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Human–wildlife conflict and coexistence: a case study from Senkele Swayne’s Hartebeest Sanctuary in Ethiopia

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Human–wildlife conflict presents major challenges to both wildlife managers and rural livelihoods. Here, we investigated human–wildlife conflict in and around Senkele Swayne’s Hartebeest Sanctuary (SSHS). We estimated the densities of wild animals within SSHS and conducted questionnaire interviews about livestock predation and crop raiding patterns with individuals in 378 households occurring <3000 m outside the Sanctuary’s borders. Respondents reported that hyenas *Crocuta crocuta* and African wolves *Canis anthus* were the only livestock predators and were responsible for combined losses of ~ 10% (29 207 USD) of their livestock over a three-year period. Hyenas preyed on cattle, goats, sheep, donkeys and horses, whereas African wolves targeted only goats and sheep. Hyena predation occurred both inside and outside SSHS, whereas African wolf predation occurred mainly near the inside periphery of the sanctuary. Most (58%) of the respondents experienced crop raiding of their farms by Swayne’s hartebeest *Alcelaphus buselaphus swaynei*, warthogs *Phacochoerus africanus* and/or crested porcupines *Hystrix cristata*. Nearly two-thirds (64%) of the crop raiding occurred 1–1500 m from the sanctuary. Potatoes and maize were the most commonly raided crops. Local communities used guarding, patrolling, loud noises, smoky fires, flashes of light, fences and trenches as deterrence methods. Of the crop raiding species, only Swayne’s hartebeests were regarded positively, while warthogs and crested porcupines were viewed negatively by respondents. We conclude that although SSHS is of critical conservation value to the Swayne’s hartebeest, the surrounding communities endure significant livestock predation and crop raiding by wild animals sheltered in the sanctuary. The survival of this relict population of Swayne’s hartebeest in the sanctuary remains at risk unless the human–wildlife conflict in surrounding areas is resolved. This calls for site-specific measures in consultation with the local community.

Keywords: crop raiding, density, livestock predation, questionnaire interviews, Swayne’s hartebeest

While humans and wildlife have a long history of co-existence, the frequency of human wildlife conflicts has risen in recent decades, especially in the tropics (Eustace et al. 2018, Mbise et al. 2018). This increase has mainly been driven by the growth of the Earth’s human population and consequent expansion of human activities into wildlife habitats (Lyamuya et al. 2014), along with the inability of local stakeholders and wildlife managers to mediate such conflicts (Seoraj-Pillai and Pillay 2016, Atickem et al. 2017, Eustace et al. 2018). Human–wildlife conflict is now regarded

as one of the main obstacles to successful wildlife management, especially outside of protected areas (Eustace et al. 2018). The two main causes of human–wildlife conflict in most regions of the tropics are livestock predation and crop raiding (Distefano 2005, Inskip and Zimmermann 2009).

Previous studies have revealed that the intensity and economic toll of livestock predation varies widely between areas. For instance, in Kenya, within two private ranches adjacent to the boundary of Tsavo East National Park, three carnivores – lions *Panthera leo*, spotted hyenas *Crocuta crocuta* and cheetahs *Acynonyx jubatus* – were responsible for most of the predation of domestic animals (Patterson et al. 2004). The combined area of the ranches totals 690 km², and they have lost an average of 2.4% of the total herd per annum, amounting to economic losses of 8749 USD per annum over a four-year period (Patterson et al. 2004).

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Further, a study in the 1040 km² Golan grassland plateau, Israel found that golden jackal *Canis aureus* predation accounted for the loss of 1.5–1.9% of the calves born each year on local farms, where jackal density had increased 10-fold within a decade, resulting in economic losses of ~42 000 USD per year (Yom-Tov et al. 1995). Lastly, in the 2150 km² Bale Mountains of southern Ethiopia, a total of 704 livestock were reported to have been killed by wild carnivores – primarily spotted hyenas, leopards *Panthera pardus*, and African wolves *Canis anthus* – causing an estimated 13 054 USD in economic losses over a 3-year period (Atickem et al. 2010).

Communities close to protected areas suffer not only from livestock predation, but also from crop raiding which is frequently the biggest cause of conflict (Treves et al. 2006, Graham et al. 2009). Unlike livestock predation, which is carried out by carnivores, crop raiding is typically done by herbivores, omnivores, rodents and birds (Weladji and Tchamba 2003, Inskip and Zimmermann 2009, Sserwanga 2018). Agricultural fields adjacent to wildlife habitats in tropical ecosystems are especially susceptible to crop raiding (Distefano 2005). For example, near the 2410 km² Xishuang Banna Nature Reserve in China, Asian elephants *Elephas maximus* were responsible for large-scale crop and property damage, causing 314 600 USD in economic losses over a four-year period (Distefano 2005). The degree of crop raiding varies widely depending upon the types of crops planted and the specific wildlife species involved (Ogra 2008, Mwakatobe et al. 2014, Gobosho et al. 2015). For instance, crops raided by elephants *Loxodonta africana*, olive baboons *Papio anubis*, bush pigs *Potamochoerus larvatus*, warthogs *Phacochoerus africanus*, grivet monkeys *Cercopithecus aethiops* and crested porcupines *Hystrix cristata* in Gera, southern Ethiopia included food grains such as wheat, rice, bananas and fruit (Gobosho et al. 2015), whereas warthogs at Bénoué Wildlife Conservation Area in north Cameroon raided mainly maize and millet (Weladji and Tchamba 2003).

Understanding the nature and extent of human–wildlife conflict is known to be an important precondition for both effective wildlife management and the spatiotemporal co-existence of wildlife and humans (Mekonnen et al. 2019). In particular, to develop and implement management plans to mitigate human–wildlife conflict, detailed studies of crop raiding by herbivores and/or livestock predation by carnivores must be carried out, often involving systemic and intensive interviews with local informants (Treves et al. 2006, Inskip and Zimmermann 2009, Seoraj-Pillai and Pillay 2016). In this study, we explored human–wildlife conflict in and around Senkele Swayne’s Hartebeest Sanctuary (SSHS), a small protected area in southern Ethiopia where a relict population of the Ethiopian endemic Swayne’s hartebeest persists. Along with Maze National Park (Tamrat et al. 2020), SSHS is one of the only two sites where this endangered species remains extant (IUCN 2017). SSHS is also home to a variety of other herbivorous, omnivorous and carnivorous mammals, and is set in a human-dominated landscape where local people engage in farming and livestock husbandry. The demand for agricultural expansion and rangelands for livestock grazing by local communities often creates conflict with the conservation priorities of the SSHS.

The loss of livestock and crops from wildlife have furthered tensions between the local community and the Sanctuary (Nobuko 2004).

Though the local community is permitted to utilize the Sanctuary for livestock grazing, (Lewis and Wilson 1977, Lewis and Wilson 1979, Gebre and Yirga 2004), human–wildlife conflicts related to livestock predation and crop raiding in and around the sanctuary has not been previously studied. In this study, we aim to determine the: 1) abundance of livestock predators and crop raiding species, 2) extent of livestock predation at varying distance intervals from the center of the sanctuary, 3) extent of crop raiding by different wildlife species at varying distance intervals from the center of the sanctuary, 4) main crop types being raided and their stages of crop growth at the time of raiding, 5) different methods used by local farmers to deter crop raiders at varying distance intervals from the center of the sanctuary and 6) local farmers’ attitudes towards the various wildlife species at the sanctuary, particularly crop raiders.

Material and methods

Study area

Senkele Swayne’s Hartebeest Sanctuary (SSHS) was established by the Ethiopian Wildlife Conservation Organization in 1976, primarily to protect the endangered Swayne’s hartebeest *Alcelaphus buselaphus swaynei* endemic to southern Ethiopia (Lewis and Wilson 1979). SSHS is located between 7°07′–7°12′N and 38°15′–38°19′ E along the western side of the Great Rift Valley at altitudes ranging from 1904 to 2211 m a.s.l. The sanctuary is the smallest protected area (55.9 km²) in Ethiopia. Its monthly maximum and minimum temperatures range from 21–26°C and 8–15°C, respectively (Lemessa 2015), while annual rainfall ranges from 600 to 1200 mm and is bimodal in pattern (Lemessa 2015). A typical annual cycle consists of a dry season extending from October to May and a heavy rainy season extending from June to September (Lemessa 2015). In some years, a short rainy season may occur in March and/or April as well, interrupting the long dry season (Lemessa 2015). Mammals that occur in SSHS include Swayne’s hartebeest, bohor reedbuck *Redunca redunca*, warthogs, oribi *Ourebia ourebi*, African wolves, spotted hyenas, anubis baboons *Papio anubis*, vervet monkeys *Chlorocebus pygerythrus* and several rodent species (Nobuko 2004).

SSHS is encircled by human settlement except to the east which is dominated by hillsides and valleys covered with natural vegetation. The main vegetation type in the sanctuary is montane savanna, consisting of several different habitat types, including savanna woodland, open grassland and open shrubland. The savanna woodland occurs only around the center of the sanctuary (Mamo et al. 2012). The local community consists of agro-pastoral people whose economy depends on both livestock rearing and crop-based agriculture (Nobuko 2004). Cattle, sheep, goats, donkeys and horses are the main livestock species maintained in the area. The local people and their livestock enter the sanctuary throughout the year (Tamrat unpubl.).

The main crops planted by the local community are maize *Zea mays*, cabbage *Brassica oleracea*, potatoes *Solanum tuberosum*, finger-millet *Eleusine coracana*, ensete *Ensete ventricosum* and beans *Vicia faba*. Maize and finger-millet are planted from late April to early May and harvested in September and October. Beans are planted in June and harvested in October and November. Potatoes are planted twice a year, in late April to early May and in late August to early September, and are harvested in July to August and December to January, respectively. Cabbage and ensete are planted in June and July and are harvested throughout the dry season. Crops in the fields surrounding the sanctuary experience frequent raiding by wildlife from the sanctuary (Lewis and Wilson 1977, 1979, Gebre and Yirga 2004).

Carnivore abundance

To investigate carnivore abundance in SSSH, we applied the call-up method (Omoya et al. 2014, Midlane et al. 2015). We established one calling station near the center of the sanctuary (station 1) and another on the sanctuary periphery close to a village (station 2). Spacing the calling stations 5 km apart helped to avoid double counting (Fig. 1B). During call-ups, we used audio files of gnu *Connochaetes gnou*-hyena distress, jackal and hyena-jackal sounds (these recordings can be accessed in Supplementary material Appendix 1). Calls were broadcasted at each station continuously at full volume using a MP3 player connected to a mega-phone (Monacor TM-45) from the roof of a vehicle. Each call-up consisted of two cycles of 20 min of playbacks each followed by 10 min of silence to identify and count the responding carnivores (Yirga et al. 2017). The mega-phone was rotated 90° every five minutes during the broadcast (Yirga et al. 2014). Pieces of beef were placed a few meters from the vehicle to provide an olfactory signal as well. Only spotted hyenas and African wolves responded to the call-ups and meat lures. We counted the responding hyenas and African wolves in the dark based

on both their unique vocalization patterns and eye reflection from the spotlight. M. Tamrat and three trained observers counted the responding carnivores from each of the four sides of the vehicle using powerful torches (creating visibility of up to 20 m) immediately after the last broadcast. The call-ups were repeated eight times at 15-day intervals at each station from October 2018 to December 2018.

Herbivore and omnivore abundance

We used the total census count method (Harcourt and Fossey 1981, Plumptre and Cox 2006) for estimating the abundance of herbivores and omnivores in SSSH in 2017. First, we established seven blocks averaging 7.9 km² each (range: 5.1–10.6 km²) that covered the entirety of the sanctuary (Fig. 1B). We used paved roads that are used for patrolling purposes for demarcating blocks. Counting teams of three–four individuals each, spaced at intervals of 300 m were assigned based on the size of each block. M. Tamrat, the warden, wildlife experts and scouts at the sanctuary comprised the counting group. We spotted and counted herbivores and primates along established transect routes within each block, relying on visual and acoustic cues to locate them (Kie 1988, Caro 2016). The counts were repeated six times (three times during the wet season and three times during the dry season) over a single year.

Questionnaire interviews

Prior to conducting interviews with local people, we carried out random surveys to estimate the distance human–wildlife conflicts extended from the sanctuary. We found that crop raiding events only occurred within 3000 m from the borders of the sanctuary in the western, northern and southern directions. This informed our decision to limit our human–wildlife conflict surveys to households within a 3000 m buffer of the sanctuary in the three directions. No conflict

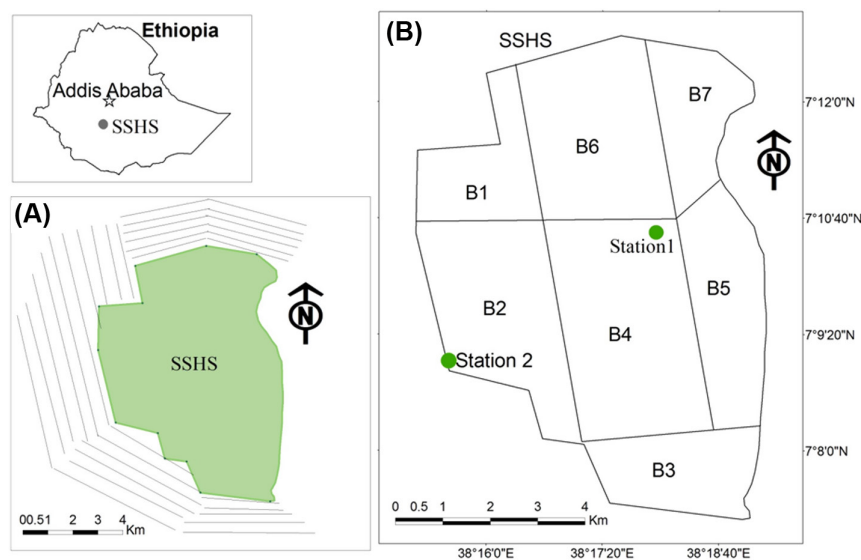


Figure 1. Maps of Senkele Swayne's Hartebeest Sanctuary (SSHS). (A) Depicts transect routes outside the sanctuary. The lines outside SSSH represent distance intervals used for questionnaire interviews. (B) Depicts the seven blocks (B1–B7) established in the sanctuary. We used these blocks for herbivore and omnivore population counts. The two stations used as calling points to estimate carnivore abundances are also depicted.

was reported to the east which consists of natural habitat without human settlement for 5 km beyond the eastern boundaries of the sanctuary. According to Regional Agriculture and Rural Development Office (RARDO) records for 2015 (RARDO, unpubl.), 6873 households encircled the sanctuary in these three directions. We determined the sample size for household interviews following Israel (1992) sample size determination. Hence, the necessary sample size determined at 5% precision and 95% confidence level was 378 households.

We conducted surveys using questionnaires at 500 m intervals from the outside boundary of the sanctuary within the 3000 m buffer previously described (Fig. 1A). At each interval, we conducted interviews at 63 randomly selected households. We trained three teams consisting of sanctuary wildlife experts, guides, scouts and language translators to conduct the questionnaire interviews. We tested the questionnaire before the commencement of actual data collection through a pilot study of 55 respondents in the local community and subsequently made improvements to the questionnaire where necessary (Supplementary material Appendix 2). We preferentially interviewed either the male or female head of each household; however, when both were unavailable, we interviewed the eldest member of the family if he/she was above 18 years old.

The respondents were asked whether they had lost any livestock to carnivore predation during the past three years (2016–2018). If they answered 'yes', we asked a series of questions about the number and type(s) of livestock predated, month, year, approximate time, place of predation and the predator species responsible. Respondents identified the predator based on the following evidence: 1) direct sighting, if the attack happened within the respondent's enclosure and the respondent was made aware of it, often by a dog barking (Atickem et al. 2010); 2) indirect signs, if paw prints or body hair from the predator were left on or near the killed livestock; and/or 3) vocalizations, if they were produced by the carnivore and heard by the respondent.

Whenever owners reported livestock predation outside of their enclosures, we asked them the specific location relative to known physical features such as roads, valleys and camp sites. Based on this information from informants, we recorded the GPS coordinate for each livestock predation location and categorized it as belonging to one of six 500 m distance intervals (1–500, 501–1000, 1001–1500, 1501–2000, 2001–2500 and 2501–3000 m) from the sanctuary. For predation events within the sanctuary, we calculated the negative distance starting from the boundary (0 m) towards the center of the sanctuary (3000 m) and assigned the events to –500 m intervals (–1 to –500 m, –501 to –1000 m, etc.). We asked each informant the numbers of each type of livestock owned by their household. The average value of each livestock was calculated based on the prices of 15 individuals of each livestock variety at local markets.

We also asked each informant about the occurrence of crop raiding on his or her farmland during 2018. If their answer was 'yes', we asked a series of questions regarding the wild animal species involved in crop raiding, types of crops raided, developmental stages of these crops (i.e. seedling, vegetative, flowering or mature), and the months raiding

occurred to better understand the nature of the crop damage experienced. We also asked about the deterrent methods used by informants and members of their households to protect their crops against raiding by wild animals. In particular, we asked each of the informants whether they used guarding, patrolling, loud noises, smoky fires, flashes of light, fences or trenches (Supplementary material Appendix 3) to protect their crops from damage. We also examined the informants' attitudes towards crop feeding wild animal species by asking them to categorize their attitude towards each species as 'positive', 'neutral' or 'negative'.

Data analysis

We used Pearson χ^2 -tests to compare differences in 1) the abundance of predators between the two calling stations, 2) the number of reported livestock kills by each predator species and 3) when reported predations occurred (day or night). To examine livestock predation patterns along 500 m distance intervals from the sanctuary, we used a generalized linear mixed effect model with a Poisson link using number of livestock predated as the response variable. Distance and livestock species were used as fixed effects. We used direction (i.e. the areas located in three directions, Fig. 1A) as a random factor to account for variation among areas. We also used a logistic regression with a generalized linear mixed effect model to predict responses of interviewed households (i.e. yes/no) across distance intervals in relation to 1) crop damage by wildlife species, 2) crops raided in the area and 3) different deterrence techniques applied in the area, analyzed separately. Lastly, crop developmental stages at the time of raiding were analyzed using a generalized linear model with a Poisson link. The number of respondents was used as the response variable. In all models, we used site (i.e. the three directions from the sanctuary) as a random factor to account for variation among areas. All analyses were carried out in R ver. 3.5.1 (<www.r-project.org>).

Results

Carnivore abundance and predation on livestock

A total of 53 hyenas (density = 0.95 ind. km⁻²) and 13 African wolves (density = 0.23 ind. km⁻²) responded to the 16 calls. More hyenas responded at station 2 (on the periphery; n = 32) than at station 1 (in the center; n = 21), though this difference was not statistically significant ($\chi^2 = 0.201$, df = 1, p = 0.654). However, the abundance of African wolves was significantly higher at station 2 (n = 11) than at station 1 (n = 2) ($\chi^2 = 16.858$, df = 1, p < 0.001). In total, 10% of the livestock owned by the people interviewed for our study (n = 378) were reported to have been predated over a three-year period by hyenas and African wolves. Hyenas reportedly killed cattle, sheep, goats, donkeys and horses, whereas African wolves killed only goats and sheep. Livestock worth a local market value of 29 207 USD were reported to have been killed by wild carnivores over the three-year period (n = 378 households, Table 1). Thus, each household lost an estimated 26 USD per year to livestock predation, or

Table 1. Number of livestock predation events by spotted hyenas and African wolves around Senkele Swayne's Hartebeest Sanctuary over a three-year period (2016–2018), according to informants from 378 households near the sanctuary. Financial loss estimates were based on the local market prices (in Ethiopian birr converted to USD) in January 2019 for individuals of each livestock type. The numbers in the parenthesis indicate percentages from totals.

Livestock	Total number	No. predated by hyenas	No. predated by African wolves	Total livestock predated (%)	Costs per head in \$	Total costs in \$
Cattle	6064 (57.4)	556 (57.7)	0 (0.0)	9.2	36	20 016
Sheep	2529 (23.9)	212 (22.0)	67 (69.7)	11.0	18	5022
Goats	1352 (12.8)	115 (11.9)	32 (32.3)	10.9	14	2058
Donkeys	392 (3.7)	43 (4.6)	0 (0.0)	11.0	25	1075
Horses	236 (2.2)	37 (3.8)	0 (0.0)	15.7	28	1036
Total	10 573	963 (90.7)	99 (9.3)	10.0		29 207

2.9% of mean annual per capita GDP in Ethiopia over the same period (Shiferaw 2017).

Hyenas accounted for significantly more livestock predation events than African wolves ($\chi^2=700.02$, $df=1$, $p<0.001$). Hyenas killed many ($n=668$) livestock outside of the sanctuary, while only two sheep were killed by

African wolves outside the sanctuary. All other African wolf kills were inside the sanctuary, though most occurred close to the borders (Fig. 2A). Hyena predation exhibited a trend of decreasing from the periphery towards the center of the sanctuary, whereas outside the sanctuary their predation patterns were nearly consistent across the 500 m intervals out

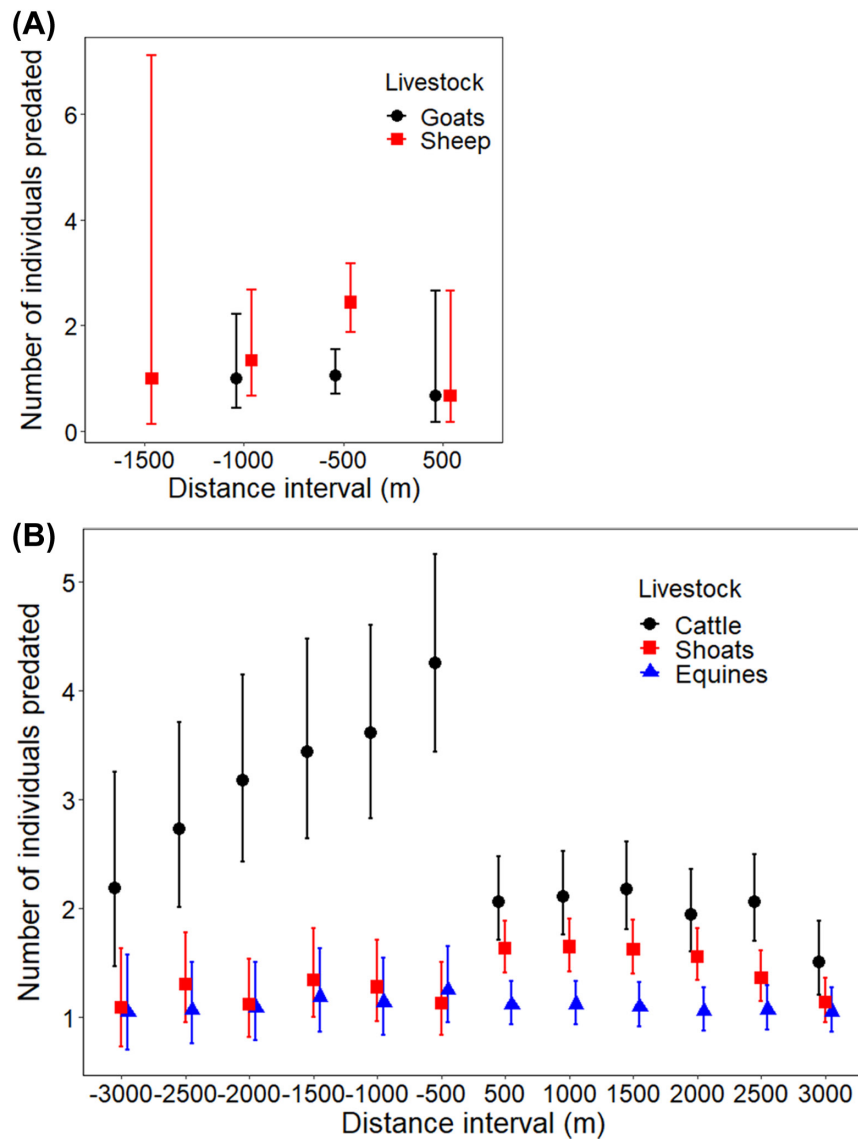


Figure 2. African wolves' (A) and hyenas' (B) predation patterns on livestock at 500 m distance intervals inside and outside of Senkele Swayne's Hartebeest Sanctuary. Negative distance intervals refer to intervals from the border towards the center of the sanctuary. 'Shoats' refers to sheep and goats, and 'Equines' refers to donkeys and horses.

to 3000 m from the sanctuary borders (Fig. 2B). Hyena predation was most common in the wet season (especially June–September), whereas African wolf predation was most common during the dry season (especially January to February, Supplementary material Appendix 4). Livestock predation occurred significantly more often during the night ($n = 850$) than during the day ($n = 212$) (Table 2: $\chi^2 = 383.28$, $df = 1$, $p < 0.001$).

Herbivore and primate population estimates

Among herbivores at SSHS, Swayne's hartebeests had the highest density estimate ($9.32 \text{ ind. km}^{-2}$), followed by warthogs ($3.27 \text{ ind. km}^{-2}$) and oribi ($2.63 \text{ ind. km}^{-2}$), while bohor reedbuck had the lowest density ($0.11 \text{ ind. km}^{-2}$). Both primate species occurred at low densities in the sanctuary (anubis baboons: $0.30 \text{ ind. km}^{-2}$; vervet monkeys: $0.25 \text{ ind. km}^{-2}$) (Supplementary material Appendix 5). Because of their secretive nature, we were unable to detect crested porcupines during our censuses so their density remains known.

Crop raiding

Of the total respondents ($n = 378$), 58.2% reported the occurrence of crop damage. Species reportedly involved in crop raiding were Swayne's hartebeest, warthogs and crested porcupines. The trends in crop damage by these animals varied along the distance gradient from the sanctuary, showing the strongest damage closest to the sanctuary (Fig. 3). More than two-thirds (67.4%) of the reported cases of crop damage occurred within 1500 m of the sanctuary. Warthogs caused the most crop damage at all distance intervals, whereas crested porcupines caused the least damage at all but one interval. Overall, warthogs accounted for 43.2% of the reported cases of crop damage, while Swayne's hartebeest and crested porcupines accounted for 33.8% and 23.0%, respectively ($n = 660$ reports of crops damage). Nearly all of the crop raiding occurred at night (96.2%; $n = 660$).

Crop raiders were reported to damage potatoes, maize, finger millet, beans, cabbage and ensete. Potatoes (21.1% of households) and maize (19.9%) were the most raided crops overall (Fig. 4). Potatoes were reported to be the most raided crops within 1500 m of the sanctuary while maize was the most raided crop between 1500 and 3000 m. Ensete was the least raided crop type, reported by only 12.0% of households.

The patterns of crop raiding by wild animals varied at different crop developmental stages. Swayne's hartebeests

Table 2. Livestock predation events by spotted hyenas and African wolves across different time periods (day or night) and locations (inside SSHS, outside SSHS and not within a livestock enclosure, or outside SSHS and within a livestock enclosure) over a three-year period (2016–2018).

Species	Locations			Time	
	Inside	Outside	Enclosure	Day	Night
Hyena	295	121	547	113	850
African wolf	97	2	0	99	0
Total	392	123	547	212	850

fed mainly on the seedling stage. They were reported to carry out most of their crop raiding during a short period (May–June). However, crested porcupines mainly raided crops at the mature stage. They reportedly raided crops from July through November. Warthogs raided crops at all stages, though especially at the mature stage (Fig. 5). Only warthogs were reported to raid crops year round with a peak in raiding activity from May to December (Supplementary material Appendix 6).

The methods used by farmers to deter crop raiding varied along a 3000 m distance gradient from the sanctuary. Farmers closest to the sanctuary mainly used a combination of guarding, patrolling, fencing and trenching, whereas those at further distances from the borders more commonly set smoky fires, flashed lights and made noise to scare crop raiders (Fig. 6). The attitudes of respondents towards each crop raiding animal species varied. While attitudes of respondents towards Swayne's hartebeest were very positive (90.5%), attitudes towards warthogs and crested porcupines were strongly negative (94.2% and 82.6%, respectively) (Supplementary material Appendix 7).

Discussion

We found that local communities surrounding Senkele Swayne's Hartebeest Sanctuary (SSHS) experienced both livestock predation and crop raiding. Hyenas and African wolves are the two large carnivore species present in the study area, and both are involved in livestock predation. Hyenas were by far the most important predators of livestock in terms of the number and economic value of the livestock killed. Hyenas are also major livestock predators at many other locations in Africa, including in the Maasai steppe, Tanzania (Kissui 2008) and Bale Mountains National Park, Ethiopia (Atickem et al. 2010) where they were responsible for 58% and 57% of reported livestock predation, respectively.

While African wolves occurred primarily near the periphery, hyena abundance was comparable between the periphery and center of SSHS. This more even distribution of hyenas can probably be explained by the greater ability of hyenas to exist in varied landscapes via a combination of livestock predation (Kissui 2008, Mbise et al. 2018), predation on wild animals (Kissui 2008, Girmay et al. 2015) and/or feeding on discarded refuse in human dominated areas (Gidey and Bauer 2010, Yirga et al. 2014). Conversely, a recent study in the Guassa Community Conservation Area of northern Ethiopia revealed that livestock accounted for less than 20% of the diet of African wolves, with rodents and arthropods being the biggest contributors (Gutema et al. 2019). Moreover, when preying on livestock around SSHS, African wolves focused only on goats and sheep, the livestock of lowest economic value.

Predation events by hyenas and African wolves were both highest within the first 500 m belt inside the borders of SSHS, and the number of livestock killed declined towards the center of the sanctuary. Outside the sanctuary, hyena predation exhibited consistent trends at each 500 m distance interval out to 3000 m. Similar hyena predation trends were reported in the eastern Serengeti ecosystem, Tanzania (Mbise et al. 2018) and at waste dumping sites in northern

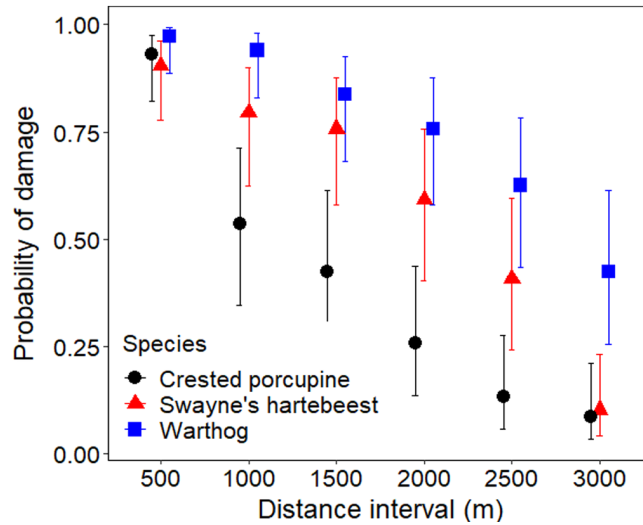


Figure 3. Probability of crop damage by wild animals along a distance gradient in Senkele Swayne's Hartebeest Sanctuary surroundings.

Ethiopia (Girmay et al. 2015). This might be because hyenas are opportunistic feeders (Kolowski and Holekamp 2006, Schiess-Meier et al. 2007) that make regular visits to human settlement areas where they can find discarded food (Gidey and Bauer 2010, Yirga et al. 2013) and carry out opportunistic livestock attacks (Sogbohossou et al. 2011). Most hyena predation events were on livestock in enclosures. Similar studies along the border of a Kenyan reserve (Kolowski and Holekamp 2006) and in a peri-urban area in northern Ethiopia (Gidey and Bauer 2010) found that hyena predation is highest when livestock are in enclosures.

Livestock predation by hyenas around SSHS reached its highest frequency during the wet season, while African wolf predation peaked during the dry season. Hyenas appeared to predate livestock in accordance with its abundance as livestock populations around SSHS are greatest during the wet

season (Berhanu 1974). The greater predation of livestock by African wolves during the dry season around SSHS is consistent with the results of research on African wolf diets at Guassa Community Conservation Area, Ethiopia where their biggest dietary focus was on rodents and arthropods, with livestock as a dietary supplement peaking in the dry season (Gutema et al. 2019).

This study also revealed that crops on farms nearest to SSHS experienced the highest frequencies of damage by the three raiding species in the area: warthogs, Swayne's hartebeest and crested porcupines. Crops closer to the sanctuary had a higher incidence of raiding, mirroring the pattern described for crops near other protected areas such as Serengeti National Park, Tanzania (Mwakatobe et al. 2014) and Tadoba-Andhari Tiger Reserve, India (Bayani et al. 2016). Warthogs were reported to be the most frequent crop

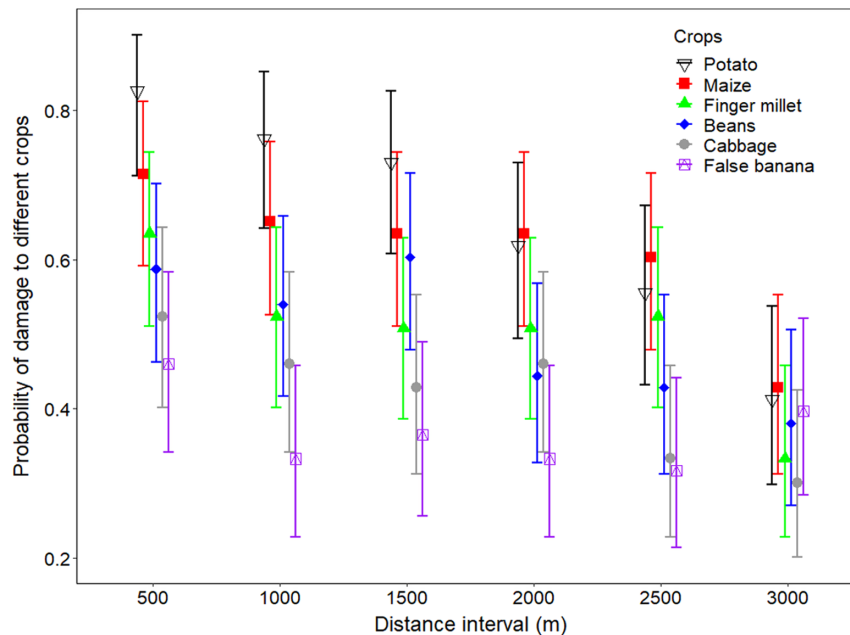


Figure 4. The probability of different crops raided by wild animals along a 3000 m distance gradient from Senkele Swayne's Hartebeest Sanctuary.

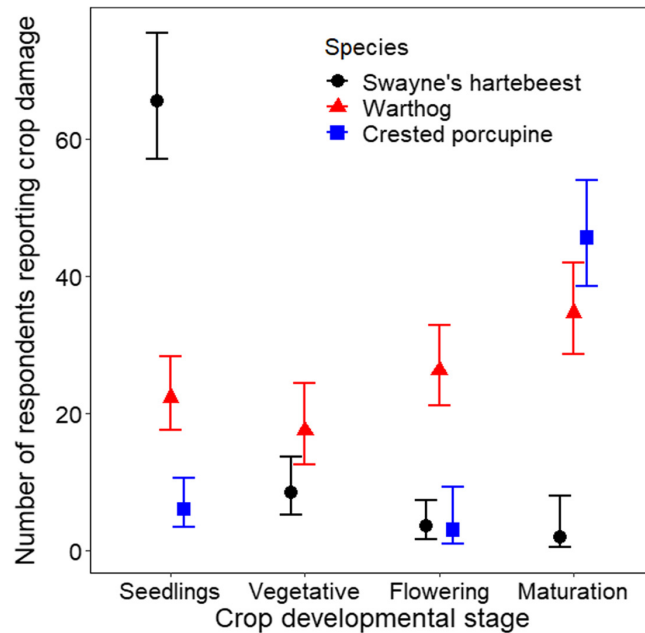


Figure 5. Reports by local households ($n=378$) of crop damage by three wild animal species in relation to crop developmental stage on farms near Senkele Swayne's Hartebeest Sanctuary.

raiders throughout our surveyed area. Like Pittiglio (2009) and Mwakatobe et al. (2014), we found that crop raiding by warthogs and crested porcupines peaked in the latter half of the year when favored crops like maize and potatoes matured. However, warthogs also raided dry season crops such as cabbage and ensete. Studies at Bénoué Wildlife Conservation Area, north Cameroon and Gera, southern Ethiopia also found warthogs to be among the most common crop raiding species on nearby farms (Weladji and Tchamba 2003, Goboshu et al. 2015). Swayne's hartebeests around SSHS primarily raided maize during its two-month seedling stage in May and June. Both warthogs and Swayne's hartebeests ventured greater distances from the sanctuary to raid crops than the more secretive crested porcupines.

Unlike at many other sites throughout Africa (Hill 2000, Cancelliere et al. 2018), anubis baboons and vervet monkeys did not raid crops around SSHS. This is probably because the populations of both primates are small and occur only in the scattered woodland habitats at the center of SSHS, >4 km from the nearest agricultural fields. The area in between consists of open grassland where much herbivore and livestock grazing occurs and local people frequently guard their livestock. Moreover, this area is flat and without shrub or tree cover, and thus given their small numbers, baboons and vervets may be afraid to cross through these human and livestock dominated grasslands to reach the farms outside the borders of the sanctuary. Both oribi and bohor reedbeek also did not raid crops around SSHS, consistent with the rarity

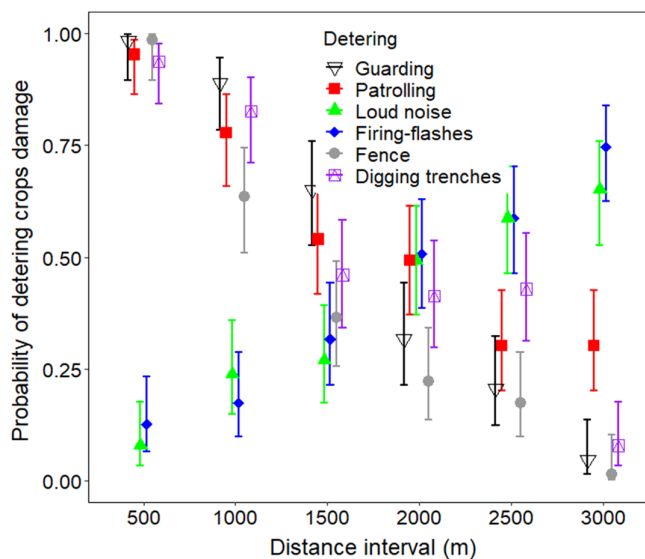


Figure 6. Probability of use of different deterrence methods by farmers to prevent crop raiding along a 3000 m distance gradient extending from Senkele Swayne's Hartebeest Sanctuary.

of reports of crop raiding by these species elsewhere in Africa (Gobosho et al. 2015, Cancelliere et al. 2018).

Respondents reported that potatoes and maize were the most raided crops at all distance intervals from SSHS. They are also among the most raided crops at other sites in Ethiopia and around Africa (e.g. Gera, Ethiopia (Gobosho et al. 2015); Serengeti National Park, Tanzania (Mwakatobe et al. 2014, Caro 2016)). Respondents living <1500 m outside the borders of SSHS most often used a combination of guarding, patrolling, fencing and digging trenches to deter crop raiding animals. These strategies required greater energetic and financial investment than those of respondents >1500 m from the sanctuary who more often used loud noises, smoky fires and flashes of light to deter crop raiding wildlife. Lower intensity deterrence strategies were possible at greater distances from SSHS because visits from crop raiders were less common in these outlying areas.

Attitudes towards the three crop raiding species around SSHS varied widely. The vast majority of members of the local community reported regarding Swayne's hartebeest positively, while warthogs and crested porcupines were viewed negatively. There are several potential reasons for the difference in how these species are perceived. Crop raiding by Swayne's hartebeest's is mostly restricted to maize and occurs primarily during a short two-month period. Swayne's hartebeest are also easier to deter than the other species by constructing simple fences. Finally, and probably most importantly, many locals have developed a strong cultural attachment to Swayne's hartebeest in recent decades. With Swayne's hartebeest's numbers having dropped substantially due to widespread hunting during a period of political upheaval in the late 1980s, the leaders of the local longstanding traditional administration system (Ta'a 2016) ('Gadaa') developed and enforced a law requiring the payment of 100 cattle for the killing of a single Swayne's hartebeest (Tadese 2019). This decision is largely credited with stopping hunting of Swayne's hartebeest, promoting a strong appreciation for Swayne's hartebeest among the local human populace, and saving the taxon from imminent extirpation at SSHS.

Conclusion

This study provides baseline data on livestock predation and crop raiding for developing an appropriate wildlife management plan to facilitate the long-term coexistence of local people with wild animals in the SSHS area. Hyenas account for 91% of the livestock predation in the area, while African wolves account for the remainder. Livestock predation was most intense near the periphery of SSHS, though hyenas also preyed on many livestock out to as far as 3000 m from the sanctuary. Most livestock were preyed on from poorly constructed livestock enclosures. The local communities that surround SSHS also experience crop raiding by three species: warthogs, Swayne's hartebeest and crested porcupines. Warthogs were reported to engage in the most crop raiding and were the only species to exhibit this behavior year round. Local community members used a variety of methods to protect their crops from raiding, with farmers <1500 m from SSHS using more financially and energetically expensive deterrence techniques than farmers >1500 m from the

sanctuary. We conclude that although SSHS is of critical conservation value to the Swayne's hartebeest, the surrounding communities endure significant livestock predation and crop raiding by wild animals sheltered in the sanctuary. The survival of this relict population of Swayne's hartebeest in the sanctuary remains at risk unless the human-wildlife conflict in surrounding areas is resolved.

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Author contributions – MT, AA and NCS conceived the study. MT performed the fieldwork. MT and DT analyzed the data and interpreted the results. MT wrote the first draft of the manuscript; PJJ, MT and DT extensively revised the manuscript, and NN, AA, PE, AB and NCS provided additional important revisions to the manuscript.

Ethics – The Ethiopian Wildlife Conservation Authority's (EWCA's) Policy for Management of Wildlife Resources guidelines have been followed.

Competing interests – We declare that we have no competing interests.

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Supplementary material (available online as Appendix wlb-00712 at <www.wildlifebiology.org/appendix/wlb-00712>). Appendix 1–7.