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Effects of Northern Bobwhite Management on Raccoon Abundance, Habitat Selection, and Home Range in Southwest Missouri

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Effects of Northern Bobwhite Management on Raccoon Abundance, Habitat Selection, and Home Range in Southwest Missouri

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Biological Sciences

by

Jacob Cody McClain
The College of William and Mary
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ABSTRACT

Habitat management has become vital for northern bobwhite (*Colinus virginianus*) conservation. In Missouri, efforts to conserve remaining populations on public lands have included the use of two management models. The Intensive Management Model (IMM) promotes hard edges, by creating a juxtaposition of different habitat types, while the Extensive Management Model (EMM) maintains a grassland-dominated landscape through the processes of fire and grazing. Preliminary results suggest that bobwhite success is significantly higher on EMM sites than IMM sites. Management efforts through IMM may be hindered by unintentionally managing for nest predators like raccoons (*Procyon lotor*). Nest predators may forage more often in northern bobwhite nesting habitat under IMM than EMM because grassland fields are smaller, and woody edge and corridors are abundant. The habitat diversity created by IMM may allow for larger populations of nest predators when compared with EMM. I used camera traps and GPS-collars to investigate how IMM and EMM effect 1) the mesopredator community structure, 2) raccoon abundance and density, 3) raccoon habitat use, and 4) raccoon home range. I estimated that raccoon densities were 9.9 and 5.6 per km^2 for the two IMM sites and 7.2 and 2.6 per km^2 at the two EMM sites and I found no clear relationship between treatments. Raccoon densities may be influenced by percent timber and woodland of the area rather than the management model itself. I found that the median distance from a woody edge into open habitats like grasslands of IMM site raccoons was greater than that of EMM site raccoons. I found that IMM site raccoons used tree lines, fencerows, timber-grassland edges, woody draws, and shrub-scrub-grassland edges as movement corridors while EMM site raccoons used woody draws, and shrub-scrub-grassland edges. I found that IMM site raccoons used grasslands, where the majority of northern bobwhite nests occur, proportional to availability,

while EMM site raccoons avoided grasslands. Managers can possibly reduce nest encounter rates by raccoons through reduction in timber-patch sizes, removal of movement corridors, and increase grassland patch sizes.

DEDICATION

To my loving and ever-supportive wife and companion, Jennifer Murray-McClain, who followed me half-way across the country to an unfamiliar land so that I could study varmints. This one’s for you, Jennifer.

To my son, Rowan Joseph McClain, who has woken me every morning since his birth with flailing limbs, reminding me to get up, and get to work.

To my mom, Helen McClain, and father, Joseph McClain, who nurtured and supported my love of all things wild.

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INTRODUCTION

Northern bobwhite (*Colinus virginianus*) populations have steadily declined across their range over the last 50 years (Burger *et al*., 2001; Sauer *et al.*, 2011; Morgan *et al*., 2014). Habitat loss and degradation through advanced succession and industrial farming are thought to be the main causes of this decline (Brennan, 1991; Burger *et al.*, 2001). Habitat management has become vital to northern bobwhite conservation (Rosene, 1969; Brennan, 1991; Rollins and Carroll, 2001).

Typical management by the Missouri Department of Conservation (MDC) and across much of the Southeast includes promoting long, linear-edge habitat by creating a juxtaposition of various habitat types including grasslands, woodlands, shrub-scrub, bare ground, timber, strip-crops, and large agricultural fields (Stoddard, 1931; Rosene, 1969; Burger *et al.*, 1995; Taylor and Burger, 1997). However, MDC uses an alternative strategy as well to manage northern bobwhite called the Extensive Management Model. Under EMM the Conservation Area (CA) is grassland dominated, less fragmented, and managed through fire and grazing.

Pilot research (F. Loncarich, MDC, pers. comm) suggested that bobwhite nesting effort and nesting success was higher on EMM than IMM CAs. IMM management may positively impact nest predators both demographically and functionally, possibly resulting in higher nest encounter rates. Mesomammals are the most important group of nest predators (Rollins and Carrol, 2001) and IMM management may be improving habitat for these species (Taylor and Burger, 1997). IMM creates a highly diverse and heterogeneous landscape that researchers have found to be important for raccoons (Gehrt and Fritzell, 1988; Chamberlain et al., 2003), an important nest predator (Fies and Puckett, 2000). Understanding how IMM and EMM affect the nest predator community, density, and habitat use could help guide northern bobwhite management efforts.

I conducted a camera trap study and estimated density for 4 CAs in southwest Missouri to compare how IMM and EMM affected raccoon populations and the predator community. Additionally, I outfitted 9 raccoons from 2 CAs with GPS collars and tracked them through the northern bobwhite nesting season. My objectives were to; 1) compare habitat selection by raccoons living under IMM or EMM management; 2) compare median distances from woody edge into grassland or agriculture habitat patches between IMM and EMM CA raccoons; and 3) create a Utilization Distribution to visualize use hotspots and likely movement corridors by individual raccoons.

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Chapter I

Effects of Northern Bobwhite (*Colinus virginianus*) Habitat Management on Raccoon (*Procyon lotor*) Abundance and Nest Predator Community.

JACOB C. McCLAIN

Abstract

Northern bobwhites suffer high rates of predation at all life stages and habitat management efforts to reduce these predation rates may positively impact bobwhite populations. Current habitat management strategies in southwest Missouri may be beneficial to nest predators like raccoons (*Procyon lotor*). Missouri Department of Conservation (MDC) manages habitat on public Conservation Areas (CAs) under either the Intensive or Extensive Management Model. The intensive management model (IMM) promotes hard-edges by juxtaposing patches of grassland, savanna, shrub-scrub, woodland, timber, strip-crops, and bare ground; while the Extensive Management Model (EMM) uses fire and grazing to maintain grassland-dominated CAs. I conducted a 1 year camera-trap survey on 4 CAs to assess how IMM and EMM affected raccoon abundance, and to document the mammalian nest predator community at each CA. I documented raccoons, Virginia opossums (*Didelphis virginiana*), coyotes (*Canis latrans*), armadillos (*Dasypus novemcinctus*), and bobcats (*Lynx rufus*) at all four CAs. Species richness of potential nest and brood predators were 8 and 6 for IMM CAs and 7 and 8 for EMM CAs. I estimated raccoon densities of 9.9 and 5.6 per km^2 on IMM CAs and 7.2 and 2.6 per km^2 on EMM CAs. There was no difference in raccoon densities between management models, however I did find that raccoon density was positively related to percent forest cover. Raccoon abundance may be limited by availability of denning trees, territoriality, and competition for food resources. Managers with the goal of conserving northern bobwhite populations may be able to limit raccoon populations by reducing forest patch sizes or selectively removing large den trees.

Introduction

Across their range, northern bobwhite populations have been declining for the past 50 years (Morgan *et al*., 2014; Sauer *et al*., 2011) due to habitat loss and through land use changes

(Brennan, 1991; Burger *et al*., 2001). Long term habitat management has become vital to conserve remaining bobwhite populations (Rosene, 1969; Brennan, 1991). Predation is the primary source of northern bobwhite mortality and is thought to be contributing to bobwhite decline in poor habitats (Rollins and Carol, 2001; Cook, 2004). Northern bobwhites are most vulnerable to predation during the egg and chick life stages. Average yearly nest failure, estimated from three long-term studies ranged from 66-82 percent (Rollins and Carol, 2001), suggesting nest predators may be having negative impacts on northern bobwhite populations.

Sandercock *et al*. (2008) modeled northern bobwhite population demographics and predicted that bobwhite populations may not viable based on current survival rates, and that chick survival is one of the most important parameters in explaining population growth/decline. Likewise, Gates et al. (2012) found that nest success was the second most important vital rate when modeling population dynamics for northern bobwhite in Ohio. Therefore, relatively small increases in nesting success rate could have a strong positive effect on population growth, as clutch size averages 12-15 eggs (Rosene, 1969). Indeed, simulations of northern bobwhite demographic responses to elimination of three important nest predator species suggested a 55 percent population increase (Rader *et al*., 2011). Many different species have been documented preying on northern bobwhite nests (Rosene, 1969; Terhune *et al*, 2005), however, mesomammals are the most important group of nest predators (Rollins and Carroll, 2001). Top mesomammal nest predators include raccoons, opossums, striped skunks (*Memphitis memphitis*), nine-banded armadillo (*Dasypus novemcinctus*), bobcats (*Lynx rufus*) and coyotes (*Canis latrans*) (Fies and Puckett, 2000; Staller *et al*., 2005). Research on these mesomammals indicated increasing populations across the Midwest and Southeastern regions (Lovell *et al*., 1998; Hubbard *et al*., 1999) and Burger (2001) argued that a lack of knowledge of the nature of predator communities prevents accurate assessment of habitat quality and understanding of population processes, limiting the effectiveness of management efforts. The diverse community and abundance of mesopredators may respond differently to certain management practices used by private and public entities.

Typical habitat management in the Southeast and in Missouri has focused on creating edge-heavy, highly fragmented landscapes with the juxtaposition of various habitat types including grassland, forest, agriculture, bare ground, and woodland (Rosene, 1969; Burger *et al.*, 1994). Aspects of this intensive management model (IMM), as the Missouri Department of Conservation (MDC) refers to it, has been implemented since the early days of northern bobwhite conservation though disking, planting row crops, and thinning timber(Stoddard, 1931; Rosene, 1969). However, IMM may also improve habitat quality for nest and brood predators, as suggested by Taylor and Burger (1997) after finding high nest predation rates on a site similarly managed in Mississippi. The habitat diversity and high-levels of fragmentation created by IMM may result in greater variety and biomass of resources for mesopredators to use, thereby positively affecting mesopredator population sizes. Research suggests mesopredators are attracted to hard edges, like those created by IMM, because of high prey density (Blumenthal and Kirkland, 1976; Gates and Gysel, 1978; Ratti and Reese, 1988). If IMM does encourage higher densities and greater diversity of mesopredators, bobwhite nest encounter rates by these predators may also be higher.

MDC also manages some CAs under the Extensive Management Model (EMM). Under EMM, MDC uses fire and cattle grazing to create and maintain an open grassland habitat. Compared to IMM, EMM has fewer hard, linear edges and consists of mostly large, contiguous patches of native grasses. Additionally, EMM areas lack the habitat type diversity found on IMM areas. EMM may result in relatively lower mesopredator abundances as habitat homogeneity may make food resources more difficult to find. Indeed, estimated raccoon densities were lowest in grassland systems when compared to other rural habitats (Zeveloff, 2002). Low densities of mesopredators may allow for higher densities of northern bobwhite and other grassland nesting birds.

I hypothesized that raccoon abundances would be higher on IMM CAs than on EMM CAs and that nest predator species richness would be higher on IMM than on EMM CAs. I conducted a 1-year camera trap study of the mesopredator community on two IMM and two EMM CAs managed by Missouri Department of Conservation during the northern bobwhite breeding season. My primary objectives were to: 1) assess how the management treatments affected abundance of raccoons and opossums; and 2) document the mesopredator community present under the two management treatments.

Methods

MDC provided four CAs managed in southwest Missouri as my study sites: 2 IMM CAs including Robert E. Talbot CA (Talbot) and Shawnee Trail (Shawnee) CA, and 2 EMM CAs including Stony Point Prairie (Stony) and Wah-Kon-Tah Prairie (Wah-Kon-Tah) (Fig. 1). Functionally, IMM sites consisted of a mix of habitat types, while EMM sites were dominated by grasslands (Table 1). Talbot CA consisted of 17.6 km^2 of a mixture of habitat types including timber, woodlands, savannas, strip-crop, shrub-scrub, mixed and native grasses, and large agricultural fields. Shawnee CA consisted of 14.9 km^2 of a patchwork of native grassland, old fields, ponds, forest, wetlands, and agricultural fields. Stony consisted of 5.3 km^2 of mostly prairie grasses and forbs with a patchwork of brushy draws, and relatively small amounts of forest. Wah-Kon-Tah consisted of 12.3 km^2 of prairie grasses and forbs, and ~2 percent timber.

All four study sites were ≤ 80 km apart and were located in an agriculture/pasture dominated landscape on the border between the Ozark Plateau and the Central Lowlands (NPS 2017).

I used infrared game cameras to survey mesopredator populations. I mounted camera traps onto trees, fence posts, and stakes at a height between 30 and 90 cm. The overall goal of camera trap placement was to increase photo-capture probability of target species (Royle *et al*., 2013). I chose camera trap locations based on three criteria including: evidence of mesopredator activity (game trails, tracks, and scat), proximity to other camera traps, and overall coverage of study site and habitat types. Distance between active camera traps was <700 m to increase the likelihood that individual raccoon home ranges would include multiple camera trap locations (Chandler and Royle, 2013). I baited camera traps twice per week with 3-4 cups of dry dog food and 1-2 tablespoons of fish oil to attract mesopredators to the camera trap. I checked cameras and collected the imagery data once per week. If a camera documented little to no mesopredator activity for >2 weeks, I moved it to a new location (Royle et al. 2013). I set cameras traps to a 10-minute delay to reduce double-counting.

I camera trapped during the northern bobwhite pre-nesting and nesting seasons (March-September, 2016), and all available camera traps (26) were deployed together on the same CA to increase the photo sample size of raccoons. I camera trapped each CA consecutively, alternating between an IMM and an EMM site and deployed camera traps for between 35-50 days at each of the four CAs. I trapped in the following order: Wah-Kon-Tah, Shawnee, Stony, and Talbot. Because camera trapping did not occur simultaneously across all four CAs, I assumed that adult mesopredator population abundances did not change over the course of the study.

I estimated species richness by counting the number of possible nest predator species detected by cameras at each CA. I considered any mammalian carnivore or omnivore a potential nest predator. I only used images that I could ID the species with 100 percent accuracy.

I used a spatial mark-resight (SMR) model applied to unmarked populations to estimate abundance (Chandler and Royle, 2013) of raccoons on each of the four study CAs using spatially correlated count data from each camera trap in the survey. The SMR model assumed that ≥ 2 camera traps are located within each raccoon's home range. My data met this assumption based on raccoon home range sizes for two of the four CAs (See chapter 2) and those found in previous studies (Pedlar, 1997; Zeveloff, 2002). The SMR model assumed that successive photos were independent. Therefore, I considered capture events independent when >30 minutes had passed between successive photo captures of the same species, and only used independent data in the model (Jimenez *et al.*, 2017). Because the SMR model assumed population closure (Royle et al. 2013); I ignored photo-data of raccoon kits.

The SMR model that I used required that I estimate abundance for a contiguous area. However, because CAs were irregularly shaped, some adjacent private land not managed by MDC was included in the abundance estimation, introducing a confounding factor. However, because > 70 percent of the area consisted of public CA land, I felt that estimates reflected the true impacts of the treatments on abundance. I divided the estimated mean abundance by the total area (km^2) surveyed to estimate raccoon densities on each of the four CAs. I converted abundance estimates to density estimates to allow for comparison among CAs of unequal size. One possible confounding variable would be raccoons that spend part of the time outside the survey area (See chapter 2) would essentially remove themselves from being sampled, making density estimates less precise. Meeting this assumption was most problematic at Stony CA because of its small size compared to the other three CAs. I addressed this concern by deploying 7 cameras on private land surrounding Stony. Models in the SMR family for unmarked populations have been shown to be accurate though simulations (Chandler and Royle, 2013; Jimenez *et al.*, 2017) and were sufficient for my purpose of comparing abundance across four CAs.

I estimated habitat type coverage for each CA using MDC data (MDC, 2017). I compared estimated raccoon densities by percent forest cover with a linear regression.

Results

My camera traps recorded 3,315 images of potential nest/brood predators across the four CAs (Table 2). Raccoon photos (1,508) accounted for 45 percent of the images. The number of camera detections of raccoons were variable among the four CAs (Fig. 2). I documented nest predator species richness of 8, 6, 7, and 8 for Talbot, Shawnee, Stony, and Wah-Kon-Tah respectively. I detected raccoons, opossums, coyotes, armadillos, and bobcats on all four CAs. Talbot had the most photos of raccoons, opossums, coyotes, armadillos, and bobcats. I documented long-tailed weasel only at Talbot, striped skunks only at Shawnee, otters only at Stony, and red foxes only at Wah-Kon-Tah. Additionally, I documented the presence of feral cats at Talbot and Wah-Kon-Tah while feral dogs were present at Talbot, Stony, and Wah-Kon-Tah.

Raccoon abundance was higher at Talbot than any other CA, while raccoon abundance was similar at the remaining three CAs (Fig. 3). I estimated densities of 9.9, 5.6, 7.2, and 2.6 per km^2 for Talbot, Shawnee, Stony, and Wah-Kon-Tah respectively. I did not find any obvious patterns between raccoon densities by treatment type. I did find that estimated densities increased with percent forest cover (Fig. 4).

Discussion

While the management model did not explain raccoon densities, the IMM CA Talbot clearly had the highest raccoon density. Dijak and Thompson (2000) found that at the local scale in Missouri, raccoon abundances were highest in forest edges adjacent to streams and crop fields, similar to those created by IMM. Noren (1941) found that raccoons were abundant in cropland intermixed with woodlands landscapes, a combination more similar to IMM CAs than EMM. Raccoon density at Wah-Kon-Tah was similar to those found in northern prairie habitats (Zeveloff, 2002) while Stony had a raccoon density almost three times that of Wah-Kon-Tah. Because Stony was less than half the size of the other CAs, raccoon abundance may be influenced more by the habitat on surrounding private lands than by the habitat of the CA itself, possibly confounding management effects. Likewise, raccoon densities may have differed between the IMM CAs because Talbot had greater amounts of forest and fewer large agricultural fields than Shawnee Trail.

Raccoon densities on the four CAs may have been influenced by differences in forest cover. Raccoon population sizes may be limited on Shawnee, Stony, and Wah-Kon-Tah, due to lack of denning sites. Nearly 22 percent of Talbot is forest or woodland, while these habitat types on Shawnee, Stony, Wah-Kon-Tah, and make up only 2.7, 4.0, and 1.6 percent, respectively of the total land cover. I found a positive relationship between percent forest and woodland cover and raccoon density in pasture/agricultural landscapes (Fig. 5). Beasley and Rhodes (2012) found evidence that in agricultural landscapes of northcentral Indiana, lack of suitable tree cavities reduced reproductive success and limited local population size of raccoons. Henner *et al*. (2004) found that in southern Illinois, mean forest patch size was positively correlated with selection of daytime resting sites (DRS) by raccoons in an agricultural/prairie landscape. Raccoons are often highly adaptable and will rest and den in other structures such as rock crevices, brush piles, and buildings if forest is not available (Gehrt 2003). However, such alternative DRS may not be in abundance on the agriculture-grassland dominated Shawnee or the grassland-dominated Stony and Wah-Kon-Tah and therefore be limiting population size there.

Differences in forest cover among CAs may also affect how raccoon populations respond to top-level predators such as coyotes. The mesopredator release hypothesis (MRH) states that mesopredator abundances are higher in the absence of a top-level carnivore like coyotes or wolves due to a reduction in predation and competition (Crooks and Soule, 1999; Prugh *et al.* 2009). Cove *et al*. (2012) found a negative relationship between coyote detection and increasing forest cover. Although, coyotes were detected at all four CAs, partial predator release may be occurring on CAs with more woody cover as it may protect individuals from predation, resulting in mesopredator population increases. Larger mesopredator populations could result in high northern bobwhite nest detection rates.

Low amounts of woody cover may affect suitable foraging habitats. Raccoons often appeared on cameras associated with cover such as woody draws, forest edges, and riparian zones; habitat features that are limited on Shawnee, Stony and Wah-Kon-Tah. Barding and Nelson (2008) found raccoons foraged on forest edges more than expected. Likewise, Beasley *et al*. (2007) found raccoons consistently selected forest habitat during the activity hours and suggested that abundance might be dependent on availability of forest cover. Low amounts of woody cover could cause higher rates of competition for resources, resulting in lower raccoon densities.

Camera traps documented some species of the nest predator community including striped skunks, red fox, river otters, and long-tailed weasels <5 times total across all four CAs. This lack of data likely reflects low detection probability rather than low abundances for these species. Hackett *et al.* (2007) found detection probabilities near zero during late spring and summer for eastern spotted skunks in both Arkansas and Missouri using three different techniques. Likewise, Crooks *(*2002*)* found low detection rates of long-tailed weasel. Other survey methods, such as sign surveys (Crimmins *et al.*, 2009), during different seasons may be better suited to assess abundance of certain species. Therefore, no conclusions should be made about the abundances of these species on the CAs based on my results.

Based on my results, managers may be able to limit raccoon populations through reduction in forest cover. I do recognize however that additional research across many sites is needed to better understand the relationship between forest cover and raccoon density. Lower densities of nest predators could result in fewer higher northern bobwhite nesting success, and therefore benefit northern bobwhite populations.

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Table 1. Percentages of each habitat type by Conservation Area in southwest Missouri during the spring and summer of 2016.

Habitat	Talbot	Shawnee	Stony	Wah-Kon-Tah
Old Field	28.9	3.3	0.0	0.0
Forest and Woodland	21.7	2.7	4.2	1.6
Wetland	1.1	0.8	0.0	0.0
Lakes/Ponds	0.7	2.7	0.2	0.3
Crop Land	15.9	40.4	0.0	0.0
Savanna	6.8	0.0	0.0	0.0
Grassland	24.6	50.0	95.6	98.1

Table 2. Survey data collected on possible northern bobwhite nest predators at four Conservation Areas in southwest Missouri using camera traps during the spring and summer of 2016.

Conservation Area	Raccoon	Opossum	Coyote	Armadillo	Red fox	Bobcat	Skunk	Weasel	Otter	Cat	Dog
Talbot	881	692	50	109	0	30	0	1	0	5	3
Shawnee	65	66	28	18	0	1	1	0	0	0	0
Stony	444	262	21	52	0	23	0	0	4	0	2
Wah-Kon-Tah	118	327	38	47	4	2	0	0	0	8	13

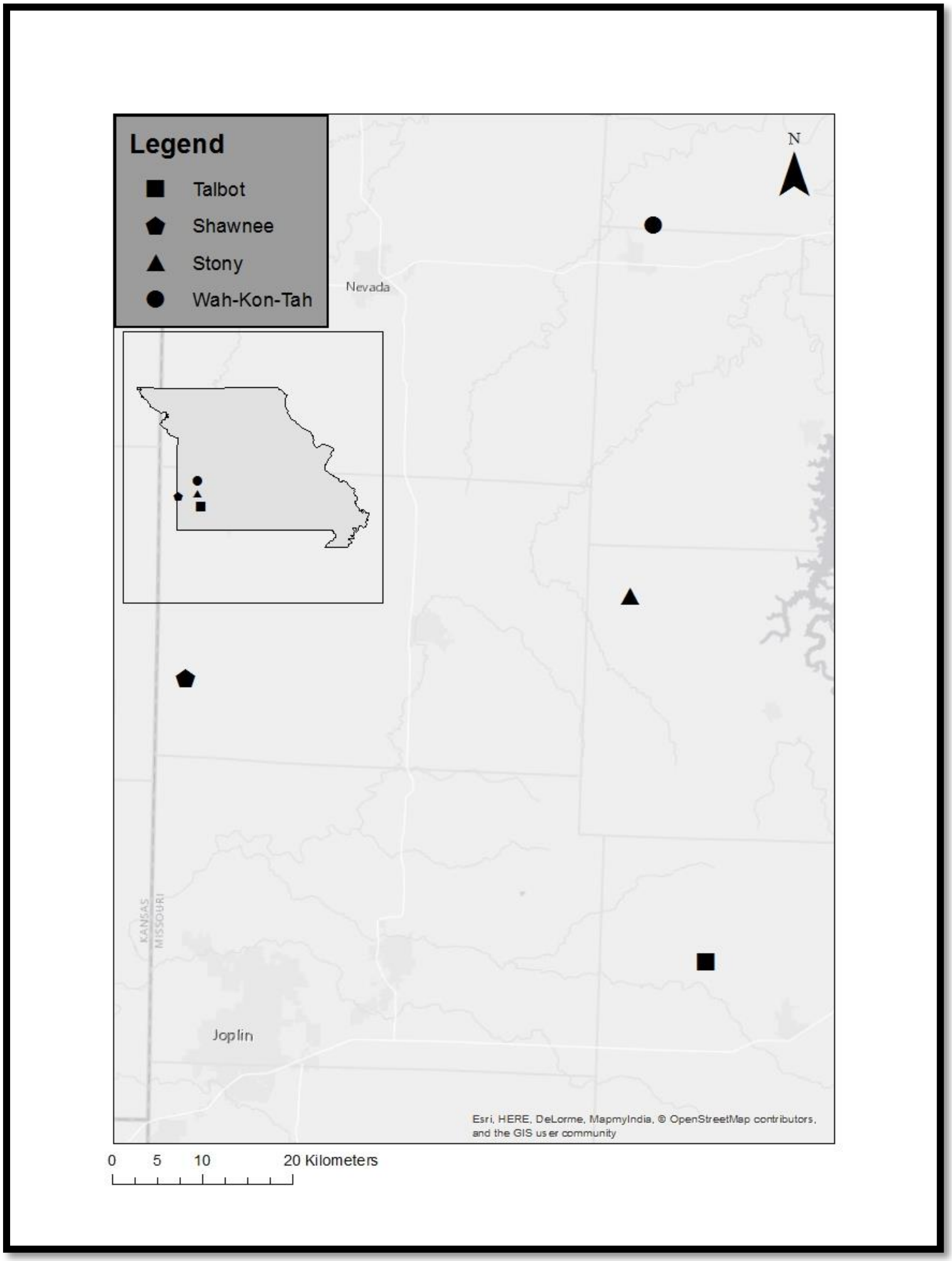


Figure 1. Map depicting locations of Intensive Management Model Conservation Areas Talbot and Shawnee, and Extensive Management Model Conservation Areas Stony and Wah-Kon-Tah in southwest Missouri.

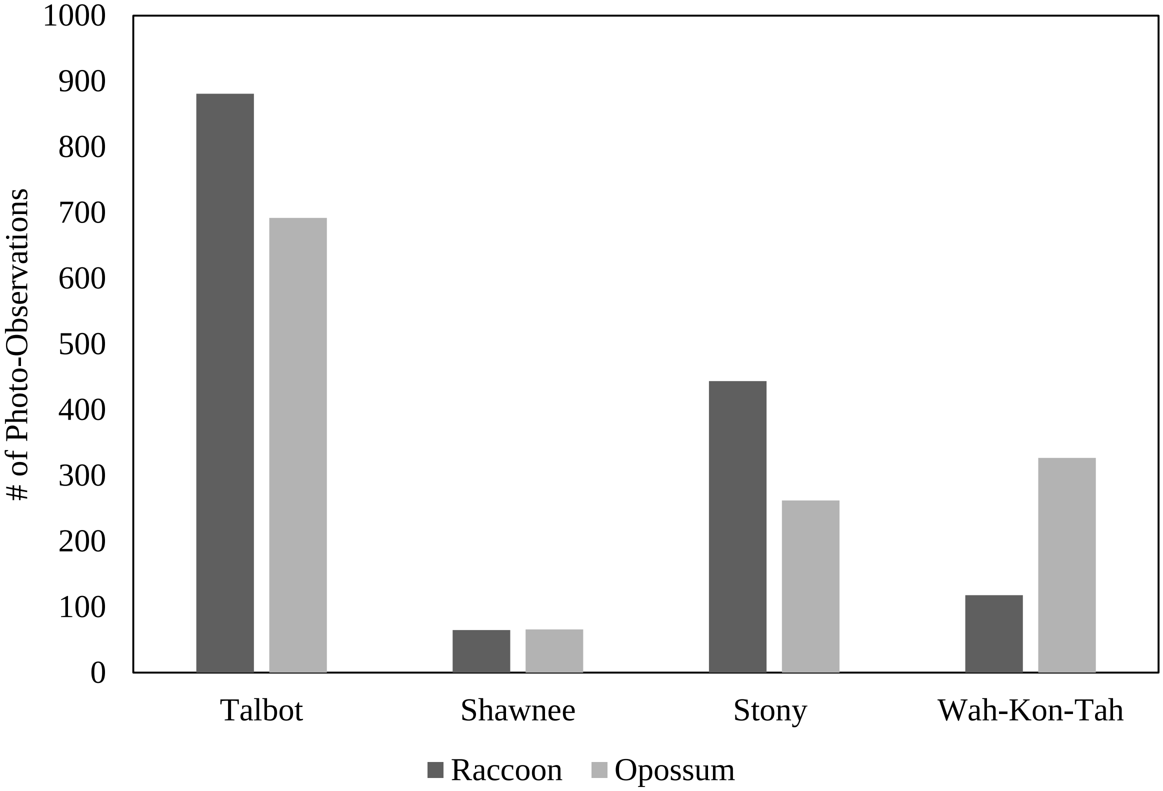


Figure 2. Camera trap data for raccoons and opossums by Conservation Area in southwest Missouri.

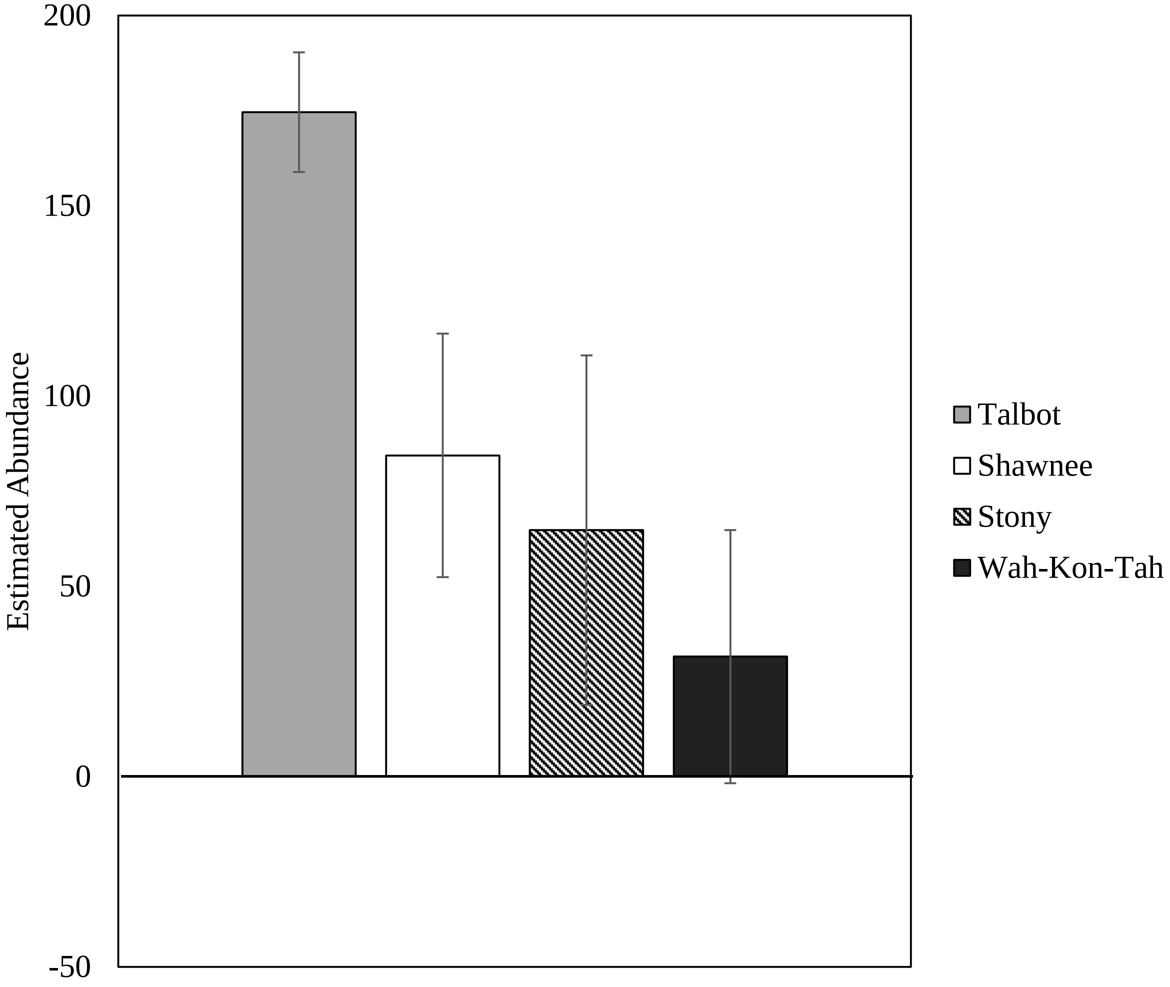


Figure 3. Raccoon abundance estimates and standard deviations at two Intensive Management Model Conservation Areas (Talbot and Shawnee) and two Extensive Management Conservation Areas (Stony and Wah-Kon-Tah) in southwest Missouri during 2016.

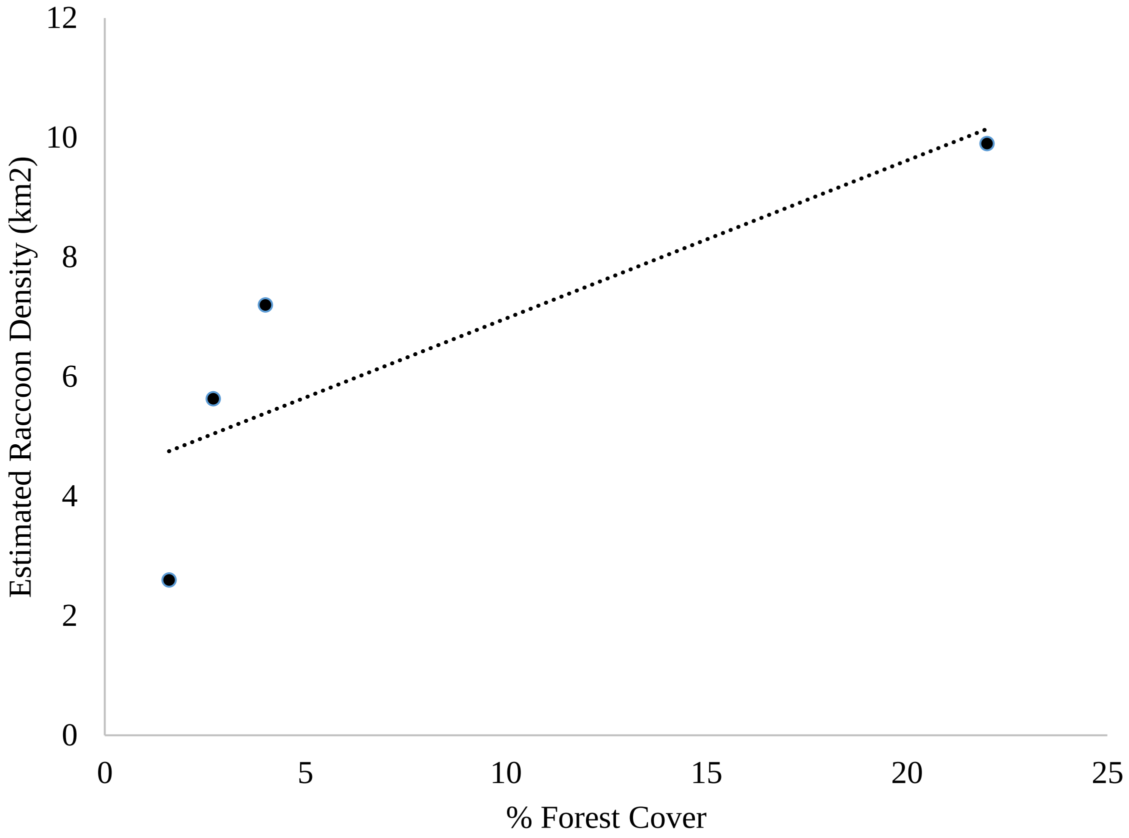
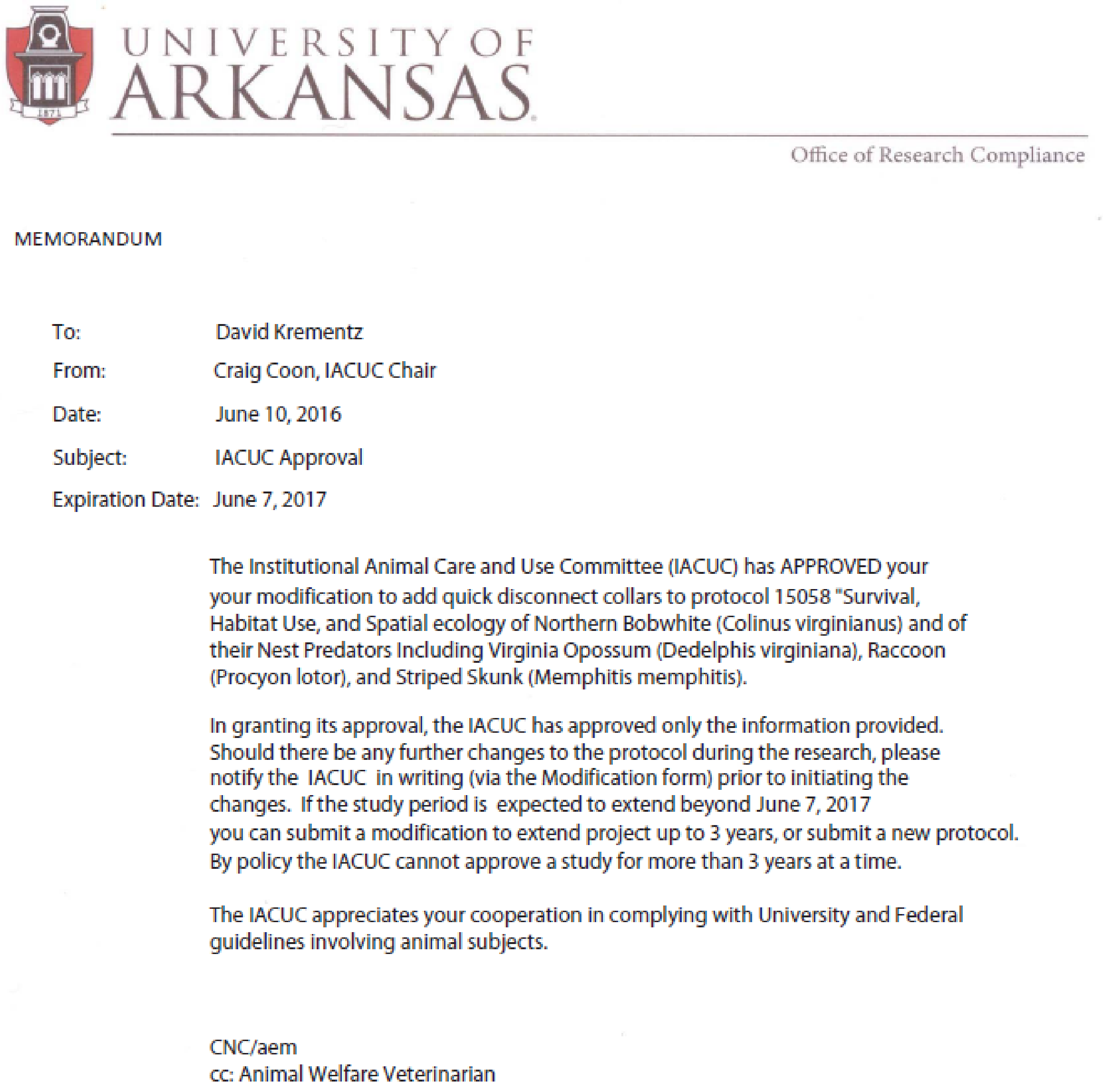


Figure 4. Relationship between estimated raccoon density during 2016 and percent forest for four Conservation Areas surveyed using camera traps in southwest Missouri.

Appendix



UNIVERSITY OF
ARKANSAS
Office of Research Compliance

MEMORANDUM

To: David Krementz
From: Craig Coon, IACUC Chair
Date: June 10, 2016
Subject: IACUC Approval
Expiration Date: June 7, 2017

The Institutional Animal Care and Use Committee (IACUC) has APPROVED your your modification to add quick disconnect collars to protocol 15058 "Survival, Habitat Use, and Spatial ecology of Northern Bobwhite (Colinus virginianus) and of their Nest Predators Including Virginia Opossum (Dedelphis virginiana), Raccoon (Procyon lotor), and Striped Skunk (Memphitis memphitis).

In granting its approval, the IACUC has approved only the information provided. Should there be any further changes to the protocol during the research, please notify the IACUC in writing (via the Modification form) prior to initiating the changes. If the study period is expected to extend beyond June 7, 2017 you can submit a modification to extend project up to 3 years, or submit a new protocol. By policy the IACUC cannot approve a study for more than 3 years at a time.

The IACUC appreciates your cooperation in complying with University and Federal guidelines involving animal subjects.

CNC/aem
cc: Animal Welfare Veterinarian

Chapter II

Effects of Two Management Models on the Habitat Use and Home Range of a Common Northern Bobwhite (*Colinus virginianus*) Nest Predator, the Raccoon (*Procyon lotor*)

JACOB C. McCLAIN

Abstract

Habitat loss has greatly reduced northern bobwhite (*Colinus virginianus*) populations nationwide, and habitat management has become vital to the species' conservation. The Intensive Management Model (IMM) promotes edge, by creating a juxtaposition of different habitat types, while the Extensive Management Model (EMM) uses fire and grazing to maintain a grassland-dominated landscape. Preliminary results in Missouri suggest that bobwhite nesting success and effort is significantly higher on EMM areas than IMM areas. The success of IMM efforts may be reduced by unintentionally managing for nest predators like raccoons (*Procyon lotor*). Raccoons may forage more often in northern bobwhite nesting habitat living on IMM than EMM CAs because fields were smaller, and woody edge and corridors was abundant. I conducted a GPS-telemetry study on two Conservation Areas (CAs) in southwest Missouri to see how IMM and EMM affects raccoon habitat selection, time spent on CA, home range size, and Utilization Distributions (UD). I used a dynamic Brownian Bridge to estimate home range sizes and UDs for each raccoon. Raccoons had an average 95 percent home range of 3.21 ± 0.61 (SE) and 2.844 ± 0.36 (SE) km^2 on the IMM CA and the EMM CA respectively. Based on the estimated UDs, IMM raccoons used tree lines, fencerows, roads, timber-grassland edges, woody draws, and shrub-scrub-grassland edges as movement corridors while EMM raccoons used woody draws, and shrub-scrub-grassland edges. IMM CA raccoons on average spent more time (58 ± 9.3(SE) percent) within the boundaries of the CA than EMM CA raccoons (26.5 ± 9.3(SE) percent). Selection ratios (*w*) suggested that IMM CA raccoons used grasslands more proportionally to availability while EMM CA raccoons avoided grasslands. Both IMM and EMM CA raccoons selected for shrub-scrub and timber. I found that the median distance from a woody edge into grasslands of IMM CA raccoons was greater than that same distance for EMM CA raccoons (t =

2.28; p=0.028). Incidental nest encounter rates by raccoons may be higher on IMM areas as raccoons spend more time on the CA itself, go farther into grasslands, and do not avoid grassland habitat.

Introduction

Northern bobwhite (*Colinus virginianus*) populations have steadily declined across their range over the last 50 years (Burger *et al*., 2001; Sauer *et al.*, 2011; Morgan *et al*., 2014). Habitat loss and degradation through ecological succession and industrial farming are thought to be the main causes of this decline (Brennan, 1991; Burger *et al.*, 2001). Because of these large-scale land use changes, habitat management has become necessary and a common practice for governments and private land owners that are serious about northern bobwhite conservation (Rosene, 1969; Brennan, 1991; Rollins and Carroll, 2001).

Typical management by the Missouri Department of Conservation (MDC) and across much of the Southeast includes promoting long, linear-edge habitat by creating a juxtaposition of various habitat types including grasslands, woodlands, shrub-scrub, bare ground, timber, strip-crops, and large agricultural fields (Stoddard, 1931; Rosene, 1969; Burger *et al.*, 1995; Taylor and Burger, 1997). This type of management creates a highly fragmented landscape and is referred to as the Intensive Management Model (IMM) in Missouri. IMM has been shown to produce suitable habitat for northern bobwhites in certain parts of Missouri (Burger *et al*., 1995) and components (*i.e.* promotion of hard woody edge, planting food plots) of the IMM has been championed and used since the early days of northern bobwhite conservation (Stoddard, 1931; Rosene, 1969). However, implementing IMM through planting crops, disking fields, and thinning timber is expensive, labor intensive, and requires annual efforts.

An alternative management model used by MDC may be more efficient and effective at managing for northern bobwhite. Some CAs owned by the state are managed more holistically under the Extensive Management Model (EMM). EMM CAs are managed through the processes of prescribed fire and grazing cattle. Grazing fees result in a net monetary increase for Missouri Department of Conservation from EMM CAs (F. Loncarich, MDC, pers. comm). EMM CAs lack the habitat type diversity, landscape fragmentation, and large amounts of linear edge found on IMM. Additionally, grassland patches are much larger and contiguous on EMM CAs than those found on IMM CAs. Pilot research (F. Loncarich, MDC, pers. comm) suggests that bobwhite nesting effort and nesting success is higher on EMM than IMM CAs. The vast majority of northern bobwhite nests occur in grassland environments (Stoddard, 1931; Rosene, 1969), and management may impact nest predator use of northern bobwhite nesting habitat.

IMM and EMM may have different effects on nest predators that are believed to have localized effects on northern bobwhite populations (Errington and Stoddard, 1938; Rollins and Carrol, 2001; Staller *et al.*, 2005). Many species across multiple taxa have been documented destroying northern bobwhite nests (Stoddard, 1931; Rosene, 1969), however, mesomammals are responsible for the majority of nest predation events (Rollins and Carrol, 2001). For example, mesomammals accounted for 90 percent and 59.4 percent of nest predation events in studies in Virginia and Florida respectively (Fies and Puckett, 2000; Staller *et al*., 2005). While the species most responsible for nest predation varies from system to system, raccoons are often near the top (Hernandez *et al.,* 1997; Staller *et al*., 2005). Renfrew *et al*. (2003) found that raccoons were one of the most common nest predators of grassland birds. Land use changes and certain management strategies may positively influence predator efficiency and make northern bobwhite more vulnerable to predation (Hurst *et al*., 1996; Rollins, 1999), therefore exacerbating population declines.

Differences in habitat selection of nest predators like raccoons may be the cause of lower nest success rates on IMM sites when compared to nest success rates on EMM sites. IMM may positively impact nest predators both demographically and functionally by providing high habitat heterogeneity, high fragmentation, and large amounts of linear woody edge, possibly allowing for larger populations and increased foraging efficiency. These habitat modifications may be limiting northern bobwhite reproductive success. Burger *et al*. (1994) demonstrated a significant negative relationship between artificial northern bobwhite nest predation rates and prairie fragment size. IMM may increase grassland habitat use by mesopredators like raccoons because in Alabama, raccoons were found to select small, grassy openings when foraging (Fisher, 2007) – not the large grassland openings managed for under EMM. Raccoons and other mammalian nest predators may spend more time foraging in open grassland habitats if escape cover in the form of woody vegetation is in abundance nearby. Renfrew *et al*. (2003) demonstrated that radio-marked raccoons stayed within 150 m of woody vegetation. Likewise, long-linear landscape elements such as edge habitat, fencerows, and tree-lines are common on IMM CAs and may concentrate predator activity and increase nest encounter rates of edge-nesting birds like the northern bobwhite (Newbury and Nelson, 2007; Rich *et al*., 1994). Indeed, Barding and Nelson (2008) found that raccoons in northern Illinois followed linear habitat features as they foraged.

I conducted a 1-year GPS telemetry study of raccoons at two Conservation Areas (CAs) in southwest Missouri during the northern bobwhite nesting season. One of my objectives was to compare habitat selection by raccoons at the population and individual (2nd order) levels (Johnson, 1980) between CAs under IMM and EMM. At the population level I estimated separate selection ratios (*w*) for each study site at the CA (only used GPS points where raccoons were within the boundaries of the CA) and landscape scales (used GPS points from CA as well as surrounding private land). I hypothesized that IMM raccoons would use grassland habitats proportional to their availability while raccoons living on a grassland-dominated EMM CA would avoid open grassland areas. I also compared median distances from woody edge into the grassland and hypothesized that IMM raccoons go farther into grasslands than EMM raccoons. I also estimated home range size and UDs for each individual raccoon to determine movement corridors and use hotspots to identify possible danger zones for nesting northern bobwhite. Additionally, I analyzed northern bobwhite nesting habitat selection using basic summary statistics from data provided by MDC.

Methods

I selected two CAs in southwest Missouri: Robert E. Talbot CA (IMM) and Stony Point Prairie (EMM) (Fig. 1). Habitat on the IMM CA consisted of a juxtaposition of timber (>50 percent canopy cover), woodlands (30-50 percent canopy cover), savannas (<30 percent canopy cover), strip-crop (fields <4 hectares buffered by thin strips {~30m} of idle soil), shrub-scrub (dominated by shrubs, brush, and young trees), grassland (mixed, native, and cool season grasses), and agricultural fields (fields >0.04 km^2). Conversely, habitat on the EMM CA consisted of grassland (native grasses) with relatively small amounts of timber and shrub-scrub. Grassland patches were on average 0.10 and 0.20 km^2 in size for the IMM CA and the EMM CA. Study sites were <40 km from one another and both were located in a pasture/grassland dominated landscape between the Ozark Plateau and the Central Lowlands (NPS 2017).

I trapped raccoons on both study areas during June and early July, 2016 using live-traps baited with dog food and fish oil. Trap sites had two traps open at any one time and were located

>400 m from one another. Trapped raccoons were anesthetized using isoflurane gas (Bentler *et al*., 2012). I determined sex based on the presence of testicles or nipples and recorded body mass. I classified raccoons into two age groups: immature and mature. Because trapping occurred in June I assumed individuals with a mass > 3.5 kg were >1 year of age given that immature raccoons would not have the time to reach such body size given an average birth date of mid-April and known growth curves for this species (Sanderson, 1961; Sanderson and Nalbandov, 1973). All research and handling of raccoons followed the approved Institutional Animal Care and Use Committee (IACUC) protocol #15058-1.

I attached LiteTrack GPS collars (Lotek Wireless Inc, Newmarket, Ontario) to raccoons >1 year old on the IMM CA (n=5) and the EMM CA (n=4) (Table 1). Individuals with a mass (>3.5 kg) were selected and collared in order to insure that the GPS collar (~150g) would be less than 5 percent of the animal's body weight (Silvy, 2012). I only GPS-collared one individual raccoon at each trapping site. I programed GPS collars to collect location data every 30 minutes between 20:00 and 07:00. I set the GPS schedule to match with raccoon foraging hours based on game camera data from the previous year for both CAs, and on Carver *et al*. (2011) who found the bulk of remotely triggered photos occurred between 20:00 and 06:00. Data were stored on board the GPS unit and were remotely collected from the date of trapping to when the collar stopped functioning. GPS tracking coincided with the northern bobwhite breeding season, starting in early spring and extending through early fall (Stoddard, 1931; Rosene, 1969).

I estimated 95 percent home ranges and Utilization Distributions (UDs) for each individual using dynamic Brownian Bridge Movement Models (dBBMM) (Kranstauber *et al*., 2012, 2013; R package= "*move*"). I used UDs from the dBBMM to identify expected movement pathways, and used hotspots of individual raccoons (Horne *et al*. 2007). I calculated the mean and standard errors of percent time spent within the CA for the IMM and EMM sites using the GPS locations. Discontinuous core use areas may be a result of an arbitrary smoothing factor of the dBBMM.

I collected used and available habitat data under designs II and III of Manly *et al*. (2002). Design II compares use to availability at the population level within the study area. In design III, habitat selection is considered at the individual raccoon level, as use is compared to availability within an animal's home range.

I estimated habitat type selection by raccoons using design II at the landscape and CA scales using selection ratios (*w*) as described by Manly *et al*. (2002) in Microsoft excel. I created a minimum convex polygon (MCP) in a GIS around all raccoon GPS locations for each CA. I used the MCP to calculate habitat availability at both the landscape and CA scales (Fig. 2). The advantage of using two scales is that analysis of raccoon habitat selection of only the CA, where habitat management is occurring, will not be affected by how raccoons behave on the adjacent private land.

I used selection ratios (Manly *et al*., 2002) to examine variation in habitat selection among individual raccoons within the boundaries of their 95 percent home range (design III) that I estimated using the dBBMM. Selection ratio values >1 indicated selection, values <1 indicated avoidance of a habitat type, and values close to 1 indicate proportional use (Manly *et al*., 2002). I calculated the total area (km^2) and proportion of each habitat type within the 95 percent home range of each animal using a GIS to be used as availability data for selection ratio analysis for each raccoon.

I calculated the distance to woody edge (m) from a point located in a non-woody habitat such as grassland for each used point using a GIS. To examine the median distances that raccoons moved into grasslands from a woody edge by treatment type, I calculated the mean of the median distances by individual raccoons. I used a one-tailed t-test to compare the mean of the median distances across raccoons between treatment types using program R (R Core Team 2016. R Version 3.3.2).

Although there were sex ratio differences between the number of GPS-collared raccoons on the IMM and the EMM CAs (see below), I found no significant habitat selection differences between males and females. Hence I performed all analyses without regard to sex. Analysis of individual selection ratios (*w*) revealed no obvious differences between males and females in regards to habitat type selection (Table 2). Additionally, Fisher (2007) found raccoon habitat selection did not differ by sex and Chamberlain *et al*. (2003) found no sex differences in habitat associated with raccoon locations. I found no difference between male and female median distance to woody edge (t-test, $t = 0.34$, p-value $= 0.75$).

I was provided northern bobwhite nest location data for the IMM CA (2 years) and the EMM CA (3 years) by MDC. MDC trapped and radio-collared northern bobwhite coveys from December to February. MDC documented active nests by tracking females. I compared nest habitat and distance to woody edge for nests that were available to GPS-collared raccoons by selecting nests that were within the MCPs described above. I calculated the distance to woody edge (m) and habitat type for each nest using a GIS. I estimated the mean distance to woody edge (m).

Results

I marked 4 males and 1 female raccoon at the IMM CA and 1 male and 3 female at the EMM CA. GPS collars were functional for variable periods of time because collars were deployed and failed at different times during the study (Table 1).

Raccoons had similar 95 percent home range and core use area sizes under IMM and EMM (Fig. 3). Raccoons spent on average, almost twice the time within the boundaries of the IMM CA than the EMM CA (Fig. 4). Estimated UDs suggested that hotspots for both IMM and EMM raccoons centered on timber-grassland and shrub-scrub-grassland edge habitats (Figs. 5-6). UDs revealed likely movement pathways included tree lines and shrub-scrub riparian corridors for EMM raccoons (Fig. 6). UDs for IMM raccoons also revealed use of tree lines, woody draws, roads, and strips of shrub-scrub as movement corridors (Fig. 5). UD maps suggest that some IMM raccoons use what I will refer to as broken tree lines, where at times the distance between trees or other woody cover would be >40 m apart (Fig 5).

All individual raccoons were documented in multiple habitat types during foraging hours, however at the IMM CA, three individuals completely avoided some habitat types including strip crop, savanna, and woodland within their home ranges. Selection ratio analyses at the 95 percent home range level revealed variation in habitat preferences among individual raccoons at both the IMM and EMM CAs. However, all IMM CA and EMM CA individuals had selection ratio values of <1 for grassland indicating some degree of avoidance of this habitat type (Table 2). Most individuals from both the IMM and the EMM CA had selection ratios >1 for ponds, timber, and shrub-scrub, suggesting that most individuals preferred these habitat types.

I found that within the boundaries of the CA, raccoons as a population selected and avoided certain habitat types at both the IMM and the EMM CAs (Fig. 7). Raccoons avoided grasslands on both the IMM CA and the EMM CA. However, IMM CA raccoons had a grassland selection ratio (w = 0.87 ± 0.05 (SE)) more than twice that of EMM CA raccoons, and near a value of 1.0 indicating more proportion selection to availability of that habitat type . Both IMM and EMM CA raccoons selected shrub-scrub and timber habitats. Raccoons on the IMM CA also selected agriculture and avoided strip crop, and woodland habitats. IMM CA raccoons used savanna proportional to availability. Raccoons on the IMM CA selected ponds (*w* = 11.2 ± 7.1 (SE)) while EMM CA raccoons avoided ponds (*w* = 0.45 ± 2.93 (SE)). Ponds were rare on the landscape of both the IMM and the EMM CA.

I found evidence for habitat selection by IMM and EMM CA raccoons at the landscape level (Fig. 8). At the landscape level, IMM and EMM CA raccoons positively selected for shrub-scrub and timber habitats and avoided grassland. I found IMM CA raccoons showed no preference for agriculture, timber, or shrub-scrub habitat types. EMM raccoons avoided agricultural habitats at the landscape level. At the landscape level both IMM (*w* = 8.4 ± 2.8 (SE)) and EMM CA (*w* = 5.2 ± 1.5 (SE)) raccoons selected for ponds. Additionally, I found that IMM CA raccoons (76.1 m) traveled farther away from woody edges than EMM raccoons (39.5 m) when in open habitat types (t = 2.28, p=0.028).

MDC found 51, 3, and 1 nests in grassland, shrub-scrub, and timber respectively on the EMM CA. On the IMM CA, 17, 6, 2, 1, 1, and 1 nests were located in grassland, strip crop, agriculture, shrub-scrub, savanna, and woodland respectively. EMM CA nests were located 124 ± 12.5 m (SE) from a woody edge while nests on the IMM CA were 108 ± 15.1 m (SE) from a woody edge (Figure 9).

Discussion

Home ranges and core use areas of raccoons on the IMM and EMM sites were similar in size. Similarities in home range estimates may be explained by EMM CA raccoon use of private land off the CA, where the landscape was far more similar to IMM, possibly resulting in more similar habitat use and foraging strategies. Surrounding private land at the EMM CA consisted of agricultural fields, woodland, tree-lines and small patches of forest. Additionally, mean home range estimates may have been similar because of sex differences. Home range sizes are often larger for males than females (Gehrt and Frttzell, 1997). However given the large variation in home range sizes among individuals of the same sex within a given population, I believe it unlikely that there were true significant differences between home range sizes of animals living on IMM vs EMM. Home ranges were slightly larger than those previously found (2.66 ± 0.14 km^2 for males; 1.22 ± 0.52 km^2 for females) in grassland-dominated systems with interspersed woodlands in Kansas (Kamler and Gipson, 2003a).

Utilization Distributions showed IMM CA raccoons used tree lines, fencerows, roads, timber-grassland edges, woody draws, and shrub-scrub-grassland edges as movement corridors while EMM CA raccoons used woody draws, and shrub-scrub-grassland edges. My results were consistent with Pedlar et al. (1997) who found that raccoons frequently used fencerows and other features associated with woody cover, and Barding and Nelson (2008) who found that raccoons in northern Illinois followed linear habitat features as they foraged. Northern bobwhite nests located along or nearby tree-lines, woody draws, and timber-grassland edges may be in greater danger of being destroyed by raccoons than nests not associated with these features. Ellison et al. (2013) found that raccoon activity nearly ceased, and grassland bird nesting densities increased after the removal of tree rows at sites in Wisconsin when compared to control sites. Reducing woody edges and corridors may limit raccoon use of northern bobwhite nesting habitat, and therefore nest encounter rates.

All individual raccoons were documented in multiple habitat types during foraging hours, demonstrating that raccoons were feeding on a diversity of resources. Variability in selection ratios (*w*) of top selected and avoided habitats of individual raccoons within the same population suggest variation in habitat preference and adaptability among individuals within the IMM and EMM CAs. All individuals from the EMM CA used all habitat types available within their 95 percent home range, while only two of five raccoons from the IMM CA used all habitats available to them. In other systems, raccoons have been documented using all available habitat types and landscape heterogeneity is likely important when establishing home ranges (Byrne and Chamberlain, 2011). The habitat heterogeneity of the IMM CA may allow raccoons to optimize foraging by selecting patches where resources are high while ignoring others depending on seasonal availability of resources. Likewise, the lack of habitat heterogeneity on the EMM CA may explain why raccoons spent more time off the CA on private land. Therefore, one consequence of EMM is the development of a less diverse system that may be less attractive to mesopredators like raccoons.

Significant selection against grasslands for both IMM CA and EMM CA populations at the landscape level suggests that raccoons focus foraging efforts in other habitat types. Newbury and Nelson (2006) found that raccoon pathways were highly linear, not tortuous, on grassland reserves, suggesting nest searching was not occurring. Nest encounter by raccoons on the IMM and EMM CAs may occur incidentally when individuals, moving through a field to get to, or back from, foraging sites, flush incubating birds or pick up a scent and then opportunistically take the eggs. IMM CA raccoons, when foraging within the boundaries of the study area, likely use grasslands more frequently than the EMM CA raccoons, which may result in higher nest encounter and encounter rates. Open grassland fields on EMM CAs are larger in size than those found on the IMM CA. Raccoons may be more likely to forage in, or cross through, the smaller fields created by IMM (increasing the rate of nest encounter), than the larger prairie fields found on EMM CAs. Grassland habitats contained 61 and 92 percent of all documented northern bobwhite nests on the IMM CA and EMM CA respectively. EMM CA raccoons strongly avoided grassland habitats, while IMM raccoons used grasslands proportional to their availability which may result in higher rates of nest encounter.

I found that EMM CA raccoons were avoiding the interior of large contiguous habitat patches such as grasslands and favored foraging along timber-grassland and shrub-scrub grassland edges. IMM CA raccoons had an average median distance to woody edge of almost twice that of EMM CA raccoons, suggesting that IMM allows for greater movement into open habitats like grasslands. Renfrew et al. found that raccoons would only travel up to 150 m from wooded areas (2003). While northern bobwhite nests on the IMM and EMM CAs, on average were similarly located, in terms of distance to woody edge, because IMM CA raccoons travel farther into open habitats such as grasslands, a greater proportion of nests would be available to them.

Raccoons in my study system may be avoiding more open habitats to avoid detection and predation by coyotes (*Canis latrans)* or bobcat (*Lynx rufus*) which have been documented as raccoon predators in other systems (Cepek, 2004; Kamler and Gipson, 2003b; Tewes *et al*., 2002). Gehrt and Prange (2007) found that 45 percent of raccoon home ranges had <10 percent overlap with coyote core use areas, and only 14 percent of raccoons exhibited >50 percent overlap, suggesting that raccoons were avoiding areas where coyotes were especially active. I detected coyotes on both CAs using game cameras (See chapter 1).

IMM CA raccoons at the landscape and study area scales disproportionately used ponds to their availability, possibly to prey upon crayfish, frogs, and fish. Some individual ponds had few or no visits from GPS-collared raccoons perhaps due to low forage availability, lack of woody cover, territoriality, or steep banks making foraging difficult. About ~ 6 percent of individual raccoon points were located at ponds at the IMM CA. While 6 percent may seem like raccoons did not depend too heavily on ponds, foraging efficiency may be high because of high prey densities, allowing raccoons to shorten foraging periods. Therefore, ponds appear to be a very important habitat type for IMM CA raccoons. EMM CA raccoons used ponds on private land but avoided those on the Conservation Area itself. Raccoons may have avoided ponds within the EMM CA because they were located ~300 and ~275 m from any relatively large, contiguous patch of woody habitat, which would force individuals to cross open grassland where they may be more susceptible to predation. As stated above, Renfrew et al. found raccoons stay within 150 m from wooded areas (2003), and our results suggest that raccoons generally stay within 200 m of woody vegetation, preventing raccoons from foraging in most ponds located on the EMM CA. Likewise, as previously stated, Burger *et al*. (1994) demonstrated that artificial northern bobwhite nest predation rates were higher in prairie fragments < 0.15 km^2. Grassland patches were on average 0.10 and 0.20 km^2 on the IMM CA and the EMM CA respectively. Additionally, heavily used, nearby riparian shrub-scrub and timber habitats may have provided greater escape cover and possibly better foraging opportunities than that found around ponds. EMM may cause raccoons to be more reluctant to cross open grassland habitats, likely lowering the northern bobwhite nest encounter rate.

IMM CA and EMM CA raccoons also positively selected for shrub-scrub at both the landscape and study area levels, possibly to forage on fruits. Blackberries (*Rubus* spp.), American plum (*Prunus americana*), and common persimmon (*Diospyros virginiana*) and other fruits which are common on our study areas are important forage for raccoons in many systems (Schoonover and Marshall 1951, Smith and Kennedy 1987). Additionally, shrub-scrub habitats within our study areas were also often associated with riparian zones which would provide forage in the form of crayfish, frogs, and other animals known to be eaten by raccoons (Johnson, 1970; Smith and Kennedy, 1987). Shrub-scrub would also provide enough cover for raccoons to climb into to escape predation by coyotes and possibly bobcats. Although MDC documented few northern bobwhite nests within shrub-scrub habitat, many nests were found in the adjacent grasslands.

Based on my results, EMM may be a superior management model for reducing northern bobwhite nest encounter by raccoons. EMM CA raccoons foraged closer to woody edges than IMM CA raccoons, providing more safe spaces for northern bobwhite to nest in because woody cover is relatively limited on EMM CAs. Additionally, limited habitat heterogeneity on EMM CAs may explain why raccoons establish part of their home ranges on adjacent private land where there was a greater habitat variety and possibly, resources to utilize. A raccoon that mainly forages off the CA, like what I documented at the EMM CA, greatly reduced its probability of encountering a northern bobwhite nest.

On the IMM CA, woody edge is linear, abundant, and never far off, allowing for greater use by raccoons of relatively smaller grassland areas where the observed majority of northern bobwhites were nesting. Management for northern bobwhite has emphasized the establishment of woody cover as a key to successful habitat management (Stoddard, 1931; Rosene, 1969), however based on my data, I believe the IMM may create woody edge that benefits mesopredator populations more than northern bobwhite populations. More research is needed on the effects of how cover is distributed and maintained across the landscape and its effects on both northern bobwhite and the mesopredator community. Cover is abundant on the EMM CA, the majority of which is in the form of brush, thickets, and woody draws, rather than the linear, hard woody edges created via IMM. EMM management may provide all the benefits of woody cover that northern bobwhite need while reducing encounter rates with raccoons.

Managers may be able reduce raccoon use of northern bobwhite nesting habitat through reduction in timber-patch sizes, removal of woody corridors such as tree-lines and increase grassland patch sizes. Likewise, pond placement may be important to consider as IMM raccoons showed heavy preference for ponds that were often surrounded by grasslands. As a result, as raccoons move to and from grassland-associated ponds, the probability of encountering/detecting a nest likely increases. If ponds are a necessary part of a management plan they may be less attractive to raccoons if placed either within or far from woody cover which would reduce movement of raccoons through grassland habitats.

Understanding how management influences nest predator (*e.g.* raccoons) foraging activity and space use is important for effective conservation of populations of northern bobwhite (Burger, 2001: Rollins and Carroll, 2001). Future work should focus on how IMM and EMM affect the habitat selection of other key nest predators such as opossums, skunks, and snakes. Identifying problem species would allow for precise management to reduce nest encounter rates and possibly allow for larger northern bobwhite populations. Likewise, ensuring that top carnivore species like coyotes remain present in both IMM and EMM CAs should limit raccoon use of northern bobwhite nesting habitat. This study provides information on how two management strategies affects the avoidance/preference of habitat types and home range and core area use sizes of raccoons. Understanding differences in habitat selection and home range will help managers create environments which limit raccoon use and reduce nest encounter rates.

Acknowledgements

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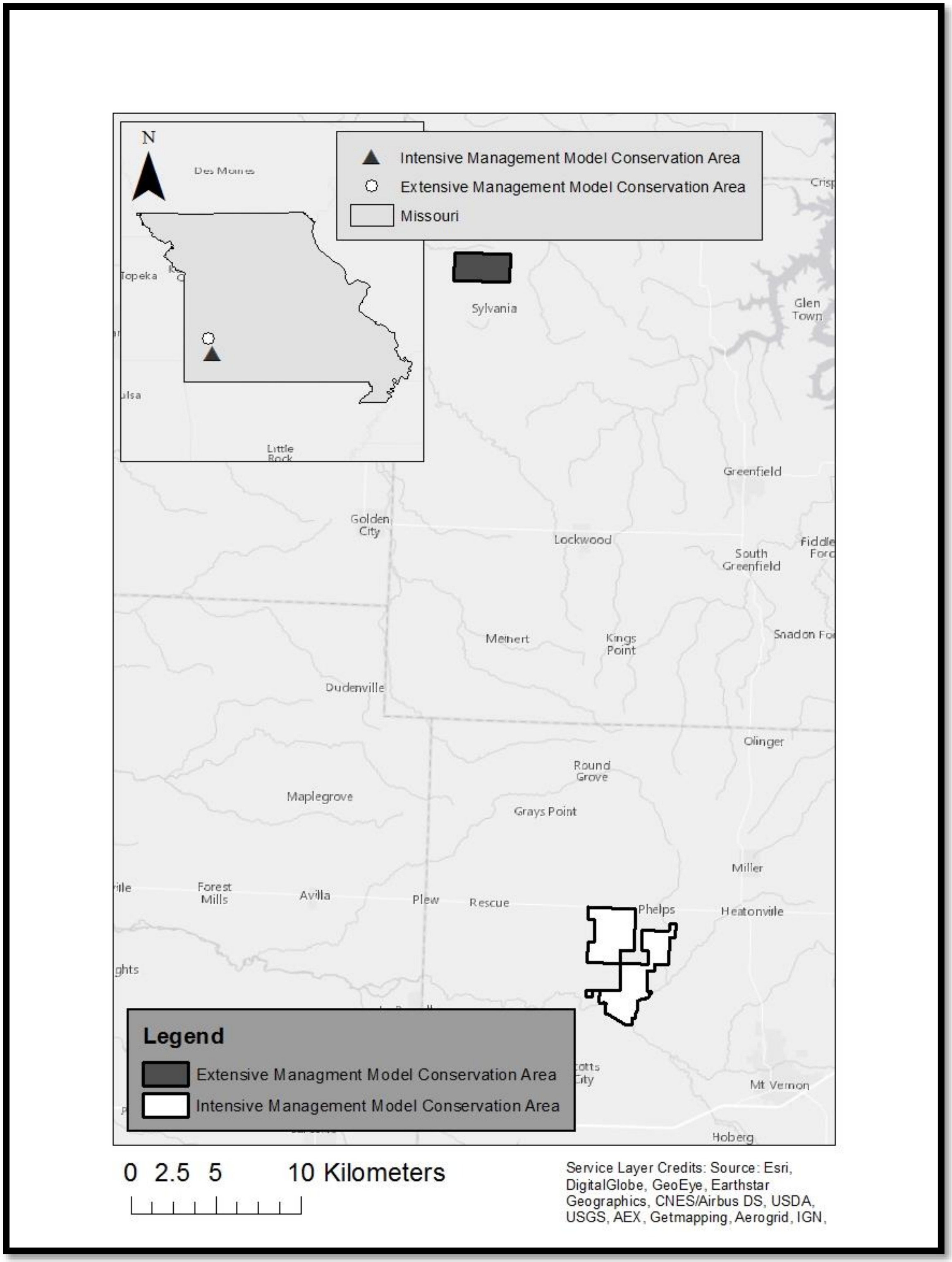
Table 1. Histories for each raccoon collared with a GPS collar (*Procyon lotor*) on tow Conservation Areas study sites under different management models in southwest Missouri during 2016.

Management Model	GPS ID #	Start Date	End Date	Days Tracked	Points Collected	Sex
Intensive	30109	2016-06-09	2016-10-18	131	2440	M
Intensive	30110	2016-07-16	2016-07-29	13	202	F
Intensive	30113	2016-06-10	2016-08-15	66	1006	M
Intensive	30115	2016-06-29	2016-07-19	20	330	M
Intensive	30118	2016-06-24	2016-08-28	65	1248	M
Extensive	30111	2016-06-16	2016-08-09	54	781	F
Extensive	30114	2016-07-02	2016-09-11	71	1141	M
Extensive	30116	2016-06-22	2016-09-16	86	1641	F
Extensive	30117	2016-07-02	2016-10-19	109	1832	F

Table 2. Habitat selection ratios for each individual GPS-collared raccoon by management Model. Selection ratio values >1 indicate preference while those <1 indicate avoidance.

Management Model	GPS ID #	Sex	Agriculture	Grassland	Pond	Savanna	Strip Crop	Shrub-Scrub	Timber	Woodland
Intensive	30109	M	0.087	0.777	4.386	0.497	0.334	1.457	3.703	0.621
Intensive	30113	M	0.575	0.780	16.344	0.000	-	2.343	1.538	0.128
Intensive	30115	M	1.847	0.852	0.942	-	0.000	0.434	2.326	0.000
Intensive	30118	M	1.805	0.839	2.314	-	3.314	0.909	0.839	-
Intensive	30110	F	-	0.124	-	0.000	0.258	2.909	1.436	0.000
Extensive	30111	F	0.687	0.519	-	-	-	0.379	2.841	2.955
Extensive	30116	F	0.822	0.227	0.574	-	-	5.525	2.806	-
Extensive	30117	F	0.966	0.800	12.169	-	-	0.636	1.568	-
Extensive	30114	M	1.118	0.534	9.158	-	-	4.220	1.789	-



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN,

Figure 1. Two study sites in southwest Missouri USA where raccoons were trapped, GPS-collared, and tracked in the summer and autumn of 2016.

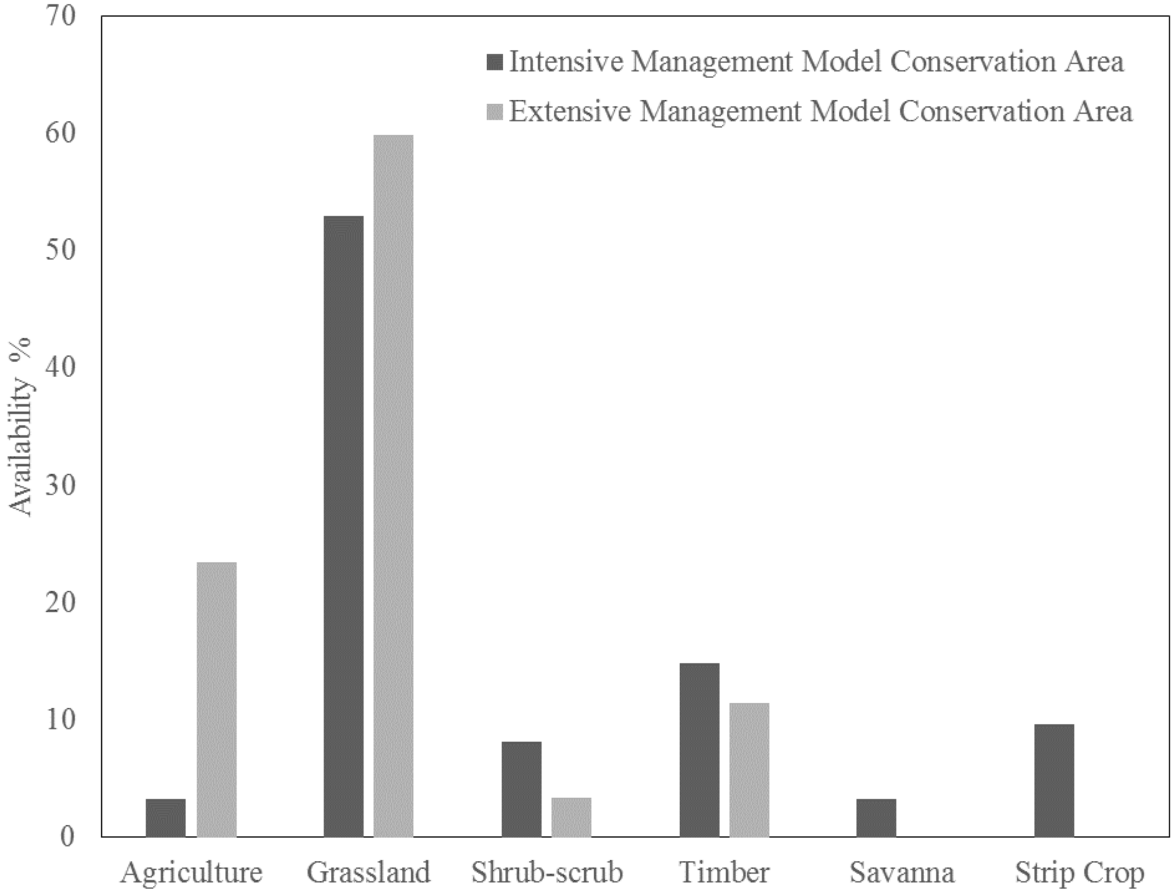


Figure 2. Habitat type availability at the landscape level by Conservation Area.

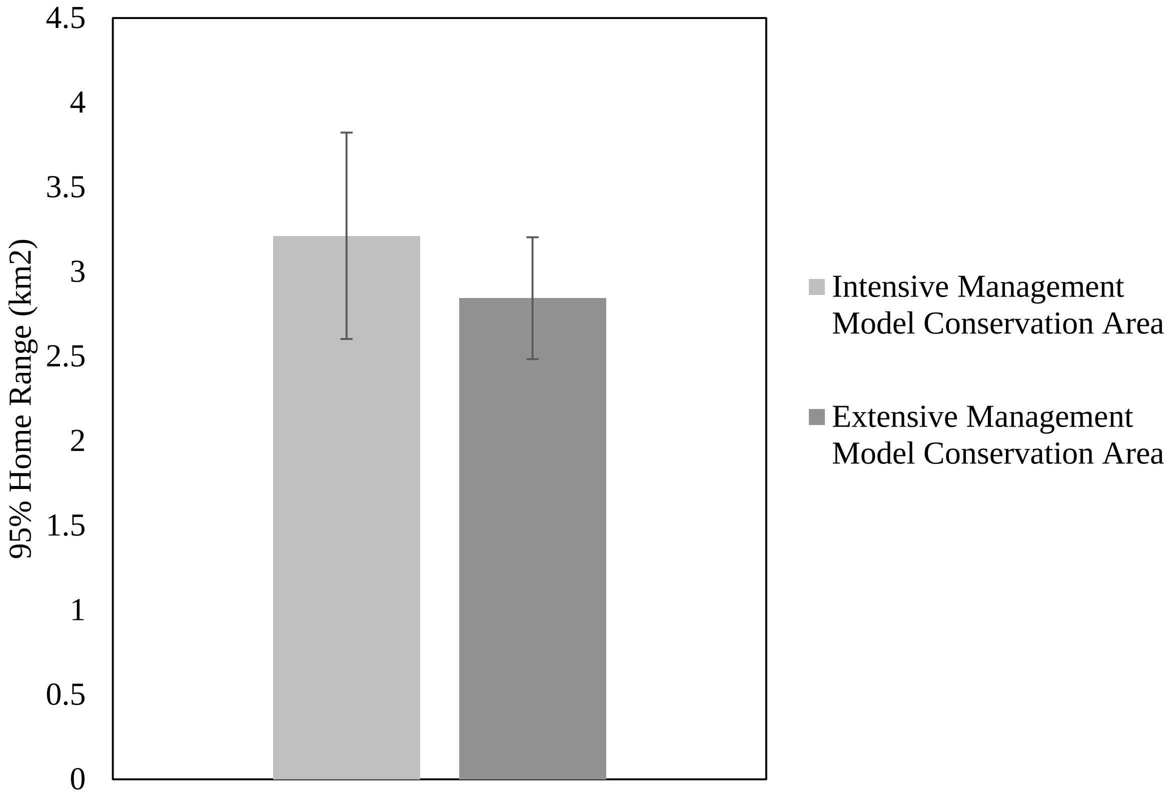


Figure 3. Means and standard errors of 95percent home ranges derived from the dynamic Brownian Bridge Utilization Distributions (UDs) for five raccoons living under the Intensive Management Model, and four raccoons living under the Extensive Management Model. Data used for these estimates were collected during the summer and early fall of 2016.

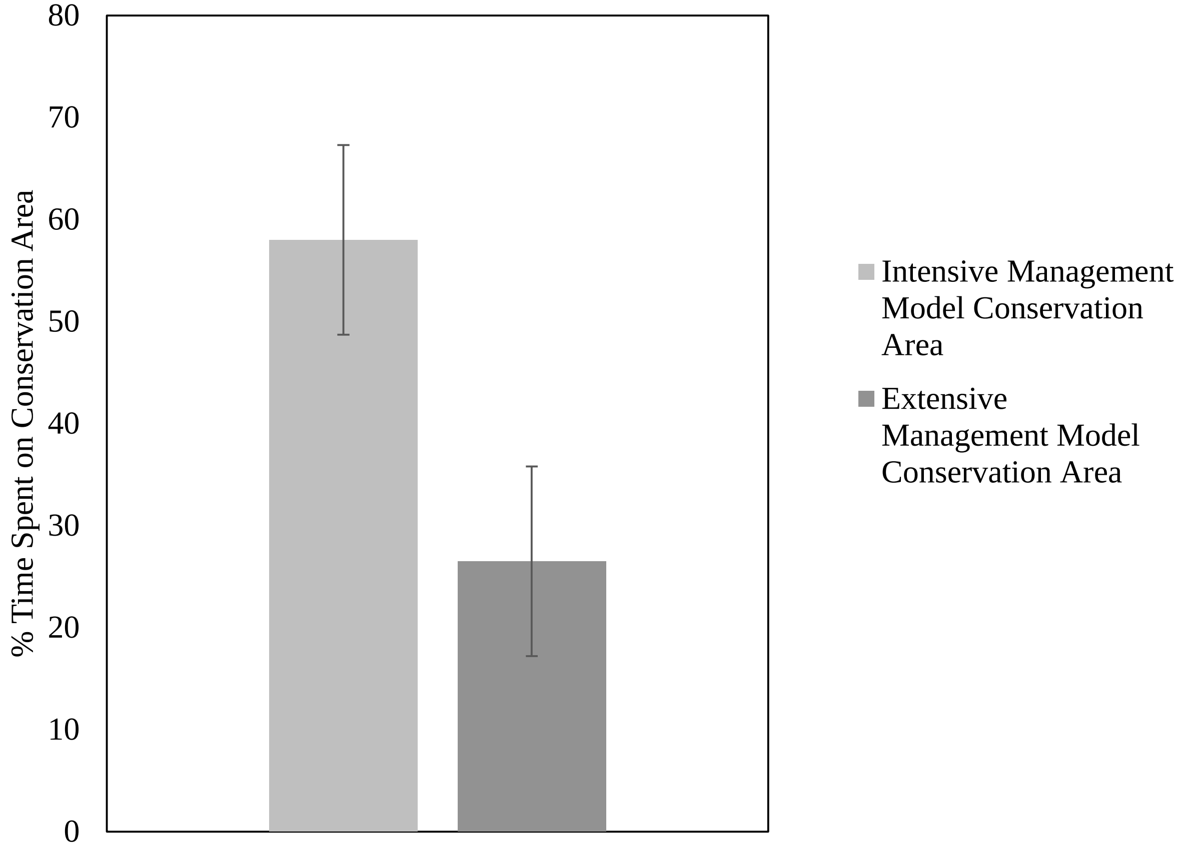


Figure 4. Means and standard errors of time spent within the boundaries of Intensive Management Model Conservation Area and the Extensive Management Model Conservation Area derived from GPS location data from five and four raccoons respectively. Data used for these estimates were collected during the summer and early fall of 2016.

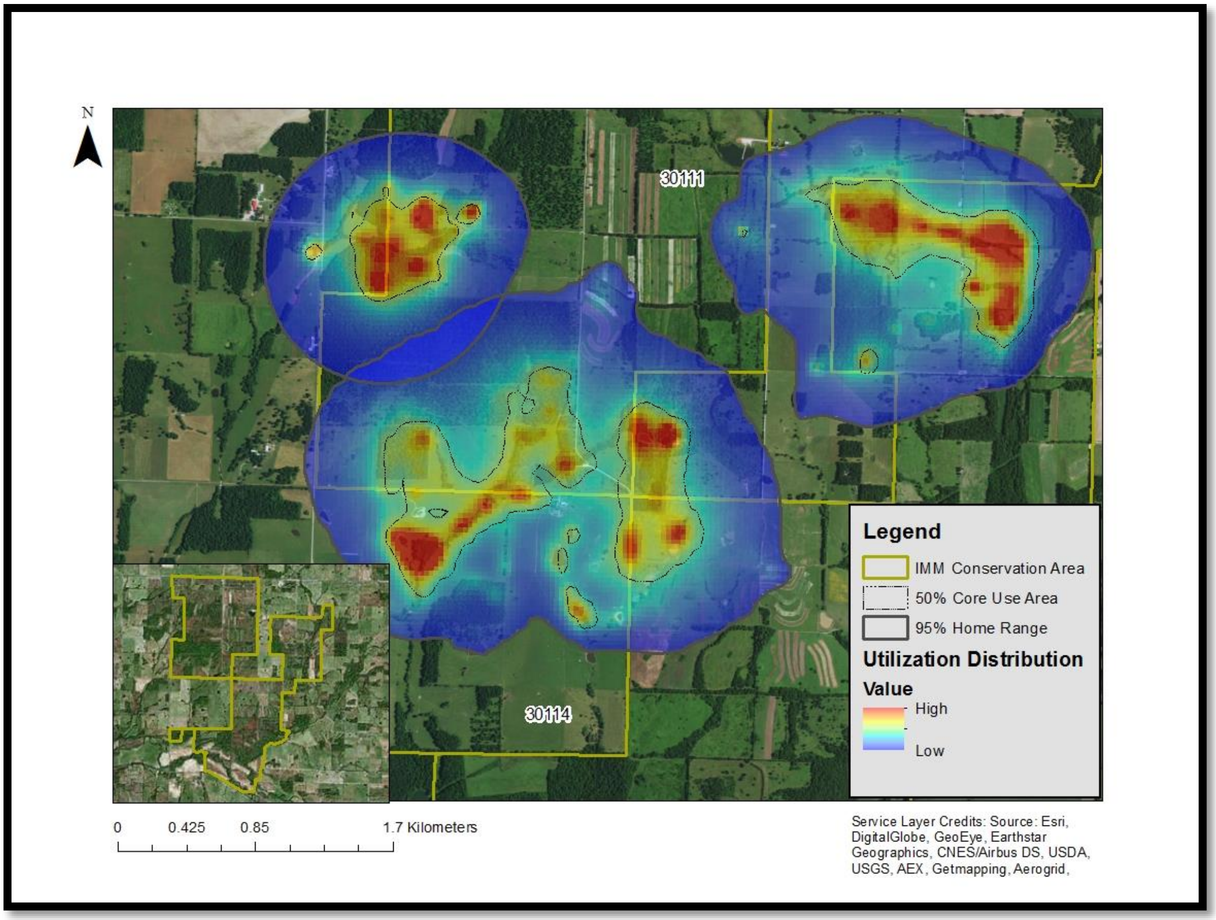
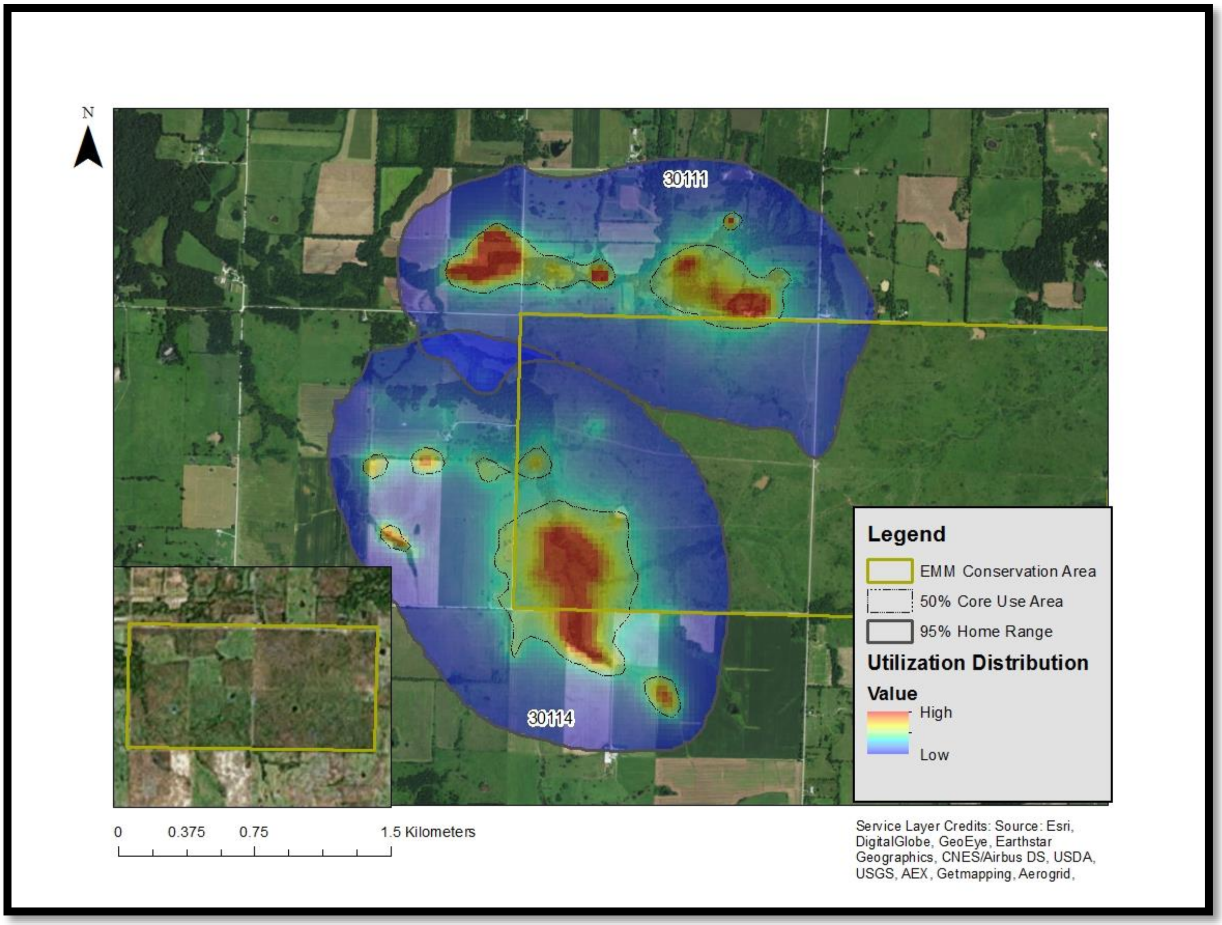


Figure 5. Utilization Distributions (UDs), home ranges, and core use areas for three mature male raccoons marked on the Intensive Management Model (IMM) Conservation Area. Home ranges are labeled with the raccoon GPS ID #. UDs reveal use hot spots in red and areas of low use in dark blue. Contiguous, linear patches of like-colors likely indicate repeatedly used movement corridors. Data used for these estimates were collected during the summer and early fall of 2016.



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid,

Figure 6. Utilization Distributions (UDs), home ranges, and core use areas for two mature raccoons marked on the Extensive Management Model (EMM) Conservation Area. Raccoon # 30111 is female, while #30114 is male. UDs reveal use hot spots in red and areas of low use in dark blue. Contiguous, linear patches of like-colors likely indicate repeatedly used movement corridors. Data used for these estimates were collected during the summer and early fall of 2016.

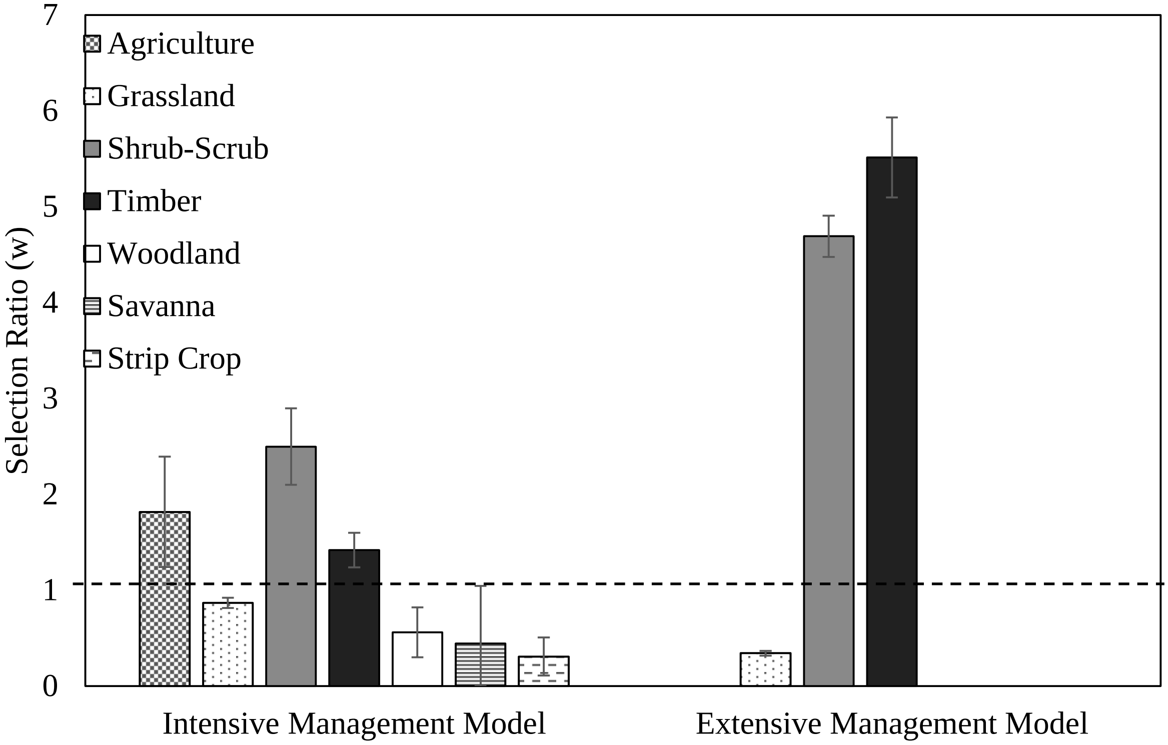


Figure 7. Habitat type selection ratios and standard errors estimated for Intensive Management Model Conservation Area raccoons and Extensive Management Model Conservation Area raccoons within the boundaries of the CA. Selection ratios (*w*) >1 indicate selection and those <1 indicate avoidance.

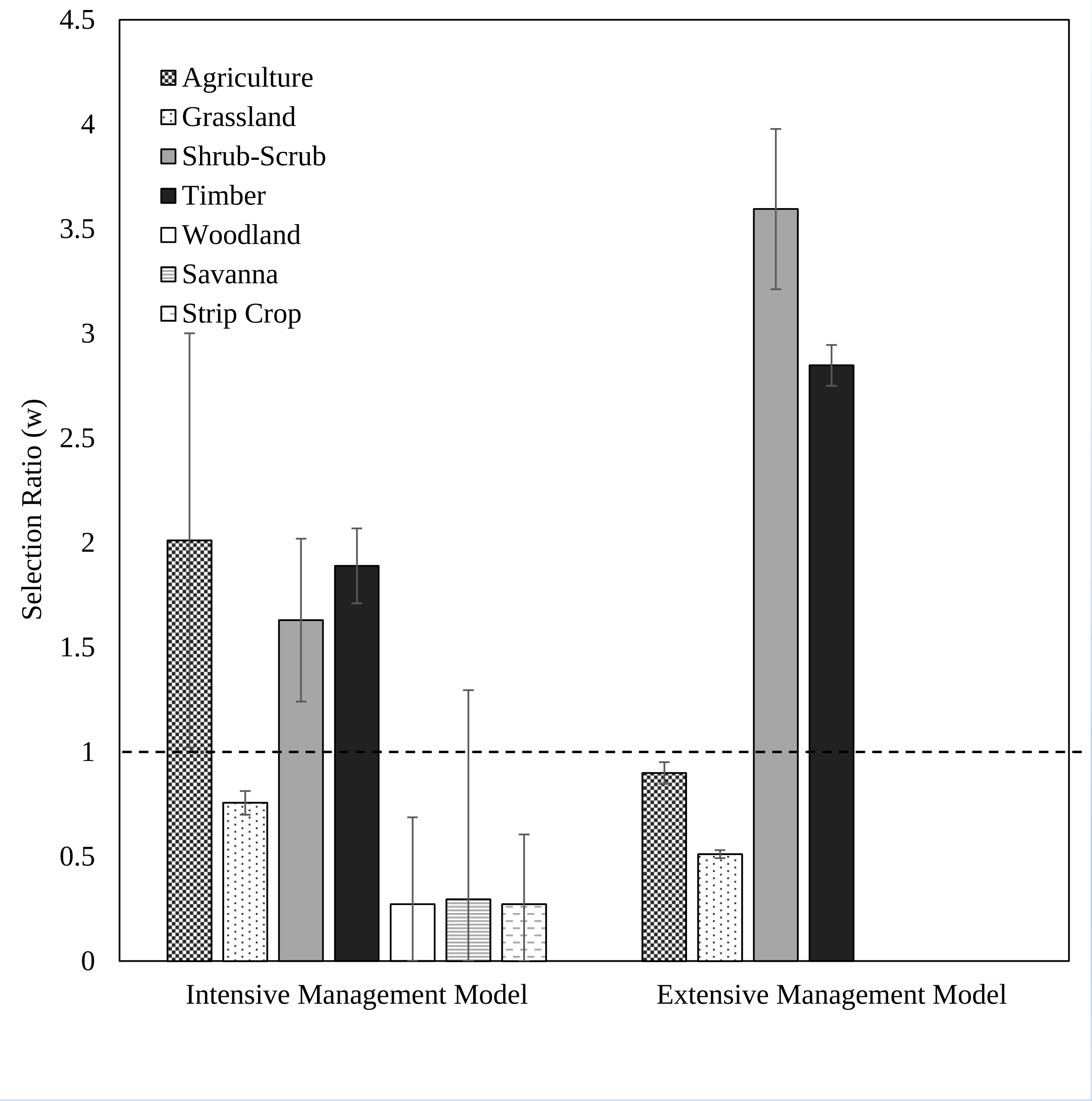


Figure 8. Raccoon population habitat selection ratios at the landscape level. Selection ratio (*w*) values >1 indicate selection for the corresponding habitat type while *w* values < 1 indicate avoidance.

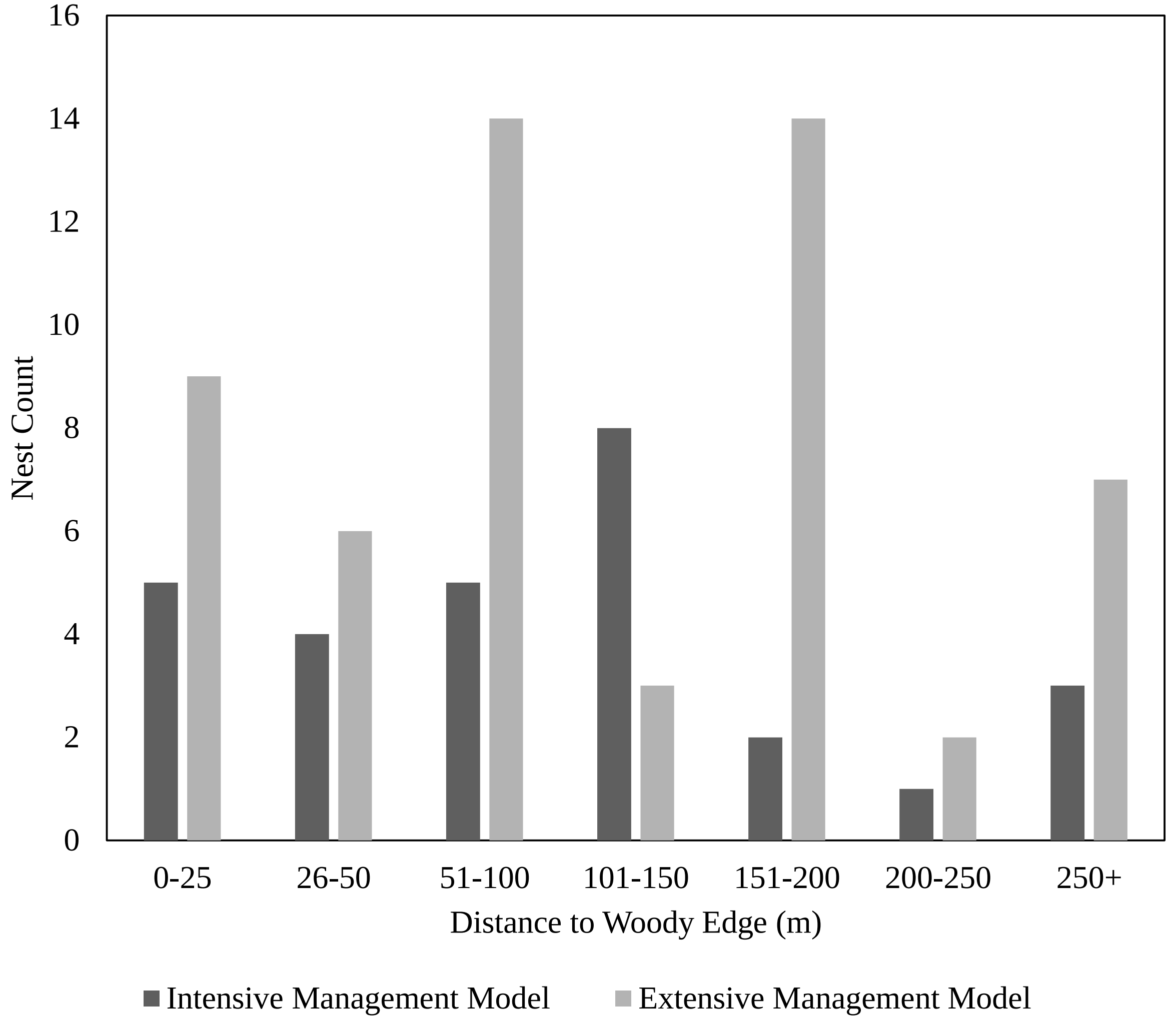
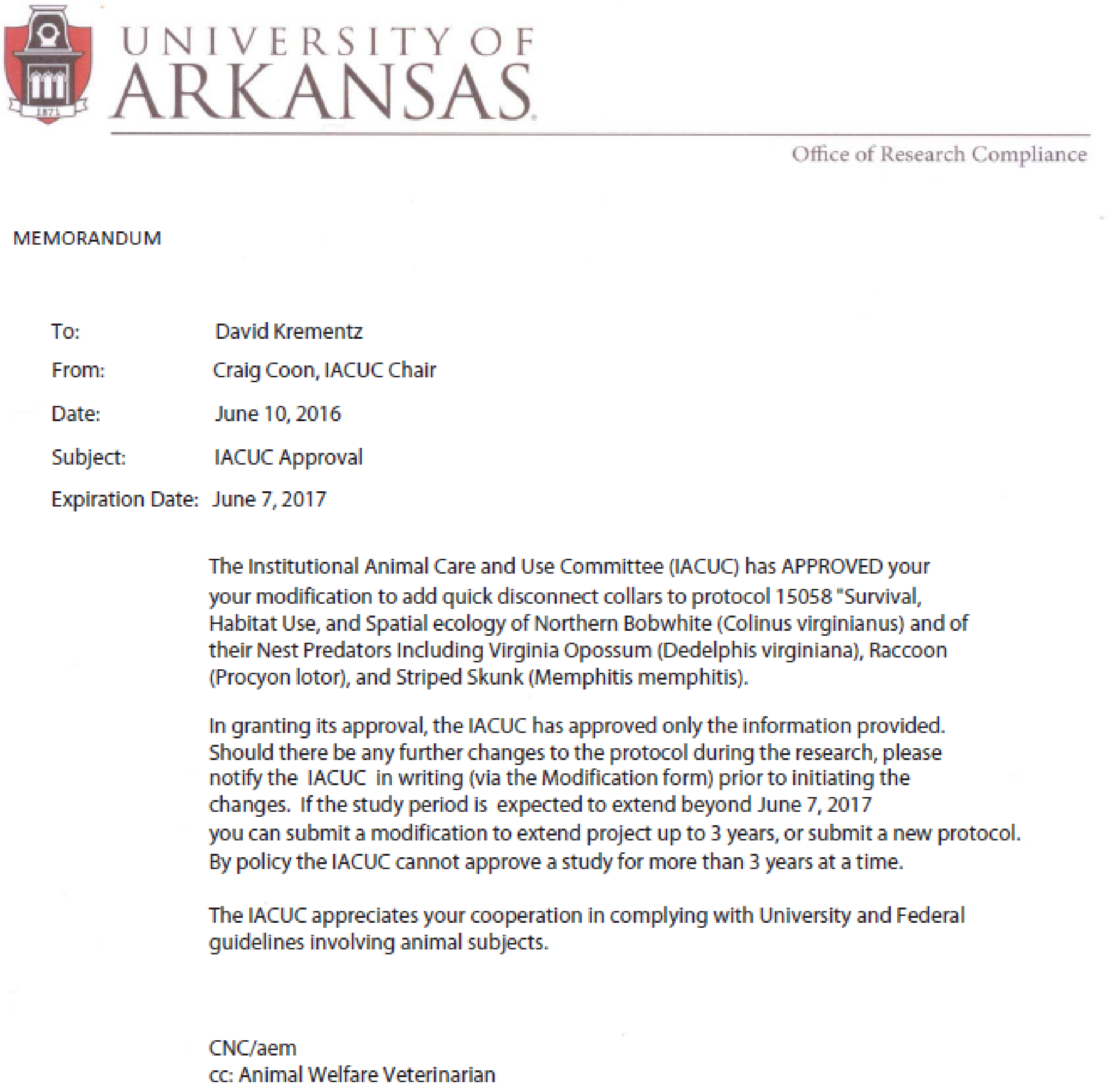


Figure 9. Frequency histogram by management model of northern bobwhite nest locations (2014-2016) in regards to woody edge.

Appendix



UNIVERSITY OF
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Office of Research Compliance

MEMORANDUM

To: David Krementz
From: Craig Coon, IACUC Chair
Date: June 10, 2016
Subject: IACUC Approval
Expiration Date: June 7, 2017

The Institutional Animal Care and Use Committee (IACUC) has APPROVED your your modification to add quick disconnect collars to protocol 15058 "Survival, Habitat Use, and Spatial ecology of Northern Bobwhite (Colinus virginianus) and of their Nest Predators Including Virginia Opossum (Dedelphis virginiana), Raccoon (Procyon lotor), and Striped Skunk (Memphitis memphitis).

In granting its approval, the IACUC has approved only the information provided. Should there be any further changes to the protocol during the research, please notify the IACUC in writing (via the Modification form) prior to initiating the changes. If the study period is expected to extend beyond June 7, 2017 you can submit a modification to extend project up to 3 years, or submit a new protocol. By policy the IACUC cannot approve a study for more than 3 years at a time.

The IACUC appreciates your cooperation in complying with University and Federal guidelines involving animal subjects.

CNC/aem
cc: Animal Welfare Veterinarian

CONCLUSION

In order to slow or reverse northern bobwhite (*Colinus virginianus*) population declines, good management practices are necessary. One common management strategy across the Southeast may benefit nest predators like the raccoon (*Procyon lotor*). Publically owned Conservation Areas (CAs) in Missouri are managed under the Intensive Management Model (IMM) or the Extensive Management Model (EMM).In this thesis, I have presented a foundation for understanding how these two northern bobwhite habitat management strategies used by the Missouri Department of Conservation (MDC) in southwest Missouri affect the nest predator community, and the habitat use, density, and home range of raccoons.

I found that IMM CA raccoons used grassland patches proportional to availability while EMM CA raccoons avoided this habitat type. Additionally, I found a significant difference between median distances to woody edge between treatments with IMM CA raccoons going farther into open habitat types like grasslands. I also found that EMM CA raccoons spend less time within the boundaries of the CA as IMM raccoons. I found differences in the mesopredator community structure and raccoon density among Conservation Areas but no difference by treatment. I found that raccoons repeatedly used tree-lines, woody edges, fencerows and other cover as movement corridors. Raccoon density appeared to be related to percent forest cover. Future work should delve deeper into the possible relationship between forest cover and raccoon density by adding additional sites.

Future work should focus on how other known predators, nest and otherwise, respond demographically and functionally to IMM and EMM. Knowledge of how predators behave and respond to certain practices may help biologist hone management practices to benefit northern bobwhite.