

**A peer-reviewed version of this preprint was published in PeerJ on 9 July 2015.**

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Winterbach HEK, Winterbach CW, Boast LK, Klein R, Somers MJ. 2015. Relative availability of natural prey versus livestock predicts landscape suitability for cheetahs *Acinonyx jubatus* in Botswana. PeerJ 3:e1033  
<https://doi.org/10.7717/peerj.1033>

# Relative availability of natural prey versus livestock predicts landscape suitability for cheetahs *Acinonyx jubatus* in Botswana

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Prey availability and human-carnivore conflict are strong determinants that govern the spatial distribution and abundance of large carnivore species and determine the suitability of areas for their conservation. For wide-ranging large carnivores such as cheetahs (*Acinonyx jubatus*) suitable conservation areas beyond protected area boundaries are crucial to effectively conserve them both inside and outside protected areas. Although cheetahs prefer preying on wild prey, they also cause conflict with people by preying on especially small livestock. We investigated whether the distribution of cheetahs' preferred prey and small livestock biomass can be used to explore the current potential suitability of agricultural areas in Botswana for the long-term persistence of its cheetah population. We found it gave a good point of departure for identifying priority areas for land management, the threat to connectivity between cheetah populations and areas where the reduction and mitigation of human-cheetah conflict is critical. Our analysis showed the existence of a wide prey base for cheetahs across large parts of Botswana's agricultural areas which provide additional large areas with high conservation potential. Twenty percent wild prey biomass proved to be possibly the critical point to distinguish between high and low predicted levels of human-cheetah conflict. We identified focal areas in the agricultural zones where restoring wild prey numbers in concurrence with effective human-cheetah conflict mitigation efforts are the most immediate conservation strategies needed to maintain Botswana's still large and contiguous cheetah population.

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2 The strong linear relationships that exist between the density of African large carnivores and the  
3 biomass of their natural prey (Hayward, O'Brien, & Kerley, 2007) point to prey availability as the  
4 primary natural determinant that governs the spatial distribution and abundance of large carnivore  
5 species and determines the suitability of an area for their conservation (Broekhuis et al., 2013; Fuller &  
6 Sievert, 2001; Gittleman & Harvey, 1982; Hayward, O'Brien, & Kerley, 2007). For competitively  
7 inferior species, such as cheetahs and African wild dogs (*Lycaon pictus*), interspecific competition,  
8 especially from lions (*Panthera leo*) and spotted hyaenas (*Crocuta crocuta*), can also exert a strong  
9 influence on their movements, behaviour and density (Durant, 2000; Van der Meer et al., 2013). This  
10 occurs predominantly inside protected areas where densities of lions and spotted hyaenas tend to be  
11 high (Creel, Spong & Creel, 2001). In human-dominated landscapes human activities and their conflict  
12 with predators are often as strong a determinant factor as prey availability in the occurrence and  
13 survival of large carnivores (Gusset et al., 2009; Marker et al., 2003; Schuette, Creel & Christianson,  
14 2013; Woodroffe & Ginsberg, 1998) With few protected areas large enough to contain the wide-  
15 ranging behaviour of large carnivores, the management of suitable conservation areas beyond protected  
16 area boundaries are necessary to effectively conserve large carnivore species both inside and outside  
17 protected areas (Woodroffe & Ginsberg, 1998). This requires the assessment of both the distribution  
18 and abundance of suitable prey and the potential levels of human-carnivore conflict, often on a large  
19 geographic scale.

20 The cheetah is Africa's most endangered felid (Marker et al., 2007) and is listed as Vulnerable with  
21 a declining population trend by the IUCN Red List of Threatened Species (Durant et al., 2008). They  
22 are one of the most wide-ranging terrestrial carnivores and need extensive areas to sustain viable  
23 populations (IUCN/SCC, 2007). Cheetahs feed on a diverse wild prey base ranging from animals as  
24 small as scrub hares (*Lepus saxatilis*) to as large as zebras (*Equus quagga*), but generally select the  
25 most abundant locally available prey up to 135 kg with a strong preference for those with a body mass

26 between 14 kg – 40 kg (Clements et al., 2014). At least 75% of the cheetah's resident range in southern  
27 Africa falls outside protected areas (IUCN/SSC, 2007). In southern Africa this falls mostly on  
28 farmlands where competition with other large carnivores is low and a sufficient small to medium-sized  
29 wild prey base still occurs (Lindsey & Davies-Mostert, 2009; Klein, 2007; Marker & Dickman, 2004).  
30 Consequently, conservation efforts in human-dominated landscapes are critical for this species long-  
31 term survival. Although cheetahs prefer preying on wild prey (Marker et al., 2003), they also cause  
32 conflict with people by predating on livestock which generally involves small stock (sheep and goats)  
33 and occasionally calves and foals (Marker et al., 2003; Ogada et al., 2003; Selebatso, Moe & Swenson,  
34 2008; Woodroffe et al., 2007).

35 Botswana is important for the regional and global long-term survival of cheetahs. It has a large and  
36 still contiguous cheetah population and hosts the second largest national population with  $\pm 1\ 786$   
37 animals (Klein, 2007) after Namibia with  $\pm 3\ 138 - 5\ 775$  animals (Hanssen & Stander, 2004; Marker  
38 et al., 2007). It also forms the major connecting range for the southern African cheetah population  
39 which is largest known free-ranging resident cheetah population comprising  $\pm 6\ 500$  animals  
40 (IUCN/SCC, 2007). Around half of the Botswana cheetah population occurs outside conservation  
41 areas on rangeland (Winterbach & Winterbach, 2003). In 2009, a Draft National Conservation Action  
42 Plan for Cheetahs and African Wild Dogs in Botswana was prepared by the Department of Wildlife  
43 and National Parks (DWNP). One of the primary targets set out in the national plan is obtaining  
44 quantitative knowledge regarding the main threats to securing a viable cheetah population across its  
45 range in Botswana. However, scientific information on cheetah distribution and density on a country-  
46 wide scale is nearly impossible to obtain, but the urgent conservation status of threatened species such  
47 as cheetahs can ill-afford to wait for detailed scientific information before policy decisions are made.  
48 Therefore, an objective, clear system of evaluation, based on the best available and reliably correlated  
49 information, is needed that can be used as a basis to support policy setting (Theobald et al., 2000).

50 We used the distribution of cheetahs' preferred prey and small stock biomass as the most essential  
51 components to explore the current potential suitability of agricultural areas for the long-term  
52 persistence of cheetahs in Botswana. The percentage prey biomass of small stock and prey biomass  
53 combined was used as the primary indicator of probable levels of human-cheetah conflict. Our analyses  
54 demonstrated that wild prey combined with livestock can provide a country-wide overview of the  
55 suitability of the Botswana landscape for cheetahs without the use of complex modelling. It allows for  
56 prudent conclusions as a point of departure for identifying specifically priority areas for land  
57 management, the threat to connectivity between cheetah populations and areas where the reduction and  
58 mitigation of human-cheetah conflict is critical.

## 60 **Study Area**

61  
62 The Republic of Botswana is ca 582 000 km<sup>2</sup> in size and is landlocked with Namibia, South Africa,  
63 Zimbabwe, and Zambia as its neighbours. Roughly 50% of its 2 million people (3.5 people / km<sup>2</sup>) live  
64 in rural villages and small settlements (Central Statistics Office, 2014).

65 The mean altitude above sea level is 1 000 m (515 – 1 491 m a.s.l.). The climate is arid to semi-arid  
66 with highly variable rainfall and periodical severe droughts. Mean annual rainfall varies from 650 mm  
67 in the north-east to 250 mm in the south-west. Average maximum daily temperatures range from 22° C  
68 in July to 33° C in January and average minimum temperatures from 5° C to 19° C respectively  
69 (Department of Surveys and Mapping, 2001). Only two perennial rivers occur; the Okavango River  
70 which fans out into the Okavango Delta and the Kwando/ Linyanti/Chobe river system which forms the  
71 boundary with Namibia and Zambia. The Makgadikgadi Pans is a seasonal wetland with natural  
72 perennial water holes in the Boteti River providing critical dry season water sources for wildlife in  
73 Makgadikgadi National Park (MNP). Across the rest of the country, scattered pans and ancient

74 riverbeds periodically hold water during the wet season. Considerable seasonal variations in the density  
75 and distribution of ungulate species occur and the blocking of migration routes by veterinary fences has  
76 led to ungulate die-offs during drought years (Bergström & Skarpe, 1999; Verlinden, 1998). Seasonal  
77 migrations of Burchell's zebra and blue wildebeest (*Connochaetes taurinus*) still occur inside MNP  
78 (Brooks, 2005), and zebra migrate between MNP and the Okavango Delta (Bartlam-Brooks, Bonyongo  
79 & Harris, 2011).

80 Approximately 38% of the land use in Botswana is designated for wildlife utilization; 17% as  
81 protected areas (national parks and game reserves) and 21% as Wildlife Management Areas (WMAs)  
82 (Figure 1). WMAs are primarily designed for wildlife conservation, utilisation, and management  
83 (Hachileka, 2003), however, unlike protected areas; people are permitted to reside within WMAs and  
84 to own and graze livestock there. Protected areas and WMAs do not have 'predator-proof' fences, with  
85 the exception of the western and southern boundary of MNP which provides only a partial barrier due  
86 to its poor upkeep.

87 Five percent of the country is residential areas and 57% consists of rangeland (of which roughly  
88 70% is tribal / communal grazing land), 25% is state land, 5% freehold land leased for large-scale  
89 commercial ranching (Department of Surveys and Mapping, 2001). In the Draft National Predator  
90 Strategy (Winterbach & Winterbach, 2003), the country was sub-divided into two main predator  
91 management zones; Conservation Zones comprising of national parks, forest reserves, sanctuaries and  
92 WMAs, and the Agricultural Zones consisting of rangelands, residential and mining areas (Figure 1).

93 Livestock (mainly cattle) rearing is the primary economic activity over large parts of Botswana and  
94 constitutes 70 - 80% of the agricultural GDP (Botswana Ministry of Agriculture 2011). In the 2012  
95 household survey, the livestock population in Botswana was estimated as 2.6 million cattle, 1.8 million  
96 goats and 300,000 sheep, most of which were located on the more fertile eastern side of the country  
97 (Botswana Ministry of Agriculture 2011). Approximately 92% of this livestock are in the traditional

98 cattle post system on communal grazing land (Botswana Ministry of Agriculture 2011). Botswana's  
99 key environmental issues include water scarcity and pollution, rangeland degradation and  
100 desertification, loss of biodiversity, deforestation, and an increased frequency of periodic droughts  
101 (Wingqvist & Dahlberg, 2008).

102 In Botswana, cheetahs are a protected species. Before 2000, cheetahs could be hunted or captured  
103 under and in accordance with the terms and conditions of a Director's permit (Wildlife Conservation  
104 and National Parks Act (Act No. 28 of 1992)). However, since 2000, a statutory instrument disallowed  
105 the killing of cheetahs for any reason (Botswana Government Gazette, 2000), and in 2005, a US\$ 113  
106 fine or term in prison was added (Botswana Government Gazette, 2005), although the latter is rarely  
107 enforced. Botswana has an unutilized CITES quota of five cheetah per annum (Klein, 2007).

## 109 **Methods**

111 The first parameter we used to determine landscape suitability was the biomass of wild prey species  
112 which occur in Botswana that are preferred prey or in the preferred weight range (body mass 14 kg –  
113 40 kg ) for cheetahs (Clements et al., 2014) (Table 1), hereafter termed 'wild prey'. We included Red  
114 lechwe (*Kobus lechwe*) as one of the preferred prey of cheetah in the seasonal floodplains of the  
115 Okavango Delta (pers. comm.). We did not include calves of the larger wild prey since population  
116 numbers were collected during the dry season when calves were not prevalent. The second parameter  
117 we used was the biomass of goats and sheep (herein referred to as 'small stock') as the main livestock  
118 whose depredation is a significant predictor of human-cheetah conflict levels (Supplementary material  
119 Appendix 1). The third parameter was the percentage that wild prey biomass contributed to the total  
120 biomass of wild prey and small stock combined to indicate probable levels of conflict (herein referred  
121 to as 'percentage wild prey'.



122 We calculated wild prey and small stock biomass in Large Stock Units (LSU = body weight 0.75)  
123 per 12' grid cells from the combined data of six country-wide annual dry season aerial surveys  
124 conducted by DWNP between 2001 and 2005 and in 2007. Aerial surveys during the drought years  
125 before 2001 and very wet years after 2007 were excluded. Cheetah biomass strongly correlates with  
126 lean season prey biomass (Fuller & Sievert, 2001) and we felt the six aerial surveys used in this study  
127 best represented the general distribution of prey and small stock biomass on a country-wide scale.  
128 Although aerial surveys tend to undercount small mammal species, such as steenbok (*Raphicerus*  
129 *campestris*) and duiker (*Sylvicapra grimmia*), it is the only feasible method for wildlife monitoring on  
130 a country-wide scale. We assumed that using a combined data set from six aerial surveys was sufficient  
131 to determine the general distribution of wild prey and small stock biomass across Botswana.

132 We utilized the broad landscape suitability stratification for large carnivores in Botswana from  
133 (Winterbach et al., 2014) and refined it in the agricultural zones based on the distribution of wild prey  
134 biomass, small stock biomass and the percentage wild prey biomass to identify homogeneous strata. To  
135 determine if there is a critical percentage wild prey that can be used to differentiate between high and  
136 low probable levels of conflict, we used data on livestock attacks by cheetahs between 1995 and 2006  
137 consisting of problem animal conflict reports and farms questionnaire surveys ( $N = 188$ ) conducted  
138 during 2004 and 2005. We calculated the number of aerial survey grids with livestock attacks in  
139 different categories of percentage wild prey biomass in the Kgalagadi, Ghanzi Agricultural Zones and  
140 the western strata of the Central Agricultural Zone. From this we calculated the frequency of livestock  
141 attacks per grid cell for each category (Supplementary material Appendix 2) and used a chi-square test  
142 to test whether the observed frequency of conflict reports has the same frequency as the grids per  
143 category of percentage wild prey. Observations were classified into categories independently and all  
144 categories had expected frequencies  $> 5\%$ . We used Bonferroni intervals (Byers, Steinhorst &

145 Krausman, et al. 1984) to test for categories with observed frequencies that differed significantly from  
146 the expected.

147 To test our classification of suitable and unsuitable areas for cheetahs we investigated the reported  
148 presence, transience and absence of cheetahs using questionnaire surveys ( $N = 89$ ) conducted during  
149 2012 and 2013 that targeted primarily game ranchers and commercial livestock farmers in the game  
150 ranching regions of the Central, Ghanzi, Ngamiland and North East regional districts. Farmers were  
151 asked to record the status of cheetahs on their property as present (visual sightings or tracks seen at  
152 least quarterly), transient (visual sightings or tracks seen less frequently than quarterly) or absent  
153 (never seen cheetahs or its tracks). We used a chi-square test with Bonferroni simultaneous confidence  
154 intervals (Byers, Steinhorst & Krausman, et al. 1984) to test the hypothesis that farmers reported  
155 cheetahs as present, transient or absent in similar proportions on grid cells with different percentage  
156 wild prey categories. We used the Natural Breaks (Jenks) function in ArcMap 9.3.1 that best grouped  
157 similar values and maximize the differences between groups to identify categories of landscape  
158 suitability for the long-term persistence of cheetahs. We identified five categories of suitability, based  
159 on the proportion of grid cells in each sub-stratum that had  $\leq 20\%$  wild prey.

160

## 161 **Results**

162

163 The distribution of cheetah wild prey biomass and the percentages of wild prey biomass in the different  
164 categories are shown in Figure 2 and Figure 3, respectively. Although cheetah wild prey occurred  
165 widely in the agricultural zones, it contributed only 0 – 5% of the total biomass (wild prey plus small  
166 stock) available to cheetahs in the eastern parts of both the Central Agricultural Zone and the  
167 Kgalagadi Agricultural Zone 1.

168 The percentage wild prey biomass in the Kgalagadi and Ghanzi Agricultural Zones and the western  
169 strata of the Central Agricultural Zone combined was  $\leq 20\%$  in 235 of the 403 grids (58.3%) and  $>$   
170  $80\%$  in 136 grids (33.7%) with the remaining 32 grids (8%) between  $> 20\%$  and  $\leq 80\%$ . The number of  
171 conflict reports recorded per grid for the percentage wild prey biomass intervals ranged from 0.23 to  
172 0.81 reports per grid cell with a mean of 0.49 and standard error of 0.25 ( $N = 8$ ) (Table 2). The number  
173 of conflict reports was consistently below the mean when the percentage wild prey biomass exceeded  
174  $20\%$  (Figure 3).

175 We subsequently selected  $0\%$ ,  $> 0$  to  $\leq 20\%$ ,  $> 20$  to  $\leq 80\%$ , and  $> 80$  to  $\leq 100\%$  as the main  
176 categories of percentage wild prey biomass. The observed frequency of conflict reports in grids from  
177 the separate categories differed significantly from the expected ( $\chi^2 = 52.42$ ,  $df = 1$ ,  $P < 0.001$ ). Conflict  
178 reports were more frequently than expected ( $P = 0.05$ ) in grids with  $0\%$  wild prey biomass, and  
179 significantly lower than expected in areas with  $> 20\%$  wild prey biomass ( $\alpha = 0.05$ ,  $Z = 2.4977$ ) (Table  
180 3). We therefore took grids with  $\leq 20\%$  wild prey biomass as representing areas with high predicted  
181 levels of conflict, and  $> 20\%$  wild prey biomass as areas with low predicted levels of conflict.

182 We rated the five categories of landscape suitability identified in ArcMap as very high ( $0 - 6.7\%$   
183 grid cells with  $\leq 20\%$  wild prey), high ( $6.8 - 25\%$ ), medium ( $25.1 - 50$ ), low ( $50.1 - 75\%$ ) or  
184 unsuitable ( $75.1 - 100\%$ ) and provide a country-wide landscape suitability map for the long-term  
185 persistence of cheetahs in Botswana (Figure 4) (Supplementary material Appendix 3). The  
186 conservation zones were the most suitable for the long-term persistence of cheetahs, while the  
187 agricultural zones consisted of a mosaic of medium suitability to unsuitable. The classification of some  
188 strata as unsuitable for cheetahs was supported by the questionnaire data where the proportion of  
189 farmers that reported cheetahs present or absent differed significantly between suitable and unsuitable  
190 cheetah areas ( $\chi^2 = 129.11$ ,  $df = 3$ ,  $P < 0.001$ ). A hundred per cent of farmers reported cheetahs absent

191 in the unsuitable areas ( $n = 10$ ) significantly more than would be expected by chance and only 13.9 %  
192 of farmers reported cheetahs absent within the suitable areas ( $N = 79$ ) ( $\alpha = 0.05$ ,  $Z = 2.4977$ ) (Table 4).

193

## 194 **Discussion**

195

196 Our results show that the distribution of cheetah wild prey and small stock biomass can provide a good  
197 information basis to evaluate the landscape suitability for cheetahs on a country-wide scale and  
198 indicate priority areas for conservation actions. In Botswana, 20% wild prey biomass showed to be a  
199 potentially critical point to distinguish between high and low predicted levels of human-cheetah  
200 conflict. The distribution of the categories of percentage wild prey biomass (Figure 3) clearly  
201 highlights areas where locally-adapted conflict mitigation strategies are a priority, for example along  
202 the western and eastern boundaries of the Okavango Delta. In addition, the landscape suitability map  
203 (Figure 4) shows strata where currently the long-term persistence of cheetahs is highly unlikely, such  
204 as in the eastern part of the Central Agricultural Zone, and where connectivity within the cheetah  
205 population is threatened, such as between the Northern and Southern Conservation Zones.

206 The distribution of cheetah wild prey biomass provides a wide prey base across large parts of the  
207 agricultural areas in Botswana. In fact, the greater resource availability in Botswana may be causal to  
208 the considerably higher density, smaller home range sizes and generally larger body size of cheetahs in  
209 Botswana compared to Namibia (Boast et al., 2013). The significant reduction in conflict reports in  
210 areas with  $> 20\%$  wild prey biomass confirms adopting an integrated livestock-wildlife management  
211 approach in the communal rangelands of Botswana as an effective conflict mitigation strategy to  
212 maintain key areas in the agricultural zones for cheetah conservation.

213 Almost 50% of Botswana's cheetah population occurs in agricultural areas (Klein, 2007). Support  
214 from both livestock and game farmers for cheetah conservation outside protected areas is low in

215 Botswana (Selebatso, Moe & Swenson, 2008) and retaliatory killing of cheetahs is considered to be  
216 widespread (Klein, 2007). Livestock farmers view cheetahs as the fourth most problematic predator,  
217 following leopards (*Panthera pardus*), jackals (*Canis mesomelas*) and wild dogs, while sixty percent  
218 (60%) of private game farmers rate them as the second top stock predators (Selebatso, Moe &  
219 Swenson, 2008). As in Namibia (Marker et al., 2003), cheetahs in Botswana prey predominantly on  
220 local native game (Cheetah Conservation Botswana unpubl data). This preference for wild prey has  
221 also been shown for other large carnivores even in areas where livestock is predominant (Hemson,  
222 2003; Ogara et al., 2010; Woodroffe et al., 2005), and maintaining wild prey populations within  
223 livestock areas is viewed as a feasible way to decrease livestock depredation (de Azevedo & Murray,  
224 2007; Mizutani, 1999).

225 Steenbok and duiker are two of the generally most common prey for cheetahs in Botswana (Klein,  
226 2007). The high density of steenbok and duiker (range 0.261 - 4.319 animals / 100 km<sup>2</sup>) calculated  
227 from the six aerial surveys in the Ghanzi Community Stratum (stratum 7.2) suggests that livestock do  
228 not necessarily displace small ungulates to the extent that large ungulates are displaced (Riginos et al.,  
229 2012). However, conflict with people seems to have a stronger influence on cheetah numbers than wild  
230 prey biomass when livestock numbers are high. In the Ghanzi Farms Stratum (stratum 7.1) there was a  
231 sample point where cheetah density was too low to calculate despite having more wild prey than  
232 neighbouring areas with 0.7 cheetahs / 100 km<sup>2</sup> (Boast & Houser, 2012; Kent, 2010). This shows the  
233 potential negative impact of human conflict on the cheetah population even where there is a good wild  
234 prey base but it formed a small percentage to the total biomass due to the high small stock biomass.

235 The Okavango Delta is nearly surrounded by two agricultural strata (strata 6.2 and 6.4 in Figure 4)  
236 that are currently unsuitable for the long-term persistence of cheetahs. Wild prey biomass is low and  
237 PAC reports show conflict levels between farmers and cheetahs are high. Together with the low  
238 suitability of agricultural stratum 6.3, the free movement of cheetahs from the Northern Conservation

239 Zone towards the Central Kalahari Game Reserve (CKGR) is impeded and we therefore assumed that  
240 cheetahs found in these strata are most likely transients. A second linkage between the Northern and  
241 Southern Conservation Zones extends from MNP to the south-west across the most northern part of the  
242 Central Agricultural Zone. PAC reports indicate cheetah presence in this corridor (Figure 4). Concerted  
243 efforts in conflict mitigation to ensure functional corridors are essential to maintain connectivity  
244 between the smaller northern cheetah population and that of the south, especially in the light that  
245 (Dalton et al., 2013) found that the northern cheetah population showed some degree of genetic  
246 isolation. However, the small sample size ( $N = 4$ ) of cheetahs from the north and its isolation by  
247 distance from the rest of the samples may have contributed to their findings. Our study emphasises the  
248 urgent need for intensive genetic studies to accurately determine gene flow across the country.

249 In the Southern Conservation Zone, the WMAs in the Western Kgalagadi Conservation Corridor  
250 (WKCC) connect the CKGR to the Kgalagadi Transfrontier Park (KTP), Botswana's two largest  
251 nationally protected areas (Conservation International Botswana, 2010). The Schwelle, which lies  
252 south within the WKCC, provides crucial wet season forage to ungulates and is one of the most  
253 important wildlife areas in Botswana, preserving the Kalahari Ecosystem (Anonymous, 2008). The  
254 Schwelle also holds almost half of the cheetahs in the Southern Conservation Zone (Klein, 2007). The  
255 increasing demand for livestock grazing areas and already extensive use of parts of the WKCC for  
256 cattle production is a concern in maintaining this corridor for large predators and wildlife in general.  
257 For example, the proposed changing of the land use from wildlife to cattle in the eastern section of the  
258 WKCC (Anonymous, 2008) has the potential to enlarge the unsuitable areas for cheetahs across the  
259 Kgalagadi Agricultural Zones 1 and 2, and PAC reports show human-cheetah conflict is already  
260 widespread here. The implementation of effective conflict mitigation strategies will be essential to  
261 prevent the formation of a wide barrier to the free movement of cheetahs both between the CKGR and  
262 KTP, and further south connecting with the South African cheetah population.

263 The Dry North (stratum 3.1) provides a linkage with Hwange National Park in Zimbabwe. The  
264 importance of this linkage lies in that it enlarges the northern Botswana cheetah population. The aerial  
265 surveys showed wild prey biomass in the central part of the stratum overall to be low, to zero in some  
266 grid cells. However, large parts of this area are dominated by Miombo and mopane (*Colophospermum*  
267 *mopane*) woodland and close-tree *Acacia* savannah (Department of Surveys and Mapping, 2001). The  
268 low wild prey biomass is probably a function of the limitation of aerial surveys to detect small, cryptic  
269 species in these dense habitats (Jachmann, 2002). A high density of small wild prey, especially duiker  
270 and steenbok, was recorded in the western part of this area during a ground survey done in 2011  
271 (Winterbach, unpubl. data). Limiting the uncontrolled development of artificial water points in this  
272 stratum is an important conservation strategy for cheetahs as the wide-spread availability of water may  
273 increase large ungulate numbers leading to a corresponding increase in lions and spotted hyaenas that  
274 are dominant competitors of cheetahs (Creel, Spong & Creel, 2001; Durant, 2000; Mills & Gorman,  
275 1997).

276 Namibia and Botswana protect approximately 77% of the southern African cheetah population  
277 (IUCN/SCC, 2007). The most important linkage between the Namibian and Botswana population lies  
278 in the Ghanzi Agricultural Zone, where landscape suitability for cheetahs ranges between medium on  
279 the commercial farms (stratum 7.1) to low on the community farms (stratum 7.2). The proposed re-  
280 alignment of the western boundary of the WKCC to enlarge the communal grazing area for the cattle  
281 industry (Anonymous, 2008) will not only further threaten the functionality of the WKCC for wildlife,  
282 but also potentially threaten the connectivity with the Namibian cheetah population.

283 Conservation of free-ranging cheetah populations is multi-faceted and needs to be addressed from  
284 an ecological, biological and socio-economic management perspective. Despite the threats, Botswana  
285 has a large and still contiguous cheetah population with wide-spread natural movements allowing  
286 substantial gene flow (Dalton et al., 2013). However, its contiguous nature is threatened and may cease

287 if corridors are not maintained. Cheetahs have vast tracts of intact habitat in the conservation areas for  
288 persistence, and the wide-spread availability of wild prey across the agricultural zones provides  
289 additional large areas with high conservation potential. On a micro-scale, some studies found habitat  
290 structure, such as dense woodland and open savannah, have an even stronger effect on the areas the  
291 different social groups of cheetahs prefer to utilize than absolute wild prey density (Bissett & Bernard,  
292 2007; Muntifering et al., 2006). Spatial data indicating land degradation were not available to include  
293 in the landscape suitability map. However, the wide-spread rangeland degradation and desertification  
294 in the agricultural areas of Botswana (Moleele et al., 2002) reduces the availability of suitable wild  
295 prey, as well as sufficient grass cover for cheetahs for stalking, concealment from other predators, and  
296 movement between areas (Broomhall, Mills & du Toit, 2003; Marker, 2003; Mills, Broomhall & du  
297 Toit, 2004; Purchase & du Toit, 2000). This study showed that restoring wild prey numbers in focal  
298 areas in concurrence with effective human-cheetah conflict mitigation efforts are the most immediate  
299 conservation strategies needed to ensure the long-term survival of cheetahs in Botswana. With this is  
300 the restoration of degraded rangeland which will not only recover habitat for cheetahs and their wild  
301 prey but also benefit farmers by increasing the carrying capacity for livestock, which in itself may  
302 increase their tolerance for cheetahs on their land (Marker, 2003).

303

#### 304 **Acknowledgements**

305

306 Thanks to Laurie Marker, J. W. McNutt, E. Fabiano and R. Kotze for valuable comments on the  
307 manuscript. This manuscript was made possible by the Department of Wildlife and National Parks,  
308 Ministry of Environment, Wildlife and Tourism, Gaborone, Botswana.

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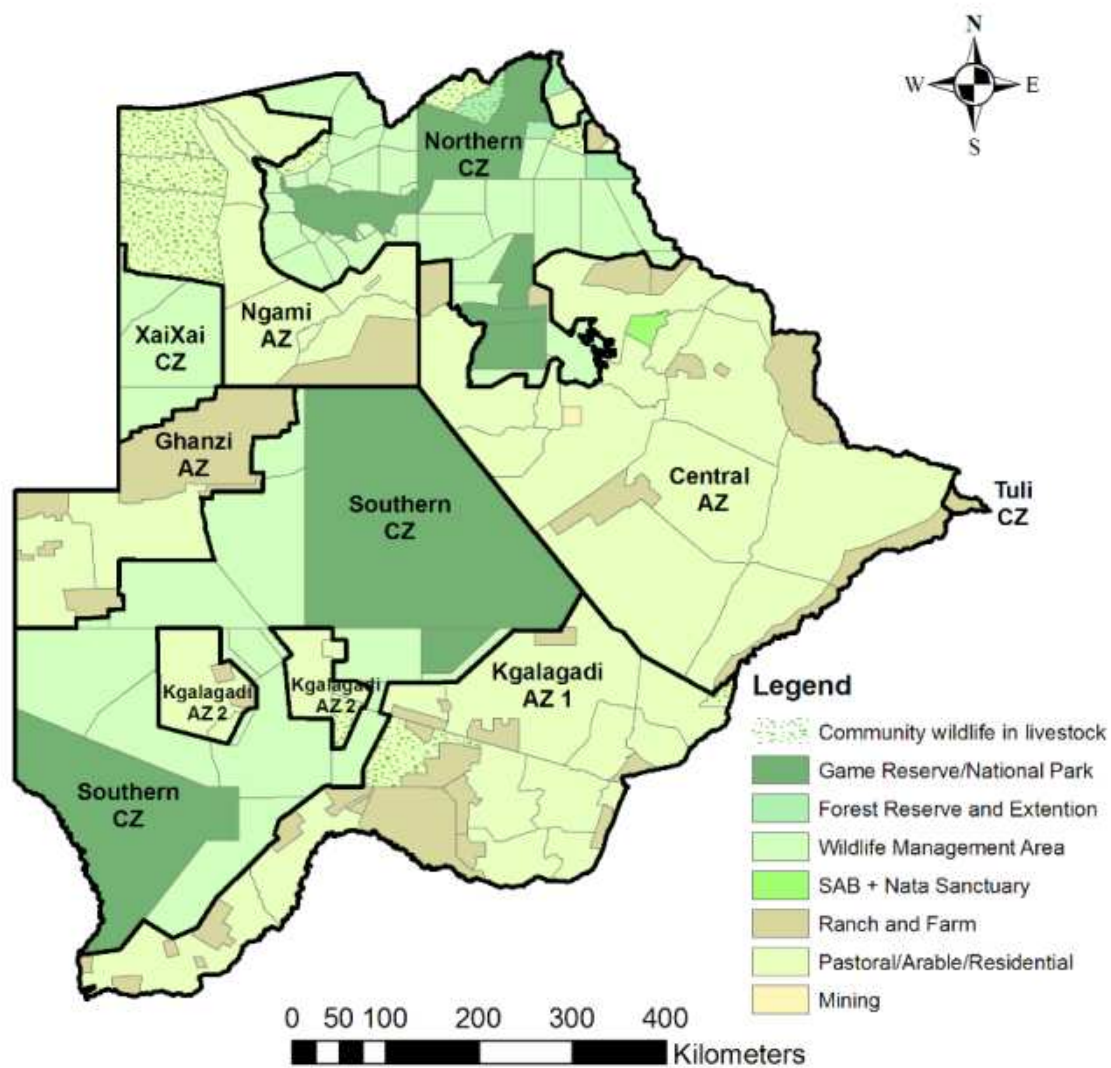


Figure 1. Land use categories present in Botswana.

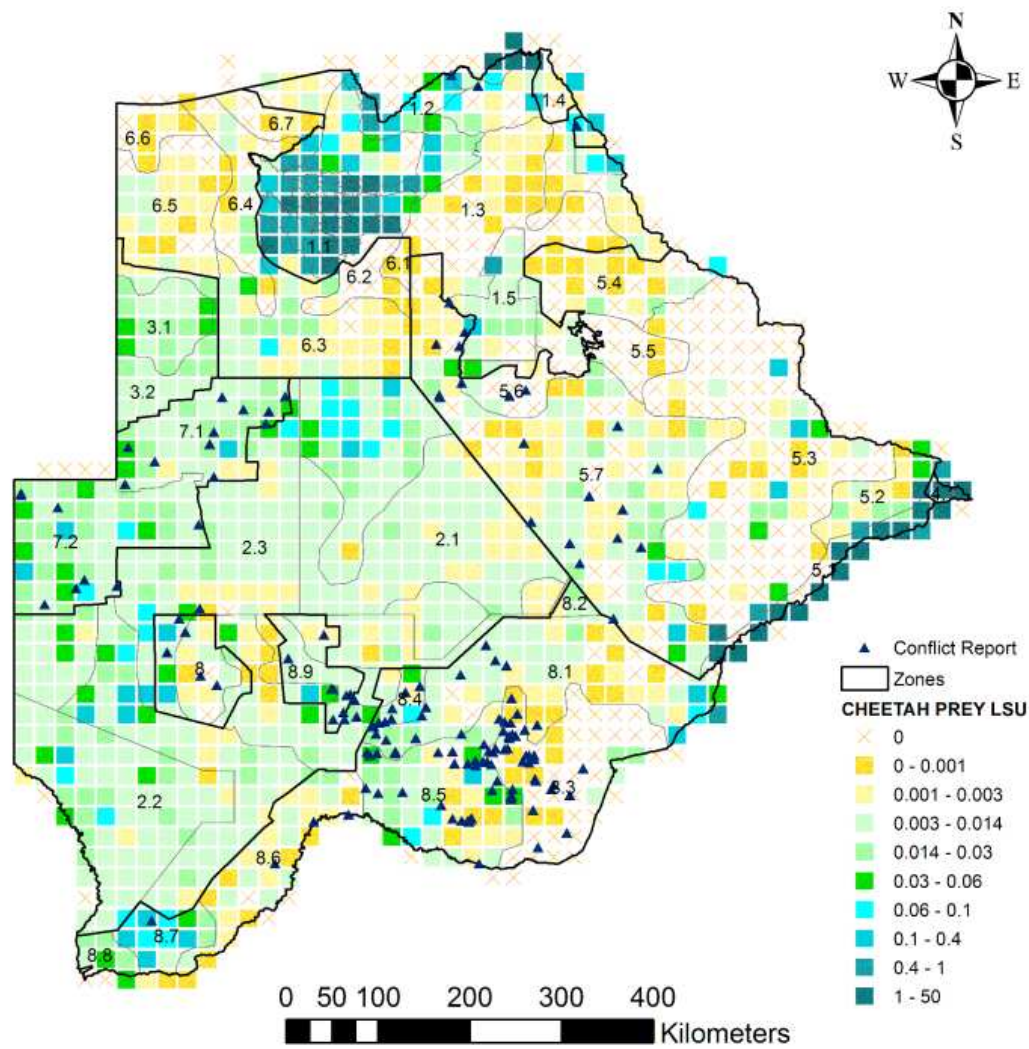


Figure 2. The distribution of cheetah prey biomass (LSU) across Botswana.



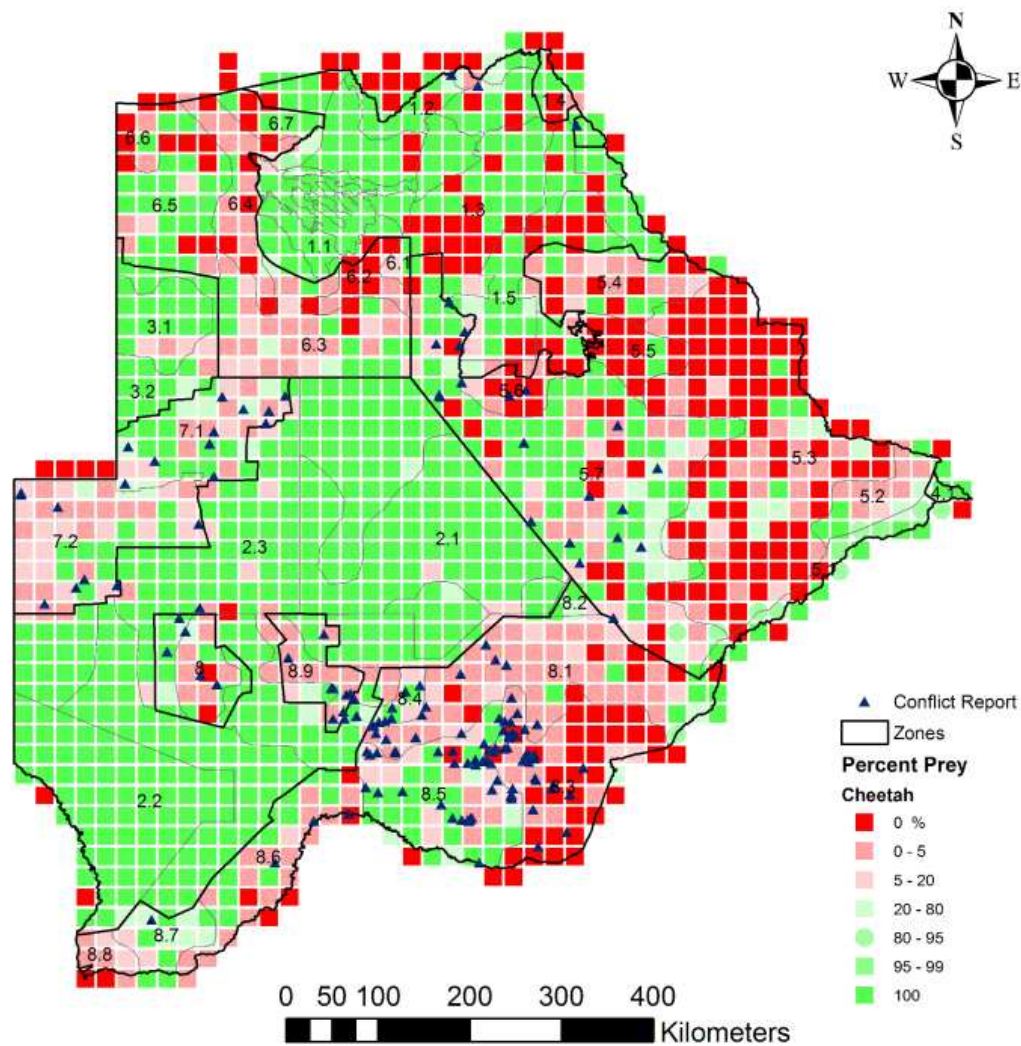


Figure 3. The distribution of the percentage cheetah prey biomass (LSU) of small stock and prey biomass combined across Botswana.

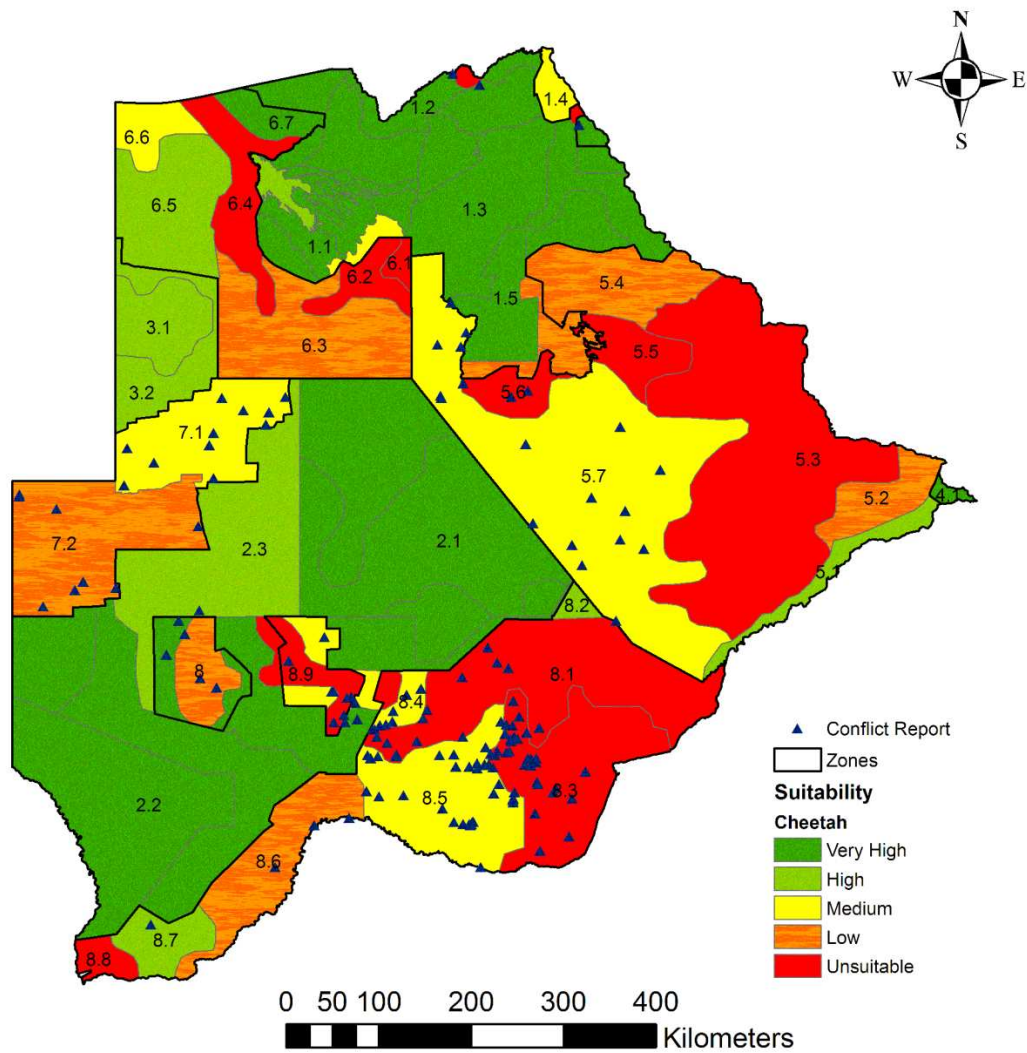


Figure 4. Map of the landscape suitability of Botswana for the long-term persistence of cheetahs.

Table 1. Wild prey species occurring in Botswana and identified as within the preferred weight range of cheetah's prey (body mass 14 – 135 kg, Clements et al, 2014).

<i>Species</i>	<i>Scientific name</i>	<i>Weight (kg)</i>	<i>LSU conversion</i>
Red lechwe	<i>Kobus leche</i>	72	0.25298
Ostrich	<i>Struthio camelus</i>	68	0.24237
Warthog	<i>Phacochoerus africanus</i>	45	0.17783
Impala	<i>Aepyceros melampus</i>	45	0.17783
Reedbuck	<i>Redunca arundinum</i>	40	0.16279
Springbok	<i>Antidorcas marsupialis</i>	26	0.11785
Duiker	<i>Sylvicapra grimmia</i>	15	0.07801
Steenbok	<i>Raphicerus campestris</i>	10	0.05756

Table 2. The frequency distributions of 12' grids in the Kgalagadi and Ghanzi Agricultural Zones and the western strata of the Central Agricultural Zone in Botswana, and livestock attacks by cheetahs in these areas from 1995 to 2006 categorised by the percentage that cheetah's wild prey biomass contributed to the total biomass of wild prey and small stock combined.

<i>Percentage wild prey</i>	<i>Number of grids</i>	<i>Number of livestock attacks</i>	<i>Attacks per grid</i>
0	43	34	0.79
>0 to ≤ 1	48	39	0.81
>1 to ≤ 2	33	9	0.27
>2 to ≤ 5	48	27	0.56
>5 to ≤ 10	40	9	0.23
>10 to ≤ 20	23	15	0.65
>20 to ≤ 80	32	8	0.25
>80 to ≤ 100	136	47	0.35
TOTAL	403	188	

Table 3. Simultaneous confidence intervals for cheetah livestock attacks ( $N = 188$ ) recorded (observed values) with the number of grid cells ( $N = 403$ ) in the categories of the percentage that cheetah's wild prey biomass contributed to the total biomass of wild prey and small stock combined in the Kgalagadi and Ghanzi Agricultural Zones and the western strata of the Central Agricultural Zone in Botswana ( $k = 4, \alpha = 0.05, Z = 2.4977$ ).

<i>Percentage wild prey</i>	<i>Expected Proportion <math>P_{io}</math></i>	<i>Observed Proportion <math>P_i</math></i>	<i>Bonferonni intervals for <math>P_i</math></i>	<i>Use index <math>P_i / P_{io}</math></i>	<i>Significant</i>
0	0.106700	0.180851	$0.1107 \leq P_i \leq 0.2510$	1.69	+
>0 to $\leq 20$	0.476427	0.526596	$0.4357 \leq P_i \leq 0.6175$	1.11	0
>20 to $\leq 80$	0.079404	0.042553	$0.0058 \leq P_i \leq 0.0793$	0.54	-
>80 to $\leq 100$	0.337469	0.250000	$0.1711 \leq P_i \leq 0.3289$	0.74	-

445 Table 4. Simultaneous confidence intervals for the presence, transience and absence of cheetahs based  
 446 on 89 questionnaire completed by farmers in areas deemed suitable and unsuitable for cheetahs in  
 447 Botswana ( $k = 4$ ,  $\alpha = 0.05$ ,  $Z = 2.4977$ ).

<i>Observation</i>	<i>Expected</i>	<i>Observed</i>	<i>Bonferonni</i>	<i>Use</i>	
	<i>Proportion</i>	<i>Proportion</i>		<i>index</i>	<i>Pi/</i>
<i>Type</i>	<i>Pio</i>	<i>Pi</i>	<i>intervals for Pi</i>	<i>Pio</i>	<i>Significant</i>
Absent in unsuitable area	0.026462	0.112360	$0.0287 \leq Pi \leq$ 0.1960	4.25	*+
Present in unsuitable area	0.085687	0.000000	$0.0000 \leq Pi \leq$ 0.0000	0.00	*-
Absent in suitable area	0.209493	0.123596	$0.0365 \leq Pi \leq$ 0.2107	0.59	0
Present in suitable area	0.678358	0.764045	$0.6516 \leq Pi \leq$ 0.8765	1.13	0

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