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Influence of Livestock Guardian Dogs on Mesocarnivore Activity in Central Texas

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Abstract: The use of livestock guardian dogs (LGDs; *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 LGDs has been based on queries of rancher satisfaction with LGD performance, yet little is known regarding LGD influence on mesocarnivores, including those species against which they protect livestock. Here, we examined whether the presence of LGDs amid livestock resulted in a decrease in the detectable presence of carnivores within pastures they occupied throughout 1 year on a ranch in central Texas. Four LGDs were fitted with GPS collars to collect their positions and evaluate their spatial distribution across the ranch over the course of a year. To detect and quantify the presence of carnivores across the ranch, a remote camera grid continuously surveyed the residing carnivore community over the course of a year. We detected eight mesocarnivore species, and noted variable effects on activity by each species in relation to LGD presence. We determined that key environmental factors determined a

relatively large proportion of variation in mesocarnivore activity, but LGD presence in an area alone did not. Interestingly, most mesocarnivore activity was highest in areas without livestock, and thus, LGDs. Our results lend credibility to the notion that LGDs do not adversely affect activity of non-target mesocarnivores. For those concerned with livestock-wildlife coexistence and managing predation, this insight provides a promising future for the use of LGDs in the context of minimizing non-target impacts when using this predation management tool.

Key Words: Livestock guardian dogs (LGDs), non-invasive sampling, mesocarnivores, predator control, GPS collars

The decline of large carnivores across North America over the last two centuries (Laliberte and Ripple 2004) caused shifts among extant carnivore guilds, which in turn may directly or indirectly alter community structures (Ripple and Beschta 2004, Prugh et al. 2009, Roemer et al. 2009, Ripple et al. 2013). The absence of large carnivores can release competition pressure placed on mesocarnivores (Soulé et al. 1988, Crooks and Soulé 1999, Berger and Conner 2008, Ritchie and Johnson 2009) and researchers are just beginning to explore their direct and indirect ecological effects on members of this guild; often with regard to intraguild competition, prey communities, and trophic interactions (Paine 1969, Estes et al. 1998, Arias-Del Razo et al. 2012, Miller et al. 2012).

Mesocarnivores may fill multiple ecological roles in an ecosystem, from apex predators to primary consumers (Feldhamer et al 2003, Prugh et al 2009, Ritchie and Johnson 2009). 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 seedbearing primary producers within a community (Jordano et al. 2007, Rosalino et al. 2010, Jensen et al. 2012, Miller et al. 2012). Nevertheless, 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 (Wade and Bowns 1982, Roemer et al. 2009, Natl. Agrl. Stats. Srvc. 2010,Palmer et al. 2010). While interest in the community ecology of mesocarnivores has emerged in recent years, science must address practical carnivore conservation in the context of balancing human-wildlife conflict, especially with regard to ranching operations (Prugh et al. 2009, Ritchie and Johnson 2009, Newsome et al. 2015, Treves et al. 2016).

These conflicts typically come in the form of livestock losses to predation from carnivores (Pearson and Caroline 1981, Sacks and Neale 2007). At the turn of the 21st century, the National Agricultural Statistics Service (hereafter NASS) within the United States Department of Agriculture (hereafter USDA) reported an estimated annual loss of $16.5 million in sheep 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 (Natl. Agrl. Stats. Srvc. 2000, USDA-APHIS-WS. 2015*a*). As recently as 2014, the United States Department of Agriculture Animal and Plant Health Inspection Service (hereafter 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 (USDA-APHIS-WS 2015*b*). The nationwide stocking of sheep fell to 89% of its historical high from the 1950s in 2008 (Palmer et al. 2010) with recent numbers in 2015 standing at approximately 5.28 million head overall (USDA-APHIS-WS 2015*b*). 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). Improved techniques for mitigating wildlife damage from carnivores have been sought in recent decades, as active and often lethal forms of predator control may no longer be effective in every setting or situation.

Strategies to mitigate livestock depredations range from lethal removal to the integration of domestic animals with strong defensive behaviors such as llamas (*Lama glama*), donkeys (*Equus assinus*), and domestic dogs (*Canis lupus familiaris*) into their stock (Linhart et al. 1979, Green and Woodruff 1983, Meadows and Knowlton 2000, Dohner 2007). Livestock raisers in Europe and Asia have employed livestock guardian dogs (hereafter LGDs) since antiquity to help protect their livestock groups (Dawydiak and Sims 2004), yet their behavior and effectiveness at deterring predator species from livestock has scarcely been quantified. The inferences of most LGD studies have been based primarily on queries of rancher satisfaction, rather than empirical trials and field-based study design (Andelt 1992, Coppinger et al. 1983, Green and Woodruff 1983, Green et al. 1984). Since their introduction to U.S. ranches in the 1970s, the use of LGDs in North America has grown, facilitating some study and experimentation regarding shepherding practices, including evaluations of different LGD breeds (Andelt 1999) and mixed breeds (Black and Green 1981). Nevertheless, limited data exists regarding the behavior of LGDs relative to the execution of their guardian duties.

LGDs rarely physically confront predators, instead they respond to livestock threats by presenting themselves as territorial deterrents (visual, auditory and perhaps olfactory) to other carnivores (Findo 2005). The appeal of LGDs as a tool to manage wildlife damages rose from reports of fewer livestock losses from ranchers who used them (Andelt and Hopper 2000), and from empirical evidence that LGD presence may offset livestock predation loss in experimental trials (Linhart et al. 1979, McGrew and Blakesley 1982). Considerations for the time and expense of lethal control practices for the ranchers or regional government may also factor in to the choices available to livestock producers with regard to predator control (Green et al. 1984, Palmer et al. 2010). Among those that favor LGDs due to their less-than-lethal approach to wildlife damage management, the question remains: although LGDs appear to reduce damages to livestock, what intended consequences do they have for the ecosystems and wildlife? Non-target effects must be considered for LGDs, just as with any wildlife damage management tool.

Given the lack of data on effects on non-target wildlife, we seek to examine the influence of LGDs on mesocarnivores cohabitating the rangelands of the Edwards Plateau region of central Texas, the largest sheep and goat production region of the state, leading the USA in sheep numbers, mohair produced, and losses of these livestock to predation (Gober 1979, USDA-APHIS-WS 2015*b*). Concretely, we evaluate the influence of LGDs upon a mammalian mesocarnivore community in the context of intense sheep and goat production, to (1) determine the relative influence of LGDs on the activity of members of the mesocarnivore community compared to habitat factors and (2) to examine whether a reduction in activity occurs for members of the guild likely to pose a threat to livestock.

Study Area

We conducted our study on the Martin Ranch; a 2,026.6 ha ranch in Menard County, Texas owned and operated by Texas A&M AgriLife Research (hereafter Martin Ranch) in the Edwards Plateau Ecological Region (Gould 1966). Elevation at the Martin Ranch ranges from 613 m to 678m, averaging 648 m above sea level amid subtle rolling hills scattered throughout the countryside. Climate is characterized by semi-arid conditions, 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; Natl. Ocnc. and Atms. Admn.2016).

Dominant overstory vegetation cover for carnivores found across the site consists mostly of plateau live oak (*Quercus fusiformis*), with intermittent juniper (*Juniperus ashei),* and mesquite (*Prosopis glandulosa*) woodlands atop understories comprised of native grasses, cactuses, brush species, and forbs (Wrede 2010, Natl. Res. Cons. Srvc. 2015). The 4 prevailing ecological sites found on the ranch are described by the Natural Resources Conservation Service (Natl. Resc. Consv. Srvc. 2015) as Low Stoney Hill, Clay Loam, Shallow, and Draw. Low Stoney Hill and Shallow sites occur at higher elevations, which feature thinner soils, and support shrub-dominated plant communities while Clay Loam sites support open mesquite-Texas wintergrass savannahs typically found above and alongside the draws (Natl. Res. Cons. Srvc. 2015). Vegetation occurs on relatively shallow clayloam soils (< 5cm) atop limestone bedrock, often exposed in the arid draws carved out through periodic flooding.

Animal Management

Net-wire livestock fences divide the ranch into 9 pastures, averaging 224ha per pasture. The ranch contains 58 km of unpaved roads, which receive varying degrees of use. 22 troughs drawn from water wells provide consistent water supply throughout the ranch. The ranch supported approximately 200 sheep, 200 goats, 100 cattle, and 4 LGDs over the course of the study period according to a decision-deferred rotational grazing regime. University staff whelped, weaned, and raised LGDs with a number of the sheep in bonding pens prior to deployment on the ranch. LGDs roam freely on the ranch, with occasional handling by humans for health exams and vaccinations. Self-feeders supply an *ad libidum* diet of kibble placed at 7 feeders located at water troughs throughout the ranch. Lethal predator control is a common practice throughout the surrounding area though it has not been practiced on the ranch for at least 5 years prior to the onset of this study.

Methods

We collected field data at the Martin Ranch study site for a yearlong period, from May 2016 through April 2017. In order to assess the presence and activity of mesocarnivore species across the study area over time, we deployed trail cameras Martin Ranch, and checked them at monthly intervals throughout the study period (Zielinski and Kucera 1995, Schauster et al. 2002, Kelly 2008). We fitted LGDs with GPS locating collars (Global Positioning System, Vertex series model; Vectronic Aerospace, Germany; hereafter GPS collars), which logged locations at a 3 hours interval (8 times daily), then transmitted data via satellite.

Remote Camera Data

To detect the presence of carnivore species on a continuous basis throughout the year, we set up a remote camera array according to 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 (Burton et al. 2015). We generated camera locations (Figure 1) accordingly in ArcMap (v.10.4.1 ESRI software, ESRI, Redlands, CA, USA; hereafter ArcMap). All cameras were attached to t-posts installed at a height of 45 cm from ground level. To avoid biased representations of animal activity, no cameras were baited (Kelly 2008). Each pasture contained at least 1 camera for pasture-level representation across the study site. We checked all cameras monthly to collect photographic detection data stored on memory cards along with depleted batteries, replacing them at each interval through the study term.

Three camera models were available for use at the onset of the study. The camera grid comprised of 4 Reconyx HC600 Hyperfire, 8 Bushnell Trophy Cam, and 8 Moultrie M-80 digital remote cameras. We set all cameras to take photos at 3 megapixel resolution in a 3 photo series (1-second interval between photos in a series) at medium sensitivity. All photographic detections of mesocarnivore species derived throughout the year were entered into a relational database (FileMaker Pro v.14, Apple *Inc*., Cupertino, CA, USA; hereafter relational database) for each detection, noting: (1) the species detected, (2) the date and time of occurrence and (3) the location of the camera where each detection took place.

Spatial Data

We fitted the 4 LGDs with GPS locating collars programmed to record the location of each animal once every 3 hours. Collars transmitted positions to the laboratory servers daily via IRIDIUM satellite communication. All locations were exported from proprietary software (GPS x; Vectronic Aerospace Gmbh, Berlin) to our relational database at the conclusion of the study and were accessed from this database directly from R for analysis using the *RODBC* package (Ripley and Lapsley 2017). We applied a fixed kernel density estimator (KDE; Worton 1989) using the reference smoothing parameter algorithm across all locations of all dogs to estimate the relative intensity of LGD space use across the study site. LGD space use can be viewed as the probability of an LGD occurring at any location in space throughout the study site at any given time over the course of the study as well as the proportion of time an LGD spent at any given location. We considered LGD space use intensity (hereafter SUI) as an explanatory variable for determining whether their distribution across the study site influenced the detections of mesocarnivores in areas the LGDs were present.

We also considered elevation, slope, and canopy cover as explanatory variables for associating mesocarnivore detections with environmental variables under the presumption that mesocarnivore activity in the study area may be influenced by such factors which determine habitat characteristics. Even throughout a range of 65 m, both slope and elevation largely drive vegetation associations in the region as a consequence of periodic hydrological events that aggressively drive soils and plant communities in this region. As plateau live oak accounts for the majority of tree canopy on the ranch, the cover it provides may also drive the distribution of mesocarnivores, particularly the semi-arboreal species such as gray fox and ringtail (Trapp 1978, Haroldson and Fritzell 1984). Percent slope and elevation were derived in ArcMap from 10m resolution digital elevation maps available from the Texas Natural Resource Information System (TNRIS; http://www.tnris.org). Oak canopy cover was derived from the 2016 National Agriculture Imagery Program 1m resolution color-infrared images, accessed through TNRIS. Oak canopy cover was identified using an interactive supervised classification (Campbell and Wynne 2011) derived using spectral analysis tools within ArcMap, and was readily distinguishable as a separate spectral class apart from juniper and mesquite. Percent canopy cover was then calculated from this classified output at a 10m resolution as the average of the 1 m pixels (n=100) within each 10 m pixel. Values of LGD space use intensity, slope, elevation, and canopy cover were extracted from the location of each camera and used as predictors to explain variation in mesocarnivore activity.

Data Analysis

We first amassed total counts and proportional frequencies of mesocarnivore detections per species from all cameras across the grid over the entire study period. To account for variations in down time between cameras due to battery depletion or camera failure, detections were converted to a daily rate (detections per day) by dividing the total number of detections of each species for each camera by the total number of days each camera was active. Species detected less than 5 times over the course of the study were excluded from subsequent analysis due to lack of inferential power in such small sample sizes.

We used redundancy analysis (RDA; Legendre and Legendre 2012) to evaluate relationships between mesocarnivore activity, LGD activity, and the environmental variables of slope, elevation, and canopy cover. RDA can be viewed as a multivariate multiple regression that is capable of accommodating collinear explanatory variables. This allows for the simultaneous analysis of the relationships between each species, the relationship of each species with chosen explanatory variables, as well as the relationships between all explanatory variables given. RDA utilizes permutation testing, permitting analysis without distributional assumptions (Legendre and Legendre 2012) and produces a triplot of the relationships between the predictors (as applied here) of LGD activity, elevation, slope, and oak canopy cover to the responses of mesocarnivore detection rates. The triplot is a superimposition of 2 biplots (one PCA of the response variables, constrained by a PCA of the explanatory variables). The bottom and left axes are the scales of the centered response variables and are also the scales in which the cameras are plotted. The top and right axes are the scales of the standardized explanatory variables. Type II scaling (which preserves the relationships between variables) was used to produce the graphical representation of these results. In this output of the analysis, variables pointing the same direction are positively correlated while those pointing opposite directions are negatively correlated, and variables which are plotted at 90^0 to each other are uncorrelated. We used the *rdaTest* package (Legendre and Durand 2014).

We performed all analyses using 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

Mesocarnivore Detections

5,966 trap days from the 18 remote cameras yielded 1,269 detections of mesocarnivores throughout the yearlong sampling period. Among these detections, we observed 8mesocarnivore species at the ranch, including American badger (*Taxidea taxus*; hereafter badger), bobcat (*Lynx rufus*), coyote (*Canis latrans*), gray fox (*Urocyon cinereoargenteus*), raccoon (*Procyon lotor*), ringtail (*Bassaris cusastutus*), and both striped (*Mephitis mephitis*) and hog-nosed (*Conepatus mesoleucus*) skunks. No large carnivores were detected across the study site, despite recent sightings in the region of mountain lion (*Puma concolor*) and black bear (*Ursus americanus*).

Of the 6,570 potential trap days, we censored 604 (9.2%) due to camera failure, depleted batteries, or full memory cards (mostly due to wind-triggers from vegetation). Cameras detected mesocarnivores in varying proportions, including American badger (n= 3), bobcat (n= 34), coyote (n= 1), gray fox (n= 685), raccoon (n= 386), ringtail (n= 13), and skunk (n= 147; Table 1, Figure 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. We aggregated all skunk detections into 1 species category (*i.e*., skunk) due to our inability to discern the two species in those 10 photographic detections. Coyote [n = 1] and badger [n = 3] detections were excluded from analysis due to few detections for these species.

Influence of LGDs on Mesocarnivore Detection Rates

We captured 85.7% of the overall variation in mesocarnivore activity in the first 2 canonical axes of our RDA (Figure 4). The 4 explanatory variables used in the analysis (Elevation, Slope, Canopy Cover, and SUI) combined explained 29.5% of the overall variation in mesocarnivore activity observed). The combined effect of these 4 variables was not a significant predictor of mesocarnivore activity (P = 0.22), which is likely due to the small number of sampling units (*i.e.* cameras) across the available space of the ranch (n = 18), however, the relationships between variables are still interpretable. SUI and elevation were highly correlated explanatory variables (r = 0.85).

LGD SUI was strongly and negatively correlated with bobcat activity (r = -0.70) and highly correlated with both raccoon (r = 0.70) and ringtail activity (r = 0.94; Table 2). To lesser degree, LGD space use was negatively and moderately correlated with gray fox activity (r = -0.41) though weakly so with skunk activity (r = -0.27).

Each mesocarnivore species exhibited varied responses to the 3 environmental variables assessed. Bobcat activity was found to be positively correlated with canopy cover (r = 0.67) with a strong negative correlation pertaining to elevation (r = -0.89). Gray fox activity was strongly and negatively correlated with elevation (r = -0.71), yet positively correlated with slope (r = 0.66). Raccoon activity was strongly correlated with slope (r = 0.78) and to a lesser degree with canopy cover (r = 0.38). Ringtail activity was positively correlated with elevation (r = 0.96), which was the only environmental association of note for this species. Skunk activity was modestly correlated with both oak canopy cover (r = 0.54) and slope (r = 0.44), while negatively correlated with elevation (-0.74). Given the high degree of redundancy between SUI and elevation observed in Figure 4, the effects between these 2 variables on mesocarnivore activity could not be adequately partitioned.

Discussion

We detected some strong relationships in the activity of mesocarnivores in our study to our set of explanatory variables (Table 2). Slope, elevation, and canopy cover represent aspects of habitat for many species, and can have strong influences on activity patterns. Bobcats and gray foxes showed greater activity at lower elevation sites with extensive canopy cover, and high slopes, respectively. Raccoons were active in steep, wooded sites, similar to that of skunks.

Ringtail activity was higher as elevation increased. Given the ecology of these species, such associations follow typical patterns of habitat associations. The species most often cited as the source of livestock losses, coyotes, did not occur in sufficient numbers during our study as to draw inference to patterns of activity. However, we did not detect a strong influence of LGD SUI alone on the activities of mesocarnivores observed throughout the study period that did not coincide with similar influences from environmental variables. Although it is tempting to assert that LGDs are the source of variability in mesocarnivore patterns of space use, we lack sufficient data to elucidate this relationship fully.

Nevertheless, in the course of our study, species most often associated with losses of livestock with which LGDs are charged (e.g. bobcats, gray foxes), exhibited a greater degree of activity where LGDs did not occur. This is likely the result of close LGD associations with livestock in areas where environmental factors benefitted livestock, but not such mesocarnivore species. To wit, we observed extremely high fidelity to livestock animals (Appendix 1), primarily stocked in pastures that were also higher in elevation (Low Stoney Hill ecological sites; Figure 1). These sites typically contain a greater diversity of browse species, considered more appropriate for sheep and goats (Holecek et al. 2011), compared to lower elevation areas, such as clay loam ecological sites, which exhibit greater grass production were stocked with non-LGD-bonded cattle. For those seeking to use LGDs, these results may suggest that strategic placement of livestock could also assist in minimizing contact between LGDs and mesocarnivores of depredation concern, while also demonstrating the tendency of LGDs to remain closely bonded with their livestock charges.

Given a lack of clear, negative effects due solely to LGDs in our study, there is reason to suspect that LGDs fulfill their task without significantly disrupting the mesocarnivore community, thereby fulfilling needs of agricultural producers and conservationists alike. The importance of this cannot be understated: the goal of any non-injurious predation management practice is to provide for coexistence with predatory wildlife. In many ways, the lack of a clear, negative effect on mesocarnivore activity from LGDs is a hallmark of an effective practice, given a lack of predation losses expressed on the part of livestock managers at Martin Ranch since introduction of LGDs (J. Walker, personal communication). The precise influences of LGDs (or any introduced species used as a management tool) on various taxa calls for further scrutiny, regarding both carnivore guild dynamics and to explore any potential unintended consequences stemming from their introduction into landscapes.

At a broader level, for those seeking to manage natural systems for the benefit of both livestock and wildlife, purposeful management requires knowledge of human actions, including animal introductions, and their effects upon many species on the landscape in addition to predation management. Regardless of a negative or positive effect, if LGD presence affects mesocarnivore space use, one must consider the magnitude of effect on an ecosystem. Additionally, one must not assume a functional relationship based on conjecture that considers LGDs behavior comparable to that of a wild canid. For example, some suggest that gray foxes may benefit from a release of intraguild competition pressure placed upon them by coyotes and bobcats in pastures where LGDs are present (Chamberlain and Leopold 2005, Farias et al. 2005, Donadio and Buskirk 2006). Although some have hypothesized that LGDs may function as surrogates for wolves this way, thereby counteracting the effects of mesocarnivore release (*sensu* Soulé 1986), such a concept assumes active avoidance based on coyote-wolf interaction ecology, with no empirical data from coyote-LGD interactions (*Canis lupus*; Buskirk 1999; Crabtree and Sheldon 1999*a*,*b*; Berger and Conner 2008; Ripple et al. 2013). We, on the other hand, documented a negative relationship between LGD SUI and gray fox activity that coincided closely with environmental factors.

Non-lethal tools for predation management may appear to fulfill needs for coexistence with native wildlife, but those managing for wildlife damage must critically evaluate the potential effects of these tools on other species. Our study addressed the mesocarnivore guild present at our study site, however the effect of LGDs on other wildlife species remains unknown. For obscure carnivores, as well as for threatened or endangered species that inhabit grazing lands, potential effects from LGDs should also factor into decisions regarding the use of LGDs to manage damage to livestock. In Texas, many livestock producers also incorporate incomes from wildlife, either by harvest or wildlife watching, into their annual revenue stream. If it should be observed that LGDs strongly influence the abundance, activity patterns, or presence of economically valuable game species in the state, such as white-tailed deer (*Odocoileus virginianus*) or wild turkeys (*Meleagris gallopavo spp.*), then such effects may potentially exceed local human tolerance for LGDs.

Appreciation for the role of carnivores in ecosystems has grown in accordance with the use of nonlethal tools to mitigate wildlife conflict in recent decades, and LGDs continue to gain popularity among ranching operations both across the country and globally (Findo 2005, Treves et al. 2009, Palmer et al. 2010, Van Bommel and Johnson 2012). As of 2014, 23.5% of sheep producers used LGDs to guard their livestock, a more than 2-fold increase from 10 years prior (Anim. Plnt. Hlth. Inspct. Srvc. 2015*b*). Although a wildlife damage management tool must be socially acceptable to ensure widespread adoption and support, without due scientific evaluation of the total effect of the tool on ecosystems, one may inadvertently degrade the system. Here, we presented a preliminary case study on the matter and call upon conservationists, scientists, and wildlife damage managers to initiate further evaluations upon other influences LGDs may place upon rangeland communities.

Management Implications

This study provides some first insights into the effects of LGDs on the mesocarnivore community, both target and non-target. Given that we could not detect a strong, negative influence of LGDs on mesocarnivore activity, our results indicate that this tool may provide necessary protection to livestock without strong disrupting nontarget mesocarnivores unnecessarily. Further, spatial arrangement of livestock according to environmental factors may play a role in minimizing contact between mesocarnivores of concern and livestock. Although we could not investigate effects on coyote activity due to few detections of this species, livestock managers on our study site indicate a reduction in livestock losses to predation since the introduction of LGDs to the property. Given these results, the use of LGDs in rangeland systems appears to be a potentially beneficial predation management practice that achieves goals of livestock raisers and conservationists seeking to minimize negative interactions between livestock and mesocarnivores.

We implore managers and researchers to consider potential effects of LGDs on other species and community assemblages, as grazing lands provide habitat for a great diversity of species. For many livestock raisers, income from hunting leases produces much needed revenue. LGDs must be evaluated for effects on the use of space and well-being of such game species. For those considering the use of LGDs within the range of protected species, additional concern over LGD impacts on local fauna should be addressed by careful study.

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Table 1. Camera detections and proportional frequencies for each mesocarnivore species observed at the Martin Ranch from May 2016 through April 2017.

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%

Table 2. Correlation coefficients between the predictor variable of LGD activity measured in terms of space use intensity (SUI), Elevation, Slope, and Canopy Cover and the response variables of mesocarnivore activity (per species sufficiently detected) across a stratified random camera grid over the course of 1 year at the Martin Ranch in Menard County, Texas.

	Bobcat	**Gray Fox**	**Raccoon**	**Ringtail**	**Skunk**
LGD Activity (SUI)	-0.70	-0.41	0.70	0.94	-0.27
Elevation	-0.89	-0.71	0.23	0.96	-0.74
Slope	-0.32	0.66	0.78	0.34	0.44
Canopy Cover	0.67	0.09	0.38	-0.27	0.54

Figure 1. The 2026.6 ha Martin Ranch study site delineated by 9 fenced pastures, displaying the distribution of each ecological site across the ranch and the stratified random locations of each remote camera (n = 18) deployed.

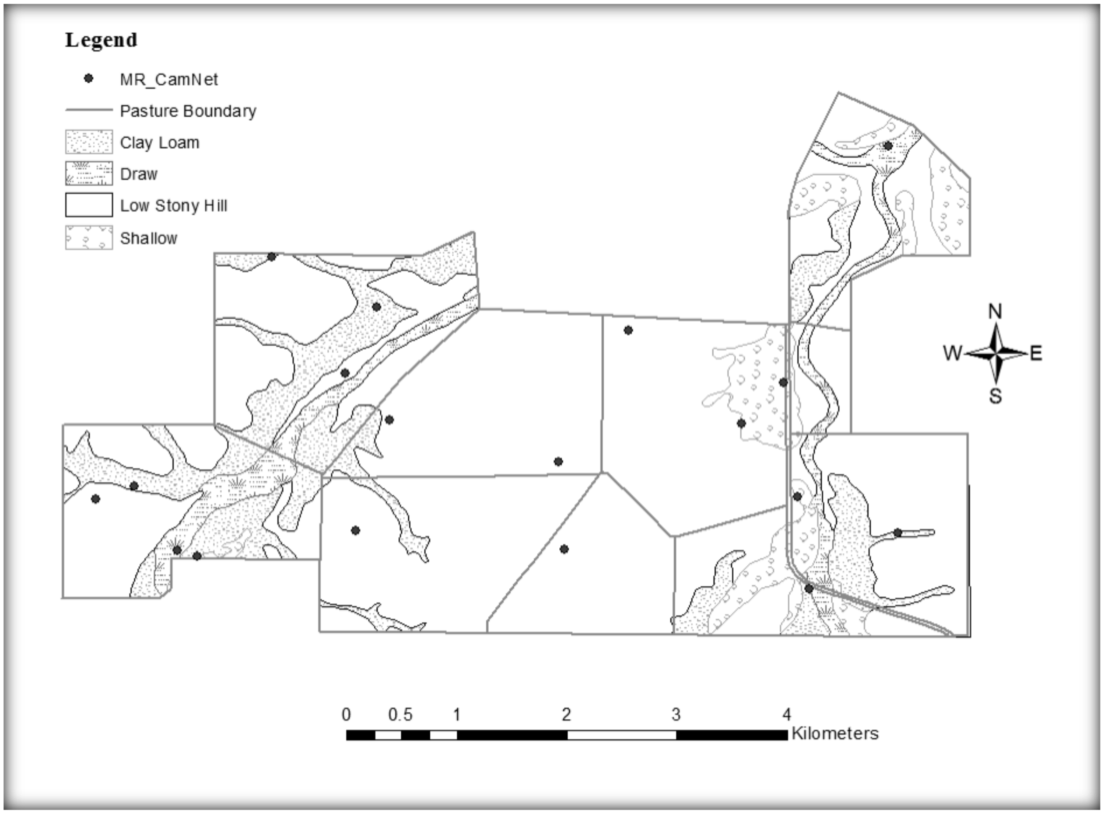


Figure 2. Proportions of all mesocarnivore detections by species observed across the camera grid at the Martin Ranch from May 2016 through April 2017.

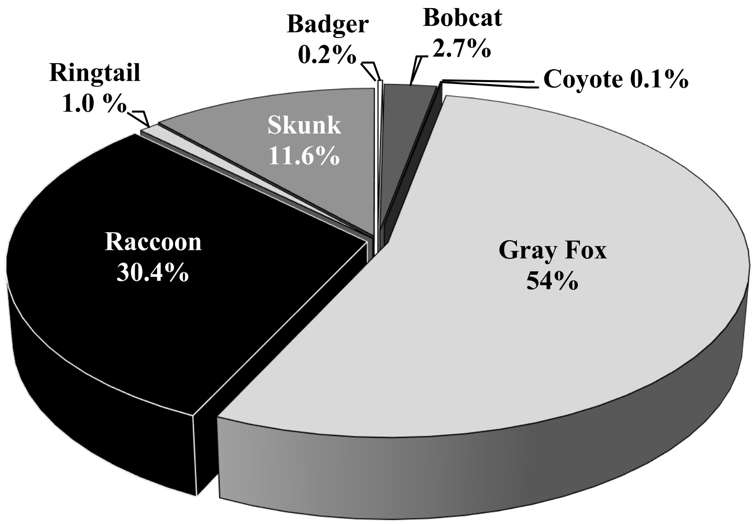
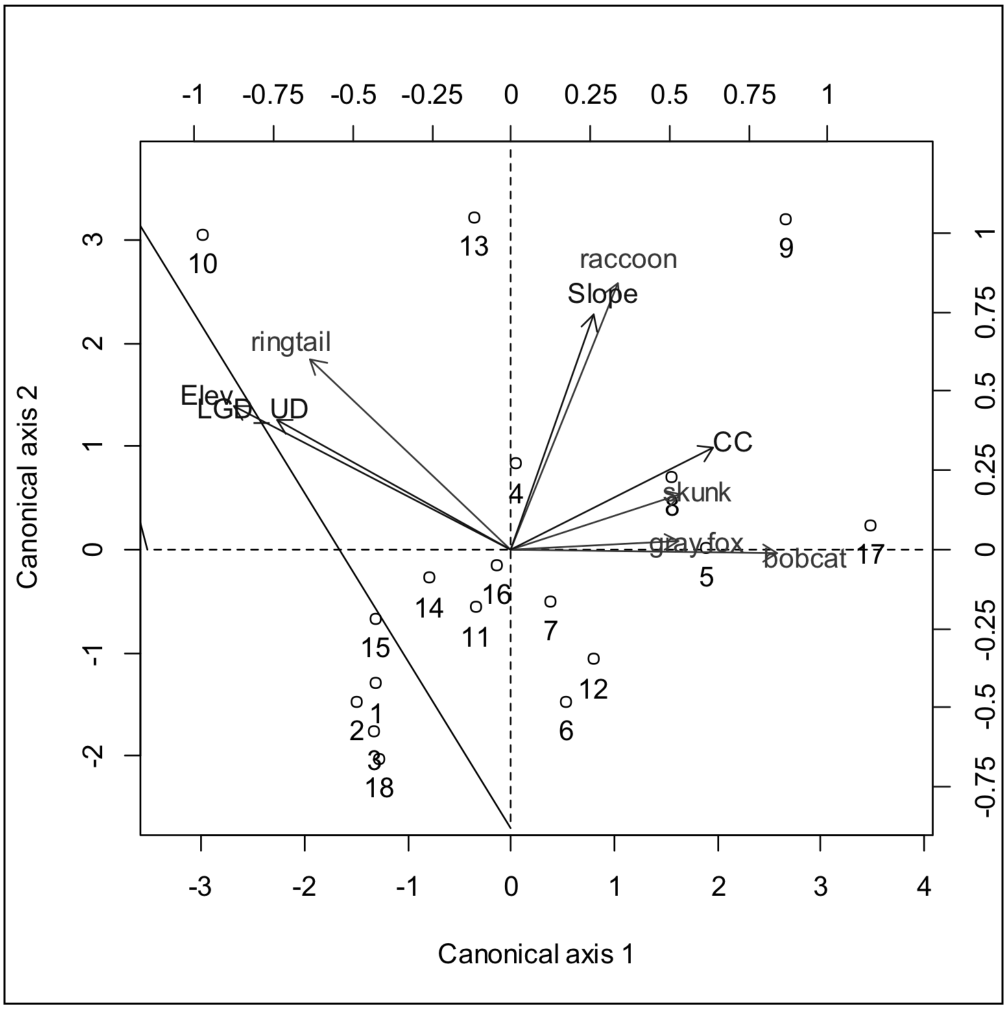


Figure 3. Triplot of relationships between mesocarnivore detection rates (responses), LGD activity(LGD UD), elevation, slope, and canopy cover (CC) (predictors). Bottom and left axes are the scales of the centered response variables, and are also the scales in which the cameras (by number) are plotted. The top and right axes are the scales of the standardized explanatory variables. This plot is type II scaled to preserve relationships between variables. Variables pointing the same direction are positively correlated, those pointing opposite directions are negatively correlate, and variables at 90° are uncorrelated.



Appendix 1. Total counts, means, and ranges of proximity fixes, and percentage of days associated with livestock for UHF collared livestock within ~300 m of a GPS collared LGD at the Martin Ranch from July 2016 through April 2017.

LGD (by name)	Proximity fixes per day			# Days w/o fixes	# Days w/ < 10 fixes	% Days near livestock
	n	Mean± S.E.	Range			
Reginald [a]	28903	93.8 ± 3.4	1 – 355	0	12	100.00%
Alfred	42143	136.8 ± 5.1	0 – 456	2	5	99.35%
Nigel	21497	69.8 ± 2.6	0 – 287	2	11	99.35%
Elizabeth	41537	134.9 ± 4.9	0 – 406	2	5	99.35%

[a]Denotes the LGD primary association with goat herd