given the data. A list of all models used in the analysis can be found in Appendix 4. There were 3 individuals with a portion of their home range that was burned during the study. We determined the proportion of time spent inside of these recently burned areas pre and post fire. However, two of those individuals (male 3 and male 7) were not considered independent from one another, due to their similar movement patterns.

We also calculated Ivlev electivity indices using the formula Ivlev= (U% - A%) /(U% + A%) where U is the fraction of GPS locations recorded by the animal within the variable and A is the fraction of random points representing area available. An A value of 1 indicates complete preference for a variable, while a value of -1 indicates complete avoidance. This was done for both Design II (population preference within the landscape) and Design III (individual preference within their home range). Additionally, we calculated actual home range for each resident utilizing a 95% KDE (Seaman & Powell 1996).

RESULTS

A total of ten coyotes (7 males, 3 females) were trapped and collared for this study. Morphometric data for each individual can be found in appendix 5. However, 3 coyotes were removed from the analysis due to collar failure (2) and migration out of the area (1). The remaining coyotes consisted of 5 residents (4 males, 1 female) and 2 transients (1 male, 1 female). Coyotes were considered residents if they maintained relatively small home ranges, and transients if they very mobile throughout the study area (Kamler & Gipson 2000, Grinder & Krausman 2001, McClennen et al. 2001, Kamler et al. 2005). A total of 24,530 GPS points were collected and used for Design II selection, of which a subset of 19,203 of those points were used for Design III selection. The annual home range size (95% KDE) for the 5 resident coyotes was 5.66 ± 0.70 km^2 and ranged from 4.10 to 7.50 km^2.

Design II Resource Selection

A total of 7 coyotes were used to analyze resource selection for Design II selection (population level) (Manly et al. 2004). We examined possible correlation between individual predictor variables and r^2 values did not exceed 0.3, indicating no strong correlation (Hinton et al. 2015). When evaluating population preference on the landscape, AICc indicated that the full model with all additive variables was the best model to determine resource selection (Table 2). The top model suggests that coyote presence is negatively related to oil well density, presence of trees, and distance to road, and positively related to distance to oil wells and time since fire (Table 3).

Design III Resource Selection

We chose 5 resident individuals with a distinct home range for Design III selection (home range level) (Manly et al. 2004). We checked individual predictor variables for correlation and r^2 values did not exceed 0.42, indicating no strong correlation (Hinton et al. 2015). We found that the top model included the additive variables of distance to oil, distance to roads, and time since fire was the best fit for evaluating coyote resource selection within their home range (Table 4). The top model suggests that within a coyote home range there is a positive relationship with distance to oil wells, and a negative relationship with time since fire and distance to roads (Table 5).

Ivlev Electivity Indices

Mean Ivlev electivity indices showed that coyotes were actively avoiding oil wells (Figures 1 & 2). The variable "distance to oil wells" indicated an avoidance for areas closer to oil well, decreasing in strength as the distance from the oil well increased, and did not vary substantially between Design II and Design III (Figure 1). The variable "density of oil wells" indicated an avoidance for areas with a density of oil wells >1, and a preference for areas that had 0 oil wells within 0.5km (Figure 2). Mean Ivlev electivity indices for the variable "distance to roads" indicated a weak avoidance for areas <100 & >500 meters to roads, and a preference for areas >100 and <500 meters to roads (Figure 3). The data also suggested there is a weak avoidance of areas that were categorized by tree cover at both scales. Additionally, the overall relationship with fire remains unclear, but based on the three individuals whose home ranges were burned during the study, it seems they prefer areas immediately after a burn, for approximately 3 weeks, and then lessen use of these areas with additional time (Figure 4).

DISCUSSION

Our study suggests that coyotes avoid oil well structures on the landscape. We found that coyotes preferred areas that were greater than 1km away from oil wells, and that the distance to the nearest oil well was the biggest determining factor for area utilization at the landscape and home range scale. Studies on coyote space use in relation to anthropogenic pressures demonstrate a strong avoidance of any human presence on the landscape, with a preference for grasslands and natural areas over cropland and urban areas (Grinder & Krausman 2001, Tigas et al. 2002, Gosselink et al. 2003, Riley et al. 2003, Atwood et al. 2004, Gehrt et al. 2009, Gese et al. 2012, Lesmeister et al. 2015). The resource selection of this coyote population mirrors other studies that have evaluated space use and movement patterns in relation to oil development by animals (Carpenter et al. 2010, Lendrum et al. 2012). Additionally, has even been documented that coyotes will avoid areas with wind turbines, versus areas without wind turbines, when both areas have similar habitat characteristics (Winder et al. 2014). It appears that coyotes exhibit behavioral plasticity, and can adapt to many ecosystems, though they will continue to avoid unnatural features on the landscape (Lesmeister et al. 2015). Human alteration of habitats has the potential to influence important species interaction and ecological processes, such as predator–prey relationships, reduction in fitness, and a disruption in the trophic cascade which could potentially lead to broader ecological impacts (Naugle

2011, DeGregorio et al. 2014, Hethcoat & Chalfoun 2015, Van Fleet et al. 2015). With this data, we can add to the pool of knowledge on coyote resource selection, and suggest that coyotes will avoid anthropogenic structures and energy development in rural landscapes. Future studies should evaluate longer time periods to see if over time coyotes could become desensitized to the presence of oil wells. It would be interesting to investigate what features of energy development that are disrupting coyote utilization of that area (e.g. noise, human presence, increased traffic). The increase in oil development on the TPP, and the changes in coyote resource selection could potentially have an effect on prey species diversity, abundance, and distribution.

We found that coyotes preferred areas that were between 200 and 500 meters away from primary roads, but this variable was not as strong as distance to oil wells. We did not include secondary roads in our analysis, which may be utilized more often, since they exhibit less traffic but still function as corridors. One study suggested that transient individuals utilize roads more often than resident coyotes (Hinton et al. 2015). However, our design II (included 5 residents, 2 transients) and design III (only 5 residents) selection maintained similar Ivlev patterns, which could suggest there wasn’t a difference in transient and resident usage of roads.

We found limited evidence suggesting that coyotes alter their behavior to prescribed fire regimes, and the overall response remains unclear. The TPP has an average of a three year fire return interval where fires occur in patches to create a heterogeneous landscape (Winter et al. 2013). Therefore, coyotes on the TPP have multiple patch types to choose from with various plant structures and composition related to time since fire. Home ranges covered more than one patch type, so we expect coyotes would not shift their home ranges in response to the fire. It is not unexpected that coyotes are not avoiding or preferring recently burned areas, since they are a generalist predator, capable of successfully adapting to many landscapes (Bekoff & Wells 1986). Therefore are not constrained by the variables that limit other grassland species to a vegetation structure primarily influenced by fire (e.g. ease of movement, protection from abiotic factors, and access to resources). Our data also showed a weak avoidance of woody vegetation vs grassland vegetation. A few studies suggested that coyotes utilize forested areas extensively for diurnal cover (Atwood et al. 2004), and also more often in the cool season (Holzman et al. 1992); but other studies suggest that in forested areas, coyotes will prefer open areas such as clear cuts, cropland, and early successional areas (Schrecengost et al. 2009, Boisjoly et al. 2010, Crimmins et al. 2012, Hinton et al. 2015). Our study did not evaluate use of woody vegetation area temporally or seasonally, but it is possible that we could find greater use during the winter or diurnally.

In conclusion, other studies have suggested that wildlife habitat has been greatly reduced by increased energy development (Naugle 2011). In a landscape that is likely to continue to be fragmented, it is imperative to understand how predators are being affected by energy development and human encroachment. Coyotes represent an emerging shift in top predator species in prairie ecosystems; it is crucial to examine these species in order to understand the changes in behavioral ecology and how these changes affect the ecosystem in novel ways.

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TABLES

Table 1. Landscape features that were considered in resource selection by coyotes at the Tallgrass Prairie Preserve, Osage County, Oklahoma, for 2015 and 2016. Variable code indicates how each feature was represented in the models. Included is a description of each variable.

Variable Code	Variable	Variable Description
Density	Density of oil structures within 0.5km	Structures that were considered included oil well pump jacks, and tank batteries that were within 0.5km of a coyote location
Dist.Oil	Distance to the nearest oil structure (meters)	Structures that were considered included oil well pump jacks and tank batteries
Roads	Distance to the nearest primary road (meters)	Paved and maintained gravel roads that were at >2 meters wide were considered primary roads
TSF	Time since most recent fire (days)	Days since that area had been burned most recently
Trees	Presence of woody vegetation	This was binary for cover of trees vs. grassland at 10 m resolution

Table 2. AICc (Akaike information criterion values) results for the top 5 models from Design II resource selection models utilizing GLM for analysis at the Tallgrass Prairie Preserve, Osage County, Oklahoma, for 2015 and 2016. Predictors represent variables that were used in the model, and support for each model indicated by df (degrees of freedom), ΔAICc and w_i (Akaike model weights).

Model Formula	df	ΔAICc	w_i
Density + Dist.Oil + Roads + Trees + TSF	6	0.0	0.902
Density + Dist.Oil + Roads + Trees	5	4.4	0.098
Density + Dist.Oil + Roads	4	39.1	<0.001
Density + Dist.Oil + Roads + TSF	5	40.7	<0.001
Dist.Oil +Roads + Trees + TSF	5	647.5	<0.001

Table 3. Summary of results for the top model from the Design II AICc (Akaike information criterion values) table at the Tallgrass Prairie Preserve, Osage County, Oklahoma, for 2015 and 2016. All variables were significant (Pr (>|z|), with $p < 0.05$, and Estimate indicates the effect of each variable (direction and strength).

	Estimate	SE	Z Value	P
Intercept	0.06884	0.02820	2.438	0.020
Density	-0.01634	0.00722	-22.625	<0.001
Trees	-0.01688	0.02640	-6.407	<0.001
Roads	-0.00117	0.00003	-46.720	<0.001
TSF	0.00003	0.00001	2.538	0.011

Table 4. AICc (Akaike information criterion values) results from the top 5 models for Design III resource selection models utilizing GLMM for analysis at the Tallgrass Prairie Preserve, Osage County, Oklahoma, for 2015 and 2016. Support for each model indicated by df (degrees of freedom), ΔAICc and w_i (Akaike model weights).

Model Formula	df	ΔAICc	w_i
Dist.Oil + Roads + TSF + (1|Tag_ID)	5	0.0	0.4
Dist.Oil + Roads + Trees + TSF + (1|Tag_ID)	6	0.8	0.27
Density + Dist.Oil + Roads + TSF + (1|Tag_ID)	6	1.4	0.2
Density + Dist.Oil + Roads + Trees + TSF + (1|Tag_ID)	7	2.2	0.13
Dist.Oil + Roads + (1|Tag_ID)	4	122.1	<0.001

Table 5. Summary of results for the top model from the Design III AICc (Akaike information criterion values) table at the Tallgrass Prairie Preserve, Osage County, Oklahoma, for 2015 and 2016. All variables were significant (Pr (>|z|), with $p < 0.05$, and Estimate indicates the effect of each variable (direction and strength).

	Estimate	SE	Z Value	P
(Intercept)	0.07453	0.27079	0.28	0.780
TSF	-0.14830	0.01335	-11.11	<0.001
Dist.Oil	0.97043	0.01597	60.77	<0.001
Roads	-0.21780	0.01167	-18.66	<0.001

FIGURES

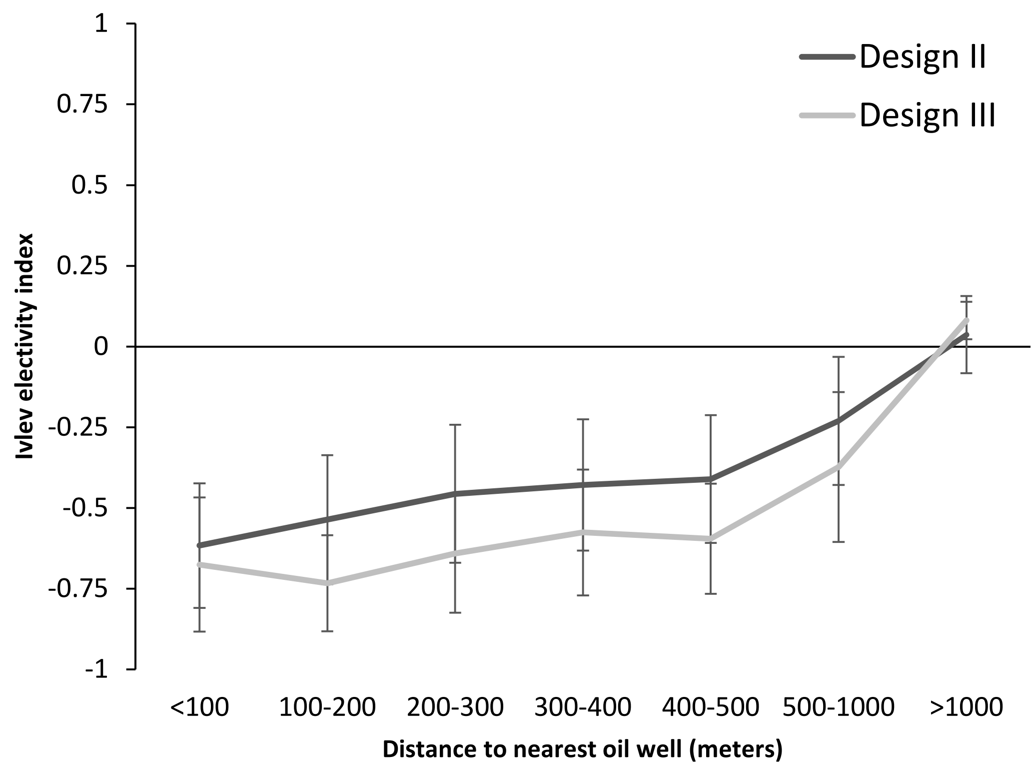

Figure 1. Ivlev electivity indices for coyotes relative to distance to nearest oil well (meters), on the Tallgrass Prairie Preserve, Osage County, Oklahoma for 2015 and 2016, n=7 was used for Design II and n=5 was used for Design III. Error bars are equal to the standard error. Potential values range from -1 (complete avoidance) to 1 (complete preference). The dark line represents the Design II analysis, population preference. The light line represents Design III analysis, individual preference within a home range.

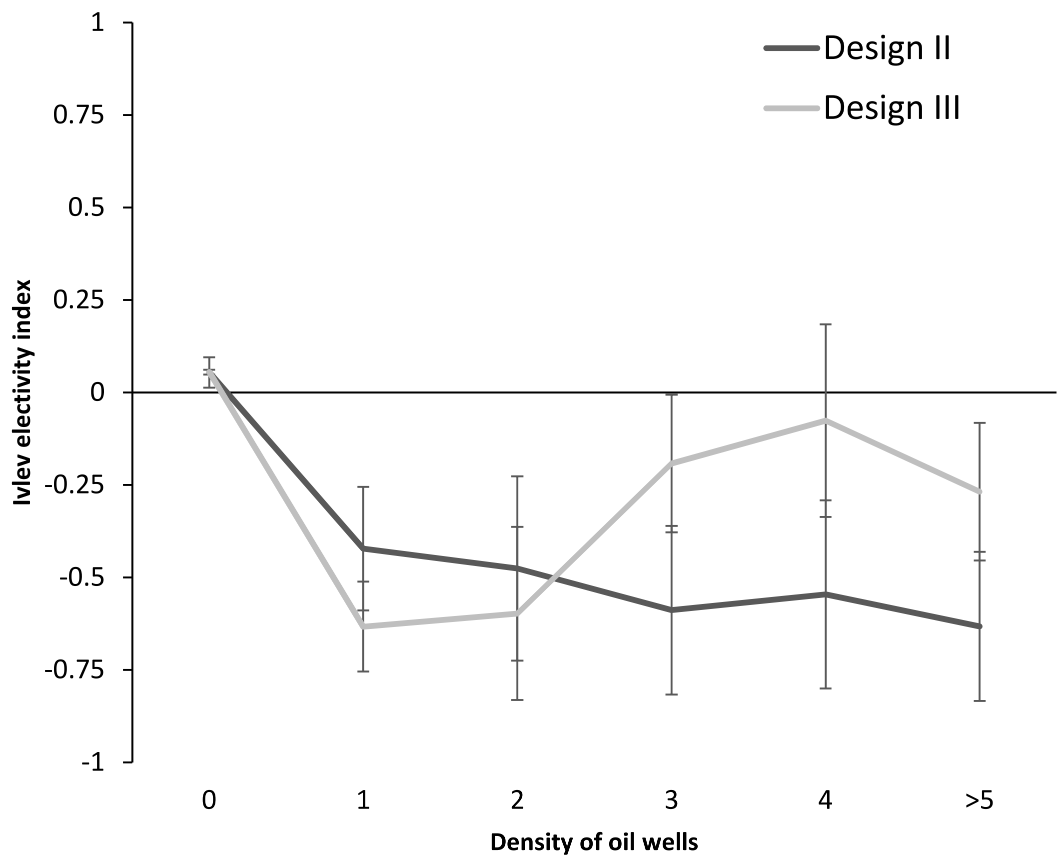

Figure 2. Ivlev electivity indices for coyotes relative to density of oil wells, on the Tallgrass Prairie Preserve, Osage County, Oklahoma for 2015 and 2016. n=7 was used for Design II and n=5 was used for Design III. Error bars are equal to the standard error. Potential values range from -1 (complete avoidance) to 1 (complete preference). The dark line represents the Design II analysis, population preference. The light line represents Design III analysis, individual preference within a home range.

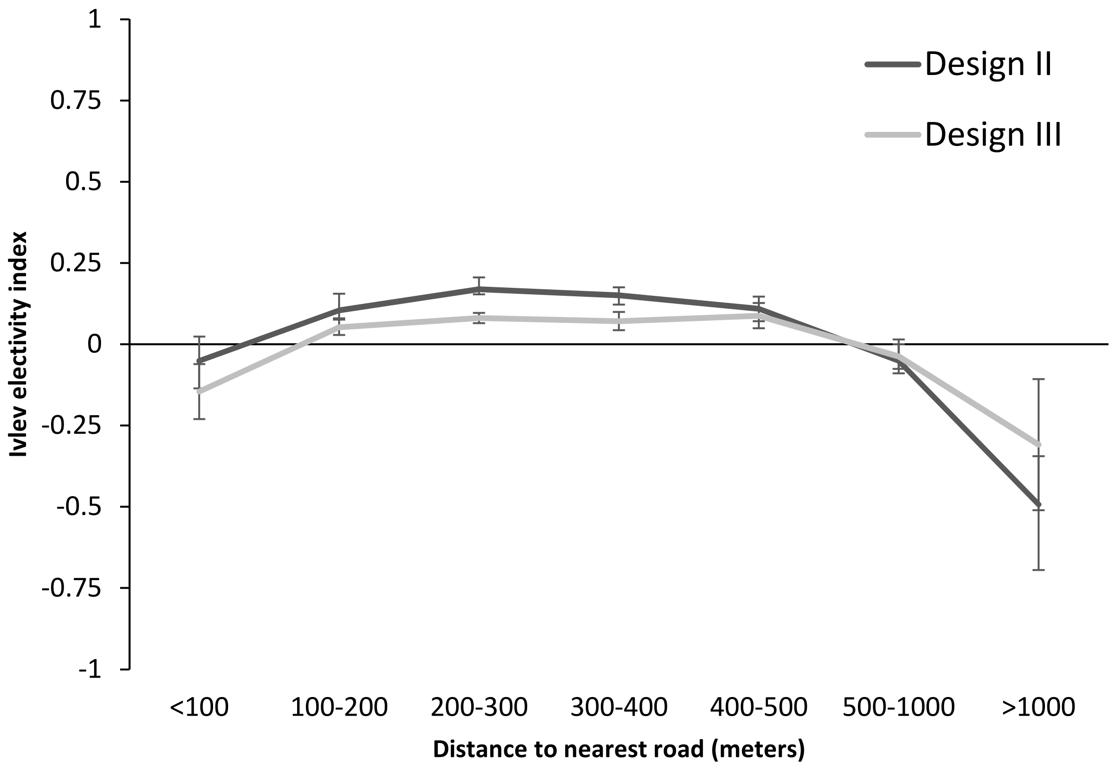

Figure 3. Ivlev electivity indices for coyotes relative to distance to nearest road (meters), on the Tallgrass Prairie Preserve, Osage County, Oklahoma for 2015 and 2016. n=7 was used for Design II and n=5 was used for Design III. Error bars are equal to the standard error. Potential values range from -1 (complete avoidance) to 1 (complete preference). The dark line represents the Design II analysis, population preference. The light line represents Design III analysis, individual preference within a home range.

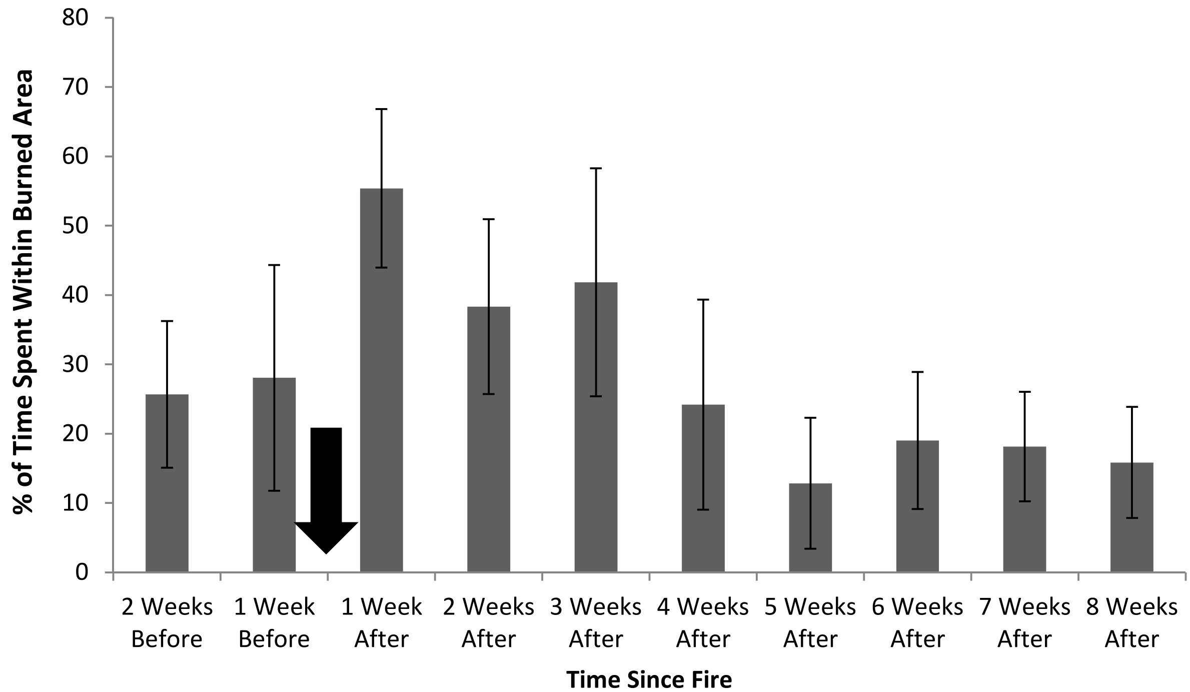

Figure 4. Average percent of time spent within a burned area by 3 individual coyote pre and post fire on the Tallgrass Prairie Preserve, Osage County, Oklahoma for 2015 and 2016. The arrow indicates the event of a prescribed fire within the coyote's home range. Error bars are equal to standard error and n=3.

CHAPTER II

TEMPORAL ACTIVITY PATTERNS OF COYOTES (CANIS LATRANS) ON THE TALLGRASS PRAIRIE

ABSTRACT

Due to the extirpation of many large, native carnivores the coyote has become one of the most widespread and successful predators in North America. They are now considered apex predators in many ecosystems. For this reason, it is important to understand how they respond to anthropogenic disturbances. For this study, ten coyotes were captured, fitted with GPS collars, and monitored for 18 months. By using GIS data from the collars we were able to assess how coyote temporal activities were affected by energy development in the Tallgrass Prairie Preserve (TPP). Based on our data, the coyotes on the nature preserve are primarily nocturnal, which could be an indicator of temporal activity shifts due to anthropogenic pressures. However, we had one coyote who had migrated off the preserve that was diurnal, possibly indicating less anthropogenic pressure, or just an outlier in our data. Our findings suggest that the behavior of this coyote population mirrors other studies that have evaluated temporal activity patterns in relation to human presence. Coyotes represent an emerging shift in top predator species in prairie ecosystems; it is crucial to examine these species in order to understand the changes in behavioral ecology and how these changes affect the ecosystem in novel ways.

INTRODUCTION

The coyote (*Canis latrans)* has become one of the most widespread and successful predators in North America (Gehrt et al. 2010). The species' high reproductive potential, effective dispersal ability, and ability to adapt to a variety of conditions attribute to their abundance (Bekoff & Wells 1986). They were historically limited to the Great Plains, but due primarily to the extirpation of large carnivores they can now be found from Canada south to Central America (Bekoff & Wells 1986). They now occur in novel landscapes such as row crop agriculture and urbanized areas.

With the expansion of agriculture and urban sprawl over the past century and the subsequent energy developments, the landscape has become increasingly fragmented. These developments can lead to animal displacement, altered home ranges, and an increase in nutritional and psychological stress (Northrup & Wittemyer 2013). Within fragmented landscapes, wildlife are still subject to natural biotic and abiotic factors that influence their behavior even though the broader context of the landscape has changed. One specific adaptation which aids in coyote success in areas under increasing anthropogenic pressure is an alteration in temporal activity patterns (Kitchen et al. 2000, Grinder & Krausman 2001, Gehrt et al. 2009). Studies have shown that coyotes are nocturnal in more urbanized areas (Kitchen et al. 2000, Grinder & Krausman 2001), but diurnal and crepuscular in rural environments (McClennen et al. 2001, Gehrt et al. 2010). However, evidence suggests that coyote ocular development is best suited for diurnal and crepuscular activity (Kitchen et al. 2000). This shift in temporal activity patterns is hypothesized to be caused by increased anthropogenic pressures (Kitchen et al. 2000, Grinder & Krausman 2001), but other factors that could potentially influence this behavior include: seasonal changes, prey abundance and distribution, avoidance of interspecific predation, or social organization (Kitchen et al. 2000).

Coyotes play a vital role in many modern ecosystems, they are considered a keystone species in some ecosystems and aid in controlling microherbivore and mesopredator communities (Henke & Bryant 1999). They are also considered the dominant and top predator in many ecosystems, including the tallgrass prairie, an endangered ecosystem (Litvaitis & Shaw 1980, Crimmins et al. 2012). This area was once estimated to be 66 million ha and stretched from Canada to central Texas prior to European settlement (Samson & Knopf 1994). Estimates of remaining area are less than 3% (Deluca & Zabinski 2011). This decline is due primarily to conversion to other land uses such as crops and urban/suburban sprawl (Samson & Knopf 1994). Furthermore, the tallgrass prairie region is experiencing an increase in energy development that has caused additional habitat loss (Allred et al. 2015). Grasslands are particularly vulnerable to fragmentation from energy development because of their concurrence to sedimentary basins that hold hydrocarbon deposits (Naugle 2011).

In this study we aimed to characterize coyote temporal activity patterns in an area that is highly fragmented by energy development. Effects of energy and urban development on animals can vary among species and geographically within a species' distribution, so interactions can be difficult to predict (Ludlow et al. 2015). Phenotypic adaptations to local conditions should be taken into account when discussing the ecological impacts of predators (Bekoff & Wells 1986). To have a complete understanding of the tallgrass ecosystem it is important to include information on the current apex predator.

METHODS

Study Area

This study took place at the Tallgrass Prairie Preserve (hereafter TPP) near Pawhuska, Oklahoma in Osage County, located between 36.73° and 36.9°N latitude, and 96.32° and 96.49°W longitude (Palmer 2007). The TPP covers 15,700 ha and is owned and managed by The Nature Conservancy. TPP is located in the southern end of the Flint Hills region and is the largest preserved tract of tallgrass prairie left in North America (Hamilton 2007). The goal of the TPP is to protect biological diversity and landscape heterogeneity (Payne & Caire 1999, Hamilton 2007). The management includes: maintaining a fire regime that promotes heterogeneity, controlling and removing invasive species, and sustaining and reintroducing species that were historically abundant in the area (Hamilton 2007). The TPP is about 90 percent grassland and 10 percent forest. Approximately 2500 bison graze on approximately 10,000 hectares of the preserve (Palmer 2007). The TPP has recently experienced increased energy development that has resulted in additional roads, power lines, vehicle traffic, site development, and human activity. It serves as an excellent laboratory to test ecological questions.

Coyote Capture

We captured coyotes beginning January 2015 using foothold devices that met animal welfare performance criteria outlined in the Wildlife Techniques Manual (Silvy 2012), Oklahoma State Hunting and Trapping Regulations, The Guidelines of the American Society of Mammologists for the Use of Wild Mammals in Research (Sikes &

Gannon 2011), and the Oklahoma State University Institutional Animal Care and Use Committee protocol (AG-14-24). We used spring loaded leg hold traps with an offset jaw (MB-550-RC 2-coiled) to minimize injury. The offset jaws close quicker and coyotes are less likely to pull out of them, making the traps more efficient and injuries less likely. We placed traps in locations that showed signs of coyote activity (e.g. scat, tracks, and kill sites), and near areas that coyotes frequented (e.g. ponds, trails, fence lines). We baited the traps with a commercially available coyote gland lure and coyote urine. We set approximately 10 traps, 4 nights per week. We checked all trapes twice per day (at dawn and in the evening). Additionally, we monitored weather and trapping did not occur if extreme weather conditions were predicted, such as snow, lightening, or high temperatures. We continued trapping until 10 coyotes were caught and collared (May 2015).

After a coyote was trapped, anesthesia was administered with a Pneu-Dart "Blo-jector" blow pipe and "type P" disposable darts. The anesthesia used was xylazine at a concentration of 100ml/mg and dosage of 1mg/kg in conjunction with ketamine hydrochloride at a concentration of 100ml/mg and a dosage of 10mg/kg (Plumb 2011, Boitani & Powell 2012). Ketamine and xylazine have proven to be effective in anesthetizing canids and maintaining researcher and animal safety (Silvy 2012). After the coyote was anesthetized, the researcher approached the coyote slowly and inspected it to confirm it was thoroughly sedated. The researcher checked their blink and pinnal reflex before removing the animal from the trap. If the coyote's paw had been injured in by the trap a betadine antiseptic solution was applied to the foot. An ophthalmic eye solution was applied to the eyes and then they were covered with a bandana to prevent debris from injuring their eyes during procedures Respiration, temperature, and heart rate were monitored (Kreeger & Seal 1986) every ten minutes throughout the process. Respiration was monitored visually, temperature was monitored using an anal thermometer, and heart rate was monitored using the femoral artery. Each coyote was placed in a burlap sack and approximate weight was taken using a spring scale, then fitted with a Lotek G5C 275D Pinnacle Lite Iridium Satellite Collar GPS tracking collar. At the conclusion of the procedures, the coyote was injected with yohimbine at 0.15 mg/kg intramuscularly as an antagonist to xylazine approximately 40 minutes after initial sedation (Silvy 2012). The coyote was monitored from a safe distance (>3 meters) until it seemed to be fully recovered and left the area.

The GPS transmitters were programed to record a location every hour and to transmit the data every day for the first two weeks. Initially there were 24 locations a day, but after the first two weeks the collar settings were adjusted so that a location was taken every 2 hours and transmitted the data every 2 days (12 locations a day). After 18 months, the electronic timer signaled a small explosive to release the collars.

Data Analysis

We assumed that missing GPS location points meant coyotes were in their dens or in dense vegetation (i.e. not active). Missing GPS location, or missed fixes, occurred when the GPS unit on the collar fails to receive signals from 3 or more satellites and thus, cannot calculate and record a position (Graves & Waller 2006). The TPP is primarily a flat landscape, so rough topography and tree cover are not a significant factor that would hinder GPS signals (Sager-Fradkin et al. 2007, Belant 2009). Periods of inactivity were compared between animals in the study to determine if there were certain times of the day when coyotes were most likely to be active or not active. Seasonally temporally activity was compared between individuals on the TPP. Two seasons were used: winter (December through April), which includes breeding and gestation; and summer (May through November), which includes pup rearing and dispersal (Laundre & Keller 1984, Grinder & Krausman 2001).

RESULTS

A total of 6 coyotes (4 males, 2 females) were used to make inferences about their temporal behavior on the TPP. Two coyotes migrated off the preserve (1 male, 1 female) and were not included in the analysis, but were used for comparison. Coyotes on the preserve were most active from 0200 - 0800h in the winter, and 0000 – 0800h in the summer (Figure 1). Female 2, an individual who migrated off the preserve and 50km north, was most active from 0600 – 1600h (Figure 2). Male 6, who was on a private cattle ranch just north of the TPP, had similar activity patterns to resident coyotes, being primarily active from 2000 - 0600 (Figure 2).

DISCUSSION

The coyotes on the tallgrass display similar nocturnal behavior as coyotes in urban environments (McClennen et al. 2001).The nocturnal/early morning temporal activity of coyotes on the preserve would suggest that they have altered their behavior to more nocturnal. It is possible this is due to anthropogenic pressures like: energy development and consistent traffic from preserve officials, oilmen, and visitors. Increased nocturnal activity by predators could lead to increased predation potential of nocturnal prey species, and potentially, this could disruption of the trophic cascade, leading to broader ecological impacts (Naugle 2011). The behavior by male 6, the coyote near the preserve, mimics this anthropogenic avoidance behavior, while the coyote that migrated north (female 2) demonstrates diurnal behavior. It is possible that female 2 was an outlier and displays abnormal activity patterns for the species, or it is possible she was not subjected to the same anthropogenic pressures and therefore did not alter her behavior to be nocturnal.

We do not believe that the GPS signal was inhibited by vegetation structure and topography. During times when the coyotes in our study were most active (0200 - 0800), our fix rate was 99.5% ± 0.2% (mean ± SE). This is similar to other studies in non-forested landscapes that demonstrated a success rate of 94.9% ± 2.6% to 100% fixes within control groups (Di Orio et al. 2003, Frair et al. 2004). The high success of GPS fixes indicates that coyotes were not bedded (resting, i.e. not active) and illustrates their nocturnal/early morning activity. In contrast, we had lower fix rates of 60.6% ±7.8% (mean ± SE) when we suspected coyotes to be least active (1200 - 2200). These results echo studies that found when animals were bedded GPS fix rates were considerably lower (Bowman et al. 2000, Graves & Waller 2006).

In conclusion, wildlife habitat and landscape connectivity have been reduced by increased energy development and urban sprawl (Naugle 2011, Allred et al. 2015). With these factors projected to increase as the human population increases, it is important to understand how wildlife are affected by these developments. It is believed that coyotes who exhibit nocturnal behavior do so to avoid human interactions, and in the absence of those strong anthropogenic pressures, they are more likely to be diurnal/crepuscular (Kitchen et al. 2000, Grinder & Krausman 2001, McClennen et al. 2001). The changes in coyote temporal activity behavior could affect other species within the community, due to coyote's role as top predator and keystone species in many ecosystems (Henke & Bryant 1999, Prugh et al. 2009)

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FIGURES

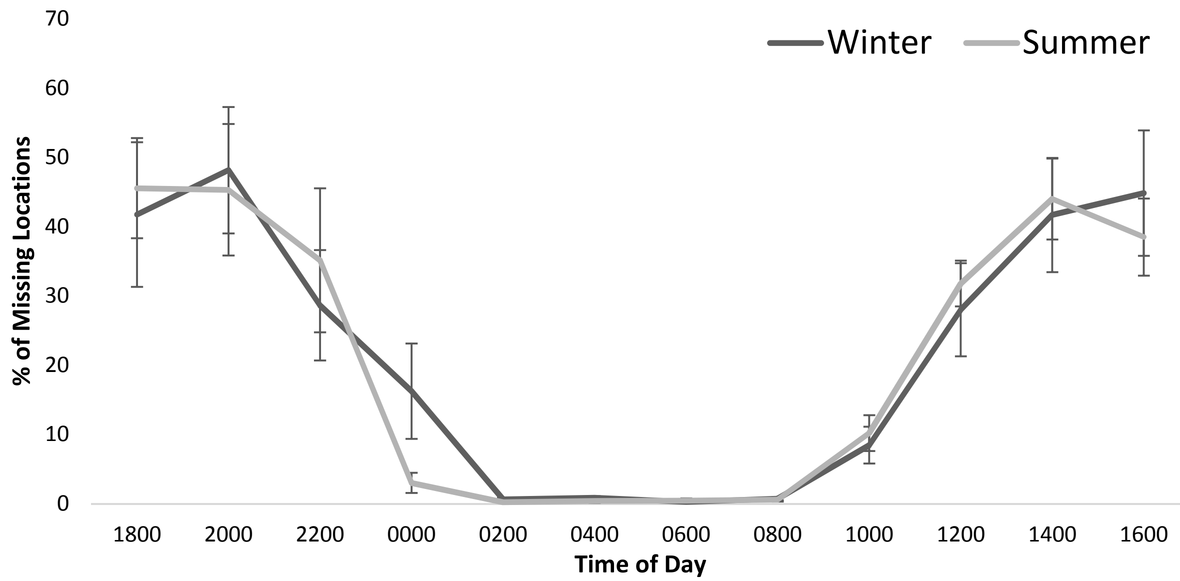


Figure 1. Percent of missing locations for each hour separated by season (summer and winter) for 6 coyotes on the Tallgrass Prairie Preserve, Osage County, Oklahoma during 2015 and 2016.. Missing locations indicates inactivity in a coyote, 0%= most active, while a higher number indicates less activity, mean ± SE.

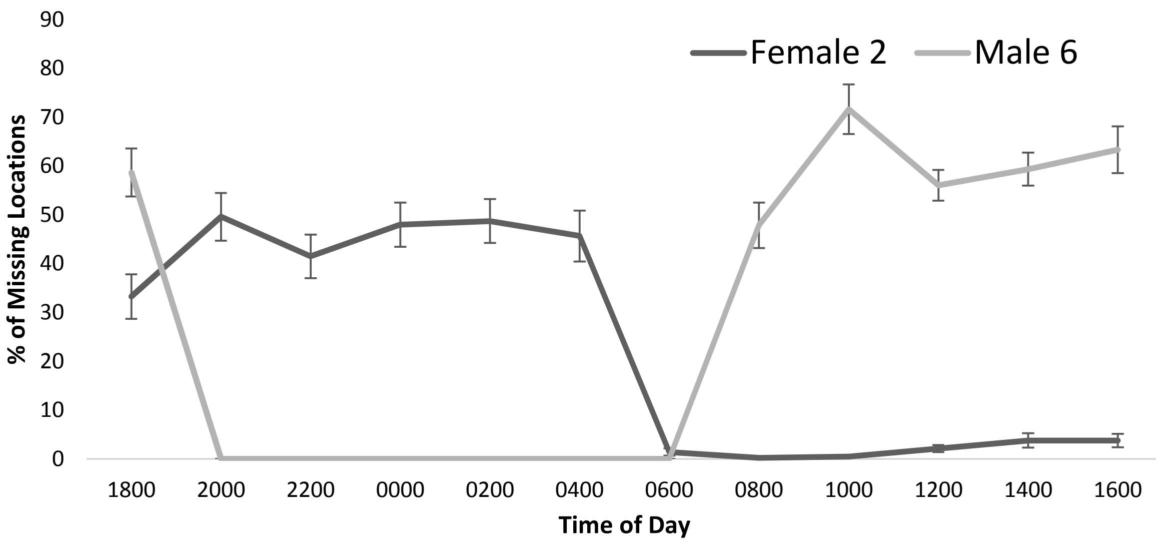
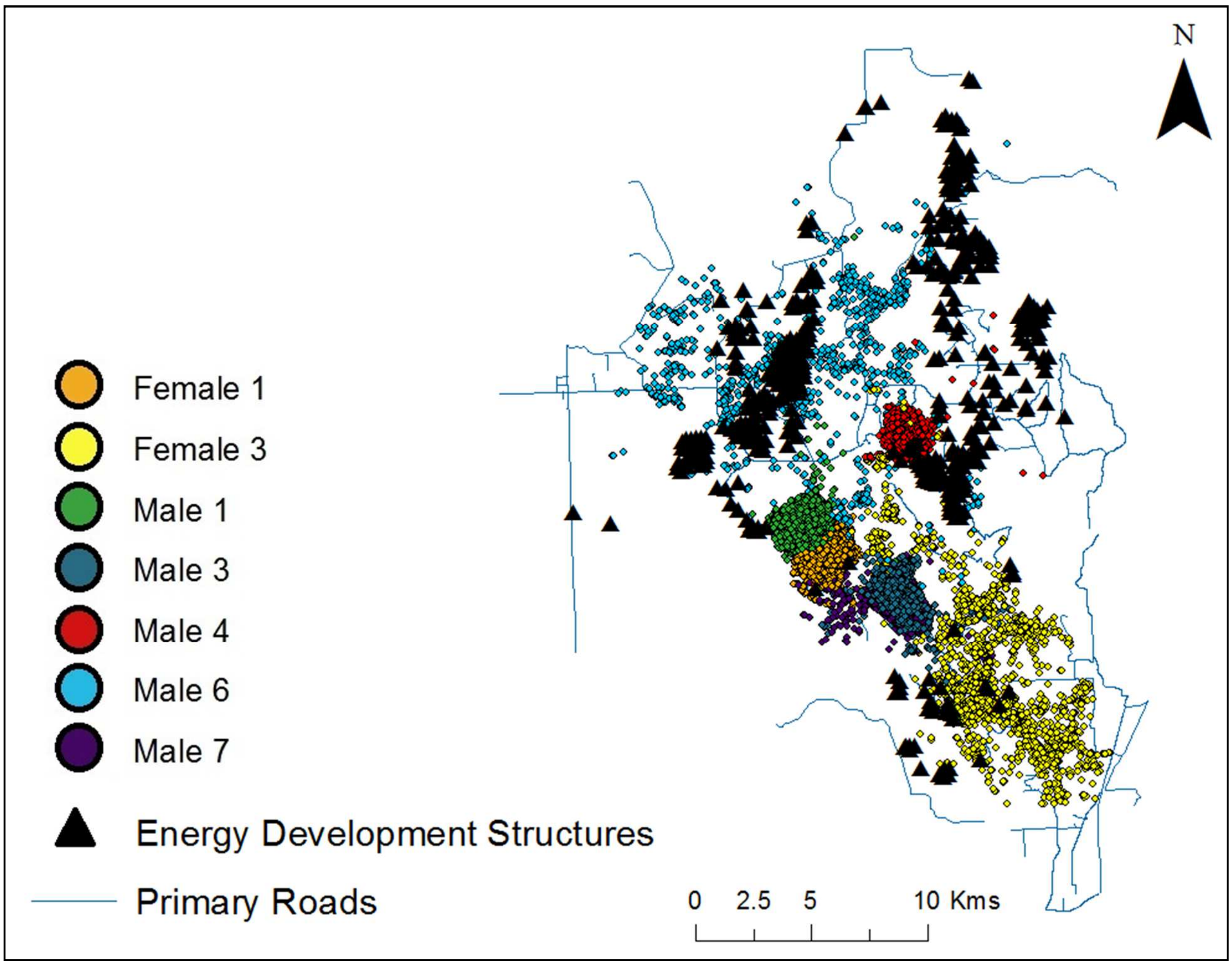


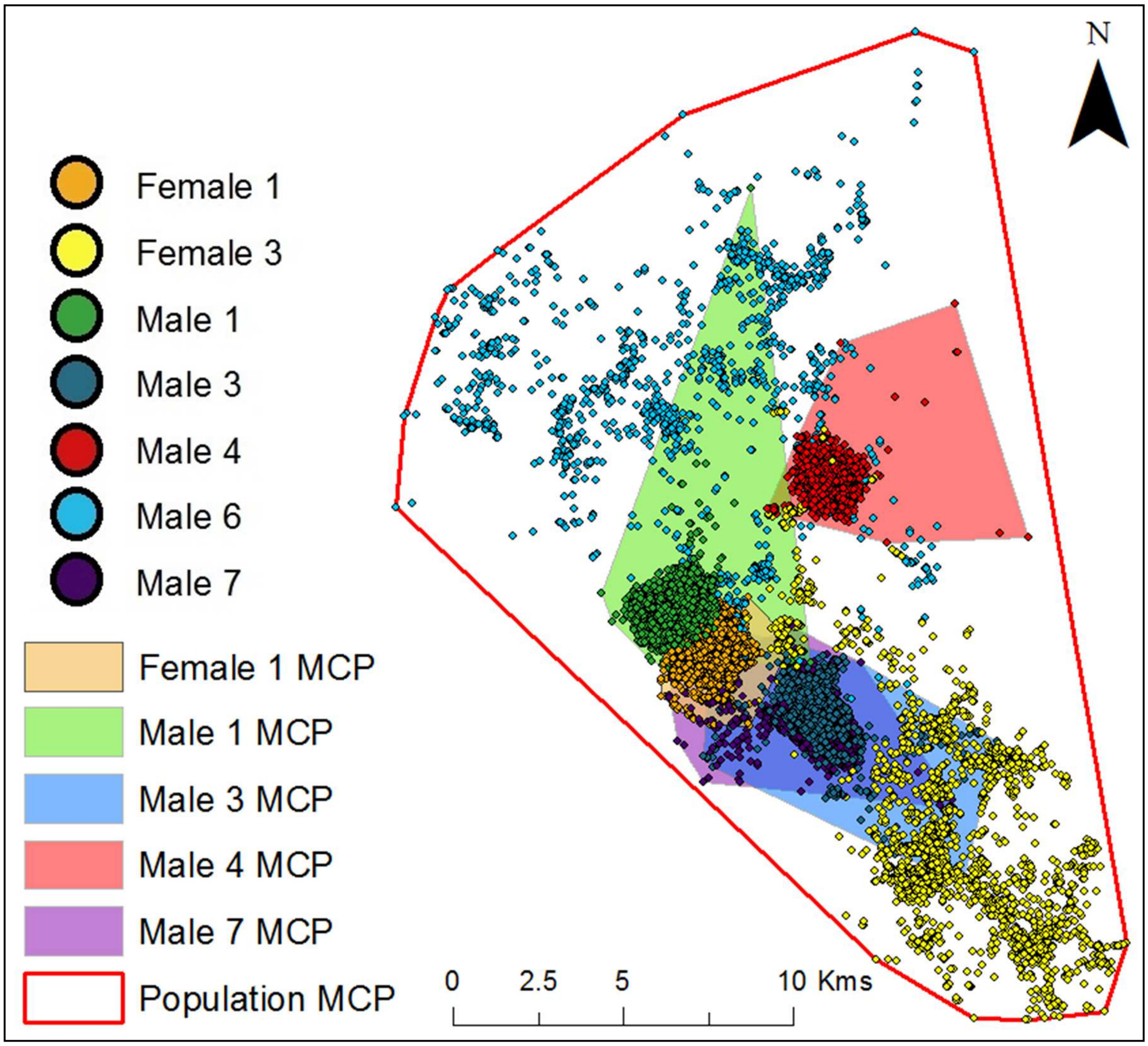
Figure 2. Percent of missing locations for each time period for 2 coyotes who migrated off the nature preserve. Missing locations indicates inactivity in a coyote, 0%= most active, while a higher number indicates less activity, mean ± SE.

APPENDICES

1. Map showing primary roads and energy development structures that were used for resource selection analysis at The Tallgrass Prairie Preserve, Osage County, Oklahoma for 2015 and 2016. Individual coyote GPS locations are also shown.



2. Map of individual coyote GPS locations accompanied by MCP for residents and a population MCP that encompasses all coyote points and the Tallgrass Prairie Preserve, Osage County Oklahoma for 2015 and 2016. The population MCP was used for design II resource selection, while individual, resident MCPs were used for design III resource selection.



3. AICc (Akaike information criterion values) results from all models for Design II resource selection models utilizing GLM for analysis at the Tallgrass Prairie Preserve, Osage County, Oklahoma for 2015 and 2016. Support for each model indicated by df (degrees of freedom), ΔAICc and w_i (Akaike model weights).

Model Formula	ΔAICc	w_i	df
Presence~ Density + Trees + Roads + TSF + Dist.Oil	0	0.902	6
Presence~ Density + Trees + Dist.Oil + Roads	4.4	0.098	5
Presence~ Dist.Oil + Roads + Density	39.1	<0.001	4
Presence~ Dist.Oil+ Roads + TSF + Density	40.7	<0.001	5
Presence~ Dist.Oil+ Roads + TSF+ Trees	647.5	<0.001	5
Presence~ Trees+ Dist.Oil + Roads	664.9	<0.001	4
Presence~ TSF+ Dist.Oil + Roads	668	<0.001	4
Presence~ Dist.Oil + Roads	681.4	<0.001	3
Presence~ Roads + TSF + Density + Trees	1236.4	<0.001	5
Presence~ Trees + Density + Roads	1237.4	<0.001	4
Presence~ TSF+ Roads + Density	1275.2	<0.001	4
Presence~ Density + Roads	1279	<0.001	3
Presence~ Density + Trees + Dist.Oil + TSF	2391.9	<0.001	5
Presence~ Trees+ Dist.Oil + Density	2440.9	<0.001	4
Presence~ TSF+ Dist.Oil + Density	2463.3	<0.001	4
Presence~ Density + Dist.Oil	2501.2	<0.001	3
Presence~ Trees + TSF + Dist.Oil	2812.2	<0.001	4
Presence~ TSF + Dist.Oil	2864.2	<0.001	3
Presence~ Trees + Dist.Oil	2882.3	<0.001	3
Presence~ Dist.Oil	2922.8	<0.001	2
Presence~ Trees + TSF + Density	3183.7	<0.001	4
Presence~ Density + Trees	3192.9	<0.001	3
Presence~ Density + TSF	3251.4	<0.001	3
Presence~ Density	3255.9	<0.001	2
Presence~ Trees + Roads	3440	<0.001	3
Presence~ Trees + TSF+ Roads	3441.9	<0.001	4
Presence~ Roads	3448.7	<0.001	2
Presence~ TSF + Roads	3450.3	<0.001	3
Presence~ Trees + TSF	4682.1	<0.001	3
Presence~ Trees	4693.2	<0.001	2
Presence~ TSF	4711.3	<0.001	2
Presence~1	4719	<0.001	2

4. AICc (Akaike information criterion values) results from the all models for Design III resource selection models utilizing GLMM for analysis at the Tallgrass Prairie Preserve, Osage County, Oklahoma for 2015 and 2016. Support for each model indicated by df (degrees of freedom), ΔAICc and wi (Akaike model weights).

Model Formula	ΔAICc	w_i	df
Presence~ TSF + Dist.Oil + Roads + (1|Tag_ID)	0	0.4	5
Presence~ Dist.Oil + Roads +TSF + Trees + (1|Tag_ID)	0.8	0.27	6
Presence~ Dist.Oil + Roads +TSF + Density + (1|Tag_ID)	1.4	0.2	6
Presence~ TSF+ Trees + Density + Dist.Oil + Roads + (1|Tag_ID)	2.2	0.13	7
Presence~ Dist.Oil + Roads + (1|Tag_ID)	122.1	<0.001	4
Presence~ Roads + Trees + Dist.Oil + (1|Tag_ID)	122.9	<0.001	5
Presence~ Dist.Oil + Roads + Density + (1|Tag_ID)	123.3	<0.001	5
Presence~ Density + Trees + Dist.Oil + Roads + (1|Tag_ID)	124	<0.001	6
Presence~ Dist.Oil +TSF + (1|Tag_ID)	351.2	<0.001	4
Presence~ Trees +TSF + Dist.Oil + (1|Tag_ID)	351.9	<0.001	5
Presence~ Density +TSF + Dist.Oil + (1|Tag_ID)	353.1	<0.001	5
Presence~ Density + Trees + Dist.Oil +TSF + (1|Tag_ID)	353.9	<0.001	6
Presence~ Dist.Oil + Trees + (1|Tag_ID)	456.1	<0.001	4
Presence~ Trees + Density + Dist.Oil + (1|Tag_ID)	458.1	<0.001	5
Presence~ Dist.Oil + (1|Tag_ID)	464.2	<0.001	3
Presence~ Dist.Oil + Density + (1|Tag_ID)	466.2	<0.001	4
Presence~ TSF+ Trees + Density + Dist.Oil + Roads	1575.2	<0.001	6
Presence~ Roads +TSF + Density + Trees + (1|Tag_ID)	3915.2	<0.001	6
Presence~ Density +TSF + Roads + (1|Tag_ID)	3938.1	<0.001	5
Presence~ Trees + Density +TSF + (1|Tag_ID)	4027	<0.001	5
Presence~ TSF + Density + (1|Tag_ID)	4062.6	<0.001	4
Presence~ Roads + Trees +TSF + (1|Tag_ID)	4314.9	<0.001	5
Presence~ TSF + Roads + (1|Tag_ID)	4332.6	<0.001	4
Presence~ TSF + Trees + (1|Tag_ID)	4384.5	<0.001	4
Presence~ Roads + Trees + Density + (1|Tag_ID)	4396	<0.001	5
Presence~ TSF + (1|Tag_ID)	4411.3	<0.001	3
Presence~ Density + Trees + (1|Tag_ID)	4478.8	<0.001	4
Presence~ Density + Roads + (1|Tag_ID)	4498.2	<0.001	4
Presence~ Density + (1|Tag_ID)	4599.6	<0.001	3
Presence~ Roads + Trees + (1|Tag_ID)	4836.7	<0.001	4
Presence~ Trees + (1|Tag_ID)	4877.1	<0.001	3
Presence~ Roads + (1|Tag_ID)	4931.1	<0.001	3
Presence ~ 1 + (1|Tag_ID)	4982.8	<0.001	2

5. A table listing morphometric for each coyote captured. The table includes: coyote number, date of capture, sex, tag id, and weight (lbs).

Coyote Number	Date of Capture	Sex	Tag ID	Weight (lbs)
1	1/24/2015	F	Female 1	30
2	1/24/2015	F	Female 2	35
3	1/27/2015	M	Male 1	30
4	1/27/2015	M	Male 2	25
5	2/9/2015	M	Male 3	25
6	2/14/2015	M	Male 4	23
7	2/16/2015	F	Female 3	27
8	4/6/2015	M	Male 5	23
9	5/2/2015	M	Male 6	30
10	5/4/2015	M	Male 7	27

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VITA

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