Spring 3-27-2023

Spatial and Temporal Patterns of Red Foxes and Coyotes through Camera Traps and Citizen Science

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An Undergraduate Honors Thesis
Submitted in Partial Fulfillment of
University Honors Program Requirements
University of Nebraska-Lincoln

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March 27, 2023

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ABSTRACT

Wildlife may change their temporal activity patterns or spatial distribution in response to human activity in developed landscapes. Citizen science and camera trap approaches have both been used to study wildlife in urban areas, though both methods have their strengths and weaknesses. I studied the temporal activity and spatial occurrence of red foxes (*Vulpes vulpes*) and coyotes (*Canis latrans*) in Lincoln, Nebraska to test ecological and methodological hypotheses. Specifically, I compared camera trap detections of red foxes and coyotes to observations of red foxes made by residents of Lincoln. Using these two data streams, I evaluated temporal activity patterns and spatial distribution of the two species in urban and rural areas in greater Lincoln. For the temporal analyses, I made quantitative comparisons using data from camera trapping and observations by citizens. For the spatial analyses, I made visual and descriptive comparisons of the patterns evident from the two data sources. I found that the temporal activity patterns of red foxes reported by citizen scientists and camera traps differed, but the temporal activity patterns of red foxes and coyotes did not. Using a single-species occupancy model with the camera trap data, I found that red foxes occupied urban areas more than rural areas ($\beta = 2.22$; 95% CI [0.35 to 4.09]) and the probability of red fox occupancy was 0.82 for urban sites and 0.34 for rural sites. Citizen science observations of red foxes were highest in northern Lincoln and camera trap detections of red foxes were more common in southern Lincoln. My results suggest that citizen science observations biased temporal activity pattern results toward diurnal activity. However, including citizen science observations also appeared to augment spatial distribution data by observing foxes in areas where camera traps could not be placed. I recommended that citizen science can lead to a better understanding of wildlife ecology in urban areas since it can be cost-effective and augment data from other sources as long as potential biases are accounted for.

KEYWORDS activity pattern, camera trap, *Canis latrans*, citizen science, coyote, spatial distribution, red fox, rural, urban, *Vulpes vulpes*

ACKNOWLEDGEMENTS

I thank J. Benson and K. Dougherty for their immense support and guidance throughout the thesis process. I thank J. Benson, K. Dougherty, and J. Grewal for providing the camera trap data as well as all the students in the Mammalogy class for their participation in data gathering. I thank all of the organizations that allowed access to their lands to set up camera traps (Nebraska Game and Parks, Lincoln Parks and Recreation, Waverly Parks and Recreation, and Seward Parks and Recreation). I thank K. Dougherty for providing access to his iNaturalist data and his guidance about the R programming language. I thank all those that participated in the citizen science project for gathering data. I also thank J. Grewel and L. Powell for their support in the revisions of this thesis.

Studying animals in their natural habitats under uncontrolled circumstances can be quite challenging. As a result, researchers have come up with various methods and tools to study free-ranging wildlife. Some of those methods include camera traps and GPS (Global Positioning System) or VHF (Very High Frequency) telemetry (Karlin and Paz 2015; Long et al. 2015; Zwerts et al. 2021). Researchers frequently use camera traps to estimate the presence, distribution, and density of wildlife species (Dheer et al. 2022; Wearn and Glover-Kapfer 2019; Zwerts et al 2021). However, camera trap methods can be expensive to implement and maintain (Lasky et al. 2021). Camera traps also produce huge amounts of data in the form of videos or images, which takes time to process (Egna et al. 2020). It can also be easier to study larger animals with camera traps than smaller ones (Dheer et al. 2022).

There has been growing interest in studying wildlife populations in urban areas. Though there have been many successful studies conducted in urban environments with the use of camera traps, issues have arisen while using the technology. Camera traps can be vandalized or stolen within urban environments, requiring additional expenses to replace the cameras for studies to continue (Schwartz et al. 2014). Cameras are also often limited to public spaces, which could lead to patchy, biased data regarding habitat use (Schwartz et al. 2014). Regardless, camera traps provide good-quality data and can be implemented in urban areas. However, due to some of these challenges, especially financial constraints, many researchers are turning to urban residents to help conduct studies and experiments (Destefano et al. 2005; Dickinson et al. 2010; Farhadinia et al. 2018; Green et al. 2020; Karlin and Paz 2015; Rambonnet et al. 2019, Victor 2019).

Citizen science is a term defining the practice of involving the public in scientific research projects (Anton 2019). Citizen science is a promising approach to scientific undertakings, using people to collect data, analyze data, or both (Anton 2019). In relation to camera traps, scientists can reduce project costs by implementing citizen science (Anton 2019). One study found that, by having people implement their own cameras, the project had access to private land and could cover a larger geographical area all the while reducing project costs and vandalism of the equipment (Green et al. 2020). Utilizing citizens also increases public participation and understanding of scientific studies (Anton 2019; Green et al. 2020).

However, the citizen science approach is not without its own difficulties and challenges. The larger the citizen science project, the harder it is to implement and maintain (Lasky et al. 2021). Also, there are concerns about the quality of data collected by non-researchers, which could potentially bias the results of the study (Dorning and Harris 2019; Egna et al. 2020; Green et al. 2020). In studies where citizens analyze photos from camera traps, there is a concern surrounding misidentification, either the animal being misidentified or not recognizing there is an animal in the image provided (Egna et al. 2020). Misidentification is often related to partial views of animals in an image and the size of the animal needing to be identified (Egna et al. 2020). Observational bias is also a concern surrounding citizen science projects, in which animal presence may be exaggerated by the number of observers in an area (Dickinson et al. 2010; Doughtery 2019). These problems can be mitigated through well-written procedures and the training of volunteers (Green et al. 2020).

Many studies in urban areas have utilized both camera trap technology and citizen science, but very few studies have compared the two methods. I compared camera trap methods to citizen science approaches by studying the spatial distribution and temporal activity patterns of coyotes (*Canis latrans*) and red foxes (*Vulpes vulpes*) in Lincoln, Nebraska. Both species are large and recognizable enough to be easily identified on camera traps and through observations by people. Coyotes and red foxes also compete with one another, resulting in differences in the species spatial distribution and activity patterns (Gese et al. 1996; Gosselink et al. 2003; Lombardi et al. 2017; Mueller et al. 2018; Sergeant and Allen 1989). Both red foxes and coyotes occur in urban areas, and it is suspected that red foxes often use different areas because of interactions between red foxes, coyotes, and humans (Gehrt 2004; Gosselink et al. 2003; Mueller et al. 2018). Specifically, red foxes may be excluded from rural areas through conflict with coyotes (Gosselink et al 2003), whereas coyotes may avoid areas that are highly populated by humans due to conflict with humans (Gehrt 2004).

Lincoln, Nebraska presents an opportunity to study the differences in spatial distributions and temporal activity patterns of rural and urban coyotes and red foxes. Lincoln comprises a metropolitan area, several residential and commercial districts, as well as many green spaces, and is surrounded by the agricultural areas of larger Lancaster County. Lincoln is an effective study area because there is a relatively hard boundary between urban and rural areas that has minimal suburban sprawl in between (i.e high human density to very low human density without a continuous decline between the two). This facilitates the comparison of spatial and temporal patterns of rural and urban wildlife occupying areas in close proximity.

I tested two hypotheses with both ecological and methodological implications using a combination of camera trapping and citizen science (observation) data. First, I hypothesized that red foxes avoid coyotes to reduce competition and predation risk. Specifically, I predicted that red foxes are associated with urban areas more than coyotes (P1) and are more active during diurnal periods than coyotes (P2). Second, I hypothesized that both camera trapping and citizen science data have strengths and weaknesses for capturing spatial and temporal patterns of wildlife because of biases associated with both data streams. Here, I predicted that camera traps provide temporally unbiased data because they can monitor the entire twenty-four-hour period, whereas citizen science observations bias red fox and coyote activity patterns by over-representing diurnal activity when humans are most active (P3). I also predicted that citizen scientists detect red foxes and coyotes in areas where camera traps cannot be deployed, thus enriching spatial distribution data (P4).

STUDY AREA

I compared traditional camera trap techniques to novel citizen science approaches by studying the spatial distributions and temporal activity patterns of coyotes and red foxes in Lincoln, Nebraska. The city of Lincoln is a mid-sized city that spans approximately 260 km^2 with just under 300,000 residents. Lincoln comprises multiple residential areas and commercial districts, a main metropolitan area, highways, and country roads, as well as many green spaces and agricultural environments. Lincoln is surrounded by rural Lancaster County, which is mainly made up of large agricultural and ranch areas. The parks and nature reserves that make up Lincoln's green spaces, as well as the agricultural areas, is habitat for many wildlife species. Unlike what is seen in many cities, Lincoln has a minimal suburban sprawl with urban and rural areas in close proximity to one another.

METHODS

Students in the Mammalogy course at the University of Nebraska-Lincoln as well as students and faculty associated with the Lincoln Urban Wildlife Project and I used MCG-12631 trail cameras to set up camera traps around Lincoln, Nebraska (Figure 6). We set up the cameras approximately 1.9 kilometers apart, which was based upon the home range size of red foxes in Lincoln (Dougherty 2019) and allowed us to achieve a level of independence between sites. We configured the camera traps to take three photos in quick succession every time motion is detected by the trap. We set it up so that there will be a five-minute delay between the three-photo photo bursts to prevent picking up the same animal multiple times. We made sure that all of the photos will have the date and time recorded on them.

We set up camera traps in areas that seemed likely to be visited by wildlife. These areas may have scat or some sort of pathway that could be used by wildlife. We also set up the cameras in areas where human activity was likely to be low. This helped prevent the cameras from being tampered with, vandalized, or stolen by people. We set up the cameras at about shoulder height (about 1.2 meters above the ground) facing the direction of possible animal activity. We placed red fox urine about two and a half meters away from the camera as an attractant. We checked the cameras every two weeks to gather data, replace the batteries, and place new attractants.

I also gathered urban red fox data by utilizing Kyle Dougherty's iNaturalist website. Dougherty (2019) had citizen scientists record the location of red foxes within the Lincoln City Limits. He had citizen scientists record sightings between January 2018 and December 2022 (Dougherty 2019).

I used the "overlap" package in R, version 4.2.2 to conduct all my temporal analyses (R Core Development Team 2020). The "overlap" package uses temporal data from camera traps to identify and evaluate temporal activity patterns of wildlife (Meredith and Ridout 2022). I created kernel density plots to visualize the temporal activity patterns of red foxes and coyotes and then analyzed the patterns using Rao's Spacing Test to determine if the patterns differed from a uniform temporal activity pattern using the "circular" package in R (Lund et al. 2022). This allowed me to determine if the temporal activity patterns of red foxes and coyotes fit a nocturnal, crepuscular, or diurnal pattern by identifying peaks in temporal activity and by evaluating temporal activity patterns differed from a uniform distribution with Rao's Spacing Test. I then compared temporal activity patterns of red foxes and coyotes (P2) with Watson's U^2-Test of Homogeneity to evaluate whether the patterns differed significantly using "circular" (Lund et al. 2022). I compared temporal activity patterns from the camera traps and citizen science approaches for the same species (P3) using Watson's U^2-Test of Homogeneity.

I estimated the occupancy of red foxes in urban and rural areas of greater Lincoln by recording whether or not a red fox or coyote was detected at each camera site during specific sampling occasions. Specifically, each site received a score of 0 (not detected) or 1 (detected), depending on whether a red fox was detected at that site during sequential week-long sampling occasions (Santos et al. 2019). I created a single-species single-season occupancy model using the "unmarked" package in R (Chandler et al. 2022) to evaluate the spatial occurrence of red foxes in Lincoln, Nebraska relative to the anthropogenic presence (urban or rural sites) and coyote occupancy (P1; P4). I created the urban/rural variable by assigning a 0 to rural sites (areas outside the Lincoln City Limits) and a 1 to urban sites (areas within the Lincoln City Limits). I created the coyote variable by assigning a 1 to sites that detected a coyote and a 0 to sites that did not detect a coyote. The occupancy model allowed me to estimate site occupancy across all sites with imperfect detection. The model has a sampling component and a processing component. The sampling component evaluates the variation in a sample through detection probability and the processing component evaluates variation based on biological processes, such as the effects of urban/rural areas or coyote presence on fox occupancy. I created a null model with no covariates to determine the detection probability of foxes and fit additional models containing covariates to evaluate factors influencing occupancy of red foxes. I conducted model selection using Akaike's information criterion corrected for small sample size (AICc; Parameter et al.

2003). I calculated ΔAICc as the difference in AICc values of a given model relative to the best fitting model to evaluate models with respect to parsimony and model fit. Specifically, I considered models with ΔAICc <2 to be strongly supported and >2 to suggest that the model is uninformative.

I compared the camera trap spatial data to the iNaturalist data descriptively and visually by creating observation maps using the “ggplot2” package (Wickham et al. 2023). This allowed me to describe the differences and similarities in the observations so I could compare the methods. I only used fox observations to draw the comparisons as the observations from the iNaturalist data were mainly red fox sightings.

RESULTS

Temporal Analysis

Based on the camera trap analyses, urban coyotes did not differ significantly from a uniform temporal activity pattern (RST $p > 0.05$) with peaks in activity around 09:00 and 20:00 (Figure 1). Rural coyotes appeared to have a more nocturnal activity pattern (RST $p < 0.05$) and were more active in nighttime hours between 20:00 and 06:00 with slight decreases in activity at 00:00 and 04:00 (Figure 2). Camera trap data indicated that urban red foxes were crepuscular (RST $p < 0.05$) with activity peaking around 07:00 and 20:00-21:00 (Figure 3). Rural red foxes did not differ significantly from a uniform pattern, (RST $p > 0.05$), although the plot suggested a peak in activity around 03:00 and a smaller peak around 18:00 (Figure 4). Camera trap data of urban coyotes and red foxes showed that the species shared similar activity patterns (WT $p > 0.05$) as did rural coyotes and red foxes (WT $p > 0.05$).

Red foxes reported by citizen scientists on the iNaturalist website appeared to exhibit a strong diurnal activity pattern (RST $p < 0.05$) with very little evening or nighttime activity.

Citizens observed a strong peak of activity around 07:00 and a smaller peak in activity around 17:00 (Figure 5). Urban red foxes detected by camera traps and red foxes reported by citizen scientists did not suggest similar activity patterns (WT $p < 0.05$).

Spatial Analysis

The model that was best supported for red fox occupancy was the model containing only the urban variable, followed by the urban/coyote model, the null model, and the coyote model (Table 1). The model suggested that urban areas have a positive influence on red fox occupancy (β = 2.22; 95% CI [0.35 to 4.09]) and that the probability of red fox occupancy was 0.82 for urban sites and 0.34 for rural sites. The probability of detection of red foxes by our camera sites was relatively low (0.36).

Red foxes reported by citizen scientists occurred mostly in urban areas, with fewer red foxes observed in rural areas (Figure 7). Many observations were clustered, especially in northern Lincoln (Figure 7). Conversely, camera trap sites in southern Lincoln detected more foxes than sites in northern Lincoln (Figure 8). Citizen scientists observed more foxes in urban areas (n = 428) than in camera traps (n = 105) and observed more foxes in rural areas (n = 17) than in camera traps (n = 10; Table 2).

DISCUSSION

My first prediction was not supported in that temporal activity patterns did not differ significantly between coyotes and red foxes in either urban or rural areas. The similarity in temporal activity patterns between red foxes and coyotes is consistent with other studies researching potential temporal differentiation between the two species (Gese et al. 1996; Gosselink et al. 2003; Lombardi et al. 2017; Mortensen 2021; Mueller et al. 2018). This may indicate that there is no need for temporal differentiation because the species are already avoiding one another spatially. My second prediction was partially supported in that red foxes are more likely to inhabit urban areas than rural ones. The model of red fox occupancy containing the single variable of landscape type, either urban or rural, had the most support. The variable for coyote presence on red fox occupancy was not informative (Table 1), so I cannot definitively conclude that red foxes are avoiding coyotes spatially, though more coyotes were detected by camera traps in rural areas (n = 85) than in urban areas (n = 60; Table 2). Regardless, it has been observed that there is conflict and competition between the two species (Gese et al. 1996; Gosselink et al. 2003; Lombardi et al. 2017). Coyotes and red foxes tend to share a similar diet and habitat preference (Gosselink et al. 2003; Lombardi et al. 2017). Coyotes are also known to be aggressive toward red foxes and have been documented killing red foxes (Gese et al. 1996; Gosselink et al. 2003). As a result, due to the limited observations of foxes in rural areas, it is possible that red foxes avoid rural areas as coyotes may be more likely to inhabit these areas and are aggressive toward red foxes.

Red foxes may use urban habitats because coyotes are more likely to avoid areas used by humans. One study did find that coyotes prefer less-developed rural areas (Mueller et al. 2018). Coyotes tend to be persecuted by humans, leading to conflict between humans and coyotes which was discussed by Mortensen (2021) who suggested that coyotes may avoid people in Lincoln, Nebraska. Red foxes may also use more areas because they provide suitable habitats for foraging opportunities, cover/den sites, as well as access to water (Lombardi et al. 2017). Urban areas may also be a way for red foxes to stay away from agricultural practices, such as increased use of herbicides, loss of cover from woodlands, and the increased agricultural production of row crops (Gosselink et al. 2003).

My third prediction was supported as red fox observations gathered by citizen scientists were heavily diurnal, with very few observations during nighttime hours. As predicted, red fox observations by citizen scientists were most common during the daytime when humans are more likely to be active and outside. It is possible that foxes are more active in the daytime than expected, or it could be that individual foxes were observed by multiple people, therefore inflating the activity pattern results. Citizen science studies that rely on observational data may have multiple biases, such that activity patterns can be influenced by the number of observers and the times that observers are active (Lasky et al. 2021). In this study, people may have also misreported times when foxes were observed, potentially creating additional bias. For example, if an individual saw a fox early in the morning but reported the time of sighting to later that same morning (05:00 vs. 08:00). This could change inference regarding the overall activity pattern of the foxes in the area, moving from a potential crepuscular pattern to a diurnal one.

My fourth prediction was also supported by my data in that the spatial distribution of red foxes detected by camera traps and red foxes observed by citizen scientists differed. Visualizing where red foxes were reported indicated that there were clusters of activity in two separate areas of Lincoln, Nebraska (Figures 7 & 8). Camera traps in south Lincoln detected many foxes whereas citizen scientists found many foxes in north Lincoln. Two different clusters of red fox occupancy were caught by two different methods, which may support my hypothesis that there are strengths and weaknesses in both approaches. For instance, citizen science data bay have been biased as observations of foxes may be proportional to the number of people in the area (Lasky et al. 2021). Additionally, multiple observations of one fox may overrepresent fox occupancy in a certain area, such as UNL’s East Campus. Students and faculty on East Campus may have been more informed of the study and may have reported more fox sightings as a result.

Regardless, many of the observations were made in areas without camera traps, which provided a better overview of where foxes are located in Lincoln, Nebraska.

There were some potential discrepancies in the data that may have influenced some of the results. Mainly, the minimal observations of rural foxes on both camera traps and by citizen scientists. Small data samples could have biased the temporal results, impacting the analysis of the activity pattern as well as the overlap between the species. More data is needed around rural red foxes to better support spatial and potentially temporal differentiation between red foxes and coyotes. However, due to the consistencies in observations between citizen scientists and camera trap detections of rural red foxes, it may be possible that rural detections are rare due to the competitive exclusion of red foxes by coyotes in rural areas (Lombardi et al. 2017; Mueller et al. 2018). Second, there were limitations and missing information with some of the iNaturalist data. Some citizen scientists didn't record a time a fox was observed or a location where the fox was observed, leaving out crucial data for research.

To better compare citizen science approaches to camera trap methods, I suggest gathering coyote sightings data from Lincoln Animal Control and completing a point-process model. A point-process model assumes that points do not depend on each other and are random. As such, a point-process model will determine if observations made by citizen scientists are random or are not random (indicating the potential use of a species; Baddeley and Turner 2006). A point process model will also address some observational bias by adding corrections for edge effects (Dougherty 2019). My study did not have any substantial data collected from citizen scientists regarding coyotes. A point-process model would also allow for a better analysis of the spatial distribution of both coyotes and red foxes, allowing for a better comparison between the two species. I also suggest gathering more data on rural red foxes, if at all possible. This can be done through capture-recapture methods for spatial data or even GPS collars to gather both temporal and spatial data. It may also be beneficial to change the citizen science approach to a method that would provide additional data and information. For example, citizen scientists could submit data from personal security cameras, like Ring devices, or provide camera traps to individuals who are interested. This could address the limitation of camera traps as passive data collection devices up in specific locations that may bias the results. This method has been implemented successfully and yielded high-quality results, though it isn't without its own challenges (Green et al. 2020).

IMPLICATIONS

Both methods, camera traps and citizen science, do have their strengths and weaknesses. Camera traps provide high-quality temporal data due to the ability to observe the full twenty-four-hour time period. However, cameras must be placed in locations where they will not be stolen or damaged. This can limit the spatial distribution and the number of cameras deployed in a study and may make it difficult to use in residential areas. Depending on the citizen science approach, this method can also provide high-quality results. However, there are many limitations to consider. For example, citizen science observational data may not be a good fit to study nocturnal species. One must also take into account that observational data may be influenced by the number of recorders in an area. This can sometimes be addressed through careful study design. Overall, citizen science may be a good method to use alongside other methods, like camera traps, when implementing studies in urban environments. As long as potential biases are recognized and used with other data collection methods, citizen science is a cost-effective strategy that has the potential to augment study results and lead to a better understanding of wildlife ecology in urban areas.

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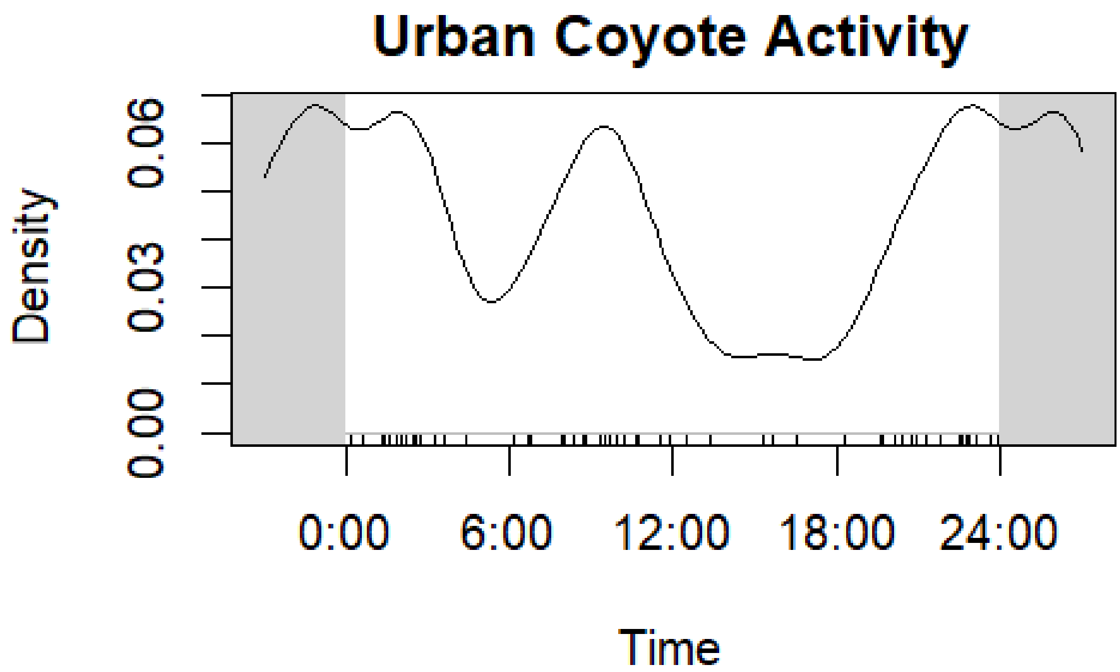

Figure 1: A plot representing the density of coyotes detected in urban areas across the daily 24-hour period by camera traps in Lincoln, Nebraska from January 2020 to October 2022. A rug was added to show observations that were made at specific times, with more observations equaling more activity from coyotes (*n* = 60).

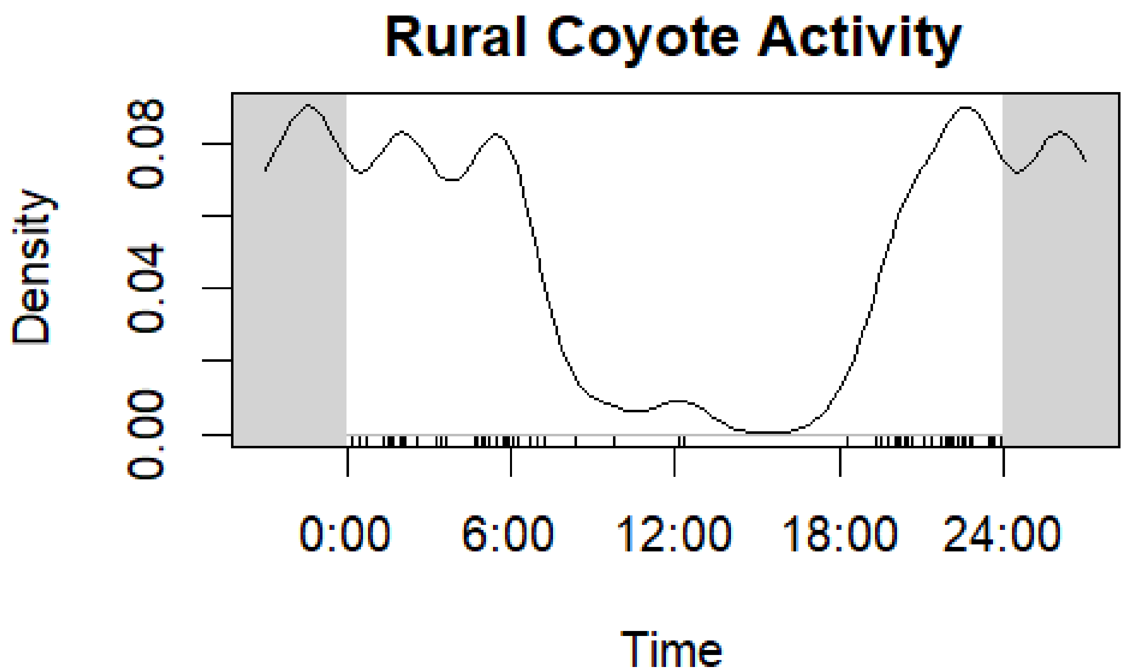

Figure 2: A plot representing the density of coyotes reported in rural areas by camera traps in Lincoln, Nebraska from January 2020 to October 2022 across the daily 24-hour period. A rug was added to demonstrate observations made at specific times, with more observations showing more activity of coyotes (*n* = 85).

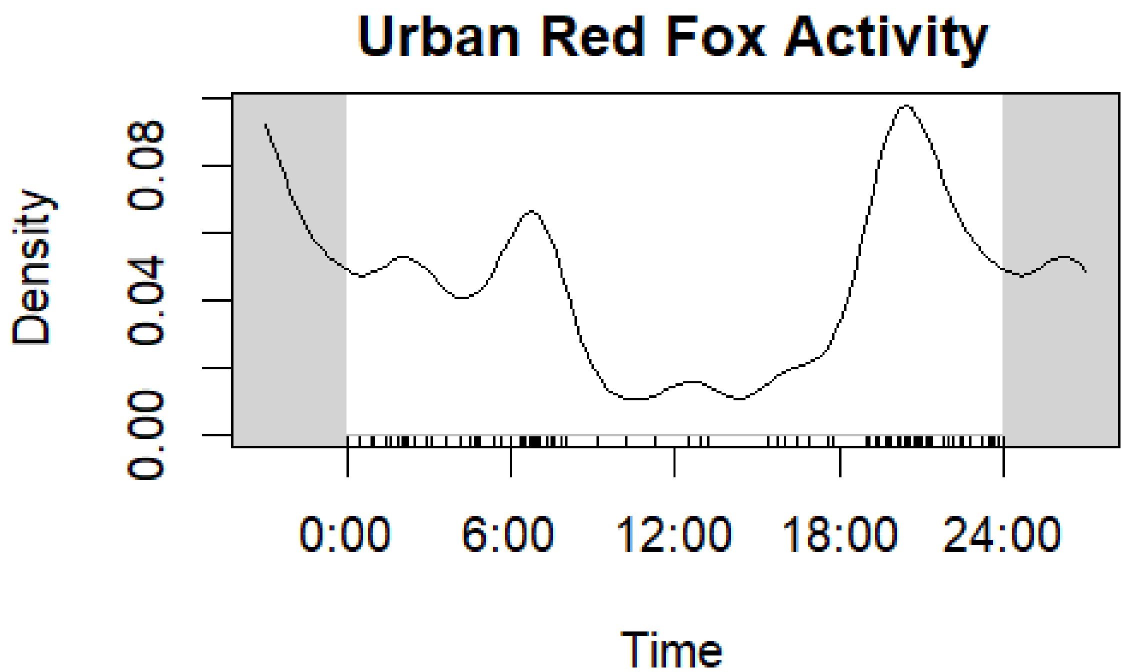

Figure 3: A plot representing the density of red foxes observed in urban areas across the 24-hour period by camera traps in Lincoln, Nebraska from January 2020 to October 2022. A rug was added to show observations that were made at specific times, with more observations representing more activity (*n* = 105).

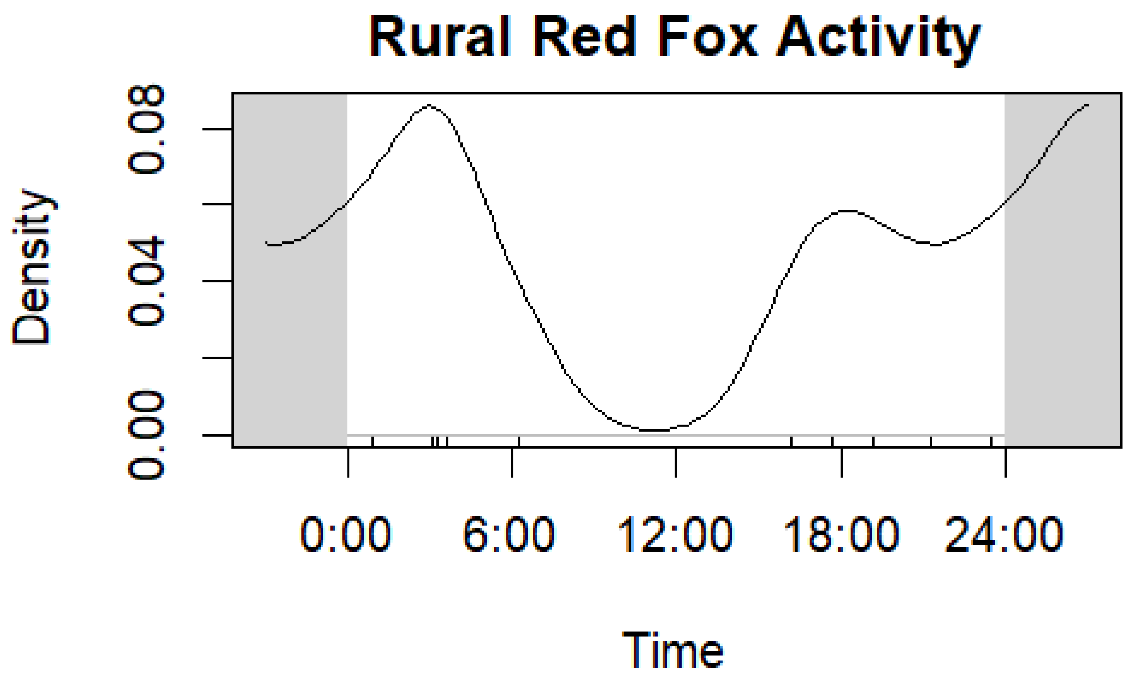

Figure 4: A plot representing the density of rural red foxes detected by camera traps across a 24-hour period in Lincoln, Nebraska from January 2020 to October 2022. A rug was added to show observations made at specific times, with more observations equaling more activity from red foxes (*n* = 10).

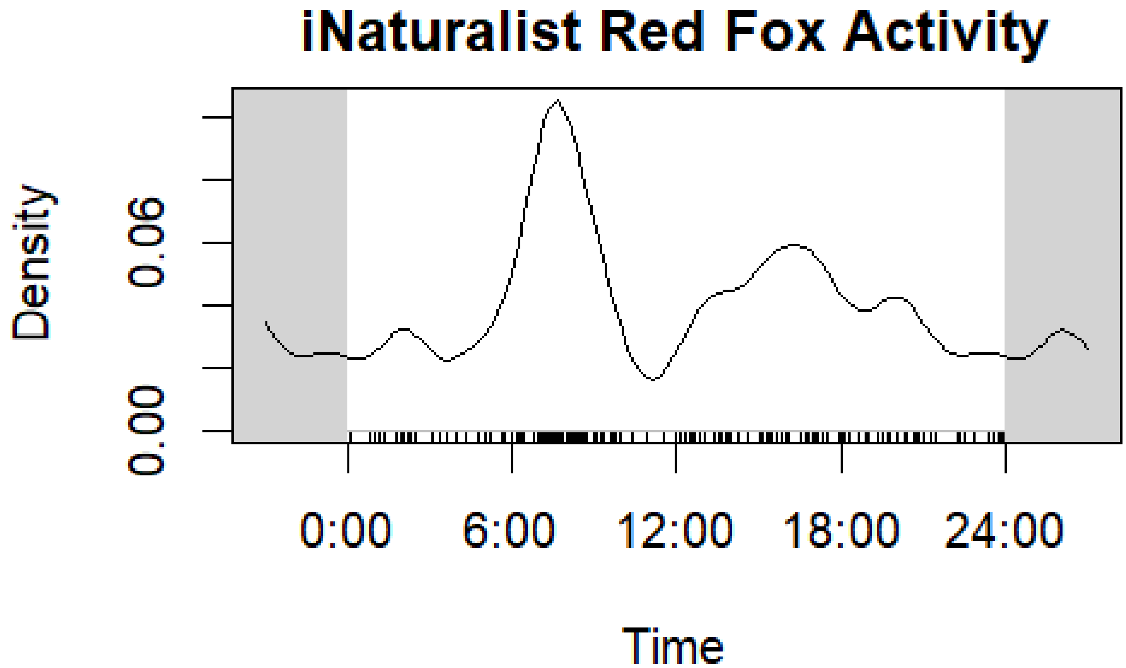

Figure 5: A plot representing the density of red foxes in urban areas observed by citizen scientists across a 24-hour period in Lincoln, Nebraska from January 2018 to December 2022. A rug was added to show the number of observations reported at specific times. The more observations made at one time represent a higher activity level of foxes (*n* = 205).

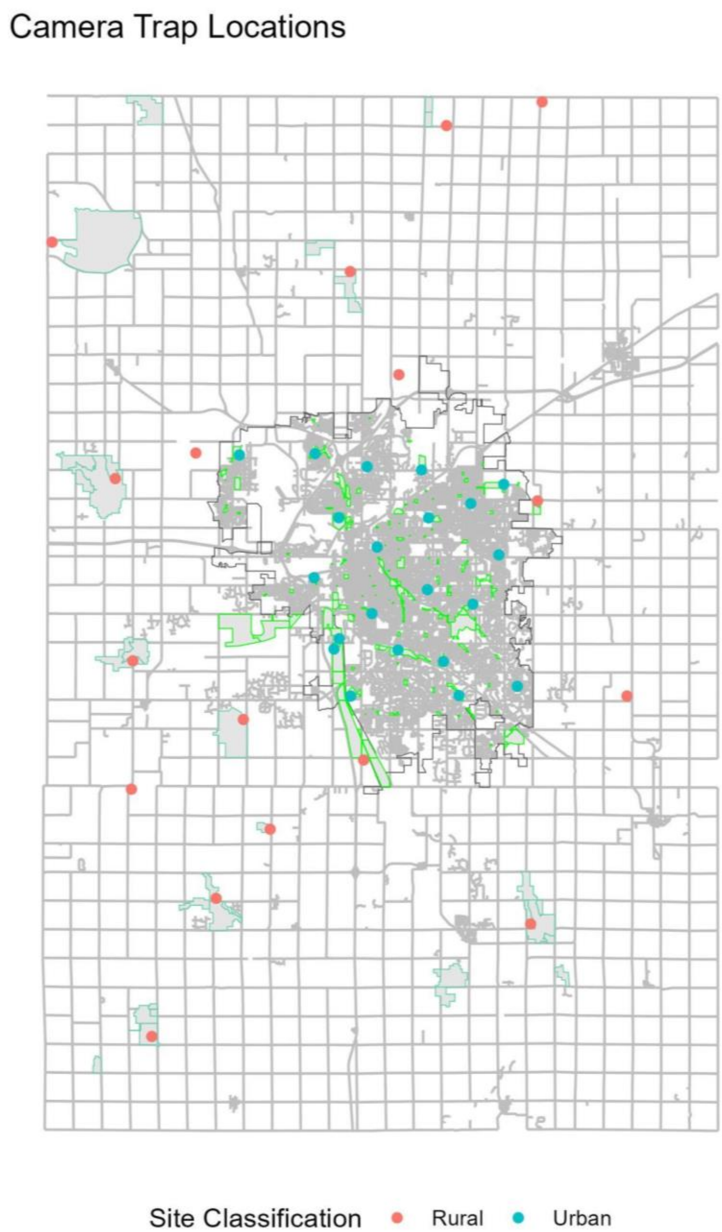

Figure 6: A map showing the locations of the camera traps used in the city of Lincoln and Lancaster County. Red dots indicate camera traps placed in rural areas and blue dots indicate camera traps placed in urban areas. Green areas are parks within Lincoln and the teal areas are properties owned by the Nebraska Game and Parks Commission.

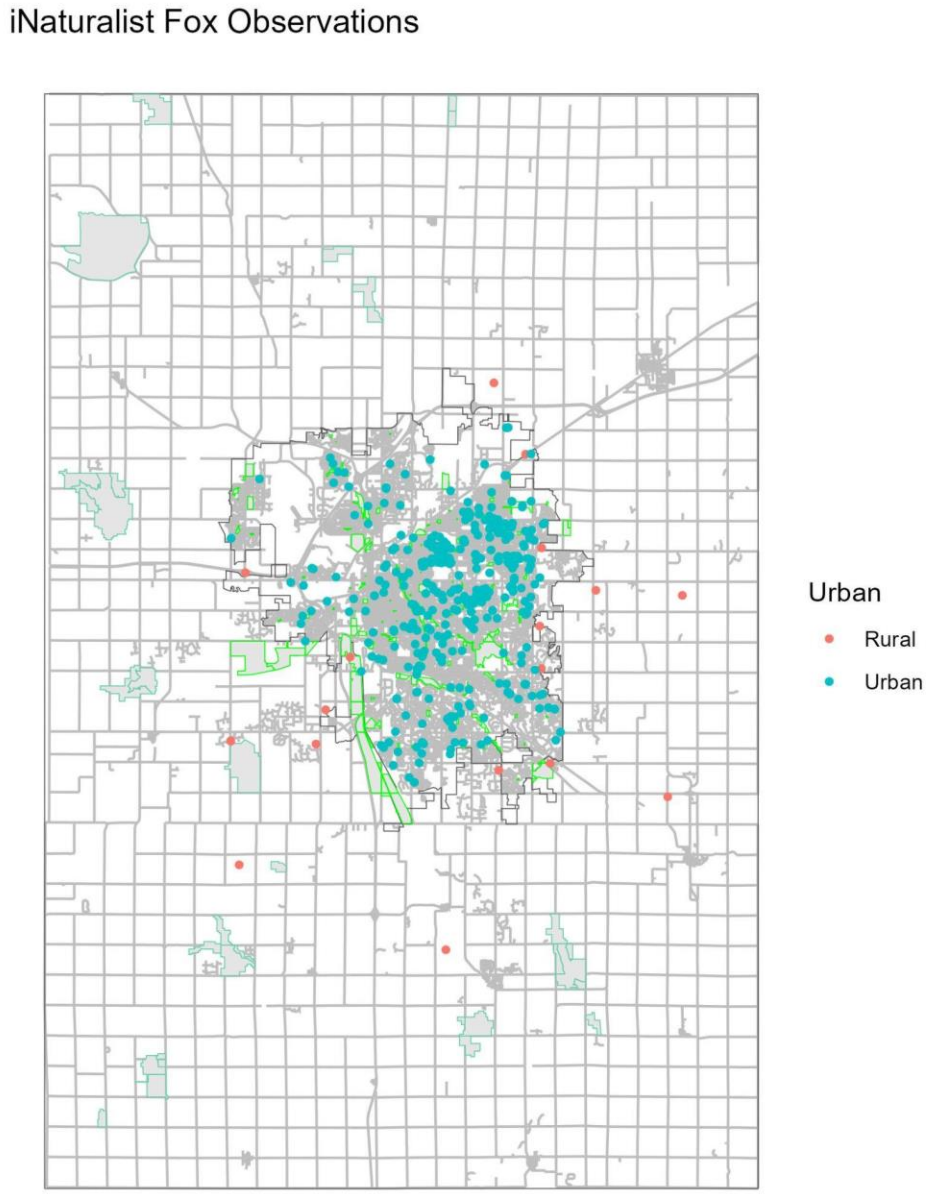

Figure 7: A map of all fox sightings in Lincoln, Nebraska by citizen scientists using the recording platform iNaturalist from January 2018 to December 2022. Blue dots are foxes observed in urban areas, red dots are foxes reported in rural areas. Green polygons represent parks in Lincoln while the teal polygons are properties of the Nebraska Game and Parks Commission.

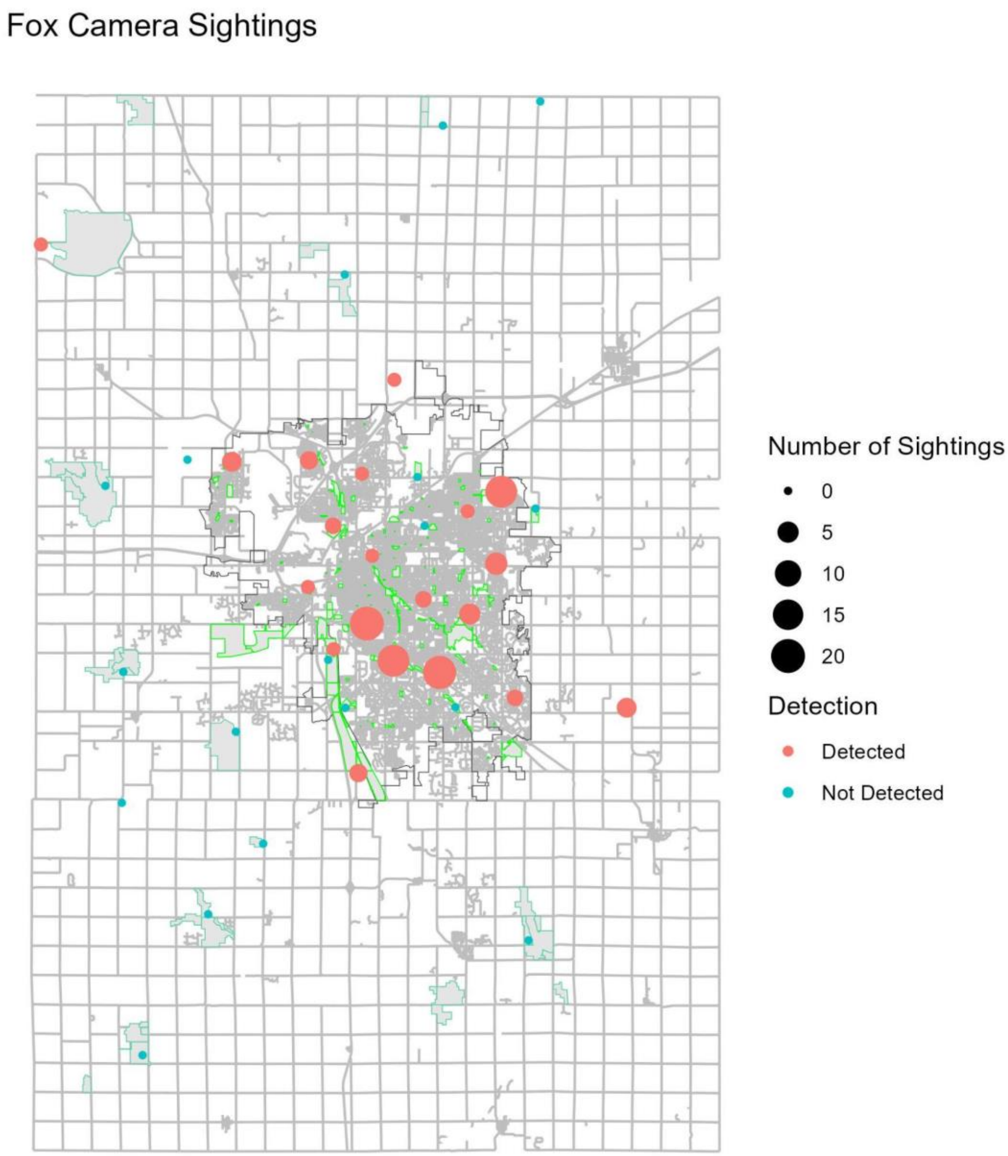

Figure 8: A map showing the number of foxes captured at each camera trap in Lincoln, Nebraska from January 2020 to October 2022. The size of the dot represents how many foxes were detected at specific camera traps. Red dots indicate that foxes were detected at specific sites while blue dots indicate sites where foxes were not detected. Green polygons indicate parks in Lincoln, and teal polygons indicate properties owned by the Nebraska Game and Parks Commission.

Model	# of Parameters	AICc	ΔAICc
Urban	1	248.29	0.00
Coyote	1	255.35	7.06
Urban + Coyote	2	250.68	2.39
Null	0	253.16	4.87

Table 1: A table of the AICc and ΔAICc values for the Urban, Coyote, Urban + Coyote, and Null models created from camera trap data in Lincoln, Nebraska from January 2020 to October 2022. The table also contains the number of parameters used in each model.

Method Type	Urban	Rural
Camera Trap Fox	105	10
Camera Trap Coyote	60	85
iNaturalist CitSci Fox	428	17

Table 2: A summary of the number of sightings of red foxes and coyotes observed in urban and rural areas using both camera traps and citizen science in Lincoln, Nebraska. Camera trap data was collected from January 2020 to October 2022 and the citizen science data was collected from January 2018 to December 2022. The number of observations of coyotes using citizen science approaches was not included due to insufficient data.