Influence of woody cover and other landscape characteristics on Northern raccoon (*Procyon lotor*) occupancy

by

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B.S., Pittsburg State University, 2021

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Horticulture and Natural Resources
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2024

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Abstract

Northern raccoons (*Procyon lotor;* hereafter raccoon) are generalist omnivores prevalent across North America. Raccoons occur in a variety of landscapes, especially those including woody areas. Increases in woody cover over the last century may have benefited northern raccoons. My first objective was to evaluate the influence of woody cover and other landscape drivers influencing raccoon occupancy in the contiguous United States. My second objective was to evaluate raccoon occupancy on a smaller scale within Kansas where grasslands are being lost to woody encroachment.

To assess continental-scale patterns, I used camera trap data from Snapshot USA from 2019–2021. I analyzed data from 4,512 camera trap survey points and linked raccoon occupancy to land cover variables derived from the 2021 National Land Cover Database (NLCD; Dewitz 2023), 2023 National Hydrography Database (NHD; USGS 2023), and 2022 Rangeland Analysis Platform (RAP; Jones et al. 2018) tree layer. Occupancy models revealed interactions between the proportion of woody cover and the proportion of cropland land use within 1 km was most parsimonious. This effect of woody cover was positively influenced by the proportion of cropland. Occupancy was greatest when there was a proportion of woody cover at 0.10 and a proportion of cropland at 0.90 (β_{woody} = 0.632, SE = 0.119; β_{crop} = 4.121, SE = 0.715; $\beta_{woody:crop}$ = 1.905, SE = 0.359). Additionally, raccoon occupancy is greater in areas closer to water (β = -0.722, SE = 0.0773). My results indicate woody cover may increase raccoon use, particularly in landscapes with cropland. Raccoons provide many positive and negative impacts to ecosystems and may benefit from altered cropland landscapes that provide minimal woody cover.

Building on these findings, I aimed to find if similar patterns of raccoon occupancy are observed in woody encroached areas specifically within Kansas. The invasion of woody species

is a major threat to grasslands and grazing operations. Woody species invasion not only poses challenges for grasslands and grazing operations but also contributes to a widespread decline in grassland bird species. The presence of woody plants may benefit nest predators like raccoons. My objective was to relate woody cover to raccoon occupancy in landscapes that can provide inference on how woody encroachment could alter raccoon distributions. I used camera traps and remotely sensed data to evaluate the influence of landscape composition on raccoon occupancy in Kansas. I conducted a stacked single-season occupancy analysis to identify relationships with site covariates. My most-supported single-season occupancy model included the additive influence of proportion of grassland within 1 km and distance to water and suggested that occupancy probabilities were lower at survey points with greater proportions of grassland and farther from water sources ($\beta_{intercept}$ = -1.89, SE = 0.25, β_{grass} = -1.072, SE = 0.22, $\beta_{distwater}$ = -0.58, SE = 0.24; Fig. 2). Another competitive model included proportion of cropland within 1 km and proportion of woody cover within 1 km in an additive model and suggested that raccoon occupancy increased with woody cover and cropland ($\beta_{intercept}$ = -1.81, SE = 0.24, β_{crop}= 1.13, SE = 0.22, β_{woody} = 0.63, SE = 0.20). My results suggested a positive influence of woody cover, proximity to water, croplands, and a negative influence of grassland on raccoon occupancy. Consequently, raccoons may derive benefits from woody encroachment in Kansas. Conserving grassland areas may decrease raccoon occupancy and in doing so may reduce the use of areas that are important for landowners and other species and may then ease the human-wildlife conflicts that exist for this species with the potential for disease spread and damage to crops as well as benefit ground nesting birds.

Table of Contents

List of Figures vi
List of Tables viii
Acknowledgments x
Dedication xii
Chapter 1 - Land cover effects on habitat use by Northern raccoons (*Procyon lotor*) across the United States 1
- Introduction 1
- Methods 4
- Results 7
- Discussion 8

Chapter 2 - Woody encroachment expands Northern raccoon (*Procyon lotor*) distributions into remaining grassland landscapes 17
- Introduction 17
- Methods 19
- Results 23
- Discussion 25

References 41
Appendix A - Kansas Camera Trap Raccoon Images 50

List of Figures

Figure 1.1. Study area of Snapshot USA 2019, 2020, and 2021 within the contiguous United States of America with landcover type (NLCD 2021) including wooded areas (woody), shrubland/scrubland (shrub/scrub), grassland (grass), cropland (crop), and developed areas (development), and other landcover types not evaluated (other). A single, unbaited camera trap was set and assessed at each study site (n = 4,512) across three years and the resulting data were used to evaluate raccoon (*Procyon* lotor) occupancy among landcover types..... 13

Figure 1.2. The influence of woody cover within 1 km interacting with different proportions of cropland (Low (0.0); top, Medium (0.45); middle, High (0.90); bottom) within 1km on site occupancy probabilities for raccoon (*Procyon lotor*) in the contiguous USA. I assessed site (n = 4,512) occupancy by raccoons using camera traps distributed in the contiguous USA across 3 years (2019, 2020, and 2021). Occupancy probabilities (solid colored line) and 95% confidence intervals (colored shaded) were estimated from my best supported, single-season occupancy model. 14

Figure 1.3. The influence of distance to water (m) on site occupancy probabilities for raccoon (*Procyon lotor*) in the contiguous USA. I assessed site (n = 4,512) occupancy by raccoons using camera traps distributed in the contiguous USA across 3 years (2019, 2020, and 2021). Occupancy probabilities (solid colored line) and 95% confidence intervals (colored shaded) were estimated from my best supported, single-season occupancy model. 15

Figure 2.1. Study area of Kansas, USA with Kansas study sites (Harold & Olympia Lonsinger Sustainability Farm and private property (HOLSF): blue points, Saline Experimental Ranch (SER) & Hadley Foundation Ranch (HFR): white points, Kirwin National Wildlife Refuge (KNWR): gray points, Konza Prairie Biological Station (KONZA): purple points, Fort Riley Military Installation (FRMI): green points) with the NLCD and EarthDefine reclassified layer landcover types: cropland (brown), grassland (yellow), woody cover (green), and all other landcover types (red). A single, unbaited camera trap was set and assessed at each study site (n = 210) across Kansas and the resulting data were used to evaluate raccoon (*Procyon* lotor) occupancy among landcover types from 03 January 2023 - 17 July 17, 2023, and 06 June 2024 – 25 July 2024. 30

Figure 2.2. The influence of distance to a water source and proportion of grassland on occupancy of raccoon (*Procyon lotor*) in Kansas, USA. I evaluated raccoon occupancy by using camera traps (n = 210) placed on Fort Riley Military Reservation, Konza Prairie Biological Station, and areas within north-central Kansas during the winter 2023, summer 2023, and summer 2024. Predicted occupancy probabilities (solid lines) and 95% confidence intervals (light colored fill) were estimated using the best supported model based on AIC_c (grassland + distance to water). 31

Figure 2.3. The influence of proportion of woody cover within 1 km and different proportions of cropland (Low; top, Medium; bottom left, High; bottom right) within 1km on raccoon (*Procyon lotor*) occupancy in Kansas, USA. I evaluated raccoon occupancy using camera traps placed on Fort Riley Military Reservation, Konza Prairie Biological Station, and areas within north-central Kansas during the winter 2023, summer 2023, and summer 2024. Predicted occupancy probabilities (solid lines) and 95% confidence intervals (light colored fill) were estimated using the competitve model (woody cover + cropland). 32

Appendix Figure A.1. Picture of Northern raccoon (*Procyon lotor*) caught on camera traps in Kansas 50

Appendix Figure A.2. Picture of Northern raccoon (*Procyon lotor*) caught on camera traps in Kansas 50

Appendix Figure A.3. Picture of Northern raccoon (*Procyon lotor*) caught on camera traps in Kansas 51

Appendix Figure A.4. Picture of Northern raccoon (*Procyon lotor*) caught on camera traps in Kansas 51

Appendix Figure A.5. Picture of Northern raccoon (*Procyon lotor*) caught on camera traps in Kansas 52

List of Tables

Table 1.1. Candidate occupancy models of raccoon (*Procyon lotor*) occupancy from Snapshot USA data. Single-season occupancy models were constructed using the R package "unmarked" (Kellner et al. 2023). K = no. of parameters, ΔAICc = the difference in AICc (Akaike's Information Criterion adjusted for sample size) relative to smallest value, AICc weight = predictive weight that the model carries, -2 log L = log-likelihood value. p = detection probability. Covariates: interactive model with proportion of woody cover within 1km & proportion of cropland within 1km buffer (woody_crop_inter), additive model with proportion of woody cover within 1km & proportion of cropland within 1km buffer (woody_crop_add), proportion of cropland within 1km buffer (crop), proportion of shrubby/scrubby areas within 1km (shrub_scrub), distance (m) to nearest water source (water), proportion of developed areas within 1km (develop), proportion of other landscape features not evaluated within 1km buffer (other), proportion of grassland within 1km buffer (grass), proportion of woody cover within 1 km buffer (woody),and the null model (.). 16

Table 2.1. Single-season occupancy models describing detection and use by raccoons (*Procyon lotor*) across study sites (n = 182) within Kansas, USA. I used camera trap data to document the presence and absence of raccoons in the summer (2023, 2024) and winter (2023) seasons. Woody, Crop, and Grass = proportions of landcover types within 1 km buffer surrounding sites; Water = Euclidean distance (m) to nearest water source; Month = month that cameras were active (January, February, May, June, July); Site = different location that cameras were active (Harold and Olympia Lonsinger Sustainability Farm Hadley Foundation Ranch, Fort Riley Military Reservation, Saline Experimental Range, Kirwin National Wildlife Refuge, Konza Prairie Biological Station). Intercept model and Null model were also provided. Models were ranked from lowest to highest AIC_c values (Akaike's Information Criteria, adjusted for small sample size). K = number of parameters per model; ΔAIC_c = Difference in AIC_c values of lowest AIC_c value model and the AIC_c value of the model being assessed; w_i = model weight; LL = Log likelihood........ 33

Table 2.2. Mean estimates and standard deviation of the proportion of woody cover, proportion of cropland, and proportion of grassland within 1km of cameras for each study site and mean estimate and standard deviation of daily raccoon detections per camera. SD = standard deviation. 39
Table 2.3. Literature comparison of the use of cropland. Time of Year = the month in which the study took place (with winter and summer seasons separated into two rows), State = the state or province in which the study took place. Method = the method of detecting raccoons (*Procyon lotor*). Use of cropland = whether there was a positive (+) or negative (-) use of cropland found in the literature. 40

Acknowledgments

This project wouldn’t have been possible without the support, dedication, and expertise of the individuals listed below.

I want to vehemently thank the Department of Horticulture and Natural Resources, Kansas State University, and the McIntyre Stennis funds for their financial support. I want to thank all Snapshot USA contributors and creators for these amazing datasets I was able to use. I want to thank the creators of the Rangeland Analysis Platform for the use of their data. I want to thank the United States Geological Survey for the access to many of their datasets. The scientists that contributed to these datasets have made my life and the life of many other scientists easier with these resources. I cannot state enough how grateful I am for their hard work and dedication in producing and providing these datasets.

I want to thank the Kirwin National Wildlife Refuge, The Hadley Foundation, Craig Poore and Poore family and Dr. Keith Harmoney for their use of the land and support for this project. Without these organizations and individuals, this project would not have succeeded.

Many individuals contributed to my growth at Kansas State University. I want to thank my fellow lab mates (both old and new). I thank my committee members Dr. Dan Sullins, Dr. Adam Ahlers, and Dr. Tania Kim for their consistent encouragement, helpful perspectives, and incredible support. I am blessed and immensely grateful to have had two advisors, Dr. Christine Rega-Brodsky & Dr. Dan Sullins, that genuinely care for my development not only as a good scientist but as a good person. Both individuals placed their trust in me and gave me all the support and resources I could ask for when pursuing my career in wildlife ecology. I cannot overstate how much their mentorship has meant to me. I was lucky to meet and establish friendships with many fellow Kansas State graduate students and colleagues, and I want to thank all of them for their support and friendships.

I want to thank my friends and family for their love and support. My brother, Cameron, for being there for me always and making me laugh till I cry. My church family for keeping me ground in my faith. These people watched me grow not only in Manhattan as a scientist but as a godly man throughout my life. I'm so grateful for their love and support.

Lastly, I want to thank my beautiful wife, Kristen. I am so thankful for her faith in me. I would not be where I am now without her and her love and trust in me. I am overwhelmed with love and gratitude for the support she showed me through the good times and the bad times. You have persevered right next to me. I am so proud and honored to be your husband.

Dedication

I dedicate this thesis to two people. First, I dedicate this to my wife, Kristen. My work is not possible without her sacrifice and support for me. I will always be so thankful that she chose to follow me on this journey. Lastly, I dedicate this thesis to my Lord and Savior, Jesus Christ. My faith was crucial to my success and the success of this project. All the glory and honor go to Him. My faith in Jesus grounded me and allowed me to experience peace in the harder times of working on this project. I am immensely thankful for His faithfulness and love.

Chapter 1 - Land cover effects on Northern raccoons' occupancy (*Procyon lotor*) in the United States

Introduction

Throughout the U.S., landscapes are undergoing transformation, with increasing woody encroachment in grasslands and open areas (Furtado et al. 2021). Forest cover in the U.S. is also changing in other areas, including changes in species composition and some conversion to row-crop agriculture (Thompson et al. 2013, Riitters et al. 2020). Over the past century, U.S. landscapes have changed dramatically, with trees returning to areas previously clearcut in the Eastern U.S. and woody species increasingly invading grasslands. The invasion in grasslands is driven by altered ecological drivers and climate that favor woody expansion (Van Auken 2009, Archer et al. 2017, Cazzolla Gatti et al. 2015). In the western U.S., tree cover has increased 50% over the last 30 years, with over 25% in U.S. rangelands (Morford et al. 2022). This phenomenon, often termed 'woody encroachment,' is linked to declines in grassland wildlife, particularly in the Great Plains (Coppedge et al. 2001, Donovan et al. 2024). The effects on grassland birds are particularly well-documented and include habitat loss (Lautenbach et al. 2017), increased nest parasitism (Jensen & Cully 2005), and heightened presence of nest predators (Davis et al. 2019, Archer et al. 2017).

Simultaneously, cropland conversion has continued at a rate of over one million acres per year (2008-2016; Lark et al. 2020). While forest-dwelling mammals may benefit from expanding woody cover (Furtado et al. 2021), the broader impact of both woody expansion and cropland conversion on various species, including mesopredators, remains an active area of research. To contribute to this understanding, we aim to analyze mesopredator responses to these landscape changes, especially woody expansion, across the U.S., furthering our knowledge of their ecological effects through our target species, the northern raccoon.

Widespread distributions, adaptability to human environments, and the omnivorous diet of Northern raccoons (*Procyon lotor*, hereafter 'raccoons') make it challenging to identify ecological niche constraints for this species. Raccoons have a diverse diet including fruits, nuts, insects, small mammals, aquatic amphibians and invertebrates like frogs and crawfish. Their diet is not restrictive to wild resources and they can inhabit urban and rural areas and feed on crops and human refuse. Raccoons need habitat cover such as hollow trees, abandoned burrows, or abandoned human structures for shelter. They also require access to permanent water sources such as rivers or ponds. Woody cover provides many habitat needs through hard and soft mast as food, tree cavities as shelter, and access to water typically found near wooded areas (Grasel et al. 2021, Butt et al. 2021). Previous studies highlight a positive relationship between raccoons and woody vegetation (Dijak & Thompson 2000, Hill et al. 2023c, Chamberlain et al. 2007, Henner et al. 2004). Raccoons are known to favor areas with greater woody vegetation (Pedlar et al. 1997). However, we lack an understanding of how the composition of woody cover in landscapes influence raccoon occupancy and have limited knowledge of minimum woody cover thresholds that may limit occupancy by raccoons at a national scale. This is a knowledge gap that can be addressed to manage this species effectively and with currently available nationwide camera trapping data.

Trees serve multiple purposes for raccoons throughout the year by providing food and cover. Trees can be used as escape cover when near fencerows and habitat edges (Pedlar et al. 1997). Trees also function as daily resting places with concealment from predators and various weather conditions (Hill et al. 2023a, Beasley et al. 2007a). During the spring and summer female raccoons often inhabit tree cavities for pregnancy and parturition (Rabinowitz & Pelton 1986). The selection of dens by raccoons is closely linked to the availability of nearby forage resources (Henner et al. 2004). Throughout the year, trees are used by raccoons for foraging (Johnson 1970). Woody plants provide essential hard and soft mast fruits as forage that raccoons rely on for nourishment (Smith & Kennedy 1987). Tree cover benefits raccoons by providing denning sites with tree cavities, a food resource in seasons when foraging for insects and other food sources are limited, and they provide escape cover from predators (Owen et al. 2015a, Greenwood 1982, Owen et al. 2015b).

Additionally, proximity to a water source influences raccoon habitat use (Heske & Ahlers 2016). Raccoons use habitats close to water bodies for hydration and for their plentiful food resources such as aquatic invertebrates, fish, and amphibians (Troyer et al. 2014). Wetland habitats serve as a foraging and resting ground for this species (Milling & Gehrt 2023). Raccoon survival and reproductive success can be influenced by the access to water sources. Areas near water offer better shelter and foraging opportunities that are crucial for raising young (Troyer et al. 2014). Tree cover and proximity to water sources can be crucial factors in raccoon occupancy (Baldwin et al. 2006). Given the multifaceted benefits that trees provide to raccoons, it is crucial to understand how changes in tree cover and landscape patterns influence raccoon occupancy over broad spatial scales.

My objective was to evaluate the influence of woody cover and other cover types on raccoon occupancy. I hypothesized that a baseline threshold of woody cover in a landscape may be needed for raccoon occupancy. I hypothesized that raccoon occupancy would be influenced by the presence of water based on previous literature (Chamberlain et al. 2007, Baldwin et al.

2006, Hill et al. 2023b). I hypothesized that raccoon occupancy would be influenced by cropland and/or would interact with woody cover (Beasley & Rhodes 2008, Newbury & Nelson 2007).

Methods

First, I assessed the nationwide Snapshot USA 2019, 2020, and 2021 campaign data (Cove et al. 2021, Kays et al. 2022, Shamon et al. 2024). Data collection periods spanned from 17 August 2019 through 24 November 2019, 14 July 2020 through 3 December 2020, and 21 July 2021 through 24 December 2021. The Snapshot USA dataset included detections from 4,512 unbaited camera-trap survey points distributed across the contiguous United States deployed in spatially segregated arrays (Fig. 1.1). The study area encompassed the entire contiguous United States spread among 48 states and the District of Columbia. I use the term study sites to describe camera arrays in which the data was collected by the same camera trapper. The camera trap survey points are the individual camera locations within arrays. Cameras were placed 0.2–5.0 km away from another camera within each array and were deployed ~ 30-50 cm off the ground. Each study site (camera trap array) was set to achieve a minimum of 400 camera nights (cameras * # nights) of data during the months of September and October (mean # of camera trap nights per camera trap survey point = 38, range = 7 - 142). All contributors cameras were picked up after the minimum of 400 camera nights was achieved and then all contributors uploaded the camera trap data from SD cards to a data management system (www.wildlifeinsights.org, emammal.si.edu). I separated raccoon observations from the larger dataset to assess their occupancy. My survey period was from the 28th (second week of July) to the 52nd (last week of December) week of all three years to ensure inclusion of all active cameras. I excluded camera trap survey points from Alaska and Hawaii based on published literature on the native distribution of the raccoons showing they do not occur in these areas

(*Procyon lotor*; Latham 2008). Raccoons have expanded into Southern Canada but have yet to establish a native population in Alaska. There are no native populations in Hawaii. I created detection histories from the subset of the Snapshot USA stacked data using the R statistical software (R core team 2024). I then created a data frame detailing weekly detections during each deployment period across all camera trap locations. I removed outlying deployments that only had one week of detections to allow for evaluating detection probability among repeated weekly survey periods. I then used the weekly detections to link raccoon occupancy to different landscape variables.

Then, for my analysis, I sought to relate raccoon occupancy to important landscape variables based on *a priori* hypotheses (Fig. 1.2). I obtained landcover variables from the 2021 National Land Cover Database (NLCD) at a 30-meter resolution, the 2023 National Hydrography Database (NHD) at a 10-meter resolution, and the 2022 Rangeland Analysis Platform (RAP) at a 30-meter resolution. I used RAP because NLCD lacked the inclusion of woody areas detected by RAP. I quantified cover types by using NLCD layers to identify grassland and cropland and other cover types and I used RAP to identify tree cover surrounding each camera site. I quantified proximity to water resources from the 2023 National Hydrography Database (NHD) to get locations of available water near my survey points.

I acquired percentages of woody cover within each pixel from the 2022 Rangeland Analysis Platform (RAP). Woody cover values ranged from zero to one hundred. The RAP layer used satellite imagery to provide woody cover data which has known issues with the misidentification of irrigated cropland for woody cover. To improve the woody cover layer, I removed all areas falling in cropland based on NLCD (2021). I then created a binary raster layer from the woody cover layer by identifying areas as woodland that had ≥6.7 % woody cover based on the root mean square error (RMSE) of the woody layer (Jones et al 2018). I used the 1km scale because it better aligns with estimates of raccoon space use (Hill et al. 2023c, Palomo-Munoz et al. 2024, Wait & Ahlers 2020). I then combined the woody cover layer with the grassland, cropland, shrubland/scrubland, developed areas, and all other cover types (open water, perennial snow/ice, barren land, etc.) using the raster calculator function in ArcGIS Pro. To quantify woody cover, grassland, cropland, shrubland/scrubland, developed areas, and other cover types surrounding each camera I calculated the proportion of each landcover variable within the 1 km buffer.

I used the R package 'unmarked' to model raccoon occupancy in relation to my landscape covariates (Kellner et al. 2023; Fiske & Chandler 2011). I standardized my continuous covariates prior to fitting models. I fit a single season occupancy model holding occupancy constant to provide mean estimates of occupancy and detection probability from my null model using 'occu()' functions in the 'unmarked' package (Royle & Dorazio 2009, Kellner et al. 2023).

I assumed there were no variables that influenced detection probability and used the intercept only model. I then fit single season occupancy models by keeping detection probability constant and evaluating the influence of our hypothesized landscape covariates on occupancy. I fit ten single season occupancy models which included woody cover within 1km, cropland within 1km, grasslands within 1km, shrubland/scrubland within 1km, developed areas within 1km, other landcover types (perennial snow/ice, barren land, etc.), distance to water, and the additive and interaction effects of the woody cover and cropland variables.

Lastly, I evaluated model performance using AIC_c (Akaike Information Criterion adjusted for small sample sizes) to rank the models based on parsimony (Burnham & Anderson 2002) and select the best supported model for evaluation. I evaluated the ΔAICc values of each model and identified my best supported model (ΔAICc $\leq$ 4.00) using an information-theoretic approach (Burnham & Anderson 2002, Arnold 2010, Sutherland et al. 2023). I evaluated the best supported occupancy model and any competitive models by looking at the beta coefficients for overlap with zero at the 95% confidence interval. I used the R statistical software to run all models and to calculate AIC_c values for each model (R core team 2024).

Results

I analyzed 4,512 camera trap survey points spanning 48 states and the District of Columbia (Fig. 1.1). The naïve occupancy estimate was 0.20. The total number of trap nights surveyed was 172,425 (mean surveys per camera = 6.11 weeks, range = 2 – 21 weeks). The total number of images with at least one raccoon detection over the survey period was 38,211. The mean number of raccoon detections per camera per week was 1.35 (SD = 4.38, range = 0–193). I used the null model for detection (p = 0.109, SE= 0.005).

The interaction between the proportion of woody cover within 1 km and the proportion of cropland within 1 km was the best supported single season occupancy model and carried 100% of the model weight (Table 1.1). Occupancy increased with woody cover and cropland within 1km and was greatest in landscapes having 0.10-0.20 proportion of woody cover and 0.45-0.90 proportion of cropland within 1km of camera sites (β_{woody} = 0.632, SE = 0.119, $\beta_{cropland}$ = 4.121, SE = 0.715, $\beta_{woody*cropland}$ = 1.905, SE = 0.359, Fig. 1.2). At sites with lower proportions of cropland, increased proportions of woody cover had less of an impact on raccoon occupancy relative to sites $\geq$ 0.45 proportion of cropland. For example, raccoon occupancy only slightly increased with the proportion of woody cover in landscapes having no cropland (Fig. 1.2). As the proportion of cropland increased, the probability of occupancy was greater at lower levels of woody cover and the slope increased more drastically as woody cover increased. For example, when the proportion of cropland was 0.90 the probability of occupying the study areas was 99% at a woody cover proportion of just 0.17 (Fig. 1.2).

The distance to water occupancy model ($\beta_{distwater}$ = -0.722, SE = 0.077) was related to raccoon occupancy as I had predicted. However, the model was not well supported based on AICc. The distance to water source model was not well supported based on AIC_c but did not overlap zero at the 95% confidence interval. As the distance to a water source increased raccoon occupancy decreased. Occupancy sharply decreased between 2000 and 4000 meters from a water source (Fig. 1.3).

Discussion

My results indicated that landscapes composed of a large proportion of cropland (0.9) and a low proportion of woody cover (0.1) can have the highest probability of occupancy by raccoons. This contrasts with other studies in which agricultural areas were not found to be an important predictor for raccoon use (Barding & Nelson 2008). The interaction between cropland and woody cover may also play an important part in understanding raccoon use of different landscapes. Raccoons occupy areas with greater proportions of woody cover because of the important resources' trees provide (Zamuda et al. 2022, Owen et al. 2015b). Greater occupancy of croplands could be due to the time in which the cameras were deployed. Harvest season for many crops overlapped during the months in which the cameras were active (USDA 2024). Therefore, the abundance of resources from the harvest season and the protection and resources from the wooded areas likely provided raccoons with suitable foraging adjacent to shelter. I did not determine a woody cover baseline threshold needed for raccoon occupancy. Though I observed woody cover proportions as low as 0.10-0.20 could support high raccoon occupancy when in landscapes having a cropland proportion of 0.45 or higher.

Clear linkages of raccoon occupancy to woody cover are needed for understanding how modern landscape changes have impacted raccoon populations. There have been widespread changes over the last 100-200 years in woody cover post European settlement and widespread suppression of fire beginning in the early 1900s. In the eastern regions of the US, woody species have largely re-established after extensive clearcutting in the early 1900s (Nowacki & Abrams 2008). As the regrowth of these woody species moved westward, woody encroachment arose as a process in which these species could spread throughout the Great Plains due to changes in ecological drivers (Hoff et al. 2018, Ling et al. 2023). In the Great Plains, changes including fire suppression and climate change can favor the encroachment of woody species into former grasslands (Wilcox et al. 2022, Londe et al. 2022). Changes in fire regimes have allowed for woody encroachment in many ecosystems since fire-sensitive woody plants will spread without fire to suppress them (Ling et al. 2023, Sayedi et al. 2024). Increased CO_2 levels due to climate change can favor C3 species which include most woody plants and can enhance their photosynthetic efficiency and growth rates relative to C4 grasses (Hager et al. 2016, Sage et al.1989).

Based on my results, such landscape changes in woody cover could benefit raccoons at landscape scales particularly in areas where woody species have become more prevalent adjacent to cropland. Increased occupancy in wooded areas suggests that raccoons could benefit from low levels of woody encroachment in agricultural landscapes. Due to increased woody cover in several parts of the U.S., it is possible that raccoons may occupy landscapes that were not previously occupied.

The encroachment of woody plants may allow for increased forage opportunities for raccoons including the predation of ground nesting bird nests. Raccoons can prey upon ground-nesting birds in more upland and grassland areas (Fiderer et al. 2019). Therefore, my results suggest that woody encroachment could increase the use of adjacent cover types by raccoons due to increased tree cover. This increased occupancy in landscapes with increasing woody cover could potentially lead to increased nest predation of ground nesting birds potentially including wild turkey (*Meleagris gallopavo*), northern bobwhite (*Colinus virginianus*), ring-necked pheasants (*Phasianus colchicus*), and mallards (*Anas platyrhynchos*)).

When in proximity to wooded areas, croplands can benefit raccoons by providing them with abundant forage and shelter. In the contiguous USA, crops such as corn, soybeans, and wheat can overwhelm the landscape (Spangler et al. 2020). Over the past several years, there has been a trend towards consolidation with larger farms operating more cropland. This shift in farming has led to more extensive monocultures such as soybeans and corn, which can provide benefits for raccoons as they forage for the harvest crop leftovers (Hannah et al. 2020). Raccoons are opportunistic foragers and will exploit the abundant forage in croplands including the insects and small mammals that thrive in these cropland environments. Additionally, raccoons often use croplands as travel corridors and foraging grounds, especially near water sources (Newbury & Nelson 2007). This seasonal abundance of food helps raccoons store energy reserves for the winter months, making croplands beneficial for raccoons during the fall (Hill et al. 2023a). Therefore, land conversion to row-crop agriculture may influence the occupancy of raccoons and increase the use of those cropland landscapes especially if they include proportions of woody cover.

The presence of water impacted raccoon occupancy (Fig. 1.4). Raccoon occupancy was greater in areas closer to water. My results align with other published research demonstrating the importance of proximity to water for raccoon use (Heske & Ahlers 2016, Milling & Gehrt 2023).

Distance to water is an important predictor of raccoon habitat due to the critical need of water for hydration and food resources found near water sources. However, my results showed that the proportion of woody cover and cropland had a stronger influence on raccoon occupancy than water at this broad nationwide scale (Table 1.1).

Though raccoons are a generalist species, this species has been known to benefit from foraging on the edges of woody areas, fencerows, and mowed trails (Barding & Nelson 2008). The configuration of these woody cover areas and croplands were not evaluated in my study. Therefore, it is imperative that further studies look at the impact of connectivity among diverse landcover types with mesopredators such as raccoons. I expect that in addition to having at least a proportion of 0.10 woody cover in a 1km radius landscape that connectivity of these wooded areas to larger wooded areas and wooded drainages may impact raccoon occupancy.

Raccoons may be a nuisance; nonetheless, raccoons are a native species and do provide many ecosystem services. They play an important role in the environment. Raccoons prey on a multitude of pests ranging from insects to rodents which help stabilize populations (Troyer et al 2014). Raccoons also consume carrion, which helps in the decomposition process and reduces the spread of disease (Bartoszewicz et al. 2008, DeVault et al. 2011). In some states raccoons are prey for larger predators such as mountain lions (*Puma concolor*;Wilckens et al. 2016). They also aid in plant propagation through the spreading of plant seeds which helps to maintain biodiversity (Stanton et al. 2022). Raccoons have also provided some economic value. Historically, this species contributed to the economy through fur harvesting (Newbury & Nelson 2007).

Each positive benefit that raccoons have can be viewed as an inverse negative effect. For example, raccoons are good dispersers of seeds which can have a negative effect when the seeds of woody plants are spread into grasslands (Moore & Dittel 2020, Cordero et al. 2023). Raccoon's role as a decomposer is a positive benefit but with the increased population of these species, they are more often the carrion that needs decomposed (Stanton et al. 2022, Bartoszewicz et al. 2008, DeVault et al. 2011). While they are a prey species in the states that have larger predators, in states that don't have larger predators they can become too abundant and require humans to control populations (Troyer et al. 2014, Oe et al. 2020). Historically raccoons carried economic value in the fur harvest trade, but as the value of raccoon pelts decreased, trappers shifted their focus to more valuable species which allowed for larger populations of raccoons today (Bauder et al. 2020). Raccoons provide many positive and negative impacts to our ecosystem and therefore we should take careful consideration when managing this species.

My results indicate a need for further research on the effects of raccoon activity in landscapes with woody cover and cropland. Raccoons occupying these areas may impact these ecosystems through crop damage and potential predation on ground-nesting bird nests. Future studies could evaluate these. to deepen our understanding of this species' effects on the landscape.

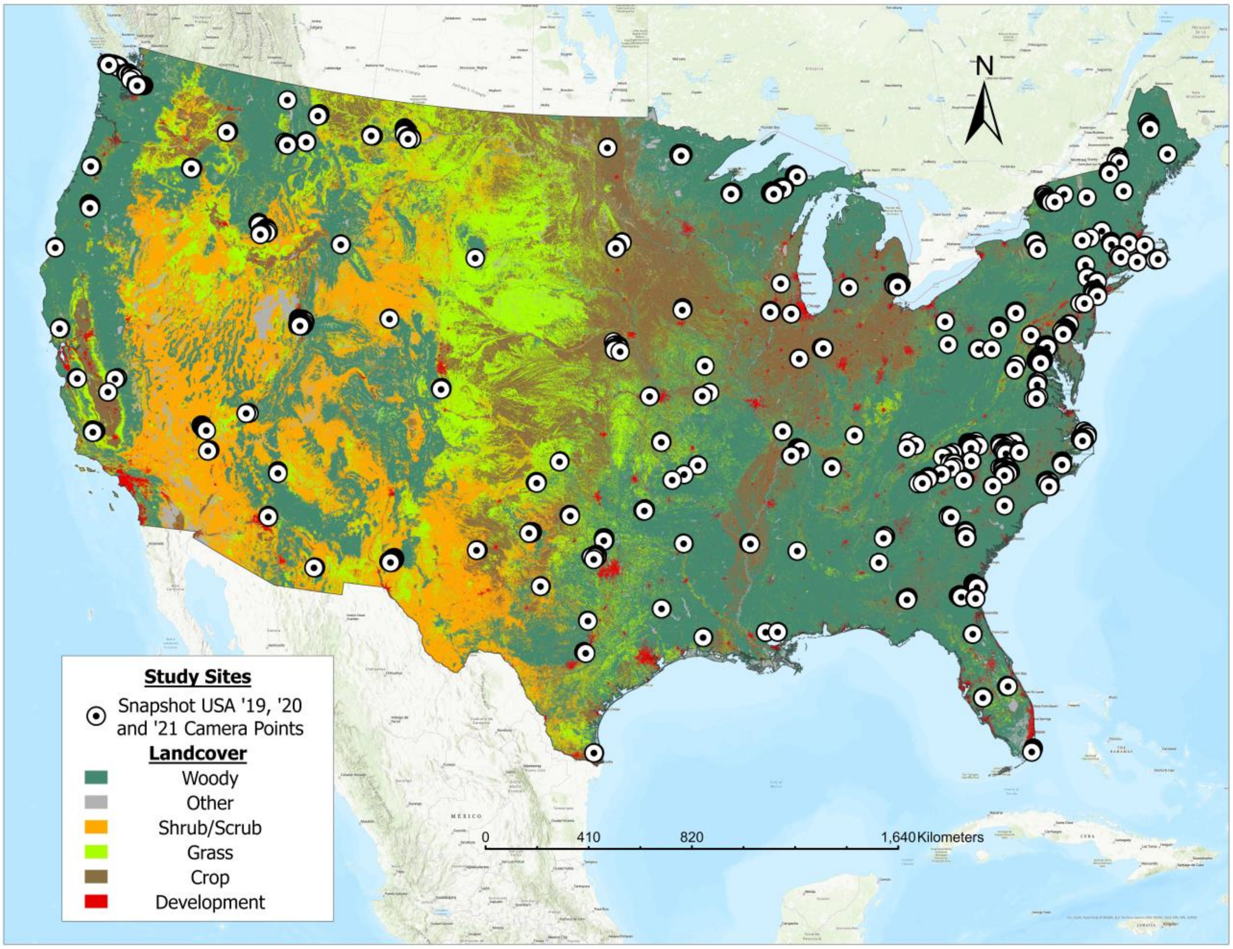

Figure 1.1. Study area of Snapshot USA 2019, 2020, and 2021 within the contiguous United States of America with landcover type (NLCD 2021) including wooded areas (woody), shrubland/scrubland (shrub/scrub), grassland (grass), cropland (crop), and developed areas (development), and other landcover types not evaluated (other). A single, unbaited camera trap was set and assessed at each study site (n = 4,512) across three years and the resulting data were used to evaluate raccoon (*Procyon* lotor) occupancy among landcover types.

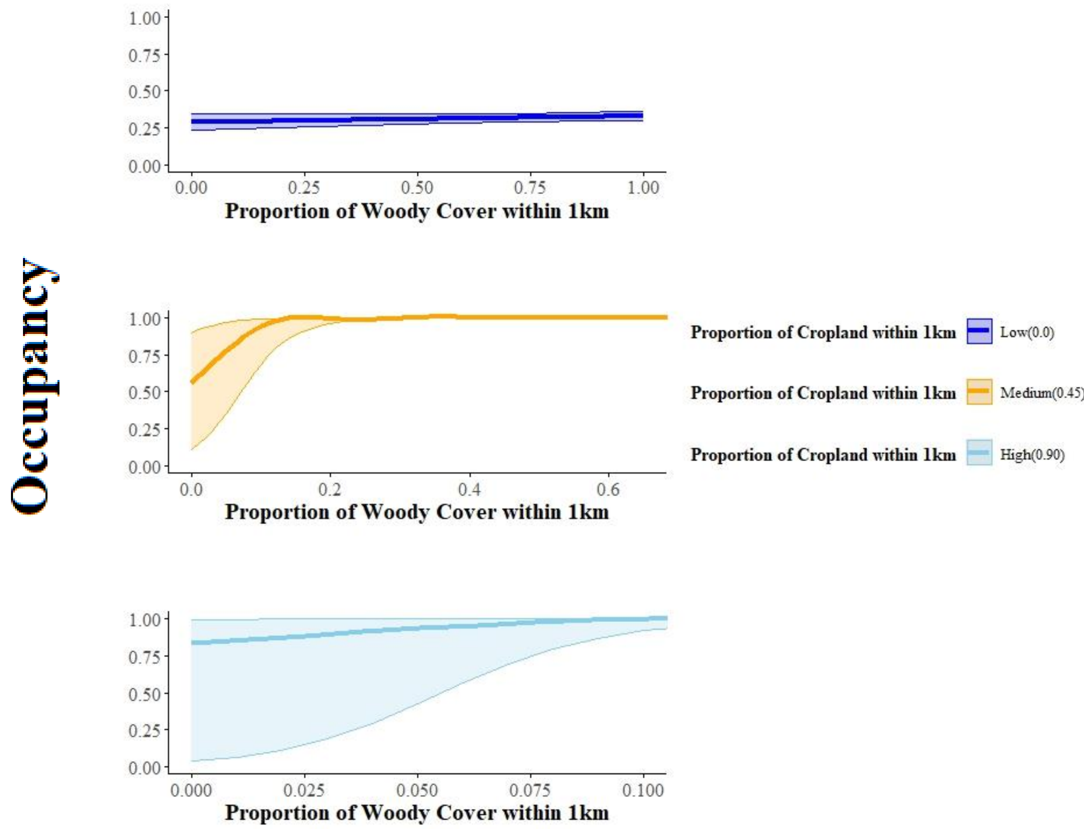

Figure 1.2. The influence of woody cover within 1 km interacting with different proportions of cropland (Low (0.0); top, Medium (0.45); middle, High (0.90); bottom) within 1km on site occupancy probabilities for raccoon (*Procyon lotor*) in the contiguous USA. I assessed site (n = 4,512) occupancy by raccoons using camera traps distributed in the contiguous USA across 3 years (2019, 2020, and 2021). Occupancy probabilities (solid colored line) and 95% confidence intervals (colored shaded) were estimated from my best supported, single-season occupancy model.

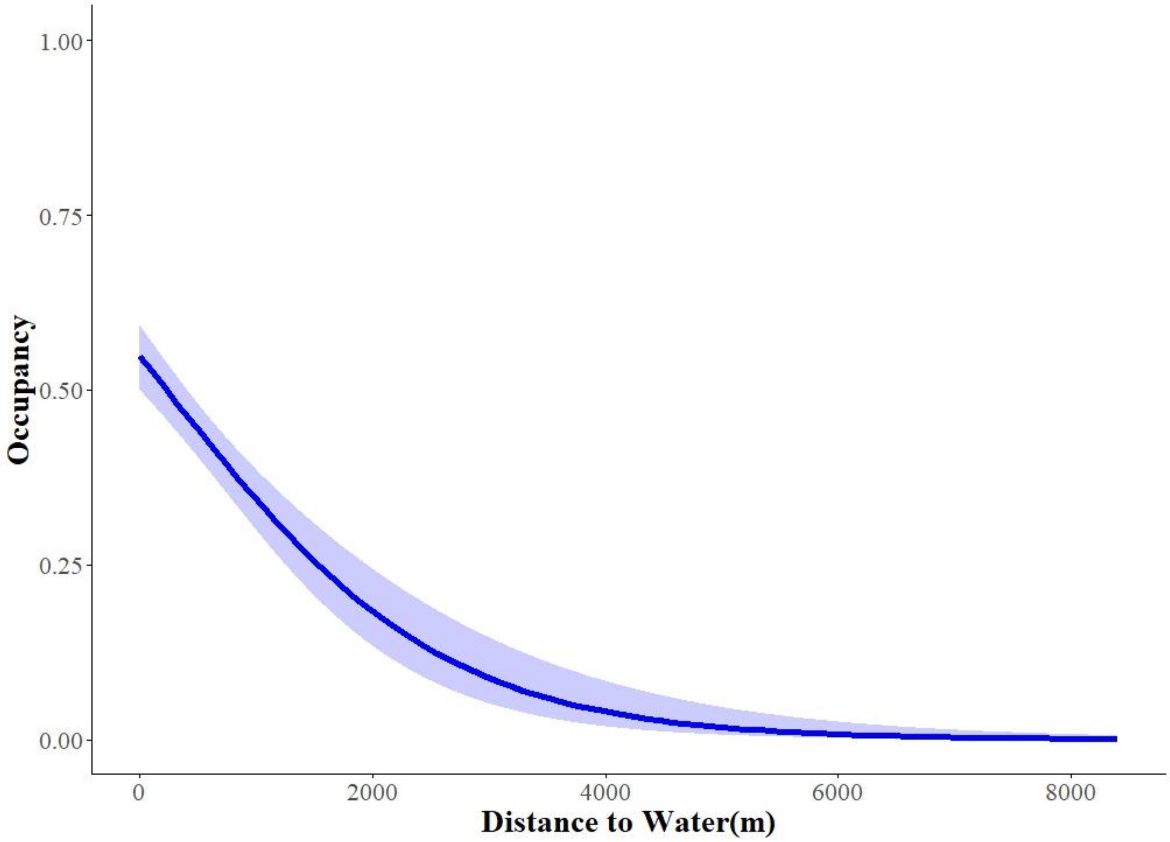

Figure 1.3. The influence of distance to water (m) on site occupancy probabilities for raccoon (*Procyon lotor*) in the contiguous USA. I assessed site (n = 4,512) occupancy by raccoons using camera traps distributed in the contiguous USA across 3 years (2019, 2020, and 2021). Occupancy probabilities (solid colored line) and 95% confidence intervals (colored shaded) were estimated from my best supported, single-season occupancy model.

Table 1.1. Candidate occupancy models of raccoon (*Procyon lotor*) occupancy from Snapshot USA data. Single-season occupancy models were constructed using the R package "unmarked" (Kellner et al. 2023). K = no. of parameters, ΔAICc = the difference in AICc (Akaike's Information Criterion adjusted for sample size) relative to smallest value, AICc weight = predictive weight that the model carries, -2 log L = log-likelihood value. p = detection probability. Covariates: interactive model with proportion of woody cover within 1km & proportion of cropland within 1km buffer (woody_crop_inter), additive model with proportion of woody cover within 1km & proportion of cropland within 1km buffer (woody_crop_add), proportion of cropland within 1km buffer (crop), proportion of shrubby/scrubby areas within 1km (shrub_scrub), distance (m) to nearest water source (water), proportion of developed areas within 1km (develop), proportion of other landscape features not evaluated within 1km buffer (other), proportion of grassland within 1km buffer (grass), proportion of woody cover within 1 km buffer (woody),and the null model (.).

***Models*[1, 2]**	***K***	***-2 log L***	***ΔAICc***	***AICc weight***
Ψ(woody_crop_inter)p(.)	5	-4754.43	0	1
Ψ(woody_crop_add)p(.)	4	-4763.43	16.00	0
Ψ(crop)p(.)	3	-4764.62	16.37	0
Ψ(shrub_scrub)p(.)	3	-4831.62	150.37	0
Ψ(water)p(.)	3	-4836.63	160.39	0
Ψ(develop)p(.)	3	-4844.39	175.92	0
Ψ(other)p(.)	3	-4891.63	270.38	0
Ψ(.)p(.)	2	-4901.42	287.96	0
Ψ(woody)p(.)	3	-4927.11	341.35	0
Ψ(grass)p(.)	3	-4944.42	375.96.	0

[1]*Minimum AICc = 9518.88*

Chapter 2 - Woody encroachment expands Northern raccoon (*Procyon lotor*) distributions into remaining grassland landscapes

Introduction

Woody vegetation is expanding into grasslands and savannas and threatening remaining grassland ecosystems worldwide (Archer et al. 2017). Intensive grazing by livestock (Wick et al. 2016), climate change resulting in increased frequency and intensity of precipitation and drought (Snell et al. 2022, García et al. 2020, Ratajczak et al. 2012), fire suppression by humans (Li et al. 2022, Fowler & Beckage 2019), increased CO_2 levels (Scheiter & Higgins 2009, Raubenheimer et al. 2022), and the condition of soil and substrates (Kgosikoma & Mogotsi 2013) are all factors contributing to woody encroachment globally. Woody encroachment into native grasslands can reduce grassland biodiversity (Ratajczak et al. 2012, Mogashoa et al. 2021, Wieczorkowski & Lehmann 2022), reduce resources such as light, water, and nutrients (Twidwell et al. 2021, Archer et al. 2017, Acharya et al. 2018), and lead to establishment of exotic grasses (Alofs & Fowler 2013). Additionally, woody encroachment has been linked to widespread, grassland bird declines (Coppedge et al. 2001).

Woody encroachment could influence predation rates on grassland bird nests by mesopredators (Davis et al. 2019, Patten et al. 2006). Grassland bird species have declined by more than 700 million breeding individuals across 31 species since 1970 (Rosenberg et al. 2019). This in part may be due to increased nest predation rates through habitat loss and human impacts (Ibáñez-Álamo et al. 2015). Highly fragmented grasslands can experience greater nest predation rates particularly by edge-associated species (Renfrew & Ribic 2003). Though nests are not always targeted by predators, incidental predations are common (Vickery et al. 1992). Woody encroachment may facilitate the movement of predators into previously unused areas (McIntire

2024). Therefore, woody plant invasions, in conjunction with the opportunistic foraging behavior of mesopredators, may lead to increased predation rates on grassland bird nests. However, our knowledge of how woody encroachment impacts mammalian species, such as mesopredators, distributions is still ongoing.

Raccoons (*Procyon lotor*) are mesopredators that use woody areas for forage and shelter and may expand into, or increase population sizes in, grasslands following woody encroachment (Beasley et al. 2007b, Hill et al. 2023b, Barding & Nelson 2008). Raccoons are native to the United States and range from southern Canada to Panama. They are nocturnal omnivores (Bider et al. 1968, Rulison et al. 2012) allowing them to exploit many different food resources (Gautrelet et al. 2024, Lotze & Anderson 1979) and use forest edges adjacent to agricultural fields and water resources (Dijak & Thompson 2000). Woody areas provide food resources for raccoons such as hard and soft mast (Smith & Kennedy 1987). Raccoons can also use deciduous trees as daytime resting places, denning sites, and shelter from weather and predators (Wilson & Nielsen 2007). Woody encroachment can increase edge habitat between forested areas and grasslands which could increase habitat use in those areas (Barding & Nelson 2008). Raccoons could benefit from the resources that are provided by these encroaching woody species in Kansas but the influence of these woody species at landscape scales remains unevaluated (Wait & Ahlers 2020).

My objectives were to evaluate if there is a minimum woody cover threshold for raccoon occupancy and the relative influence of other landscape factors on site occupancy. I hypothesized raccoon occupancy probabilities would increase with greater amounts of woody cover surrounding camera survey points. I also hypothesized that proximity to a water source and agriculture (i.e., row-crop agriculture) would positively influence occupancy alone, or through an interaction with woody cover. My secondary objective was also to evaluate how camera trap placement at entirely random locations vs. nearest trees may influence raccoon detections. I hypothesized there would be an increased detection rate with camera traps deployed on trees compared to camera traps placed at random locations relative to nearest trees.

Methods

Study Area

I surveyed six different counties within Kansas, USA (Fig. 2.1). My sampling occurred on the Harold and Olympia Lonsinger Sustainability Farm (HOLSF) and private property owned in Osborne and Smith County, the Saline Experimental Ranch (SER) in Ellis County, Hadley Foundation Ranch (HFR) in Ellis County, Kirwin National Wildlife Refuge (KNWR) in Phillips County, Konza Prairie Biological Station (KONZA) in Riley County, and Fort Riley Military Installation (FRMI) in Riley and Geary County. The properties varied in vegetation composition and structure. The SER and HFR study sites had smaller portions of woody cover and bigger portions of grassland whereas the HOLSF and private property in Osborne and Smith County study sites had more encroaching woody cover and cropland portions of the landscape (Table 2.2). The SER and HFR had dispersed oil extraction rigs with associated roads for maintenance. The KNWR, KONZA, and FRMI sites had bigger portions of grassland and smaller portions of cropland (Table 2.2). Although SER, HRF, KNWR, KONZA, and FRMI were mostly grassland dominated, they had areas with dense woody cover primarily near water sources. The HOLSF and private property in Osborne and Smith County had substantial amounts of woody encroachment in the pastured areas (Table 2.2). Much of the woody encroachment at the HOLSF and throughout our survey locations consisted of eastern red cedar trees (*Juniperus virginiana*) and honey locust trees (*Gleditsia triacanthos*) though Siberian elm (*Ulmus pumila*), hackberry

(*Celtis occidentalis*), Fraxinus spp., Russian olive (*Elaeagnus angustifolia*), eastern cottonwood (*Populus deltoides*), and black willow (*Salix nigra*) were present in many of the Osborne and Smith County pastured grassland sites. Smooth brome (*Bromus inermis*) was a primary herbaceous vegetation in the Osborne and Smith County pastured grassland sites.

Camera trap deployments

I established 210 camera sites (104 sites at FRMI, 36 sites at HOLSF, 10 sites at SER, 9 sites at HFR, 23 sites at KNWR, 28 sites at KONZA) to estimate raccoon occupancy across a gradient of woody vegetation cover. At each site, I established a single unbaited motion-sensing camera (Bushnell Prime Trail Cam® ; Model 119932C or Bushnell Trophy Cam® ; Model 119717CW) oriented north/south to avoid solar glare. Each day was considered an independent survey. Cameras were active during winter and summer seasons an average of 26 days (SE= 0.61, range = 15 – 46 days) at each site. After the cameras were retrieved, I used photo processing software (www.wildlifeinsights.org) to manually document detections (1) and non-detections (0) of raccoons at each site. I created a 46-day detection history for each site. When cattle (*Bos taurus*) or bison (*Bison bison*) were present I wrapped the camera in a makeshift wire cage to reduce contact damage.

I sampled 104 camera survey points during 03 January 2023 – 07 February 2023 on FRMI in conjunction with another study (Byrd 2024). At these points, I used a combination of motion sensor (1 photos per trigger, 3 second delay) and time-lapse triggers (one photo every 30 min). Both trigger functions were used according to the other study's protocol for our FRMI cameras. I placed cameras on the nearest structure (e.g. trees, posts) at ~ 1 m above the ground. This was specific to my FRMI camera points all other Kansas cameras were placed on u-posts. I cleared all tall vegetation with hedge trimmers within fifteen meters of the camera. I used memory cards (16 GB) for each camera to store images on. Camera points were separated by ≥ 1 km Euclidian distance using a geographic information system (ArcGIS Pro ; Esri 2024). This was to ensure spatial independence for each of the study points. At all other sites (HOLSF. SER, HFR KONZA, and KNWR), I randomly selected camera locations. All cameras (except FRMI) were set to trigger with motion detection, one photo per trigger, and a three second delay. I attached cameras to fence posts or steel u-posts (5' Steel Fence Light Duty U-Post) approximately 0.5 meters off the ground (Kays et al. 2022). I cleared herbaceous vegetation or woody branches from the field of view approximately 15 m in front of the camera. Camera traps were out from May 2023 to July 2023 and June 2024 to July 2024 and were out for a minimum of fourteen trap nights.

Characterizing landcover

I quantified woody cover at each site from a GIS layer produced by a private remote sensing company (EarthDefine; www.earthdefine.com) at a 5-m resolution. I quantified other land cover variables such as cropland (cultivated crops), grassland (herbaceous, hay/pasture), and all other landcover variables combined in one) using the National Landcover Database (Dewitz 2023, NLCD 2021). I resampled the NLCD layer using the nearest neighbor resampling technique in ArcGIS Pro. I then combined the EarthDefine layer with my resampled NLCD layer to create a reclassified landcover layer at the 5m resolution. Using ArcGIS Pro (Esri 2024), I extracted proportion estimates of croplands (cultivated crops), grasslands (herbaceous, hay/pasture), woody cover, and all other landcover types (developed areas, open water, etc.) within a 1-km circular buffer of my study sites. I chose the 1km buffer based on other published literature (Palomo-Munoz et al. 2024, Wait & Ahlers 2020). I measured the Euclidian distance

(m) from each study site to the nearest water source using the 2023 National Hydrography Dataset (USGS 2023).

Data Analysis

I developed stacked single-species, single-season occupancy models (Kellner et al. 2023) to evaluate the influence of my measured landcover variables on raccoon occupancy. I assumed that any changes in occupancy among years were random and I was not interested in annual changes in occupancy but the underlying pattern among years. I used the intercept only model to estimate detection probability and account for imperfect detection. For my occupancy analysis, I fit models that included covariates and their additive and interactive effects based on *a priori* hypotheses for raccoon occupancy as well as an intercept only model (n=21). I did not include variables that were correlated ($|r| \geq 0.50$) within the same model. I ranked models by parsimony using Akaike's Information Criterion corrected for small sample sizes (AIC_c; Burnham & Anderson 2002). For occupancy models, I evaluated the importance of all models with a ΔAIC_c of ≤ 4.00) using an information theoretic approach (Burnham & Anderson 2002). I declared models as informative if the model's beta coefficients did not overlap zero at the 95% confidence intervals. I then evaluated the best-supported model and the covariate influence by plotting the predicted occupancy probability in relation to the hypothesized covariates. I determined that any probability of raccoon occupancy at 0.10 or lower was considered highly unlikely to occupy the area. I determined our minimum woody cover threshold by using the predicted occupancy probability (< 0.10).

Evaluating camera placement on nearest tree vs. true random location

During the 2024 summer season, I compared raccoon detections at cameras placed on nearest trees as opposed to cameras placed on posts at completely random locations. For this analysis, we generated random points at the KONZA study site that were at least 1 km apart. I then placed a trail camera at the specific coordinates of the random point by attaching the camera to a small u-post that was pounded in the ground. I then placed a camera at the tree nearest to the random location. I placed 28 cameras on the posts at random locations and 28 cameras at paired trees closest to the random locations KONZA sites. These tree sites underwent the same protocol as the other Kansas sites to reduce any bias and only differed in placement on trees rather than at purely random locations. We estimated the mean number of raccoons detected at cameras on posts compared to those on nearest trees.

Results

From 03 January 2023 - 17 July 17, 2023, and 06 June 2024 – 25 July 2024, 210 cameras were active for 5,155 trap nights. I detected raccoons at 36 of my 210 sites (0.17 naïve occupancy). The mean number of raccoon detections per day among all sites was 0.11 (SD = 0.96) and varied from 0 detections per day to 0.5 detections per day among study sites (Table 2.2). Based on my null model for detection and occupancy, per survey detection probability was low ($p = 0.124$ SE = 0.011) and corrected site occupancy was 0.184 (SE = 0.028). I accounted for detection (Table 2.1) using the null detection probability model for my occupancy analysis.

My most-supported occupancy model ($w = 0.43$) included the additive influence of proportion of grassland within 1 km and distance to water and indicated that raccoon occupancy was lower in areas having more grassland within 1km that were further from water sources ($\beta_{grass} = -1.072$, SE = 0.22, $\beta_{water} = -0.58$, SE = 0.24;Table 2.1; Fig. 2.2). Raccoon occupancy was greater in landscapes without grassland and closer to water (< 10 meters; $\Psi = 0.84$) than at high (0.90) proportions of grassland and farther from a water source (> 700 meters; $\Psi = 0.01$).

There were three other competitive models including the interactive effects of grass and distance to water, the additive effects of woody cover and cropland, and study site, respectively ($\Delta AIC_c < 4.00$). The additive effects of cropland within 1 km and woody cover within 1 km indicated that occupancy increased with woody cover and cropland ($\beta_{crop} = 1.13$, SE = 0.22, $\beta_{woody} = 0.63$, SE = 0.20). Within my study area, raccoons were approximately four times more likely to occupy sites with a 0.58 proportion of woody cover compared to a 0.18 proportion of woody cover in landscapes that lacked cropland (proportion of cropland =0.0). In landscapes with some (0.45) cropland, raccoons were approximately two times more likely to occupy sites with a 0.29 proportion of woody cover compared to a 0.01 proportion of woody cover.

At our lowest predicted raccoon occupancy (0.05), woody cover was absent (0.0). At a woody cover of proportion of 0.18, predicted occupancy was 0.10. Therefore, the minimum woody cover threshold was between a proportion of 0.0 - 0.18 woody cover within a 1 km radius.

The study site model demonstrated some variation in raccoon occupancy among study sites with the greatest occupancy at the HOLSF site and the lowest occupancy probability at the KONZA site ($\beta_{intercept\ (FRMI)} = -1.69$, SE = 0.27, $\beta_{HFRy/SER} = -1.04$, SE = 1.07, $\beta_{KNWR} = -1.24$, SE = 1.06, $\beta_{KONZA} = -10.17$, SE = 76.52, $\beta_{HOLSF} = 1.91$, SE = 0.47). There was considerable variation in occupancy at camera locations within the sites making this model less informative than local differences in landscapes (1km scale). For example, a single camera within our HOLSF site had a total of 248 detections and another camera within that same HOLSF site had 0.

Camera placement on trees vs. true random location results

My 28 randomly placed camera sites had 0 detections whereas my 28 nearest tree camera trap locations had a total of 23 detections for an average of 1.59 detections per camera per day (SD = 5.19, range = 0 – 17 detections). The mean “distance to the nearest tree” for my summer 2024 tree versus post analysis was approximately 81 meters (SD = 65.89, range = 3.67 – 271.97 m).

Discussion

Raccoon occupancy was positively influenced by the proportion of woody cover, proximity to water, and the proportion of cropland at the landscape scale. Conversely, raccoon occupancy was negatively related to the proportion of grassland cover at the landscape scale. My main objective was to evaluate the influence of woody cover and my occupancy results were consistent with other studies’ indicating that woody cover can be an important predictor for raccoon use (Pedlar et al. 1997, Heske & Ahlers 2016, Beasley et al. 2007b). Woody cover provides multiple benefits for raccoons. I determined from our study that within Kansas, a woody cover threshold needed for raccoon occupancy may be between 0 – 18% woody cover at a 1 km scale.

Raccoon occupancy was negatively influenced by the proportion of grassland and distance to water at a landscape scale. This aligns with many studies reporting grasslands to have a negative influence on raccoon occupancy (Barding & Nelson 2008, Newbury & Nelson 2007, Milling & Gehrt 2023). Water availability is important when considering raccoon habitat use (Heske & Ahlers 2016, Milling & Gehrt 2023) as many studies show raccoons favor wetlands (e.g., Barding & Nelson 2008, Greenwood 1982, Milling & Gehrt 2023). My results align with the many studies that observe the use of water to be a crucial predictor of raccoon habitat use.

I propose that raccoons benefit from woody encroachment within Kansas based on my results. The high occupancy probability in landscapes having both cropland and woodland suggests that landscapes with minimal woody cover in proximity to croplands could be largely occupied by raccoons. My results correspond with previous studies indicating that raccoons have greater occupancy probabilities in areas with more forest cover which provide essential resources such as shelter, foraging opportunities, and protection from predators (Zamuda et al. 2022, Owen et al. 2015a). Barding and Nelson (2008) observed that raccoons used wetlands, forest edges, and avoided grasslands and crop fields.

In contrast to raccoons, woody encroachment has a negative influence on grassland bird abundance and nest success (Graves et al. 2010). A study in southwestern Wisconsin documented that the removal of trees and shrubs that intersected a grassland area reduced the activity of raccoons and other woodland predators (Ellison et al. 2013). By conserving Kansas grasslands and indirectly decreasing raccoon use in these areas, this could also minimize diseases spread by raccoons that could have harmful effects for human and animal health (Pieracci 2019).

Occupancy models indicated a positive influence of cropland on raccoon occupancy. However, studies evaluating cropland use by raccoons are inconsistent (Milling & Gehrt 2023, Crimmins et al. 2016, Beasley & Rhodes 2010; Table 2.3). Differences in the type of crops planted and other site-specific factors may play a part in the consistency of these studies as well as the season in which the studies occur (Berry et al. 2017). These crop fields may be a food resource for raccoons not only through consumption of the crops themselves such as corn but also through the prey species such insects and small mammals that also consume crops. In addition to providing a food resource, raccoons often use croplands as travel corridors especially near water sources (Newbury & Nelson 2007).

In the past, raccoons played a crucial role in the fur trade, by significantly boosting the economy through fur harvesting (Newbury & Nelson 2007). Raccoons help in the decomposition process by consuming carrion and indirectly reducing the spread of disease by reducing the presence of decaying matter on the landscape (Hill et al. 2023a). Raccoons can also keep pest populations stable by preying on insects and rodents that plague row-crops (Troyer et al 2014). Raccoons spread plant seeds which help to promote biodiversity in certain areas (Stanton et al. 2022). Though raccoons do provide benefits to our ecosystem, at large populations sizes, the benefits may be outweighed by the negative impacts that this species can have on other wildlife and for Kansas landowners (Troyer et al. 2014). In my study site, raccoons appeared to be the most abundant in landscapes that were the most altered from the historic grassland state and although raccoons can provide numerous ecosystem services, this species may become overabundant in this region and therefore, landscape scale habitat management efforts that minimize its distribution could be beneficial.

Camera placement on trees vs. true random location results

My comparison of raccoon detections at nearest trees to those at completely random locations (cameras mounted on posts) indicated a substantial effect of small movements (mean =81 m) of the camera to nearest tree. We observed no raccoons at the 28 completely random placed cameras on posts compared to 23 detections at paired nearest trees. Although this is a small sample size and further research is needed these results are interesting because many studies move cameras from a random location to the nearest tree when conducting field research, such placement would be indicative of broad landscape scale patterns but might hide finer scale factors influencing habitat use by raccoons. Wooded areas are used frequently by raccoons in radiomarked & camera trap studies (Beasley & Rhodes 2010, McClain 2017). Future research could consider the configuration of wooded areas in addition to the broadscale landscape composition of woody cover as raccoons appear to use wooded areas at even small proportions in landscapes. These woody areas that provide corridors for raccoons use, movement, and connectivity of linear woody habitats may be important. Alternatively, finer scale assessment of woody cover immediately surrounding areas used by raccoons may be needed to fully understand woody cover requirements for raccoons. Deploying camera traps on the nearest tree rather than on randomly placed posts could lead to overestimating raccoon habitat use at finer scales.

Management Implications and Future Directions

Over the last forty years, raccoon abundance has increased in Kansas (Peek 2023). Over this same period woody species have increased 57% in some riparian areas in Kansas and the amount of cropland has increased by at least 20 million hectares in the Great Plains (Keen et al. 2023, Augustine et al. 2021). My results provide a mechanism linking increased woody cover to increased raccoon occupancy and distribution in Kansas over this 40-year period. In addition, further conversion of grassland to cropland could be beneficial for raccoons. Recent landcover changes and current land use appear to provide adequate habitat for this generalist species while grassland dependent wildlife continues to decline (Rosenberg et al. 2019). Therefore, there is no current management action needed to promote raccoon populations. However, because raccoons can be active nest predators for grassland birds of interest and can become overabundant in certain situations (Beasley & Rhodes 2008, Milling & Gehrt 2023, Davis et al. 2019), management seeking to decrease the distribution of these species in the Great Plains would involve conserving large grassland dominated landscapes with minimal woody cover (<10% within 1 km) that are greater than 600 m from nearest water source. Adding additional ponds within large grasslands may increase raccoon occupancy. Management that actively promotes grasslands including removal of woody species and prescribed fire to limit establishment of woody cover would likely reduce raccoon occupancy and would benefit more grassland dependent wildlife that are declining.

Future research should assess the effects of woody cover on nest predation rates by raccoons on ground nesting birds. Meso-predator species forage opportunistically within grassland areas (Vickery et al. 1992). The influence of increased woodland habitat in grassland dominated areas may increase the probability of nest predation by raccoons. This hypothesis could be evaluated by assessing predators (eg. snakes, raptors, other mesocarnivores, etc.) within woody encroached areas. My study provides information on the potential use of woody encroached areas by raccoons and implications for how we manage grassland areas and raccoons. Removal of invasive woody species and restoring fire as a natural disturbance based on historic fire return intervals in grasslands could be beneficial for ground nesting birds that raccoons predate. Other research in longleaf pine savannahs has documented a 50-80% decreased in raccoon use following the use of prescribed fire (Jones et al. 2004).

Figures

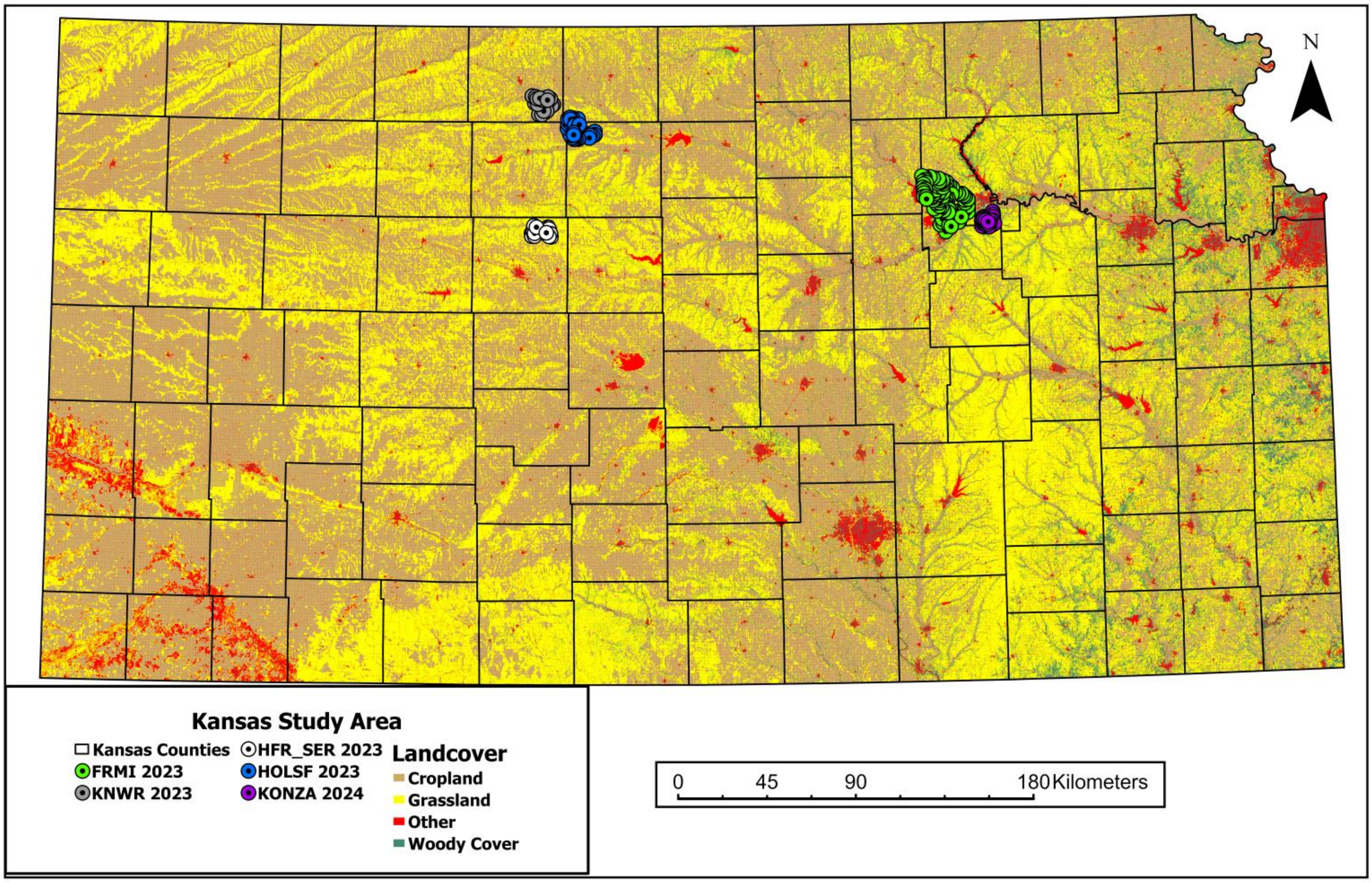

Figure 2.1. Study area of Kansas, USA with Kansas study sites (Harold & Olympia Lonsinger Sustainability Farm and private property (HOLSF): blue points, Saline Experimental Ranch (SER) & Hadley Foundation Ranch (HFR): white points, Kirwin National Wildlife Refuge (KNWR): gray points, Konza Prairie Biological Station (KONZA): purple points, Fort Riley Military Installation (FRMI): green points) with the NLCD and EarthDefine reclassified layer landcover types: cropland (brown), grassland (yellow), woody cover (green), and all other landcover types (red). A single, unbaited camera trap was set and assessed at each study site (n = 210) across Kansas and the resulting data were used to evaluate raccoon (*Procyon* lotor) occupancy among landcover types from 03 January 2023 - 17 July 17, 2023, and 06 June 2024 – 25 July 2024.

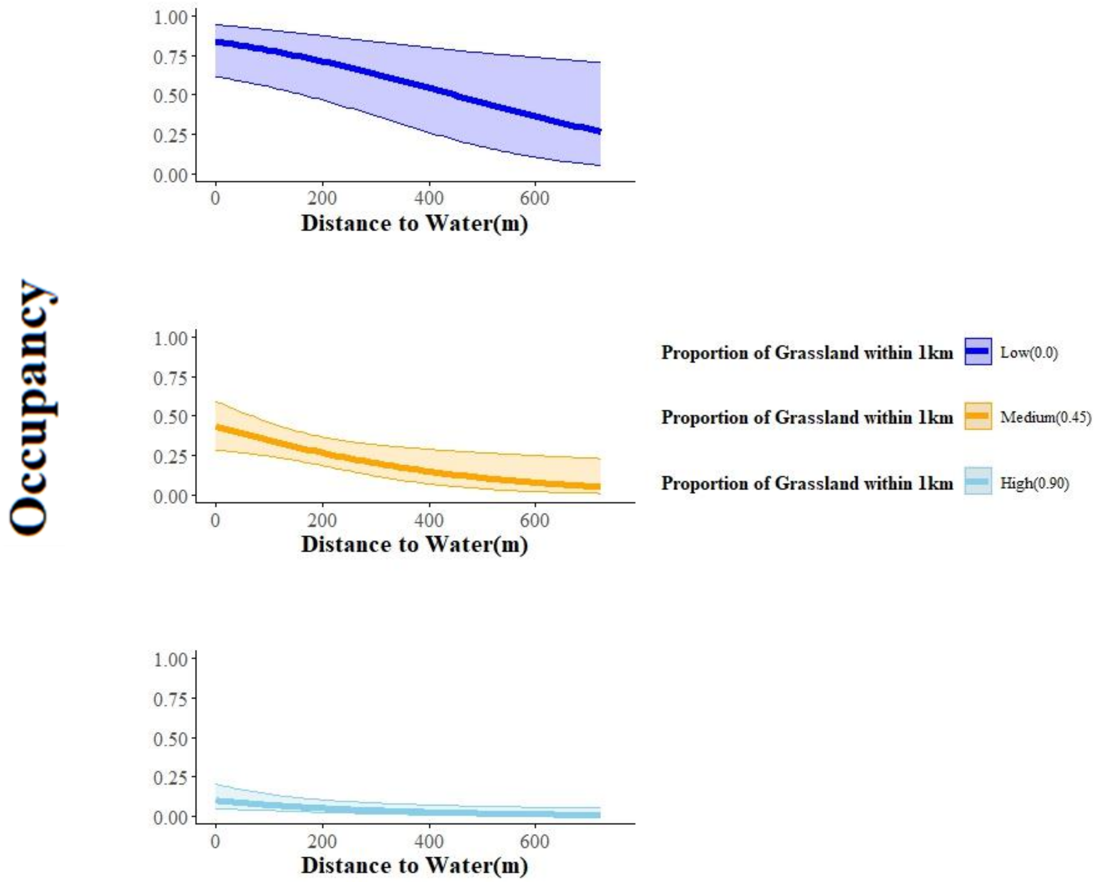

Figure 2.2. The influence of distance to a water source and proportion of grassland on occupancy of raccoon (*Procyon lotor*) in Kansas, USA. I evaluated raccoon occupancy by using camera traps (n = 210) placed on Fort Riley Military Reservation, Konza Prairie Biological Station, and areas within north-central Kansas during the winter 2023, summer 2023, and summer 2024. Predicted occupancy probabilities (solid lines) and 95% confidence intervals (light colored fill) were estimated using the best supported model based on AIC$_c$ (grassland + distance to water).

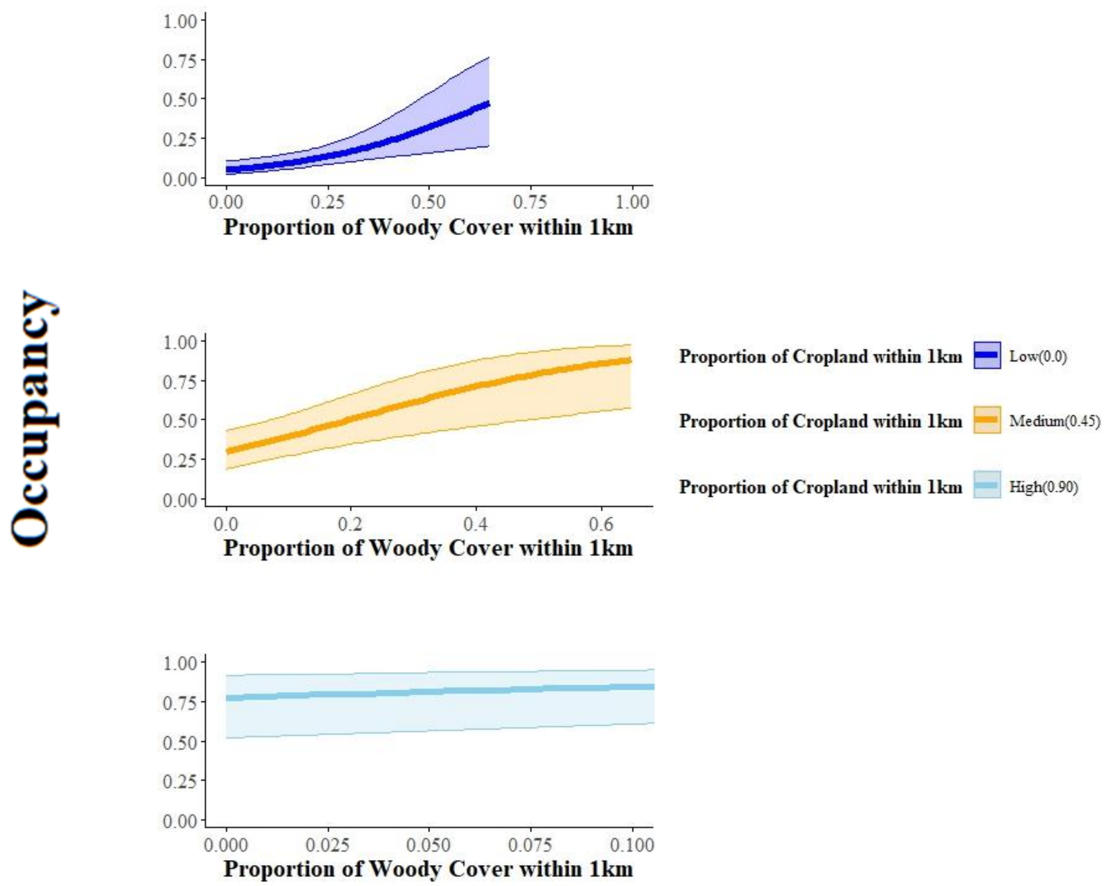

Figure 2.3. The influence of the proportion of woody cover within 1 km and different proportions of cropland (Low; top, Medium; bottom left, High; bottom right) within 1km on raccoon (*Procyon lotor*) occupancy in Kansas, USA. I evaluated raccoon occupancy using camera traps placed on Fort Riley Military Reservation, Konza Prairie Biological Station, and areas within north-central Kansas during the winter 2023, summer 2023, and summer 2024. Predicted occupancy probabilities (solid lines) and 95% confidence intervals (light colored fill) were estimated using the competitive model (woody cover + cropland).

Table 2.1. **Single-season occupancy models describing detection and use by raccoons (*Procyon lotor*) across study sites (*n* = 182) within Kansas, USA. I used camera trap data to document the presence and absence of raccoons in the summer (2023, 2024) and winter (2023) seasons. Woody, Crop, and Grass = proportions of landcover types within 1 km buffer surrounding sites; Water = Euclidean distance (m) to nearest water source; Month = month that cameras were active (January, February, May, June, July); Site = different location that cameras were active (Harold and Olympia Lonsinger Sustainability Farm Hadley Foundation Ranch, Fort Riley Military Reservation, Saline Experimental Range, Kirwin National Wildlife Refuge, Konza Prairie Biological Station). Intercept model and Null model were also provided. Models were ranked from lowest to highest AIC_c values (Akaike's Information Criteria, adjusted for small sample size). K = number of parameters per model; ΔAIC_c = Difference in AIC_c values of lowest AIC_c value model and the AIC_c value of the model being assessed; w_i = model weight; LL = Log likelihood.**

Model	K	AIC_c	ΔAIC_c	w_i	LL
Occupancy					
Grass + Water	4	842.20	0.00	0.43	-417.00
Grass * Water	5	843.54	1.34	0.22	-416.62
Crop + Woody	4	844.92	2.72	0.11	-418.36
Site	6	845.59	3.39	0.08	-416.59
Grass	3	846.78	4.58	0.04	-420.33
Crop * Woody	5	846.98	4.78	0.04	-418.34
Month	6	847.13	4.93	0.04	-417.36
Grass + Woody	4	848.64	6.45	0.02	-420.22
Grass + Woody + Season	5	849.55	7.35	0.01	-419.63
Grass * Woody	5	850.09	7.89	0.01	-419.90
Crop + Water	4	850.51	8.31	0.01	-421.16
Crop	3	852.20	10.00	0.00	-423.04
Crop * Water	5	852.48	10.28	0.00	-421.09

Grass * Woody * Season	9	855.36	13.16	0.00	-418.23
Water	3	869.04	26.84	0.00	-431.46
Water + I (Water^2) (quadratic)	4	869.76	27.56	0.00	-430.78
Water + Woody	4	870.06	27.86	0.00	-430.93
Water * Woody	5	870.32	28.12	0.00	-430.01
Null	2	874.02	31.82	0.00	-434.98
Season	3	874.91	32.71	0.00	-434.40
Woody	3	875.43	33.23	0.00	-434.65

Table 2.2. Mean estimates and standard deviation of the proportion of woody cover, proportion of cropland, and proportion of grassland within 1km of cameras for each study site and mean estimate and standard deviation of daily raccoon detections per camera. SD = standard deviation.

	Grassland		Cropland		Woody Cover		Raccoon detections per day	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Lonsinger	0.34	0.16	0.60	0.17	0.02	0.02	0.50	2.29
Konza	0.86	0.11	0.01	0.03	0.12	0.08	0.00	0.00
Kirwin	0.58	0.24	0.19	0.19	0.02	0.03	0.01	0.03
Hadley/SER	0.83	0.19	0.06	0.15	0.03	0.03	0.04	0.18
FRMI	0.72	0.21	0.02	0.03	0.19	0.16	0.04	0.20
All sites	0.67	0.25	0.14	0.24	0.12	0.14	0.11	0.96

Table 2.3. Literature comparison of the use of cropland. Time of Year = the month in which the study took place (with winter and summer seasons separated into two rows), State = the state or province in which the study took place. Method = the method of detecting raccoons (*Procyon lotor*). Use of cropland = whether there was a positive (+) or negative (-) use of cropland found in the literature.

Literature	Time of Year	State	Method	Use of Cropland
Milling & Gehrt 2023	April, May	Manitoba	Radio collar	(-)
Crimmins et al. 2016	April, May, June	Minnesota & Iowa	Track surveys	(+)
Beasley & Rhodes 2008	March, April, May	Indiana	Radio collar	(+)
Beasley & Rhodes 2010 (Summer)	May, June, July, August, September, October	Indiana	Radio collar	(+)
Beasley & Rhodes 2010 (Winter)	November, December, January, February, March, April, May	Indiana	Radio collar	(+)
Barding & Nelson 2008	April, May, June, July, August	Illinois	Radio collar	(-)
Heske & Ahlers 2016	May, June, July	Illinois	Track stations	(-)
Berry et al.2017 (Summer)	June, July, August, September, October	Illinois	Camera traps	(+)
Berry et al. 2017 (Winter)	November, December, January, February, March	Illinois	Camera traps	(-)
Durbin 2024 (Summer and Winter)	May, June, July, January, February	Kansas	Camera traps	(-)

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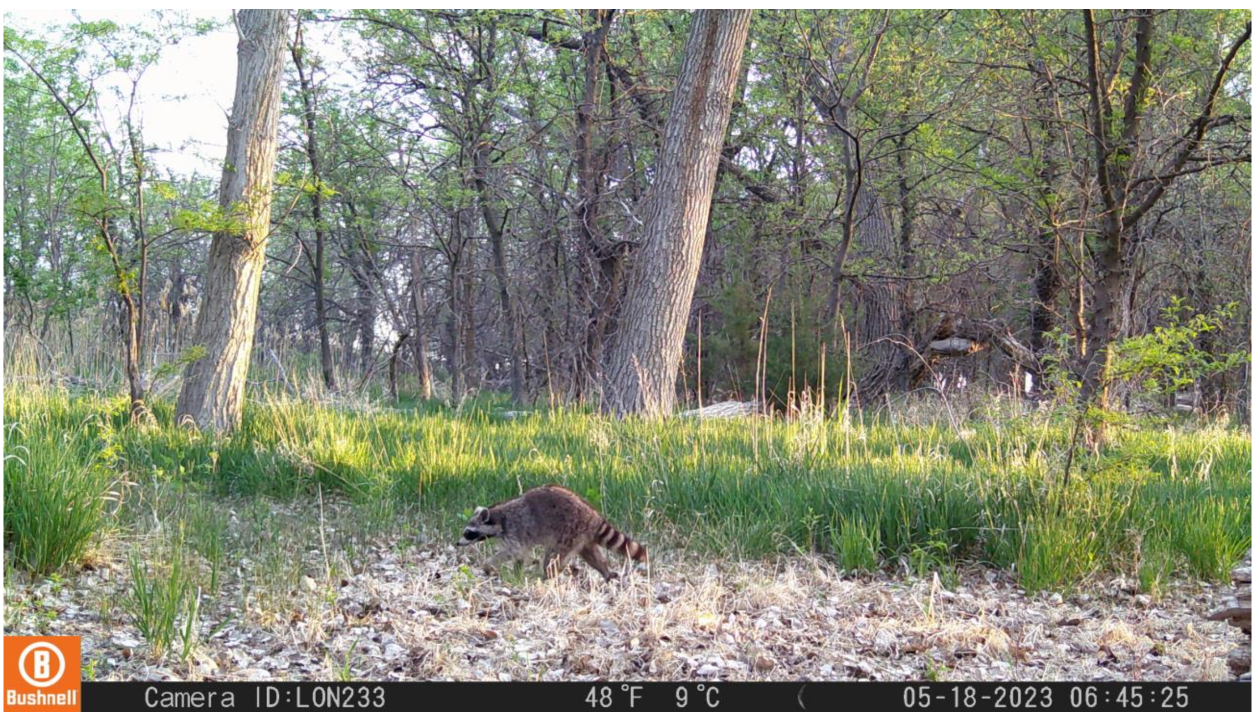
Appendix A - Kansas Camera Trap Raccoon Images

Appendix Figure A.1. Picture of Northern raccoon (*Procyon lotor*) caught on camera traps in Kansas

Appendix Figure A.2. Picture of Northern raccoon (*Procyon lotor*) caught on camera traps in Kansas

Appendix Figure A.3. Picture of Northern raccoon (*Procyon lotor*) caught on camera traps in Kansas

Appendix Figure A.4. Picture of Northern raccoon (*Procyon lotor*) caught on camera traps in Kansas



Appendix Figure A.5. Picture of Northern raccoon (*Procyon lotor*) caught on camera traps in Kansas