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Original Research Article

Livestock depredation by large carnivores in northern Botswana

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A B S T R A C T

Human-carnivore conflict is a leading cause of large carnivore declines and minimizing these conflicts is vital to maintaining viable carnivore populations. Often, however, conservation agencies and governments do not have a proper understanding of conflicts prior to establishing mitigation programs or are unable to collect the appropriate data to verify claims of livestock loss. We investigated livestock depredation events in the Eastern Panhandle of the Okavango Delta, Botswana between October 2014 and December 2016 and compared these investigations with concurrent Problem Animal Control (PAC) information from the Botswana Department of Wildlife and National Parks (DWNP) compensation program. Only animals killed in livestock enclosures or while being herded qualify for reimbursement through the compensation program, but DWNP is typically unable to verify claims. We identified wildlife sign at the depredation event location and collected information from the livestock owner to determine the species responsible for the attack, time of the attack, the livestock lost, and the husbandry methods employed. In total, 116 livestock were killed and 13 more injured in 102 confirmed wild carnivore attacks. Most (90%) attacks occurred while livestock were unattended and freely grazing in multi-use, communal areas. Cows, oxen (castrated male cows) and calves (*Bos taurus* and *B. t. indicus*) were killed most often and African lions (*Panthera leo*) were responsible for 74% of investigated attacks, while African wild dogs (*Lycaon pictus*) accounted for 13%, leopard (*Panthera pardus*) 8%, and spotted hyena (*Crocuta crocuta*) 5%. Valuation of verified losses totaled ~$30,000 over the study period. There were 50% more events reported to DWNP for compensation than we confirmed through independent investigations. In its current form, the compensation program does not seem sustainable, nor does it enable the verification of claims. While compensation programs should not be abandoned, programs designed to provide monetary reimbursement for losses caused by predators should require timely reporting and in-depth investigation of depredation events. Additional conflict mitigation strategies should target increasing livestock husbandry methods in the area, with a specific focus on herding.

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1. Introduction

People and predators have tenuously coexisted for millennia, but over recent decades the level of conflict has increased due to rising human populations and changes in human activities (Woodroffe, 2000; Conover, 2002; Graham et al., 2005; Madden and McQuinn, 2014). Large carnivores are typically no longer tolerated by humans as they frequently kill livestock and occasionally kill people (Woodroffe, 2000; van Eeden et al., 2018). Predators are often killed in retaliation, and these killings are the primary threat to large carnivores worldwide (Woodroffe, 2001; Woodroffe et al., 2007). Because of this, populations of these species are declining and their ranges are contracting (Dickman et al., 2011). The removal of large carnivores can have major cascading impacts on ecological communities, destabilizing ecosystems and their food webs (Ripple et al., 2014; Newsome et al., 2017). In addition to their ecological importance, large carnivores are extremely valuable as a source of monetary income from ecotourism, however local communities bear the considerable costs of living with these predators (Macdonald et al., 2010). The impact of livestock depredation where carnivore distributions overlap with farming practices can have a negative effect on local farmers, causing loss of income and food while also adversely impacting rural development (Treves and Karanth, 2003; Graham et al., 2005; Woodroffe et al., 2007; Thorn et al., 2013). Given that retaliatory killings are a major threat to large carnivores, mitigating human-carnivore conflict (HCC) is vital to achieving successful carnivore conservation; however, this requires site-specific management based on both biological and social data (Treves and Karanth, 2003, Inskip and Zimmermann, 2009).

HCC has increasingly been studied around the globe in an attempt to better understand the drivers of conflict and enable coexistence with large carnivores (e.g., Palmeira et al., 2008; Aryal et al., 2014; Ohrens et al., 2015; Singh et al., 2015). In a literature review focused on the conservation of African carnivores, Winterbach et al. (2013) identified a number of ecological (e.g., livestock predation), socioeconomic (e.g., people's attitudes towards carnivores), and political (e.g., conservation policy development and implementation) factors as key drivers of large carnivore conservation. Researchers, governments, and conservation agencies have made a concerted effort to study and establish conflict mitigation strategies that target these drivers, which include but are not limited to evaluations of livestock predation (e.g., Lichtenfeld et al., 2015; Weise et al., 2018), people's attitudes towards carnivores (e.g., Hemson et al., 2009; Thorn et al., 2012), and conservation policy development and implementation (e.g., Dickman et al., 2011; Mossaz et al., 2015; Ravenelle and Nyhus, 2017). Despite these and numerous other studies, there is no consensus as to the most effective conflict mitigation interventions (Eklund et al., 2017). Therefore, site-specific factors should direct mitigation strategies (Treves and Karanth, 2003, Inskip and Zimmermann, 2009).

Governments try to reduce conflicts and alleviate the financial burden for farmers who lose livestock to predators through compensation programs, but often factors impacting those losses are not well understood (Mabille et al., 2015). In an attempt to facilitate human-carnivore coexistence, the Botswanan government established a compensation program under the purview of the Department of Wildlife and National Parks (DWNP; DWNP, 1998). The program was overhauled in 2013, increasing reimbursement levels to 100% of averaged market value for losses to African lions (*Panthera leo*) and 35% for losses to other species of conservation concern, i.e., African wild dogs (*Lycaon pictus*), cheetahs (*Acinonyx jubatus*), and leopards (*Panthera pardus*; DWNP, 2013). While the program was designed to reimburse farmers for animals killed in livestock enclosures or while being herded, DWNP officials are typically not able to verify claims of livestock depredation due to limited resources. This results in false claims being paid out. Implementing conflict mitigation strategies without proper understanding of the system and levels of conflict can lead to wasted resources and can have negative overall effects on both wildlife conservation and people's attitudes towards wildlife (Graham et al., 2005; Nyhus et al., 2005).

Here we assess the level of HCC in the eastern Panhandle of the Okavango Delta, Botswana to help inform conflict mitigation strategies. According to DWNP, 30–50% of the local lion population was removed by villagers as a result of targeted killings and indiscriminate poisoning events in response to high numbers of livestock losses in 2013. The lion is often responsible for livestock losses and, as a result, killed in retaliation (Ikanda and Packer, 2008; Hazzah et al., 2009; Hemson et al., 2009). HCC is the leading cause of lion population declines across the continent (Woodroffe, 2001) and lions have been extirpated from over 80% of their historic range (Riggio et al., 2013). Lion populations throughout Africa are vanishing quickly with current estimates hovering around 20,000 individuals (Chardonnet, 2002; Bauer and Van der Merwe, 2004; Riggio et al., 2013; Bauer et al., 2015; Bauer et al., 2016). Human-lion conflict mitigation is a high priority for the species' long-term persistence (Woodroffe, 2001), and more secure livestock husbandry practices, e.g., predator-proof livestock enclosures and sound herding practices (Ogada et al., 2003; Lichtenfeld et al., 2015), have proven effective at decreasing conflicts with lions and other predators (Breitenmoser et al., 2005; Woodroffe et al., 2007).

Following the high levels of conflict experienced in 2013, we initiated an assessment of HCC and established conflict mitigation strategies in the eastern Panhandle. Our aim was to independently assess the levels of livestock depredation and compare those records to DWNP Problem Animal Control (PAC) data. The PAC data are the basis for the national compensation program that aims to minimize conflicts by reimbursing villagers for losses incurred from predators. We hypothesized that there would be more depredation (PAC) events reported to DWNP than we identified through independent investigations. Additionally, we predicted that lions and spotted hyenas (*Crocuta crocuta*) would be responsible for the highest percentage of livestock loss in the area (Ogada et al., 2003; Kolowski and Holekamp, 2006; Mponzi et al., 2014). We predicted that villagers file false depredation reports blaming lions when spotted hyenas were responsible for losses to receive compensation. As such, lions would have a larger percentage of the PAC reports compared to our independent investigations. For our independent depredation investigations, we hypothesized that most depredation events would happen in the veld as opposed to the village due to a very limited herding culture in the area.

2. Study area

This study was conducted in the eastern panhandle of the Okavango Delta of northern Botswana (between −18.986419°, 22.449220° and −18.563485°, 22.936769°; Fig. 1) within a portion of the Kavango-Zambezi Transfrontier Conservation Area (KAZA). The KAZA has been identified as an area of critical importance for lion conservation (Funston, 2014). The Okavango Delta lies within the northern portion of the Kalahari Desert and is a freshwater alluvial system that supports one of southern Africa's most sought-after wildlife tourism regions. Large carnivores found in the area include the African lion, leopard, cheetah, spotted hyaena, and African wild dog.

Our research efforts encompassed portions of five government defined wildlife management areas (WMAs), NG 11, NG 12, NG 22, NG 23, and NG 23A (Ngamiland), which are gazetted for human habitation, conservation, and photographic tourism (Fig. 1). NGs 11 and 12 are multiuse WMAs where people live, farm and utilize natural resources. NG 22 is designated as a community-run wildlife conservation area, while NGs 23 and 23A are leased to ecotourism companies for photographic tourism. In NGs 11 and 12, people are concentrated in four villages (Beetsha, Eretsha, Gudigwa, and Gunotsoga) and in smaller familial settlements called cattle posts. Village populations, including people living at associated cattle posts, range from approximately 700-1600 people (Botswana Population and Housing Census, 2011). The local villagers are subsistence farmers who keep livestock (cattle, *Bos taurus/indicus*; goat, *Capra hircus*; horse, *Equus caballus*; and donkey *Equus asinus*) and grow crops. Average herd size in the area is approximately 12 individuals per farmer (LeFlore, unpublished data). Livestock are typically protected overnight in thorn branch enclosures or thick, wooden branch enclosures, referred to locally as “kraals” (Fig. 2). Historically, there was a strong herding culture, but, as children are now going to school and moving to more developed areas, these herding practices have been largely abandoned.

In conjunction with our conflict investigations described in this manuscript, we established a range of conflict mitigation strategies. We developed an early warning system linked to lion GPS satellite collars and issued “lion alerts” to villagers via a telephone tree when collared individuals moved into areas where livestock typically graze and within ~5–8 km of villages (see Weise et al., 2019). Additionally, we built 12 predator-proof kraals at cattle posts with historically high levels of conflict (see Weise et al., 2018). We employed six local villagers to help with these efforts and worked closely with community

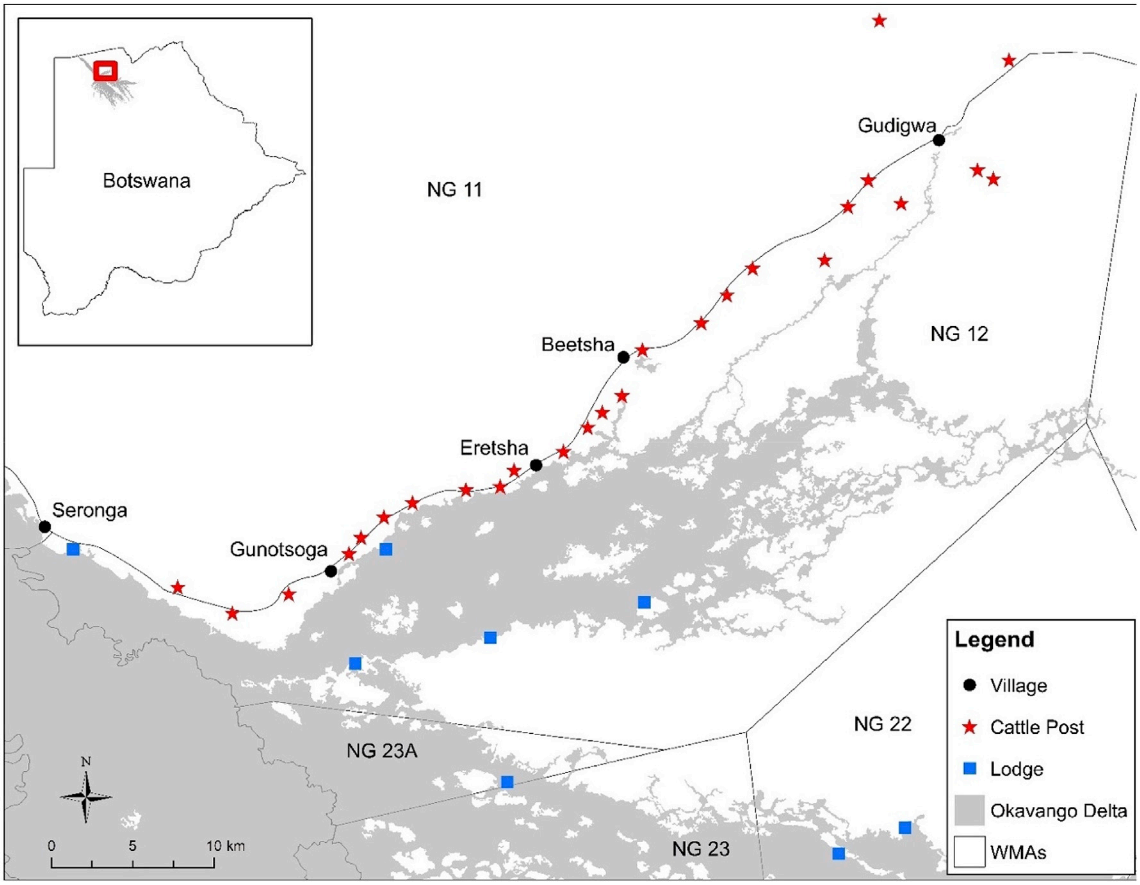

Fig. 1. Lion conflict study area in northern Botswana with locations of associated villages and connecting road, cattle posts, safari lodges, and Wildlife Management Area boundaries.

Fig. 2. Traditional kraal structures in northern Botswana. A: thorn branch style construction, B: thick wooden branch construction. Photos by E. LeFlore.

members and leadership. We also regularly led educational sessions in the villages and at local schools to share project updates and information about local lion prides.

3. Methods

PAC data were collected from the DWNP Seronga office between October 2014 and December 2016; years of inquiry were 2009–2016. These data were extracted from DWNP documents where villagers reported their livestock losses to DWNP, the police, and/or wildlife volunteers. The reports contained information such as: date of incident, village, cattle post (when applicable), species responsible, and number and species of livestock lost. These reports were compiled from the area villages by DWNP to enable compensation payments for livestock losses. We digitally transcribed data from archive books and calculated descriptive statistics and Chi-square goodness of fit tests using R Statistical software (R version 3.5.1; R Core Team, 2018). Chi-square tests were based on estimates of large carnivore relative abundance from density estimates in published literature (lion = 5.8/100 km^2, Cozzi et al., 2013; spotted hyena = 14.4, Cozzi et al., 2013; African wild dog = 3.5, Creel et al., 2004; leopard = 1.5, Winterbach, 2008).

When a depredation event occurred, farmers were encouraged by village chiefs and elders to work with our conflict research and mitigation program as the information they provided assisted with the implementation of future conflict mitigation. When livestock farmers reported losses to us, we would accompany them to the kill site. We documented the GPS location, probable time of the incident and habitat. We looked for tracks and sign of carnivore species to determine the species responsible for the incident, i.e. killing bites, claw marks, feeding style, predator spoor, among others. Since villagers were self-reporting incidents, we only investigated depredation events that were brought to our attention. Descriptive statistics and Chi-squared goodness of fit tests were calculated using R Statistical software and based on published species population densities as above. We used a Pearson's product moment correlation test to compare the number of depredation events per village to village specific attributes (estimated values for human population, livestock population, number of livestock per person, and number of cattle posts) and village specific management actions (number of employees from our research program, number of predator-proof kraals built, number of lion alerts issued and an estimate of our overall effort/time spent in each village). The estimates of livestock per village were obtained from Botswanan Department of Veterinary Services records and our effort/time spent per village was estimated post hoc.

An Optimized Hot Spot Analysis (Arc GIS Version 10.5.1; based on the Getis-Ord Gi* statistic) was conducted to see if investigated depredation event locations were significantly clustered together (optimal fixed distance band based on peak clustering at 6.5 km with resulting heat map grid cell size of 4.7 km^2). PAC data did not have an associated point location and could not be included in this analysis. The hot spot analysis relies on z-scores for all investigated depredation event locations in the data set, with significantly positive scores indicating significant clustering of high predation locations (hot spots) and significantly negative scores indicating significant clustering of low predation locations (cold spots). A heat map depicting warm/hot spots (areas with a higher chance of depredation event occurring, e.g., positive z-scores) and cool/cold spots (areas with lower chance of a depredation event occurring, e.g., negative z-scores) was created based on these results.

4. Results

For the focal villages (Beetsha, Eretsha, Gudigwa, and Gunotsoga), governmental PAC records showed that five carnivore species were reported to kill livestock from 2009 through 2016, totaling 588 individual reports (Table 1). Of all PAC reported incidents, lions were reported to be responsible for significantly more events (81%, n = 477) than expected when accounting for species estimated relative abundance of large carnivores as described above ($\chi^2 = 1195.73$, df = 4, $p < 0.001$). African wild dogs were responsible for 13% (n = 79) of reported events, leopards for 4% (n = 22), spotted hyenas 1% (n = 7), and caracal (*Caracal caracal*) depredations represent less than 1% of all reports (n = 1; not included in Chi-squared test). The number of

Table 1
Percent (no. of events in parentheses) of Problem Animal Control (PAC) incidents by species reported to the Department of Wildlife and National Parks (DWNP) between 2009 and 2016 for focal villages (Gunotsoga, Eretsha, Beetsha, and Gudigwa) in the lion conflict study area in northern Botswana.

Predator	2009[a]	2010	2011	2012	2013	2014	2015	2016	Total
	(24)	(53)	(46)	(113)	(159)	(47)	(80)	(66)	(588)
Lion	71	25	72	80	93	89	89	95	81
Wild dog	8	64	26	16	4	2	6	2	13
Leopard	21	9	0	4	1	6	3	2	4
Spotted hyena	0	2	2	1	1	2	0	2	1
Caracal	0	0	0	0	1	0	0	0	0
Unknown	0	0	0	0	0	0	3	0	0
Percent of total	4	9	8	19	27	8	14	11	100

[a] indicates an incomplete year of data.

reports spiked in 2012 and 2013, totaling 113 and 159 reports, respectively, equating to 46% of all reported events during the eight-year span (Fig. 3 & Table 1). The most (38%, n = 225) PAC reports came from the village of Gudigwa (Table 2), followed by Gunotsoga (22%, n = 132), Eretsha (22%, n = 128), and Beetsha (18%, n = 103). There was a significant difference in the number of reports received from each village ($\chi^2 = 9.44$, df = 3, $p = 0.024$). In 588 PAC events, 609 individual livestock were claimed to have been lost, with bovids (cattle and goats) making up 94% of losses (Table 3). Every year between 2009 and 2016, bovids made up at least 91% of the animals reported killed by predators. Over the same time frame, the Botswanan government valued the livestock lost to predators at US$185,590 (Tables 4 and 5). Excluding 2009, a year of incomplete records, farmers in the four focal villages claimed livestock losses valued at an average of US$25,576 per year between 2010 and 2016.

Between October 2014 and December 2016, we investigated 102 livestock depredation events, of which lions were responsible for 75 (74%; Table 6), significantly more events than expected when accounting for species estimated relative abundance ($\chi^2 = 156.75$, df = 4, $p < 0.001$). During these 102 investigated depredation events a total of 129 individual livestock (cattle, goat, horse, donkey) were attacked, 116 individuals killed and 13 injured (Table 7). Bovids were taken most often, comprising of 97% of all livestock killed. During the study, the value of killed livestock was a total of $29,925 USD (Table 8). Focusing on complete data years of 2015 and 2016, the average yearly loss to predators in the study area was $14,188 USD. Of the 102 events, 79% (n = 80) of them were filed with DWNP for reimbursement through the governmental compensation program. Significantly more depredation events (90%, n = 92; Table 6) ocurred in the veld while livestock were grazing and unprotected, as opposed to at the kraal (10%, n = 10; $\chi^2 = 65.922$, df = 1, $p < 0.001$). On only six occasions were there people with the herd that was attacked. Most attacks occurred in NG 12 (vs. NG 11) where livestock were typically grazing due to water and food availability and were more likely to encounter predators (Fig. 4).

In our investigations, the most depredation events occurred in Beetsha (39%, n = 40; Table 9), followed by Eretsha (28%, n = 29), Gunotsoga (19%, n = 19), Gudigwa (8%, n = 8), and Seronga (5%, n = 5). There was a significant difference in the number of events per village ($\chi^2 = 68.118$, df = 5, $p < 0.001$). When standardized by the estimated number of livestock and separately by the estimated number of livestock per person, there was still a significant difference between the number of depredation events per village ($\chi^2 = 22.975$, df = 4, $p < 0.001$; $\chi^2 = 14.915$, df = 4, $p = 0.005$). Our conservation efforts and management activities centered on where there were the most depredation events (Table 9). The number of livestock depredation events per village was positively correlated, but not significantly, with estimated livestock population (r = 0.76, $p = 0.21$), estimated number of livestock per person (r = 0.74, $p = 0.15$), the number of our employees (r = 0.75, $p = 0.15$), the number of predator-proof kraals built by our program (r = 0.79, $p = 0.11$), and the number of lion alerts (r = 0.87, $p = 0.06$; Table 9). There was a significant positive correlation between the number of depredation events per village and the estimated amount of effort and time we spent in the corresponding village (r = 0.93, $p = 0.02$). The number of depredation events per village was not correlated with the human population (r = −0.37, $p = 0.53$) or the number of cattle posts (r = −0.05, $p = 0.94$) in the respective village.

On average, investigated depredation events took place x = 6.1 km ($\sigma = 2.7$ km) from the nearest village center and x = 2.7 km ($\sigma = 2.2$ km) from the nearest cattle post. A spatial assessment (optimized hot spot analysis) of investigated depredation events yielded two major depredation hot spots, southeast of Eretsha and east of Beetsha where depredation events were significantly clustered (Fig. 5). Warm and hot spots had positive z-score values while cool and cold spots had negative z-score values; all red hot spots incorporated areas where depredation events were significantly clustered with *p*-values < 0.01 (Fig. 5).

5. Discussion

While lions were confirmed to be responsible for about 75% of losses in our study area, local farmers reported to the government that lions were responsible for over 80% of depredation events. A direct comparison between individual PAC reports and our investigated events was not possible due to a lack of fine grain information in PAC reports. As independent

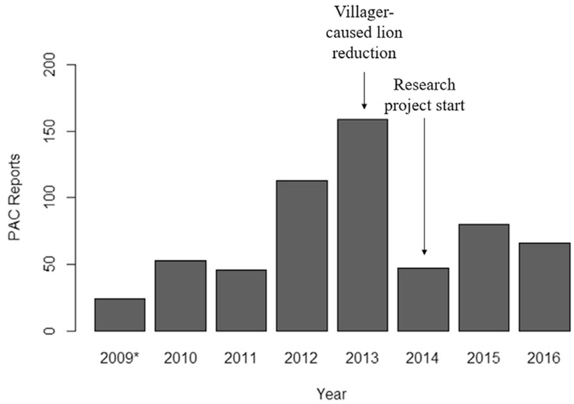

Fig. 3. Number of Problem Animal Control (PAC) reports filed with the Department of Wildlife and National Parks (DWNP) between 2009 and 2016 for focal villages (Gunotsoga, Eretsha, Beetsha, and Gudigwa) in the lion conflict study area in northern Botswana.* indicates an incomplete year of data.

Table 2
Percent (no. of events in parentheses) of Problem Animal Control (PAC) incidents by village reported to the Department of Wildlife and National Parks (DWNP) between 2009 and 2016 for focal villages (Gunotsoga, Eretsha, Beetsha, and Gudigwa) in the lion conflict study area in northern Botswana.

Village	2009[a]	2010	2011	2012	2013	2014	2015	2016	Total
	(24)	(53)	(46)	(113)	(159)	(47)	(80)	(66)	(588)
Beetsha	8	6	13	26	12	28	25	17	18
Eretsha	33	9	11	19	11	36	40	33	22
Gudigwa	46	72	76	48	30	19	16	26	38
Gunotsoga	13	13	0	7	47	17	19	24	22
Percent of total	4	9	8	19	27	8	14	11	100

[a] Indicates an incomplete year of data.

Table 3
Percent of livestock lost (no. of livestock lost in parentheses) in all Problem Animal Control (PAC) incidents reported to the Department of Wildlife and National Parks (DWNP) between 2009 and 2016 for focal villages (Gunotsoga, Eretsha, Beetsha, and Gudigwa) in the lion conflict study area in northern Botswana (609 individual livestock were reported lost in 588 events).

Livestock	2009[a]	2010	2011	2012	2013	2014	2015	2016	Total
	(26)	(53)	(46)	(113)	(159)	(47)	(89)	(76)	(609)
Bovids									
Cow	42	53	59	60	60	45	46	46	54
Calf	27	13	9	8	9	15	10	22	12
Bull	12	13	15	15	10	13	24	9	14
Ox	8	13	15	6	11	21	15	14	12
Goat	12	2	0	4	1	0	0	3	2
Subtotal	100	94	98	93	91	94	94	95	94
Equids									
Horse	0	0	0	5	6	4	2	3	4
Donkey	0	4	0	1	3	2	3	3	2
Subtotal	0	4	0	6	8	6	6	6	6
Unknown	0	2	2	1	1	0	0	0	1
Percent of total	4	9	8	19	26	8	15	12	100

[a] Indicates an incomplete year of data.

investigators, villagers may have been unaware of our research program, and we recognize this as a potential bias in our data. However, we maintained positive relationships with community members and elders, regularly communicated with all local stakeholders, routinely presented program information and updates at village meetings, and worked closely with DWNP and local authorities. We suggest villagers recognize the limited resources available to DWNP and report losses suffered to spotted hyenas as losses to lions. Villagers are not compensated for losses to spotted hyenas but do receive compensation for livestock

Table 4
Average livestock valuation from farmers (n = 86) who lost livestock between October 2014 and December 2016 and the Botswanan government livestock compensation rates in U.S. dollars (USD) and Botswanan pula (BWP).

Livestock	Farmer value USD (BWP)	Government value USD (BWP)
Bull	425 (4,130)	565 (5,500)
Ox	320 (3,100)	310 (3,000)
Cow	295 (2,860)	310 (3,000)
Calf	220 (2,150)	100 (1,000)
Horse	310 (3,000)	255 (2,500)
Goat	100 (1,000)	45 (450)
Donkey	50 (500)	20 (200)

Table 5
Government valuation (in USD) of livestock lost in all Problem Animal Control (PAC) incidents reported to the Department of Wildlife and National Parks (DWNP) between 2009 and 2016 for focal villages (Gunotsoga, Eretsha, Beetsha, and Gudigwa) in the lion conflict study area in northern Botswana. 609 individual livestock were reported lost in 588 events (no. of livestock lost in parentheses).

Livestock Lost	2009[a]	2010	2011	2012	2013	2014	2015	2016	Total
	(26)	(53)	(46)	(113)	(159)	(47)	(89)	(76)	(609)
Bovids									
Cow	3,410	8,680	8,370	21,080	29,760	6,510	12,710	10,850	101,370
Calf	700	700	400	900	1,400	700	900	1,700	7,400
Bull	1,695	3,955	3,955	9,605	9,040	3,390	11,865	3,955	47,460
Ox	630	2,170	2,170	2,170	5,580	3,100	4,030	3,410	23,250
Goat	135	45	0	180	45	0	0	90	495
Subtotal	6,560	15,550	14,895	33,935	45,825	13,700	29,505	20,005	179,975
Equids									
Horse	0	0	0	1,530	2,295	510	510	510	5,355
Donkey	0	40	0	20	80	20	60	40	260
Subtotal	0	40	0	1,550	2,375	530	570	550	5,615
Total	6,560	15,590	14,895	35,485	48,200	14,230	30,075	20,555	185,590

[a] Indicates an incomplete year of data.

Table 6
Percent (no. of incidents) of investigated depredation events that occurred at livestock kraals vs. in the veld attributed to each responsible carnivore species in the lion conflict study area in northern Botswana between October 2014 and December 2016.

Species	Veld	Kraal	Total
	(92)	(10)	(102)
Lion	67	8	74
Wild dog	13	0	13
Spotted hyena	7	1	8
Leopard	4	1	5
Unknown	1	0	1
Percent of total	90	10	100

lost to lions. We recorded a 7% increase for reported losses to spotted hyenas, with a corresponding decrease in lion records compared to the DWNP PAC data. African wild dog and leopard records were similar between the two analyses, so the discrepancy is likely due to false claims to DWNP for compensation. The lack of compensation for losses to spotted hyena does not give local farmers any incentive to accurately report depredation events when they happen, especially if there is no government investigation of depredation events. Additionally, 21% of our investigated depredation events were not reported to DWNP for compensation, some because they were not eligible for reimbursement (i.e. losses to spotted hyena) or would yield below market value for the lost stock (i.e. losses to leopard and wild dog) and others (i.e. losses to lion) because farmers were frustrated with the compensation program.

Table 7
Confirmed total number (T) of individual livestock killed and injured (K/I) by predators from 102 investigated depredation events in the lion conflict study area in northern Botswana between October 2014 and December 2016.

Livestock	Lion	Wild dog	Spotted hyena	Leopard	Unknown	All Species	Percent of total
	T (K/I)	T (K/I)	T (K/I)	T (K/I)	T (K/I)	T (K/I)	
Bovids							
Cow	47 (42/5)	8 (6/2)	5 (5/0)	1 (1/0)	1 (1/0)	62 (55/7)	48
Calf	21 (19/2)	2 (2/0)	4 (4/0)	5 (4/1)	0 (0/0)	32 (29/3)	25
Ox	21 (18/3)	3 (3/0)	0 (0/0)	0 (0/0)	0 (0/0)	24 (21/3)	19
Bull	4 (4/0)	1 (1/0)	0 (0/0)	0 (0/0)	0 (0/0)	5 (5/0)	4
Goat	1 (1/0)	1 (1/0)	0 (0/0)	0 (0/0)	0 (0/0)	2 (2/0)	1
Subtotal	94 (84/10)	15 (13/2)	9 (9/0)	6 (5/1)	1 (1/0)	125 (112/13)	97
Equids							
Horse	2 (2/0)	0 (0/0)	0 (0/0)	0 (0/0)	0 (0/0)	2 (2/0)	1
Donkey	2 (2/0)	0 (0/0)	0 (0/0)	0 (0/0)	0 (0/0)	2 (2/0)	1
Subtotal	4 (4/0)	0 (0/0)	0 (0/0)	0 (0/0)	0 (0/0)	4 (4/0)	3
Total	98 (88/10)	15 (13/2)	9 (9/0)	6 (5/1)	1 (1/0)	129 (116/13)	100
Percent of total	76	12	7	5	1	100	

Table 8
Government valuation (in USD) of livestock killed by predators in 102 investigated depredation events in the lion conflict study area in northern Botswana between October 2014 and December 2016.

	2014[a]	2015	2016	Total
Livestock Lost	5	50	61	116
Depredation Events	5	44	53	102
Livestock Valuation (in USD)				
Bovids				
Cow	1,240	7,440	8,370	17,050
Calf	0	1,400	1,500	2,900
Bull	0	0	2,825	2,825
Ox	310	2,480	3,720	6,510
Goat	0	45	45	90
Subtotal	1,550	11,365	16,460	29,375
Equids				
Horse	0	255	255	510
Donkey	0	40	0	40
Subtotal	0	295	255	550
Total	1,550	11,660	16,715	29,925

[a] Indicates an incomplete year of data.

Lions were the major culprits in all reported livestock depredation events, affirming local opinions about which predators were most harmful to rural farmer's livelihoods. Lions are known to cause the most damage in some circumstances (e.g., Laikipia District, Kenya, Ogada et al., 2003) but spotted hyenas have been shown to cause the most damage in others (e.g., outside Massai Mara National Reserve, Kenya, Kolowski and Holekamp, 2006; Massai Steppe, Tanzania, Mponzi et al., 2014). Cattle were the most common domestic prey choice (targeted in 96% of investigated livestock attacks and 92% of PAC data livestock lost) as lions predominantly prey on large ungulates (Hayward and Kerley, 2005) and cattle are the most prevalent domestic animal in the area. Where lions take the most livestock, larger livestock (cattle) are taken most frequently (Ogada et al., 2003), and where spotted hyenas are the worst offenders, smaller stock (sheep and goats) are lost most frequently (Kolowski and Holekamp, 2006; Mponzi et al., 2014). While there were correlations between the number of depredation events per village and both the estimated numbers of cattle and estimated number of cattle per person, none were statistically significant. As the number of livestock increases the chance of depredation also increases. Similarly, there was a non-significant, positive correlation between the number of depredation events and the number of project employees, the number of predator-proof kraals built, and the number of lion alerts sent per village. Mitigation efforts were more intensive in areas with higher rates of conflict and there was a significant correlation between the number of depredation events and an estimate of our efforts/time spent in each village. We investigated conflicts when they occurred and thus spent more time in villages with higher levels of conflict. We recognize that our simultaneous involvement in conflict mitigation could have biased the number of reports we received from villagers. Though we established the same mitigation practices in all focal villages, the intensity of these mitigation efforts differed as a result of conflict intensity. The level of this bias is not directly quantifiable, and we present our results with this caveat.

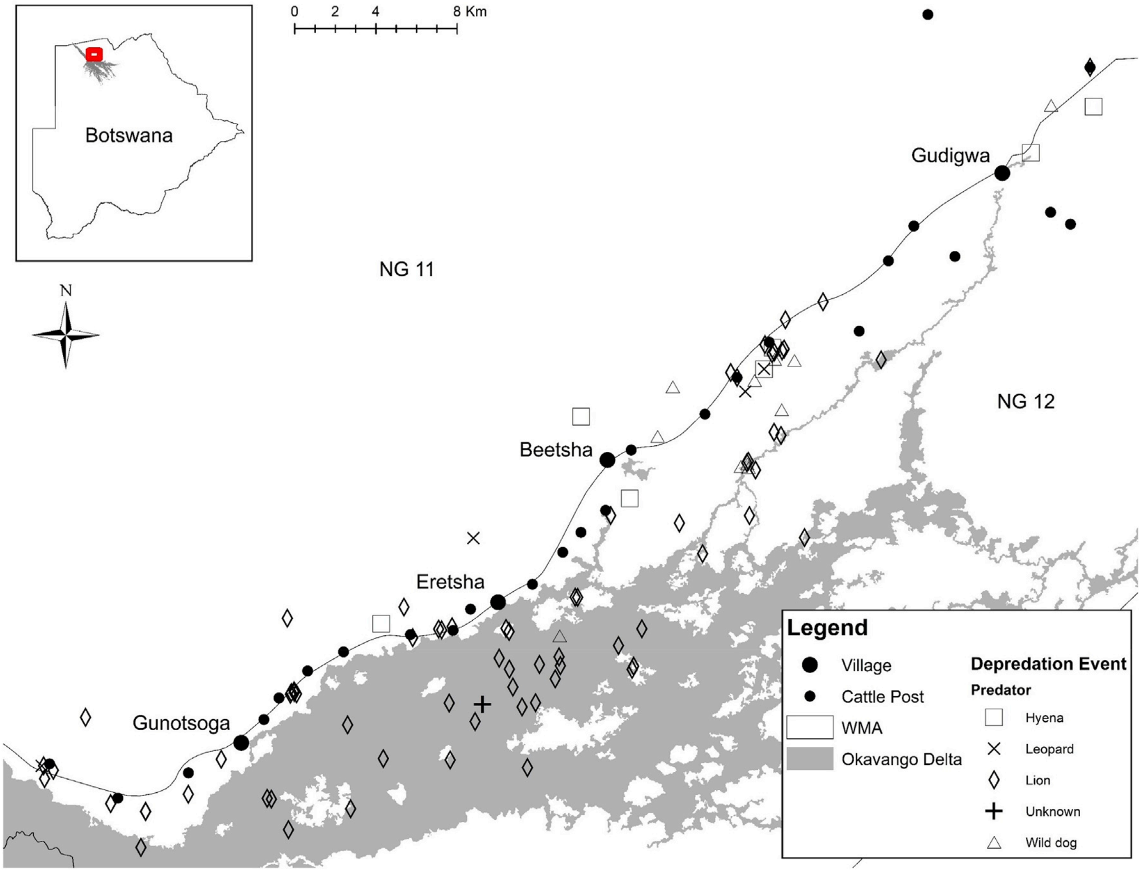

Fig. 4. Distribution of investigated depredation events documented in the lion conflict study area in northern Botswana between October 2014 and December 2016.

Table 9
Investigated depredation events (n = 102) attributed to each village with associated attributes and management actions in the lion conflict study area in northern Botswana between October 2014 and December 2016.

Village	Village Attributes					Management Actions			
	No. events	Est. human population	Est. livestock population	Est. no. livestock/ person	No. cattle posts	No. employees[a]	Pct. effort/ time	No. predator-proof kraals	No. lion alerts
Beetsha	40	1,585	4,122	3	8	3	30	3	26
Eretsha	29	912	1,678	2	4	2	30	4	19
Gudigwa	8	725	1,176	2	11	1	15	2	9
Gunotsoga	19	953	824	1	6	0	20	2	23
Seronga	5	3,716	2,002	1	4	1	5	1	0
Unknown	1	–	–	–	–	–	–	–	–
Total	102	7,891	9,802	1	33	7	100	12	77
Correlation to no. events (r)		−0.37	0.67	0.74	−0.05	0.75	0.93	0.79	0.87
p-value		0.53	0.21	0.15	0.94	0.15	0.02	0.11	0.06

[a] Indicates six local employees and one western employee.

The total value of livestock we confirmed lost to predators was ~US$30,000 in just over two years, with average yearly losses totaling ~ US$14,000. Based on the estimated local population (Botswana Population and Housing Census, 2011) and average household sizes in the area (LeFlore, unpublished data), that level of loss equates to about US$25 per household per year. Between 2009 and 2016, the value of all livestock losses reported to the government was ~US$185,600, an average of US$25,575 per year across four villages and US$45 per household. There was a drop in reported livestock losses in 2014 which

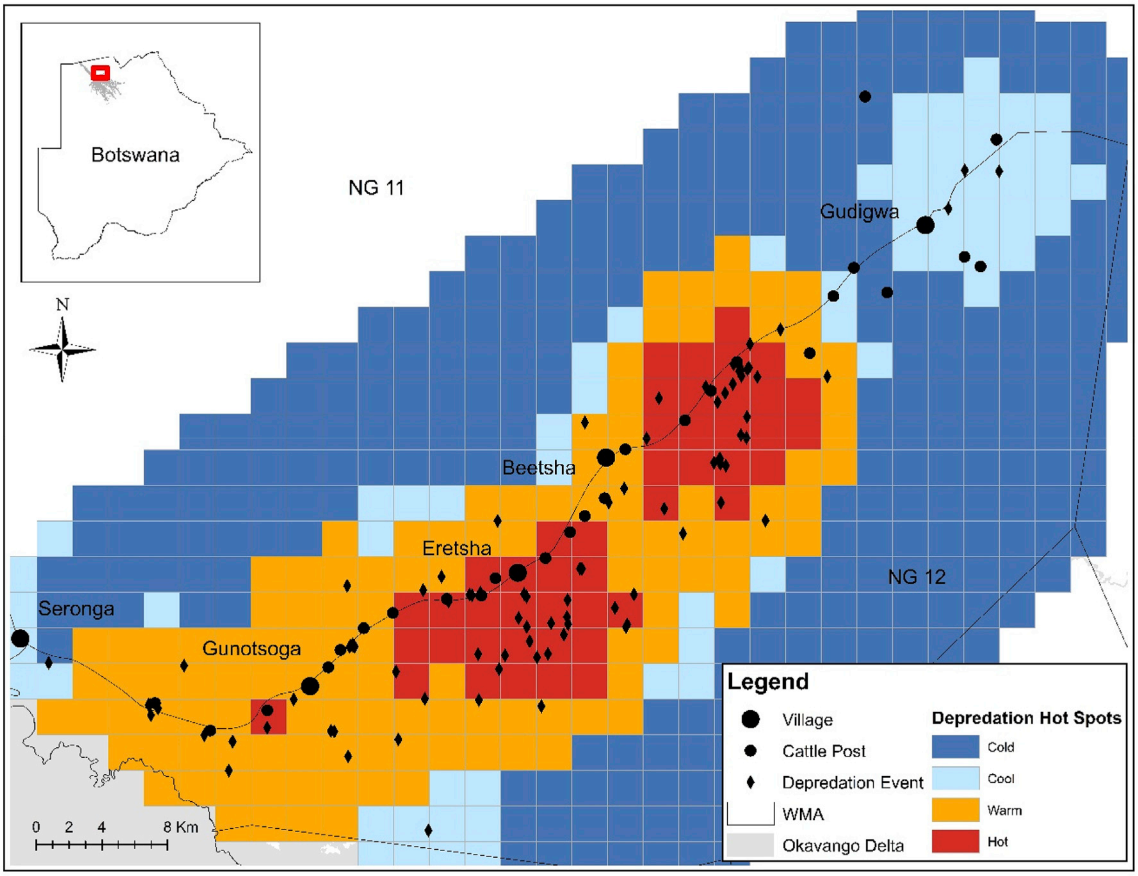

Fig. 5. Investigated depredation event hotspots in the lion conflict study area in northern Botswana between October 2014 and December 2016 based on optimized hot spot analysis conducted in ArcGIS.

was likely due to villagers killing 30–50% of lion population in 2013 following high levels of conflict. Typically, all farmers do not experience losses at similar levels; losses are disproportionately distributed amongst farmers, affecting a minority of individuals (Thirgood et al., 2005; Dickman et al., 2011). Suffering the loss of one individual to a depredation event could cost a farmer twenty times as much as the average per household yearly rate of loss (average market value of a bull = US$565). Given average herd sizes in the study area, suffering even one event could be extremely detrimental to local farmers and more than one in a year could be catastrophic (Thirgood et al., 2005).

Most depredation events occurred while livestock were either grazing unguarded or left out in the veld overnight. Livestock husbandry is quite limited in the region (Hemson et al., 2009; Weise et al., 2018), and there is no longer a strong herding culture. As children and teenagers are now going to school there are fewer young men to take responsibility for herding the livestock. Traditional livestock herding and husbandry efforts have largely been abandoned in western Europe, North and South America, and portions of Africa (Breitenmoser et al., 2005). In East Africa a strong herding culture persists, primarily due to continued risk of livestock theft (Frank, 1998; Ogada et al., 2003; Frank et al., 2005; Woodroffe et al., 2007), and most of the livestock losses occur at and around the "boma" (kraal/livestock enclosure; Ogada et al., 2003; Frank et al., 2006). In our area, livestock are most at risk away from cattle posts and villages in conflict hotspots southeast of Eretsha and east of Beetsha where depredation events were significantly clustered. Sound livestock husbandry and herding practices are vital to minimizing conflict with predators (Ogada et al., 2003; Breitenmoser et al., 2005 Woodroffe et al., 2007).

Overall, there were 50% more depredation events reported to DWNP than were reported to and investigated by us between 2015 and 2016, years of complete data (Tables 1 and 8). While we were likely unable to investigate every depredation event that actually occurred, given our extensive efforts to establish and maintain positive relationships with community members and continued presence in the area, it seems unlikely that an additional 50% of depredation events occurred and were not reported to us. Instead, we postulate this discrepancy is a result of the factors described above, and villagers are likely falsely reporting losses, purposefully or not, to receive compensation from the government by reporting animals lost to drought, starvation, or disease as animals lost to predators. On at least 5 occasions we were called to investigate a dead animal with no signs of predator attack. Without adequate resources to investigate claims of livestock loss, DWNP has limited ability to determine which claims are accurate and which are attempts to take advantage of the compensation system.

6. Management implications

It is beneficial for villagers to receive compensation for losses and alleviate the economic burden of predator conflict (Naughton-Treves et al., 2003; Nyhus et al., 2005), however the government-run compensation program is unable to sustainably reimburse claims in its current form. To ensure that the program is not being exploited, rigorous and prompt investigation of claims should be established. Ineffective compensation programs may actually increase retaliatory killings (Nyhus et al., 2005). While the program has shortcomings, it should not be abandoned altogether because, similar to other regions, villagers support and expect reimbursement and ceasing payments can cause increased retaliation and hostility (Bangs et al., 1998; Naughton-Treves et al., 2003; Treves et al., 2009). Furthermore, compensation programs lacking adequate incentives for farmers to properly care for livestock can lead to poor livestock husbandry and disregard for preventative measures (Dyar and Wagner, 2003; Swenson and Andren, 2005). Compensation schemes in Botswana and around the globe must include a variety of factors to be effective (see Nyhus et al., 2005). The most critical factors include: correct and speedy confirmation of losses; timely and fair payments; clear protocols, rules, and guidelines that connect payment and appropriate conservation management practices; and an understanding of the cultural and socio-economic systems. Our work underscores the importance of investigating depredation events as a part of compensation programs.

Finally, our results show that most losses occur in the veld and while livestock are unguarded. Therefore, we suggest conflict mitigation efforts focus on increasing herding and livestock husbandry practices in the region. In many cases, conflict mitigation programs focus on securing the livestock enclosure (e.g., our efforts, Lichtenfeld et al., 2015). However, this is likely not the most effective strategy in Botswana (Weise et al., 2018). Governments and conservation organizations would be wise to assess damages prior to establishing mitigation strategies.

Declarations of interest

None.

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