ANALYZING HABITAT FRAGMENTATION ON MESO-CARNIVORE TEMPORAL AND SPATIAL BEHAVIOR IN NEWARK, DELAWARE

by

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A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the Degree of Bachelor of Science in Wildlife Conservation and Ecology with Distinction

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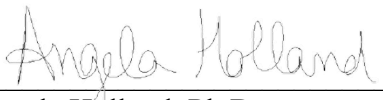
Approved: 

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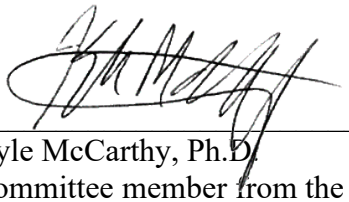
Approved: 

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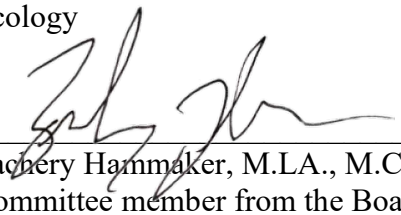
Approved: 

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ABSTRACT

Habitats are divided into smaller patches when anthropogenic alterations such as agriculture and urbanization increase landscape fragmentation. Species abundance and distribution are inadvertently affected as they adapt to these changes. In this study, I investigated detection rates of raccoons (*Procyon lotor*) and red foxes (*Vulpes vulpes*) across different fragmented patches on a working farm complex in Newark, Delaware, and how they may be temporally influenced by, or spatially utilize, fragmentation. During the summer of 2025, 12 cameras were stationed at specific human-disturbed habitat patches and corridors located in fragmented fields and forests. I found that raccoon presence and activity were dependent on time of day rather than location; in contrast, red fox presence increased from day to night and was strongly associated with fragmented fields. These responses indicated species-specific behavior within patchy landscapes. This research provides insight into how mesocarnivores adapt temporally and spatially to growing habitat fragmentation and human disturbance.

Chapter 1

INTRODUCTION

Species abundance and distribution are inadvertently impacted by landscape fragmentation due to sprawling agriculture and urbanization (Pereira 2024). In the eastern United States, mesocarnivores have changed their spatial and temporal habits due to the exponential growth of fragmented areas (Egan 2018). Mesocarnivores have shorter lifespans, smaller home ranges, and higher fecundity, making them better suited to adjust their distributions and behaviors in urbanized environments than most apex predators (Rodriguez 2021). Larger carnivores are either few or nonexistent in the eastern United States (Egan 2018). However, the coyote's historical range has only recently extended from the Great Plains into Delaware and Maryland. They have been slow to range into Delaware from the North, so for this study, they were not prominent enough to document. Native mesocarnivores like raccoons (*Procyon lotor*) and red foxes (*Vulpes vulpes*) are prime examples of adaptation to habitat fragmentation.

The red fox possesses one of the broadest geographic ranges among terrestrial carnivores. Like many canid species, they demonstrate considerable ecological adaptability and can modify their behavior in response to landscape change (Black et al. 2024). They may show greater intraspecific variation in habitat preference and spatial behavior when occupying human-dominated environments. Red foxes are

hypothesized to exhibit temporal variation in activity and habitat-dependent differences in detection probability (Fiderer 2019).

Raccoons are hypothesized to readily exploit urban areas and demonstrate generalist behavior across habitat types (Egan 2018). Previous research shows their diverse preferences for shrub swamps, edges of water bodies, woodlands, and linear landscape features such as forest edges and mowed trails when foraging at night due to their omnivorous diets (Fiderer 2019; Barding & Nelson 2008). Fragmented landscapes with extensive edge and contrasting land cover concentrate raccoon densities in contemporary agricultural and residential landscapes due to a combination of available den sites, water, and supplemental food (Barding & Nelson 2008; Hoffman & Gottschang 1977). Raccoons will use corridors as travel routes and feeding areas, commonly during nighttime hours (Hoffman & Gottschang 1977).

Habitat fragmentation and landscape structure can influence wildlife movement, habitat use, and activity patterns in urban ecosystems. My study concentrates on a successional urban forest, wetlands, and corridors with tree canopy edges on the South Campus of the University of Delaware. These research sites are separated by cropland, impervious structures, and roads that mesocarnivores may navigate while utilizing forest edges and transition zones. For analysis, study locations were categorized into broader habitat classes representing fragmented forest and fragmented field environments. Raccoons and red foxes, two species commonly associated with fragmented landscapes, were selected as focal species due to their adaptability to human-altered environments. I examined how habitat fragmentation

and temporal conditions influenced the activity patterns and detection probabilities of red foxes and raccoons across fragment habitat types. Understanding these responses may improve future wildlife management strategies in urbanized landscapes and provide insight into how mesocarnivores adapt to fragmented habitats.

Chapter 2

MATERIALS AND METHODS

2.1 Study Area Description

This study was conducted in Newark, located within New Castle County in northern Delaware, associated with a blend of urbanization (suburban development and commerce) and a history of agriculture. Newark has hot, muggy summers and cold, often snowy winters. The 30-year average temperature (1991-2020) was 13.17 °C, and annual precipitation averaged 119.27 cm (National Centers for Environmental Information [NCEI] n.d.). The region is shaped by its position between the Piedmont and the Atlantic Coastal Plain, mixed with uplands and low-lying coastal plains. It includes patches of deciduous forest, grasslands, wetlands, agricultural fields, and pasture. Networks of small streams and drainage systems create riparian corridors with wet soils and dense vegetation, reflecting significant human influence and natural variation. This study was located at a 350-acre dairy farm complex on the campus of the College of Agriculture and Natural Resources (CANR) (*Figure 1*). It includes 85 tilled-crop acres, 30 paddies, six wetlands, and two woodlands, providing a mixed-use and dynamic landscape where mesocarnivores can move and exploit edges, corridors, and resource-rich patches.

Figure 1. Google Earth Aerial imagery illustrating the spatial distribution of study sites within a heterogeneous landscape for the activity of raccoon and red fox observed on the South Campus of the University of Delaware in Newark, Delaware, during summer 2025. Study areas outlined in yellow. Map created using QGIS.

2.2 Methods

Twelve Reconyx Hyperfire 2 game cameras were dispersed in four habitat types: 1) a non-forested riverine wetland with partial tree canopy and streams, 2) a riparian corridor, connected to the wetland, that runs through cropland, 3) a forested roadside wetland, and 4) a 35-acre successional urban forest fragment that was established in 1972 (left undisturbed) and has a dense understory. These research sites are separated by cropland, impervious structures, and roads. Seven of the cameras were placed in the woodlot along a pre-existing grid system, with three being forest interior locations,

and four cameras placed along the forest edge points to detect species presence near edge habitats and compare edge versus interior activity. Three cameras were positioned within riparian corridors, and one was positioned in both forested and non-forested wetland habitats. Each camera system was configured to record motion capture per five rapid-fire pictures throughout the day. Cameras did not rotate to different locations during data collection. Motion video was not deployed. No scent lures or bait were deployed to avoid spatial biases. Photographs were grouped into independent detection events using a 30-minute interval threshold, such that multiple images of the same species captured within 30 minutes at the same camera location were considered a single detection. All cameras were stationed on June 11, 2025, and checked weekly; they were collectively taken down in August 28th and 29th, 2025.

2.3 Data Analysis

I processed all camera trap images and recorded mesocarnivore presence using Time-lapse 2 (Greenberg 2016). I used R programming software to evaluate the effects of temporal and habitat variables on mesocarnivore detection for all statistical analyses (R Core Team 2021). In R with the package lme4, I constructed generalized linear mixed models (GLMMs) using a logit link function and a binomial error distribution. Detection (presence/absence) was modeled as a response variable for both the raccoon and red fox datasets, with time block (day [08:00-16:59], crepuscular [05:00-07:59 and 17:00-20:59], night [21:00-04:59]) and habitat group (fragmented

field vs. fragmented forest) included as categorical fixed effects. Hourly detections were divided by the number of cameras deployed within each habitat type (fragmented forest: n = 7; fragmented fields: n = 5) to standardize detection rates across unequal sampling effort. To account for repeated measures and spatial dependence, I used camera location as a random effect.

I developed a candidate set of models to evaluate the relative influence of temporal and habitat variables, which included null, single-variable, additive, and interaction models. Model selection was performed using Akaike's Information Criterion (AIC), where better model fits were indicated with lower AIC values. I considered models within $\triangle AIC \leq 2$ as competitive. I generated the top-ranked model for each species for predicted detection probabilities. I calculated predicted values and associated confidence intervals to visualize and assess temporal activity patterns and habitat relationships. In R, I generated tables using model-derived predictions and graphs in Microsoft Excel to illustrate differences in detection frequency across time blocks and habitat types.

Chapter 3

RESULTS

3.1 Raccoon Results

Between the species, model selection results indicated variation in the relative importance of temporal and spatial factors. Raccoons were detected in a total of 244 independent detection events across all camera sites. Detections were higher in the fragmented forest (n = 136) compared to fragmented fields (n = 108). For temporal activity patterns, I found that raccoons were most frequently detected at night (n = 154), followed by crepuscular periods (n = 85) (*Figure 2*). The model including time block as the sole categorical fixed effect received the strongest support based on AIC values, outperforming both habitat-only and interaction models (*Table 1*). This suggests that the primary driver of raccoon detection probability was temporal variation. This pattern was supported by my model estimates, with moderate detections occurring at crepuscular periods ($\beta = 3.0607 \pm 0.46$ SE) and the highest at night ($\beta = 3.8603 \pm 0.45$ SE), relative to daytime conditions.

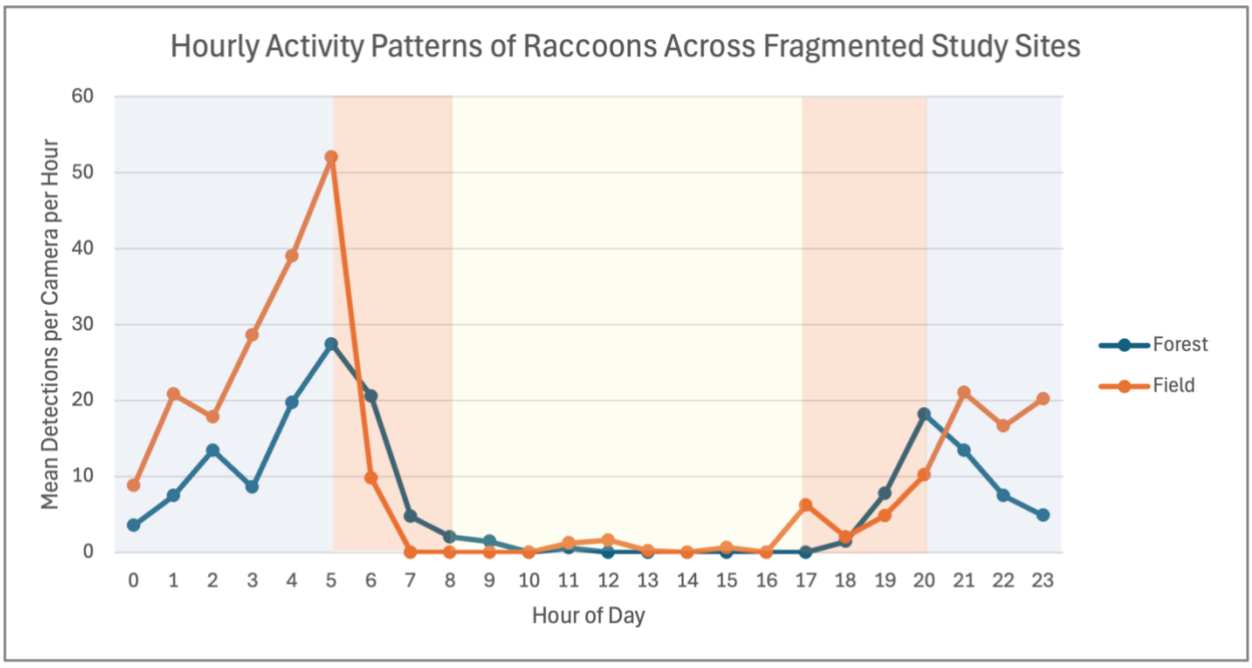


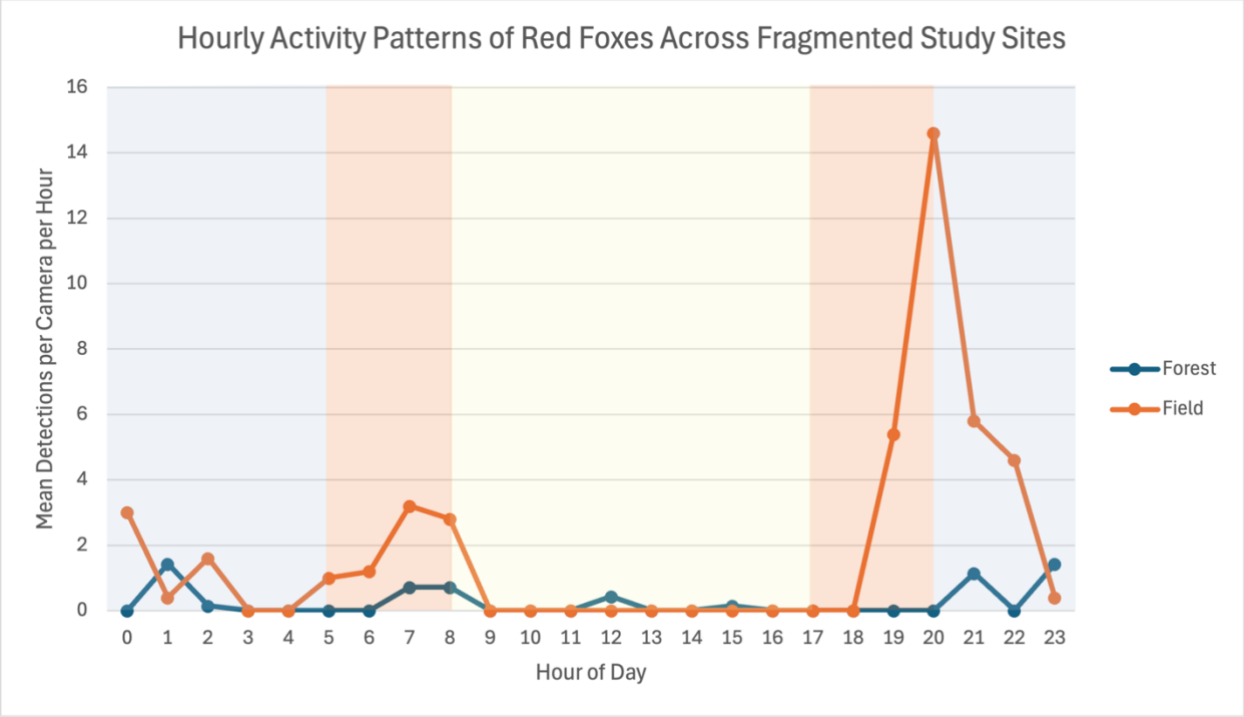
Figure 2. Hourly activity patterns of raccoons across fragmented field and forest habitats on the South Campus of the University of Delaware in Newark, Delaware, from a 2025 camera trap sampling effort, illustrating differences in detection frequency by hour and habitat type. Values represent the mean number of raccoon detections per camera at each hour of the day, calculated by dividing total detections within each habitat type by the number of cameras deployed (forest: n = 7; fields: n = 5). Raccoon detections were highest during night and crepuscular periods, with reduced daytime activity. Shaded regions represent daytime (yellow), crepuscular periods (orange), and nighttime (blue).

Raccoon Model Selection				
Variables	**df**	**AIC**	**DeltaAIC**	**Weight**
Timeblock	4	1,248.50	0.00	0.47
Habitat x Timeblock	7	1,249.05	0.55	0.35
Habitat + Timeblock	5	1,250.42	1.92	0.18
Null	2	1,451.41	202.91	0.00
Habitat	3	1,453.33	204.83	0.00

Table 1. Summary of Akaike's Information Criterion (AIC) model selection results for raccoon detection models across fragmented field and forest habitats on the South Campus of the University of Delaware in Newark, Delaware, from a 2025 camera trap sampling effort, including daytime, crepuscular, and nighttime time blocks.

3.2 Red Fox Results

Red foxes were detected in a total of 43 independent detection events across all sites. They were more frequent in fragmented fields (n = 33) than in the fragmented forest (n = 10), unlike raccoons. The temporal activity was also primarily nocturnal (n = 20) and crepuscular (n = 21), with few daytime detections (n = 2) (*Figure 3*). Red fox detection probability was best explained by the interaction between habitat group and time blocks, which had the lowest AIC value among candidate models (*Table 2*).



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Red Fox Model Selection				
Variables	**df**	**AIC**	**DeltaAIC**	**Weight**
Habitat x Timeblock	7	401.19	0.00	0.92
Habitat + Timeblock	5	406.40	5.21	0.07
Timeblock	4	410.81	9.62	0.01
Habitat	3	424.39	23.20	0.00
Null	2	428.81	27.62	0.00

Table 2. Summary of Akaike's Information Criterion (AIC) model selection results for red fox detection models across fragmented field and forest habitats on the South Campus of the University of Delaware in Newark, Delaware, from a 2025 camera trap sampling effort, including daytime, crepuscular, and nighttime time blocks.

Red fox activity varied both temporally and spatially, with differences in temporal variation by habitat type. In forest habitats, detection probabilities generally increased from day to night ($\beta = 1.109 \pm 0.82$ SE), suggesting a positive temporal effect, however there was no difference between crepuscular and night detections in the forest habitat. The relatively large standard error and lack of statistical significance indicate that these trends should be interpreted cautiously. In the field and smaller fragments, there were fewer detections during the day than in the forested habitat ($\beta = -14.92 \pm 29.94$ SE), but more detections in the crepuscular ($\beta = 17.57 \pm 29.95$ SE) and nighttime frames ($\beta = 16.14 \pm 29.94$ SE). Across time blocks, a large standard error relative to the coefficient suggests considerable uncertainty and low precision surrounding this habitat effect. My results demonstrated that temporal factors

primarily influenced raccoon activity, whereas red fox activity exhibited both temporal and habitat-dependent variation. These species-specific responses were highlighted by environmental structure and temporal conditions within the study areas.

Chapter 4

DISCUSSION

4.1 Species-Specific Differences

Using both temporal and spatial behavioral patterns, my study examined how habitat fragmentation affects mesocarnivores' responses and adaptations. The results indicated species-specific differences in how raccoons and red foxes utilize a changed landscape, highlighting the importance of behavioral flexibility in fragmented environments. There was no strong habitat effect for raccoons, suggesting that they exhibit similar behaviors in both of the tested habitats. This species' temporal pattern is consistent with research demonstrating predominantly nocturnal and exploitative behaviors of raccoons in a wide range of environments, including human-modified and edge-dominated landscapes (Prange et al. 2004). Their flexibility in habitat use supports my hypothesis that raccoons readily adapt to fragmented systems by utilizing available resources across habitat boundaries, rather than specializing within a single habitat type (Egan, 2018; Prange et al., 2004).

The temporal and spatial behavior of red foxes exhibited a more habitat-specific behavior compared to raccoons, likely responding to differences in resource availability, cover, or prey distribution associated with particular habitat types. In contrast to previous studies reporting that red foxes have a general preference for woodland over wetlands, the difference in this study may reflect regional variation in habitat availability, prey distribution, or the influence of habitat landscape within my

study site (Fiderer 2019). The stronger association with wetland and fragmented field habitats supports the selective habitat use of red foxes within a fragmented landscape, where red fox presence is influenced by landscape structure and disturbance gradients, with positive associations with vegetated habitats and negative associations with urban and cattle proximity (Alexandre et al. 2020). Their increasing detection probability from day to night aligns with known crepuscular and nocturnal tendencies in highly populated areas to limit human-wildlife interactions (Black et al. 2024).

4.2 Limitations and Future Direction

A key assumption of my study was that detection probability remained relatively consistent across habitats and time blocks. However, this assumption may have been partially violated due to differences in vegetative densities and visibility. The forest site had more visual obstruction than the wetland and riparian habitats, which may have decreased the likelihood of detecting mesocarnivores on camera traps independent of true habitat preference. Camera placement may also have influenced species detectability across sampling locations. Sample size also represented a limitation of this study, particularly red fox detections, which were comparatively low across several habitat and time block combinations. As a result, rather than exclusively representing differences in habitat use or activity patterns, my findings may reflect variation in detectability. Future studies could improve the statistical power by increasing the number of camera trap sites, extending the sampling duration for

seasonal coverage, and incorporating additional habitat variables related to edge density and human disturbance.

4.3 Conclusion

Nonetheless, both temporal and spatial dimensions should be considered when evaluating wildlife responses to habitat fragmentation. Species-specific strategies emerge because mesocarnivores cannot respond uniformly to environmental change, reflecting the contrasts in ecological flexibility and habitat preferences. Finer-scale habitat classifications, including explicit edge metrics, can further clarify the role of habitats in shaping mesocarnivore behavior.

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