THE INFLUENCE OF LIVESTOCK PROTECTION DOGS ON MESOCARNIVORE ACTIVITY IN THE EDWARDS PLATEAU OF TEXAS

A Thesis

by

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ABSTRACT

The use of livestock protection dogs (LPDs; *Canis lupus familiaris*) to deter predators from preying upon sheep and goat herds continues to increase across the United States. Most research regarding the efficacy of LPDs has been based on queries of rancher satisfaction with their performance, yet little is known regarding whether LPDs actually displace the predators they are commissioned to protect livestock from. Here, I examined whether the presence of LPDs amid livestock resulted in fewer observable detections of carnivores in pastures they occupied throughout 1 year on a ranch in central Texas. To detect and quantify the presence of carnivores across the ranch, a remote camera grid and scat transects were simultaneously surveyed to compare results produced between each method. Four LPDs were fitted with GPS collars to collect their positions and evaluate their occupancy across the ranch over time. These GPS collars also collected proximity data on a random sample of UHF collared sheep (n = 40) and goats (n = 20) to gauge the frequency to which the LPDs were near livestock.

Remote cameras and scat surveys detected the same mesocarnivore species (badger [*Taxidea taxus*], bobcat [*Lynx rufus*], coyote [*Canis latrans*], gray fox [*Urocyon cinereoargenteus*], raccoon [*Procyon lotor*], ringtail [*Bassariscus astutus*], and skunk species), though in different proportions. No large carnivores were detected and no significant difference was observed between the results of the 2 methods across sampling units (U=164.5; P=0.37, Mann-Whitney U-test) or over time (U=68; P=0.84, Mann-Whitney U-test). Both methods detected a rise in mesocarnivore activity during the fall and early winter. LPDs were within 100–300 m of livestock for 99–100% of days evaluated. Detections of known depredators to livestock (bobcat and coyote) were 31.2% lower in pastures occupied by LPDs amid livestock ($\chi^2=5.91$, $df=1$, $P<0.05$ and $\chi^2=0.45$, $df=1$, $P>0.05$, respectively) and lower for raccoon ($\chi^2=6.84$, $df=1$, $P<0.01$), while detections of less ominous gray foxes were significantly higher in LPD occupied pastures ($\chi^2=13.21$, $df=1$, $P<0.01$). These results provide support for LPDs as a predator management tool which can displace known depredators of livestock from the pastures and herds they protect.

DEDICATION

This thesis is dedicated to the many incredible people I’ve worked with and befriended in the field throughout the west in the 7 years prior to arriving at Texas A&M University to pursue a Master’s degree. This thesis also is dedicated to the LPDs of the Martin Ranch (Sirs Reginald, Alfred, Nigel, and the Queen) for being obliging participants in this study, as well as the extremely courteous rattlesnake who let a brother walk away unharmed after unwittingly stepping upon it in the dense broomweed.

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My lab-mate Justin French was an equal collaborator in the conception and development of this project and his contributions to this study cannot go without mention or due appreciation, especially as he begrudgingly hiked over 250 km of transects to collect ~700 scat samples over the past year. Also special thanks extend to Jerry and Mitzi French for so generously hosting us on our field excursions to the Hill Country when original plans fell through. This turned into a venture that bears to mind a most excellent quote, “Every rose has its thorn, just like every cowboy sings a sad, sad song”. – Poison 1988. Be excellent to each other.

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Contributors

This work was occasionally supervised by a thesis committee consisting of faculty member John M. Tomeček [advisor] and Professor Nova J. Silvy [co-advisor] of the Department of Wildlife and Fisheries Sciences as well as Professor Fred E. Smeins of the department of Ecosystem Science and Management.

All work for the thesis was completed independently by the student, with the field component and initial study design performed in collaboration with Justin French, also a graduate student of the Department of Wildlife Fisheries and Sciences.

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CHAPTER I

INTRODUCTION

The decline of large carnivores across North America over the last 2 centuries (Laliberte and Ripple 2004) has resulted in shifts among extant carnivore guilds which may directly or indirectly alter community structures (Estes et al. 1998, Ripple and Beschta 2004, Ripple et al. 2013). One direct effect stemming from the absence of large carnivores is the release of competition pressure placed on smaller mesocarnivores (Soulé et al. 1988, Crooks and Soulé 1999, Berger and Conner 2008, Prugh et al. 2009, Ritchie and Johnson 2009). Mesocarnivore species can fill multiple ecological roles from apex predators (where larger carnivores are absent) to primary consumers, and research has just begun to explore the direct and indirect ecological effects members of the guild may impart, often in regard to intraguild competition, prey communities, and trophic interactions (Estes et al. 1998, Roemer et al. 2001, Donadio and Buskirk 2006, Berger et al. 2008, Roemer et al. 2009, Miller et al. 2012).

Though research tends to focus on the often negative effects of mesocarnivores on livestock and prey populations (Henke and Bryant 1999, Sacks and Neale 2007, Razo et al. 2012), many species within the guild are omnivorous, aiding in both seed dispersal and the regulation of granivorous rodent populations, theoretically contributing to the reproductive success of seed-bearing primary producers within a community (Jordano et al. 2007, Rosalino et al. 2010, Jensen et al. 2012, Miller et al. 2012). Regardless of the potentially beneficial impacts on ecosystem productivity, most mesocarnivores are considered pests to agricultural communities in North America and have been subject to eradication and control efforts at the private, state, and federal levels (Roemer et al. 2009, NASS 2010, and Palmer et al. 2010). While interest in the community ecology of mesocarnivores has emerged among ecologists in recent years, there also remains need for work which addresses carnivore conservation in the context of balancing human-wildlife conflict, especially in regard their impact on ranching operations (Prugh et al. 2009, Ritchie and Johnson 2009, Newsome et al. 2015, Treves et al. 2016).

The loss of functionally defenseless livestock species such as sheep and goats to predation from carnivores results in substantial economic losses to the ranching industry. At the turn of the 21st century, the United States Department of Agriculture's (USDA) National Agricultural Statistics Service (NASS) reported an estimated annual loss of $16.5 million in sheep and lambs and a loss of $3.4 million in goats to predators, the majority of which (60.7% and 35.6%, respectively) have been attributed to coyotes (NASS 2000). As recently as 2014, the United States Department of Agriculture's Animal and Plant Health Inspection Service (APHIS) reported that 1.8% of adult sheep and 3.9% of lamb losses in the U.S. were attributed to predators, with damages valued at over $18 million (APHIS 2015). The nationwide stocking of sheep fell to 89% of its historical high in 2008 (Palmer et al. 2010) with recent numbers in 2015 standing at approximately 5.28 million head overall (APHIS 2015). Despite changes to the market over the last several decades, ranchers have largely citied loss to predation as being the main reason they have given up sheep production (Landivar 2003, Jones 2004, Palmer et al. 2010).

Strategies to mitigate livestock depredations range from lethal predator removal to the integration of domestic animals with strong defensive behaviors such as llamas (*Lama glama*) and trained dogs into sheep and goat herds (Linhart et al. 1979, Meadows and Knowlton 2000).

Livestock protection (or guard) dogs (hereafter LPDs) have been used for centuries in Europe (Dawydiak and Sims 2004), yet their behavior and effectiveness at deterring predator species from livestock has scarcely been quantified, with data based primarily on queries of rancher satisfaction with the dogs since their introduction to U.S. ranches in the 1970s (Andelt 1992, Coppinger et al. 1983, Green and Woodruff 1983, Green et al. 1984, Dohner 2007). Since then, the use of LPDs on U.S. ranches has grown, facilitating some study and experimentation regarding shepherding practices; which include evaluations of different LPD breeds (Andelt 1999) and deployment of mixed-breed dogs rather than imported purebreds by Navajo ranchers to protect livestock in the American Southwest (Black and Green 1981).

LPDs rarely physically confront predators, instead behaviorally responding to livestock threats by presenting themselves as territorial deterrents (both visually, audibly and likely aromatic) to other carnivores (Findo, 2005). Empirical evidence that LPD presence may offset predation loss to livestock from both experimental trials (Linhart et al. 1979, McGrew and Blakesley 1982), and reports of fewer livestock losses from ranchers who use them (Andelt and Hopper 2000) has bolstered their appeal as an alternative to lethal methods of predator control such as snares, aerial hunting, and poisoning given the time and expense of such practices for the rancher or regional government (Green and Woodruff 1983, Palmer et al. 2010). To date however, little is known as to what effects the dogs may have on carnivore communities cohabitating a shared range given the defensive behaviors they exhibit.

In the course of this study, I endeavor to empirically evaluate the impacts of LPDs upon a mammalian carnivore community, to (1) determine whether they displace species known to depredate on sheep and goats and (2) to examine whether such a displacement occurs for other members of the guild not as likely to pose a threat to livestock. As Texas is the largest producer of mohair in the nation and stocks more sheep than any other U.S. state (APHIS 2015), I chose to examine the influence of LPDs on the carnivores cohabitating the rangelands of the Edwards Plateau region of central Texas. To address these objectives, reliable information was first sought regarding the composition, distribution, and activity of carnivore species at the study site. Two common survey methods for carnivores were applied at the study site to amass detections of the guild as well as to evaluate the discrepancies between each detection method. This information may inform livestock producers with regard to husbandry practices, predator activity, and the functional role of LPDs to the potential end of reducing net losses due to predation. Additionally, this information may appeal to ecologists and managers seeking to evaluate methods which may reduce human-wildlife conflict and maintain biological diversity across a landscape.

CHAPTER II

FIELD SITE DESCRIPTION AND APPLIED METHODS

STUDY AREA

Field data was collected in the rangelands of Menard County, Texas on a 2,026.6 ha ranch owned by Texas A&M University AgriLife Research referred to as the Martin Ranch. The property is situated in the Edwards Plateau Ecological Region of Texas that averages an elevation of 722 m above sea level between subtle rolling hills scattered throughout the countryside. Climate is typical of central Texas; characterized by moderate, dry winters and hot, humid summers which produced a mean annual temperature of 18°C and a mean precipitation of 58 cm over a 30 year average. January is the coldest month (0–16°C) of the year and July is the hottest (21–35°C; National Oceanic and Atmospheric Administration 2016). The dominant over story vegetation found across the site is live oak (*Quercus virginiana*), juniper (*Juniperus ashei),* and mesquite (*Prosopis glandulosa*) woodlands with understories comprised of native grasses, cactus, and forbs (Wrede 2010, NRCS 2015). The 4 prevailing ecological sites found on the ranch are described by the National Resources Conservation Service (NRCS 2015) as Low Stoney Hill, Clay Loam, Shallow, and Draw (Fig. 2.1 and Table 2.1). These sites are more heterogeneous towards the draws and support varied aggregations of vegetation (NRCS 2015). Vegetation occurs on clay loam soils atop limestone bedrock which can become exposed in the arid draws that have been gradually carved out through periodic flooding.

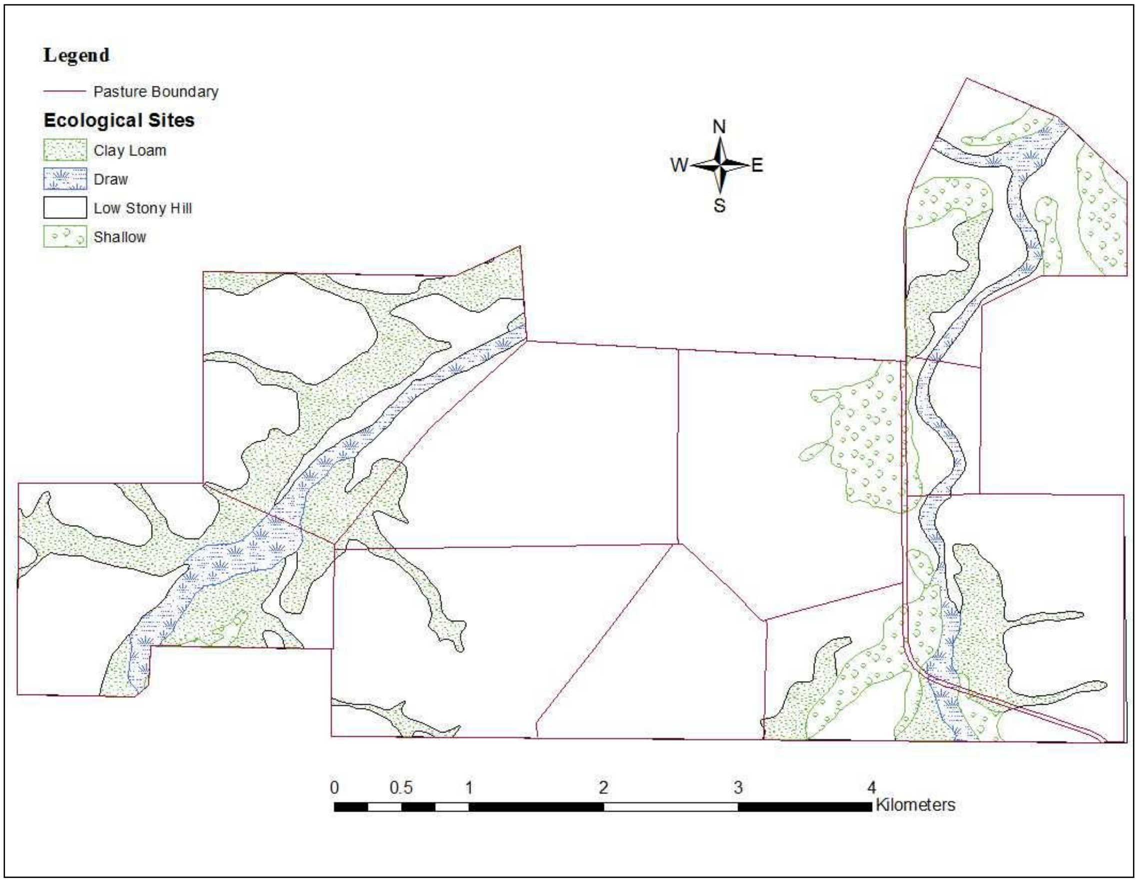


Figure 2.1. The Martin Ranch study site delineated by pasture boundaries and ecological sites.

Table 2.1. Prevailing ecological site composition across the Martin Ranch in Menard County, Texas. Ecological sites listed by rank in terms of area in hectares and percent cover of total area.

Ecological Site	Area (ha)	% Area
Low Stony Hill	1,458.75	71.98
Clay Loam	306.47	15.12
Shallow	148.21	7.31
Draw	113.27	5.59
Total	2,026.7	100.00

The ranch is divided into 9 fenced pastures which average 224 ha per pasture. Sheep and goats grazed one-third to nearly half of the pastures throughout the year. LPDs were placed in the same pastures as the livestock for their protection from local predators. The ranch hosted 200–300 head of sheep, 100–200 head of goats, 100 head of cattle, and 4 LPDs over the course of the study period. Ranch hands partitioned sheep, cattle, and goat herds into different pastures on a decision-deferred rotational grazing regime pending management priorities. The 4 resident LPDs of the ranch were of the Great Pyrenees pedigree (all 5 years of age by the end of the sampling period) and were raised with a number of the sheep residing on the ranch soon after being weaned. The principal forms of predator determent the LPDs displayed involved territorial vocalizations and placing their formidable mass between the herd and the perceived threat. None were trained to attack any specific species. The LPDs were reared to be semi-feral and were consistently observed alongside the livestock they protect, with 3 dogs primarily integrated among the sheep while the fourth integrated with the goat herd. The dogs were sustained on a diet of kibble placed at 7 feeders located throughout the ranch. 22 water troughs also were distributed throughout the 9 pastures of the ranch to support all residing livestock.

Texas A&M University employees visited the ranch several times a week to check on the livestock and lease hunters periodically used the ranch during conventional hunting seasons though no humans permanently reside there. The ranch has an unimproved road network comprised of nearly 58 km of unpaved roads which receive varying degrees of use. Lethal predator control is a common practice throughout the surrounding area though it has not been practiced on the ranch for the past 5 years; thereby the potential exists for this site to serve as refugia for the local carnivore community. In addition to coyotes, bobcats, and gray foxes, other confirmed mesocarnivore species on the ranch are badger, raccoon, ringtail, and both striped (*Mephitis mephitis*) and hog-nosed (*Conepatus mesoleucus*) skunks.

METHODS

Field data were collected at the Martin Ranch study site from the onset of May 2016 through the end of April 2017 to span the course of a year. Several preliminary trips were made to develop and refine protocols before data collection commenced. In order to assess the distribution of mesocarnivore species across the study area, I employed scat transects and a remote camera grid at the study site which were checked on the same monthly intervals throughout the study duration. All resident LPDs were fitted with GPS collars, which logged their locations 8 times daily via satellite telemetry over the course of the year. I assessed the association of LPDs with livestock through daily readings from a sample of UHF collared livestock, the signals of which were logged by the 4 GPS collars of the LPDs when UHF collars were within a range of 100–300 m of the LPDs.

Remote Camera Detections

To detect the presence of carnivore species on a continuous basis throughout the year, I established a remote camera grid to cover the study site, placing 18 cameras across the ranch at a density of 1 camera per 0.9 km^2. Camera locations were randomly generated in ArcMap (v.10.4.1 ESRI software, ESRI, Redlands, CA, USA; hereafter ArcMap) utilizing a stratified random design in order to distribute the 18 cameras across the 4 ecological sites found throughout the ranch in proportion to the total area available for each site (Table 2.1). This method was instated to evaluate the relative use of each ecological site by carnivore species based on camera detections observed in each site. All cameras were attached with bailing wire to

T-posts installed at a height of 45 cm off the ground as to be mounted on a plane relative to the carnivores detected, then positioned at an azimuth which exposed the greatest amount of unobstructed area at each location. To avoid biased representations of animal activity, no cameras were ever baited. Each pasture contained at least 1 camera to derive unit area-based comparisons of carnivore detections in relation to LPD presence (or absence) across the study site at the pasture level. Camera locations were stored in and located with handheld GPS units (Garmin 60sc and Oregon models) which I physically checked on a monthly basis for operation as well as to collect and replace memory cards along with depleted batteries.

The camera grid was comprised of 4 Reconyx HC600 Hyperfires, 8 Bushnell Trophy Cams, and 8 Moultrie M-80 digital remote cameras. Cameras of all 3 models were set to the following parameters: photographic mode with 3 MP (Mega-Pixel) resolution (3.1 MP on the Reconyx) at 3 photos per series (with a 1-second interval between photo series), and at medium sensitivity. I entered all photographic detections of mesocarnivore species derived throughout the year into a relational database (FileMaker Pro v.14, Apple *Inc*., Cupertino, CA, USA; hereafter relational database) noting: (1) the photographed species, (2) any behavior observed, (3) the location of detections by both camera and pasture, and (4) both the date and time in which detections took place. Observed behavior was annotated when the animal photographed in the detection series was traveling, foraging, idle, investigating the camera itself, scent marking (urinating or rubbing), or interacting with another member of the same species.

Scat Detections

Another commonly used method for detecting carnivore species in an area involves surveying for their scats (i.e., feces) along road networks as canids and their conspecifics tend to use roads in high proportion to their availability on a landscape (Güthlin et al. 2014, Carreras-Duro et al. 2016). Often these scat surveys are performed using replicate transects along roadways of some established length. I placed 22 scat transects, each 1 km in length, along the unpaved road network of the ranch at randomly derived center points (ArcMap v.10.4.1) to where no 2 transects overlapped, and that all transects were confined within the boundaries of the pastures that center points fell into. Each pasture contained at least 2 transects to derive unit area-based comparisons of carnivore detections in relation to LPD presence (or absence) across the study site at the pasture level. I surveyed all scat transects at the same intervals coinciding with the remote camera grid checks in order to compare monthly detection rates obtained between the 2 survey methods. Initially, all scats were cleared from designated transects on the first day of the study to avoid oversampling the first sampling period.

For all surveys conducted throughout the year, the same 2 trained observers each sampled a consistent set of 11 transects. All transects were surveyed by walking both sides of the road, stopping to identify, measure, and collect all carnivore scat encountered. The observers noted the relevant date, survey number, and corresponding pasture for each transect surveyed. All carnivore scats encountered were ascribed a species designation and assigned: (1) a unique reference code, (2) an observer confidence appraisal of species identification (on an ascending scale of 1–4), (3) a measurement for width (at the widest point of the scat to the nearest millimeter) and length (to the nearest 0.5 cm), (4) the ecological site from where it was deposited, and (5) when applicable, a context for its placement pertaining to fence lines, trail or road junctions, elevated positioning, or conglomeration of multiple scats at one location.

To aid each observer in reducing the number of misidentified scats collected over time, I created a project-specific scat identification field guide for reference during surveys that was based both on knowledge from an experienced tracker and information from reputable field guides on scat identification (Elbroch 2003 and Moskowitz 2010). Upon the establishment of all transects, I conducted a preliminary scat collection trip to train the other observer on the protocol and come to a consensus between observers with regard to the identification of scats at the species level before data collection commenced. Species identification through scat DNA assay was not feasible for the timeline and budget of this project, though the option will be highly considered for a random subset of the scats collected should resources for such work materialize.

Finally, to evaluate the use of roads per species, all transects along the ranch's road network were categorized into 1 of 3 road types according to their level of use as: (1) gravel roads (which are the most heavily accessed road type on the ranch), (2) 2-track roads (used enough to where vegetation cannot fill in the tire tracks) and (3) rough roads (course cut lines seldom used). I additionally stratified the position of scat along the roadways, noting each scat's placement in either the tire tread, median, or shoulder of a given transect. All scat data was entered into the relational database for subsequent analysis.

GPS and UHF Collar Data

The 4 LPDs on the ranch were fitted with GPS collars (Global Positioning System, Vertex series model; Vectronic Aerospace, Germany; hereafter GPS collars) programmed to record the location of each of the 4 dogs once every 3 hours, yielding 8 time-delineated locations per day, per dog. LPD positions were downloaded from the collars, placed into the relational database and plotted into ArcMap for each monthly interval to evaluate their distribution across pastures over time.

In order to assess the association of LPDs to livestock over time, short range UHF (Ultra High-band Frequency) collars were placed on a representative sample of livestock, so that the GPS collars attached to the LPDs could store nearby UHF collar frequencies detected (within a range of 0 to 100–300m) several times per day between 1 and 3 hour intervals. This sample consisted of 40 UHF collars incrementally fastened onto the neck of sheep while in line for shearing and 20 UHF collars fitted to goats that I herded up and collared at random. Originally, 20% of sheep and 20% goats on the ranch were equipped with UHF collars. Three months into the sampling period, stock increased at the ranch to which 13.3% of sheep and 10% of goats were collared for the latter 9 months of the study. I partitioned the livestock proximity data obtained for each LPD into the monthly intervals coinciding with the camera grid and scat transect data for the latter 10 months of the year-long sampling period, as this technology was inoperable for the first 2 months of the study duration.

CHAPTER III

SAMPLING METHOD COMPARISON FOR MESOCARNIVORES

Non-invasive methods to survey multiple species have gained interest among the wildlife community in the past few decades, particularly as a means to survey mammalian carnivores (Zielinski and Kucera 1995, Gompper et al. 2006, Burton et al. 2015). Two of the most common non-invasive methods used to survey carnivore species in areas of interest are transect-based surveys for identifiable scat (i.e., feces, hereafter scat) and the deployment of remote-sensing cameras to amass detections of local species over a given period of time (Gompper et al. 2006, Lesmeister et al. 2015, Carreras-Duro et al. 2016). Non-invasive studies frequently use either method to detect carnivores in a given landscape, though relatively few have used more than one method with which to base inferences upon or have sought to evaluate results produced between methods (Gompper et al. 2006, Güthlin et al. 2014, Dempsey et al. 2015).

The method of implementing remote cameras to survey for wildlife is an evolving practice consisting of a wide variety of techniques and survey designs, pending the research project's study objective (Kays et al. 2010, Locke et al. 2012). Methods range from employing single cameras at targeted points of interest to sophisticated random block or stratified random designs with multiple cameras comprising a grid in manners which better withstand statistical scrutiny (Kays et al. 2010, Burton et al. 2015). Remote camera systems have existed since the 1950s when researchers rigged pressure-sensitive triggers to film cameras, often connected to dry cell battery-powered flashes (Gysel and Davis 1956, Kucera and Barrett 1993). Today compact stand-alone digital remote cameras dominate the market, offering a variety of features and sensitivity ranges for researchers to consider with regard to their study design (Kelly 2008, Rowcliffe et al. 2011, and Wellington et al. 2014).

The photographic images the remote cameras provide can be used to gauge animal activity, evaluate behavioral patterns, social dynamics, and in some cases animal sex and condition, as well as verify the presence of rare species in a given area (Jackson et al. 2006, Wearn et al. 2013). Wildlife researchers also have applied remote cameras to identify marked individuals for mark-recapture (or re-sight) based population estimation (Gray and Prum 2012, Dundas et al. 2014, Parsons et al. 2015). A more recent shift in the use of remote cameras involves calculating estimates of relative abundance or abundance estimates founded upon the principles of the ideal gas law (Hutchinson and Waser 2007, Rowcliffe et al. 2014, Cusak et al. 2015, Ramsey et al. 2015). Remote cameras present researchers with a flexible tool for surveying wildlife, as data can be collected on either a continuous or incremental basis (given the variety of settings available on most camera models) whenever suitable for the project at hand, while considering the limits of battery life, capacity for digital memory storage, technological malfunctions, and impacts of severe weather.

Another flexible tool which can offer researchers a wide breadth of data is to survey for (and collect) scats deposited by species of interest in a given area. Scats can provide a variety of biological assessments ranging from dietary analysis, physiological condition, identification of sex, reproductive stature of individuals, parasite loads, bioaccumulation of toxins, habitat selection, degree of overlap with other species, range or landscape occupancy, and relative abundance (Schauster et al. 2002, Wasser et al. 2011, Güthlin et al. 2014, Reid 2015, Napoli et al. 2016). Survey methods for scat typically involve either trained canines (or scat detection dogs) or trained human observers to survey an area via the species-specific olfactory signatures of target species which the scat detection dogs are trained to detect, or by species-specific visual signatures of scat a trained human can detect (Wasser et al. 2004, 2011; Oliveira et al. 2012). Much like the art of animal tracking, the identification of scats by species is a practice rooted in the history of tribal cultures across the globe that has been applied to wildlife studies since at least the 1940s (Scott 1941, 1947; Greer 1955).

Scat sampling can be performed at random, within quadrants or within a grid; however the use of fixed-length transects along roads, game trails or a designated azimuth are more commonly performed as these can be replicated and quantified as sampling units (Güthlin et al. 2012, Carreras-Duro et al. 2016). Scats encountered along transects can be measured and characterized, identified at the species or group level, spatially marked, and are often removed to clear the sampling unit of scats so that deposition rates can be calculated at known intervals of time (Sanchez et al. 2004, Gompper et al. 2006, Losinger et al. 2016). Scats encountered upon survey can be collected for laboratory analysis if diet composition, hormone balance, isotopic signature, parasite load, or genetic evaluations are of interest to research scientists.

Both methods can yield count data in the form of species detections over time and confirm the presence or occupancy of a species in a given area at the time of detection. Remote cameras have the added benefit of demarcating photographic detections with date and timestamps, and as such are often used to evaluate temporal activity patterns for species of interest (Ridout and Linke 2009, Lesmeister et al. 2015). Identification of given species through photographic detections is more transparent and requires less observer skill compared with the aptitude involved in identifying scats by species in the field or through the analysis of molecular

DNA. Scat morphometrics can help partition species designations, but the identification of scats at the species level also entails a degree of qualitative description and artful interpretation, often considering the diet composition, physical character, and aroma of the scat along with environmental and potential behavioral contexts regarding scat placement (Elbroch 2003, Wight 2008; Moskowitz 2010). In that regard, both methods have the capacity to capture some form of animal behavior, with photographic detections requiring less quantitative ambiguity to impart for ethological means.

For the lack of temporal resolution or ease of species-level inferences, scat transects do have the benefit of practicality, being a method independent of technological reliance which is able to be performed anywhere a trained human (or canine) can access. The cost associated with establishing remote camera grids, potential for data loss due to technological malfunctions or the effects of wind, and time budgets required to set up a camera grid system and extract data (which vary in scale from a few to hundreds of thousands of photographs pending project duration and the number of cameras involved), can dissuade researchers from choosing to implement the method when aiming to survey animals on the landscape. Further comparison between the data produced by each method and the cost per sample obtained is needed to evaluate the degree to which the 2 methods vary when looking to survey a wildlife community. This information may be valuable to pragmatic wildlife researchers, managers, land owners, and outdoor enthusiasts alike.

To examine how these 2 survey methods vary, I implemented both at a study site in the Edward Plateau of Central Texas, with the specific aim of surveying the carnivore community of the area. Large carnivores such as black bear (*Ursus americanus*) and cougar (*Puma concolor*) are rare if not generally absent through most of the Edwards Plateau as a result of concerted extirpation in the previous 2 centuries, though occasional reports and documentation of activity still occur (Texas Parks and Wildlife 2008). Mesocarnivore species comprise the known carnivore guild throughout the region, ranging in size from the coyote and bobcat at the larger end of the body mass scale (9.6–11.4 kg) to the ringtail (0.87–1.1 kg) at the smaller end (Feldhamer et al. 2003). Here, I amassed detections of mesocarnivores from both remote camera and scat transect data over the course of a year to evaluate the data produced per method.

The objective of this study is to compare the results produced from these 2 non-invasive survey methods to (1) determine if the detections produced per method exhibited consistent trends over time and (2) determine if the overall outcome produced by each method significantly varies. I expect that rates of mesocarnivore detections should remain relatively constant throughout the year and that detections produced per method would not significantly vary from one another. Should any notable variation be evident in the results of either method, than such variation will hereto be described and further explored.

METHODS

Field data were collected at the Martin Ranch study site from the onset of May 2016 through the end of April 2017. In order to detect and assess the activity of mesocarnivore species across the study area, I employed scat transects and a remote camera grid at the study site which were checked on the same monthly intervals throughout the study duration. Refer to Chapter II for explicit detail regarding the methods used for this study.

DATA ANALYSIS

All observations of mesocarnivores from photographic detections and scat depositions were first tallied by species and month and then summed to obtain year-long totals and averages. To account for any variation in the length of time which passed between surveys and checks throughout the year, all photographic detections and scat depositions were standardized by calculating observations as a detection rate per day. Detection rates were calculated by dividing the total number of observations per species or month (pending the categorical direction of analytics assessed) by the total number of respective cameras (n = 18) or scat transects (n = 22) across the study site. Detection rates were standardized in this manner to yield an analogous form of data between the methods for comparison.

Monthly totals for photographic detections and detection rates were plotted over the course of the year-long sampling period. Monthly totals for scat depositions and deposition rates were similarly plotted together along with the number of mesocarnivore scats identifiable at the species level. This was performed to provide context for the degree of uncertainty implicated in scat identification at the species level while still representing these detections of the guild. To address the first study objective, standardized detection rates for both camera grid and scat transect detections were plotted over the annual cycle to compare signals of activity over time.

To assess the assumptions of normality for both data, the distributions of count data across both the camera grid and scat transects were first plotted out then measures of central tendency and variation were quantified. The dispersion index for both datasets yielded a variance far greater than their means, and the resulting negative-binomial distributions fit well with plotted probability distributions calculated for each dataset. Therefore, non-parametric tests were chosen in order to address the second study objective.

Coefficients of variation were calculated to compare the variance observed between the sampling methods. Mann-Whitney U tests (Mann and Whitney 1947) were used to determine if mesocarnivore detections between the 2 methods significantly varied both between intervals and overall. I selected this test as it is suitable for count data and can be used regardless of data distribution so long as both datasets share the same distribution trend. Both the camera and scat transect locations were randomly derived at the onset of the study and were thus not suitable for any pair-wise comparisons between individual sampling units.

Using data from the initial ancillary timestamp of each photographic detection series, the distribution of temporal activity spanning the daily cycle was plotted for all mesocarnivore detections. Time stamps from all photographic detections of mesocarnivores were plotted throughout a 24-hour period in order to observe whether any daily activity patterns of the guild could be ascertained from the camera data. Photographic detections were grouped by circadian activity period per species to gauge species-level proclivity for nocturnal, diurnal, and crepuscular cycles. The crepuscular period was designated as a 3-hour span centered upon the average time of sunrise and sunset for each month of the year, with diurnal and nocturnal periods separated by the 2 crepuscular periods per given day. Due to the small sample sizes of photographic detections obtained for badger, coyote, hog-nosed skunk, and ringtail, no attempt was made to quantify the degree to which the activity patterns of the 8 mesocarnivore species overlapped (Ridout and Linkie 2009). Observations from photographic detections which fell into the 6 classified behaviors were tallied per category for each species. Percent occurrence of each behavior was determined then plotted by species. Detections of each species were grouped according to the 4 available ecological sites represented by either the placement of cameras or scats across the ranch. Relative proportions of detections were then plotted to compare ecological site use per species.

For the scat data of each mesocarnivore species, comparative ranges and means for width and length measurements observed were tabulated in addition to the relative proportions calculated for all other categorical attributes sampled (road type, position of scat on road, context, and observer confidence appraisal). To compare any behavioral patterns in the placement of scats between species, I plotted the percent occurrence for all contextual variables pertaining to the placement of scats across the ranch.

Distributions for the continuous variables of scat width (diameter) and length measurements were plotted for each species. Both data sets met the assumption of normality using Shapiro-Wilk tests (Shapiro and Wilk 1965), even though the ringtail and badger scats yielded small sample sizes ($n = 8$ and $n = 18$, respectively). A test for the homogeneity of variance between the scat samples per species yielded an $F_{\max}$ below the critical value for scat diameter ($F_{\max} = 2.97$, $a = 7$, $df = 8$) though not for scat length ($F_{\max} = 10.94$, $a = 7$, $df = 8$). Having met the assumption of equal variance, a post hoc one-way ANOVA (Fisher 1921) was performed on the scat diameter data to determine if the width ranges observed among and between the mesocarnivore species was significant. As scat length data did not meet the assumption of equal variance, a non-parametric post-hoc Kruskal-Wallace test (Kruskal and Wallis 1952) was used to determine if significant variation exists between the scat lengths of each species.

. As a course indication of observer identification accuracy for scats, I plotted the distribution of observed widths for designated bobcat, coyote, and gray fox scats for a comparison to analogous measurements taken from genetically verified samples presented by the work of Reid (2015), wherein scat diameter was 1 of 2 morphometric variables reported to significantly vary between these 3 species. The distributions of scat widths for these 3 species were additionally plotted in a comparative histogram in order to visually gauge the degree of overlap which occurs between the species for this morphometric indicator.

Data Analysis was performed using Microsoft Excel (Microsoft Corporation. 2007, Redmond, Washington, USA), Minitab 18 (Minitab Inc. 2017, State College, Pennsylvania, USA), and R statistical software (R Foundation for Statistical Computing. Vienna, Austria) using the RStudiov.0.99.903 graphic user interface (RStudio, Inc. Boston, Massachusetts, USA).

RESULTS

Remote Camera Detections

A total of 5,966 trap days was recorded between the 18 remote cameras of the camera grid, yielding 1,269 detections of mesocarnivores throughout the year-long sampling period. Of the 6,570 potential trap days which existed for the year, 604 (9.2%) were lost due to camera failure, dead batteries, or full memory cards caused by wind-blown vegetation within the detection zone of the camera. Photographic detections of mesocarnivores comprised of badger (*n* = 3), bobcats (*n* = 34), coyote (*n* = 1), gray fox (*n* = 685), raccoon (*n* = 386), ringtail (*n* = 13), and skunks (*n* = 147; Table 3.1), of which 115 detections were of striped skunks, 22 detections were of hog-nosed skunks, and 10 detections were of skunks unidentifiable at the species level (Table A-1, Appendix 1).

Table 3.1. Remote camera detections of mesocarnivores per species and by month across 18 cameras checked monthly at the Martin Ranch in the Edwards Plateau of central Texas. Total detections, average number of detections, as well as a detection rate (calculated as the number of detections per day) per species and by sampling period are additionally listed. Data were collected from May 2016 to April 2017 to coincide with scat transects surveyed during the same intervals.

	Monthly interval	Badger	Bobcats	Coyotes	Gray fox	Raccoon	Ringtail	Skunk	Total	Detection rate
2016	May	0	0	0	27	16	1	16	60	0.123
	June	0	0	0	22	12	0	3	37	0.069
	July	0	1	0	12	12	1	2	28	0.054
	August	1	0	0	46	17	0	0	64	0.115
	September	0	4	0	42	20	1	6	73	0.123
	October	0	3	0	96	53	3	11	166	0.263
	November	0	1	0	38	37	1	3	80	0.222
	December	1	7	1	121	84	3	41	258	0.319
2017	January	0	6	0	88	37	1	21	153	0.327
	February	0	3	0	118	24	1	23	169	0.268
	March	1	6	0	32	32	1	8	80	0.222
	April	0	3	0	43	42	0	13	101	0.160
	Total Detected	3	34	1	685	386	13	147	1,269	-
	Average per month	0.25	2.83	0.08	57.08	32.17	1.08	12.25	105.75	0.189
	Detection rate[a]	0.0005	0.0057	0.0002	0.1148	0.0647	0.0022	0.0246	0.21	0.030[b]

[a] Calculated as number of detections per day (# of photo detected ÷ 5,966 trap days [18 camerasx365 days – 604 lost trap days])

[b] Average detection rate across all species identified

Contrary to expectations, detection totals per month varied over the year in an apparent oscillation of mesocarnivore activity throughout an annual cycle, in which a considerable increase in detections was observed from October through February with substantially fewer detections observed during the hotter months of May through August as shown in Figure 3.1. Here, detection rates were additionally presented along a secondary axis to normalize any potential effects which variations in the length of time between camera checks imposed upon the total number of detections observed per month.

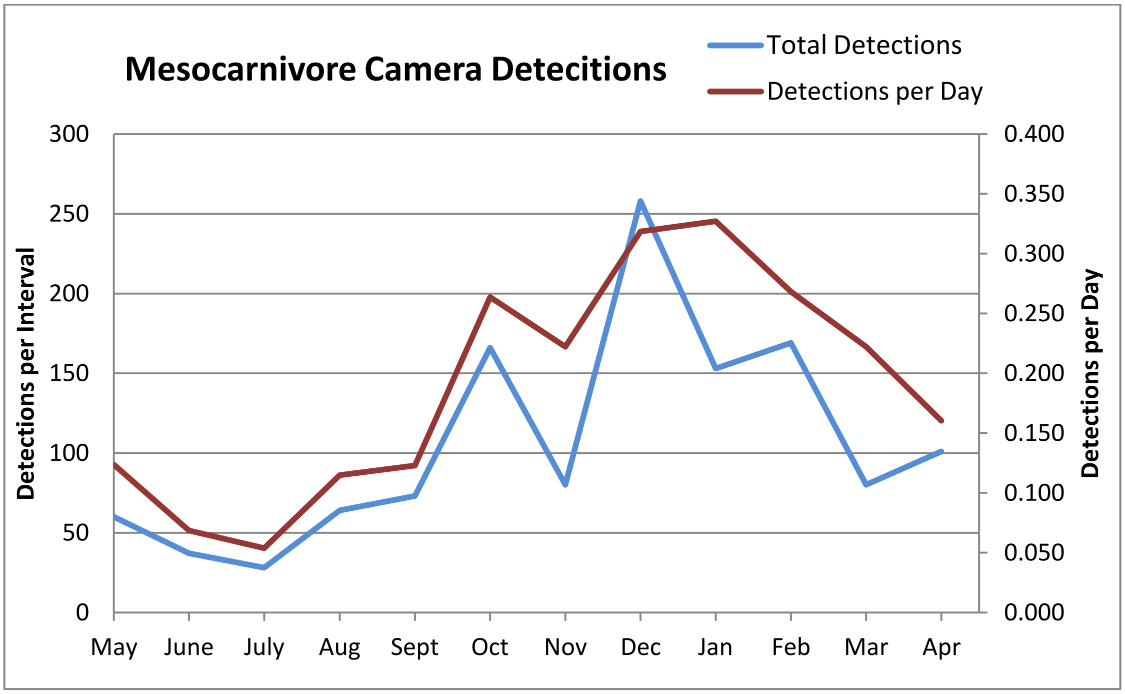


Figure. 3.1. Monthly camera detections totals of mesocarnivores throughout the year-long sampling period. Detection rates (number of photo detections per day corrected for number of camera trap days) also plotted throughout the year, corresponding to the secondary Y axis shown.

Throughout the year, the activity of the mesocarnivore guild was substantially lower in the daylight hours (Fig. 3.2). Photographic detections occurred predominantly during the nocturnal (59.0%) and crepuscular (26.8%) periods while comparatively few occurred during the diurnal period (14.2%; Table 3.2). Gray foxes were responsible for 85.1% of all diurnal detections observed across the guild (149 out of 175 diurnal detections) through the year.

Bobcats and gray foxes exhibited the highest proportions of detections in the diurnal period at the species-level (38.2% and 22.6%, respectively), while at least a quarter of all detections fell within the crepuscular period for each species save for those of the striped skunk. Striped skunks had the highest proportion of nocturnal detections observed (75.7%), followed by raccoons (71.4%). Relative proportions of nocturnal detections for badger, hog-nosed skunks, and ringtail also were considerable (Fig. 3.3), although the latter 3 species yielded low samples of detections through the year (*n* = 3, *n* = 22, and *n* = 13, respectively).

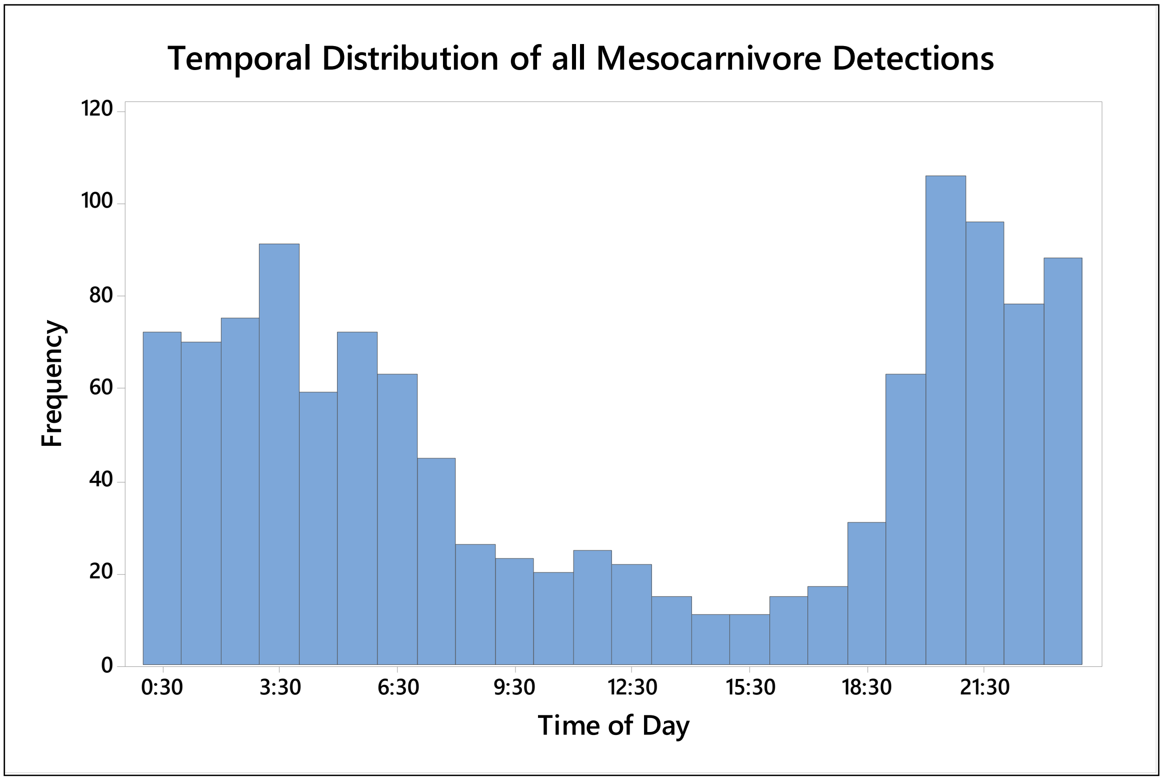


Figure 3.2. Temporal distribution for the daily activity pattern of mesocarnivores detected on the remote camera grid throughout the year-long sampling period.

Table 3.2. Total and percentage of photographic detections for each daily activity period per mesocarnivore species.

	Nocturnal		**Diurnal**		**Crepuscular**	
Species	**Detections**	**% of Total**	**Detections**	**% of Total**	**Detections**	**% of Total**
Badger	2	66.7%	0	0.0%	1	33.3%
Bobcat	7	20.6%	13	38.2%	14	41.2%
Coyote	0	0.0%	0	0.0%	1	100.0%
Gray Fox	335	50.8%	149	22.6%	176	26.7%
Raccoon	272	71.4%	10	2.6%	99	26.0%
Ringtail	8	61.5%	1	7.7%	4	30.8%
Striped Skunk	87	75.7%	2	1.7%	26	22.6%
Hog-nose Skunk	14	63.6%	0	0.0%	8	36.4%
Totals:	725	59.0%	175	14.2%	329	26.8%

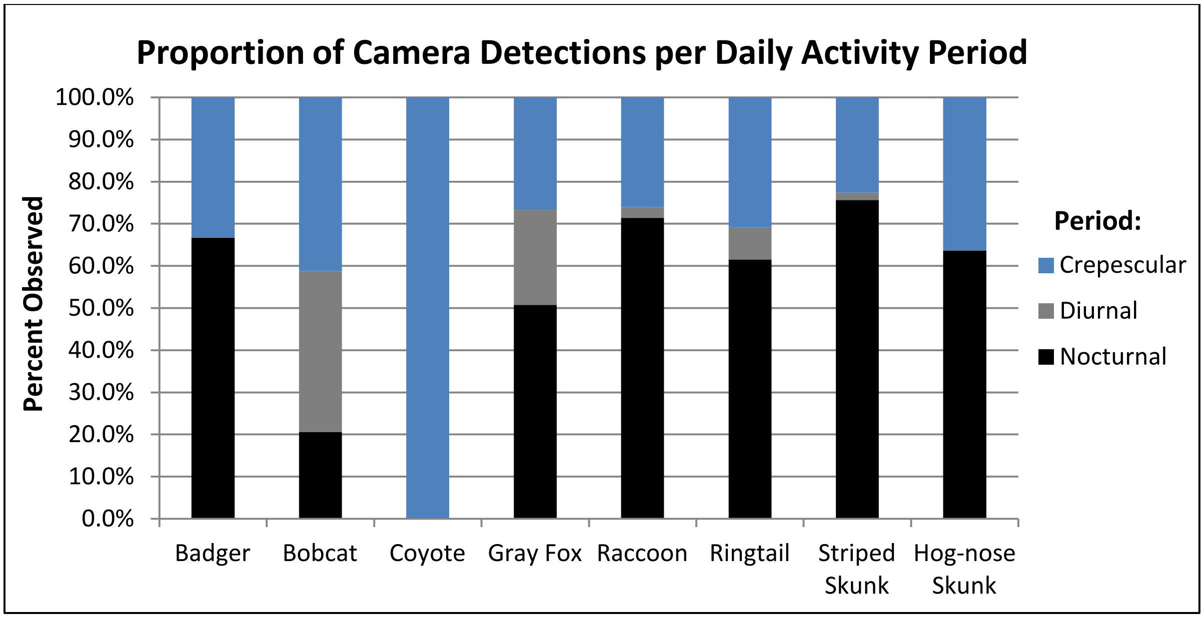


Figure 3.3. Relative proportions of photographic detections per daily activity period for each mesocarnivore species. Asterisk (*) next to species name denotes small sample size of detections with which to base comparisons.

Of the 1,296 photographic detections of mesocarnivores observed, 1,206 observations could be classified into the 6 behavioral categories delineated. A majority of these detections captured mesocarnivores in travel (54.31%) or investigating the camera itself (27.03%) as shown in Table 3.3. Foraging behavior observed (at 8.3% overall) was attributed mostly to raccoons, gray foxes (some with small rodents in their mouths), and skunks. A few rare interactions between individuals were observed which included courting behavior exhibited by a pair of bobcats and an altercation between a pair of gray foxes (Appendix 2). Relative proportions of behaviors observed per mesocarnivore species were plotted for context (Fig. 3.4), though it should be noted that detections for badger, coyote, ringtail, and hog-nosed skunks yielded low sample sizes for this comparison.

Table 3.3. Totals for classified behaviors observed among the photographic detections per species throughout the year-long sampling period. Behavioral categories included traveling, foraging, idle, investigating the camera itself, scent marking (urinating or rubbing), and interacting with another member of the same species.

Species	Traveling	Foraging	Idle	Investigating camera	Scent marking	Interaction
Badger	1	0	0	2	0	0
Bobcat	17	1	3	11	1	1
Coyote	0	0	0	1	0	0
Gray Fox	410	23	89	123	12	3
Raccoon	145	44	13	171	0	0
Ringtail	9	1	0	2	0	0
Striped Skunk	60	27	2	14	0	0
Hog-nose Skunk	13	4	1	2	0	0
Total:	655	100	108	326	13	4
% Occurrence:	54.31%	8.29%	8.96%	27.03%	1.08%	0.33%

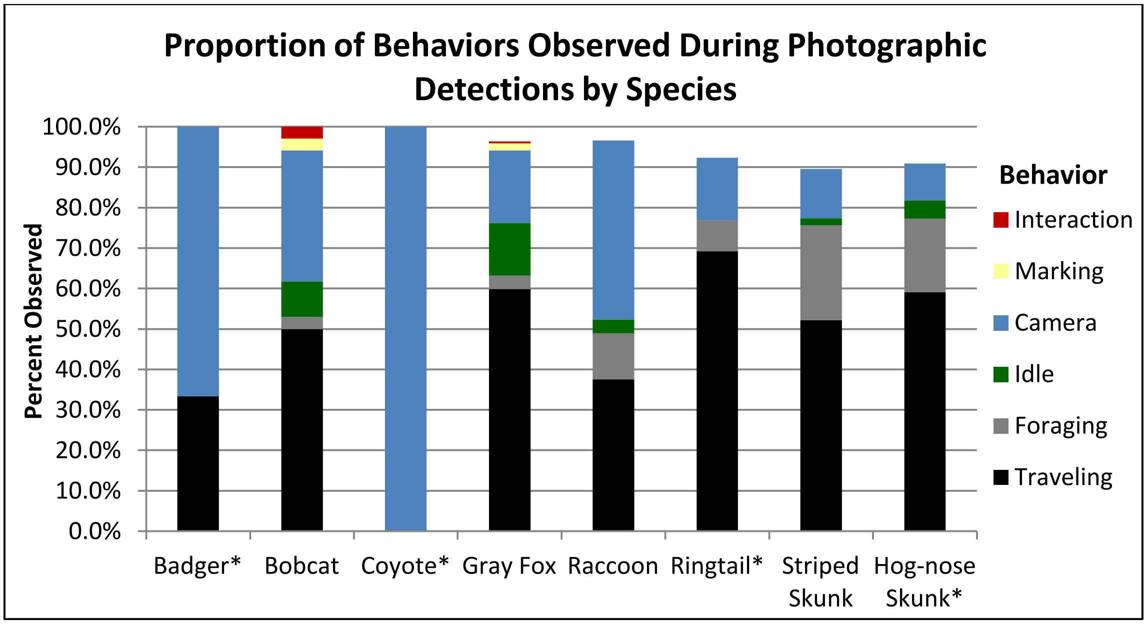


Figure 3.4. Proportion of behaviors observed among the photographic detections for each species throughout the year-long sampling period. Behavioral categories include observed traveling, foraging, being idle, investigation of the camera itself, scent marking (urinating or rubbing), and interacting with another member of the same species. Asterisk (*) next to species name denotes small sample size of detections with which to base comparisons.

Scat Detections

A total of 8,030 trap days yielded 1,391 scat detections of mesocarnivores throughout the year-long sampling period. 14.95% of all scats collected (*n* = 208) could not be identified at the species level and were thus dismissed from further comparison, yielding 1,183 mesocarnivore scat samples for subjection to statistical analysis and trends. Of these detections, scats from badger (*n* = 18), bobcats (*n* = 161), coyote (*n* = 70), gray fox (*n* = 624), raccoon (*n* = 233), ringtail (*n* = 8), and skunk (*n* = 69) were observed and removed from all transects throughout the year (Table 3.4). No attempt was made to discern between skunk species from the Mephitidae scats observed. The potential existed for scats to completely decay between monthly intervals (pending diet composition; Sanchez et al. 2004, Losinger et al. 2016), thus monthly counts may not yield absolute totals, but instead representative totals for each interval. As all transects were checked at the same temporal frequency, it is assumed the potential for this occurrence was equivalent across all transects and therefore all totals observed were meaningful counts.

As observed with camera detections throughout the year, total scat detections per month varied in the same apparent oscillation of mesocarnivore activity throughout an annual cycle, wherein a substantial increase in detections was observed from September through February and a marked decrease in detections occurred from May through August (Fig. 3.5). As done for the camera grid data, scat detection rates were presented here along a secondary axis to normalize any potential effects in which variations in the length of time between surveys may have imparted upon the total number of scats observed per month.

Table 3.4. The number of mesocarnivore scats detected per species and by month across 22 scats transects sampled regularly at the Martin Ranch in the Edwards Plateau of central Texas. Total detections per species, average number of detections, as well as a detection rate (number of detections per day) are additionally listed. Data was collected from May 2016 to April 2017 to coincide with the remote camera grid established on site during the same intervals.

	Monthly interval	Badger	Bobcats	Coyotes	Gray fox	Raccoon	Ringtail	Skunk	Total identified	Detection rate	Unknown	Percent unknown	Overall
2016	May	0	4	0	34	17	1	0	56	0.094	11	19.6%	67
	June	0	6	3	18	7	0	0	34	0.052	17	50.0%	51
	July	0	4	8	26	14	1	4	57	0.089	9	15.8%	66
	August	0	6	4	16	15	0	0	41	0.060	8	19.5%	49
	September	1	8	1	98	42	0	6	156	0.215	44	28.2%	200
	October	4	15	4	120	41	2	13	199	0.258	52	26.1%	251
	November	0	8	2	47	15	1	3	76	0.173	4	5.3%	80
	December	5	44	10	76	25	3	14	177	0.179	12	6.8%	189
2017	January	4	16	8	58	17	0	5	108	0.189	11	10.2%	119
	February	3	32	14	66	11	0	10	136	0.177	13	9.6%	149
	March	0	11	8	24	6	0	4	53	0.120	5	9.4%	58
	April	1	7	8	41	23	0	10	90	0.117	22	24.4%	112
	Total Detected	18	161	70	624	233	8	69	1,183	-	208	-	1,391
	Average/mo.	1.50	13.42	5.83	52.00	19.42	0.67	5.75	98.58	0.14	405	-	115.92
	Detection rate[a]	0.002	0.020	0.009	0.078	0.029	0.001	0.009	0.147	0.021	0.050	-	

[a] Calculated as number of detections per day (# of scats detected÷8,030 trap days [22 transectsx365 days])

[b] Average detection rate across all species identified

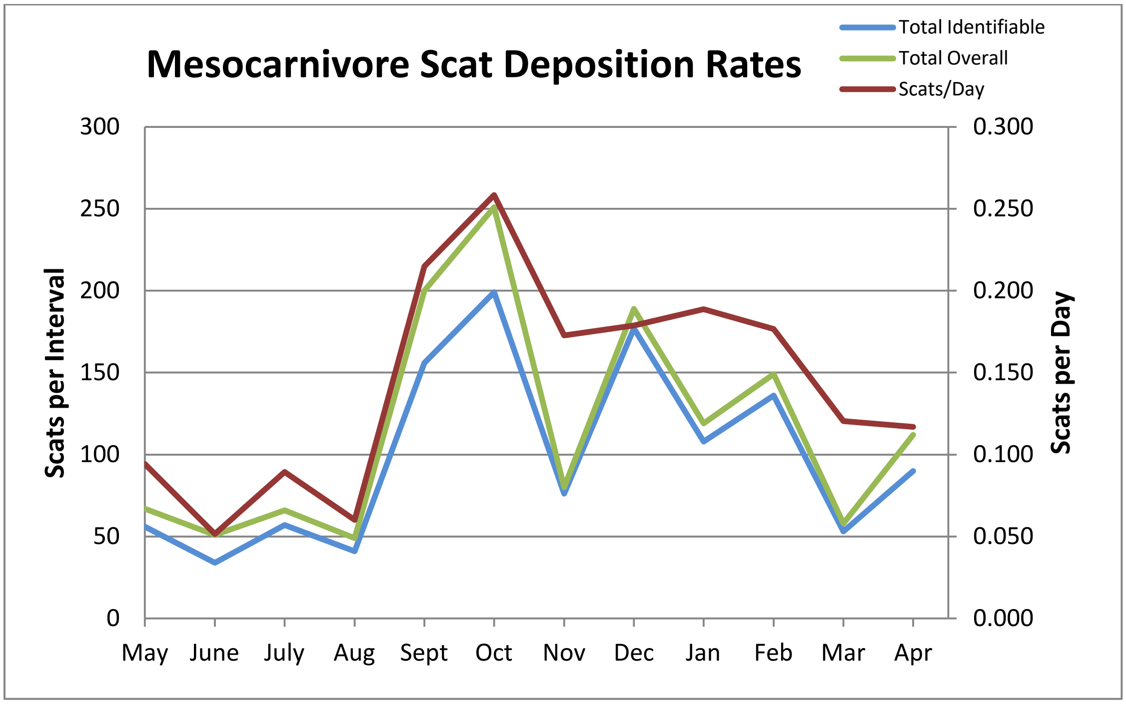


Figure 3.5. Scat detection totals from mesocarnivores per month throughout the year-long sampling period. Detection rates (number of scats per day corrected for number of trap days) also plotted throughout the year, corresponding to the secondary Y axis shown.

The post hoc one-way ANOVA performed on scat diameter data (Fig. 3.6) detected significant variation between the scat widths of each mesocarnivore species ($P = 0.01$; Table 3.5). Results from the ensuing post hoc Tukey test (Tukey 1949) indicated that coyote scat diameters (21.59 ± 0.54 mm) were significantly different from the remainder of the guild. Pair-wise combinations that were not found to be significantly different from each other were those of: (1) bobcat (19.53 ± 0.36 mm) and raccoon (19.78 ± 0.31 mm), (2) gray fox (14.68 ± 0.68 mm) and badger (14.25 ± 1.08 mm), (3) badger and skunk (12.59 ± 0.56 mm), and (4) skunk and ringtail (11.00 ± 1.61 mm). All other species comparisons produced statistically significant differences in the means ($P < 0.05$) for scat diameter observed.

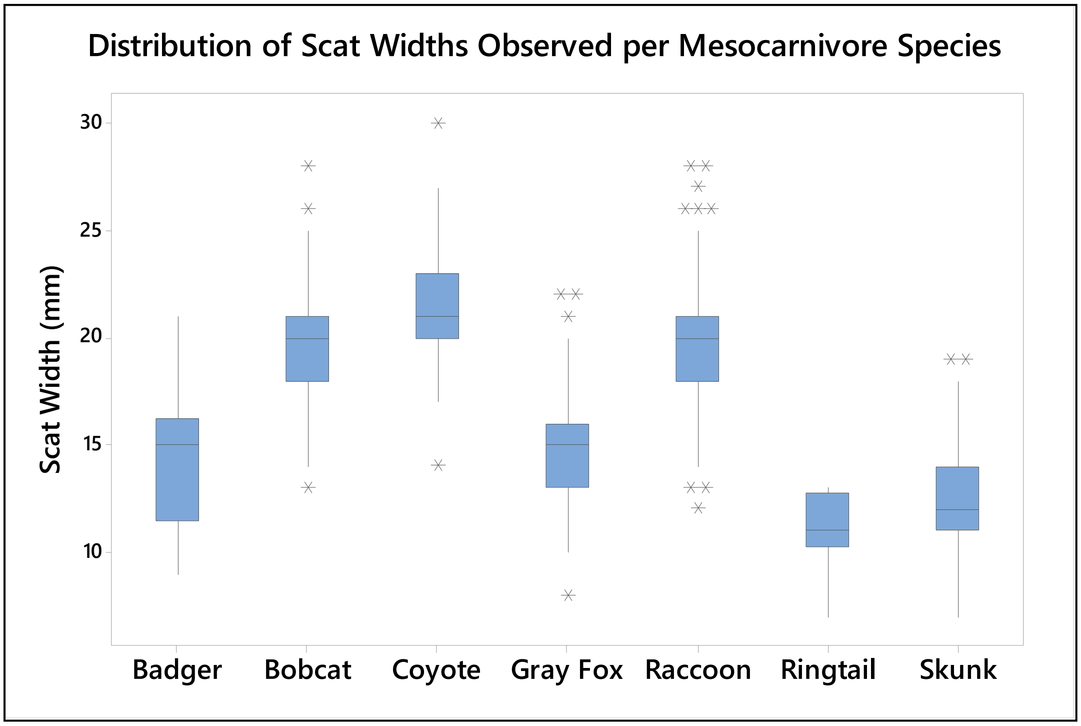


Figure 3.6. Box and whisker plot for the distributions of scat widths per species examined. Sample medians indicated by horizontal lines within the quartile ranges represent by the blue boxes, with the vertical lines indicating the range of the sample and asterisks representing the outliers of each dataset.

Table 3.5**.** ANOVA test results for variation in scat diameter between species.

Source	*df*	SS	Variance	F-Value	F-Critical
Between Scats	6	8935	1,489.15	274.24	≈2.09
Within Scats	1,133	6149	5.43		
Total	1,139	1,5083			

The post hoc Kruskal-Wallace test detected significant variation in the length of scats between the species (χ^2= 182.81, *df* = 8, *P*< 0.001), though the test lacks the power to identify which pairings of data account for the significant variation observed (Fig. 3.7).

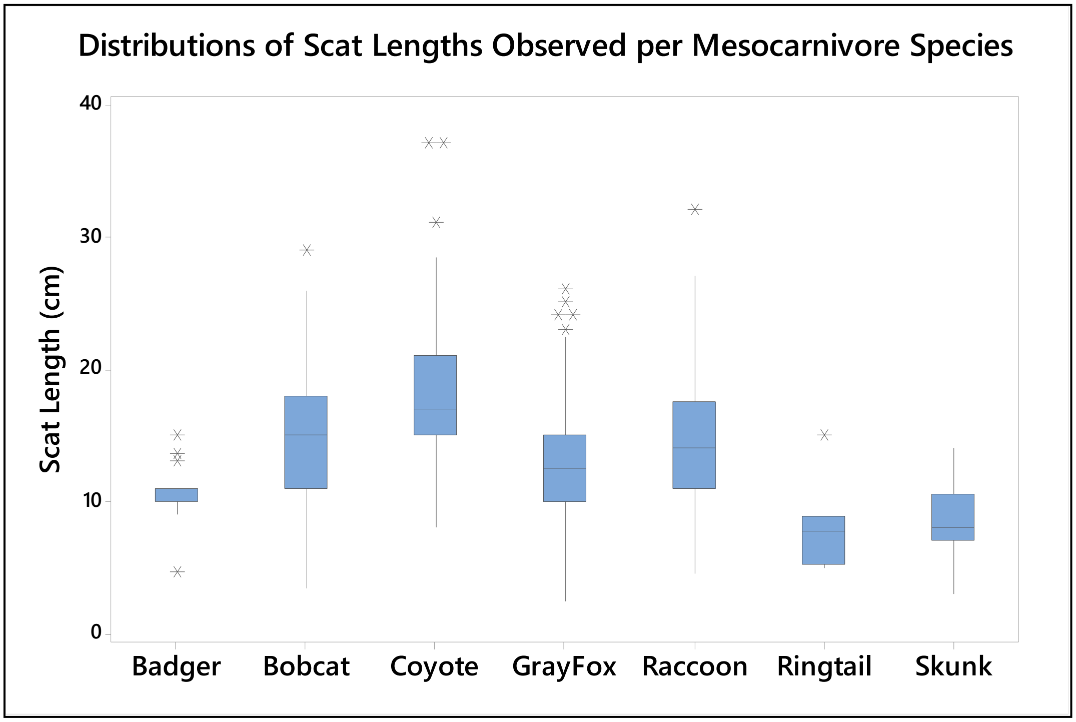


Figure 3.7. Box and whisker plot for the distributions of scat lengths per species examined. Sample medians indicated by horizontal lines within the quartile ranges represent by the blue boxes, with the vertical lines indicating the range of the sample and asterisks representing the outliers of each dataset.

Plotted width distributions for scat widths identified as being from bobcat, coyote, and gray fox were compared to the results adapted from Reid (2015; Fig. 3.8). Median diameters, quartiles, and ranges for bobcat, coyote, and gray fox scats at the Martin Ranch in Menard County, Texas were similar to those which Reid measured and affirmed genetically per species in Santa Cruz County, California, although an accurate mean comparison test could not be performed between the 2 sets of data, given the lack of descriptive data Reid (2015) presented. A comparison between the distributions of the 2 datasets was intended as a course measure of observer accuracy to gauge the degree of consensus between the results of the 2 studies as genetic analysis was not a feasible option here. Comparative width distributions are shown in Figure 3.9.

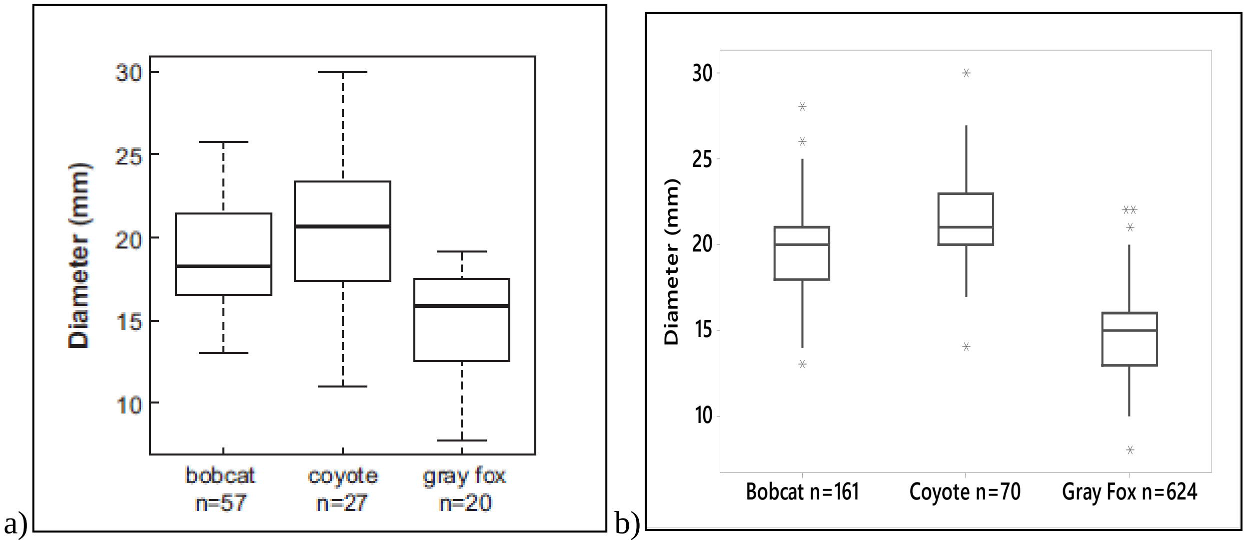


Figure 3.8. Comparison of bobcat, coyote, and gray fox scat width distributions observed in (a) Santa Cruz County in west central California adapted from Reid (2015) and (b) the Menard County in the Edwards Plateau of central Texas. Quartiles and medians for this study were higher for bobcat, analogous for coyote, and lower for gray fox, which notably had much higher sample sizes obtained per species.

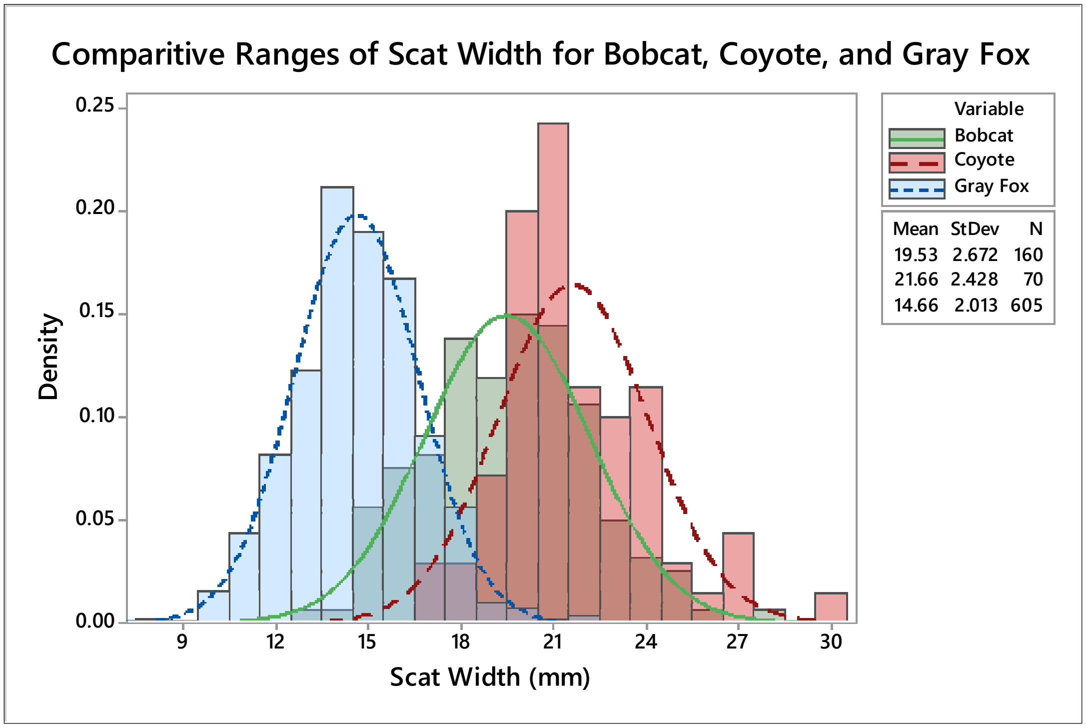


Figure 3.9. Distribution of scat widths observed for all bobcat, coyote, and gray fox scats measured throughout the study duration. Amorphous scats, which could not be confidently measured for width, were excluded from these distributions.

The range, mean, and standard error results for scat measurements, along with mean observer confidence and relative percent composition of scats placed within each ecological site and per road type and position are listed per species in Table 3.6 and Table 3.7 for comparison. Here, road types were delineated by gravel (Type 1), 2-track (Type 2), and rough (Type 3) roads. Position on the road pertains to the placement of each scat on the tire track, median or shoulder of the road transects.

Variables pertaining to the contextual placement of scats (along fence lines, trail or road junctions, among multiple scats, or elevated on a platform) revealed that of all mesocarnivores, bobcats, coyotes, and gray foxes were most likely to deposit multiple scats in a given area and appeared least likely to deposit scats along fence lines (Fig. 3.10). Skunks and raccoons deposited their feces on elevated platforms such as rocks, cacti, or other objects more frequently than initially expected.

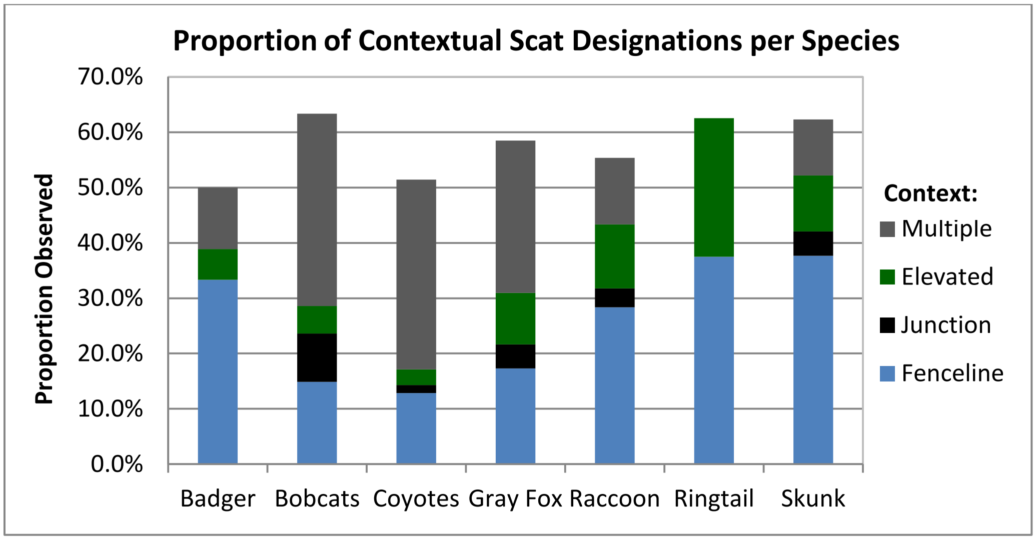


Figure 3.10. Proportion of contextual attributes observed for all scats throughout the year-long sampling period. Categories for deposition context pertain to scat placement adjacent to a fence line, at a trail or road junction, elevated on a physical platform, or placed in a group comprising multiple scats.

Table 3.6. Ranges, means, and standard error for mesocarnivore scat width and length measurements taken along with percent composition of observed categorical variables per species at the Martin Ranch in the Edwards Plateau of central Texas from May 2016 to April 2017. All scats were measured for width at the widest portion of the scat to the nearest mm, length to the nearest 0.5 cm, assigned an observer confident appraisal (on an ascending scale of 1–4), noted for any context of placement pertaining to fence lines, trail or road junctions, elevated stature, or conglomeration of multiple scats, and marked for which of 4 ecological sites the scat was placed in (ecological sites present denoted as LSH = Low Stoney Hill, CL = Clay Loam, D = Draw, S = Shallow).

Species	Scat width		Scat length		Obvs	Context for scat placement				Ecological site distribution			
	Range (mm)	Mean ± S.E.	Range (cm)	Mean ± S.E.	Conf.	Fenceline	Junction	Elevated	Multiple	LSH	CL	D	S
Badger	9 - 21	14.2 ± 1.1	4.5 - 15	10.7 ± 2.2	2.44	33.3%	0.0%	5.6%	11.1%	50.0%	27.8%	16.7%	5.6%
Bobcats	13 - 28	19.5 ± 0.4	3.5 - 29	15.2 ± 0.7	3.29	14.9%	8.7%	5.0%	34.8%	32.3%	38.5%	19.9%	9.3%
Coyotes	17 - 30	21.6 ± 0.5	8 - 45.5	18.7 ± 1.0	2.74	12.9%	1.4%	2.9%	34.3%	48.6%	35.7%	10.0%	5.7%
Gray Fox	8 - 22	14.7 ± 0.2	2.5 - 26	12.5 ± 0.4	2.87	17.3%	4.3%	9.3%	27.6%	65.9%	19.6%	9.3%	5.3%
Raccoon	12 - 28	19.8 ± 0.3	4.5 - 32	14.5 ± 0.7	2.92	28.3%	3.4%	11.6%	12.0%	75.1%	15.9%	5.6%	3.4%
Ringtail	7 - 13	11.0 ± 1.6	5 - 15	8.0 ± 3.0	2.00	37.5%	0.0%	25.0%	0.0%	87.5%	12.5%	0.0%	0.0%
Skunk	7 - 19	12.6 ± 0.6	3 - 14	8.5 ± 1.2	2.65	37.7%	4.3%	10.1%	10.1%	75.4%	13.0%	5.8%	5.8%

Table 3.7. Percent composition of mesocarnivore scats deposited per species by both road type and placement on the roads of the Martin Ranch in the Edwards Plateau of central Texas from May 2016 to April 2017. Road Types were delineated by gravel (Type 1), 2-track (Type 2), and rough (Type 3) roads. Position on the road was delineated for each scat by its placement on the tire track, median or shoulder of the road transects.

Species	Road type			Position on road			% not marked
	Type 1	Type 2	Type 3	Tire track	Median	Shoulder	
Badger	11.1%	72.2%	16.7%	33.3%	55.6%	11.1%	0.0%
Bobcats	5.6%	75.2%	19.3%	57.9%	36.5%	5.7%	1.3%
Coyotes	12.9%	67.1%	20.0%	37.7%	52.2%	10.1%	1.4%
Gray Fox	21.2%	65.7%	13.1%	55.5%	32.5%	12.0%	1.0%
Raccoon	15.0%	75.1%	9.9%	56.0%	32.3%	11.6%	0.4%
Ringtail	25.0%	75.0%	0.0%	50.0%	25.0%	25.0%	0.0%
Skunk	5.8%	84.1%	10.1%	70.6%	17.6%	11.8%	1.5%

Comparison of Results between Methods

Between the 2 sampling methods, trends in mesocarnivore activity coincided throughout the year (Fig. 3.11), with a peak in detections during the cooler months (~October through February) and a drop in detections during the hottest 3 months of the year (June through August). A peak amplitude (or range) of 0.273 detections per day (hereafter DPD) with an rms (root-square mean) of 0.0965 DPD was observed for the annual oscillation of activity produced by the photographic detection rates. Scat deposition rates produced an oscillation of activity with the peak amplitude of 0.206 DPD with an rms of 0.072 DPD.

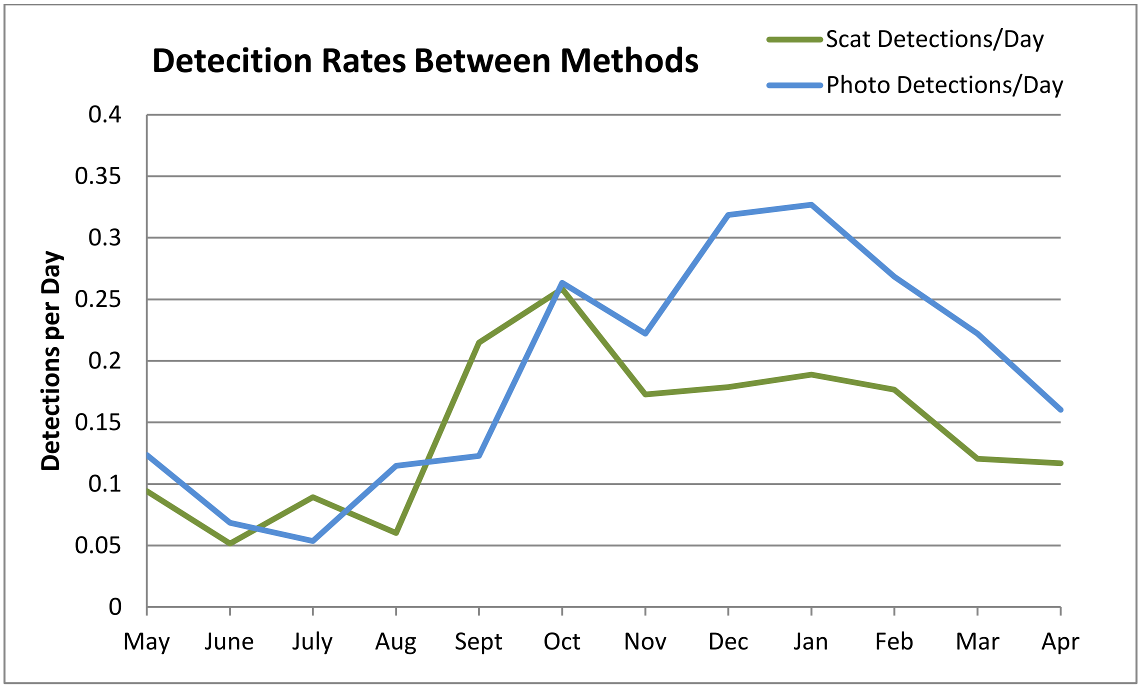


Figure 3.11. Detection rates for mesocarnivores from both scat transects and camera detections per month throughout the study duration. Detection rates calculated as the number of scats per day corrected for the number of trap days requisitioned for each respective method.

The mean difference between the monthly detection data of both methods was 7.17 ± 0.13 (*SE*; Fig. 3.12). The coefficient of variation (CV) between the 2 datasets yielded a difference of 6.82%. No significant difference between the monthly detections of the camera grid and the scat detections was observed over time (*U* = 68; *P* = 0.84, Mann-Whitney U-test), coinciding with the analogous trends both methods exhibited throughout the year (Fig. 3.11) and the small mean difference observed.

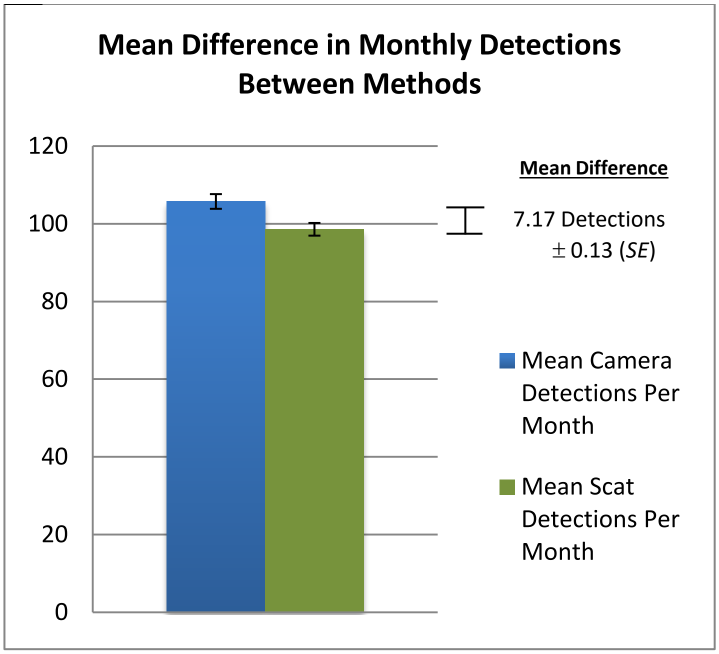


Figure 3.12. Mean difference between monthly detections of camera and scat data over the year-long sampling period.

The mean difference between detections for mesocarnivores produced for each sampling unit (i.e., cameras or transects) was 16.13 ± 0.09 (Fig. 3.13). The coefficient of variation (CV) between the 2 datasets yielded a difference of 7.95%. Although a higher amount of detections per sampling unit were produced by the camera grid, no significant difference between the medians of the camera grid and the scat transects was observed (U = 164.5; *P* = 0.37, Mann-Whitney U-test).

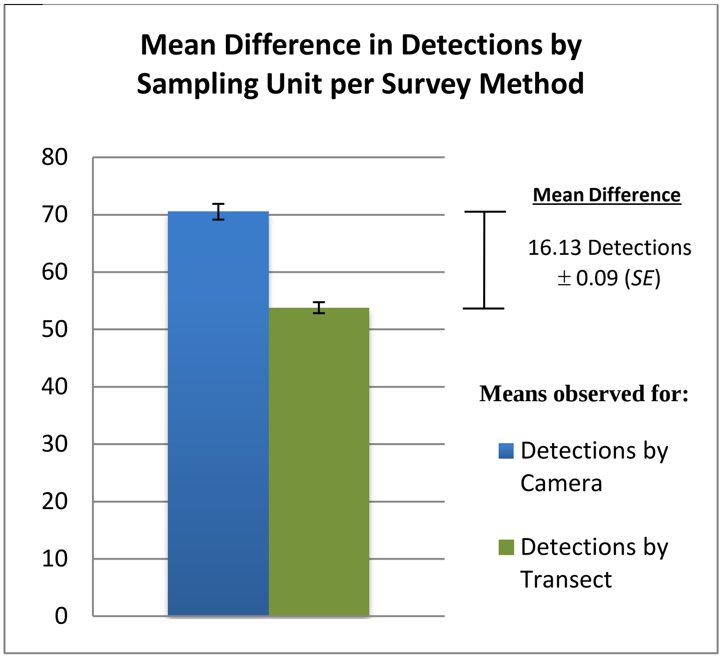


Figure 3.13. Mean difference of detections between the remote camera grid and scat transect datasets across respective sampling units.

Both survey methods detected the same species (excepting the lack of species level identity from mephitidae scats observed), though the relative proportions of species detected noticeably varied between methods for bobcat, coyote, and raccoon (Table 3.8). As no significant difference was observed between the results of the 2 methods, proportions of detections by species for both survey methods throughout the year were combined to provide a baseline for researchers seeking to gauge the expected detectability of mesocarnivores in this region of the Edwards Plateau using either survey method (Fig. 3.14).

Table 3.8. Observed detections and proportional frequencies per survey method for each mesocarnivore species observed at the study site.

Results by:	Badger	Bobcats	Coyotes	Gray fox	Raccoon	Ringtail	Skunk
Camera detections	3	34	1	685	386	13	147
Proportional Frequency	0.24%	2.68%	0.08%	53.98%	30.42%	1.02%	11.58%
Scat depositions	18	161	70	624	233	8	69
Proportional Frequency	1.52%	13.61%	5.92%	52.75%	19.70%	0.68%	5.83%

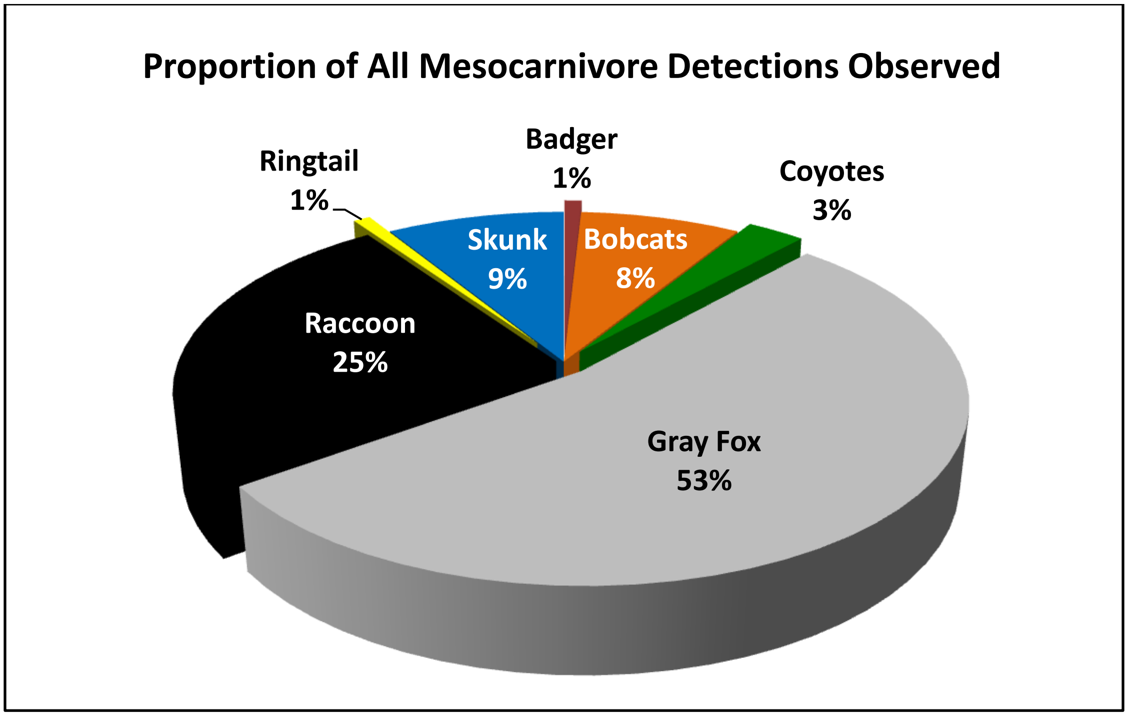


Figure 3.14. Proportions of all mesocarnivore detections by species observed from both the camera grid and the scat transects results combined.

It should be noted that scat transects produced nearly 5 times as many bobcat detections as those on the camera grid and that scats depositions comprised 39.6% fewer detections of raccoons as did photographic detections. Most notably, only 1 coyote was detected on the camera grid throughout the entire study period, whereas coyote scats where found consistently throughout the year, though in proportionately low levels of occurrence compared to other species of similar size. Coyote tracks were also detected on the road system for 5 of 12 survey checks at the ranch, which indicates some likelihood for their residential occupancy at the study site and reinforced observer confidence in scat identifications for this species throughout the year.

The relative proportion of detections in each ecological site varied per species with no apparent consensus between survey methods (Figs. 3.15 and 3.16).

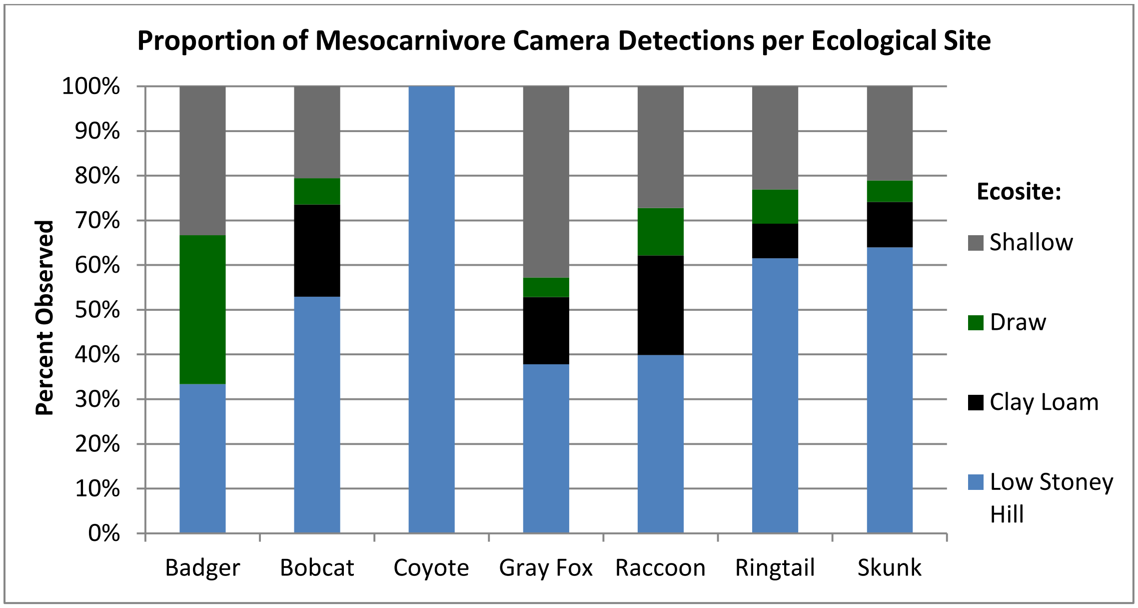


Figure 3.15. Proportions of photographic detections of mesocarnivores observed within each ecological site throughout the year-long sampling period. Small sample sizes (*n* < 30) for badger, coyote, and ringtail were obtained compared to the remains of the guild.

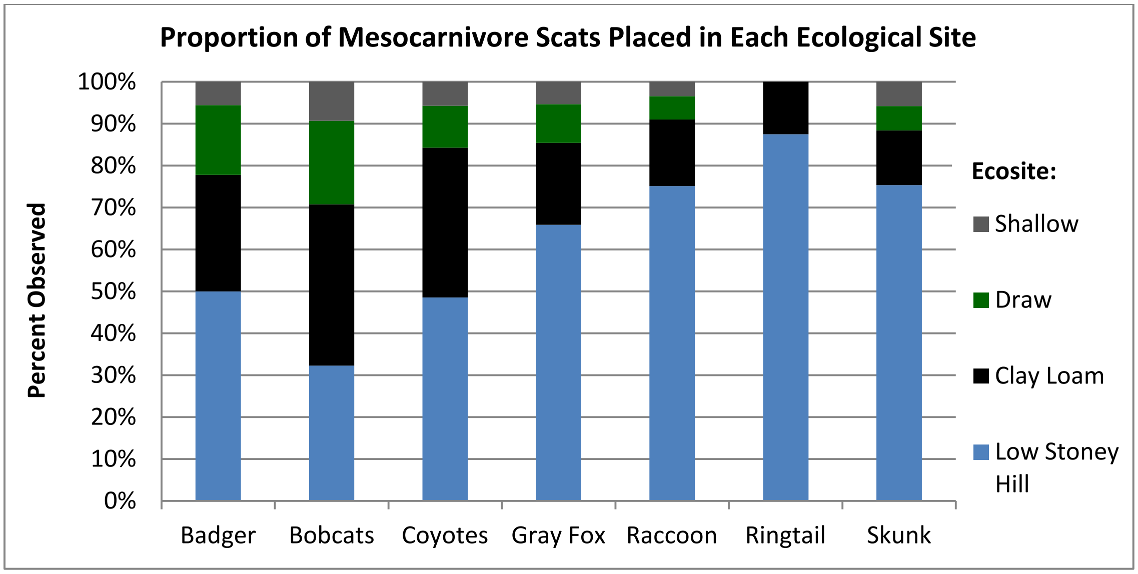


Figure 3.16. Proportions of scats found within each ecological site throughout the study duration. Small sample sizes (*n* < 30) for badger, coyote, and ringtail were obtained compared to the remains of the guild.

DISCUSSION

Both the remote camera grid and scat transects produced count data that were not constant over time yet exhibited consistent trends throughout the year. In departure from my original expectation, both methods documented a marked increase in detections coinciding with the cooler time of the year, which resulted in apparent sine waves of animal activity. Thus, the comparative trends in detection rates between the 2 methods were quantified as waveforms to compare each peak in mesocarnivore activity over time. By adapting a known descriptive standard from physics based upon the magnitude (peak amplitude) and duration (rms) of the cycles observed, this practice could have potential use in comparing analogous trends of activity between datasets.

The lull of activity observed for both datasets in the summer months may be a response to temperature, season, or the parturition and rearing of young coinciding with the late spring and summer for these species (Feldhamer et al. 2003). Conversely, the observed peak of activity may coincide with the timing availability of prey and fruiting bodies of plants in Texas (Andelt and Andelt 1984). The height of vegetation in front of the camera, which was not measured in this study, likely factored in to the low amount of detections observed in the summer months, which coincides with the peak growing season for regional forbs and grasses. Likewise, vegetation height may have obscured some scats from being detected during this same period along transects placed on type 2 and 3 roads in the growing season.

The small mean difference observed between the data of each method supports the notion that no meaningful difference exists between the outcome of their detections, either across sampling units or over time. Therefore, both methods appear to obtain similar signals of count data for the mesocarnivore guild, although the discrepancies between the methods should be further explored and described here. This study was not designed to derive abundance estimates per species from this count data but rather to use both camera and scat detections as measures of activity in a given area for each mesocarnivore species.

For researchers seeking to evaluate the activity of similar mesocarnivores on the landscape, the results of this study suggests that a remote camera grid is a suitable method for obtaining sufficient samples of detections for gray foxes, raccoons, and skunks. Scat transects produced greater yields of bobcat, coyote, and badger detections on the landscape than the camera data. Though uncommon in the region, it should be noted that neither method detected any sign of cougar, black bear, spotted skunks (*Spilogale spp.*), hooded skunks (*Mephetis macroura*), or *Mustela* species across the ranch. Both survey methods were equally capable of detecting gray foxes and raccoons on a frequent basis, while the camera grid produced more raccoon detections and twice as many skunk detections as the scat surveys. The higher level of skunk detections produced on the camera grid may possibly be due to their propensity for methodical foraging (26.2% of photographic detections were of foraging behavior, more than the remains of the guild), a behavior which may increase their tendency to wander in and out of the detection zone of a given camera.

The low amount of detections both methods produced for badger and ringtail imply that use of even 2 sampling methods may not be suitable for surveying the entire mesocarnivore guild, an assertion coinciding with the conclusions of Gompper et al. (2006). Both methods here were based upon random designs, and neither method was effective at detecting these 2 species on a consistent basis. While I cannot account for their density at the study site, the few ringtail and badger detections obtained is likely a function of the behavioral ecology of these 2 species. Ringtails accumulate their deposited feces in latrines and their range is limited by the availability of standing water or sufficient fruit crops and structures which provide cover (Trapp 1978, Chevalier 1984). Badgers spend most of the diurnal period underground and while most above-ground foraging occurs at night, they often deposit feces in dead-end excavations made within their burrows (Lindzey 1976, Goodrich 1994). Surveys intended to include these species may benefit from an adaptive study design considering such behaviors. In contrast, raccoons and skunks also deposit feces in latrines (Elbroch 2003, Feldhamer et al. 2003, Moskowitz 2010), yet each species deposited feces along roadways frequently enough to have their presence represented throughout the study site over time.

The variability in the detections each method produced for certain species suggests the survey method itself may affect a species' detection probability, thus imparting positive or negative bias upon the detections, statistical testing, and scope of inference reported for a given species (Dempsey et al. 2014, Güthlin et al. 2014, Carreras-Duro et al. 2016). Combining the results of 2 or more methods standardized in the same manner may yield more representative levels of detections across the guild, and may provide for more robust levels of inference, as variations in detections stemming from a given methodology can be assessed to guide further research and draw more informed conclusions for patterns observed (Gompper et al. 2006).

For species of interest, most researchers seek to obtain sufficient numbers (often $n \geq 30$) of detections required for statistical inference (Mace 1964, Bean et al. 2012). The scat transects produced adequate numbers of detections in this regard for both bobcats and coyotes, whereas the remote camera grid fell short of this underlying objective for the 2 largest mesocarnivores of the guild in the region. This finding may be of interest to those looking to evaluate the landscape use of these carnivores before imparting conclusions or management decisions regarding a particular site. In areas where predators are controlled, the presence of cameras as anthropogenic features could negatively bias detections of wary species such as coyotes and bobcats, and positively bias uncontrolled species with investigative tendencies such as raccoons and gray foxes. In the solitary detection of a coyote obtained, the animal was briefly investigating the camera which had photographed it. The lack of any other coyote detections on the camera grid compared to the number of scats observed throughout the year may be indicative of their wariness and not necessarily their lack of presence in the region. In contrast, 44.3% of all raccoon detections on the grid ($n = 171$ of $n = 386$) were of individuals investigating the camera as a novel item on the landscape.

Scat transects for carnivore activity are typically conducted upon trails or roads as the probability of detection for carnivores along linear features has been demonstrated to be higher than those which span the backcountry (Güthlin et al. 2012). Güthlin et al. (2012) determined that carnivore sign along roads is more reliable for gauging activity rather than estimates of abundance in this regard. With remote cameras, biased outcomes also may arise from non-random camera placement, camera height, settings, and model of cameras used, as well as the use of lures or bait at camera sites (Kelly 2008, Rowcliffe et al. 2011, Wellington et al. 2014, Burton et al. 2015). In a camera trap survey of a mesocarnivore guild in Southern Illinois, Lesmeister et al. (2015) observed a higher proportion of coyote relative to both gray fox and bobcat detections, while raccoons comprised 88.95% (*n* = 40,029) of all photographic detections obtained from the mesocarnivore guild, a finding which heavily contrasts with the results obtained here in the Edwards Plateau of Texas. Lesmeister et al. (2015) attributed the high proportion of raccoon detections to the attractant of bait placed in front of their cameras. No bait was used in this study, as my intent here was to survey the natural activity of each species with as little imposed bias as possible.

The continuous collection of data and the ability of cameras to mark detections with timestamps to gauge temporal activity are appealing advantages of the method and this technology (Ridout and Linke 2009). Scats may be deposited on the transects at any given time between the monthly checks just as animals may be photographed at any given time between the checks, however temporal information on scat depositions is limited to the frequency of the survey interval chosen. Daily activity patterns can be observed per species on the camera grid over time which can address questions related to the timing of their activity in given areas

(Ridout and Linke 2009, Locke et al. 2012). Remote cameras also can capture behavioral time budgets and assess differences in behaviors per species, a practice most often utilized at carcass sites for feeding by different scavenger species (Lewis and Lafferty 2014, Rogers et al. 2014, and Olsen et al. 2016). Differences in behavior captured on camera was gauged between mesocarnivore species in a purely exploratory context with no specific question in mind other than whether this information could be useful in ethological studies. As no cameras were baited and 95% of all photographic detections of mesocarnivores yielded observations which could be placed into the 6 behavioral categories delineated here, the use of randomly placed remote camera data appears to be a practical application for ethological research.

Camera failures can result in incomplete data such as described here, where full detection inventories were lacking for at least one camera per month. Scat transects were void of this issue, as this method is free from the limitations of technological dependency although not free from data loss in the form of unidentifiable or misidentified scats. The misidentification of scats by observers may be best evaluated through genetic assays which can provide a margin of error and an objective level of observer confidence regarding species identification, as opposed to the subjective measure ascribed to scats encountered on the landscape by surveyors, as presented here.

The majority of unidentifiable scat was amorphous and comprised of frugivorous content, indicative of the omnivorous diet which gray foxes, raccoons, skunks, and coyotes tend to exhibit while taking advantage of seasonal prickly pear (*Opuntia lindheimerii*), agarita (*Mahonia trifoliolata*), Texas persimmon (*Diospyros texana*) and tossahio (*Cylindropuntia leptocaulis*) blooms in the region (Feldhamer et al. 2003, Wrede 2010). The initial peak of scats observed in

September coincided with the larger prickly pear bloom of the year and many mesocarnivore scats from this time were comprised of their seeds, a finding which coincides with a study performed on coyote diets in south Texas by Andelt and Andelt (1984). They inferred that low digestible content in frugivorous scats accounted for the surge in deposition rates during the peak bloom of fruiting plants in the region and called for a method of standardization to account for the effect of diet on scat deposition rates when researchers seek to estimate relative density or abundance of coyotes in the region. Their considerations may well be applicable to all omnivorous mesocarnivore scat surveys. Scat deposition rates remain measures of observable activity in an area, and as such were deemed a suitable measure for comparison to the observable activity of photographic detections presented here.

Both scat width and length were found to significantly vary between the species though only scat width data met the assumption of equal variance and could be tested through a more robust parametric test. Scat width is anecdotally regarded as a better morphometric character for distinguishing between carnivore species than scat length although overlap still occurs between species, which extends to error and uncertainty (Danner and Dodd 1982, Reid 2015). Reid (2015) evaluated the efficacy of morphometric scat identification through predictive models based on genetic analysis of species-verified scats and cautioned the use morphometric measurements alone as prognostic indicators of species identity. As genetic validation could not be assessed for this study, scat width and length measurements were taken as metrics which may help eliminate species from consideration in the identification of scats, but not solely confirm that a scat is from a given species without due consideration of scat characteristics such as diet composition, tapered ends, twists, segments, surface structure, aroma, and contextual variables such as the nature of placement, scrapes, and scent marking (Wilcomb 1956, Elbroch 2003, Moskowitz 2010). The consideration of such variables may be a subjective art requiring some experience to arrive at consistent species designations. As such, research evaluating the efficacy of scat identification by trained observers may seek to consider categorical variables such as context and character of scat to further evaluate the basis for which observers are inclined to partition scats by species.

Differences in the contextual placement of mesocarnivore scat were assessed here in a purely exploratory context to gauge whether or not this information could inform the deposition patterns between mesocarnivore species. The most notable pattern observed from this data was that bobcat, coyote, and gray foxes exhibited comparatively high proportions of occurrence for placing multiple scats along roads, a finding which supports anecdotal knowledge (Neil Wight, Cybertracker track and sign specialist 2008 and Dan Hanshe, White Pines tracking program instructor 2008, personal communication). Coyotes, bobcats, and gray foxes can exhibit considerable range overlap despite intraguild competition (Chamberlain and Leopold 2005, Farias et al. 2005, Donadio and Buskirk 2006). The high tendency for placing multiple scats along roads may therefore be a function of intraguild territoriality in addition to species specific communication. Trends regarding the use of different road types, scat position on road, and ecological sites were described here, but not adequately addressed, thus further research is required to explore the impacts of these variables upon the detectability of mesocarnivores, as different species may exhibit preferential selection for a given ecological site, road type, or scat placement.

The results presented here are intended to inform other researchers seeking to evaluate the activity of seemingly obscure and often difficult to detect carnivores in the landscape. Both methods have their benefits and imperfections. This study compared the results of only 2 non-invasive sampling methods available to researchers. Hair snares, track transects, track plate boxes, and bait stations are other non-invasive methods that can be applied in a variety of landscapes to obtain observations of carnivores. Further comparisons regarding the efficacy of non-invasive sampling methods across several mesocarnivore guilds would serve to better refine and inform method choice for species of interest within a guild whose ecology and community dynamics have just started to be explored.

CHAPTER IV

THE INFLUENCE OF LPDS ON MESOCARNIVORE ACTIVITY IN THE EDWARDS PLATEAU OF TEXAS

Non-lethal forms of predator control have gained interest among ranchers as alternatives to traditional lethal predator removal at the private, state, and federal levels (Treves et al. 2009, Palmer et al. 2010). Predator eradication attempts have not always been effective for reducing livestock mortality, and in a review of multiple tests, 80% of non-lethal methods were found to be effective at reducing livestock mortality, as opposed to 29% efficacy found for lethal methods (Treves et al. 2016). LPDs are a largely nonlethal form of predator control as they rarely physically confront predators yet are purported to repel them with territorial behaviors and imposing stature (Linhart et al. 1979, Findo, 2005). As such, the use of LPDs may be an appealing substitute for lethal forms of predation control when management objectives account for the conservation of multiple carnivore species across a landscape (Treves et al. 2016).

Carnivore species that overlap in range tend to partition themselves spatially, temporally, and through diet selection to reduce interspecies competition for the resources available (Donadio and Buskirk 2006). Body mass or size of a carnivore has an influence on prey and forage selection in order to fulfill species-specific metabolic demands and has been known to influence intra-guild interactions (Lesmeister et al. 2015). In North America, terrestrial mammalian carnivores range in body mass from the 30 g female least weasel (*Mustela nivalis*) to the 725 kg male Kodiak brown bear (*Ursus arctos middendorffi*; Feldhamer et al. 2003). A division between large carnivores and the remains of their guild is oft distinguished through body mass alone, and an arbitrary divide of 15 kg has been proposed for delineation (Buskirk 1999, Gehrt and Clark 2003). In a loose sense, carnivores < 15kg are typically referred to as "mesocarnivores" though a more functional definition has been offered by Prugh et al. (2009) as any mid-ranking predator in a food web, regardless of its size or taxonomy. As such, larger mesocarnivores may outrank or out-compete smaller mesocarnivores in a given food web, especially within areas where large carnivores are absent (Ritchie and Johnson 2009, Roemer et al. 2009).

Large carnivores are termed apex predators when they have been shown to exude an influence on the abundance or behavior of sympatric species that is disproportionate to their abundance on a landscape (Paine 1969, Ripple et al. 2013). "Mesopredator release" is a concept describing the natural phenomena where medium-sized carnivores are more abundant in the absence of larger carnivores (Soulé et al. 1988, Roemer et al. 2009). More recently, researchers have broadened the term as an expansion in the density, distribution, or the change in behavior of a middle-rank predator, resulting from a decline in the density or distribution of an apex predator (Prugh et al. 2009). In the presence of apex predators, the dynamic theoretically releases competition pressure placed on smaller carnivores by the middle-ranked predators thereby leading to an expansion in the density or distribution of smaller carnivores (Miller et al. 2012). I additionally seek to investigate whether LPDs exude such an influence upon smaller predators as they are essentially large carnivores in a range system where such wild apex predators have since been extirpated for more than a century.

The abundance of carnivores in an area is dependent upon available prey, suitable habitat, and levels of intra and inter-specific competition (Paine 1966, Mills and Knowlton 1991).

Pending the species, individual size, and foraging behavior, mesocarnivores have a varied diet ranging from insects, eggs, carrion, fruit, and vegetative matter to small prey comprising of rodents, birds, and reptiles to larger prey such as lagomorphs, deer, and even smaller carnivore species such as skunk and raccoon (Fritts and Sealander 1978, Leopold and Krausman 1986, Rose and Prange 2015).

In the Edwards Plateau, common species capable of overtaking larger available prey including white-tailed deer (*Odocoileus virginianus*), axis deer (*Axis axis*), and livestock (such as sheep and goats) are the coyote and bobcat with the former exhibiting a diet of a generalist omnivore and the latter exhibiting a diet characteristic of an obligate carnivore (Leopold and Krausman 1986). Cougar prey on large ungulates as well and have been documented in central Texas, though their presence in the area is not ubiquitous (Texas Parks and Wildlife 2008). Regional studies found coyotes to be responsible for a majority of depredation losses to livestock along with bobcats, though to a lesser degree (Gober 1979, Pearson and Caroline 1981, Jones 1982, Wade and Bowns 1982, Neale et al. 1998). Lambs and goat kids comprise the most vulnerable age class for their kind and may present themselves as a seasonal resource for both predators in ranchlands across the country (Litvaitis and Shaw 1980, NASS 2000, Donadio and Buskirk 2006). Older, ailing sheep and goats, as well as the carcasses of the naturally deceased, would be intermittently available at best, thus wild varieties of prey would comprise more reliable perennial resources than livestock for both coyote and bobcat as well as for the remains of their guild. Considering the economic impact of predators on livestock ranching operations (NASS 2010, Palmer et al. 2010), I aim to examine the impacts of LPDs on the mesocarnivore community of the Edwards Plateau in terms of evaluating the activity of known livestock depredators (coyotes and bobcats), from the remaining mesocarnivore guild of the area (gray foxes, raccoons, skunks, badger, and ringtail) which likely pose little perennial threat to sheep and goats.

The principle objectives of this study were to: (1) determine if the presence of LPDs around livestock displaces known depredators to livestock from the herds the dogs protect, and to (2) investigate whether such a displacement (if evident) of larger or more dominant mesocarnivores (i.e., bobcat and coyote) results in a higher occurrence of activity from smaller mesocarnivores (gray foxes, raccoons, skunks, badger, and ringtail) in areas which LPDs occupy. No detections of cougar or black bear were confirmed throughout the study duration, so no inferences can be made here regarding the impact of LPDs upon large carnivores in the region.

I tested the hypothesis that LPD presence displaces known depredators of livestock from pastures which the dogs occupy while protecting livestock (H_1). If LPDs are effective at deterring known depredators away from livestock, then I predict the presence of LPDs will facilitate an increase in the presence of smaller mesocarnivores (such as foxes, raccoons, and skunks which pose little threat to hoofed livestock) in pastures which the LPDs occupy (H_2).

METHODS

Field data were collected at the Martin Ranch study site spanning a full year from the onset of May 2016 through the end of April 2017. In order to assess the distribution of mesocarnivore species across the study area, I employed scat transects and a remote camera grid at the study site which were checked on the same monthly intervals throughout the study duration. All resident LPDs were fitted with GPS collars, which logged their locations 8 times daily via satellite telemetry over the course of the year. I assessed the association of LPDs with livestock through daily readings from a sample of UHF collared livestock, the signals of which were logged by the 4 GPS collars of the LPDs when UHF collars were within a range of 100–300 m of the LPDs.

DATA ANALYSIS

A combination of both GPS collar data, UHF collar data, remote camera detections, and scat depositions were used to determine if the presence of LPDs around livestock affects the activity of mesocarnivores in pastures which the dogs occupy. Mesocarnivore activity was evaluated in terms of the number of detections produced per pasture by each survey method. In order to address the hypotheses, the first step was to test the assumption the dogs were around the livestock they were consigned to protect.

LPD Proximity to Livestock

The proximity of LPDs to livestock was evaluated based on the readings from UHF collar signals stored in the memory of each GPS collar. This technology facilitated the determination of days the LPDs were around livestock throughout the 10-month period this data was taken, and were therefore purported to be actively defending livestock in pastures they occupied. The total, percentage, and average number of days in which each LPDs was within 100–300 m of livestock was determined throughout the year along with the number of days the GPS collars stored less than 10 fixes per day.

Mesocarnivore Detections

Total counts and proportional frequencies of mesocarnivore detections per species were obtained throughout the year for each method, along with the overall proportion of detections by species produced from both survey methods combined.

A Kruskal-Wallace test (Kruskal and Wallis 1952) was used to determine whether detection rates produced for each method were uniformly distributed across the ranch or if significant variation existed between detections at the pasture level, thereby establishing a premise to further examine or explain any variation observed. In order to standardize these detection rates for testing, detections totals for each method first had to be obtained per pasture for each monthly interval. To account for the variation in the number of cameras and transects placed randomly across the ranch, the total number of monthly observations per pasture was divided by the total number of respective cameras or scat transects placed in each given pasture. Adjusted monthly detection totals were then standardized by calculating observations as a detection rate per day to account for any variation in the length of time which passed between checks throughout the year.

Influence of LPDs on Mesocarnivore Detections

GPS collar data marked the locations of the 4 LPDs across the ranch over time. 11,731 GPS locations were collected over the study period at the sample rate previously described. LPD presence was quantified at the pasture level by first plotting all LPD locations for each monthly interval (coinciding with the camera grid and scat transect intervals) into ArcMap, then identifying which pastures were occupied by LPDs (versus not) per monthly interval, and then tabulating which cameras and transects corresponded with either an LPD occupied or LPD unoccupied pasture for each monthly interval throughout the year. This was performed in order to associate every mesocarnivore detection observed (on either the remote camera grid or scat transects) with the presence or absence of an LPD at the pasture level.

Corresponding detections of mesocarnivores for both LPD occupied and unoccupied pastures were amassed and tabulated per species. To visually appraise the effects of LPDs on each mesocarnivore species throughout the year, I plotted the proportion of mesocarnivore detections which occurred in LPD occupied pastures relative to pastures not occupied by LPDs for each species. Chi-squared tests for association (Pearson 1992) were used to assess the significance of occurrence for mesocarnivore detections per species in both LPD-occupied and LPD-unoccupied pastures. Given the solitary degree of freedom involved for each comparison evaluated, all one way classification tests presented here were calculated with Yates correction for continuity (Yates 1934).

RESULTS

LPD Proximity to Livestock

A total of 134,080 proximity readings of UHF collared sheep and goats was collected by the GPS collars attached to the 4 LPDs at the ranch over the 10-month span (308 days) in which proximity data was available. LPDs were found to be within 100–300m of livestock for 99.4–100% of those 308 days, therefore pastures labeled as LPD occupied coincided with pastures occupied by both livestock and LPDs for all 10 monthly intervals assessed (Table 4.1). The combined average of proximity readings per day for the LPDs of the ranch was 108.8 ± 4.0. The number of days where less than 10 readings were obtained between the 4 LPDs ranged from 5–12 days. This data provides the longest-term quantitative assessment of its kind to date demonstrating the frequency to which LPDs associate with the livestock they are consigned to protect. Assuming each LPD is fulfilling its role as a territorial deterrent to would-be predators of livestock, we have a quantitative basis for confidence in our succeeding pasture-level analysis to compare the differences of mesocarnivore detections in both LPD (and livestock) occupied pastures to those not occupied by LPDs during a given month.

Table 4.1. Total proximity readings of individual UHF collared livestock per LPD, along with the mean, range and percentage of days the LPDs were around livestock out the 308 available days.

LPD	Proximity fixes per day			# Days w/o fixes	# Days w/ < 10 fixes	% Days near livestock
	n	Mean	Range			
Sir Reginald [a]	28903	93.8 ± 3.4	1 – 355	0	12	100.00%
Sir Alfred	42143	136.8 ± 5.1	0 – 456	2	5	99.35%
Sir Nigel	21497	69.8 ± 2.6	0 – 287	2	11	99.35%
The Queen	41537	134.9 ± 4.9	0 – 406	2	5	99.35%

[a] Denotes the LPD who associated with the goat herd

Mesocarnivore Detections

A total of 5,966 trap days was recorded between the 18 remote cameras of the camera grid, yielding 1,269 detections of mesocarnivores throughout the year-long sampling period. Of the 6,570 potential trap days which existed for the year, 604 (9.2%) were lost due to camera failure, dead batteries, or full memory cards caused by wind-blown vegetation within the detection zone of the camera. Photographic detections of mesocarnivores comprised of badger (*n* = 3), bobcats (*n* = 34), coyote (*n* = 1), gray fox (*n* = 685), raccoon (*n* = 386), ringtail (*n* = 13), and skunks (*n* = 147) (Table 4.2), of which 115 detections were of striped skunks, 22 detections were of hog-nosed skunks, and 10 detections were of skunks unidentifiable at the species level.

A total of 8,030 trap days yielded 1,391 scat detections of mesocarnivores throughout the year-long sampling period. 14.95% of all scats collected (*n* = 208) could not be identified at the species level and were thus dismissed from further comparison, yielding 1,183 mesocarnivore scat samples for subjection to statistical analysis and trends. Of these detections, scats from badger (*n* = 18), bobcats (*n* = 161), coyote (*n* = 70), gray fox (*n* = 624), raccoon (*n* = 233), ringtail (*n* = 8), and skunk (*n* = 69) were observed throughout the year (Table 4.2). No attempt was made to discern between skunk species from the mephitidae scats observed. No cougar, black bear, *Mustela* species, spotted skunks (*Spilogale spp.*) or verified hooded skunks (*Mephetis macroura*) were detected across the ranch by either method.

Upon combining proportions of detections by species produced from both survey methods, gray foxes and raccoons accounted for over 3 quarters of all mesocarnivore detections observed (53% and 25%, respectively; Fig. 4.1), while the rest of the guild comprised the remaining 22%. Scat depositions proved to be the more reliable method for detecting the known depredators of livestock among the observed guild (coyotes and bobcats). Notably, only one coyote was detected on the camera grid throughout the entire study period however, coyote scats where found consistently throughout the year, though in proportionately low levels of occurrence compared to other species of similar size. Coyote tracks also were detected on the road system for 5 of the 12 surveys at the ranch, indicating some likelihood for their residential occupancy at the study site.

Table 4.2. Observed detections and proportional frequencies per survey method for each mesocarnivore species observed at the study site.

Results by:	Badger	Bobcats	Coyotes	Gray fox	Raccoon	Ringtail	Skunk
Camera detections	3	34	1	685	386	13	147
Proportional Frequency	0.24%	2.68%	0.08%	53.98%	30.42%	1.02%	11.58%
Scat depositions	18	161	70	624	233	8	69
Proportional Frequency	1.52%	13.61%	5.92%	52.75%	19.70%	0.68%	5.83%

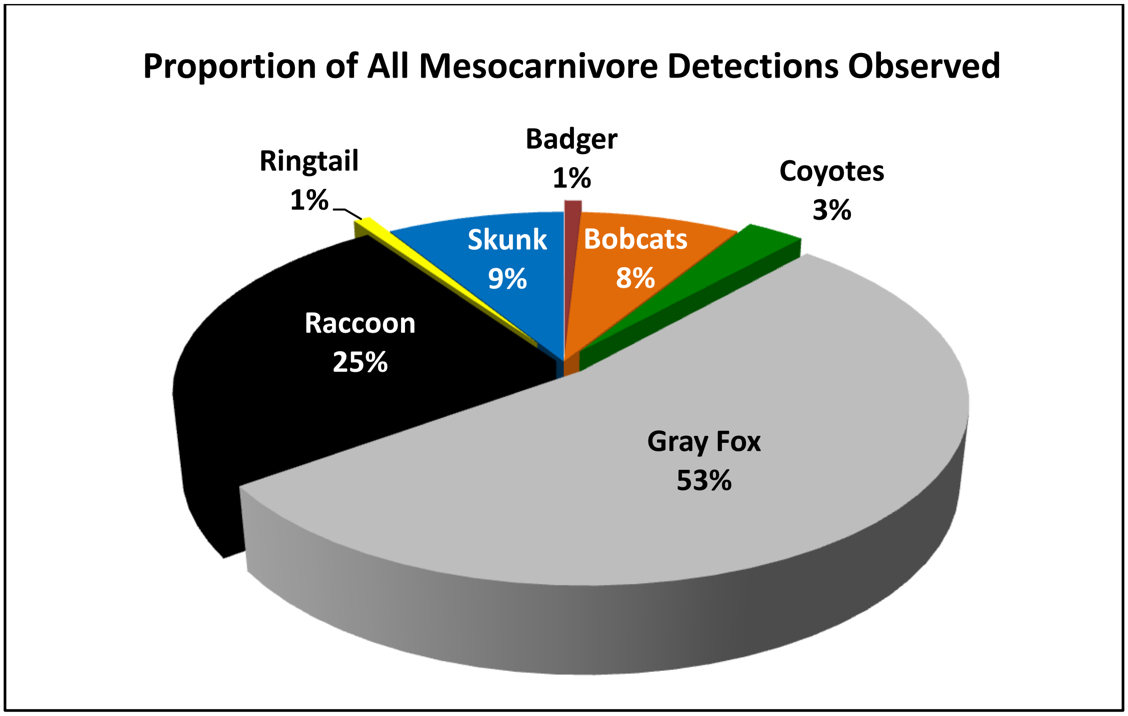


Figure 4.1. Proportions of all mesocarnivore detections by species observed from both the camera grid and the scat transects results combined.

For comparisons of mesocarnivore detections between pastures throughout the year, significant variation was observed among the camera detection rates (χ^2= 24.38, *df* = 11, $P<$ 0.05) with highly significant variation observed for scat deposition rates between the same pastures (χ^2= 40.37, *df* = 11, P< 0.01). Thereby, a premise exists with which to further explore the variation in detection rates observed at the pasture level.

Influence of LPDs on Mesocarnivore Detections

All mesocarnivore detections that occurred in LPD occupied pastures were then tabulated for each species to contrast against all detections which occurred in pastures not occupied by LPDs throughout the year prior to testing. As the detections of some mesocarnivore species notably varied between the 2 sampling methods, I compared both survey methods in this way to denote differences between the outcomes of each method in addition to their combined results.

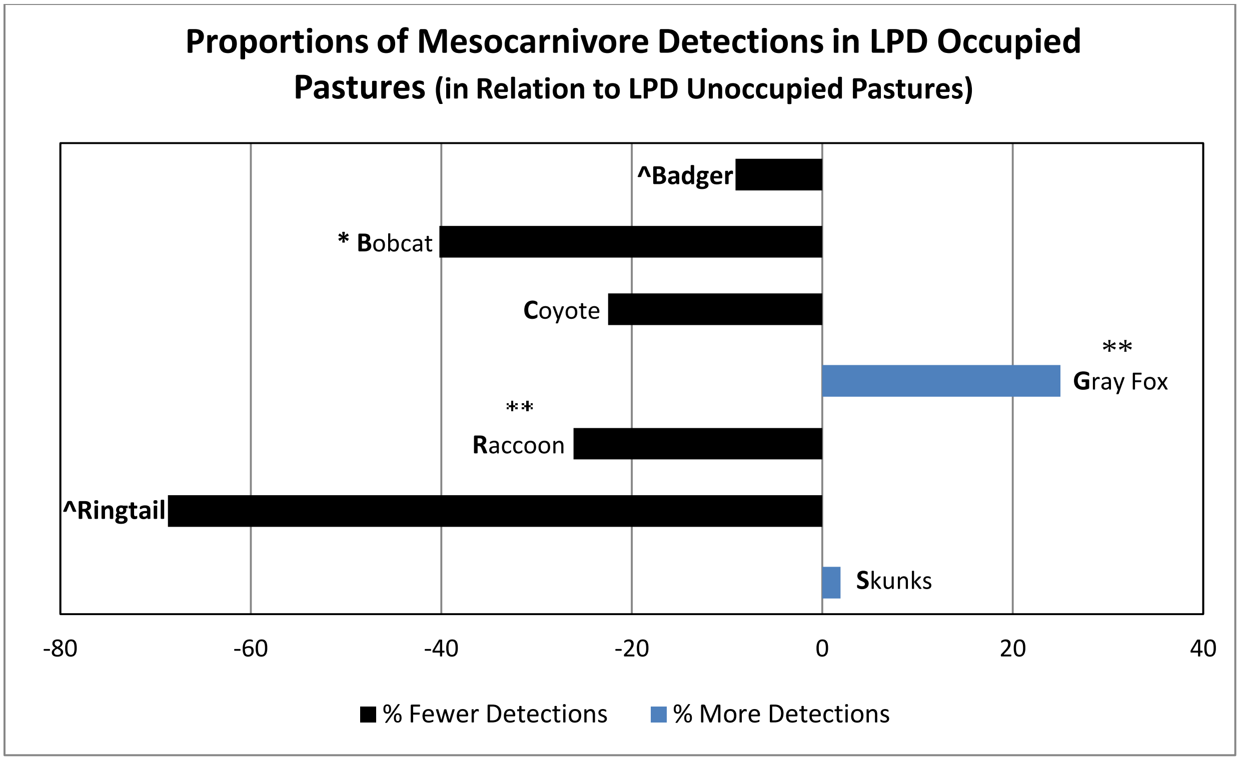
For the combined totals of the 2 methods, detections of both bobcats and coyotes were lower in LPD occupied pastures than in pastures not occupied by LPDs throughout the year (40.2% and 22.2%, respectively), though only the difference in bobcat detections proved to be statistically significant (χ^2= 5.91, *df* = 1; Table 4.3; Fig. 4.2). The significance difference observed for bobcat detections in LPD occupied pastures was influenced by the results of the scat transect data rather than that of the camera grid (Table 4.4).

Contrary to expectations, detections of raccoons also were significantly lower in LPD occupied pastures by 26.1% (χ^2= 6.84, *df* = 1, $P < 0.01$) while detections of gray foxes and skunks actually increased in LPD occupied pastures (25.0% and 1.9%, respectively). The increase in gray fox detections was statistically significant (χ^2= 13.21, *df* = 1, $P < 0.01$) though not for skunks. No assertions regarding the influence of LPDs on badger and ringtail will hereto be made given the low number of detections each survey method produced for these 2 species.

Table 4.3. Occurrence of mesocarnivore detections over the year-long sampling period by species in relation to the pasture-level occupancy of LPDs across the study site.

Camera grid	Badger	Bobcats	Coyotes	Gray fox	Raccoon	Ringtail	Skunk	Total
LPD Unoccupied	10	122	40	561	356	16	107	1,212
LPD Occupied	11	73	31	748	263	5	109	1,240
Total	21	195	71	1309	619	21	216	2,452
χ^2 Test Statistic	0.00	5.91*****	0.45	13.21**	6.84******	2.38	0.002	0.15

* Denotes significance at $P < 0.05$
**Denotes significance at $P < 0.01$



* Significant at *P*< 0.05
**Significant at *P*< 0.01
^ Denotes small sample size of observations (*n*< 60) obtained for this comparison

Figure 4.2. Proportion of mesocarnivore detections per species which occurred in LPD occupied pastures. The proportions shown are in relation to the number of detections which occurred in pastures not occupied by LPDs throughout the course of the year. Below the graph, levels of significance obtained from one way classification Chi-square tests are indicated along with a symbol demarcating which species yielded low sample sizes for comparison.

For each method, the combined difference between detections in LPD occupied and LPD unoccupied pastures for all 7 mesocarnivore species was statistically significant (camera grid χ^2= 11.73, *df* = 1, *P*< 0.01 and scat transects χ^2= 7.79, *df* = 1, *P*< 0.01). However, the direction of these outcomes differed, as the camera grid data was weighted heavily by gray fox detections. Combining the overall detections of each dataset together diluted the polarity of these signals as indicated in table 4.3 above. Chi-square tests performed upon the camera grid results demonstrated significant differences between the detections of gray fox ($\chi^2 = 37.37$, df = 1, $P < 0.01$), raccoon ($\chi^2 = 6.22$, $df = 1$, $P < 0.05$), ringtail ($\chi^2 = 11.08$, $df = 1$, $P < 0.01$), and skunks ($\chi^2 = 10.35$, $df = 1$, $P < 0.01$) at the pasture level (with regard to LPD occupancy), with no significant difference observed for badger, bobcat, or coyote. The results of the scat transects signified a significant difference for only the detections of bobcat ($\chi^2 = 8.05$, $df = 1$, $P < 0.01$), raccoon ($\chi^2 = 7.57$, $df = 1$, $P < 0.01$), and skunk ($\chi^2 = 7.79$, $df = 1$, $P < 0.01$), indicating that the survey method may impart positive or negative bias upon test results for a given species.

Table 4.4. The occurrence of mesocarnivore detections by species for both survey methods in relation to the pasture level occupancy of LPDs across the study site.

Camera grid	Badger	Bobcats	Coyotes	Gray fox	Raccoon	Ringtail	Skunk	Total
LPD Unoccupied	2	23	1	262	218	13	54	573
LPD Occupied	1	11	0	423	168	0	93	696
Total	3	34	1	685	386	13	147	1269
χ^2 Test Statistic	0.00	3.56	0.00	37.37**	6.22*	11.08**	10.35**	11.73**

Scat transects	Badger	Bobcats	Coyotes	Gray fox	Raccoon	Ringtail	Skunk	Total
LPD Unoccupied	9	99	39	299	138	3	53	640
LPD Occupied	9	62	31	325	95	5	16	543
Total Detected	18	161	70	624	233	8	69	1,183
χ^2 Test Statistic	0.06	8.05**	0.70	1.17	7.57**	1.13	18.78**	7.79**

* Denotes significance at $P < 0.05$
**Denotes significance at $P < 0.01$

DISCUSSION

The results of this study indicate the presence of LPDs amid livestock may be a causal factor for displacing known depredators of livestock away from the sheep and goats the dogs protect. When the results of both survey methods were combined, significantly fewer bobcat detections and fewer coyote detections were observed in pastures which the LPDs occupied amid livestock compared to where LPDs were absent. Furthermore, significantly fewer raccoon detections were observed in LPD occupied pastures despite the presence and potential lure of dog feeders in these pastures. Conversely, a significant increase in gray fox detections was observed in pastures occupied by LPDs as well as slight increase for skunks. These findings appear to represent a change in land use by these mesocarnivore species associated with the introduction of LPDs to designated areas of the ranch.

All 4 LPDs at the ranch exhibited a high degree of localization around the sheep and goats they protect on a daily basis. Such data has largely been lacking from prior assessments regarding the efficacy of LPDs at deterring predators and reducing livestock loss (Green et al. 1984, Andelt 1999, Andelt and Hopper 2000, Findo 2005), or had been assumed by the number of livestock sharing a pasture with an LPD (Andelt 1992). The details of these interactions will be investigated further to explore what factors best explain LPD movements and proximity to livestock over space and time. Coupled with more rigorous assessments of LPD efficacy at reducing direct predation, this information may be beneficial to range managers considering alternative measures to reduce net livestock losses and to further evaluate their potential economic benefits in rangeland systems (Green et al.1984, Van Bommel and Johnson, 2012). As LPDs and livestock were periodically rotated throughout the pastures of the ranch, there was representation of occupancy across all ecological sites present. Further research is recommended to parse out the effects of potential ecological site selection and habitat use by each mesocarnivore species in relation to the influence of LPD occupancy.

The presence of LPDs appeared to influence the activity of known depredators of livestock, as 20.6% fewer coyote scats and 37.4% fewer bobcat scats were found in LPD occupied pastures. The scat transects provided a sufficient number of detections for known depredators of livestock throughout the year with which to base statistical inferences upon whereas the remote camera grid fell short of this underlying objective. The camera grid produced twice as many bobcat detections in pastures unoccupied by LPDs, although the sample size was relatively low overall (*n* = 23 to *n* = 11, respectively). Additionally, the solitary detection of a coyote on the camera grid was in a pasture not occupied by LPDs. The variability in the detections between methods produced for certain species suggests the survey method itself may affect detection probabilities for mesocarnivores, thus imparting positive or negative bias upon both detections and consecutive test results for a given species (Dempsey et al. 2014 and Güthlin et al. 2014, Carreras-Duro et al. 2016). Combining the results of 2 or more methods standardized in the same manner may yield more representative levels of detections across the guild, and may provide for more robust levels of inference, as variations in detections stemming from a given methodology can be assessed to guide further research (Gompper et al. 2006).

Larger mesocarnivores such as bobcats and coyotes may outrank or out-compete smaller mesocarnivores such as gray foxes within areas where large carnivores are absent (Prugh et al. 2009, Ritchie and Johnson 2009, Roemer et al. 2009). Gray foxes were detected more frequently in LPD occupied pastures whereas coyotes and bobcats weren’t. This finding may indicate a behavioral shift by the foxes with regard to land use resulting from a release of intraguild competition pressure placed upon them by coyotes and bobcats, which have both been known to kill foxes and compete with them for food (Chamberlain and Leopold 2005, Farias et al. 2005, Donadio and Buskirk 2006). The release of competition pressure placed on foxes by coyotes associated with the return of apex predators has been documented with gray wolves (*Canis* *lupus*) reintroduced into Yellowstone National Park (Crabtree and Sheldon 1999*a*, 1999*b*; Berger et al. 2008; Berger and Conner 2008; Ripple et al. 2013). These premises may lend support to my theory that LPDs have the capacity to act as surrogate apex predators in a system where large carnivores are generally absent.

LPDs may present themselves as a suitable tool for managing human-wildlife conflict when management objectives factor in the conservation of multiple carnivore species across a landscape. As a nonlethal form of predation control, LPDs do not appear to directly limit carnivore populations, but rather alter their use of the landscape instead as the results presented here suggest. Here, LPD presence had different impacts upon bobcats, coyotes, and raccoons than for gray foxes as skunks. This information presents new questions pertaining to what effects LPDs may have on other carnivore species and community assemblages, including threatened and endangered species of concern such as the ocelot (*Leopardus pardalis*), jaguarondi (*Herpailurus yaguarondi*), wolf, grizzly bear, wolverine (*Gulo gulo*), fisher (*Martes pennanti*), and black footed-ferret (*Mustela nigripes*) in areas these species occupy amid ranching operations. These questions may be more adequately explored in controlled experiments (rather than a descriptive study such as this) that evaluate 2 or more ranches of similar composition, size, and relative abundance of carnivores with LPDs introduced to the experimental unit and an effective means of monitoring carnivore communities instated through each site over time.

The use of LPDs continues to gain popularity among ranching operations across the country. As of 2014, 23.5% of sheep producers used LPDs to guard their livestock, a more than 2-fold increase from 10 years prior (APHIS 2015). Texas is the largest mohair producer in the nation, and succumbs to more sheep loss (24.7% overall) than any other state (NASS 2015, APHIS 2015). As such, the findings of this study may be of particular interest to stakeholders in the Edwards Plateau region and throughout the rangelands of the west. The results of my study empirically demonstrate that LPDs can reduce the activity of predators in pastures which livestock occupy. Therefore, the applied use of LPDs in range systems appears to be an animal husbandry practice beneficial to ranchers seeking to minimize interactions between livestock and known livestock depredators.

CHAPTER V

CONCLUSIONS

No significant difference was observed between the results of the remote camera grid and scat transects across sampling units or over time. The 2 methods followed an analogous trend in detections throughout the year, which exhibited a rise in mesocarnivore activity during the fall and early winter and nadir of activity during the hotter summer months. Both the remote camera grid and scat transects detected the same mesocarnivore species, though in varied proportions by species. Gray foxes and raccoons were responsible for ¾ of all mesocarnivore detections observed. In terms of deriving sufficient samples for statistical inference, the remote camera grid produced adequate detections of gray fox, raccoon, and skunk whereas the scat transects produced sufficient detections of bobcat, coyote, gray fox, and raccoon throughout the year. These findings may inform researchers as to the more effective detection method for carnivore species of interest. When seeking to survey a carnivore guild, the application of 2 or more sampling methods is advised given the variation in detections observed between the 2 methods presented here. As neither survey method was particularly effective at detecting badger or ringtail, researchers seeking to obtain data at the guild level are encouraged to develop a sampling design which gives consideration to the behavioral ecology of these 2 species.

The presence of LPDs amid livestock resulted in fewer observable detections of carnivores known to depredate on sheep and goats in pastures they occupied across the ranch. As such these results provide support for the use of LPDs as a predator management tool to dissuade bobcats and coyotes from using the pastures they protect. Documenting more fine-scale spatial interactions between LPDs and predators would elucidate the mechanisms behind the observed displacement presented here at the pasture level. The casual factor behind the significant increase in gray fox detections observed in LPD occupied pastures was not determined here, though the release of intraguild competition pressure imposed upon gray foxes by both bobcats and coyotes in these pastures is a parsimonious explanation given known intraguild dynamics. LPDs proved to remain in close proximity to livestock throughout the 10-month period this data was collected. 3 LPDs were outside of the short range UHF signals emitted by collared livestock for only 2 days in this period. Prior to collaring these 4 LPDs, the degree of association had not been quantified for a duration exceeding a week’s time, so this association was largely unknown. These findings bear significance for livestock producers looking to use, care, and manage LPDs in rangelands across North America.

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APPENDIX 1

Table A-1. Photographic detections of striped, hog-nosed, and unknown skunks over the study duration.

Monthly interval	Striped skunk	Hognose skunk	Unknown skunk	Total
May	14	0	2	16
June	1	2	0	3
July	2	0	0	2
August	0	0	0	0
September	2	1	3	6
October	8	1	2	11
November	2	1	0	3
December	34	6	1	41
January	16	5	0	21
February	20	2	1	23
March	5	2	1	8
April	11	2	0	13
Total Detected	115	22	10	147
Average per month	9.58	1.83	0.83	12.25
Detection Rate*	0.019	0.004	0.002	0.025

Comment: Low detections of hog-nosed skunks relative to striped skunks could be indicative of their low density or detectability in the region. Further research is needed to investigate the relative abundance, density, and overlap of these 2 sympatric species.

APPENDIX 2

Photographs of uncommonly documented behaviors observed consisting of (a) a bobcat courting display (b) dominance behavior between a pair of gray foxes, and (c) the lone coyote of the camera grid.