Responses of Mammals to Native and Non-Native Riparian Forest Types in Southeastern Arizona

by

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ABSTRACT

Riparian areas are an important resource, especially in the arid southwest, for many wildlife species. Understanding species occurrence in areas dominated by non-native vegetation is important to determine if management should be implemented. Saltcedar (*Tamarix* spp.) is one of the most prevalent non-native trees in riparian areas in the southwest United States and can alter vegetation structure, but little is known about how medium and large carnivores use stands of saltcedar. Three riparian forest types make up the San Pedro riparian corridor: non-native saltcedar, native mesquite (*Prosopis* spp.) bosque, and a mixture of native cottonwood (*Populus fremontii*) and willow (*Salix goodingii*) woodlands. My goals were to determine relative use, diversity, and occupancy of medium and large mammals across forest types to evaluate use of the non-native stands. I sampled mammals along approximately 25.7 river kilometers between July 2017 and October 2018, using 18 trail cameras (six per forest type) spaced 1km apart. I summarized environmental variables around the camera sites to relate them to species occupancy and reduced them to 4 components using a Principal Component Analysis (PCA). I observed 14 carnivore species, including bobcat (*Lynx rufus*), coyote (*Canis latrans*), and coati (*Nasua narica*) over 7,692 trap nights. Occupancy of some species may have been influenced by the different components, but models showed high standard errors, making it difficult to draw firm conclusions. Most mammal species used all three forest types at some level and no surveyed forest type was completely avoided or unused. Coyote tended to have greater use in the mesquite forest while canids trended toward greater use in saltcedar forest. Based on two-species occupancy models as well as activity overlap patterns, subordinate species did not appear to avoid dominant species. No species seems significantly affected by non-native saltcedar at this time.

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TABLE OF CONTENTS

Page

LIST OF TABLES v

LIST OF FIGURES....vi

INTRODUCTION 1

METHODS 5

Study Area....5

Camera Deployment....6

Photo Management 7

Habitat Measurements 8

Data Analysis 8

RESULTS 10

Habitat Variables....10

Mammal Use 11

Mammal Diversity 12

Mammal Occupancy 12

Mammal Occupancy Interactions 13

Mammal Activity Overlap....13

DISCUSSION 13

Mammal Use....13

Mammal Diversity 14

Mammal Occupancy....14

Mammal Occupancy Interactions....15

Mammal Activity Overlap....16

Page

MANAGEMENT IMPLICATIONS....16

LITERATURE CITED....32

APPENDIX

A: SITE LOCATIONS....38

B: CAMERA DEPLOYMENT....40

C: HABITAT VARIABLE DESCRIPTIONS....42

D: HABITAT SURVEY SCHEMATIC....44

E: HABITAT VARIABLE RESULTS....46

F: OCCUPANCY MODELING RESULTS....48

G: OCCUPANCY BY FOREST TYPE....51

H: OVERALL OCCUPANCY AND DETECTION PROBABILITY....53

I: PHOTO CAPTURES....55

LIST OF TABLES

Table Page

1: Mean and Standard Errors for Habitat Variables....17

2: Component Matrix PCA Variable Loadings....18

3: Means and Standard Error for Each Component....19

4: Number of Independent Detections of Each Mammal Species....20

5: Average Number of Independent Detections per Forest Type....21

6: Top Performing Model for Each Mammal Species....22

7: Two-Species Occupancy Models for Bobcat and Mountain Lion....23

8: Two-Species Occupancy Models for Gray Fox and Coyote....24

LIST OF FIGURES

Figure Page

1: Study Sites.....25

2: Mean and SE of Detections for Mammal Families.....26

3: Mean and SE of Detections for Mammal Species.....27

4: Rényi Index 28

5: NMDS Ordination.....29

6: Overlap in Activity for Bobcat and Mountain Lion.....30

7: Overlap in Activity for Gray Fox and Coyote.....31

INTRODUCTION

Riparian vegetation lies at the interface between the aquatic and terrestrial systems (Johnson and Jones 1977) and is important as travel ways for wildlife (Elmore 1992; Osborne and Kovacic 1993). These areas are an important resource, especially in the arid southwest where compared to adjacent uplands, they offer higher water availability which supports greater diversity of vegetation and wildlife species (Zaimes 2007). In North America, these areas are considered the most productive ecosystems (Knopf et al. 1988; Chaney et al. 1990). In addition to supporting fish and wildlife habitats, these areas retain sediments and nutrients, reduce chemical inputs, stabilize stream banks, store water, and reduce runoff (Schultz et al. 2004).

In the southwestern United States, riparian areas are considered critical as wildlife areas (DeBano and Schmidt 2004). Many wildlife species depend on riparian areas during at least part of their life cycle and this is especially true in the southwest. Seventy percent of the vertebrate species listed under the Endangered Species Act depend on riparian areas (Johnson 1989). More than half of all amphibian and reptile species located within the Mojave, Chihuahuan, and Sonoran Deserts utilize riparian or wetland ecosystems (Lowe 1989). Most avian species use riparian areas for some part of their life cycle and over half of all breeding bird species in the southwest rely entirely on riparian areas (Knopf et al. 1988; Johnson et al. 1977). Small mammals in the southwest are more abundant in riparian areas than the adjacent upland areas (Doyle 1990). Despite their importance, Ffolliott et al. (2004) estimated that riparian areas comprise less than 2% of the total area of the arid western United States. Furthermore, large percentages of these areas are considered degraded or nonfunctional (Ffolliott et al. 2004; NRC 2002).

Southwest riparian areas have changed significantly and declined dramatically since the 1800s. Estimates regarding the amount of riparian vegetation lost in the southwest range from 70% to 95% (Johnson and Haight 1984; Swift 1984, Brinson et al. 1981). The most common estimate used in reference to Arizona and New Mexico is 90% of habitat lost (Ohmart and

Anderson 1986; Webb 2006). According to Johnson and Jones (1977), drainages such as the Gila and San Pedro Rivers once supported healthy riparian communities, but anthropological redirecting of water resources has resulted in many areas that are now dry and devoid of native riparian vegetation. Anthropogenic loss of water includes water diversion and dams, livestock grazing, agriculture, settlement or urbanization, recreation, mining, invasive species, and harvesting (Braatne et al. 1996). Johnson and Jones (1977) state that deterioration of riparian areas has been reflected by a decline in range habitats and available forage plants for wildlife resulting in erosion of topsoil. In place of native vegetation, changes in ecosystem conditions can allow for the proliferation of non-native and invasive plants.

Non-native invasive plants often cause major conservation threats by altering plant composition and vegetation physiognomy (Mack et al. 2000). The establishment of non-native invasive species can reduce the recruitment of native species and can also increase risk of wildfire (Bateman and Paxton 2009). Non-native saltcedar (*Tamarix* spp.) is a tree originally from Eurasia that was introduced to the Unites States in the early 1800s as an ornamental (Carman and Brotherson 1982). It lowers the water table and creates significant deposits of salt into the soil (Di Tomaso, 1998). Saltcedar has since become one of the most prevalent trees in riparian areas of the southwest (Friedman et al. 2005). Consequences of invasive vegetation on ecosystems are demonstrated throughout riparian systems of the southwest (Busch and Smith 1995) and the effects of saltcedar can include reducing physiognomic heterogeneity in areas where saltcedar forms dense monotypic stands (Bateman and Ostoja 2012).

Understanding how species interact with, or avoid, these areas dominated by invasive species is important for management strategies (Bateman et al. 2013). Animal relative use and diversity patterns in monotypic stands of saltcedar in comparison with native riparian forests has been well documented for avian, reptile, and small mammal species. However, these species interactions with saltcedar are largely unexplored for other terrestrial animal communities (Bateman and Ostoja 2012). Trends show relative use and diversity in these taxa being lower in

monotypic stands of saltcedar, higher in mixed stands for reptiles, and higher in native stands for birds (Bateman et al. 2013). Aside from rare occurrences with beavers, there is currently no known species of medium or large mammals in North America that feed on saltcedar (Bateman et al. 2013). Wildlife studies in saltcedar forests have largely overlooked medium and large mammals and especially carnivores (Bateman et al. 2013).

Two large carnivores found along the San Pedro watershed are the mountain lion (*Puma concolor*) and the American black bear (*Ursus americanus*). The mountain lion has the widest distribution of any large terrestrial mammal (excluding humans) in the Western Hemisphere (Iriarte et al. 1990). The presence of forest cover, rugged terrain, canyons, and ridgelines are key factors in mountain lion habitat quality (Dickson et al. 2013). Mountain lions are sensitive to loss of habitat, habitat fragmentation, and destruction of corridors (Dickson et al. 2013). According to Dickson et al. (2002), mountain lions in southern California prefer riparian habitat, selecting it over woodlands, chaparral, scrubland, grassland, and urban development. It is likely that riparian areas provide important stalking and feeding cover for mountain lion populations. Beier et al. (1995) found kill sites and caches most often associated with riparian vegetation types. Hopkins (1991) found that over 73% of all deer caches were found in creek bottoms. Furthermore, riparian areas can provide movement corridors (Beier and Barrett 1993; Beier 1995). American Black Bear (*Ursus americanus*) is widely distributed in North America, ranging from Canada and Alaska through parts of the United States, and in to northern Mexico (Scheick and McCown, 2014). Gantchoff and Belant (2017) found that riparian corridors were most likely to facilitate connectivity for black bears.

Large carnivores are ecologically important because of the significant effects that only a few individuals can have on the ecosystem (Ripple and Beschta 2004; Ray et al. 2005). However, most carnivores have small body size and occur in high abundance compared to apex predators (Roemer et al. 2009). Data suggests that mesocarnivores may also be important drivers in ecosystem function, structure, and dynamics (Roemer et al. 2009). Mesocarnivore species in the

family Procyonidae show a preference for riparian areas. Soykan et al. (2009) found a positive correlation between northern raccoon (*Procyon lotor*) habitat preference and riparian forests of cottonwood, willow, and ash. The coati (*Nasua narica*) occupy a diversity of habitats from oak and pine forests to lowland tropical rainforests, and occasionally range into deserts or savannas but in Arizona, they tend to occur in riparian areas (Lanning, 1976).

Badgers (*Taxidea taxus*) are often found in open grasslands with few or no shrubs or trees and in close proximity to a food source (Scobie 2002). Duquette et al. (2014) found that badgers showed no preference for riparian areas. Collins et al. (2012) found that badgers preferred mesquite to acacia shrubland. The gray fox (*Urocyon cinereoargenteus*) is a generalist but were found more frequently in riparian areas by Crooks et al. (2008). The coyote (*Canis latrans*) is also a generalist but Gifford et al. (2017) found they used riparian areas more than others. The bobcat (*Lynx rufus*) inhabits a variety of environments including subtropical swamps in the southeast, arid areas in the northwest, and temperate forests in the north (Werdelin, 1981) but in south-eastern Arizona, bobcats used grassland, scrub, woodland, and riparian areas equally (Hass, 2009). In one study, while larger skunks were seen in various habitats, western spotted skunks were only observed in the riparian forest (Crooks et al. 2008).

Other mammals known in the area include mule deer (*Odocoileus hemionus*) which showed a preference for riparian areas when grazing (Loft et al. 1991). White-tailed deer (*Odocoileus virginianus*) used riparian areas more than other available areas including uplands (Leach and Edge, 1994). Javelina (*Pecari tajacu*) have shown to be associated with proximity to water sources such as riparian (Bender et al. 2014). Crooks et al. (2008) found that riparian areas play an important role as both permanent habitat and travel corridors for a variety of wildlife, including carnivores, especially in the arid Southwest.

Vegetation use and avoidance can also be affected by species interactions. According to Lewis et al. (2015), a significant factor in ecological communities contributing to spatial and temporal distribution, is species interactions. Species with seemingly different niches can have

interactions that influence one another, especially the distribution and behavior of the subordinate species (Lewis et al. 2015). If two species have similar ecological requirements, they may coexist by exploiting different features of the ecosystem or by being active during different periods of time (Lewis et al. 2015). Another possible result of species competition is that the subordinate species changes the areas it uses, such as gray foxes (*Urocyon cinereoargenteus)* avoiding areas with a higher risk of predation by coyotes (*Canis latrans)* (Farias et al. 2012).

I sampled meso and large mammal communities in non-native saltcedar stands and in stands with dominant native vegetation, cottonwood (*Populus fremontii*), willow (*Salix gooddingii*), and mesquite (*Prosopis* spp.) using remote wildlife cameras. My objective was to determine if carnivore and meso-mammal communities use or avoid native and non-native forest types along the lower San Pedro River. Objectives include: (1) quantify habitat characteristics across riparian forests dominated by native cottonwood and willow, mesquite woodlands, and non-native saltcedar; (2) measure occupancy and detection probability of mammalian guilds to determine if relative use is similar across guilds and riparian forest types; and (3) examine circadian activity patterns of carnivores to evaluate avoidance between species across spatial and temporal scales across seasons. I predict that forest structure can be used to explain meso and large mammal communities because some species such as mountain lion and black bear may avoid riparian forests dominated by non-native saltcedar due to the density of the vegetation.

METHODS

Study Area

My study took place along the San Pedro River in Pinal County of southeastern Arizona. Some estimates of species richness along the San Pedro River range from 61 to 87 species of mammals, which are high in comparison to other semi-arid areas at similar latitude but 61 is a more conservative estimate that excludes range maps and known extirpated species (Boeer and Schmidly 1977; Woolsey 1987; Duncan 1988; Hass 2001; Soykan et al., 2009). Of the 61

mammal species observed, 16 are carnivore species (Boeer and Schmidly 1977; Woolsey 1987; Duncan 1988; Hass 2001). My study sites are on the lower San Pedro River above its confluence with the Gila River and near Aravaipa Creek (Figure 1). This study area falls within the Arizona Upland Subdivision - Sonoran Desertscrub (Brown and Lowe, 1980).

The tree composition of a riparian forest changes along a predictable gradient, determined by depth of groundwater, across the floodplain from foundational tree species to mesquite woodlands. Southwestern riparian forests of cottonwood and willow occur near streams, forming a forest of tall trees and a relatively open even-aged understory (Stromberg 2009). This is the historic riparian forest type along the waterway. Seepwillow (*Baccharis salicifolia*) and Emory's baccharis (*Baccharis emoryi*) are common understory evergreen shrubs (Szaro 1989). The mesquite woodland is comprised mostly of low height, low density trees, reaching canopy heights of approximately 5 m when surviving solely on rainfall (Stromberg et al. 1993; Martínez and López-Portillo 2003), but can reach 18 m tall and form dense woodlands if ground water is within reach of the roots (Swarth 1905; Brandt 1951). Mesquite is an intermediate forest type between upland desert and riparian areas, sometimes called xero-riparian, and includes species from both mesic cottonwood areas and Sonoran uplands. Non-native saltcedar (*Tamarix chinensis*, *T. ramosissma*, or hybrids) occupy a position intermediate in the landscape to cottonwood and mesquite forests (Bagstad et al. 2006). Saltcedar density varies based on age class and water table, but can form dense thickets of both understory and overstory layers.

Camera Deployment

I placed 18 cameras (Appendix A) approximately 1 km apart on game trails and washes with signs of mammal activity such as tracks and scat. I attached cameras to trees for a duration of about 13 months, from July 2017 and October 2018. I did not use any attractants such as sight,

sound, or scent to lure animals as to not overestimate or exclude any particular species that may be more drawn to, or avoid, these attractants.

My methods follow published works using cameras to monitor mammals. For example, Larrucea et al. (2007) suggests that trails, dirt roads, and natural washes make for easier travel and animals, especially predators, often use them to move through their range. I placed cameras in locations with evidence of carnivores, consistent with similar studies (McAdams 2012). Studies such as Lewis et al. (2015) state that cameras should be mounted roughly 1 m high and mine were between 0.75 and 1 meter high (Appendix B). I spaced cameras following the pattern of other studies (i.e., Kelly and Holub 2008) and my spacing falls within the mean found in the meta-analysis of Burton et al. (2015). As with similar projects, I chose motion activated cameras with a 0.25 second trigger with infrared for night photos (McAdams 2012). I set the cameras to take 3 consecutive photos before a 30 second delay, which is common in camera projects to avoid large numbers of photos of one individual, maximizing storage space and captures (Larrucea et al. 2007). I checked cameras bi-weekly to monthly, similar to other studies suggesting that cameras be checked biweekly for proper functioning and available capacity (McAdams 2012).

Photo Management

I imported images into the CPW Photo Management Database (Colorado Parks and Wildlife Photo Warehouse, Version 4.0.1.1; Ivan and Newkirk 2016) for archiving, identifying, and summarizing of camera data. Independent detections are any observation of a species seen over an hour apart. If multiple images of the same species are taken at the same site within 1 hour, additional image(s) are considered the same individual and removed from analysis, unless obviously a unique individual (based upon markings or other physical features). When multiple individuals occurred in one image, the image containing the largest number was used in analyses and others were considered a smaller subset of individuals and removed from analysis.

Habitat Measurements

I collected habitat variables surrounding each camera (Appendix C). I established two 30 m transects at random cardinal directions around each camera (i.e., either with a north to south or east to west orientation), recorded all shrubs and trees that intersected the transect, and measured percentages of canopy and shrub cover within the two corresponding clockwise quandrants (Appendix D). I determined the proportion of native versus non-native cover at each site. I used a concave densiometer to measure canopy cover.

I collected spatial variables using satellite imagery in Google Earth, such as distance to river, width of riparian corridor, distance to upper Sonoran Desert, distance to agriculture field, distance to nearest road, and distance to development (such as residences or out buildlings). Using ArcGIS and MODIS imagery, I calculated the vegetation index, NDVI. Normalized Difference Vegetation Index (NDVI) quantifies greeness of plants by measuring the difference between near-infrared, which is strongly reflected by and red light, which is absorbed by vegetation. For each site I calculated the average NDVI values for a 400-meter buffer around each camera for May, June, and July of 2018. A 400-meter distance was chosen so that the buffer was as large as possible while minimizing overlap. Negative values of NDVI correspond to water, while those close to zero generally correspond to barren areas of rock or sandand positive values represent shrub and grassland while high values approaching one indicate forested areas (Weier and Herring, 2000).

Data Analysis

I used a rotated Principal Components Analysis (PCA) in SPSS, using a Varimax rotation, to summarize ten habitat variables. PCA is a multivariate analysis that identifies associations among variables to reduce the number of independent variables. The PCA transforms the data into a coordinate system so that the greatest variance of data lies on the first coordinate, the second highest variance on the second coordinate, and so on (Jolliffe 2002).

I examined all mammals that were observed, which included meso carnivores (≤ 49 lbs or 22.23 kg), large carnivores (≥ 50 lbs or 22.68 kg), and herbivores. I calculated relative use for each camera by dividing total independent detections by the number of trap nights, and standardized by multiplying by 100. Trap nights per camera are determined by the number of nights cameras functioned. I excluded occurrences of domestic animals, livestock, humans, birds, and reptiles and focus only on medium and large mammal species. I used an ANOVA to analyze the difference in independent detections across forest types.

I used Rényi Index to examine mammal diversity. Rényi Index incorporates diversity calculations from several indices: species richness, Shannon, Simpsons D, and Berger-Parker indices. Communities are deemed different in diversity only when their lines do not cross or have similar ranking from all diversity indices. I used the vegan package (Oksanen et al. 2019) in R to create the Renyi index. To visually depict how sites differed in species composition, I used a nonmetric multidimensional scaling (NMDS) ordination using PC-ORD (McCune and Mefford 1999).

When examining occupancy data, I focused on single-species, single season occupancy (MacKenzie et al. 2017) because the model assumes a closed-population. Occupancy was evaluated from presence/absence data and estimated detection probability (p) and occupancy probability (Psi) for each species. I chose the summer season because it is the season for which the most data were available in terms of most functioning trap nights. Other seasons might have had fewer trap nights due to camera malfunctions and also how late in the season they were deployed or removed. My sessions for occupancy modeling are two weeks long and I included 5 sessions, for a total of 10 weeks, trying to include as much of the summer season as possible. To examine species occupancy models, I used the R-mark package in R (Laake 2013). Species such as black bear, gray fox, and mule deer did not converge when running occupancy models due to low detection probability. In these cases, a different algorithm was used to estimate detection in the models so that they would converge.

For two-species occupancy models, I also used R-mark package in R (Laake 2013), which evaluates whether or not the occupancy of a dominant species affects the occupancy of a subordinate species. These models examine the occupancy and detection probability of the subordinate species both in the presence and absence of the dominant species to determine any significant differences. One two-species model evaluated interactions between mountain lion, the dominant species, and bobcat, the subordinate species. A second two-species model evaluated the dominant coyote and the subordinate gray fox. These species pairs were selected based on literature that has shown examples of such interactions.

To evaluate overlap in activity patterns, I used the Overlap package in R (Ridout and Linkie 2009), which examines the proportion of overlap in circadian activity between two species. The Dhat 4 overlap statistic and 1,000 bootstraps to estimate the amount of overlap and we included all seasons. Again, we examined two sets of species. The first was the mountain lion and the bobcat and the second was the coyote and the gray fox.

RESULTS

Habitat Variables

I summarized ten habitat variables for each camera site along the San Pedro (Appendix E). I reduced the ten habitat variables to four synthetic components (PC1-PC4) to replace the original ten independent variables for further analysis (Table 2). PC1 explained 25.6% of variation and a high PC1 score described sites with greater distance to the river, high proportions of mesquite and catclaw acacia (*Senegalia greggii*), low proportions of cottonwood and willow, and closer proximity to the upper Sonoran Desert. A low PC1 score is explained by sites closer to the river, high in cottonwood and willow, low in mesquite, and farther from the upper Sonoran Desert. For this reason and for ease of interpretation, I labeled PC1 as Gradient of Riparian Vegetation.

PC2 explained 20.06% of variation and I labeled PC2 as Distance to Disturbance. Sites with high PC2 values have more NDVI, which is proportion of greenness, and are closer to roads and human development. Sites with low PC2 scores are farther from roads and development. PC3 explained 17.84% of variation and described sites with high PC3 scores as having high NDVI, high canopy cover, and closer to agricultural fields. I labeled PC3 as Vegetation Coverage. PC4 explained 16.27% of variation and described sites with high proportion of non-native vegetation and was labeled Proportion of Non-native. The three forest types were adequately represented in the components, with mesquite sites having high PC1 values and cottonwood sites having low PC1 values (Table 3). Saltcedar sites had high PC4 values (Table 3).

Mammal Use

I detected 14 mammal species (Table 4) over 7,692 trap nights (Table 5) from August 26th, 2017 to October 27th, 2018. The species with the most independent detections was javelina (*Pecari tajacu*). The carnivores with the most independent detections included bobcat (*Lynx rufus*), followed by coyote (*Canis latrans*), white-nosed coati (*Nasua narica*), and gray fox (*Urocyon cinereoargenteus*) (Table 4).

I compared independent detections of mammal families across the three forest types and found marginal differences for Canidae (df=2,17; F=2.643; P=0.104) and Felidae (df=2,17; F=2.651; P=0.103) (Figure 2). No significant trends in independent detections were found for Mephitidae (df=2,17; F=1.075; P=0.366), Procyonidae (df=2,17; F=0.501; P=0.616), or for all (total) mammals (df=2,17; F=0.586; P=0.569). I also compared independent detections for each species across the three forest types and found marginal differences for American badger (df=2,17; F=1.925; P=0.180), bobcat (df=2,17; F=2.09; p=0.158), and coyote (df=2,17; F=3.233; P=0.068) (Figure 3).

Mammal Diversity

I evaluated how the mammal community diversity varies across the forest types. I found that mesquite forest appears to have has the greatest species diversity (Figure 4). Consistent with that, the ordination shows that most species were associated with mesquite (Figure 5). However, raw species richness was actually the same for mesquite (14 species) and saltcedar (14 species), and lower in cottonwood (13 species), because western spotted skunks were not observed in this forest type.

Mammal Occupancy

Occupancy models show some species-specific associations with habitat components during the summer season. The model including Gradient of Riparian Vegetation (PC1) was more supported than the dot model for American badger ($\beta = 1.46$, se = 0.95) and coyote ($\beta = 13.08$, se = 10.52) (Appendix F), indicating that this component helped explain the occupancy for these species. Distance to Disturbance (PC2) was more supported than the dot model for coati ($\beta = 2.89$, se = 2.26), mountain lion ($\beta = 11.44$, se = 9.73), and mule deer ($\beta = -2.99$, se = 1.67), indicating occupancy for these species may be partially explained by this component. Vegetation Coverage (PC3) was more supported than the dot model for black bear ($\beta = 8.09$, se = 10.17), indicating it may play a role in explaining black bear occupancy. Proportion of Non-native (PC4) was more supported than the dot model for bobcat ($\beta = 5.81$, se = 3.61), indicating bobcat occupancy may be partially explained by this component. However, the 95% confidence interval for all of these beta values overlapped 0, demonstrating substantial uncertainty in the relationships. No models predicted gray fox, javelina, or skunk occupancy better than the dot models, therefore no component seemed to explain occupancy for these species. A summary of beta estimates and their standard errors for the top performing models for each species was compiled (Table 6).

Mammal Occupancy Interactions

Two-species occupancy models were run for two different pairs of species, the first was bobcat and mountain lion and the second was gray fox and coyote. The top performing model for the interaction between bobcat and mountain lion was the model assuming consistent bobcat occupancy (Psi = 0.73, se = 0.13) regardless of mountain lion presence or absence (Table 7). The same was true for consistent gray fox occupancy (Psi = 0.78, se = 0.15) regardless of presence or absence of coyotes (Table 8). Overall, there was no evidence to support that the dominant species affect the occupancy of the subordinate species.

Mammal Activity Overlap

We calculated the overlap indices of two different pairs of species. The overlap statistic ranges from 0, which is no overlap in activity, to 1, which is complete overlap. Overlap in activity between bobcats and mountain lions was relatively consistent throughout the seasons and showed no distinct patterns of avoidance (Δ = 0.83, CI: 0.72 - 0.91) (Figure 6). Overlap between gray fox and coyote was also consistent and showed no patterns of avoidance (Δ = 0.66, CI: 0.53 - 0.73). For both sets of species, overlap is somewhat high in circadian activity patterns.

DISCUSSION

Mammal Use

Coyotes were detected more in the mesquite forest. American badger, bobcat, mountain lion, and javelina were detected the most in saltcedar forest. The thick understory found in saltcedar forest might have influenced our results either positively or negatively. With limited openings in vegetation, it is easier to find well used trails, possibly skewing the causing higher detections. Furthermore, saltcedar could provide better prey hiding and thermal cover and this could increase predator use. Although mountain lions were detected most often in saltcedar,

most detections were at one single site. This might suggest a factor other than the forest type affecting these detections.

Mammal Diversity

Mammal diversity was highest in mesquite woodland, supporting the most diverse meso and large-mammal communities. Bateman and Ostoja (2012) found higher lizard diversity in mixed sites than in saltcedar stands (Bateman and Ostoja 2012). While saltcedar can play an important habitat role for some bird species, migrating birds along the Colorado River prefer mixed stands to monotypic ones (Riper et al. 2008) and avian diversity along the lower Colorado River was found to be lower in saltcedar stands than in native ones (Hinojosa-Huerta 2006). Furthermore, along the San Pedro River, the highest diversity of avian species is associated with native woodlands (Brand et al. 2010).

Mammal Occupancy

I found a mixed response in mammal occupancy to structure found across three riparian forest types. While these occupancy models showed that some components were better predictors of species occupancy compared to the dot (or null) models, many of the relationships were inconclusive because of large variation in the model, making it difficult to draw firm conclusions. Gradient of Riparian Vegetation (PC1) may explain occupancy of American badger and coyote. These species have been documented using floodplain areas, for example, Collins et al. (2012) found that badgers preferred mesquite to acacia shrubland. Stromberg (1993) found that coyotes fed on large portions of mesquite fruit. Distance to Disturbance (PC2) may explain occupancy of coati, mountain lion, and mule deer. Stromberg (1993) found that coati frequently fed on mesquite fruit. Dickson et al. (2013) found mountain lions are sensitive to loss of habitat and habitat fragmentation. Mule deer showed a marginal negative relationship with Distance to Disturbance. Deer may be avoiding predators with positive associations to this component or could be avoiding human disturbance.

Vegetation Coverage (PC3) may help explain black bear occupancy. McKinney and Pitmann (2000) found mesquite beans are an important component of black bear diet. Proportion of Non-native (PC4) appeared to help explain bobcat occupancy. Saltcedar might provide dense hiding cover for prey species thus increasing predator activity. Recommendations for future research include the evaluation of prey use in non-native stands to investigate this further. All remaining species didn't have a component that helped explain occupancy, including javelina, gray fox, and skunks.

There is no surveyed forest type that is completely avoided or unused, as most species use all three forests to some degree. No species showed a negative association to Proportion of Non-native. However, occupancy models only included data from the summer season, and this may not have been representative of occupancy over the entire year. For example, gray fox had the fewest detections in the summer season, so this might have affected our results. Future analysis should examine each of the four seasons separately to assume a closed population but then compare them to one another.

Mammal Occupancy Interactions

Regarding species occupancy interactions, neither dominant species showed a significant effect on the occupancy or detection probability of its respective subordinate species. Occupancy of each subordinate species was consistent regardless of the presence or absence of the dominant species. This is not consistent with literature where the presence of mountain lions seem to explain variation in bobcats detection probability (Lewis et al. 2015). An influence of coyotes on gray foxes might not have been detected because the semi-arboreal behaviors of gray foxes can provide some means of escape from coyotes (Chamberlain and Leopold 2005). Otherwise, it is possible differences in either set of species existed but were not detected due to small sample size.

Mammal Activity Overlap

The trends seen in circadian activity patterns seems to indicate that gray fox are more nocturnal compared to the crepuscular coyotes, which is consistent with previous research (Farias et al. 2012; Tigas et al. 2002; Grinder and Krausman 2001). However, neither pair of species showed significant partitioning of circadian activity. This pattern differs from Lewis et al. (2015) where patterns of circadian activity showed partitioning in wildland habitats. However, in this same study, it was seen that overlap activity increased in areas of exurban development, where exurban development might reduce available habitat and increase likelihood of overlap. My increased overlap patterns and lack of influence in species competition models might be due to a similar reason, where the quality riparian habitat is limited and increases chances of overlap.

Limitations were present such as a small sample size, close proximity of survey locations, and camera malfunctions. It is possible there might have been more differences in use and occupancy that I didn't detect due to small sample size. Relative use may also be skewed by the proximity of sites, which might have resulted in the repeated detection of individuals. Furthermore, it would be beneficial to examine occupancy for all seasons in addition to the summer season.

MANAGEMENT IMPLICATIONS

My study is important because there are few studies regarding mammals and saltcedar interactions within riparian areas (Bateman et al. 2013). This work documents mammal activity and occupancy across three riparian forest types and provides a baseline to evaluate future management techniques related to controlling non-native species and possible influences on carnivores. Past studies have shown that generalist species tend to be the most successful in saltcedar forests, while more specialist species are less successful (Bateman et al. 2013). No species showed a negative relationship to the non-native saltcedar forest type so it does not seem to be having any significant effect on any of the species studies in this project.

Table 1. Mean and standard errors for habitat variables measured at each camera site (n=18) along the lower San Pedro, Arizona USA in three riparian forest types from May, June, and July 2018. Riparian forest types based upon dominant woody species include: cottonwood-willow, mesquite woodland, and saltcedar.

Variable	**Mesquite (n=6)**	**Saltcedar (n=6)**	**Cottonwood (n=6)**
Distance to River (km)	0.347 ± 0.086	0.165 ± 0.034	0.048 ± 0.017
Distance to Upper Sonoran Desert (km)	0.243 ± 0.057	0.365 ± 0.041	0.337 ± 0.084
Distance to Agriculture Field (km)	0.993 ± 0.196	2.523 ± 1.981	3.047 ± 2.049
Distance to Road (km)	0.805 ± 0.091	0.693 ± 0.103	0.775 ± 0.192
Distance to Development (km)	1.163 ± 0.376	1.003 ± 0.288	0.770 ± 0.209
Proportion of *Populus*| *Salix*	0.020 ± 0.020	0.013 ± 0.013	0.787 ± 0.080
Proportion of *Prosopis*| *Acacia*	0.770 ± 0.066	0.177 ± 0.071	0.140 ± 0.062
Proportion of Non-native	0.005 ± 0.005	0.819 ± 0.048	0.186 ± 0.052
Canopy Cover (%)	65.62 ± 8.790	58.03 ± 8.290	84.38 ± 3.120
NDVI	0.388 ± 0.031	0.422 ± 0.033	0.383 ± 0.025

Table 2. Component matrix showing the habitat variables organized by their variable loadings on three principal components (PC1-PC4) derived from a rotated principal component analysis (PCA) using a Varimax rotation. Shading shows which variables loaded strongly on that component. Principal components (PC) are interpreted based upon the pattern of loadings from the variables, including their sign (±) and described below the table. The amount of variance explained by each PC reported with all three PCs explaining 79.76% among sites (n=18) in riparian forests along the lower San Pedro River, Arizona USA in three riparian forest types from May, June, and July of 2018.

Variable	**Gradient of Riparian Vegetation (PC1)**	**Distance to Disturbance (PC2)**	**Vegetation Cover (PC3)**	**Proportion of Non-native (PC4)**
Distance to River (km)	0.877	0.047	0.127	-0.005
Proportion of *Prosopis|Acacia*	0.865	-0.072	0.020	-0.427
Proportion of *Populus|Salix*	-0.699	0.208	0.389	-0.445
Distance to Upper Sonoran Desert (km)	-0.481	0.388	-0.235	0.311
Distance to Road (km)	-0.059	-0.879	0.104	-0.106
Distance to Development (km)	0.287	-0.709	-0.014	0.196
NDVI	0.259	0.627	0.533	0.438
Canopy Cover (%)	-0.155	0.086	0.883	-0.264
Distance to Agriculture Field (km)	-0.327	0.359	-0.683	-0.035
Proportion of Non-Native Vegetation	-0.193	0.017	-0.138	0.916
% of Variance Explained	25.587	20.061	17.839	16.273
Cumulative % Variance Explained	25.587	45.648	63.487	79.760

Table 3. Means and standard error for each component (PC1-PC4) based on forest type among camera study sites (n=18) in riparian forest along the lower San Pedro River, Arizona USA in three riparian forest types from May, June, and July 2018.

Forest Types	Gradient of Riparian Vegetation (PC1)	Distance to Disturbance (PC2)	Vegetation Cover (PC3)	Proportion of Non-native (PC4)
Mesquite	1.07 ± 0.23	-0.10 ± 0.35	-0.20 ± 0.34	-0.64 ± 0.18
Cottonwood	-1.04 ± 0.18	0.07 ± 0.54	0.46 ± 0.39	-0.61 ± 0.12
Saltcedar	-0.03 ± 0.19	0.03 ± 0.39	-0.26 ± 0.48	1.25 ± 0.22

PC1: Distance to River (+), Proportion *Prosopis/Acacia* (+), Proportion *Populus/Salix* (-), Distance to Upper Sonoran (-)
PC2: Distance to Road (-), Distance to Development (-), NDVI value (+)
PC3: NDVI value (+), Percent Canopy Cover (+), Distance to Ag Field (-)
PC4: Proportion Non-native (+)

Table 4: Independent detections of each species for each season in each forest type along the lower San Pedro River, Arizona USA in three riparian forest types from July 2017 to October 2018. Species are listed in alphabetical order.

Forest Types	Cottonwood				Mesquite				Saltcedar				Total
Season	**Spring**	**Summer**	**Fall**	**Winter**	**Spring**	**Summer**	**Fall**	**Winter**	**Spring**	**Summer**	**Fall**	**Winter**	
American Badger	1	1	0	2	6	6	4	0	13	6	3	5	47
Black Bear	2	3	0	0	3	3	0	0	4	3	0	0	18
Bobcat	18	17	17	14	15	33	34	11	33	22	75	74	363
Coati	20	12	37	10	2	188	8	13	5	4	3	4	306
Coyote	1	2	10	5	22	80	46	54	17	14	24	16	291
Gray Fox	1	2	4	0	1	1	29	25	6	0	11	15	95
Hooded Skunk	3	2	1	1	5	15	19	4	2	2	4	0	58
Javelina	46	100	99	42	20	253	63	40	132	205	144	83	1227
Mountain Lion	2	5	0	0	0	2	0	0	30	7	5	17	68
Mule Deer	1	19	19	0	13	47	18	1	4	20	0	1	143
Raccoon	3	16	7	3	0	0	4	0	4	8	15	3	63
Striped Skunk	7	0	4	4	3	0	2	7	4	1	3	0	35
Spotted Skunk	0	0	0	0	2	0	2	2	0	0	2	0	8
White-tailed Deer	6	33	15	32	0	4	2	1	2	25	10	3	133

Table 5. Average number of independent detections per 100 trap nights of mammals from 18 camera deployed along the lower San Pedro River, Arizona USA in three riparian forest types from July 2017 to October 2018.

Forest Type	Sample	Trap Nights	Mean Obs/100 Nights	Standard Error
Mesquite	6	2615	43.0	15.2
Saltcedar	6	2484	43.6	17.3
Cottonwood	6	2593	24.8	6.9

Table 6. Top performing model for each mammal species for occupancy (Psi) and detection probability (p). Includes data from April 30th, 2018 to July 8th, 2018. Directionality of whether a species is positively or negatively association with habitat components is the sign value for the AIC beta estimates (last three columns). Number of model parameters = npar. Study was along the lower San Pedro River, Arizona USA from July 2017 to October 2018. Beta values and standard error are presented for each model. Species are listed in alphabetical order.

Species	model	npar	AICc	ΔAICc	weight	Deviance	Gradient of Riparian Vegetation (PC1)	Distance to Disturbance (PC2)	Vegetation Cover (PC3)	Proportion of Non-native (PC4)
American Badger	psi.comp1_p.Dot	3	62.43	0.00	0.45	54.71	1.46 ± 0.95	----------	----------	----------
Black Bear	psi.comp3_p.Dot	3	50.94	0.00	0.60	43.23	----------	----------	13.08 ± 10.17	----------
Bobcat	psi.comp4_p.Dot	3	105.96	0.00	0.68	98.24	----------	----------	----------	5.82 ± 3.61
Coati	psi.comp2_p.Dot	3	61.53	0.00	0.45	53.82	----------	2.89 ± 2.26	----------	----------
Coyote	psi.comp1_p.Dot	3	85.99	0.00	0.99	78.27	13.08 ± 10.52	----------	----------	----------
Gray Fox	psi.Dot_p.Dot	2	31.11	0.00	0.31	6.27	----------	----------	----------	----------
Javelina	psi.Dot_p.Dot	2	83.72	0.00	0.34	23.78	----------	----------	----------	----------
Mountain Lion	psi.comp2_p.Dot	3	33.82	0.00	0.96	26.11	----------	11.44 ± 9.73	----------	----------
Mule Deer	psi.comp2_p.Dot	3	65.06	0.00	0.87	57.34	----------	-2.99 ± 1.67	----------	----------
Skunk	psi.Dot_p.Dot	2	71.50	0.00	0.34	18.18	----------	----------	----------	----------

PC1: Distance to River (+), Proportion *Prosopis/Acacia* (+), Proportion *Populus/Salix* (-), Distance to Upper Sonoran (-)
PC2: Distance to Road (-), Distance to Development (-), NDVI value (+)
PC3: NDVI value (+), Percent Canopy Cover (+), Distance to Ag Field (-)
PC4: Proportion Non-native (+)

Table 7. Two-species occupancy models depicting occupancy (Psi) and detection probability (r) for mountain lion (A) and bobcat (B). Mountain lion is the dominant species and bobcat is the subordinate. An uppercase (A or B) indicates the species is present, while a lowercase (a or b) indicates the absence of a species. Includes data from April 30th, 2018 to July 8th, 2018. Study was along the lower San Pedro River, Arizona USA from July 2017 to October 2018.

Model	npar	AICc	DeltaAICc	weight	Deviance
PsiA.Dot_PsiBA.Dot.EQUAL.PsiBa.Dot_pA.Dot_pB.Dot_rA.Dot_rBA.Dot_rBa.Dot	7	157.16	0.00	0.62	131.96
PsiA.Dot_PsiBA.Dot_PsiBa.Dot_pA.Dot_pB.Dot_rA.Dot_rBA.Dot.EQUAL.rBa.Dot	7	158.23	1.07	0.36	133.03
PsiA.Dot_PsiBA.Dot_PsiBa.Dot_pA.Dot_pB.Dot_rA.Dot_rBA.Dot_rBa.Dot	8	163.96	6.80	0.02	131.96

Table 8. Two-species occupancy models depicting occupancy (Psi) and detection probability (r) for coyote (A) and gray fox (B). Coyote is the dominant species and gray fox are the subordinate. An uppercase (A or B) indicates the species is present, while a lowercase (a or b) indicates the absence of a species. Includes data from April 30th, 2018 to July 8th, 2018. Study was along the lower San Pedro River, Arizona USA from July 2017 to October 2018.

Model	npar	AICc	DeltaAICc	weight	Deviance
PsiA.Dot_PsiBA.Dot.EQUAL.PsiBa.Dot_pA.Dot_pB.Dot_rA.Dot_rBA.Dot_rBa.Dot	7	140.27	0.000	0.59	115.07
PsiA.Dot_PsiBA.Dot_PsiBa.Dot_pA.Dot_pB.Dot_rA.Dot_rBA.Dot.EQUAL.rBa.Dot	7	141.06	0.788	0.39	115.86
PsiA.Dot_PsiBA.Dot_PsiBa.Dot_pA.Dot_pB.Dot_rA.Dot_rBA.Dot_rBa.Dot	8	147.07	6.800	0.02	115.07

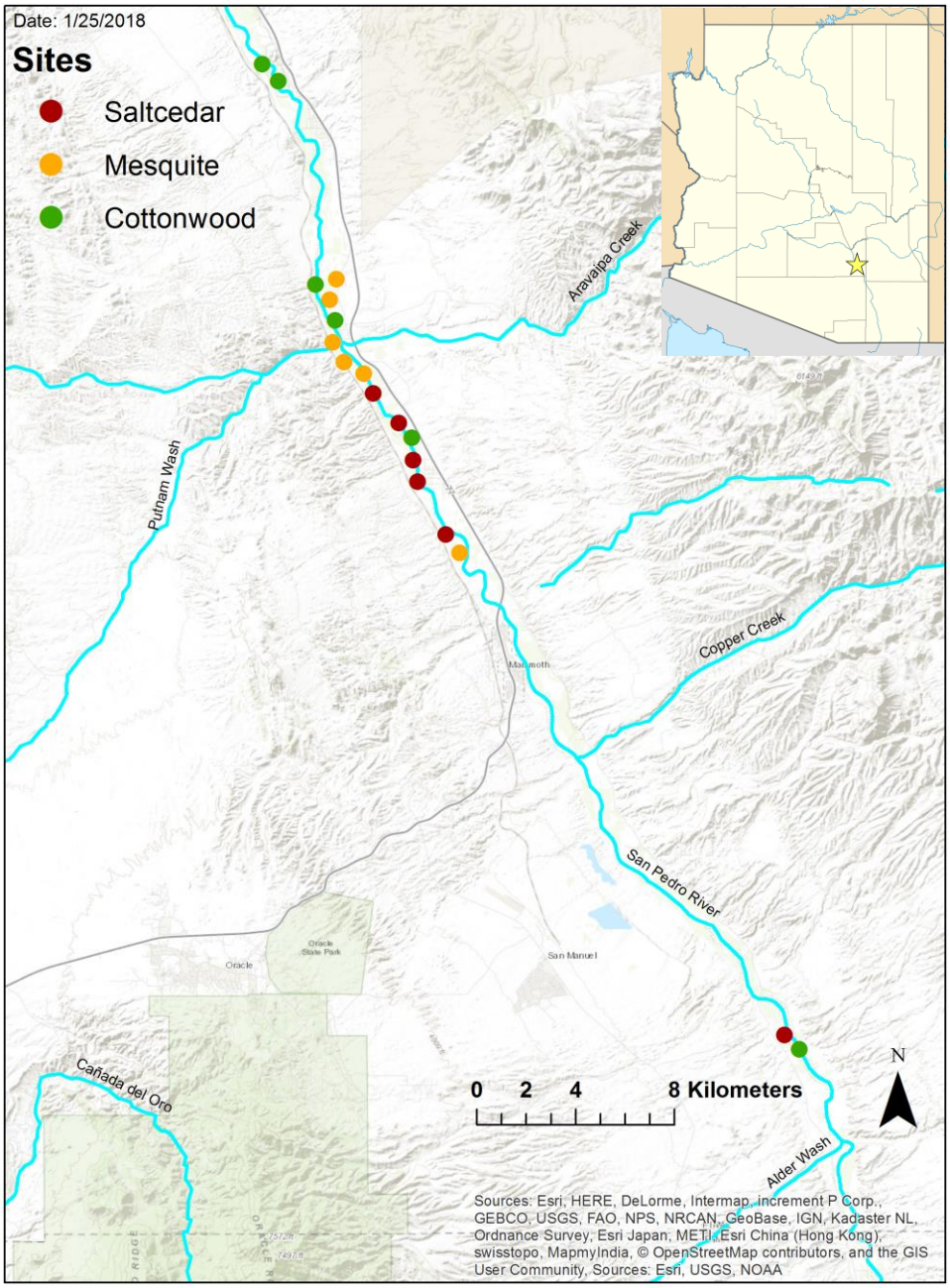


Figure 1. My study site located on the San Pedro River, Arizona USA as well as which type of vegetation is dominant in that area. Study was from July 2017 to October 2018

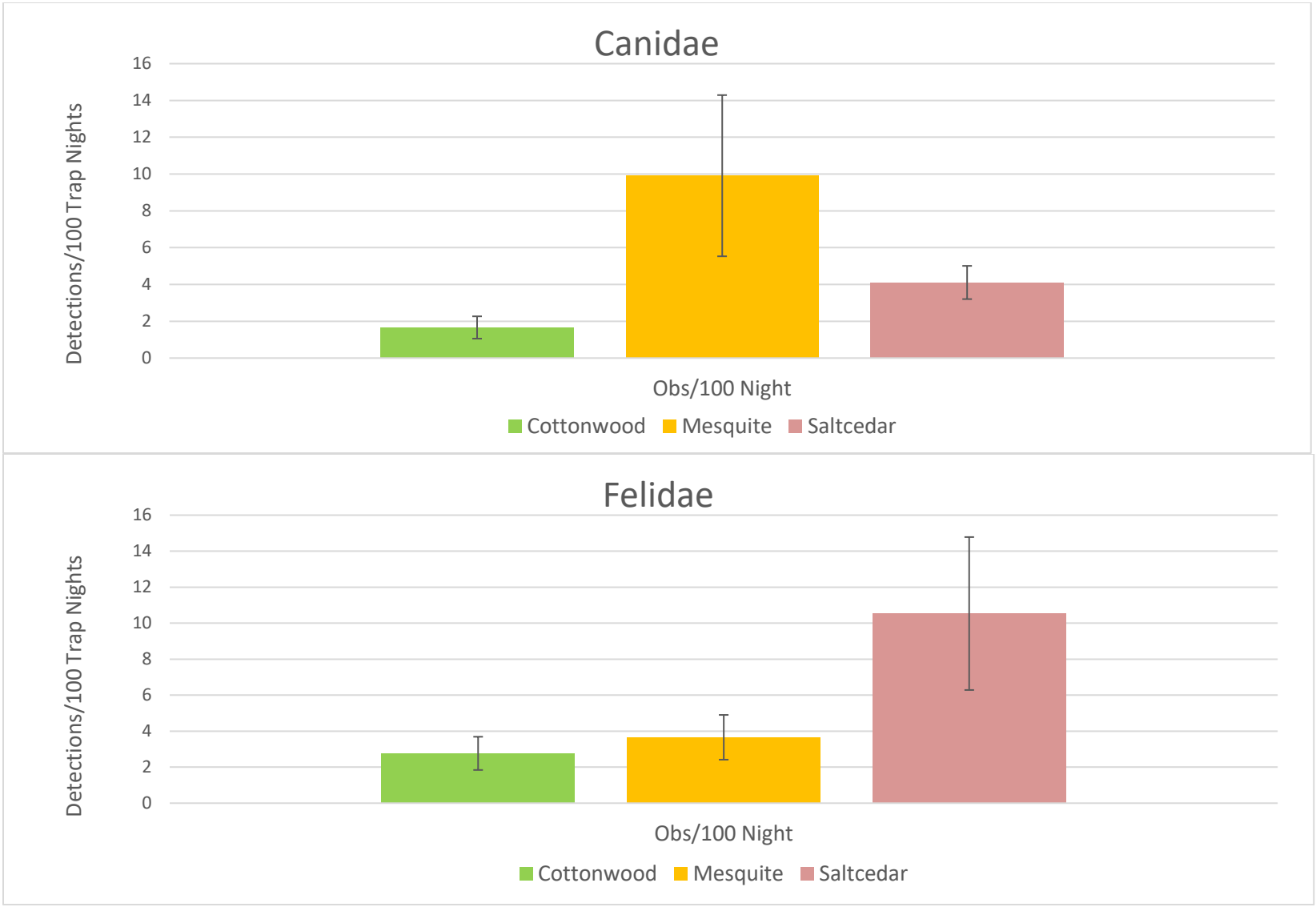


Figure 2. Mean and SE of independent detections per 100 trap nights on San Pedro River, Arizona USA from July 2017 to October 2018 for the Canidae family (*Canis latrans* and *Urocyon cinereoargenteus*) (top) and Felidae (*Lynx rufus* and *Puma concolor*).

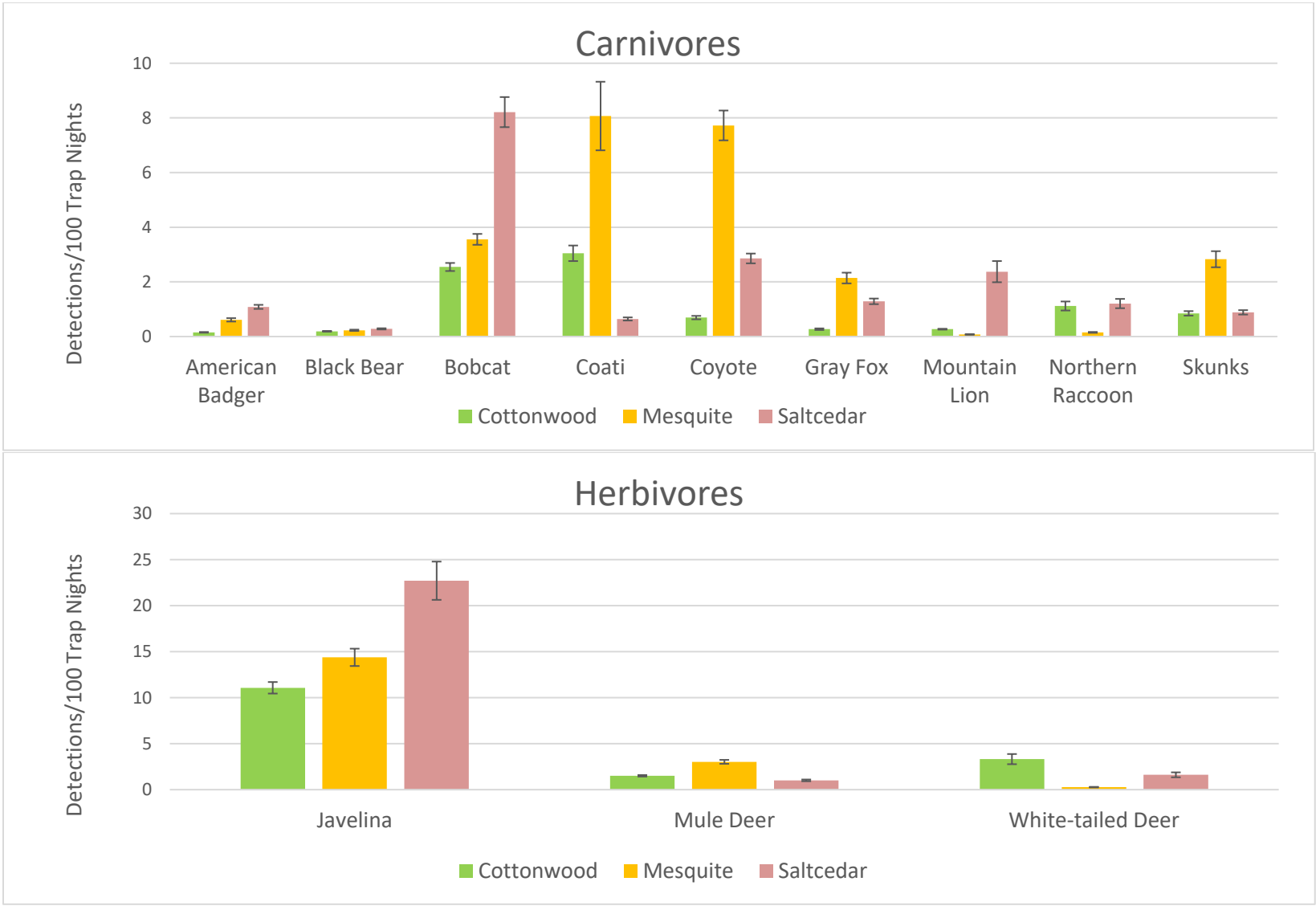


Figure 3: Mean and SE of detections per 100 trap nights on San Pedro River, Arizona USA in three riparian forest types from July 2017 to October 2018 for each species.

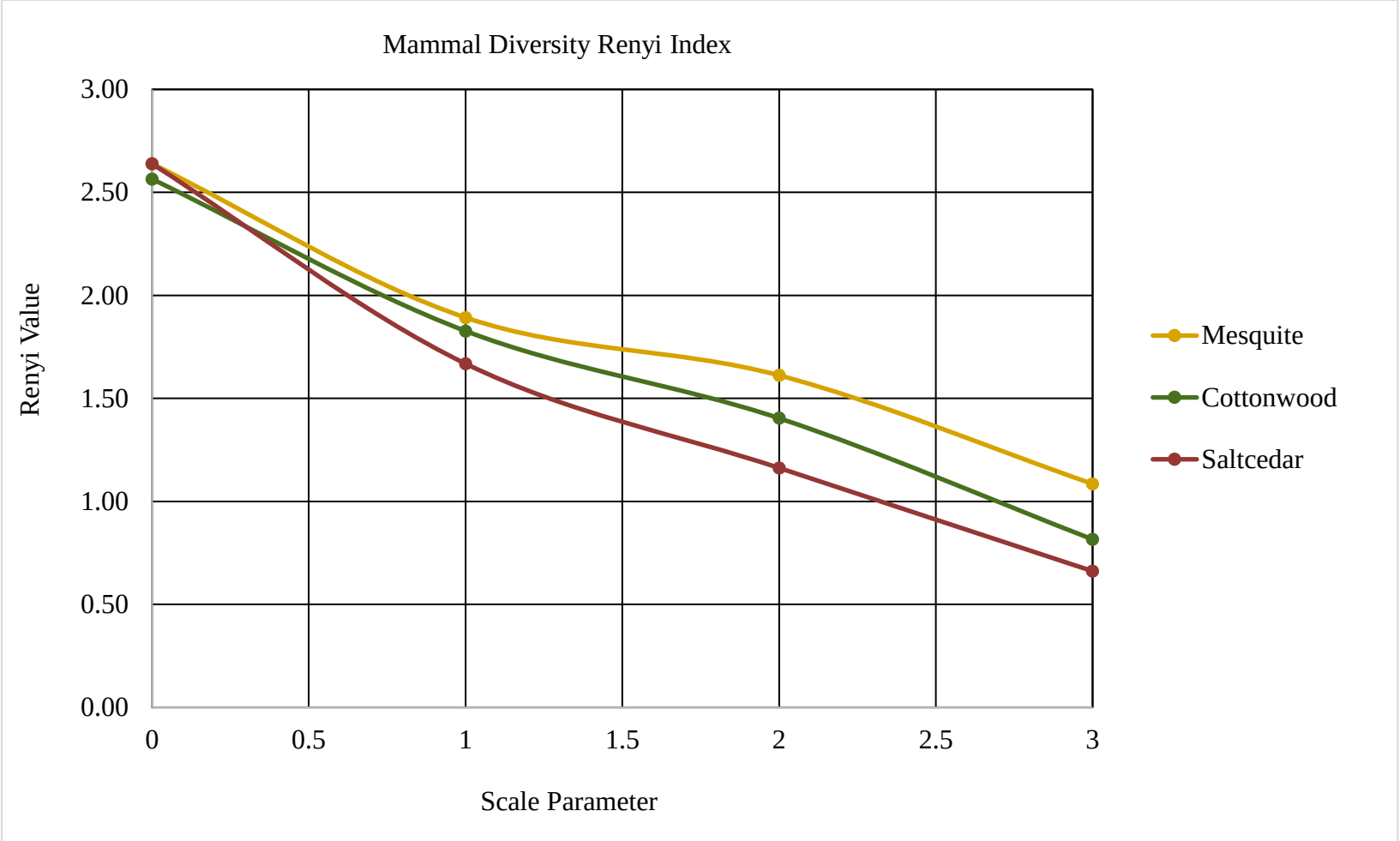


Figure 4. Rényi Index incorporates diversity calculations from species richness, Shannon, Simpsons D, and Berger-Parker indices from data collected on the San Pedro River, Arizona USA in three riparian forest types from July 2017 to October 2018. Communities are deemed different in diversity only when their lines do not cross. Rare species given less weight along the x-axis. Data for all four seasons are included.

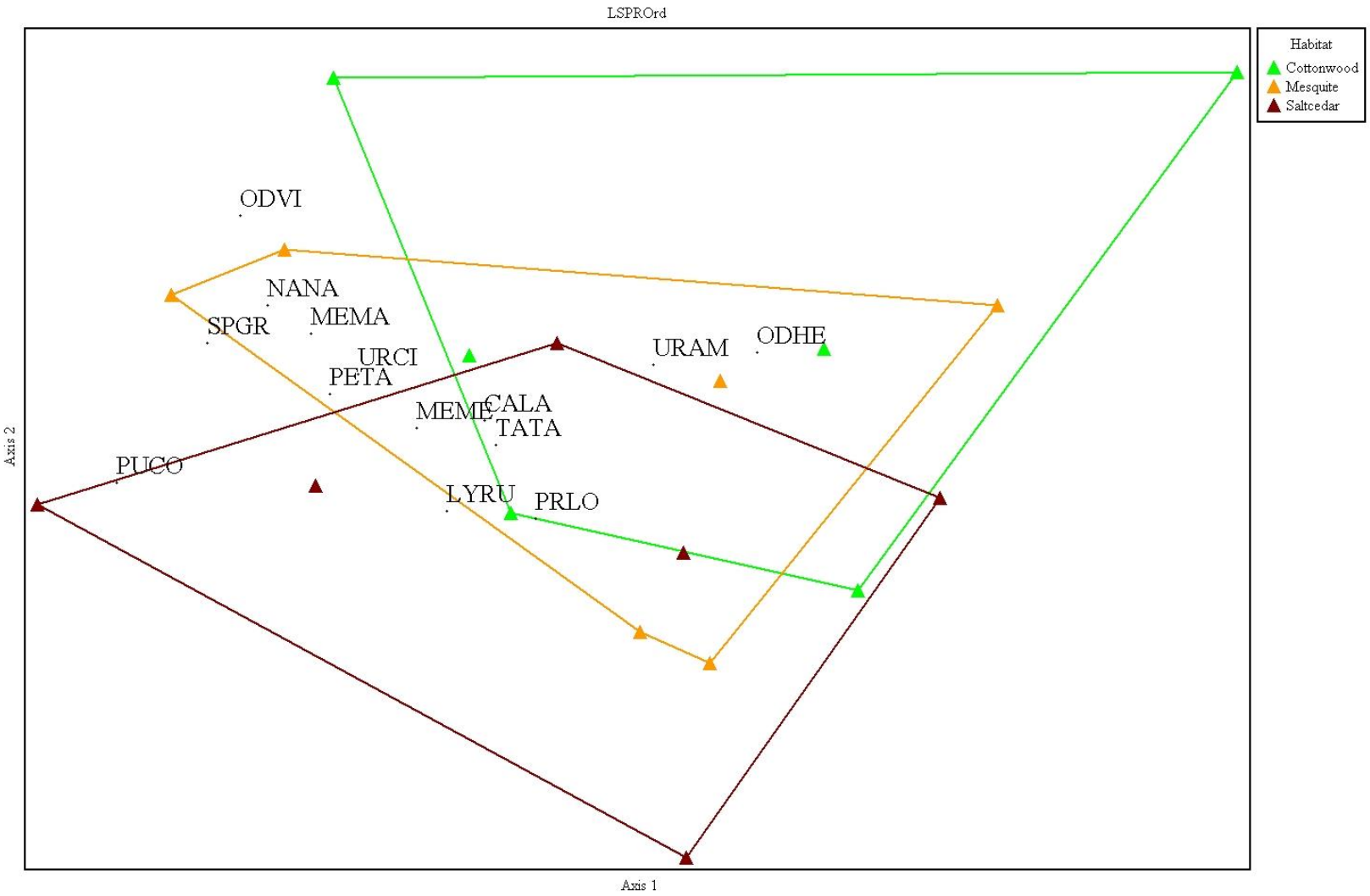


Figure 5**.** San Pedro River, Arizona USA in three riparian forest types from July 2017 to October 2018. Triangles represent sites and dots with labels represent species and where they were seen with the most frequency.

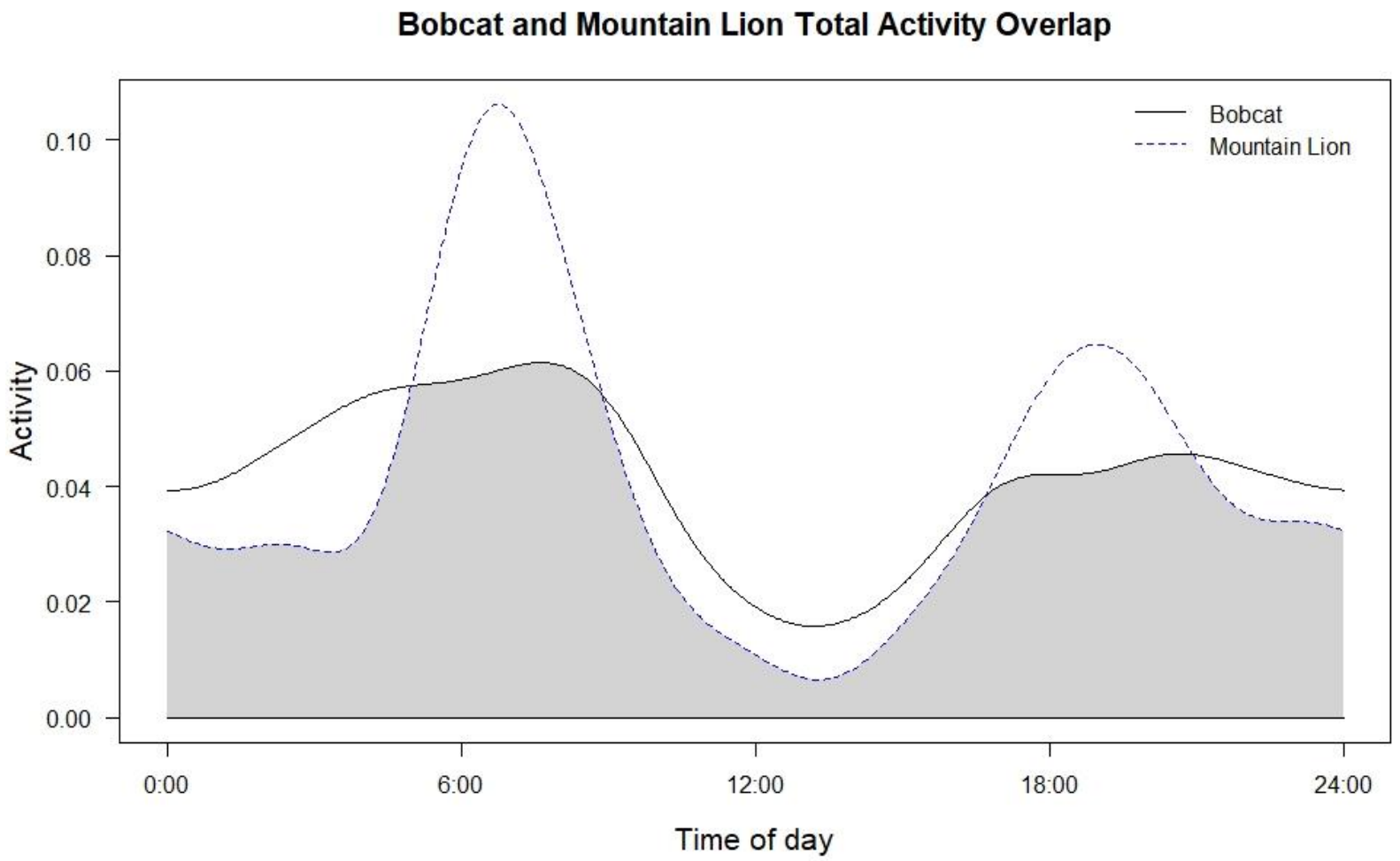


Figure 6. Overlap in activity of bobcats (n=363) and mountain lions (68) is depicted by the gray shaded area. Data for all 18 cameras was included from the lower San Pedro River, Arizona USA in three riparian forest types from July 2017 to October 2018. Dhat 4 statistic with 1000 bootstrap iterations: (Δ = 0.83, CI: 0.72 - 0.91).

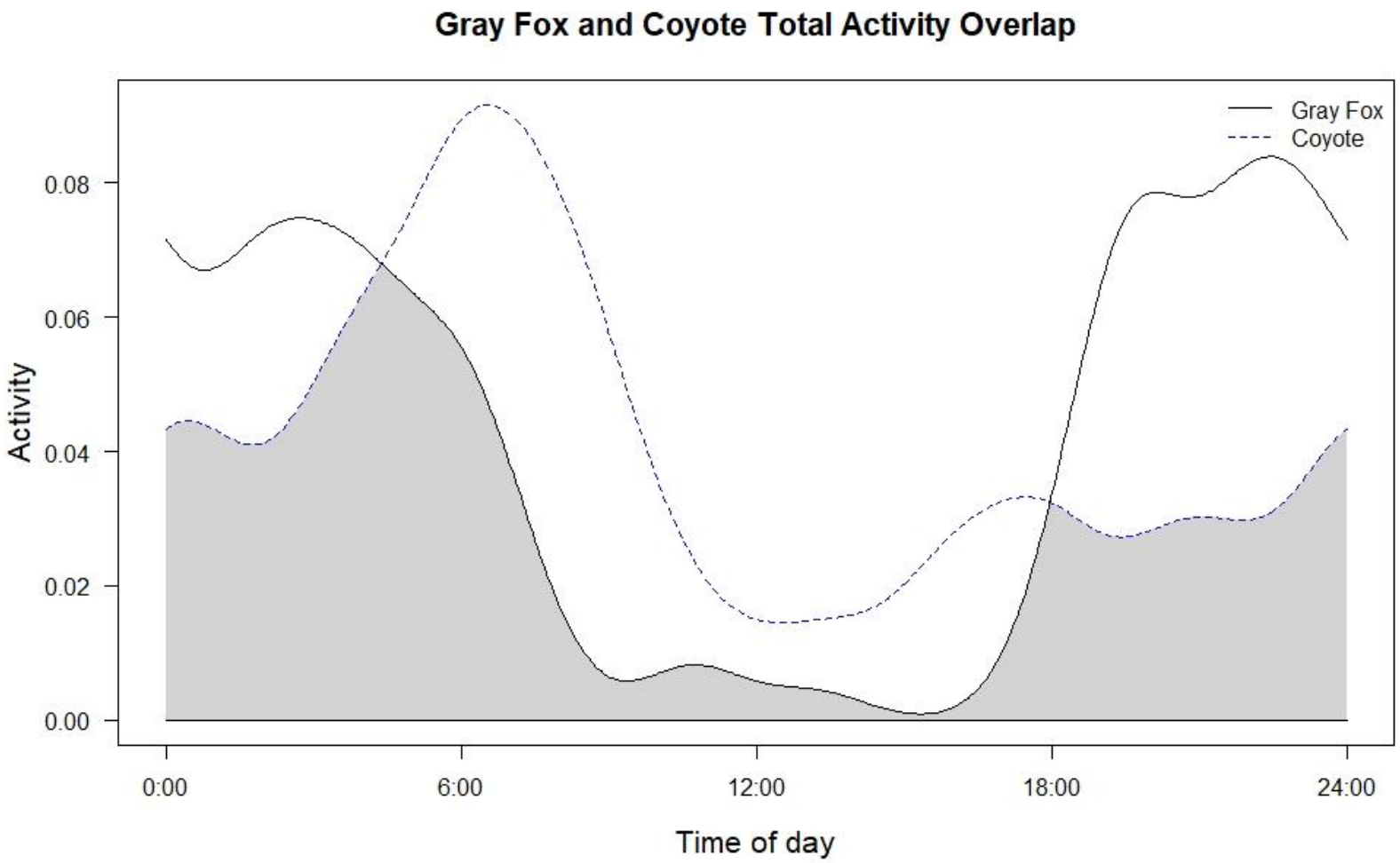


Figure 7: Overlap in activity of gray fox (95) and coyotes (291) for all four seasons is depicted by the gray shaded area. Data for all 18 cameras was included from the lower San Pedro River, Arizona USA in three riparian forest types from July 2017 to October 2018. Dhat 4 statistic with 1000 bootstrap iterations: (Δ = 0.66, CI: 0.53 - 0.73).

Literature Cited

Bagstad, K.J., Lite, S. J., & Stromberg, J.C. 2006. Vegetation, Soils, and Hydrogeomorphology of Riparian Patch Types of a Dryland River. *Western North American Naturalist*, 66(1): 23-45.

Bateman, H.L., Paxton, E.H., Longland, W. S. 2013. Tamarix as Wildlife Habitat. In Sher, A., & Quigley, M. F. (Ed.), *Tamarix: a Case Study of Ecological Change in the American West.* Oxford University Press.

Bateman, H.L, Paxton, E.H. 2009. Saltcedar and Russian Olive Interactions with Wildlife. In Shafroth, P. B., Brown, C. A., & Merritt, D. M. (2010). Saltcedar and Russian Olive control Demonstration Act Science Assessment. *Scientific Investigations Report 2009-5247. Reston, VA: ME Geological Survey. 143 p.*

Bateman, H. L., Ostoja, S. M., Redpath, S., & Ficetola, F. 2012. Invasive Woody Plants Affect the Composition of Native Lizard and Small Mammal Communities in Riparian Woodlands. *Animal Conservation, 15*(3): 294-304.

Beier, P. 1995. Dispersal of Juvenile Cougars in Fragmented Habitat. *Journal of Wildlife Management* 59:228-237.

Beier, P. and R. H.Barrett. 1993. The Cougar in the Santa Ana Mountain Range, California. Final Report. Orange County Cooperative Mountain Lion Study, Department of Forestry and Resource Management, *University of California, Berkeley, USA*.

Bender, L. C., Weisenberger, M. E., & Rosas-Rosas, O. C. 2014. Occupancy and Habitat Correlates of Javelinas in the Southern San Andres Mountains, New Mexico. *Journal of Mammalogy*, 95(1), 1-8.

Boeer, W. J., & Schmidly, D. J. 1977. Terrestrial Mammals of the Riparian Corridor in Big Bend National Park [USA]. *USDA Forest Service General Technical Report RM (USA).*

Braatne, J. H., Rood, S. B., & Heilman, P. E. 1996. Life History, Ecology, and Conservation of Riparian Cottonwoods in North America. *Biology of Populus and Its Implications for Management and Conservation,* (Part I), 57-85.

Brand, L. A., Stromberg, J. C., & Noon, B. R. 2010. Avian Density and Nest Survival on the San Pedro River: Importance of Vegetation Type and Hydrologic Regime. *The Journal of Wildlife Management*, 74(4): 739-754.

Brandt, H. 1951. Arizona and Its Bird Life. *Bird Research Foundation*.

Brinson, M. M., Lugo, A. E., & Brown, S. 1981. Primary Productivity, Decomposition and Consumer Activity in Freshwater Wetlands. *Annual Review of Ecology* and *Systematics*, 12(1): 123-161.

Brown, D. E., & Lowe, C. H. (1980). Biotic Communities of the Southwest. *Biotic Communities of the Southwest.*, (RM-78).

Burton, A. C., Neilson, E., Moreira, D., Ladle, A., Steenweg, R., Fisher, J. T., Et Al. 2015. REVIEW: Wildlife Camera Trapping: a Review and Recommendations for Linking Surveys to Ecological Processes. *Journal of Applied Ecology, 52*:675-685.

Busch, D. E., & Smith, S. D. 1995. Mechanisms Associated with Decline of Woody Species in Riparian Ecosystems of the Southwestern U.S. *Ecological Monographs, 65*(3): 347-370.

Carman, J. G., & Brotherson, J. D. 1982. Comparisons of Sites Infested and Not Infested with Saltcedar (*Tamarix pentandra*) and Russian olive (*Elaeagnus angustifolia*). *Weed Science*, *30*(4), 360-364.

Chamberlain, M. J., & Leopold, B. D. 2005. Overlap in Space Use Among Bobcats (*Lynx rufus*), Coyotes (*Canis latrans*) and Gray Foxes (*Urocyon cinereoargenteus*). *American Midland Naturalist, 153*(1): 171-179.

Chaney, E., W. Elmore, and W. S. Platts. 1990. Livestock Grazing on Western Riparian Areas. U.S. *Environmental Protection Agency*. 45 Pp.

Collins, D. P., Harveson, L. A., & Ruthven, D. C. 2012. Spatial Characteristics of American Badgers (*Taxidea taxus*) in Southern Texas. *The Southwestern Naturalist*, 57(4): 473-479.

Crooks, K. R., Grigione, M., Scoville, A., & Scoville, G. 2008. Exploratory Use of Track and Camera Surveys of Mammalian Carnivores in the Peloncillo and Chiricahua Mountains of Southeastern Arizona. *The Southwestern Naturalist*, 53(4), 510-518.

Cunningham, S. C., Gustavson, C. R., & Ballard, W. B. 1999. Diet selection of mountain lions in southeastern Arizona. *Journal of Range Management*, 202-207.

Cunningham, S. C., Kirkendall, L., & Ballard, W. 2006. Gray fox and coyote abundance and diet responses after a wildfire in central Arizona. *Western North American Naturalist*, *66*(2): 169-181.

Debano, L. F., & Schmidt, L. J. 2004. Definitions and Classifications. *Riparian Areas of The Southwestern United States Hydrology Ecology* and *Management.* CRC Press. Boca Raton, FL, 11-27.

Dickson, B. G., & Beier, P. 2002. Home-Range and Habitat Selection by Adult Cougars in Southern California. *The Journal of Wildlife Management*, 1235-1245.

Dickson, B. G., Roemer, G. W., Mcrae, B. H., & Rundall, J. M. 2013. Models of Regional Habitat Quality and Connectivity for Pumas (*Puma concolor*) in the Southwestern United States. *Plos one, 8*(12): E81898.

Di Tomaso, J. M. 1998. Impact, Biology, and Ecology of Saltcedar (*Tamarix* spp.) in the Southwestern United States. *Weed technology*, 12(2), 326-336.

Doyle, A. T. 1990. Use of Riparian and Upland Habitats by Small Mammals. *Journal of Mammalogy*, 71(1): 14-23.

Duncan, D. K., 1988. Mammal Inventory of the San Pedro Riparian National Conservation Area, Cochise County, Arizona. *U.S. Bureau of Land Management, San Pedro Project Office.*

Duquette, J. F., Gehrt, S. D., Ver Steeg, B., & Warner, R. E. 2014. Badger (*Taxidea taxus*) Resource Aelection and Spatial Ecology in Intensive Agricultural Landscapes. *The American Midland Naturalist*, 171(1), 116-128.

Elmore, W., & Kauffman, B. 1992. Riparian and Watershed Systems: Degradation and Restoration. Ecological Implications of Livestock Herbivory. *Western Society for Range Management, Denver, CO.*

Ffolliott, P. F., Debano, L. F., Baker Jr, M. B., Neary, D. G., & Brooks, K. N. 2004. Hydrology and Impacts of Disturbances on Hydrologic Function. *Riparian Areas of the Southwestern United States: Hydrology, Ecology,* and *Management*; Baker, MB, Ffolliott, PF, Debano, LF, Neary, DG, Eds, 51.

Gantchoff, M. G., & Belant, J. L. 2017. Regional Connectivity for Recolonizing American Black Bears (*Ursus americanus*) in Southcentral USA. Biological conservation, 214, 66-75.

Gifford, S. J., Gese, E. M., & Parmenter, R. R. 2017. Space Use and Social Ecology of Coyotes (*Canis Latrans*) in a High-Elevation Ecosystem: Relative Stability in a Changing Environment. *Journal of ethology*, 35(1), 37-49.

Grinder, M. I., & Krausman, P. R. 2001. Home Range, Habitat Use, and Nocturnal Activity of Coyotes in an Urban Environment. *The Journal of Wildlife Management*, 887-898.

Hass, C. C. 2001. Landscape Fragmentation and Connectivity for Carnivores in The Upper San Pedro Basin. *Fort Huachuca Wildlife Office.*

Hass, C. C. 2009. Competition and coexistence in sympatric bobcats and pumas. *Journal of Zoology*, 278(3): 174-180.

Hellgren, E.C. 1993. Status, Distribution, and Summer Food Habits of Black Bears in Big Bend National Park. *The Southwestern Naturalist* 38:77-80.

Hilty, J. A., & Merenlender, A. M. 2004. Use of Riparian Corridors and Vineyards by Mammalian Predators in Northern California. *Conservation Biology*, 18(1), 126-135.

Hinojosa-Huerta, O. 2006. Birds, Water, and Saltcedar: Strategies for Riparian Restoration in the Colorado River delta.

Hopkins, R. A. 1991. Ecology of The Puma in The Diablo Range, California. 4662-4662.

Iriarte, J. A., Franklin, W. L., Johnson, W. E., & Redford, K. H. 1990. Biogeographic Variation of Food Habits and Body Size of The America Puma. *Oecologia, 85*(2): 185-190.

Johnson, A. S. 1989. The Thin Green Line: Riparian Corridors and Endangered Species in Arizona and New Mexico. In Defense of Wildlife: Preserving Communities and Corridors. *Defenders of Wildlife, Washington*, *DC*, 35-46.

Johnson, R. R., & Haight, L. T. 1984. Riparian Problems and Initiatives in the American Southwest: A Regional Perspective. *California Riparian Systems: Ecology, Conservation* and *Productive Management.University of California Press, Berkley, CA*, 404-412.

Johnson, R. R., & Jones, D. A. 1977. Importance, Preservation and Management of Riparian Habitat: A Symposium; Tucson, Arizona; July 9, 1977.

Jolliffe, I. T. (2002). Principal Components in Regression Analysis. Principal Component Analysis, 167-198.

Kelly, M. J., & Holub, E. L. 2008. Camera Trapping of Carnivores: Trap Success Among Camera Types and Across Species, and Habitat Selection by Species, on Salt Pond Mountain, Giles County, Virginia. *Northeastern Naturalist, 15*(2): 249-262.

Knopf, F. L., Johnson, R. R., Rich, T., Samson, F. B., & Szaro, R. C. 1988. Conservation of Riparian Ecosystems in The United States. *The Wilson Bulletin*, 100(2): 272-284.

Laake, J.L. 2013. RMark: An R Interface for Analysis of Capture-Recapture Data with MARK. AFSC Processed Rep 2013-01, 25p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.

Lanning, D. V. 1976. Density and Movements of the Coati in Arizona. *Journal of Mammalogy, 57*(3): 609-611.

Larrucea, E. S., Brussard, P. F., Jaeger, M. M., & Barrett, R. H. 2007. Cameras, Coyotes, and the Assumption of Equal Detectability. *Journal of Wildlife Management, 71*(5): 1682-1689.

Leach, R. H., & Edge, W. D. 2009. Summer Home Range and Habitat Selection by White-tailed Deer in the Swan Valley, Montana. *Northwest Science*.

Lewis, J. S., Bailey, L. L., Vandewoude, S., & Crooks, K. R. 2015. Interspecific Interactions Between Wild Felids Vary Across Scales and Levels of Urbanization. *Ecology and Evolution, 5*(24): 5946-5961.

Lewis, J. S., Logan, K. A., Alldredge, M. W., Bailey, L. L., Vandewoude, S., & Crooks, K. R. 2015. The Effects of Urbanization on Population Density, Occupancy, and Detection Probability of Wild Felids. *Ecological Applications*, 25(7): 1880-1895.

Loft, E. R., Menke, J. W., & Kie, J. G. 1991. Habitat Shifts by Mule Deer: the Influence of Cattle Grazing. *The Journal of Wildlife Management*, 16-26.

Lowe, C. H. 1989. The Riparianness of a Desert Herpetofauna. In:: Abell, Dana L., Technical Coordinator. 1989. Proceedings of the California Riparian Systems Conference: protection, management, and restoration for the 1990s; 1988 September 22-24; Davis, CA. *Gen. Tech. Rep. PSW-GTR-110. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, ME Department of Agriculture; p. 143-148 (Vol. 110).*

Mack, R. N., Simberloff, D., Lonsdale, W. M., Evans, H., Clout, M., & Bazzaz, F. A. 2000. Biotic Invasions: Causes, Epidemiology, Global Consequences, and Control. *Ecological Applications, 10*(3): 689-710.

MacKenzie, D. I., Nichols, J. D., Royle, J. A., Pollock, K. H., Bailey, L., & Hines, J. E. 2017. Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence. Elsevier.

Marshal, J. P., Bleich, V. C., Andrew, N. G., & Krausman, P. R. 2004. Seasonal Forage Use by Desert Mule Deer in Southeastern California. *The Southwestern Naturalist*, 49(4): 501-506.

McCune, B., & Mefford, M. J. (1999). Multivariate analysis on the PC-ORD system.

Mckinney, B.R., and M.T. Pittman. 2000. Habitat, Diet, Home Range, and Seasonal Movement of Resident and Relocated Black Bears in West Texas. *Texas Parks and Wildlife Department, Project WER57-STATE, Austin, Texas, USA.*

Mitchell, F.S. 2001. Winter Ecology and Food Habits of Black Bears in Big Bend National Park. *Thesis, Sul Ross State University, Alpine, Texas, USA*.

Ridout, M., Matthew Linkie 2009. Estimating Overlap of Daily Activity Patterns from Camera Trap Data. *Journal of Agricultural, Biological, and Environmental Statistics* 14(3): 322-337.

Martínez, A. J., & López-Portillo, J. 2003. Allometry of Prosopis Glandulosa Var. Torreyana Along a Topographic Gradient in the Chihuahuan Desert. *Journal of Vegetation Science*, 14(1): 111-120.

Mcadams, C. 2012. Wildlife Camera Carnivore Survey: Santa Margarita Ranch, CA.

National Research Council. 2002. Riparian Areas: Functions and Strategies for Management. *National Academies Press.*

Ivan, J. S., & Newkirk, E. S. (2016). CPW Photo Warehouse: a custom database to facilitate archiving, identifying, summarizing and managing photo data collected from camera traps. *Methods in Ecology and Evolution*, *7*(4), 499-504.

Ohmart, R. D., & Anderson, B. W. 1986. Riparian Habitat. *Inventory and Monitoring of Wildlife Habitat*, 169-199.

Oksanen, J. F. Guillaume Blanchet, Michael Friendly, Roeland Kindt, Pierre Legendre, Dan McGlinn, Peter R. Minchin, R. B. O'Hara, Gavin L. Simpson, Peter Solymos, M. Henry H. Stevens, Eduard Szoecs and Helene Wagner (2019). vegan: Community Ecology Package. R package version 2.5-5.

Osborne, L. L., & Kovacic, D. A. 1993. Riparian Vegetated Buffer Strips in Water-Quality Restoration and Stream Management. *Freshwater Biology*, 29(2): 243-258.

Ray, J.C., Redford, K.H., Steneck, R.S., Berger, J. 2005. Large Carnivores and the Conservation of Biodiversity. *Washington (DC): Island Press*.

Ripple WJ, Beschta RL. 2004. Wolves and the Ecology of Fear: Can Predation Risk Structure Ecosystems? *Bioscience* 54: 755–766.

Risser, A. C. 1963. A Study of The Coati Mundi *Nasua Narica* in Southern Arizona.

Roemer, G. W., Gompper, M. E., & Van Valkenburgh, B. 2009. The Ecological Role of the Mammalian Mesocarnivore. *Bioscience*, 59(2): 165-173.

Schultz, R. C., Isenhart, T. M., Simpkins, W. W., & Colletti, J. P. 2004. Riparian Forest Buffers in Agroecosystems–Lessons Learned from the Bear Creek Watershed, Central Iowa, USA. *Agroforestry Systems*, 61(1-3): 35-50.

Soykan, C.U., Brand, L. A., Sabo J.L. 2009. Causes and Consequences of Mammal Species Richness. In Stromberg, J.C. & Tellman, B. (Ed.), *Ecology and Conservation of The San Pedro River* (Pp. 107). Tucson, Arizona: The University of Arizona Press.

Swift, B. L. 1984. Status of Riparian Ecosystems in the United States 1. *JAWRA Journal of The American Water Resources Association*, 20(2): 223-228.

Stromberg, J.C., Lite, S.J., Dixon, M.D., Tiller, R.L. 2009. Riparian Vegetation. In Stromberg, J.C. & Tellman, B. (Ed.), *Ecology and Conservation of The San Pedro River* (Pp. 107). Tucson, Arizona: The University of Arizona Press.

Stromberg, J. C., Richter, B. D., Patten, D. T., & Wolden, L. G. 1993. Response of a Sonoran Riparian Forest to a 10-Year Return Flood. *The Great Basin Naturalist*, 118-130.

Stromberg, J. C. 1993. Riparian Mesquite Forests: A Review of their Ecology, Threats, and Recovery Potential. *Journal of the Arizona-Nevada Academy of Science*, 111-124.

Swarth, H. S. 1905. Summer Birds of the Papago Indian Reservation and of the Santa Rita Mountains, Arizona. *The Condor*, 7(1): 22-28.

Szaro, R. C. 1989. Riparian Scrubland and Community Types of Arizona in New Mexico. *Desert Plants*. 9: 1-138.

Tigas, L. A., Van Vuren, D. H., & Sauvajot, R. M. 2002. Behavioral Responses of Bobcats and Coyotes to Habitat Fragmentation and Corridors in an Urban Environment. *Biological Conservation*, 108(3): 299-306.

Webb, R. H., & Leake, S. A. 2006. Ground-Water Surface-Water Interactions and Long-Term Change in Riverine Riparian Vegetation in the Southwestern United States. *Journal of Hydrology*, 320(3-4): 302-323.

Weier, J. and Herring, D. 2000. Measuring Vegetation (NDVI & EVI). [online] NASA Earth Observatory. Available at: http://earthobservatory.nasa.gov/Features/MeasuringVegetation/ [Accessed 26 Aug. 2019].

Woolsey, N. 1987. Furbearing Animals of the San Pedro Preserve, Unpublished Report for *U.S. Bureau of Land Management, San Pedro Project Office.*

Zaimes, G., Nichols, M., Green, D., & Crimmins, M. 2007. Understanding Arizona's Riparian Areas. *College of Agriculture and Life Sciences, University of Arizona* (Tucson, AZ)

APPENDIX A
SITE LOCATIONS

Site locations on the lower San Pedro River, Arizona USA in three riparian forest types from July 2017 to October 2018.

Land ownership	Property name	Site name	Forest Type	UTM Easting	UTM Northing
BOR	San Pedro Preserve	PRS-1	Cottonwood	523368	3644827
BOR	San Pedro Preserve	PRS-2	Cottonwood	524025	3644143
BOR	Cook's Lake	CKL-1	Mesquite	526388	3636121
BOR	Cook's Lake	CKL-2	Cottonwood	525536	3635898
SRP	Cook's Lake	CKL-3	Mesquite	526104	3635284
SRP	Spirit Hollow	SHA-1	Saltcedar	544532	3605490
SRP	Spirit Hollow	SHA-2	Cottonwood	545147	3604903
AZGFD	Lower San Pedro State Wildlife Area	LWA-1	Cottonwood	526335	3634444
AZGFD	Lower San Pedro State Wildlife Area	LWA-2	Mesquite	526237	3633550
AZGFD	Lower San Pedro State Wildlife Area	LWA-3	Mesquite	526690	3632750
AZGFD	Lower San Pedro State Wildlife Area	LWA-4	Mesquite	527483	3632274
AZGFD	Lower San Pedro State Wildlife Area	LWA-5	Saltcedar	527874	3631492
AZGFD	Lower San Pedro State Wildlife Area	LWA-7	Mesquite	528907	3630293
AZGFD	Lower San Pedro State Wildlife Area	LWA-8	Cottonwood	529436	3629680
AZGFD	Lower San Pedro State Wildlife Area	LWA-9	Saltcedar	529495	3628786
AZGFD	Lower San Pedro State Wildlife Area	LWA-10	Saltcedar	529661	3627911
AZGFD	Lower San Pedro State Wildlife Area	LWA-12	Saltcedar	530820	3625760
AZGFD	Lower San Pedro State Wildlife Area	LWA-13	Mesquite	531379	3625011

APPENDIX B

CAMERA DEPLOYMENT

A camera deployed in mesquite habitat on the San Pedro River, Arizona USA in three riparian forest types from July 2017 to October 2018.

APPENDIX C

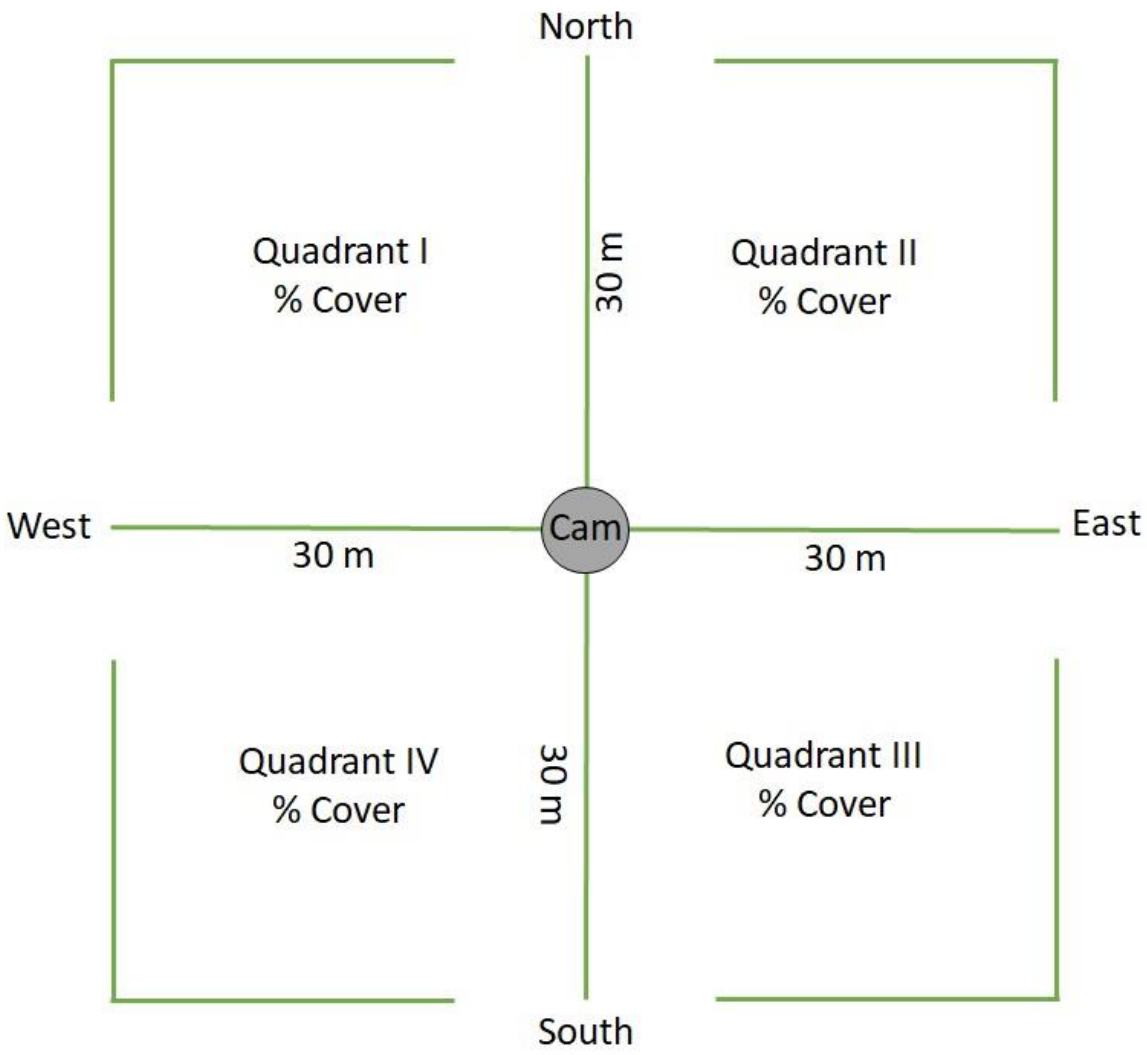
HABITAT VARIABLE DESCRIPTIONS

Descriptions of measured habitat variables around cameras deployed along the lower San Pedro River, Arizona USA in three riparian forest types from July 2017 to October 2018.

Habitat Variable	**Description**
Dist_Rvr (km)	Shortest distance from the camera to the river (km)
Dist_UppSon (km)	Shortest distance from the camera to the upper Sonoran Desert edge (km)
Dist_Ag (km)	Shortest distance from the camera to the nearest agricultural field (km)
Dist_Road (km)	Shortest distance from the camera to the nearest paved road or highway (km)
Dist_Dev (km)	Shortest distance from the camera to the nearest human development (km)
Prop_PopSal	Proportion of vegetation transect points that intersected Populus and/or Salix
Prop_ProAca	Proportion of vegetation transect points that intersected Prosopis and/or Acacia
Prop_Non-native	Proportion of trees intersecting vegetation transects that were non-native
Canopy_Cvr	Average of 8 measurements (4 each in 2 different quadrants) estimated using a densiometer
NDVI	NDVI values averages from a 400 m buffer around camera using MODIS imagery

APPENDIX D

HABITAT SURVEY SCHEMATIC



A diagram of the ground transect portion of the vegetation surveys on the San Pedro River, Arizona USA in three riparian forest types from July 2017 to October 2018.

APPENDIX E

HABITAT VARIABLE RESULTS

Habitat variable measurements for San Pedro River, Arizona USA in three riparian forest types from July 2017 to October 2018.

Site	Distance to River (km)	Distance to Upper Sonoran (km)	Distance to Agriculture Field (km)	Distance to Road (km)	Distance to Development (km)	Proportion of *Populus/Salix*	Proportion of *Prosopis/Acacia*	Proportion of Non-native	Canopy Cover (%)	NDVI
PRS1	0.01	0.49	0.43	0.84	0.70	0.90	0.00	0.12	79.7	0.36
PRS2	0.01	0.50	1.31	0.61	0.42	0.95	0.00	0.02	90.3	0.44
CKL1	0.75	0.09	1.02	0.79	1.10	0.12	0.97	0.03	90.1	0.46
CKL2	0.02	0.15	1.30	1.67	1.77	0.47	0.22	0.34	82.5	0.30
CKL3	0.38	0.30	1.86	1.16	1.20	0.00	0.63	0.00	90.8	0.42
LWA1	0.06	0.09	1.51	0.66	0.50	0.82	0.35	0.09	86.4	0.39
LWA2	0.23	0.18	1.15	0.78	0.67	0.00	0.80	0.00	44.8	0.30
LWA3	0.21	0.10	0.71	0.68	0.58	0.00	0.67	0.00	58.9	0.33
LWA4	0.19	0.42	0.60	0.50	0.48	0.00	0.95	0.00	67.9	0.48
LWA5	0.25	0.31	0.33	0.63	1.15	0.00	0.00	1.00	71.3	0.52
LWA7	0.27	0.31	0.21	0.48	1.61	0.00	0.45	0.72	67.0	0.49
LWA8	0.11	0.22	0.48	0.31	0.79	0.95	0.25	0.26	94.4	0.47
LWA9	0.18	0.51	0.69	0.68	0.25	0.00	0.12	0.88	73.5	0.46
LWA10	0.06	0.42	1.23	0.95	0.36	0.00	0.22	0.68	58.0	0.37
LWA12	0.12	0.23	0.28	1.03	2.00	0.00	0.27	0.77	60.0	0.30
LWA13	0.32	0.37	0.62	0.92	2.95	0.00	0.60	0.00	41.2	0.34
SHA1	0.11	0.41	12.40	0.39	0.65	0.08	0.00	0.86	18.5	0.40
SHA2	0.08	0.57	13.25	0.56	0.44	0.63	0.02	0.29	73.1	0.34

APPENDIX F

OCCUPANCY MODELLING RESULTS

Models of occupancy (Psi) for the summer season along the lower San Pedro River, Arizona USA in three riparian forest types. Models show the importance of habitat components (PC1-PC4) in predicting species occurrence using multiple-model inference. Psi stands for occupancy and (p) stands for detection probability. Beta values and standard error are presented for each model. The last three columns show the beta (β) values and standard error of occupancy with habitat components. Species are listed in alphabetical order.

Species	model	npar	AICc	ΔAICc	weight	Deviation	Gradient of Riparian Vegetation (PC1)	Distance to Disturbance (PC2)	Vegetation Cover (PC3)	Proportion of Non-native (PC4)
American Badger	psi.comp1_p.Dot	3	62.43	0.00	0.45	54.71	1.46 ± 0.95	----------	----------	----------
	psi.Dot_p.Dot	2	63.69	1.26	0.24	17.25	----------	----------	----------	----------
	psi.comp3_p.Dot	3	64.30	1.87	0.18	56.58	----------	----------	1.08 ± 0.83	----------
	psi.comp4_p.Dot	3	66.05	3.63	3.63	58.34	----------	----------	----------	0.49 ± 0.73
	psi.comp2_p.Dot	3	66.54	4.12	4.12	58.83	----------	0.15 ± 0.63	----------	----------
Black Bear	psi.comp3_p.Dot	3	52.43	0.00	0.47	44.72	----------	----------	8.10 ± 10.17	----------
	psi.Dot_p.Dot	2	53.10	1.56	0.21	11.37	----------	----------	----------	----------
	psi.comp4_p.Dot	3	54.46	2.03	0.17	46.74	----------	----------	----------	9.28 ± 10.40
	psi.comp1_p.Dot	3	56.02	3.59	0.08	48.30	1.01 ± 1.14	----------	----------	----------
	psi.comp2_p.Dot	3	56.18	3.57	0.07	48.47	----------	8.16 ± 12.69	----------	----------
Bobcat	psi.comp4_p.Dot	3	105.96	0.00	0.68	98.24	----------	----------	----------	5.82 ± 3.61
	psi.Dot_p.Dot	2	108.57	2.62	0.18	23.99	----------	----------	----------	----------
	psi.comp3_p.Dot	3	111.27	5.31	0.05	103.56	----------	----------	-0.27 ± 0.60	----------
	psi.comp1_p.Dot	3	111.41	5.46	0.04	103.70	-0.15 ± 0.56	----------	----------	----------
	psi.comp2_p.Dot	3	111.43	5.47	0.04	103.71	----------	0.13 ± 0.52	----------	----------
Coyote	psi.comp1_p.Dot	3	85.99	0.00	0.99	78.27	13.08 ± 10.52	----------	----------	----------
	psi.Dot_p.Dot	2	99.46	13.47	0.00	23.40	----------	----------	----------	----------
	psi.comp2_p.Dot	3	100.15	14.16	0.00	92.43	----------	-2.67 ± 2.21	----------	----------
	psi.comp4_p.Dot	3	100.65	14.66	0.00	92.93	----------	----------	----------	0.91 ± 0.82
	psi.comp3_p.Dot	3	102.34	16.35	0.00	94.62	----------	----------	-0.22 ± 1.42	----------
Javelina	psi.Dot_p.Dot	2	83.72	0.00	0.34	23.78	----------	----------	----------	----------

	psi.comp3_p.Dot	3	84.27	0.55	0.26	76.56	----------	----------	-1.18 ± 1.10	----------
	psi.comp1_p.Dot	3	85.26	1.54	0.16	77.54	0.75 ± 0.70	----------	----------	----------
	psi.comp4_p.Dot	3	85.27	1.56	0.16	77.56	----------	----------	----------	-0.78 ± 0.72
	psi.comp2_p.Dot	3	86.44	2.73	0.09	78.73	----------	0.26 ± 0.60	----------	----------
Gray Fox	psi.Dot_p.Dot	2	31.11	0.00	0.37	6.27	----------	----------	----------	----------
	psi.comp3_p.Dot	3	32.19	1.09	0.22	24.48	-9.13 ± 29.07	----------	----------	----------
	psi.comp2_p.Dot	3	32.94	1.83	0.15	25.23	----------	8.16 ± 17.28	----------	----------
	psi.comp4_p.Dot	3	33.12	2.02	0.14	25.41	----------	----------	-1.31 ± 0.97	----------
	psi.comp1_p.Dot	3	33.31	2.20	0.12	25.60	----------	----------	----------	-9.28 ± 15.92
Coati	psi.comp2_p.Dot	3	61.53	0.00	0.49	53.82	----------	2.89 ± 2.26	----------	----------
	psi.Dot_p.Dot	2	63.16	1.63	0.22	12.61	----------	----------	----------	----------
	psi.comp4_p.Dot	3	53.53	2.00	0.18	55.82	----------	----------	----------	9.28 ± 10.42
	psi.comp1_p.Dot	3	65.81	4.27	0.06	58.09	0.58 ± 1.41	----------	----------	----------
	psi.comp3_p.Dot	3	66.07	4.54	0.05	58.36	----------	----------	-0.05 ± 0.83	----------
Mountain Lion	psi.comp2_p.Dot	3	33.82	0.00	0.96	26.11	----------	11.44 ± 9.73	----------	----------
	psi.Dot_p.Dot	2	41.43	7.61	0.02	9.25	----------	----------	----------	----------
	psi.comp3_p.Dot	3	43.88	10.06	0.00	36.17	----------	----------	-0.42 ± 0.61	----------
	psi.comp1_p.Dot	3	44.33	10.51	0.00	36.62	0.08 ± 0.66	----------	----------	----------
	psi.comp4_p.Dot	3	44.34	10.52	0.00	36.63	----------	----------	----------	0.05 ± 0.65
Skunks	psi.Dot_p.Dot	2	71.50	0.00	0.34	18.18	----------	----------	----------	----------
	psi.comp3_p.Dot	3	72.36	0.86	0.22	64.65	----------	----------	0.94 ± 0.75	----------
	psi.comp1_p.Dot	3	74.33	2.82	0.08	66.61	0.17 ± 0.56	----------	----------	----------
	psi.comp2_p.Dot	3	74.38	2.88	0.08	66.67	----------	0.11 ± 0.57	----------	----------
	psi.comp4_p.Dot	3	74.39	2.88	0.08	66.67	----------	----------	----------	0.11 ± 0.62
Mule Deer	psi.comp2_p.Dot	3	65.06	0.00	0.87	57.34	----------	-2.99 ± 1.67	----------	----------
	psi.comp3_p.Dot	3	69.90	4.84	0.08	62.18	----------	----------	-8.10 ± 8.60	----------
	psi.Dot_p.Dot	2	71.50	6.45	0.03	20.95	----------	----------	----------	----------
	psi.comp1_p.Dot	3	73.23	8.17	0.01	65.52	1.33 ± 2.33	----------	----------	----------
	psi.comp4_p.Dot	3	74.32	9.26	0.00	66.60	----------	----------	----------	-0.19 ± 0.60

APPENDIX G

OCCUPANCY BY FOREST TYPE

Real estimates of occupancy and standard errors for each species during the summer season along the lower San Pedro River, Arizona USA in three riparian forest types. Species are listed in alphabetical order.

	CW	MW	SC
	Psi ± SE	Psi ± SE	Psi ± SE
American Badger	0.21 ± 0.20	0.64 ± 0.29	0.43 ± 0.26
Black Bear	0.38 ± 0.37	0.76 ± 0.52	1.00 ± 0.00
Bobcat	0.70 ± 0.20	0.52 ± 0.21	0.87 ± 0.16
Coati	0.67 ± 0.44	0.67 ± 0.44	1.00 ± 0.00
Coyote	0.00 ± 0.00	1.00 ± 0.00	0.93 ± 0.18
Gray Fox	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00
Javelina	0.42 ± 0.25	1.00 ± 0.00	0.42 ± 0.25
Mountain Lion	0.18 ± 0.16	0.18 ± 0.16	0.18 ± 0.16
Mule Deer	0.21 ± 0.19	0.84 ± 0.28	0.42 ± 0.25
Skunks	0.63 ± 0.28	0.42 ± 0.25	0.42 ± 0.25

APPENDIX H

OVERALL OCCUPANCY AND DETECTION PROBABILITY

Real estimates and standard errors for occupancy (Psi) and detection probability (p) for each species during the summer season along the lower San Pedro River, Arizona USA. Species are listed in alphabetical order.

Species	Psi ± SE	p ± SE
American Badger	0.43 ± 0.17	0.26 ± 0.10
Black Bear	1.00 ± 0.00	0.08 ± 0.03
Bobcat	0.70 ± 0.12	0.47 ± 0.07
Coati	0.79 ± 0.44	0.13 ± 0.08
Coyote	0.71 ± 0.15	0.33 ± 0.08
Gray Fox	1.00 ± 0.00	0.03 ± 0.02
Javelina	0.64 ± 0.18	0.26 ± 0.08
Mountain Lion	0.18 ± 0.09	0.44 ± 0.14
Mule Deer	0.49 ± 0.16	0.27 ± 0.09
Skunks	0.49 ± 0.16	0.27 ± 0.09

APPENDIX I

PHOTO CAPTURES

7/24/2017 1:40 AM ID:3
Cuddeback Digital

4/9/2018 9:15 AM
Cuddeback Digital

6/5/2018 6:56 AM
Cuddeback Digital

8/1/2018 6:05 AM ID:3
Cuddeback Digital

8/13/2017 4:45 PM ID:9
Cuddeback Digital

3/12/2018 11:23 AM
Cuddeback Digital

5/1/2018 7:59 AM
Cuddeback Digital

12/27/2017 10:17 AM ID:2
Cuddeback Digital

11/3/2017 5:09 PM
Cuddeback Digital

2/11/2018 5:22 PM
Cuddeback Digital

7/27/2018 6:32 AM
Cuddeback Digital

11/21/2017 7:47 PM
Cuddeback Digital

8/9/2018 7:11 AM ID:4
Cuddeback Digital

4/7/2018 6:34 AM ID:4
Cuddeback Digital

6/18/2018 3:03 AM ID:4
Cuddeback Digital

7/27/2018 6:21 AM
Cuddeback Digital

PRIMOS
093F
08-22-2017 18:34:10
TRUTH CAM35

10/3/2017 7:30 AM
Cuddeback Digital

4/4/2018 1:12 PM
Cuddeback Digital

7/26/2018 11:32 AM ID:6
Cuddeback Digital

PRIMOS
HUNTING
TRUTH CAM ULTRA 46
064 F
09-05-16
MON
05:18:11 AM