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

The cheetah is Africa's most endangered felid (Marker et al., 2007) and is listed as Vulnerable with a declining population trend by the IUCN Red List of Threatened Species (Durant et al., 2008). They are one of the most wide-ranging terrestrial carnivores and need extensive areas to sustain viable populations (IUCN/SCC, 2007). Cheetahs feed on a diverse wild prey base ranging from animals as small as scrub hares (*Lepus saxatilis*) to as large as zebras (*Equus quagga*), but generally select the most abundant locally available prey up to 135 kg with a strong preference for those with a body mass between 14 kg – 40 kg (Clements et al., 2014). At least 75% of the cheetah's resident range in southern Africa falls outside protected areas (IUCN/SSC, 2007). In southern Africa this falls mostly on farmlands where competition with other large carnivores is low and a sufficient small to medium-sized wild prey base still occurs (Lindsey & Davies-Mostert, 2009; Klein, 2007; Marker & Dickman, 2004). Consequently, conservation efforts in human-dominated landscapes are critical for this species long-term survival. Although cheetahs prefer preying on wild prey (Marker et al., 2003), they also cause conflict with people by predating on livestock which generally involves small stock (sheep and goats) and occasionally calves and foals (Marker et al., 2003; Ogada et al., 2003; Selebatso, Moe & Swenson, 2008; Woodroffe et al., 2007).

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

We used the distribution of cheetahs' preferred prey and small stock biomass as the most essential components to explore the current potential suitability of agricultural areas for the long-term persistence of cheetahs in Botswana. The percentage prey biomass of small stock and prey biomass combined was used as the primary indicator of probable levels of human-cheetah conflict. Our analyses demonstrated that wild prey combined with livestock can provide a country-wide overview of the suitability of the Botswana landscape for cheetahs without the use of complex modelling. It allows for prudent conclusions as a point of departure for identifying specifically 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.

## Study Area

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

The mean altitude above sea level is 1 000 m (515 – 1 491 m a.s.l.). The climate is arid to semi-arid with highly variable rainfall and periodical severe droughts. Mean annual rainfall varies from 650 mm in the north-east to 250 mm in the south-west. Average maximum daily temperatures range from 22º C in July to 33º C in January and average minimum temperatures from 5º C to 19º C respectively (Department of Surveys and Mapping, 2001). Only two perennial rivers occur; the Okavango River which fans out into the Okavango Delta and the Kwando/ Linyanti/Chobe river system which forms the boundary with Namibia and Zambia. The Makgadikgadi Pans is a seasonal wetland with natural perennial water holes in the Boteti River providing critical dry season water sources for wildlife in Makgadikgadi National Park (MNP). Across the rest of the country, scattered pans and ancient riverbeds periodically hold water during the wet season. Considerable seasonal variations in the density and distribution of ungulate species occur and the blocking of migration routes by veterinary fences has led to ungulate die-offs during drought years (Bergström & Skarpe, 1999; Verlinden, 1998). Seasonal migrations of Burchell's zebra and blue wildebeest (*Connochaetes taurinus*) still occur inside MNP (Brooks, 2005), and zebra migrate between MNP and the Okavango Delta (Bartlam-Brooks, Bonyongo & Harris, 2011).

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

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

Livestock (mainly cattle) rearing is the primary economic activity over large parts of Botswana and constitutes 70 - 80% of the agricultural GDP (Botswana Ministry of Agriculture 2011). In the 2012 household survey, the livestock population in Botswana was estimated as 2.6 million cattle, 1.8 million goats and 300,000 sheep, most of which were located on the more fertile eastern side of the country (Botswana Ministry of Agriculture 2011). Approximately 92% of this livestock are in the traditional cattle post system on communal grazing land (Botswana Ministry of Agriculture 2011). Botswana's key environmental issues include water scarcity and pollution, rangeland degradation and desertification, loss of biodiversity, deforestation, and an increased frequency of periodic droughts (Wingqvist & Dahlberg, 2008).

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

## Methods

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

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

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

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

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

## Results

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

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

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

We rated the five categories of landscape suitability identified in ArcMap as very high (0 – 6.7% grid cells with ≤ 20% wild prey), high (6.8 – 25%), medium (25.1 – 50), low (50.1 – 75%) or unsuitable (75.1 – 100%) and provide a country-wide landscape suitability map for the long-term persistence of cheetahs in Botswana (Figure 4) (Supplementary material Appendix 3). The conservation zones were the most suitable for the long-term persistence of cheetahs, while the agricultural zones consisted of a mosaic of medium suitability to unsuitable. The classification of some strata as unsuitable for cheetahs was supported by the questionnaire data where the proportion of farmers that reported cheetahs present or absent differed significantly between suitable and unsuitable cheetah areas ($\chi^2 = 129.11$, df = 3, $P < 0.001$). A hundred per cent of farmers reported cheetahs absent in the unsuitable areas (n = 10) significantly more than would be expected by chance and only 13.9 % of farmers reported cheetahs absent within the suitable areas ($N$ = 79) ($\alpha = 0.05$, Z= 2.4977) (Table 4).

## Discussion

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

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

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

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

Steenbok and duiker are two of the generally most common prey for cheetahs in Botswana (Klein, 2007). The high density of steenbok and duiker (range 0.261 - 4.319 animals / 100 km²) calculated from the six aerial surveys in the Ghanzi Community Stratum (stratum 7.2) suggests that livestock do not necessarily displace small ungulates to the extent that large ungulates are displaced (Riginos et al., 2012). However, conflict with people seems to have a stronger influence on cheetah numbers than wild prey biomass when livestock numbers are high. In the Ghanzi Farms Stratum (stratum 7.1) there was a sample point where cheetah density was too low to calculate despite having more wild prey than neighbouring areas with 0.7 cheetahs / 100 km² (Boast & Houser, 2012; Kent, 2010). This shows the potential negative impact of human conflict on the cheetah population even where there is a good wild prey base but it formed a small percentage to the total biomass due to the high small stock biomass.

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

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

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

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

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

Conservation of free-ranging cheetah populations is multi-faceted and needs to be addressed from an ecological, biological and socio-economic management perspective. Despite the threats, Botswana has a large and still contiguous cheetah population with wide-spread natural movements allowing substantial gene flow (Dalton et al., 2013). However, its contiguous nature is threatened and may cease if corridors are not maintained. Cheetahs have vast tracts of intact habitat in the conservation areas for persistence, and the wide-spread availability of wild prey across the agricultural zones provides additional large areas with high conservation potential. On a micro-scale, some studies found habitat structure, such as dense woodland and open savannah, have an even stronger effect on the areas the different social groups of cheetahs prefer to utilize than absolute wild prey density (Bissett & Bernard, 2007; Muntifering et al., 2006). Spatial data indicating land degradation were not available to include in the landscape suitability map. However, the wide-spread rangeland degradation and desertification in the agricultural areas of Botswana (Moleele et al., 2002) reduces the availability of suitable wild prey, as well as sufficient grass cover for cheetahs for stalking, concealment from other predators, and movement between areas (Broomhall, Mills & du Toit, 2003; Marker, 2003; Mills, Broomhall & du Toit, 2004; Purchase & du Toit, 2000). This study showed that restoring wild prey numbers in focal areas in concurrence with effective human-cheetah conflict mitigation efforts are the most immediate conservation strategies needed to ensure the long-term survival of cheetahs in Botswana. With this is the restoration of degraded rangeland which will not only recover habitat for cheetahs and their wild prey but also benefit farmers by increasing the carrying capacity for livestock, which in itself may increase their tolerance for cheetahs on their land (Marker, 2003).

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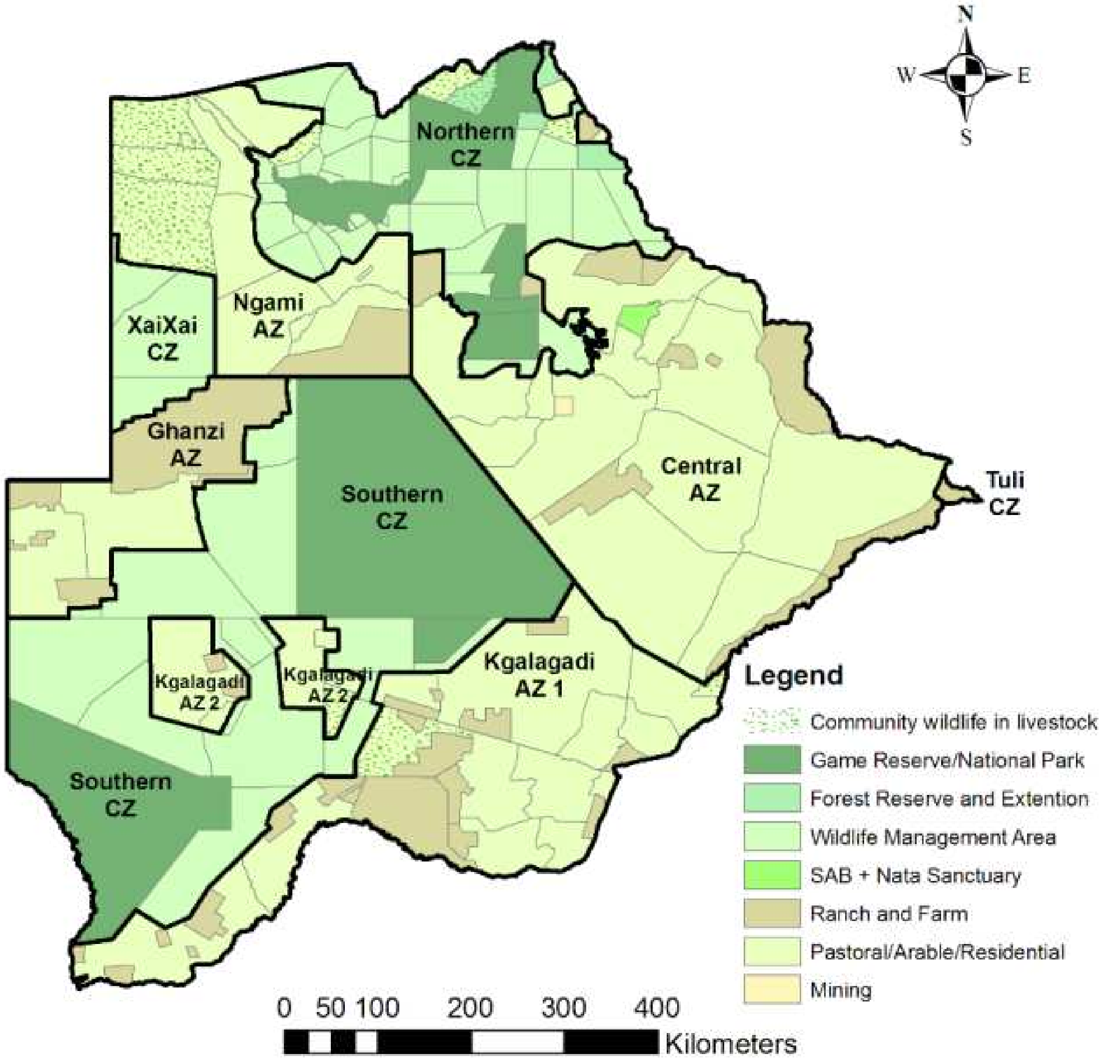


Figure 1. Land use categories present in Botswana.

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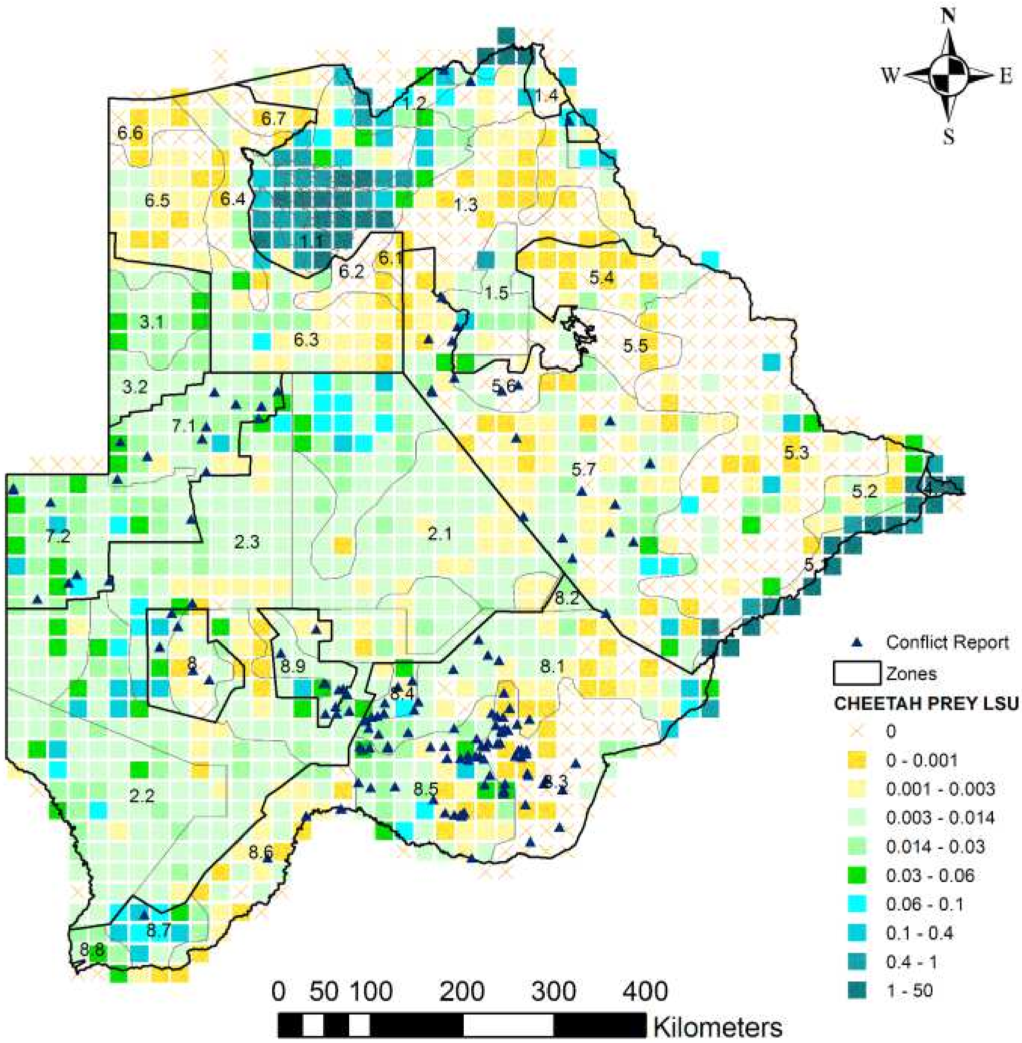


Figure 2. The distribution of cheetah prey biomass (LSU) across Botswana.

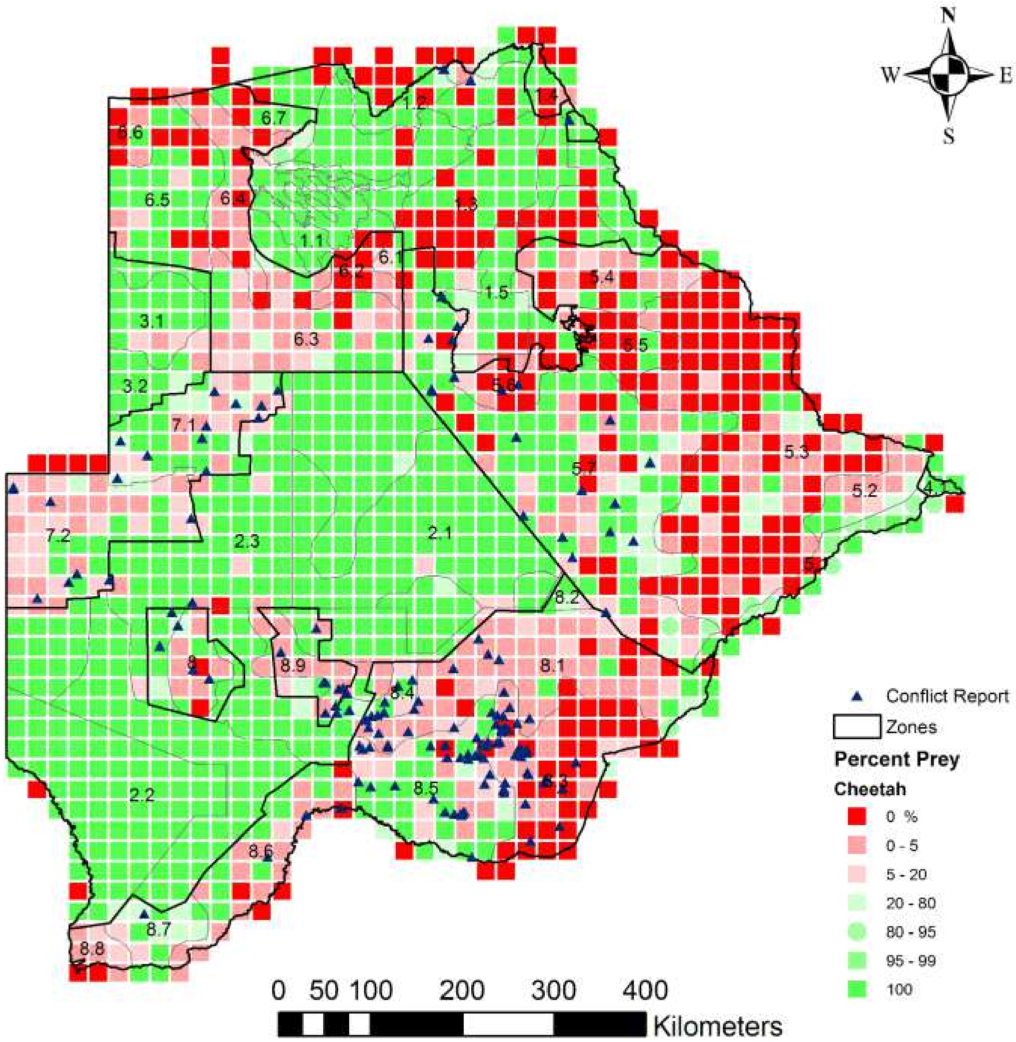


Figure 3. The distribution of the percentage cheetah prey biomass (LSU) of small stock and prey biomass combined across Botswana.

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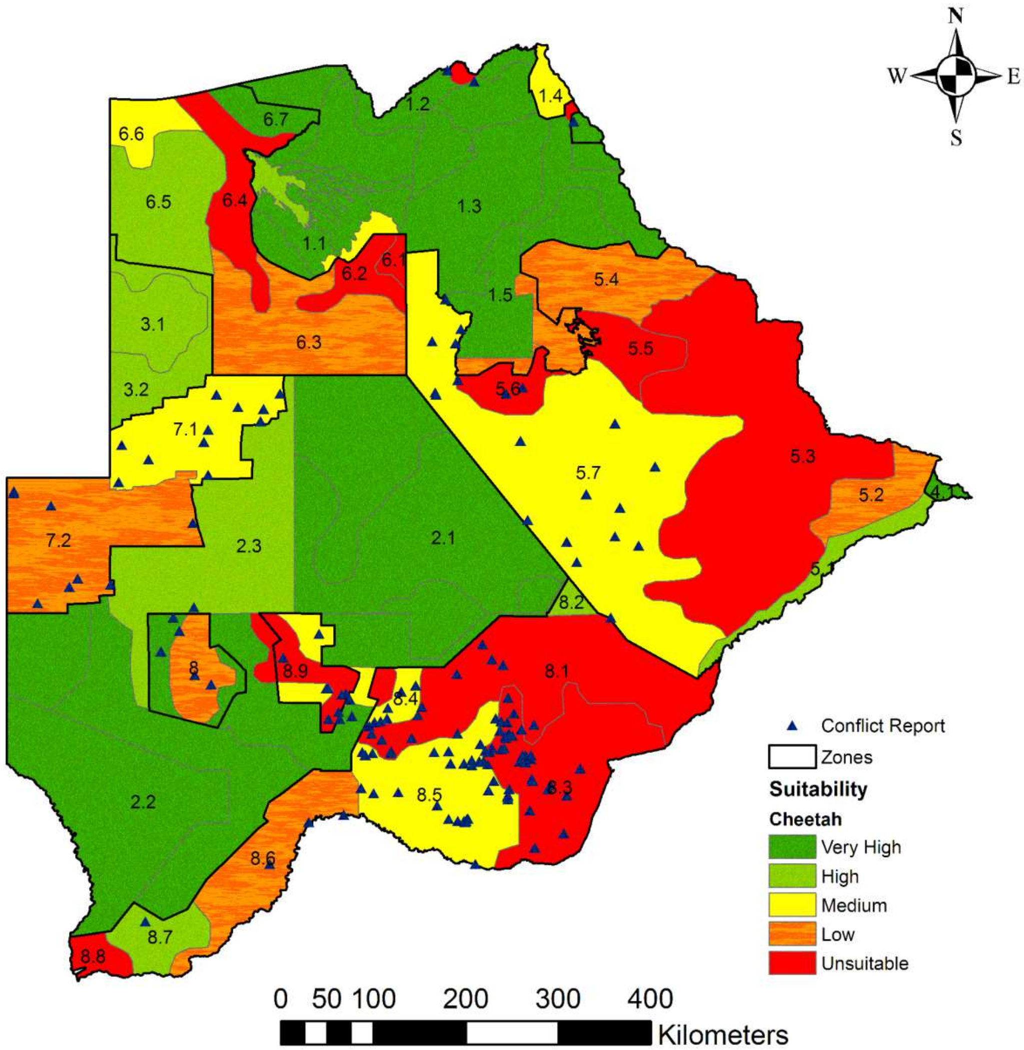


Figure 4. Map of the landscape suitability of Botswana for the long-term persistence of cheetahs.

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).

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

| *Percentage wild prey* | *Number of grids* | *Number of livestock attacks* | *Attacks per grid* |
|---|---|---|---|
| 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, α = 0.05, Z= 2.4977).

| *Percentage wild prey* | *Expected Proportion Pio* | *Observed Proportion Pi* | Bonferonni *intervals for Pi* | *Use index Pi/ Pio* | *Significant* |
|---|---|---|---|---|---|
| 0 | 0.106700 | 0.180851 | $0.1107 \leq Pi \leq 0.2510$ | 1.69 | + |
| >0 to ≤ 20 | 0.476427 | 0.526596 | $0.4357 \leq Pi \leq 0.6175$ | 1.11 | 0 |
| >20 to ≤ 80 | 0.079404 | 0.042553 | $0.0058 \leq Pi \leq 0.0793$ | 0.54 | - |
| >80 to ≤ 100 | 0.337469 | 0.250000 | $0.1711 \leq Pi \leq 0.3289$ | 0.74 | - |

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

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