Using detection/non-detection surveys and interviews to assess carnivore site use in Kenya

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Understanding species' site use patterns is important for conservation and human–wildlife conflict mitigation where humans, livestock and large carnivores coexist. We used occupancy models and interviews to evaluate site use by medium and large carnivores within the rural Meibae Community Conservancy and agriculturally-developed Salama areas of Kenya. We conducted monthly surveys for 4 months along 32 transects covering 160 km in both study areas, and collected detection/non-detection data for nine carnivore species (>10 kg) *via* direct sighting, tracks and scat. We modelled carnivore site use against both anthropogenic and environmental variables while accounting for imperfect detection, and conducted interviews to determine presence of conflict carnivores. Black-backed jackal (*Canis mesomelas)* and spotted hyaena (*Crocuta crocuta*) site use was most strongly associated with higher livestock abundance. Rare or wider-ranging species were seldom (*e.g.* cheetah, *Acinonyx jubatus*) or never (*e.g.* African lion, *Panthera leo*) detected on transect surveys but were reported during interviews. We conclude that transect surveys were unreliable for evaluating presence of less common species in our study areas. While interviews were more effective, we recommend that future interviews should account for potential false-positive detections. We make suggestions for improving surveys and recommend combining methods to quantify site use by wide-ranging and cryptic carnivores.

Keywords: occupancy modelling, detection/non-detection surveys, human–wildlife conflict, conflict interviews, carnivores, Kenya.

INTRODUCTION

Conflict between humans and wild carnivores has long challenged wildlife conservation, endangering both carnivore populations and local livelihoods (Gusset, Swarner, Mponwane, Keletile & McNutt, 2009; Mazzolli, Graipel & Dunstone, 2002; Sillero-Zubiri, Sukumar & Treves, 2007; Treves & Bruskotter, 2014). Increased rural development globally has accelerated habitat loss and land fragmentation within the last few decades (MEA, 2005; Polaina, Gonzalez-Suarez & Revilla, 2015), in turn creating a stage for increased carnivore–human interaction. In sub-Saharan Africa, for instance, habitat fragmentation from subdivision of private land for small-scale agriculture has resulted in a reduction of herbivore density (Galvin, Reid, Behnke Jr. & Hobbs, 2008; Wambua, 2008) and changes in carnivore behaviour and movement (Cozzi, Broekhuis, McNutt & Schmid, 2013). Subsequently, conflict with predators is higher for livestock owners living in proximity to undeveloped habitat or wildlife refuges (Gusset *et al.*, 2009). Spatially aggregated landscape features and anthropogenic attractants such as livestock can also act as 'conflict hotspots' (Wilson, Madel, Mattson, Graham & Merrill, 2006), where depredation events and human–carnivore conflicts are more likely to occur. Thus, understanding the relationship between carnivore site use and environmental and anthropogenic factors is crucial for effective large-scale conservation and management efforts.

In regions outside protected areas in Kenya, where carnivores directly threaten people's safety and livelihoods, tolerance is low and retaliatory killings, poisonings, and trapping of medium and

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large carnivores is common (Hazzah, Borgerhoff Mulder & Frank, 2009; Woodroffe & Frank 2005). However, local community-based conservation efforts and conservancies can play an important role in ensuring carnivore persistence (Blackburn, Hopcraft, Ogutu, Matthiopoulos & Frank, 2016; Dickman, 2010). As settlement increased in the Salama area in southern Kenya, Action for Cheetahs in Kenya (ACK) conducted verifications of livestock losses to determine circumstances of and reactions to the loss, as a part of predator monitoring and conflict mitigation between 2007 and 2013. Twenty-six per cent of 257 verified livestock losses were attributed to cheetahs (*Acinonyx jubatus*), 26% to hyaenas (*Crocuta crocuta* and *Hyaena hyaena*), 10% to leopards (*Panthera pardus*), 2% to black-backed jackals (*Canis mesomelas*), and 0.8% to African wild dogs (*Lycaon pictus*) (Wykstra, 2015). Following initiation of outreach and conflict-mitigation efforts in 2007, annual reported conflict events involving carnivores declined from 53 to 10 by 2013, with cheetah conflicts down from 20 to 1 (Wykstra, 2015). However, perception interviews conducted in 2013 with local livestock owners in Salama suggested that they still considered cheetahs to be a great threat to livestock, and livestock loss to carnivores continues. In Meibae, though cultural tolerance by the Samburu people to livestock killings is greater than in Salama, interviews in 2014 by ACK in three regions of the conservancy reported that all 30 interviewees had sustained livestock losses. Nearly 200 head of livestock were killed over one year, with the majority of attacks occurring at night and attributed to spotted hyaenas, though cheetahs, wild dogs, black-backed jackals and leopards were also identified as daytime predators (Wykstra, 2015). Retaliatory killings of predators, while apparently infrequent, have been reported in nearby communities (M. Wykstra, pers. obs.). Identifying a variety of factors affecting carnivore site use and improving strategies for surveying cryptic carnivores would allow conservation organizations working outside wildlife reserves in Kenya or other similar regions to implement additional mitigation efforts where they are needed most.

Our aims were to use a combination of occupancy models and interviews to establish (1) where human–wildlife conflicts occur, (2) which species are implicated in human–wildlife conflicts, and (3) which environmental and anthropogenic factors most influence species site use at two study areas in Kenya. This study focused on nine medium-to-large (>10 kg) carnivore species and thus included both meso- and apex predators (Wallach, Izhaki, Toms, Ripple & Shanas, 2015). Field surveys were supplemented by interviews to determine current perceptions of conflict and perceived carnivore presence in comparison to direct evidence collected in a four-month time period. Our study had a further aim of informing development of a protocol for rapid survey of cheetahs by the conservation organization Action for Cheetahs in Kenya (ACK) to map cheetah range during 2017–2018. Based on previous studies by ACK and the peer-reviewed literature (*e.g.* Andresen, Everatt & Somers, 2014; Schuette, Wagner, Wagner & Creel, 2013; Thorn, Green, Bateman, Waite & Scott, 2011), we predicted that most carnivores would be positively associated with greater prey densities but negatively associated with more densely settled areas. We further predicted that high-conflict livestock predators would selectively use areas of high livestock densities.

STUDY AREA AND METHODS

Our study took place from November 2015 to March 2016 in two areas in Kenya monitored by ACK (Fig. 1). Kenya's climate is characterized by a hot dry season from June to September, short rains in November and December, and long rains from March to May. The Salama area (278 km^2) is located in the northern Makueni County, south of Nairobi, and the Meibae study area incorporates the Meibae Conservancy in Samburu County (697 km^2), located approximately 500 km northwest of Salama. Salama is more populated (between 60 and 100 people per km^2; Makueni County, 2013) and exhibits greater variation in land use. Much of the land is subdivided into private fenced subsistence agriculture plots and small-scale livestock ranching, creating a barrier to wildlife movement during dry seasons and drought periods (Wambua, 2008). The habitat in the Salama area varies widely, from open shamba (farms) and grassland (~20% woody cover) to relatively closed woody vegetation (~75% woody cover) (FAO 2003; Kalenski, 1998).

The Meibae Conservancy supports a smaller number of permanent settlements with resident populations of about six people per km^2 (Pfister, 2009). The Samburu people living within these settlements are nomadic pastoralists who moved their livestock according to climatic and grazing

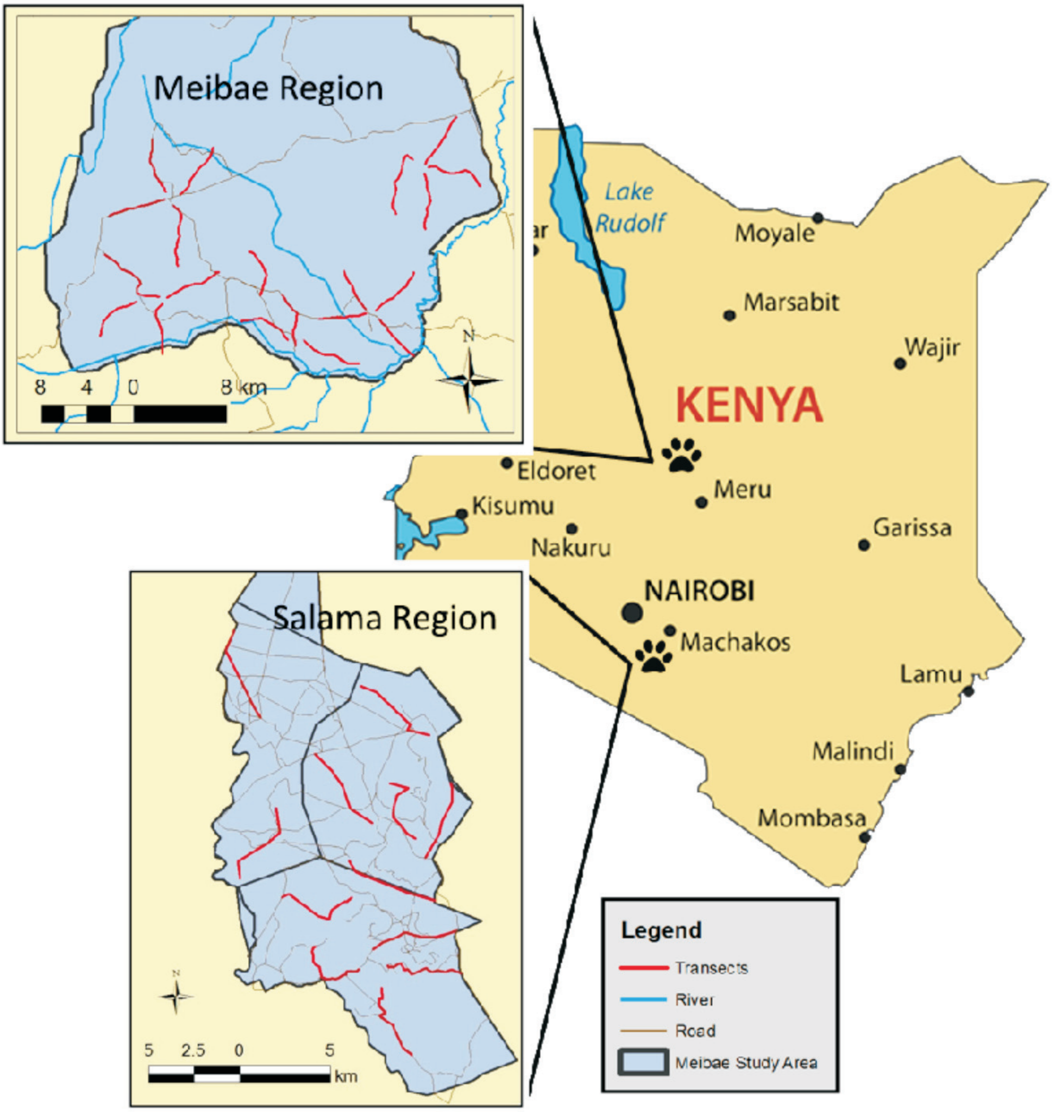

Fig. 1. Locations of Meibae and Salama study areas and medium and large carnivore detection/non-detection transects within the Republic of Kenya.

conditions. Livestock are kept in bomas (corrals) at night. During the day, livestock are herded several kilometres from the homestead for grazing and water; permanent fencing and divided pasture systems are not used. Habitat types in Meibae are less variable and are dominated by bushed woodland and short grass habitat (~65% woody cover) (FAO 2003; Kalenski, 1998).

Detection/non-detection surveys

We conducted predator surveys along transects to document direct sightings and tracks (Epps, Mutayoba, Gwin & Brashares, 2011) from December 2015 to March 2016, between the short- and long-rains seasons. We selected transect locations to maximize heterogeneity of surveyed habitats while also considering logistical factors, including accessibility, safety, and suitability of substrate for capturing tracks. We established 12 transects across the smaller Salama area, and 20 transects across the larger Meibae area (Fig. 1). Each transect was 5 km long with a 5-m searching radius on either side for carnivore incidences (*e.g.* scat, track) and a 200-m search radius for physical sightings of both predators and prey. Transects were generally surveyed between 07:00 and 09:00, early in the morning before livestock taken for grazing would erase tracks, but after sunrise to minimize encounters with dangerous wildlife. Each field assistant was responsible for walking a set of four transects within their assigned area each month; every set included at least one transect with high settlement density, one with low settlement density, one with high prey density, and one with low prey density based on data from previous patrols. Transects were spaced a minimum of one km apart on a mix of dirt roads and cross-country trails, depending on accessibility, to prevent double counting. Larger distances between transects were often unfeasible in Meibae, where the field assistants did not have access to motorized vehicles.

All transects were surveyed on foot once per month by eight ACK field assistants trained to identify and record signs of cheetah, leopard, lion (*Panthera leo*), spotted hyaena, striped hyaena, wild dog, black-backed jackal, caracal (*Caracal caracal*) and serval (*Leptailurus serval*) and to identify prey species by sight. Field assistants recorded all encountered carnivore incidences and prey encounters (as sightings only), including livestock, along each transect. Prey species recorded included small- to medium-sized ungulates, such as Thomson's gazelle (*Eudorcas thomsonii*), Grant's gazelle (*Nanger granti*), impala (*Aepyceros melampus*), dikdik (*Madoqua kirkii*), gerenuk (*Litocranius walleri*), zebra (*Equus quagga*), wildebeest (*Connochaetes taurinus*), warthog (*Phacochoerus africanus*), and some ground birds including Ostrich (*Struthio camelus*), Guineafowl (*Numida* spp. and *Acryllum* spp.) and Yellow-necked Spurfowl (*Pternistis leucoscepus*). A set of tracks thought to belong to a single individual was considered a single incidence. Scat was only included if the field assistants were able to unambiguously identify the species. Field assistants recorded type, size, and age of carnivore sign encountered along transects, as well as GPS coordinates and photographs of the sign for verification by ACK staff when identification was uncertain or unlikely.

Statistical and spatial analyses

Mean prey and livestock abundance was calculated as a measure of capture-per-unit-effort, *i.e.* the total count of wild (prey) and domestic (livestock) animals encountered on each transect divided by the number of transect survey replicates ($n = 4$). Detectability across study areas and transects was similar enough (Appendix A) that assessing abundance through distance sampling (Thomas *et al.*, 2010) would have yielded little additional resolution for the analysis. Settlement density for each transect – a proxy for level of human activity and anthropogenic development – was determined as the total number of settlements (encompassing shops, schools, houses, and shamba with houses) recorded by the field assistants within 200 m of the transect on site. Dominant ground cover and habitat type as percentage cover was designated from a combination of on-the-ground assessment by field assistants and by using ArcGIS 10.3 (ESRI, Redlands, California) to overlay transects on the FAO Africover multipurpose land cover map (FAO, 2003; Kalenski, 1998), which uses the FAO/UNEP international standard Land Cover Classification System. When using the Africover map, we obtained percentage cover by averaging the percentage cover range estimate for the habitat classification that dominated the length of the transect. We classified ground cover as bare ground, short grass (<10 cm), medium height grass (11–30 cm) and tall grass (>30 cm). We used Microsoft Excel (Microsoft, Redmond, U.S.A.) to conduct a chi-square goodness-of-fit test to assess the association between carnivore detection and ground cover type within each study area.

Single-species, single-season occupancy models were used to estimate the probability of each site being used by the target species (MacKenzie *et al.*, 2006). Notably, detection/non-detection surveys facilitate the evaluation of species–environment relationships, and when surveys are replicated, the resulting data can be leveraged using occupancy models to estimate the probability of occupancy while accounting for imperfect detection during surveys (MacKenzie *et al.*, 2002). Occupancy models can be used to assess which habitat variables best discriminate between locations that are, or are not, occupied by a species (Carroll, Noss, and Paquet, 2001; Karanth *et al.*, 2011; Schuette *et al.*, 2013). When species distributions exhibit strong associations with particular environmental features, these models can be used to make predictions of species occurrence, and by extension, assist in landscape-scale conservation programmes (Licona, McCleery, Collier, Brightsmith & Lopez, 2011; Schuette *et al.*, 2013). This approach contains three primary assumptions.

First, the occupancy state (*i.e.* occupied *vs* unoccupied) cannot change within a sampling season. Second, species detection must be independent between sites if true occupancy is being estimated (*i.e.* individuals should not be detected at multiple sites within a sampling season). While this condition may not be met in our study because of the relatively close proximity among transects and long-distance dispersal capabilities of the target species, this assumption can be relaxed if the occupancy probabilities are interpreted as the probability that the species uses the site (Mackenzie, 2005). Lastly, this approach assumes that heterogeneity in occupancy and detection probabilities can be explained using covariates or is constant (*e.g.* Royle, 2006). This last assumption is difficult to meet with certainty, but we included a variety of likely covariates to satisfy it. Importantly, occupancy modelling also accounts for imperfect detection, or 'false-absences', in which a species may occupy a site where it was not detected during the survey period (MacKenzie *et al.*, 2006).

Occupancy models were not fitted to transect data for species that were detected on fewer than 20 occasions over the four-month sampling season. This restricted the occupancy analyses to transect data for spotted hyaena and black-backed jackal. For these two species, environmental and anthropogenic covariates were included during analyses to evaluate their potential influence on detection (p) and site use (Ψ) probabilities. We checked for multicollinearity by estimating Pearson correlation coefficients for all covariates in Excel, using $|r| > 0.7$ as a threshold to identify variables as highly correlated. We also standardized all covariate values by z-transformation within Excel. We first fitted models that included time and study area (*i.e.* as a grouping variable) effects on detection probability and study area effects on site use probability; however, the data were too sparse to accommodate a time effect on detection probability (*i.e.* differences in detection probability over time). Therefore, the remaining models included combinations of study area, mean prey and livestock abundance, settlement density, and habitat (as % woody cover) (Table 1). We adjusted the prey covariate values for each carnivore species to only include wild and domestic prey species within the preferred weight range of that carnivore based on available literature. Specifically, we only included small- (1–10 kg) and medium-sized (11–50 kg) prey and livestock when calculating the covariates for black-backed jackals (Kaunda & Skinner, 2003; Klare, Kamler, Stenkewitz & Macdonald, 2010; Yarnell *et al.*, 2013), and medium- and large-sized (>51 kg) prey and livestock when calculating the covariates for spotted hyaena (Clements, Tambling, Hayward & Kerley, 2014; Hayward, 2006). Prey and livestock weights were calculated as of the female weight (Clements, *et al.*, 2014) to account for juveniles. We evaluated models using Akaike's Information Criterion corrected for small sample size (AICc), estimated the relative variable importance of predictor variables by summing the AIC_c weights across all candidate models, and model averaged predicted site use probabilities across all candidate models if competing models (*i.e.* <2 ΔAIC_c units) were discovered (Burnham & Anderson, 2002). Occupancy models were fitted using program MARK (White & Burnham, 1999). Using the resulting estimates, we estimated the number of replicate surveys (k) required to determine the true site use state of each transect with 95% confidence using the probability of detection as $1-(1-p)^k$ (*e.g.* Jackson, Weckerly, Swannack & Forstner, 2006).

Table 1. Description of covariates used for modelling carnivore site use in Meibae and Salama areas of Kenya in transect surveys conducted from November 2015 to January 2016. Except 'Region', a factor variable, covariates were treated as continuous variables and were z-transformed.

Covariate	Description
Region	Measured as a group effect comparing Meibae and Salama study sites
Livestock	Measured as total count of domestic livestock encountered along transect/ number of transect survey replicates
Prey	Measured as total count of wild prey encountered along transect/number of transect survey replicates
% Cover Woody Vegetation	Measured % of transect with woody cover type dominant based on FAO Africover (2003) standards
Settlement	Total number of settlements encountered along transect

Interviews

From early November 2015 to late January 2016, we conducted interviews at both study areas to determine presence of carnivores and frequency of livestock depredation events in and near local ranching communities. Survey protocols were reviewed and approved by the Oregon State University International Review Board (IRB Study 7022). The participants were community owners of livestock including cattle (*Bos taurus*), sheep (*Ovis aries*) and goats (*Capra aegagrus*). Interviewees could decline interviews or questions if desired. We randomly selected interviewees across the study areas by dividing the settled and accessible regions of the study areas into one-km^2 grids using ArcGIS. We then selected 30 grids in both Meibae and Salama using a random number generator to minimize potential local bias in interview responses. We chose the livestock-owning household closest to the centre point GPS coordinate of that grid for interviews. Because of lower settlement densities in Meibae, random selection of interview areas was difficult to achieve, and field assistants were allowed more flexibility in choosing interviews (*i.e.* selecting households in another nearby grid if the selected grid was uninhabited).

Participants were interviewed individually in English, Kiswahili, Kikaamba or Kisamburu by 1–2 ACK field staff members, and were asked questions pertaining to occasions of livestock depredation within the past year. Questions included frequency of wildlife sightings around the homestead and grazing area, numbers of livestock lost, predators responsible for the loss, and measures currently employed to protect livestock from wild predators (see Appendix B). Interviewers confirmed the reliability of the livestock owner in identifying the cited carnivore by presenting photos of the physical animal, tracks, and kill-style.

RESULTS

Detection/non-detection surveys

In total, we surveyed 32 5-km transects 4 times each, totaling 128 surveys and 64 km^2 (6.5% of the total study area) over the study period. Carnivores were detected on 42 of the 128 surveys, with 99 unique encounters recorded across both areas. Of those detection events, 33 occurred in Meibae and 9 in Salama. Detection frequency (percentage of total detections) was dominated by spotted hyaena (48%) and black-backed jackal (38%) (Table 2). Serval, lion, and wild dog were never detected. Across both areas, spoor encounter frequency was strongly associated with ground cover (χ^2 = 20.03, d.f. = 3, P < 0.001), such that taller vegetation was associated with lower encounter frequency. However, due to inconsistency in collection of ground cover data by the field assistants, we did not include ground cover as a covariate when modelling detection probabilities using occupancy models. As transects were designed to maximize substrate suitability (*i.e.* we selectively used areas with lower ground vegetation height and density), we did not have the data necessary to evaluate whether ground cover influences carnivore detections by field assistants.

In Salama, wild prey was encountered on 219 occasions over the four-month sampling season, while in Meibae, wild prey was encountered on 298 occasions (Table 3; see Appendix C). Habitat heterogeneity varied between Salama and Meibae, with Salama exhibiting greater variation in habitat type while Meibae was dominated by contiguous scrub vegetation (bushed woodland). Encounter frequency in Salama varied with habitat; the greatest number of encounters occurred in open grassland habitats (37%), followed closely by open woodland (34%) and bushed woodland

Table 2. Number of unique carnivore detections along transects conducted in Salama (n = 12) and Meibae (n = 20) areas of Kenya from December 2015 to March 2016.

Species	Meibae	Salama	Total
African wild dog (*Lycaon pictus*)	0	0	0
Black-backed jackal (*Canis mesomelas)*	28	5	33
Caracal (*Caracal caracal*)	1	0	1
Cheetah (*Acinonyx jubatus*)	1	0	1
Leopard (*Panthera pardus*)	4	1	5
Lion (*Panthera leo*)	0	0	0
Serval (*Leptailurus serval*)	0	0	0
Spotted hyaena (*Crocuta crocuta*)	57	6	63
Striped hyaena (*Hyaena hyaena*)	8	0	8
Total	99	12	111

Table 3. Total species richness, encounters, count and relative abundance of wild prey and domestic livestock species sighted along transects from December 2015 to March 2016 in Meibae and Salama. Abundance was calculated as a measure of capture-per-unit-effort (mean number of individuals sighted in region per survey month).

Site	Type	Species richness	Encounters	Count	Relative abundance
Salama	Wild	20	213	1195	298.8
	Domestic	3	6	105	26.3
Meibae	Wild	11	291	1659	414.8
	Domestic	5	182	9507	2376.8

(22%) habitats. Except baboons (*Papio anubis*) and Ostrich, all of the most frequently encountered and abundant species are within the weight range to be considered preferred prey for cheetahs and most other carnivores surveyed (1–182 kg; Hayward, 2006). Abundance and diversity of domestic livestock was higher in Meibae than Salama (Table 3).

Single-species, single-season occupancy model

When testing for correlation between covariates, we found no strong correlations (*i.e.* $|r| < 0.58$ in all cases). Because carnivore detections were generally low, we restricted the occupancy analyses to spotted hyaena ($n = 31$) and black-backed jackal ($n = 24$). Detection probability of spotted hyaena strongly differed between study areas but the study area did not strongly influence site use. The cumulative model weights suggested that site use was most influenced by livestock (ΣMw = 0.44), in which site use increased weakly with increased livestock abundance (Fig. 2; Table 4). Site use was almost equally influenced by prey (ΣMw = 0.23) and settlement (ΣMw = 0.25) in which probabilities decreased weakly with prey abundance and increased weakly with settlement (Fig. 2). Percentage cover of woody vegetation also had a weak negative effect on site use (ΣMw = 0.35; Fig. 2). However, standard error and confidence

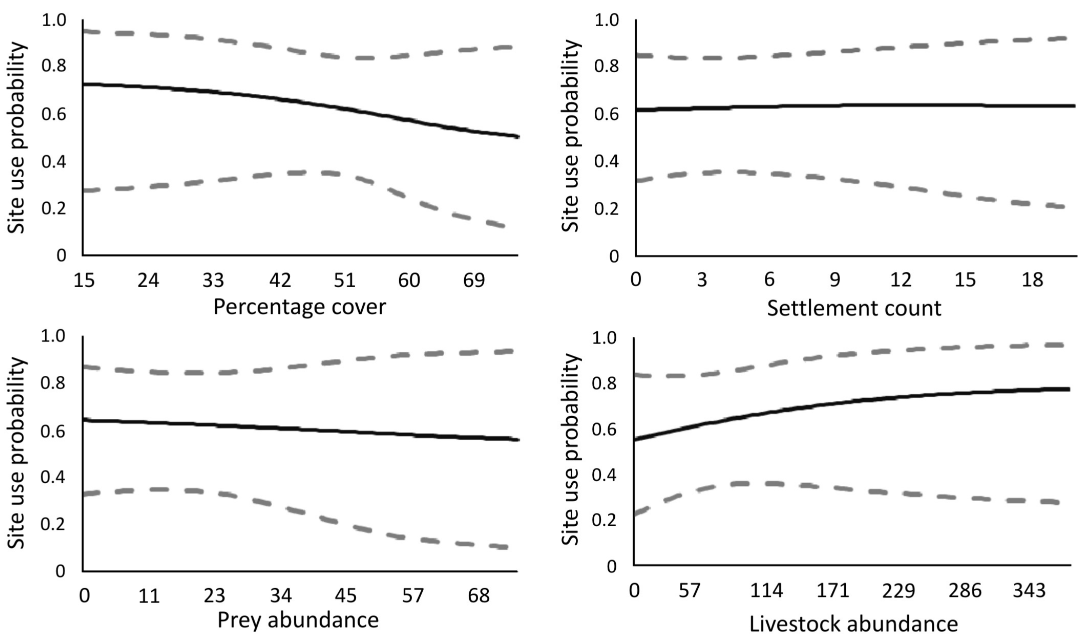

Fig. 2. Model averaged predicted site use probabilities of spotted hyaena (*Crocuta crocuta*) in the Meibae and Salama study sites in Kenya modeled against percentage cover, prey abundance, settlement count, and livestock abundance. Solid line is the mean estimate and the dashed lines represent the 95% confidence interval.

Table 4. Top ten occupancy models based on delta AIC_c values and weights for spotted hyaena (*Crocuta crocuta*) and black-backed jackal (*Canis mesomelas*), with detection (p) and site use (Ψ) probabilities based on detection/non-detection transect surveys conducted from December 2015 to March 2016 in Salama and Meibae, Kenya, where K = number of model parameters.*

Species	Model	ΔAIC_c	Weight	K
Spotted hyaena	$p_{Region}\ \Psi_{.}$	0.00	0.21	3
	$p_{Region}\ \Psi_{Livestock}$	1.52	0.10	4
	$p_{Region}\ \Psi_{\%Cover}$	2.01	0.08	4
	$p_{Region}\ \Psi_{\%Cover+Livestock}$	2.08	0.08	5
	$p_{Region}\ \Psi_{Settlement}$	2.30	0.07	4
	$p_{Region}\ \Psi_{Prey}$	2.59	0.06	4
	$p_{.}\ \Psi_{\%Cover+Livestock}$	3.12	0.04	4
	$p_{Region}\ \Psi_{Prey+\%Cover}$	3.15	0.04	3
	$p_{Region}\ \Psi_{Settlement+Prey}$	3.93	0.03	5
	$p_{\%Cover}\ \Psi_{Livestock}$	4.32	0.03	2
Black-backed jackal	$p_{.}\ \Psi_{Livestock}$	0.00	0.22	3
	$p_{.}\ \Psi_{Settlement+Livestock}$	1.88	0.08	4
	$p_{Region}\ \Psi_{Livestock}$	2.10	0.08	4
	$p_{.}\ \Psi_{.}$	2.28	0.07	2
	$p_{.}\ \Psi_{\%Cover+Livestock}$	2.30	0.07	4
	$p_{.}\ \Psi_{Settlement}$	2.56	0.06	3
	$p_{.}\ \Psi_{Prey+Livestock}$	2.62	0.06	4
	$p_{.}\ \Psi_{\%Cover}$	2.64	0.06	3
	$p_{Region}\ \Psi_{Settlement+Livestock}$	4.07	0.03	5
	$p_{.}\ \Psi_{\%Cover+Settlement}$	4.56	0.02	4

*Models within 2 ΔIC_c units of the best model are regarded as equally explanatory (Burnham & Anderson, 2002).

intervals were very broad for all covariates of site use (Fig. 2). We estimated that transects would require five replicate surveys in Meibae (probability of detection $p = 0.51$) and 17 replicate surveys in Salama ($p = 0.16$) to be 95% confident that spotted hyaena were detected if present.

Black-backed jackal site use was most strongly associated with increased livestock abundance (ΣMw = 0.65; Table 4; Fig. 3) and almost equally influenced by the other covariates. Site use decreased weakly with increasing settlement (ΣMw = 0.31; Fig. 3) and increased weakly with percentage cover of woody vegetation (ΣMw = 0.27; Fig. 3). We found little evidence of an association between black-backed jackal site use and prey density (ΣMw = 0.21; Fig. 3). Study area did not have a strong effect on site use or detection. Again, standard error and confidence intervals were broad for all covariates of site use (Table 4; Fig. 3). We estimated that transects would require five replicate surveys ($p = 0.46$) to be 95% confident that black-backed jackal were detected if present in either study area. See Appendix D for model intercepts and coefficient estimates used to predict model-averaged estimates of site use probabilities.

Interviews

Sixty interviews were conducted in total with 34 in Meibae and 26 in Salama. No respondents declined to be interviewed, though 19 of the Meibae interviews were conducted outside the pre-selected grids due to low settlement densities. Of the 60 interviewees, 53 (88%) reported experiencing livestock depredation or injury by carnivores in the previous year. Most interviewees only reported one or two conflict events, but two interviewees reported 10 or more conflict events within the year. Interviewees most frequently reported spotted hyaenas as implicated in the most recent conflict event experienced, followed by leopard and cheetah (Table 5). However, this varied by region, with spotted hyaenas most often implicated in Meibae and cheetahs most often implicated in Salama. In total, 256 livestock losses or injuries by carnivores were reported by the 53 interviewees within the previous year. The proportion of interviewees who experienced loss or injury of their livestock was higher in Meibae (100%) than Salama (73%), as was the number of livestock losses within a year (206 in Meibae, 50 in Salama). Of the depredation events reported (excluding eight responses with multiple carnivores and loca-

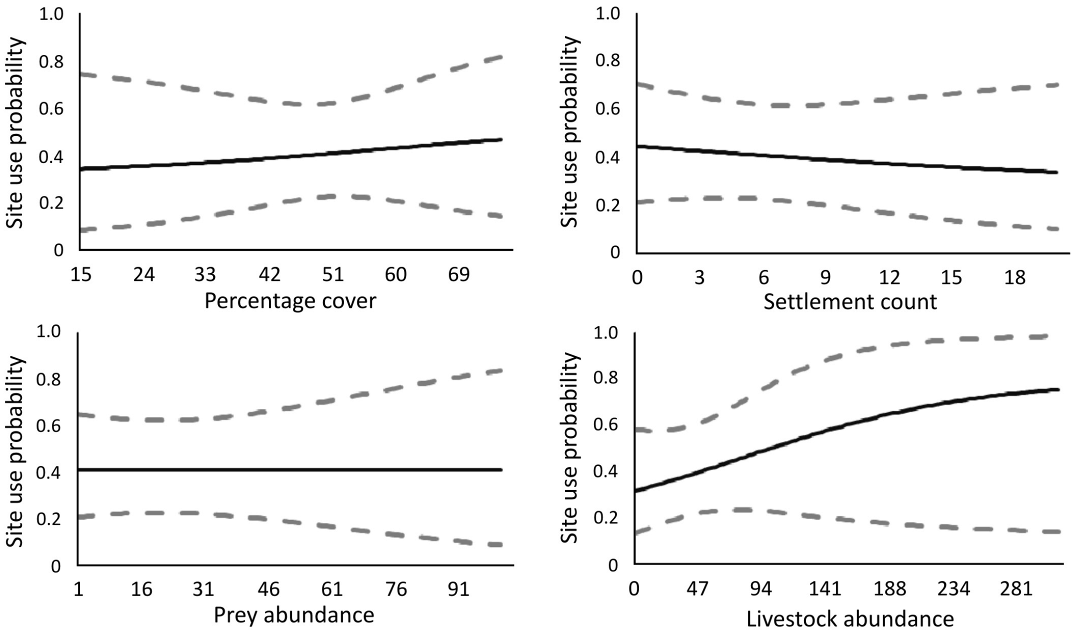

Fig. 3. Model averaged predicted site use probabilities of black-backed jackal (*Canis mesomelas*) in the Meibae and Salama study sites in Kenya modeled against percentage cover, prey abundance, settlement count, and livestock abundance. Solid line is the mean estimate and the dashed lines represent the 95% confidence interval.

tions cited), 53% (24/45) occurred while herding, 9% (4/45) occurred within proximity of the homestead but outside the boma, and 24% (11/45) occurred within the boma (Table 5). The number of conflict events was also negatively associated with increased numbers of herders, dogs and donkeys employed while herding (Fig. 4). Additionally, while all livestock owners who experienced depredations within the boma used some kind of fence, 93% of these boma fences were not

Table 5. Most recent conflict events from January–November 2015 by carnivore species and location relative to the boma, homestead, and grazing area, reported in interviews conducted in the Salama (n = 26) and Meibae (n = 34) study sites in Kenya from November 2015 to January 2016. A conflict event was defined as any livestock killed or injured by wild carnivores.

Study area	Species	Herding	Near homestead	Outside boma	Inside boma	Multiple cited*	Total
Salama	Leopard	1	0	0	2	0	3
	Cheetah	8	1	0	0	0	9
	Spotted hyaena	0	0	1	2	1	4
	Black-backed jackal	2	1	0	0	0	3
	Total	11	2	1	4	1	19
Meibae	Leopard	1	0	0	0	1	2
	Cheetah	4	0	0	0	0	4
	Spotted hyaena	2	0	0	7	0	9
	Wild dog	5	0	0	0	0	5
	Black-backed jackal	1	0	1	0	0	2
	Multiple cited*	3	0	1	0	2	6
	Total	16	0	2	7	3	28

*Multiple locations were occasionally cited by field assistants and are listed separately.

rated as predator-proof by the visiting field officers. In Salama, the most frequently sighted carnivores near homesteads and grazing areas were black-backed jackals, servals and caracals. Most other carnivores were rarely sighted by ≥50% of respondents (Fig. 5). Cheetahs, jackals, hyaenas (striped and spotted), and wild dogs were all commonly sighted in Meibae (sighted daily to monthly; Fig. 5). Lions, caracals and leopards were rarely sighted (yearly to never).

DISCUSSION

Although detection of only a single cheetah precluded a formal occupancy analysis for this target species, we determined that our transect survey methods were suitable for more common and detectable species such as spotted hyaenas and black-backed jackals. As predicted, the site with higher livestock relative abundance saw higher site use by black-backed jackals and spotted hyaenas, and detection of spotted hyaena varied strongly between the two sites. Interviews in both study areas reported numerous sightings and many examples of conflict due to livestock predation by these species. In this study, using only detection/non-detection transect surveys for wide-ranging carnivores such as cheetahs ultimately proved to be cost-ineffective and unreliable, but complimentary methods of verifying site use such as interviews proved valuable when carnivore detection during field surveys was low.

The probability of detection for spotted hyaenas and the number of unique carnivore detections were much higher in the less populated area of Meibae (Table 2). This may be due to factors such as drought, higher development densities, and greater propensity for persecution and killing of conflict predators in Salama (M. Wykstra, ACK, pers. comm., May 2016), which could result in predator avoidance or exclusion. Hyaena site use was most strongly associated with higher livestock abundances, and weakly but negatively associated with preferred prey densities, suggesting hyaena may be opportunistically favouring livestock over wild prey. This was supported by conflict events reported by interviewees particularly in Meibae, where spotted hyaenas were responsible for most recent conflict events, 78% of which occurred within the boma (Table 5). This may result from livestock husbandry practices that make domestic prey easier targets for depredation (see Table 5). Other studies in Kenya and East Africa have also suggested that hyaenas are common conflict species (Holmern, Nyahongo & Røskaft, 2007; Kolowski & Holekamp, 2006; Lyamuya, Masenga, Fyumagwa & Røskaft, 2014) and have found that depredation events are most common at night and in bomas (Holmern *et al.*, 2007; Ogada, Woodroffe, Oguge & Frank, 2003; Patterson, Kasiki, Selempo & Kays, 2004). Additionally, areas with low densities of competitively superior lions have been positively associated with hyaena survival (M'soka, Creel, Becker & Droge, 2016), such as in our field sites where lions have been largely extirpated. However, high conflict rates may still threaten long-term persistence of spotted hyaenas in these landscapes.

Black-backed jackal site use was most strongly

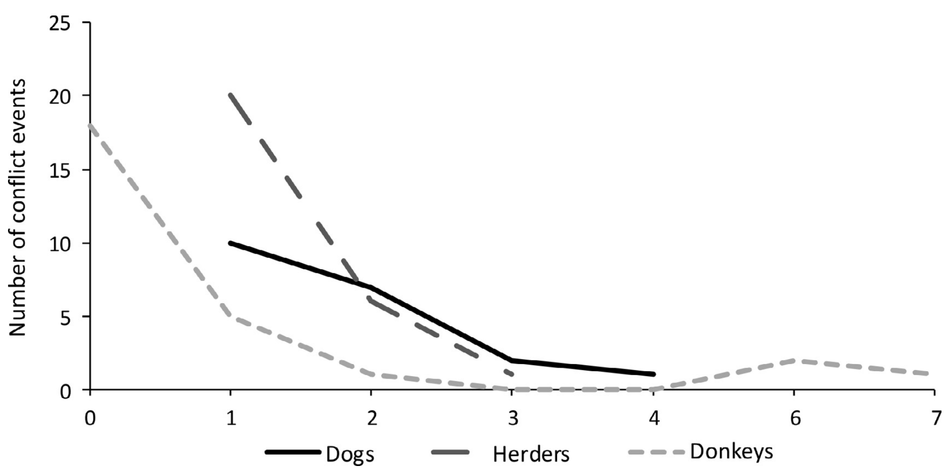

Fig. 4. Relationship between number of dogs, herders and donkeys employed while herding and number of conflict events (*i.e.* where livestock were killed or injured) occuring while herding as cited by interviewees (n = 27) between November 2015 and January 2016 in the Salama and Meibae study sites in Kenya.

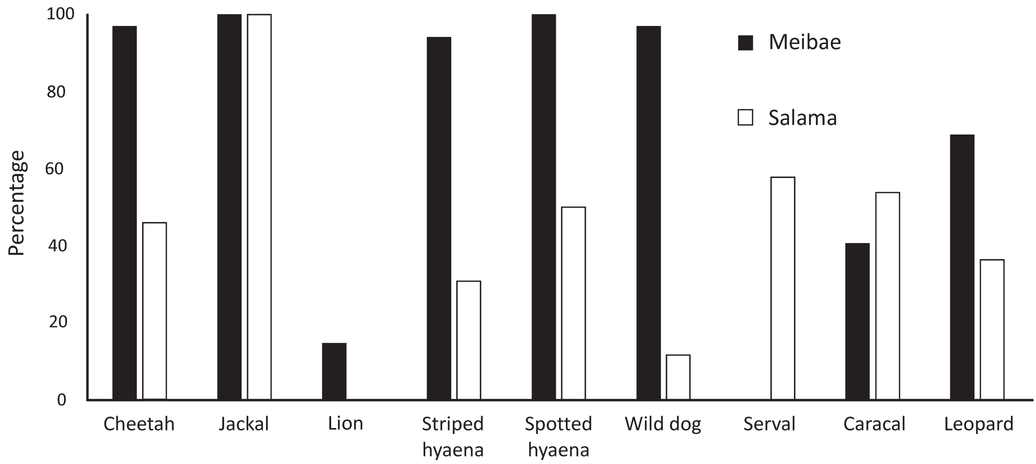

Fig. 5. Percentage of interviewees in the Salama and Meibae study areas of Kenya reporting carnivores as common (seen at least once per month on the interviewee's property or grazing area) by species during interviews conducted between November 2015 and January 2016.

associated with livestock relative abundance (Table 4), where probability of site use was greater with higher livestock relative abundance. Although black-backed jackal were responsible for only 14% of conflict events reported, they were also cited by interviewees as being common in both Salama and Meibae, suggesting that black-backed jackals are often seen near or on the interviewees' property or grazing areas. That black-backed jackal site use is positively associated with livestock relative abundance, but has a weak negative association with settlement and no association with prey density, implies that they use live-stock grazing areas where they may be opportunistic predators. This is supported by the interview data, which reports that 60% of black-backed jackal depredations occur while herding. Black-backed jackals have been found to avoid landscapes with apex predators (Yarnell *et al.*, 2013), so they may use landscapes and prey opportunities that competitively superior carnivores avoid. Jackals are also omnivores whose diet may include plant matter and invertebrates (Kaunda & Skinner, 2003; Klare *et al.*, 2010), and may also use settled and livestock-grazing areas as scavengers. For example, livestock-dense areas can provide a reliable source of carrion that the black-backed jackals may favour. Black-backed jackals have also been seen to selectively use closed woodlands and bush savanna over open grasslands (Fuller *et al.*, 1989; Kaunda, 2001), which is consistent with our results. This site selection may be due to food availability, predator avoidance, or both.

While our transect survey efforts were adequate according to previous recommendations (Andresen *et al.*, 2014), we were unable to obtain a sufficient number of detections to estimate cheetah site use using occupancy models. We detected cheetahs only once in Meibae and never in Salama over the four-month study period. In contrast, interviews with local livestock owners suggest that cheetahs are sighted at least once a month by almost all interviewees in Meibae and almost half of the interviewees in Salama. As cheetahs were most often cited as a conflict species within the past year in Salama, they may also be at higher risk of persecution by local livestock owners, which can have serious conservation implications if not properly addressed. Informal estimates by ACK based on timing and location of sign encountered on patrols and verified livestock losses suggested that there were three to seven cheetahs in Salama in 2015, which moved frequently and were rarely reported in the same area for more than two consecutive months; in Meibae, 14–30 cheetahs were estimated to be present in 2015 (Wykstra, 2015). Low cheetah densities and drought could explain low detection frequencies in Meibae. The effectiveness of detection/non-detection surveys for determining cheetah site use in our study areas, and presumably in similar areas elsewhere in Kenya, is likely to be poor for numerous reasons, including large home-range size, limited accessibility or poor substrate quality that make detecting animal signs more difficult in some areas, and afternoon rains that obliterate the tracks of diurnal animals such as cheetahs. Reported cheetah home-range sizes range from 6 km^2 (Bissett & Bernard, 2006) to >1000 km^2 (Marker, Dickman, Mills, Jeo & Macdonald, 2008). This pilot study was limited to ACK's Salama and Meibae field areas, so the efficiency of this approach may have been diminished by relatively small sampling ranges with low cheetah densities leading to reduced chances of species detections (Bailey, Hines, Nichols & MacKenzie, 2007; Mackenzie, 2005). Additionally, because of heavy fragmentation and subdivision in Salama, resident cheetahs may be restricted to undeveloped refuges on steep hills where surveys were logistically difficult and the substrate was not ideal for capturing animal tracks. Detection/non-detection surveys, if used, should be managed to increase detection probability and combined with other methods to determine site use. For example, transect surveys should be conducted during the dry season to minimize the likelihood of tracks being washed away. Also, carnivore spoor detection was significantly related to ground cover which suggests that future monitoring efforts should aim to designate transects on substrates with a higher likelihood of detecting carnivore spoor (short grass and/or bare ground) or carefully estimate the influence of this factor on detectability.

Our pilot study demonstrated that sign-based transects may not be the most effective method of determining cheetah site use in this system, but we inferred that interviews are helpful for supporting detection data and indicating species presence. If suitable substrate for detection is absent, or the effectiveness of active detection/non-detection transect surveys is compromised, interviews with local rangers and/or livestock owners may be more effective. Local livestock owners and herders in particular are likely to be very aware of carnivore presence within an area, either through regular bushwalks or from depredation events. For instance, cheetahs, striped hyaenas, wild dogs, and leopards were cited as common in Meibae by at least 70% of livestock owners interviewed, but were rarely or never detected in our transect surveys. Additionally, interviews can shed light on conflict rates and local sentiment towards predators, which can have a serious impact on carnivore conservation. Here, we concluded that reduced conflict rates were associated with more effective livestock husbandry strategies including predator-proof bomas and greater numbers of herders, donkeys, or dogs present with the livestock while herding. Greater employment of these mitigation strategies could reduce the rate of conflict events in these areas, ultimately benefiting both the livestock owners and carnivores. Additionally, interviews may be used for analyzing rate and frequency of depredation events, which can then be examined against carnivore occupancy and abundance estimates.

Interviews are, however, prone to perception bias, or may not work well in thinly-settled areas. Perception bias may lead to overestimation of the commonality of certain carnivores, particularly cheetahs, which are generally diurnal and thus more likely to be observed or detected by locals than nocturnal carnivores. The potential for misidentification may also be high, especially as leopards and servals are often mistaken for cheetah (M. Wykstra, ACK, pers. comm., May 2016). This error can be minimized if analyses of interview data used for quantifying cryptic carnivore occurrence patterns account for the possibility of false-positive detections (*i.e.* incorrectly identifying a species as present; Miller *et al*., 2011; Miller *et al*., 2013; Petracca, Ramírez-Bravo & Hernàndez-Santín, 2014; Pillay, Miller, Hines, Joshi & Madhusudan, 2014; Ruiz-Gutierrez, Hooten & Campbell Grant, 2016). In areas with low settlement density, or where accessibility is limited, interviews may not be a viable option for determining occupancy, and other survey methods (*i.e.* hair snares, scat-detection dogs, camera traps, etc.) should be considered. For example, the use of camera traps to collect detection/non-detection data in remote areas for cryptic species is an approach that has been successful in other systems (reviewed in O'Connell & Bailey, 2011), although camera-trap studies can be costly and are also not always effective (Brassine & Parker, 2015).

Black-backed jackal and hyaena site use were most strongly associated with livestock abundance. This suggests a high conflict potential for these species in areas of high livestock densities. Future studies in these regions may want to examine the effects of drought, prey availability, livestock husbandry protocols, and anthropogenic pressures on diet and prey selection by these two carnivore species. For example, conducting surveys over multiple seasons could account for differences in site use between dry and rainy seasons, when changes in water availability, vegetation growth, and prey distribution may significantly affect carnivore food choice and movement

(Davidson *et al.*, 2013; Ogutu, Kuloba, Piepho & Kanga, 2017; Sinclair *et al.*, 2007). Furthermore, surveying in times of drought could inform ongoing concerns that increased settlement and related livestock and agricultural practices in unprotected areas such as Salama and Meibae exacerbate stress on limited water resources and subsequently intensify the effects of drought on wildlife populations. We found interviews to be useful for verifying site use estimates and explaining possible relationships between carnivore site use and frequency of conflict. Additionally, mapping interview and detection/non-detection survey results may help indicate potential conflict hotspots. Finally, we recommend a combination of data collection methods, where feasible, in order to borrow strength across data sets to quantify occurrence patterns of wide-ranging cryptic carnivores using integrated models (*e.g.* Koshkina *et al.* 2017).

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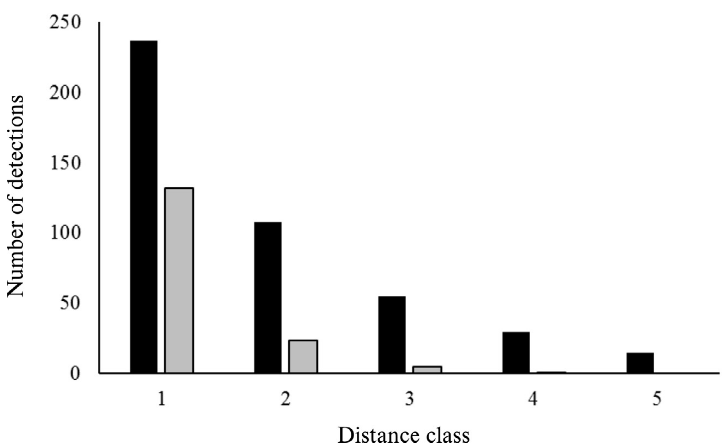
Appendix A. Detection histogram of wild and domestic prey sightings (*n* = 607) sighted along transects from December 2015 to March 2016 in the Meibae (black bars) and Salama (grey bars) areas of Kenya, grouped by perpendicular distance from transect, where 1 = 0–39 m, 2 = 40–79 m, 3 = 80–119 m, 4 = 120–159 m, 5 = 160–199 m. Eighty-five sighting values were omitted due to errors or missing data. Although not described in the main manuscript, distances to prey sightings were recorded in order to determine whether prey detectability differed between study areas. While more prey were sighted in Meibae, the rate at which sightings declined with distance appeared equivalent to the relationship between distance and detection in Salama, so further analysis to adjust prey sightings for detectability was not conducted.



Appendix B. Random Interview Survey Form 2015-2016

Date: __________
Form Number _______

Interviewer Name: _________

- Interview Officer(s):______________________________
- Date of Interview: _______________
- Name of Interviewee: ________________________
- Is this the owner of the shamba/livestock : *Yes No (If no, relationship to the owner ____________________)*

GENERAL INFORMATION

- **GPS of site: Lat__________________ Long ________________**
- Name of **Owner (**if diferent from interviewee) **:** ____
- **Owner** present for interview: *Yes No*
- How long has the **owner** lived at this site? ________________________

WATER

- What is the nearest water source to your livestock? Borehole / Dam / River / Other_______
  Distance from homestead: ___________
- Is this water accessible to wildlife? Y / N
- Where do your livestock typically take water, if different from above? _____________________________

CONFLICT INFORMATION

- Have your livestock been KILLED or INJURED by wild carnivores in the past? YES / NO
- If YES:
  - On how many occasions have livestock been KILLED or INJURED in the past year? ___________
  - Date of LAST conflict_________________
  - Time of Conflict: EARLY AM (0600-1000), MID DAY (1100-1300), AFTERNOON (1400-1600), EVENING (1700-1900), NIGHT (2000-0600)
  - Location of conflict; WHILE HERDING (> 50 m from homestead) / NEAR HOMESTEAD (< 50 m from homestead) / OUTSIDE THE BOMA (but inside homestead) / INSIDE THE BOMA
  - Vegetation cover where the conflict / occurred (**use laminated vegetation sheet)**;
    75% OR MORE OPEN 25-74% OPEN LESS THAN 24% OPEN
- Was the **Owner** actually the **Herder** on the day of the attack: *Yes No*
  If no, what is the name of **Herder(s)** ____

- Do you take precautions to prevent conflicts; YES / NO

- If YES what LEGAL precautions do you take to reduce livestock losses (DO NOT discuss any potentially illegal actions such as killing wild carnivores):

Precaution	Y / N	When? (< 6 mo / 6-12 mo / >12 mo)	Change after implementation? (Increase / Decrease / No change)	Effective? Y / N	Comments
Dog(s)					
Lights					
Noise					
Herder					
Fence					
Torches					

PREDATOR INFORMATION (This section is pertaining to what the interviewee has seen/heard leading them to identify a certain predator as the culprit.)

FOR LAST ATTACK:

- Was the predator detected at the time of the attack YES / NO
  - If **YES**, how were you alerted; PREDATOR WAS SEEN / PREDATOR WAS HEARD / DOGS / LIVESTOCK MADE NOISE / NEIGHBOR(S) / OTHER ______________
  - If **YES**, how did you respond CHASED / NO RESPONSE / SHOUTING / TORCH / DOGS / NEIGHBORS ASSISTED/ OTHER ______________
- Which predator do they think was responsible LION / LEOPARD / CHEETAH / SPOTTED HYENA / WILD DOG, JACKAL / OTHER ______________
- Evidence **interviewee** gives of conflict species; SEEN IN BOMA / SEEN ON THE KILL / KILL STYLE / SEEN NEAR LIVESTOCK / INFORMED BY SOMEONE / TRACKS / OTHER ___________
- Number of predators_________ Number of Adults________ Number of Young__________

FOR ALL ATTACKS IN THE PAST YEAR

- Which predator(s) have you identified as responsible for attacks on livestock in this past year?
  Please select all that apply: LION / LEOPARD / CHEETAH / SPOTTED HYENA / WILD DOG / JACKAL / OTHER ______________
- Evidence **interviewee** gives of conflict species
  Please select all that apply: SEEN IN BOMA / SEEN ON THE KILL / KILL STYLE /
  SEEN NEAR LIVESTOCK / INFORMED BY SOMEONE / TRACKS / OTHER ___________
- Was there adequate evidence provided by the interviewee to correctly identify the species? YES / NO

LIVESTOCK INFORMATION (*Other: donkey, dog, camel, chickens, etc.*) (Please ask interviewee to consider ALL livestock killed or injured in the past YEAR)

- Number of livestock KILLED CATTLE, _________GOAT, ________SHEEP, _________Other_______
- Age of livestock KILLED CATTLE, _________GOAT, _________SHEEP, ________Other _______
  - Number of ADULT livestock ***in herd/boma that was attacked***; CATTLE______GOAT ______SHEEP_____
  - Number of ***less than 3 mo old*** livestock ***in herd/boma***: CALF______GOAT ______SHEEP ______

GRAZING INFORMATION (*ONLY IF ATTACK HAPPENED IN THE GRAZING AREA AWAY FROM BOMA*)

- Number of herders, donkeys, and dogs ***with*** herd attacked; HERDERS ______, DONKEYS ______, DOGS ____
- How close was the donkey(s) / dog(s) / herder(s) to the animal attacked; VERY CLOSE / NEAR / FAR
  (Very close = less than 10m, Close = less than 20m, Far = greater than 20m)

BOMA INFORMATION (*ONLY FILL IF ATTACK HAPPENED INSIDE MANYATTA/SHAMBA*)

- Type of fencing: LIVE FENCE/ THORN or DEAD-WOOD FENCE / CHAIN LINK / BARB-WIRE / WIRE STRAND / WOOD-RAIL / OTHER ____
- Rating of **Overall** for protecting against predators; 1 / 2 / 3
  (1= many holes, short, weak door, 2=basic protection, good structure, less holes, 3 = predator proof)
  (Note: ask if there were changes to the fence after the attack)

GAME INFORMATION

Do you graze livestock: ON THE PROPERTY WHERE THE ATTACK OCCURRED / ON PUBLIC PROPERTY / ON NEIGHBORS' PLOTS
Do you regularly see wildlife grazing ***on your property***? YES / NO
Do you regularly see wildlife ***in your grazing area***? YES / NO

How often do you see the following either **on your property/grazing area** (Use empty rows for others);
N=Never, Y=Yearly, M=Monthly, W=Weekly, D=Daily

Buffalo	Bushbuck	Dikdik	Eland	Grants	Hartebeeste	Impala	Rabbits /hare
Thommy	Waterbuck	Warthog	Wild Pig	Zebra	Other	Other	Other

How often do you see the following predators either **on your property/grazing area** (Identify the others);
N=Never, Y=Yearly, M=Monthly, W=Weekly, D=Daily

Cheetah	Jackal	Lion	Striped Hyena	Spotted Hyena	Wild Dog
Serval	Caracal	Leopard	Other	Other	Other

Please tell the person you are interviewing… '*Action for Cheetahs in Kenya is seeking a method to evaluate the presence of predators in your area. These questions will ask about recent livestock loss and predator sightings. There may be overlap of some questions answered in previous interviews, but these questions are essential to this study. Please answer questions to the best of your ability. Personal information such as names and livestock numbers will not be released. You may decline to answer any questions. We thank you for your time and participation.*'

- *Ideally, interview head of household or the person who is most aware of the issues of the herd.*
- *Fill in **every answer** either by filling the **line** provided or **circling** the appropriate answer(s).*
- *Only if the question does not apply to the situation use **N/A***
- *If the interviewee does not know the answer write **DK** or prefers not to answer any question use **X***

Appendix C. Encounters, total count, and abundance of wild prey and domestic livestock species sighted over four-month transect season in Meibae and Salama. Abundance was calculated as a measure of capture-per-unit-effort (mean number of individuals sighted in region per survey month). Sheep and goats were combined under the collective term 'shoat'.

Site	Species type	Species	Encounters	Total count	Relative abundance
Salama	Wild	Baboon, Olive (*Papio anubis*)	12	222	55.5
		Buffalo, African (*Syncerus caffer*)	3	15	3.75
		Bushbuck (*Tragelaphus scriptus*)	5	9	2.25
		Bustard, Kori (*Ardeotis kori*)	2	4	1
		Dikdik, Gunther's (*Madoqua guentheri*)	47	88	22
		Duiker, Common (*Sylvicapra grimmia*)	5	7	1.75
		Giraffe (*Giraffa camelopardalis*)	1	5	1.25
		Gazelle, Grant's (*Nanger granti)*	3	10	2.5
		Gazelle, Thompson's (*Eudorcas thomsonii*)	20	76	19
		Guineafowl, Helmeted (*Numida meleagris*) and Vulturine (*Acryllium vulturinum*)	16	164	41
		Hare, Cape (*Lepus capensis*)	5	5	1.25
		Hartbeest, Coke's (*Alcelaphus buselaphus*)	3	20	5
		Impala (*Aepyceros melampus*)	7	61	15.25
		Monkey, Vervet (*Cercopithecus aethiops*)	20	226	56.5
		Ostrich, Common (*Struthio camelus*)	1	6	1.5
		Spurfowl, Yellow-necked (*Pternistis leucoscepus*)	47	153	38.25
		Steenbok (*Raphicerus campestris*)	5	5	1.25
		Warthog, Common (*Phacochoerus africanus*)	3	20	5
		Wildebeest, Blue (*Connochaetes taurinus*)	4	54	13.5
		Zebra, Plains (*Equus quagga*)	4	45	11.25
		Total wild	**213**	**1195**	**298.75**
	Domestic	Cow (*Bos taurus*)	5	99	24.75
		Shoat (*Capra aegagrus* and *Ovis aries*)	1	6	1.5
		Total domestic	**6**	**105**	**26.25**
Meibae	Wild	Baboon, Olive (*Papio anubis*)	7	190	47.5
		Dikdik, Gunther's (*Madoqua guentheri*)	77	189	47.25
		Gerenuk (*Litocranius walleri*)	64	295	73.75
		Gazelle, Grant's (*Nanger granti*)	13	56	14
		Zebra, Grevy's (*Equus grevyi*)	13	152	38
		Guineafowl, Helmeted (*Numida meleagris*) and Vulturine (*Acryllium vulturinum*)	14	405	101.25
		Hare, Cape (*Lepus capensis*)	24	33	8.25
		Impala (*Aepyceros melampus*)	3	34	8.5
		Kudu, Lesser (*Tragelaphus imberbis*)	3	6	1.5
		Ostrich, Somali (*Struthio molybdophanes*)	45	164	41
		Warthog, Common (*Phacochoerus africanus*)	28	135	33.75
		Total wild	**291**	**1659**	**414.75**
	Domestic	Camel (*Camelus dromedarius*)	42	542	135.5
		Cow (*Bos taurus*)	49	1891	472.75
		Donkey (*Equus africanus*)	32	225	56.25
		Shoat (*Capra aegagrus* and *Ovis aries*)	59	6849	1712.25
		Total domestic	**182**	**9507**	**2376.75**

Appendix D. Model intercepts and coefficient estimates (β) with 95% confidence interval used to predict model averaged estimates of site use probabilities for spotted hyaena (*Crocuta crocuta*) and black-backed jackal (*Canis mesomelas*) in the Salama and Meibae areas of Kenya.

Model	Model weight	Parameter	β Estimate	Lower 95% CI	Upper 95% CI
Spotted hyaena					
$p_{Region}\ \Psi_{.}$	0.21	*p* Intercept	0.04	–0.60	0.68
		p Study area	–1.69	–2.95	–0.43
		Ψ Intercept	0.58	–0.40	1.55
$p_{Region}\ \Psi_{Livestock}$	0.10	*p* Intercept	0.04	–0.60	0.68
		p Study area	–1.47	–2.85	–0.09
		Ψ Intercept	0.44	–0.52	1.41
		Livestock	0.52	–0.52	1.57
$p_{Region}\ \Psi_{\%\ Cover}$	0.08	*p* Intercept	0.05	–0.58	0.68
		p Study area	–1.72	–2.97	–0.47
		Ψ Intercept	0.61	–0.39	1.62
		% Cover	–0.37	–1.36	0.63
$p_{Region}\ \Psi_{\%Cover+Livestock}$	0.08	*p* Intercept	0.04	–0.60	0.68
		p Study area	–1.40	–2.79	0.00
		Ψ Intercept	0.45	–0.57	1.47
		% Cover	–0.81	–2.06	0.44
		Livestock	1.00	–0.38	2.38
$p_{Region}\ \Psi_{Settlement}$	0.07	*p* Intercept	0.05	–0.59	0.68
		p Study area	–1.86	–3.17	–0.55
		Ψ Intercept	0.77	–0.55	2.09
		Settlement	0.43	–1.22	2.08
$p_{Region}\ \Psi_{Prey}$	0.06	*p* Intercept	0.04	–0.60	0.68
		p Study area	–1.68	–2.94	–0.42
		Ψ Intercept	0.57	–0.40	1.55
		Prey	–0.13	–1.34	1.08
$p_{.}\ \Psi_{\%Cover+Livestock}$	0.04	*p* Intercept	–0.26	–0.84	0.32
		Ψ Intercept	0.36	–0.72	1.43
		% Cover	–0.83	–2.04	0.38
		Livestock	1.41	–0.28	3.11
$p_{.}\ \Psi_{Livestock}$	0.04	*p* Intercept	–0.25	–0.82	0.32
		Ψ Intercept	0.29	–0.64	1.22
		Livestock	0.86	–0.30	2.01
$p_{Region}\ \Psi_{Settlement+Livestock}$	0.03	*p* Intercept	0.05	–0.57	0.68
		p Study area	–1.70	–3.25	–0.16
		Ψ Intercept	0.62	–0.74	1.97
		Settlement	0.48	–1.34	2.30
		Livestock	0.55	–0.50	1.60
$p.\ \Psi_{.}$	0.03	*p* Intercept	–0.26	–0.84	0.32
		Ψ Intercept	0.23	–0.60	1.05
$p_{Region}\ \Psi_{Prey+Livestock}$	0.02	*p* Intercept	0.04	–0.60	0.68
		p Study area	–1.46	–2.85	–0.08
		Ψ Intercept	0.44	–0.52	1.40
		Prey	–0.08	–1.14	0.98
		Livestock	0.52	–0.53	1.58
$p_{Region}\ \Psi_{\%Cover+Prey+Livestock}$	0.02	*p* Intercept	0.02	–0.63	0.68
		p Study area	–1.39	–2.78	0.00
		Ψ Intercept	0.49	–0.60	1.57
		% Cover	–1.01	–2.46	0.43
		Prey	–0.50	–1.80	0.80
		Livestock	1.11	–0.43	2.66

Continued on p. 20

Appendix D (continued)

Model	Model weight	Parameter	β Estimate	Lower 95% CI	Upper 95% CI
$p_{Region}\ \Psi_{\%Cover+Prey}$	0.02	*p* Intercept	0.05	–0.59	0.68
		p Study area	–1.71	–2.95	–0.47
		Ψ Intercept	0.63	–0.40	1.65
		% Cover	–0.50	–1.62	0.62
		Prey	–0.41	–1.74	0.91
$p_{Region}\ \Psi_{Settlement+Prey}$	0.02	*p* Intercept	0.05	–0.59	0.68
		p Study area	–1.93	–3.12	–0.74
		Ψ Intercept	0.98	–0.47	2.44
		Settlement	0.89	–1.15	2.92
		Prey	–0.58	–2.07	0.92
$p_{Region}\ \Psi_{\%Cover+Settlement}$	0.02	*p* Intercept	0.05	–0.58	0.68
		p Study area	–1.78	–3.17	–0.39
		Ψ Intercept	0.67	–0.59	1.93
		% Cover	–0.33	–1.46	0.80
		Settlement	0.14	–1.54	1.82
$p.\ \Psi_{\%Cover+Settlement+Livestock}$	0.02	*p* Intercept	–0.39	–1.05	0.28
		Ψ Intercept	0.87	–1.67	3.41
		%Cover	–1.50	–4.11	1.12
		Settlement	–0.75	–2.60	1.09
		Livestock	2.21	–1.76	6.17
$p_{Region}\ \Psi_{\%Cover+Settlement+Livestock}$	0.02	*p* Intercept	0.02	–0.63	0.68
		p Study area	–1.30	–2.82	0.22
		Ψ Intercept	0.43	–0.59	1.45
		% Cover	–0.91	–2.37	0.55
		Settlement	–0.19	–1.39	1.02
		Livestock	1.06	–0.45	2.57
$p.\ \Psi_{\%Cover+Prey+Livestock}$	0.02	*p* Intercept	–0.29	–0.90	0.32
		Ψ Intercept	0.44	–0.88	1.76
		%Cover	–1.03	–2.47	0.40
		Prey	–0.43	–1.52	0.66
		Livestock	1.66	–0.66	3.98
$p.\ \Psi_{Prey+Livestock}$	0.01	*p* Intercept	–0.25	–0.83	0.32
		Ψ Intercept	0.30	–0.64	1.24
		Prey	–0.10	–0.92	0.71
		Livestock	0.86	–0.31	2.03
$p.\ \Psi_{Settlement+Livestock}$	0.01	*p* Intercept	–0.25	–0.83	0.32
		Ψ Intercept	0.29	–0.64	1.23
		Settlement	–0.01	–0.87	0.85
		Livestock	0.85	–0.33	2.03
$p.\ \Psi_{\%Cover}$	0.01	*p* Intercept	–0.26	–0.84	0.32
		Ψ Intercept	0.23	–0.60	1.05
		% Cover	–0.23	–1.01	0.55
$p.\ \Psi_{Settlement}$	0.01	*p* Intercept	–0.26	–0.84	0.32
		Ψ Intercept	0.23	–0.60	1.06
		Settlement	–0.23	–1.02	0.56
$p.\ \Psi_{\%Cover+Settlement+Prey+Livestock}$	0.01	*p* Intercept	–0.59	–1.09	–0.08
		Ψ Intercept	3.86	–3.79	11.52
		% Cover	–3.79	–10.75	3.17
		Settlement	–2.81	–8.80	3.18
		Prey	–1.48	–5.01	2.04
		Livestock	6.77	–4.97	18.51

Continued on p. 21

Appendix D (continued)

Model	Model weight	Parameter	β Estimate	Lower 95% CI	Upper 95% CI
$p_{.}\ \Psi_{Prey}$	0.01	*p* Intercept	–0.26	–0.84	0.32
		Ψ Intercept	0.23	–0.60	1.06
		Prey	–0.13	–0.94	0.68
$p_{Region}\ \Psi_{Settlement+Prey+Livestock}$	0.01	*p* Intercept	0.06	–0.57	0.68
		p Study area	–1.88	–3.12	–0.64
		Ψ Intercept	0.94	–0.68	2.56
		Settlement	1.13	–1.42	3.67
		Prey	–0.56	–2.11	0.99
		Livestock	0.56	–0.53	1.64
$p_{Region}\ \Psi_{\%Cover+Settlement+Prey}$	0.01	*p* Intercept	0.05	–0.59	0.68
		p Study area	–1.88	–3.10	–0.67
		Ψ Intercept	0.91	–0.51	2.34
		% Cover	–0.44	–1.72	0.85
		Settlement	0.59	–1.40	2.59
		Prey	–0.71	–2.41	1.00
$p_{.}\ \Psi_{\%Cover+Settlement}$	0.00	*p* Intercept	–0.25	–0.82	0.32
		Ψ Intercept	0.22	–0.62	1.05
		% Cover	–0.45	–1.38	0.47
		Settlement	–0.46	–1.39	0.46
$p_{Region}\ \Psi_{\%Cover+Settlement+Prey+Livestock}$	0.00	*p* Intercept	0.01	–0.68	0.70
		p Study area	–1.30	–3.00	0.40
		Ψ Intercept	0.47	–0.63	1.56
		% Cover	–1.07	–2.73	0.58
		Settlement	–0.13	–1.63	1.36
		Prey	–0.47	–1.74	0.81
		Livestock	1.18	–0.65	3.00
$p_{.}\ \Psi_{\%Cover+Prey}$	0.00	*p* Intercept	–0.26	–0.84	0.32
		Ψ Intercept	0.23	–0.60	1.07
		% Cover	–0.29	–1.12	0.53
		Prey	–0.23	–1.10	0.64
$p_{.}\ \Psi_{Settlement+Prey+Livestock}$	0.00	*p* Intercept	–0.25	–0.83	0.32
		Ψ Intercept	0.30	–0.64	1.24
		Settlement	0.00	–0.87	0.87
		Prey	–0.10	–0.92	0.72
		Livestock	0.86	–0.33	2.05
$p_{.}\ \Psi_{Settlement+Prey}$	0.00	*p* Intercept	–0.26	–0.84	0.32
		Ψ Intercept	0.23	–0.60	1.06
		Settlement	–0.22	–1.02	0.59
		Prey	–0.09	–0.91	0.73
$p_{.}\ \Psi_{\%Cover+Settlement+Prey}$	0.00	*p* Intercept	–0.25	–0.82	0.33
		Ψ Intercept	0.22	–0.62	1.06
		% Cover	–0.52	–1.48	0.45
		Settlement	–0.46	–1.40	0.47
		Prey	–0.22	–1.08	0.64
Black-backed jackal					
$p_{.}\ \Psi_{Livestock}$	0.22	*p* Intercept	–0.16	–0.81	0.49
		Ψ Intercept	–0.35	–1.23	0.52
		Livestock	0.98	–0.13	2.09
$p_{.}\ \Psi_{Settlement+Livestock}$	0.08	*p* Intercept	–0.17	–0.83	0.49
		Ψ Intercept	–0.36	–1.27	0.54
		Settlement	–0.39	–1.30	0.52
		Livestock	0.89	–0.28	2.07

Continued on p. 22

Appendix D (continued)

Model	Model weight	Parameter	β Estimate	Lower 95% CI	Upper 95% CI
$p_{Region}\ \Psi_{Livestock}$	0.08	*p* Intercept	–0.26	–0.97	0.45
		p g1	0.66	–1.09	2.41
		Ψ Intercept	–0.36	–1.25	0.54
		Livestock	1.05	–0.15	2.24
$p_{.}\ \Psi_{.}$	0.07	*p* Intercept	–0.09	–0.42	0.24
		Ψ Intercept	–0.18	–0.56	0.21
$p_{.}\ \Psi_{\%Cover+Livestock}$	0.07	*p* Intercept	–0.16	–0.81	0.49
		Ψ Intercept	–0.37	–1.25	0.51
		% Cover	0.29	–0.77	1.36
		Livestock	0.86	–0.29	2.02
$p_{.}\ \Psi_{Settlement}$	0.06	*p* Intercept	–0.17	–0.83	0.48
		Ψ Intercept	–0.41	–1.23	0.42
		Settlement	–0.63	–1.53	0.27
$p_{.}\ \Psi_{Prey+Livestock}$	0.06	*p* Intercept	–0.16	–0.82	0.49
		Ψ Intercept	–0.35	–1.23	0.53
		Prey	–0.04	–0.93	0.85
		Livestock	0.99	–0.13	2.11
$p_{.}\ \Psi_{\%Cover}$	0.06	*p* Intercept	–0.19	–0.85	0.48
		Ψ Intercept	–0.40	–1.23	0.43
		% Cover	0.70	–0.48	1.89
$p_{Region}\ \Psi_{Settlement+Livestock}$	0.03	*p* Intercept	–0.29	–1.02	0.44
		p g1	0.71	–1.01	2.44
		Ψ Intercept	–0.35	–1.30	0.59
		Settlement	–0.42	–1.34	0.50
		Livestock	0.97	–0.34	2.28
$p_{Region}\ \Psi_{\%Cover+Livestock}$	0.02	*p* Intercept	–0.18	–0.85	0.48
		Ψ Intercept	–0.41	–1.25	0.43
		% Cover	0.45	–0.78	1.68
		Settlement	–0.41	–1.42	0.59
$p_{Region}\ \Psi_{.}$	0.02	*p* Intercept	–0.21	–0.88	0.46
		p g1	0.42	–1.69	2.52
		Ψ Intercept	–0.40	–1.17	0.37
$p_{Region}\ \Psi_{\%Cover+Livestock}$	0.02	*p* Intercept	–0.26	–0.97	0.45
		p g1	0.66	–1.08	2.41
		Ψ Intercept	–0.38	–1.27	0.52
		% Cover	0.29	–0.73	1.32
		Livestock	0.92	–0.30	2.15
$p_{.}\ \Psi_{\%Cover+Settlement+Livestock}$	0.02	*p* Intercept	–0.17	–0.82	0.49
		Ψ Intercept	–0.37	–1.28	0.53
		% Cover	0.11	–1.05	1.27
		Settlement	–0.34	–1.36	0.67
		Livestock	0.86	–0.36	2.07
$p_{.}\ \Psi_{Settlement+Prey+Livestock}$	0.02	*p* Intercept	–0.17	–0.83	0.49
		Ψ Intercept	–0.36	–1.27	0.54
		Settlement	–0.39	–1.31	0.53
		Prey	0.00	–0.88	0.88
		Livestock	0.89	–0.29	2.08
$p_{.}\ \Psi_{Prey}$	0.02	*p* Intercept	–0.18	–0.83	0.48
		Ψ Intercept	–0.36	–1.14	0.42
		Prey	0.01	–0.80	0.81

Continued on p. 23

Appendix D (continued)

Model	Model weight	Parameter	β Estimate	Lower 95% CI	Upper 95% CI
p_{Region} $\Psi_{Settlement}$	0.02	*p* Intercept	–0.25	–0.94	0.45
		p g1	0.59	–1.23	2.42
		Ψ Intercept	–0.44	–1.25	0.37
		Settlement	–0.66	–1.56	0.24
p_{Region} $\Psi_{Prey+Livestock}$	0.02	*p* Intercept	–0.26	–0.98	0.45
		p g1	0.66	–1.09	2.42
		Ψ Intercept	–0.35	–1.25	0.55
		Prey	–0.06	–0.94	0.83
		Livestock	1.06	–0.16	2.27
p_{Region} $\Psi_{\%Cover}$	0.02	*p* Intercept	–0.22	–0.90	0.46
		p g1	0.46	–1.56	2.49
		Ψ Intercept	–0.43	–1.24	0.37
		% Cover	0.66	–0.40	1.72
$p.$ $\Psi_{\%Cover+Prey+Livestock}$	0.02	*p* Intercept	–0.16	–0.81	0.49
		Ψ Intercept	–0.37	–1.26	0.51
		% Cover	0.29	–0.78	1.36
		Prey	–0.02	–0.91	0.88
		Livestock	0.86	–0.30	2.03
$p.$ $\Psi_{Settlement+Prey}$	0.02	*p* Intercept	–0.17	–0.83	0.48
		Ψ Intercept	–0.41	–1.24	0.42
		Settlement	–0.64	–1.54	0.27
		Prey	0.06	–0.76	0.88
$p.$ $\Psi_{\%Cover+Prey}$	0.02	*p* Intercept	–0.19	–0.85	0.48
		Ψ Intercept	–0.40	–1.23	0.43
		% Cover	0.72	–0.49	1.92
		Prey	0.07	–0.75	0.89
p_{Region} $\Psi_{\%Cover+Settlement}$	0.01	*p* Intercept	–0.24	–0.94	0.45
		p g1	0.55	–1.33	2.44
		Ψ Intercept	–0.44	–1.26	0.38
		% Cover	0.40	–0.73	1.52
		Settlement	–0.45	–1.46	0.56
p_{Region} $\Psi_{\%Cover+Settlement+Livestock}$	0.01	*p* Intercept	–0.29	–1.02	0.45
		p g1	0.71	–1.02	2.43
		Ψ Intercept	–0.36	–1.30	0.58
		% Cover	0.09	–1.03	1.22
		Settlement	–0.38	–1.42	0.66
		Livestock	0.93	–0.41	2.28
p_{Region} $\Psi_{Settlement+Prey+Livestock}$	0.01	*p* Intercept	–0.29	–1.03	0.45
		p g1	0.71	–1.01	2.44
		Ψ Intercept	–0.35	–1.30	0.60
		Settlement	–0.42	–1.34	0.50
		Prey	–0.02	–0.89	0.85
		Livestock	0.97	–0.36	2.30
p_{Region} Ψ_{Prey}	0.01	*p* Intercept	–0.21	–0.88	0.46
		p g1	0.42	–1.69	2.52
		Ψ Intercept	–0.40	–1.17	0.37
		Prey	0.00	–0.77	0.76
$p.$ $\Psi_{\%Cover+Settlement+Prey}$	0.01	*p* Intercept	–0.18	–0.85	0.48
		Ψ Intercept	–0.41	–1.26	0.43
		% Cover	0.46	–0.78	1.70
		Settlement	–0.42	–1.42	0.59
		Prey	0.09	–0.74	0.91

Continued on p. 24

Appendix D (continued)

Model	Model weight	Parameter	β Estimate	Lower 95% CI	Upper 95% CI
$p_{Region}\ \Psi_{Settlement+Prey}$	0.00	*p* Intercept	–0.25	–0.94	0.45
		p g1	0.59	–1.24	2.42
		Ψ Intercept	–0.44	–1.25	0.37
		Settlement	–0.66	–1.57	0.24
		Prey	0.04	–0.72	0.81
$p_{Region}\ \Psi_{\%Cover+Prey+Livestock}$	0.00	*p* Intercept	–0.26	–0.97	0.45
		p g1	0.67	–1.08	2.41
		Ψ Intercept	–0.38	–1.27	0.52
		% Cover	0.29	–0.74	1.32
		Prey	–0.03	–0.92	0.85
		Livestock	0.93	–0.31	2.17
$p.\ \Psi_{\%Cover+Settlement+Prey+Livestock}$	0.00	*p* Intercept	–0.17	–0.82	0.49
		Ψ Intercept	–0.37	–1.28	0.53
		% Cover	0.11	–1.05	1.28
		Settlement	–0.35	–1.37	0.67
		Prey	0.01	–0.88	0.89
		Livestock	0.86	–0.37	2.08
$p_{Region}\ \Psi_{\%Cover+Prey}$	0.00	*p* Intercept	–0.22	–0.90	0.46
		p g1	0.46	–1.58	2.49
		Ψ Intercept	–0.44	–1.25	0.37
		% Cover	0.67	–0.40	1.75
		Prey	0.06	–0.72	0.84
$p_{Region}\ \Psi_{\%Cover+Settlement+Prey}$	0.00	*p* Intercept	–0.24	–0.93	0.45
		p g1	0.55	–1.35	2.44
		Ψ Intercept	–0.44	–1.27	0.38
		% Cover	0.41	–0.73	1.54
		Settlement	–0.45	–1.46	0.56
		Prey	0.07	–0.71	0.85
$p_{Region}\ \Psi_{\%Cover+Settlement+Prey+Livestock}$	0.00	*p* Intercept	–0.29	–1.02	0.45
		p g1	0.71	–1.02	2.44
		Ψ Intercept	–0.36	–1.31	0.59
		% Cover	0.09	–1.04	1.22
		Settlement	–0.38	–1.42	0.66
		Prey	–0.01	–0.88	0.86
		Livestock	0.93	–0.43	2.30