Pastoralists, Free-Ranging Livestock and Wildlife Interactions: Adaptation to Land Use Change and Grazing Resources Variability in Kalahari North, Botswana

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Declaration

The candidate confirms that the work submitted is his own, and that appropriate credit has been given where reference has been made to the work of others.

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Abstract

Conservation of African wildlife is dependent on conservation areas (CAs) and adjacent pastoral areas. Even though the number of African CAs are increasing, the wildlife population in these CAs are in general decline because they are small and isolated. With human population densities, settlements and livestock grazing pressure in communally managed pastoral areas (hereafter CGAs) adjacent to CAs increasing, CGAs have become fragmented and degraded. Increasing interaction between livestock and wildlife between CAs and CGAs is inevitable. While there is some knowledge of the positive and negative interactions between wildlife moving between CAs and livestock in pastoral areas (e.g. Mara and Serengeti regions), less is known about such interactions in free-ranging pastoral systems in the Kalahari. This study therefore, investigates interaction – specifically the levels of competition and facilitation – between livestock and wildlife and how this varies between the wet and dry season and wildlife body size functional grouping and predation risk in the Kalahari. The study analysed the spatial distribution of forage availability and vegetation heterogeneity, the spatial distribution of eleven herbivores and twelve carnivores of different body sizes (>1kg) in relation to pastoral activities, and disturbance along a livestock grazing gradient starting in CGAs and ending in CAs in the Kalahari. The study used a systematic sampling approach to survey vegetation and wildlife spoor/tracks, in addition to conducting road-side field observations and Global Positioning System telemetry. The study shows that pastoral activities are largely confined to the CGAs, within a radius of 15km from the main settlements. Free-ranging livestock reduced forage quality and quantity in both seasons studied and facilitated woody plants, forbs, unpalatable annual grasses within the 15km radius from the settlements. Large-sized herbivores and carnivores concentrated in CAs and avoided areas in CGAs impacted by pastoralism in both seasons. Medium-sized carnivores and herbivores, except Ostrich, avoided areas of high livestock grazing intensity in pastoral dominated areas and were associated with CAs and moderately grazed areas in CGAs in both seasons. Small-sized wild herbivores, except Springbok, were associated with CGAs even closer to settlements in both seasons. These results suggest that even though the pastoral areas near the CAs are important as seasonal dispersal and breeding grounds for wildlife, intensified pastoral activities, such increased livestock grazing intensity and pastoralist-induced risk in the CGAs are restricting the seasonal movements of medium to large-sized wildlife between the CAs and the adjacent CGAs. Hence it is essential for wildlife conservation efforts to focus on 1) securing the dispersal areas (i.e. CGAs) by promoting moderate livestock grazing intensity and reducing pastoralist-induced risk to attract medium to large wildlife and 2) create and maintain functional heterogeneity in CAs to attract small sized wildlife.

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Abbreviations

AM	Adaptive Management
CA	Conservation Areas
CANOCO	Canonical Community Ordination
CCA	Canonical Correspondence Analysis
CGAs	Communal Grazing Areas
CKGR	Central Kalahari Game Reserve
GIS	Geographical Information System
GLM	General Linear Model
GPS	Global Positioning System
HCA	Hierarchical Cluster Analysis
IK	Indigenous Knowledge
KTP	Kalahari Trans-Frontier Park
LGI	Livestock grazing intensity
NDVI	Normalised Difference Vegetation Index
PCA	Principal Component Analysis
SPSS	Statistical Package for Social Sciences
TGLP	Tribal Grazing Land Policy
TPK	Traditional Phenological Knowledge
VIF	Variance Inflation Factor
CAs	Wildlife Management Areas

Chapter 1

Introduction

1.1: Background

In African savanna rangelands, pastoralists, livestock and wildlife have shared the rangelands, water and forage resource for centuries under traditional moderate pastoral activities (Young, Palmer et al. 2005). In these rangelands, human settlements and pastoral activities have moved into what used to be wildlife habitat, therefore influencing the distribution of different wildlife species (Crowe 1995, Happold 1995). Consequently, the increase in human population and land use pressure threaten this co-existence (Lamprey and Reid 2004). Subsequently, the debate on the suitability of wildlife conservation in the presence of livestock production in Africa is currently ongoing (Mearns 1997, Heath 2000, Kinyua, van Kooten et al. 2000, Prins, Grootenhuis et al. 2000). The existence of wildlife on pastoral areas adjacent to the Conservation Areas (hereafter CAs or Wildlife Management Areas (CAs)) depends on their positive interactions with livestock and other anthropogenic activities. Hence, the deliberations that livestock (Voeten and Prins 1999, Prins 2000) and human activities (Weyde, Mbisana et al. 2018) could adversely impact on the resources for wildlife are raging on. CAs are a foundation of worldwide preservation efforts to protect wildlife from anthropogenic effects, such as land use changes and habitat loss (Ceballos et al .2005, Chape, Harrison et al. 2005). Henceforth, the dominant traditional conservation paradigm emphasizes the importance of CAs in protecting wildlife from anthropogenic activities (Terborgh et al 2002). This conservation paradigm assumes that pastoral activities mostly harm wildlife. Consequently, the number of CAs in Africa has increased exponentially in the recent years, however, their viability in wildlife conservation is in question because many are small and isolated (NeCArk 2008, Caro and Scholte 2007), and surrounded by pastoral areas.

CAs in African rangelands have been the principal way for wildlife conservation; however, wildlife moves seasonally into the surrounding pastoral areas (Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012), referred to as dispersal areas or buffer zones. Dispersal areas play an important role in wildlife conservation, for example, in Kenya, these areas have been reported to often contain more wildlife than the CAs (Western, Russell et al. 2009). Therefore, minimizing the competition and resource limitation within CAs (Ottichilo, De Leeuw et al. 2000). Consequently, conservationists argue that in

African pastoral areas, livestock might convert habitat and displace wildlife from these dispersal areas (Parris and Child 1973, Coe, Cumming et al. 1976). Though there is an indication that pastoral activities in Africa limit the distribution and diversity of wildlife (Prins 1992, Cumming 1999), recent studies also suggest that they could be resource facilitation between some wildlife species and moderate livestock grazing through modification of vegetation (Arsenault and Owen-Smith 2011, Odadi, Karachi et al. 2011). For example, small-sized herbivores prefer short, quality grasses maintained by moderate livestock grazing (Fryxell 1995) because of their smaller gastrointestinal tract which cannot digest more efficiently coarse vegetation (Gagnon and Chew 2000, Wilmshurst, Fryxell et al. 2000). Moreover, in areas with short grasses, there is less predation risk because of the improved visibility against the predators (Hopcraft, Anderson et al. 2012), hence favouring the predation susceptible small-sized wildlife species. Also, wildlife and livestock could be compatible due to their resource partitioning abilities (i.e. the differential use of food and space) (Hopcraft 1990, Hopcraft 2000) hence facilitation.

Nevertheless, intensification of anthropogenic activities in the pastoral areas adjacent to the CAs creates spatial heterogeneity in predation risk, forage quality and quantity between the CAs and pastoral areas (Bhola, Ogutu et al. 2012). Subsequently, most of CAs are not sufficiently large to sattisfy all the wild herbivores. Therefore, they do not contain a full range of functional resource gradients, migration corridors and seasonal habitats essential for the maintenance of the wildlife populations (Fynn and Bonyongo 2011), because forage quality and quantity is variable both spatially and temporally (Fryxell, Wilmshurst et al. 2005, Illius and O'Connor 2000, Owen-Smith and Mills 2006). As a result, the regions with conditions that minimise predation risk, and maximise forage quality and quantity will have high distribution and abundance of wildlife (McNaughton, Ruess et al. 1988, McNaughton 1990, Anderson, Hopcraft et al. 2010). For example, Bhola, Ogutu et al. 2012 reported that wildlife moves seasonally from CAs into the pastoral ranches of Mara regions in Kenya in the wet season following short, actively growing grass maintained by moderate livestock in pastoral ranches (Fryxell 1995). Therefore, avoiding predation risk in the CAs because of the tall dense grass cover (Hopcraft, Sinclair et al. 2005, Ogutu, Bhola et al. 2005). Thus, indicating resource facilitation by moderate livestock grazing intensity.

Pastoral areas, adjacent to CAs, which are referred to as dispersal areas are either communally (i.e. available for use by all community members) or privately (i.e. mainly ranches) managed. Paradoxically, despite the importance of pastoral areas adjoining CAs as seasonal dispersal ranges and breeding grounds for wildlife, in African rangelands (Bhola, Ogutu et al. 2012), there is less documentation on the relative impact of pastoral activities in communally managed pastoral areas versus CAs on the temporal and spatial distribution of multi-species wildlife of southern Africa rangelands (Verlinden 1997, Wallgren, Skarpe et al. 2009). However, dramatic land use changes and human population growth in some pastoral areas are gradually degrading wildlife habitats, hence the possibility to limit the seasonal wildlife dispersal movements between CAs and pastoral areas (Bhola, Ogutu et al. 2012). Pastoral activities/impacts herein refer to all activities and developments by pastoralists, for example, i.e. cattle posts, agriculture fields, settlements, roads, boreholes, livestock grazing intensity (LGI) and other human disturbances. A cattle post is the place where farmers keep their animals at night and to which they return every evening after the day grazing. Cattle posts encompass a watering point, kraals fenced or thorn bush enclosure, livestock are routinely kraaled at night and released in the morning depending on the season. LGI here refers to the proportion of herbaceous biomass or cover removed by livestock (cattle, sheep, goats, Donkey and Horses) grazing and trampling.

Furthermore, few studies in southern Africa rangelands (Verlinden 1997, Wallgren, Skarpe et al. 2009) have focused on resource partitioning abilities and interactions between free-ranging livestock, pastoralists and a range of multi wildlife species (i.e. herbivore and carnivores of different body sizes) in extensive rangelands. Nevertheless, such studies are critical as they might provide knowledge of the composition of multi-species wildlife and the significant driving factors behind their spatial distribution. Ultimately such kind of information can be used in the decision making concerning the management and conservation of multi-wildlife species in pastoral areas adjacent to CAs.

The distribution and seasonal movement of wildlife in African savannas have been well studied within CAs and pastoral ranches of East Africa. For example, in the CAs of Mara-Serengeti ecosystems, Kenya and Tanzania (McNaughton 1990, Ogutu, Bhola et al. 2005, Anderson, Hopcraft et al. 2010, Hopcraft, Anderson et al. 2012), between CAs and human-dominated pastoral ranches in Mara regions, Kenya (Maddox 2003, Bhola, Ogutu et al. 2012). Amazingly, the distribution and interactions of multiple wildlife species (i.e. herbivores and carnivores) and free-ranging livestock in pastoral-dominated, semi-arid, communally managed rangelands near the CAs in the Kalahari ecosystem, southern Africa are less understood. The Mara-Serengeti ecosystems are associated with the significant remaining annual migration of wildlife populations on earth (Sinclair and Arcese 1995b) and have high diversity and abundance of resident wildlife species (Broten and Said 1995) as compared to the Kalahari ecosystems. Subsequently, the environmental factors influencing the distribution of wildlife between these two ecosystems are different. Therefore, the need for an empirical study investigating the environmental factors controlling the multi-species of wildlife in the Kalahari ecosystems between communally managed rangelands and CAs.

Rangeland resources use in the Kalahari ecosystem has shifted from being dominated by wildlife to livestock production system due to the borehole technology (Cooke 1985), and the European Union Beef Protocol Agreements (Perkins and Ringrose 1996). The European Beef Protocol Agreement has led to the provision of veterinary cordon fences, hence restricting the movement of wildlife between the CAs and pastoral areas in CGAs, for example, between Central Kalahari Game Reserve (CKGR) and Kalahari Trans-frontier Park (KTP) (Perkin and Ringrose 1996, Kgabung 1999; Mbututu 2000) and the critical drought –refuge resources of the Okavango Delta, Lake Gami and the Boteti river. Furthermore, although all Kalahari ungulates, especially the wildebeests migrate into this crucial area referred to as the “Schwelle” in the wet season and disperse in the dry season, information on the influence of direct or indirect human disturbance, such illegal hunting pressure, predator control measures and livestock grazing intensity on the distribution of multiple wildlife species in this region is less documented.

Therefore, based on the above views, this thesis aims to address the relationship between the availability of forage resources, the grazing patterns of wild herbivores, and how these influence the distribution of carnivores in pastoralists-dominated communally managed areas and adjacent CAs in southern Africa. In turn, how these patterns are modified by the interactions between pastoralists and their grazing livestock. To understand the spatial distribution of multiple wildlife species, the optimal foraging theory would suggest that wild herbivores of different body sizes will primarily be influenced differently by the spatial distribution of forage availability and predation risk (Sinclair, Mduma et al. 2003, Hopcraft, Olff et al. 2010). While on the other hand carnivores will be influenced by prey availability and vegetation heterogeneity (Blaum, Rossmanith et al. 2007c,d). Hence, to achieve the aim of this study, the first area of investigation is, therefore, to understand the spatial distribution of forage availability (quality and quantity) and vegetation heterogeneity relative to land use and along pastoral activities, disturbance gradient is established (Chapter 4). Given this baseline information on the distribution of forage, the second area of investigation is to relate the spatial distribution of forage and vegetation heterogeneity to the spatial distribution of free-ranging livestock, pastoral activities (i.e. cattle posts, agriculture fields, settlements) and wild herbivores (Chapter 5) to evaluate the impacts of free-ranging livestock and other anthropogenic activities, such as pastoralists-induced risk on the distribution of wild herbivores. In turn, the influence of vegetation heterogeneity, pastoral activities and the distribution of wild herbivores (i.e. prey availability) on the distribution of carnivores is considered (Chapter 6). Lastly, the study uses the findings from Chapters 4, 5 & 6 to investigate the possibility for pastoralists, free-ranging livestock and wildlife coexistence between CAs and CGAs in southern Africa rangelands (Chapter 7).

In African rangelands, interactions between pastoralists and wildlife arise on different levels, its nature and intensity, also it evolves depending on changes in land use and resource availability (Bourn and Blench 1999). Deliberations about the level of resource competition between livestock and wildlife are currently raging on; hence other studies argue that resource competition between livestock and wild herbivores will happen if there is habitat overlap, common diet, and when the resources are limiting (De Boer and Prins 1990) or when prey and carnivores share the same habitat. Similarly, resource competition between species of carnivores of the same body size increases if there is similar habitat selection, diet, and activity pattern (Rich, Miller et al. 2016). Besides, the interactions between carnivores, pastoralists and livestock also lead to both positive and negative effects, such as improving vegetation heterogeneity by moderate livestock grazing (i.e. favouring small and medium-sized carnivores) (Blaum, Tietjen et al. 2009) and pastoralists – wildlife conflicts respectively. Nonetheless, it is not only carnivores that could negatively affect livestock through predation, but livestock grazing also increases visibility against carnivores (Schooley and Wiens 2003). Consequently, reducing food availability for carnivores through the increase of shrubs and reduction of grasses (Blaum, Rossmanith et al. 2007c,d). Therefore, the significant challenges facing conservationists, decision makers, and local communities are to manage these interactions between wildlife (i.e. herbivores and carnivores) and livestock to promote coexistence. Their interactions can result in forage resource competition/facilitation, such as water, grazing, disease transmission (both ways), and predation on livestock by wild carnivores.

Previous studies have shown that forage availability (i.e. quality and quantity) is variable both spatially and temporally (Fynn and Bonyongo 2011) between CAs and CGAs, hence seasonal movement of the wildlife amongst the CAs and the pastoral areas during the wet and dry seasons. Consequently, the interactions between pastoralists, livestock and wildlife. Studies from East Africa, show that short, actively growing grass in pastoral ranches provide quality forage, while taller grasses in CAs offer forage reserves in the dry season and during drought (Owen-Smith 2004, Hobbs, Galvin et al. 2008, Hopcraft, Olff et al. 2010). For example, studies in the Mara region, have shown that the resident herbivores moved into the CAs during the dry season possibly because of forage resource competition with livestock in the pastoral ranches (Prins 1992, Ogutu, Piepho et al. 2008). However, in the CAs the grasses are taller with high cover, hence high predation risk (Hopcraft, Sinclair et al. 2005, Ogutu, Bhola et al. 2005). Therefore, favouring larger wild herbivores because mostly they are constrained by forage quantity more than predation risk (Owen-Smith 1988). Predators use tall herbaceous cover to hide for their prey because their success rate in capturing the prey is related to landscape features (Hopcraft, Sinclair et al. 2005, Ogutu, Bhola et al. 2005). For example, lions would prefer thick vegetation and water source to successfully capture their prey, while other predators adapted for running such as African wild dog would prefer open grassland for their hunting success (Kauffman et al. 2007). Hence, indicating that vegetation heterogeneity might regulate predation risk, consequently, influencing the distribution of herbivores, therefore, the need to investigate how free-ranging livestock and other anthropogenic activities in CGAs impact on vegetation heterogeneity and in-turn the distribution of wildlife.

Even though forage quality, quantity and predation risk have been identified as the key determinants of the distribution of wildlife in African savanna ecosystems (Hopcraft, Anderson et al. 2012, Hopcraft, Olff et al. 2010), many other drivers can also influence the distribution and abundance of wildlife. For example, the diversity of soil and habitat (Olff, Ritchie et al. 2002, Cromsigt, Prins and Olff 2009), competition/facilitation for forage resource with livestock and increased pastoral activities such as livestock grazing, cultivation, water points (Creel and Creel 1996, Hoare and Du Toit 1999, Voeten and Prins 1999, Verlinden 1997, Serneels and Lambin 2001), human-induced risk such illegal hunting (Mfunda and Roskaft 2010) or human-wildlife conflict (Kissul 2008). For instance, large mammal distribution in Uganda (Queen Elizabeth National Park) were identified to be influenced by vegetation structure and fire (Klop and Prins 2008), water, predators and human activities (Field and Laws 1970). Similarly, vegetation type, distance from water, and livestock densities were shown to be the primary factors shaping wildlife distribution in south-east Kajiado, Kenya (Mworia, Kinyamario et al. 2008). In the Mara region, Kenya, forage availability (i.e. quality, quantity) and predation risk were identified as the critical determinants of wildlife distribution (Bhola, Ogutu et al. 2012).

Based on the above reviews, it shows that environmental factors regulating the distribution of wildlife vary depending on the ecosystems, hence the inconclusive relationships between CAs and CGAs wildlife status (Brashares 2010). Land use changes directly or indirectly facilitate most of the factors regulating the distribution of wildlife because it affects vegetation heterogeneity and forage availability, which might affect habitat specialists (Waltert et al. 2005). Furthermore, expansion of human population, pastoralism, may facilitate the human-wildlife conflicts because of frequent contacts (Kissul 2008) and accessibility to wildlife (Laurance et al. 2005). Nonetheless, knowledge on the environmental factors influencing the distribution of multiple wildlife species over an extensive landscape with free-ranging livestock and other anthropogenic activities in southern Africa communally managed areas near CAs is less understood. Therefore, to explore these factors, it is essential to first establish spatial distribution of forage availability and vegetation heterogeneity relative to the livestock grazing intensity, land use and other pastoral activities. Subsequently, relating the distribution of herbivores and carnivores' species to forage availability, heterogeneity and pastoral activities. This chapter, therefore, introduces gaps in knowledge on (i) the spatial distribution of forage availability and vegetation heterogeneity relative to land use and the grazing distribution of livestock, (ii) the distribution of herbivores and (iii) carnivores in southern Africa rangelands. The chapter also introduces gaps in knowledge on standard methods used to explore the distribution of wildlife and the possibility of pastoralism and wildlife coexistence.

(i) forage availability and vegetation heterogeneity

Even though previous research elsewhere, for example in East Africa has shown that forage availability (quality and quantity) influences the distribution of herbivores (Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012), the role of these factors in determining the distribution of multiple wildlife species in human-dominated communally managed rangelands (i.e. CGAs) supporting free-ranging livestock is less understood. Thus, there have been few studies on the detailed comparative analysis on vegetation heterogeneity and forage quality and quantity relative to the distribution of wildlife of different body sizes between CAs and CGAs in the southern Africa rangelands (Chapter 4). However, few studies elsewhere in Africa savannah, compared forage availability, vegetation heterogeneity to the distribution of multiple wildlife species in private ranches and CAs. For example, in West Africa, most vegetation studies were done in CAs and were not associated with the distribution of wildlife species (e.g., Mbayngone, Schmidt et al. 2008, Tefera, Snyman et al. 2007). Furthermore, few other studies on vegetation heterogeneity and forage availability were conducted in CAs and CGAs in West Africa (e.g. Devineau, Fournier et al. 2009) and southern Africa (Moleele and Mainah 2003), but not associated with the distribution of wildlife.

Spatial distribution of forage availability and vegetation heterogeneity in a landscape is determined by the interaction between the abiotic (soil quality, rainfall, fire) and the biotic processes such as livestock and wildlife grazing intensity (Anderson, Ritchie et al. 2007a, Anderson, Ritchie et al. 2007b, Bond and Keeley 2005). Nonetheless, there is indeed very little empirical evidence relating to forage availability and heterogeneity and the distribution of multiple wildlife species and free-ranging livestock in communally managed rangelands adjacent to CAs in southern Africa. Furthermore, in Southern Africa rangelands, most of the studies on effects of livestock grazing on vegetation heterogeneity, forage availability (Van Vegten 1984, Skarpe 1991, Ringrose et al. 1996, Moleele and Perkins 1998, Nsinamwa, Moleele et al. 2005, Dougill, Akanyang et al. 2016) were conducted within radii of less than 5km from livestock water points (“The piosphere effects”), however, the effects of livestock grazing extend beyond this range. Hence the need to do a detailed comparative analysis of vegetation heterogeneity, forage availability and relate to the distribution of different wildlife species along livestock grazing gradient and land use. Vegetation heterogeneity is expected to vary along livestock grazing gradient and influence the distribution of wild herbivores and carnivores of different sizes in unique ways (Chapter 4).

(ii) *Spatial distribution of free-ranging livestock and wild herbivores*

Bush encroachment, reduction of plant species palatability (from sweet to sour grass species), the increase of annual grasses, soil erosion and compaction are indicators of rangeland degradation and is a concern worldwide (Van Vegten 1981, Skarpe 1986, Trollope 1990, Perkins and Thomas 1993, Fernandez-Gimenez and Allen-Diaz 1999, Moleele and Mainah 2003, Dougill, Akanyang et al. 2016). Moreover, in semi-arid ecosystem land degradation is associated with livestock disturbance (Walker, Ludwig et al. 1981, Belsky 1990, Vetter 2005) and have been reported in CGAs of southern Africa (Abel and Blaikie 1989, Skarpe 1986, Moleele and Mainah 2003). The association of pastoralism disturbance regimes, such as grazing intensity, cultivation, settlements, water points and their related effects on plant productivity and diversity might influence the distribution and abundance of wildlife species of different body size differently (Verlinden 1997, Serneels et al. 2001).

Nevertheless, none of the previous studies have mapped the expansion and the grazing intensity of free-ranging livestock, cultivation and other anthropogenic activities relative to forage availability and vegetation heterogeneity in the Kalahari ecosystem (southern Africa). Furthermore, still in the Kalahari ecosystem, the spatial distribution and the grazing intensity of free-ranging livestock, cultivation and other anthropogenic activities have never been associated with the temporal and spatially distribution of wild herbivores and carnivores of different sizes. Therefore, there is the need for such an empirical study to establish the environmental factors influencing the distribution of different wildlife species in different seasons in the Kalahari ecosystem.

The evolutionary theory on the distribution of wild herbivores (Hopcraft, Olff et al. 2010) and empirical data in East Africa (Anderson, Hopcraft et al. 2010, Hopcraft, Anderson et al. 2012, Ogutu, Bhola et al. 2005) have identified forage quantity, quality and predation risk as the critical determinants of resident herbivores distribution in CAs and pastoral ranches (Bhola, Ogutu et al. 2012). However, the influence of these environmental factors varies with herbivore body size, feeding style and environmental gradients within the ecosystems (Hopcraft, Anderson et al. 2012, Valeix et al. 2009). Consequently, this raises fundamental questions about (i) the extent to which ecological factors (i.e. forage quantity, quality and predation risk) and mechanisms identified as shaping the distribution of resident herbivores in CAs and pastoral ranches in East Africa can be extrapolated to multiple herbivores in pastoral-dominated CGAs, supporting free-ranging livestock like in the Kalahari, southern Africa. (ii) Moreover, how do herbivores of different body size respond to the combination of forage quantity, quality, predation risk and anthropogenic activities (i.e. human disturbance or the pastoralists-induced risk) in CGAs with free-ranging livestock (Chapter 5)?

However, information on environmental factors, including the pastoralists-induced risk, influencing the distribution of multiple species herbivores in semi-arid CGAs adjacent to the CAs in southern Africa is less documented. Therefore, there is the need to test whether these theoretical expectations (as reviewed by Hopcraft, Olff et al. 2010) and the empirical data in East Africa on wild herbivores' distribution and abundance (Anderson, Hopcraft et al. 2010, Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012, Ogutu, Bhola et al. 2005) and pastoralists-induced risk are consistent with empirical data on the distribution of wildlife in pastoral dominated CGAs supporting free-ranging livestock in the Kalahari ecosystem, southern Africa. The Kalahari ecosystems also support different species of carnivores; therefore, predation is also an essential factor in shaping the distribution of wildlife (Tambling and Toit 2005). Hence temporal distribution data for carnivores relative to prey availability, pastoral activities disturbance gradient and the pastoralists-induced risk is an essential factor to evaluate the distribution of wild herbivores.

(iii) Spatial distribution of carnivores

Conservation of carnivores is vital because of the global decline mainly due to the human impact (Blaum, Tietjen et al. 2009). The increase in human population and pastoral activities around CAs may increase the isolation of CAs and edge effects (Defries et al. 2005, Wittemyer et al. 2008). Such unfavourable impacts from pastoral activities might be extreme for large-sized mammalian carnivores inclined to conflict with human (Woodroffe and Ginsberg 1998). A comprehensive understanding of how carnivores respond to pastoral activities and land use change adjacent to CAs is critical for not only conservation of carnivores, but the ecosystems in which they play a significant role (Soule et al. 2003, Terborgh 2002). Moreover, large-sized carnivores have an essential role in structuring the ecosystems by regulating and restricting the populations of prey species (Sinclair, Mduma et al. 2003), Terborgh 2002). Similarly, small-sized carnivores are vital for ecosystems changes, wildlife and plants diversity (Rogers and Caro 1998) as they restrict the populations of the organisms such as insects and rodents in semi-arid rangelands (Stenseth, Leirs et al. 2003), which could otherwise become pests.

Even though predation risk is one of the critical determinants influencing the distribution and abundance of herbivore in African savannas (Anderson, Hopcraft et al. 2010, Hopcraft, Anderson et al. 2012), the impacts of free-ranging livestock grazing intensity, land use and other pastoral activities, such as pastoralists-induced risk on the distribution of carnivores in communally managed rangelands of southern Africa are less documented (Blaum, Tietjen et al. 2009, Wallgren, Skarpe et al. 2009). Hence the impact of livestock grazing intensity and other pastoral activities on the spatial distribution carnivores in the Kalahari rangelands remains unclear. Nonetheless, recent studies in southern Kalahari revealed that small-sized carnivores are decreasing in the pastoral ranches possibly due to the indirect effect of livestock grazing intensity and direct impacts of farmers' predator control measures (Blaum, Rossmanith et al. 2007a, c, d). However, long-term conservation and management of carnivore populations in pastoral areas adjacent to CAs require reliable knowledge of critical determinants influencing their temporal and spatial distribution. Hence the need for an empirical study to get such kind of information.

(iv) Previous techniques, methods used to establish the distribution of wildlife

Despite the fact that many terrestrial mammals are nocturnal, secretive in appearance, and for the most part, they avoid being seen (Chiarello 2000, Jachmann 2002), most studies on wildlife distribution and census in African savanna rangelands commonly used aerial survey (Verlinden, Perkins et al. 1998, Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012, Gandiwa 2014), field observations (Verlinden 1997, Bergström and Skarpe 1999, Ogutu and Dublin 2004, Mworia, Kinyamario et al. 2008, Wallgren, Skarpe et al. 2009) and camera trapping surveys (Burton, Sam et al. 2012, Carter, Shrestha et al. 2012). However, these methods have limitations in establishing wildlife distribution because they do not give the details in the spatial distribution of wildlife. Therefore, indirect methods like spoor/tracks could be a realistic option to explore their distribution because they give finer details. However, few studies in the Kalahari rangelands, for example, Verlinden, Perkins et al. 1998, Blaum, Tietjen et al. 2009 used spoor/truck methods in exploring free-ranging livestock and the distribution of few wildlife. Nonetheless, in several parts of the world, conservationists depended on wildlife spoor/track surveys as an essential tool (Linde´n 1996, Danilov, Helle et al. 1996, Alberta Biodiversity Monitoring Institute 2012, Southgate and Moseby 2008). Furthermore, despite the potential of Geographic Information System (hereafter GIS), Global Positioning System (hereafter GPS) and GPS telemetry tools in monitoring the distribution of animals, none of the previous studies in the Kalahari rangelands have used these tools in determining free-ranging livestock grazing distribution and in turn associated livestock distribution to wildlife of different body sizes (Chapter 5 & 6).

(v) Possibility for pastoralism and wildlife coexistence

Coexistence between pastoral activities and wildlife is a central issue concerning conservation policies (Dickman, Macdonald et al. 2011, Woodroffe and Ginsberg 1998). Consequently, several conservation models (i.e. community based-conservation, National Parks, Game Reserves, Wildlife Management Areas) have been proposed and implemented to enable wildlife and pastoral activities coexistence at different spatial scales. The reason for separating the CAs and pastoral areas is that conservation practitioners and policymakers believe that large-sized wildlife (herbivores and carnivores) cannot coexist with pastoral activities at a finer scale (i.e. regularly using the same location) (Cardillo, Purvis et al 2004, Karanth, Gopalaswamy et al. 2011, Brashares, Arcese et al 2001). However, recent studies, indicate that moderate livestock grazing are less damaging to rangeland resources as traditionally thought (Reid 2012) and may even benefit wildlife species (Gregory and Sensenig 2010; Soderstrom and Reid 2010; Augustine et al. 2011; Woodroffe 2011; Reid 2012, Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012). Thus studies in East Africa showed that wildlife moves seasonally from CAs to pastoral ranches (Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012), because CAs do not have the full range of functional resource gradients to maintain different wildlife species (Fynn and Bonyongo 2011). Even though livestock and wildlife share most of the pastoral areas worldwide, there is little research on the interactions of multi wildlife species of different body sizes with livestock, pastoralists and the possibility for coexistence during different seasons in southern African rangelands. Consequently, quantitative information on the ability for multiple wildlife species (i.e. herbivores and carnivores of different sizes) to coexist with pastoralists, free-ranging livestock at different spatial scales in southern Africa CGAs near CAs is lacking.

1.2: Conceptual framework

The conceptual framework for this study is firstly based on resource competition and facilitation concepts between livestock and wildlife of different body sizes (Arsenault and Owen-Smith 2011), and the influence of human disturbance (pastoralists-induced risk) on wildlife distribution. Secondly, the framework is constructed on the theoretical expectations of the distribution of herbivores and carnivores as influenced by body size-resources, prey availability and predation relationships (as reviewed by Hopcraft, Olff et al. 2010). The thesis tests whether these theoretical expectations are consistent with empirical data on the distribution of wildlife of different body sizes across a vast landscape that varies in vegetation heterogeneity, forage and prey availability, due to free-ranging livestock grazing intensity, anthropogenic activities (pastoralists-induced risk) and vulnerability to predation.

i) Resource competition and facilitation

If resources are limited, it is expected that wildlife species and livestock of similar diet and body size are likely to compete (Vavra et al. 1999, Augustine et al. 2011). Therefore, the wildlife species might respond to the resource competition by changing the habitat use or diet (Loft et al. 1991, Fritz et al. 1996), such shift of foraging behaviour, might lead to spatial partitioning in their distribution (Sinclair, 1985, Hibert et al. 2010, Hopcraft, Olff et al. 2010). Nonetheless, studies elsewhere, indicate that even though various herbivore species may have similar forage prerequisites, they do not necessarily compete for resources; however, one species might facilitate another through habitat modification (Arsenault and Owen-Smith 2011, Odadi, Karachi et al. 2011). For example, areas with moderate livestock grazing in pastoral areas could facilitate wildlife distribution through habitat modification, but overgrazing by livestock may result in competition for resources with wildlife. Forage resource availability (quality and quality) and vegetation heterogeneity are predicted to vary with land use types, along a pastoral activities disturbance gradient and between seasons and its variation is foreseen to reflect the distribution and abundance of livestock, the density of cattle posts and wildlife species (Wallgren, Skarpe et al. 2009). Therefore, it is predicted that high abundance livestock and cattle post density will be a key determinant of functional heterogeneity for wildlife with high density for livestock and cattle posts decreasing functional heterogeneity creating a uniform short-grass dominated rangelands across a larger area, but increasing the chance for pastoralists-induced risk to wildlife. On the other hand, low density of livestock and cattle posts will increase functional heterogeneity and less pastoralists-induced risk to wildlife.

ii) Evolutional theoretical expectations of the distribution wildlife

The evolutionary theory on wildlife distribution and abundance (Jarman 1974, Sinclair and Arcese 1995b, Hopcraft, Olff et al. 2010) and empirical research data, for example (Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012) predict that wildlife (i.e. herbivores and carnivores) should maximise their access to crucial feeding resource requirements and reduce predation risk. Besides, the theory suggests that the choice of a habitat depends on the body size of the wildlife because the net effects of food supply and predation risk between large and small-sized wildlife defers (Hopcraft, Anderson et al. 2012). Therefore, food availability and predation risk and possibly pastoralists-induced risk could determine the habitat occupation by wildlife of different body sizes (Valeix et al. 2009). Consequently, small, medium and large-sized wildlife will select different habitats depending on their susceptibility to predation and food resource requirements. Therefore, in CGAs, pastoralists activities such settlements, cattle posts, boreholes, arable fields among others could influence the spatial distribution of herbivores because of disturbance (i.e. the pastoralists-induced risk) (de Leeuw, Waweru et al. 2001). Understanding how wildlife responds to pastoralists-induced risk is critical for conservation of wildlife and livestock management because it links the ecological function and management practices. However, information on how, forage availability, predation, pastoralists-induced risk and other anthropogenic activities are affecting the distribution of wildlife of different sizes is less documented in CGAs of Kalahari ecosystems.

1.3: Significance of the research

The study complements and extends knowledge on the current research on the ecological factors and anthropogenic activities influencing the distribution of multiple wildlife in CAs (Anderson, Hopcraft et al. 2010, Hopcraft, Olff et al. 2010, 2012), between CAs and pastoral ranches in East Africa (Bhola, Ogutu et al. 2012) and between CAs and pastoral ranches in southern Africa (Blaum, Rossmanith et al. 2007a,c,d, Verlinden 1997, Blaum, Tietjen et al. 2009, Wallgren, Skarpe et al. 2009) to pastoralists dominated CGAs supporting free-ranging livestock in southern Africa. The theory and previous research suggest that food availability (quality & quantity) and predation risk are the critical determinants of wildlife distribution (Anderson, Hopcraft et al. 2010, Bhola, Ogutu et al. 2012, Hopcraft, Olff et al. 2010). However, the role of these factors and other anthropogenic activities leading to pastoralists-induced risk, in regulating multiple wildlife species (i.e. both herbivores and carnivores) between CGAs and CAs of southern Africa is less documented. Besides, documentation and mapping of the grazing distribution of free-ranging livestock and their relationship to the distribution of multiple wildlife species in southern Africa savannah, especially the Kalahari rangelands (The Schwelle) have never been done.

Therefore, the study tests the theoretical expectations of the distribution of wildlife based on identified body size-food resources and predation relationships (Hopcraft, Olff et al. 2010) and the findings from previous research from east Africa (Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012) as to whether they are consistent with the empirical data on distribution of wildlife species of different body size in southern Africa CGAs adjacent to CAs. In addition to the ecological factors, anthropogenic activities leading to pastoralists-indiced risk could be one of the critical factors influencing the distribution of wildlife in communally managed rangelands. Thus, understanding how wildlife species of different body size respond to such anthropogenic activities in communally managed areas is significant because it links the ecological functions with management practices and justifies the protection of the critical areas (Hopcraft, Anderson et al. 2012).

Moreover, knowledge of the environmental factors influencing the interactions between pastoralists, free-ranging livestock and wildlife distribution is needed to assist in management efforts in promoting wildlife-livestock coexistence in CGAs of African savannas. Understanding how land use and other pastoral activities relate to the distribution of multiple wildlife species can help advise landuse policies to devise wildlife-friendly land use plans (Epps et al. 2011). Therefore, research that advances knowledge on the interactions between pastoralists, wildlife, livestock in important to reduce conflicts and improve the conservation of wildlife. Nonetheless, most ecological research on wildlife has been conducted in areas with livestock (Graham et al. 2005), let alone free-ranging livestock as in Kalahari rangelands. Hence research that contributes towards understanding the factors that are necessary to maintain multi-species of wildlife in CAs and adjacent pastoral areas is needed.

1.4: Purpose of the study

Conservation of African wildlife is dependent on the CAs. Even though the number of African CAs are increasing, the wildlife population (size and diversity) in these CAs are in widespread decline (Ben-Shahar, 1995, Owen-Smith and Mills 2006, Caro and Scholte 2007, Bolger et al. 2008, Ogutu et al. 2009), which can be attributed to lack of functionality of CAs (Fynn and Bonyongo 2011), because they are small and isolated (NeCArk 2008, Caro and Scholte 2007). In addition, human population densities, settlements and livestock grazing pressure adjacent to CAs have increased (Ogutu et al. 2009; therefore, influencing wildlife movements outside the CAs seasonally. Nonetheless, a wide range of CAs do not encompass both the functional wet and dry – season resources that wildlife traditionally migrated between (Fynn and Bonyongo 2011). Whilst there is some knowledge of the positive and negative interactions between wildlife moving in and out of CAs into pastoral areas, for example in the Mara (Bhola, Ogutu et al. 2012) and Serengeti (Maddox 2003, Hopcraft, Anderson et al. 2012) regions, less is known about temporal and spatial distribution of wildlife in the Kalahari considering multiple species (Verlinden 1997, Wallgren, Skarpe et al. 2009).

Furthermore, despite the fact that the evolutionary theory on the distribution of wild herbivores (Hopcraft, Olff et al. 2010) and empirical data in East Africa (Anderson, Hopcraft et al. 2010, Hopcraft, Anderson et al. 2012, Ogutu, Bhola et al. 2005) have identified forage quantity, quality and predation risk as environmental factors influencing the distribution of the resident herbivores between CAs and pastoral ranches, the fundamental questions are to what extent do these ecological factors and mechanisms, identified as shaping the distribution of resident herbivores in CAs and pastoral ranches in East Africa, be extrapolated to multiple herbivores in pastoral-dominated CGAs supporting free-ranging livestock like in the Kalahari of Southern Africa? And, how do resident wild herbivores respond to a combination of environmental factors including pastoralist induced disturbance? Therefore, this study aims to look at the levels of competition and facilitation between livestock and wildlife and how this varies between the wet and dry season, land use and wildlife body size functional grouping and predation risk in the CGAs and CAs of Kalahari. The study explores the relationship between the availability of food resources, the grazing patterns of wild herbivores and how these influence the distribution of carnivores and how, in turn, these patterns are modified by the interaction between pastoralists and their free-ranging livestock. Therefore, this involves evaluating the spatial distribution of vegetation, herbivores, carnivores, pastoral activities, the granzing patterns of livestock and their grazing intensity. The following are the overall specific objectives as per the empirical chapters:

1.4.1: Overall specific Objectives

i. Determine forage resource availability and vegetation heterogeneity in relation to the distribution of free-ranging livestock along a pastoral activities disturbance gradient in CGAs and CAs (i.e. CAs) during the wet and dry seasons (Chapter 4)

ii. Explore the interactions between wild herbivores (>1kg), pastoralists and free-ranging livestock in CGAs and CAs along a pastoral activities disturbance gradient and land use types during the wet and dry seasons (Chapter 5)

iii. Explore the interactions between carnivores (>1kg), pastoralists and free-ranging livestock grazing intensity in CGAs and CAs along a pastoral activities disturbance gradient and land use types during the wet and dry seasons (Chapter 6)

iv. To evaluate the possibility of coexistence of wildlife and free-ranging livestock across landscape along a pastoral activities disturbance gradient in CGAs and CAs in the Kalahari savanna rangelands (Chapter 7)

1.5: Expected outcomes/Hypothesis

To understand the patterns of wildlife distribution, the evolutionary theory and empirical research data from CAs and pastoral ranches suggest that herbivores will primarily maximise their access to essential feeding resource requirements and reduce predation risk (Sinclair and Arcese 1995b). Furthermore, the theory suggests that the choice of habitat by wildlife might be dependent on its body size because the net effect of food supply and predation differs between large and small-sized wildlife (Hopcraft, Olff et al. 2010). Therefore, the first area of investigation is to understand the spatial distribution of forage availability and vegetation heterogeneity relative to pastoral activities disturbance gradient and land use. Given this baseline information on forage availability and vegetation heterogeneity, the second area of investigation is to relate the distribution of forage availability and vegetation heterogeneity to the spatial distribution of pastoral activities (i.e. settlements, cattle posts, free-ranging livestock grazing intensities, watering points, arable fields among others) and the temporal and spatial distribution of wild herbivores of different body sizes. Knowing the spatial distribution of forage availability, vegetation heterogeneity, pastoral activities and wild herbivores of different sizes, the third area of investigation is thus, to relate this information with the temporal and spatial distribution of carnivores. The last area of investigation is to use the outcomes of the above areas of investigation to explore the possibility of coexistence between pastoralists, free-ranging livestock, wild herbivores and carnivores in CGAs and adjacent CAs. Consequently, the following predictions of several hypotheses as per the area of investigation or research objective are tested.

1) Spatial forage availability and vegetation heterogeneity

The key question is to find out whether forage availability (quality and quantity) and vegetation heterogeneity vary with land use types (CGAs & CAs) and along a free-ranging livestock and pastoral activities disturbance gradients between wet and dry seasons (Chapter 4). Hence it is predicted that forage availability and vegetation heterogeneity vary with land use types, along a livestock grazing gradient, and between seasons because of livestock grazing intensity. Furthermore, these variations might influence the distribution of herbivores (Chapter 5) and carnivores (Chapter 6), hence the following detailed predictions of several hypotheses on forage availability and vegetation heterogeneity.

i) Vegetation heterogeneity (i.e. a mixture of herbaceous and woody plants) was expected to increase with moderate livestock grazing and decrease within areas with increased livestock grazing intensity, and in CAs (H1a).

ii) Forage quality (i.e. short, palatable perennial and annual grasses, high grass and forb species richness and diversity) would be higher in moderately grazed areas during the wet season as maintained by less livestock grazing intensity, hence forage quality is predicted to be related to moderate livestock grazing (Hopcraft, Anderson et al. 2012, Augustine and McNaughton 2006) (H1b).

iii) However, intensive livestock grazing leads to a decrease in palatable perennial grasses and an increase in annual grasses and forbs (Fernandez-Gimenez and Allen-Diaz 1999). Hence closer to settlements and cattle posts unpalatable perennial and annual grasses, forbs and reduced grass cover were expected to occur within these areas; thus low grass quality and quantity were expected in areas with increased livestock grazing intensity in both seasons (H1c).

iv) Tall, dense grasses, high grass biomass and cover, were expected to be related to CAs than CGAs in both seasons; however, the quality of these tall and dense grass is low because of high lignin accumulation in tall grasses, hence low in digestibility (Anderson et al. 2007), but increased forage quantity (H1d).

v) The density and canopy cover of woody plants are expected to be associated with increased livestock grazing intensity in CGAs near settlements and increased density of cattle posts in both seasons due to livestock grazing (Moleele and Perkins 1998, Dougill, Akanyang et al. 2016). Besides, the density of bush encroachment woody plants species is also predicted to be closer to cattle posts and settlements, while the density of non-bush encroachers is expected to increase with distance (Moleele 1999) (H1e).

2) Distribution of free-ranging livestock and wild herbivores

What are the environmental factors regulating the distribution and the interactions of pastoralists, free-ranging livestock and wild herbivores in CGAs and adjoining CAs along a pastoral activities disturbance gradient and land use types during the wet and dry seasons (Chapter 5)? Do the differences in forage availability (quantity & quality) and vegetation heterogeneity (Chapter 4), predation risk (Chapter 6), land use, livestock grazing intensity, and the pastoralists-induced risk determine the distribution of wild herbivores in CGAs and CAs? Information on forage availability, predation risk, land use, livestock grazing intensity, and the pastoralists-induced risk is used to make predictions of several hypotheses to be tested to establish factors influencing the spatial distribution of eleven wild herbivores in relation to pastoral activities and five free-ranging livestock grazing gradient in CGAs and CAs (Chapter 5).

i) (H2a) The high density of pastoral activities such as cattle posts, arable fields, boreholes, livestock grazing intensity, livestock density would be higher closer to settlements. Therefore, free-ranging livestock would travel long distances from the settlements and cattle posts during the dry season than wet seasons because of the shortage of forage resource; hence, resource competition with wildlife is expected to be high in the dry season. Consequently, the distribution of the variety of wildlife species would be lower closer to settlements and cattle posts in CGAs because of direct and indirect disturbances (i.e. the pastoralists-induced risk) but increasing with distance from settlement and cattle posts in dry seasons.

ii) (H2b) The distribution of small-sized wild herbivores, such as Steenbok (*Raphicerus campestris* – Thunberg; 13 kg), is expected to be associated with moderately grazed areas in CGAs but increasing with distances from pastoral activities in both seasons because there are regulated by highest forage quality (Fritz and Duncan 1994; Olff et al. 2002, Bhola, Ogutu et al. 2012), the pastoralists-induced risk in human-dominated areas, and predation risk (Sinclair and Arcese 1995b) in CAs.

iii) (H2c) On the contrary, the distribution of medium herbivores, such as Red Hartebeest (*Alcelaphus bucelaphus* – Hilaire; 150kg), is predicted to occur in areas with moderate livestock grazing intensity in CGAs in wet season to benefit from enough grass biomass of adequate quality and at the same time avoiding predation risk (Cromsigt 2006; Wilmshurst, Fryxell & Bergman 2000, Bhola et al. 2005) in CAs and the pastoralists-induced risk in human-dominated areas. However, medium-sized herbivores are expected to move into the CAs because of competition for forage resource with livestock during the dry season, despite the predation risk in CAs (Bhola, Ogutu et al. 2012).

iv) (H2d) However, the distribution of large-sized herbivores, like Eland (*Tragelaphus oryx* – Pallas; 660 kg) is predicted to remain in CAs in both seasons because they are regulated by forage quantity and are not susceptible to predation risk (Fritz et al. 2002, Bhola, Ogutu et al. 2012) but negatively affected by the pastoralists-induced risk in CGAs and hence concentrate in areas with high vegetation cover.

***3) Distribution of free-ranging livestock and* carnivores**

What are the environmental factors influencing the distribution and the interactions of pastoralists, free-ranging livestock and wild carnivores in CGAs and CAs along a pastoral activities disturbance gradient land use during the wet and dry seasons (Chapter 6)? Do the differences in prey availability (Chapter 5), vegetation heterogeneity (chapter 4), predation risk, land use, livestock grazing intensity, and the pastoralists-induced risk regulate the distribution of carnivores in CGAs and adjacent CAs? The following factors are used to predict the spatial distribution of twelve wild carnivores in relation to pastoral activities and five free-ranging livestock grazing gradient in CGAs and CAs (chapter 6); Prey availability, predation risk, land use, livestock grazing intensity, and the pastoralists-induced risk. Hence the following hypotheses

i) (H3a) The spatial distribution of small (e.g. black back Jackal) and medium-sized (e.g. Cheetah) carnivores would to decrease in pastoralists-dominated areas due to the pastoralists-induced risk, predator control measures (Blaum, Rossmanith et al. 2007c,d) and increased livestock grazing intensity.

ii) (H3b) However, the spatial distribution of small to medium predators would increase with moderate grazing intensity because of vegetation heterogeneity (i.e. grasses and woody plants) (Jeltsch, Milton et al. 1996), prey availability (Blaum, Rossmanith et al. 2007c,d), less the pastoralists-induced risk and predation risk from dominant carnivores (Creel and Creel 1996, Mills and Gorman 1997) in CGAs compared to CAs in both seasons.

iii) (H3c) However, the spatial distribution of large-sized carnivores, like Lions and Spotted Hyena, would be associated with high vegetation cover, prey availability and less the pastoralists-induced risk in CAs (Ogutu and Dublin 2002, Wallgren, Skarpe et al. 2009, Hopcraft, Anderson et al. 2012) compared to CGAs where there is reduced vegetation cover and high visibility against large-sized carnivores.

iv) (H3d) Prey availability, vegetation heterogeneity, LGI, predation risk, and the pastoralists-induced risk would influence the distribution of carnivores. Prey availability, vegetation heterogeneity would positively influence the distribution of all carnivores, hence carnivores would increase in areas with high prey availability and vegetation heterogeneity. Carnivores would decrease in areas with increased livestock grazing imtensity and pastoralists induced-risk.

4) Pastoralists, free-ranging livestock and wildlife co-existence

Is it possible for pastoralists, free-ranging livestock and different types of wildlife species to coexistence in CGAs and CAs in savanna rangelands (**Chapter 7**)? It was predicted that the body size of wildlife species would determine the possibility of coexistence with pastoralists, free-ranging livestock because of factors such as predation risk and forage requirements (Bhola, Ogutu et al. 2012). Therefore, using the findings from chapters 4, 5, and 6 the predictions of hypotheses on body size of wildlife were tested to establish the possibility of coexistence.

i) It was predicted that small to medium-sized wildlife (herbivores and carnivores) would coexist with pastoralists, free-ranging livestock in CGAs in areas with moderate livestock grazing intensity because livestock could maintain grasses in short and at an active growth stage. Therefore, providing quality forage and vegetation heterogeneity and less predation risk due to increased visibility during the wet season. Small to medium-sized carnivores could benefit from prey availability (i.e. small to medium) and less large-sized carnivores, hence resource facilitation (H4a).

ii) However, the coexistence of all wildlife species (herbivores and carnivores) was expected to be minimal in pastoral impacted areas because of reduced herbaceous cover, less vegetation heterogeneity and the pastoralists-induced risk, therefore, resulting in resource competition with livestock during both wet and dry seasons (H4b).

iii) Large-sized wildlife (herbivores and carnivores) were expected concentrate in CAs but not to coexist with pastoralists, free-ranging livestock in CGAs, notably in pastoralists-dominated areas in both seasons due to resource competition, increased visibility and pastoralists induced risk (**H4c**).

To test the above hypotheses, the study analysed influences of the following environmental gradients; vegetation heterogeneity, spatial forage quality and quantity, prey availability, land use (CAs and CGAs), predation risk, free-ranging livestock grazing intensity, the pastoralists-induced risk on the distribution of five free-ranging livestock, eleven wild herbivores and twelve carnivores in the Kalahari ecosystems, Botswana. Vegetation heterogeneity was inferred from the mixture of herbaceous and woody plants. Forage quality was determined from several variables such as the grass height, grass and forb diversity, herbaceous and woody plant species composition, palatability of grass species and life forms (i.e. perennial and annual grasses) (Oudtshoon 2002). Forage quantity was inferred from livestock grazing intensity, distance travelled by livestock from cattle posts for grazing, grass cover & biomass, grass density, forb cover & biomass, forb density, bare ground, woody plants density and cover, distance from pastoral activities.

Prey availability and predation risk were inferred from the distribution of a variety of herbivores and carnivores' spoor respectively. Free-ranging livestock grazing intensity was determined from several variables such as herbaceous biomass & cover, grass palatability and life forms, woody plant cover and cattle post densities. Lastly, the pastoralists-induced risk was inferred from the distances from settlements, cattle posts and arable fields, the density of cattle posts and arable fields. The above environmental gradients were associated with the distributions of free-ranging livestock, wild herbivores and carnivores to establish environmental factors regulating their distribution in the Kalahari rangelands during the wet and dry seasons. Finally, the hypotheses on the possibility of coexistence of pastoralists, free-ranging livestock and different types of wildlife species were tested considering the association of the significant environmental factors with their distributions.

To help fill this critical information gap, the spatial distribution of eleven herbivores and twelve carnivores (>1kg) in relation to pastoral activities and five free-ranging livestock (Cattle, Goats, sheep, Donkey and Horses) grazing gradient starting from CGAs and ending in CAs in Kalahari, Botswana was analysed for two years during the wet and dry seasons. The study focused on the Kalahari rangelands for three main reasons. First, there is an expansion of free-ranging livestock production and other pastoral activities (e.g. settlements, arable fields) in an area which used to be dominated by multiple wildlife species of different body sizes. However, wildlife numbers are declining (Moleele and Mainah 2003). Secondly, the Kalahari rangelands are composed of different land use, such as CAs, CGAs, and game reserves which allows the study to compare the spatial distribution of different wildlife species between land use and along the livestock grazing gradient. Lastly, none of the previous studies conducted in the Kalahari rangelands have mapped the expansion and the grazing intensity of free-ranging livestock relative to the spatial distribution of multiple wildlife species of different body sizes.

The data was collected using a systematic sampling survey based on wildlife spoor/tracks information, road-side field observations, GIS and GPS telemetry. A detailed comparative analysis of forage availability and other environmental factors were also analysed along free-ranging livestock grazing and pastoral activities disturbance gradients and between the land uses. This analysis of pastoralists, free-ranging livestock and wildlife interactions between CGAs and CAs complements and extends current research on the factors influencing the distribution of wildlife in CAs (Anderson, Hopcraft et al. 2010, Hopcraft, Anderson et al. 2012), between CAs and pastoral ranches (Bhola, Ogutu et al. 2012, Blaum, Rossmanith et al. 2007a,c, Blaum, Tietjen et al. 2009) to pastoralist dominated CGAs supporting free-ranging livestock.

1.6: Presentation and overview of the chapters

This thesis comprises of seven Chapters that evaluates pastoralists, free-ranging livestock, wildlife interactions, and the possibility of coexistence at different spatial scales in an extensive Kalahari savanna ecosystem. Chapter 1 provides background information on the research topic and discusses relevant factors to introduce the origin of the problem, knowledge gap, and how the purpose statements close knowledge gap. It also introduces the research design and context, the broad conceptual framework, and the expected outcomes. Chapter 2 identifies the gap in scientific knowledge through the literature review on concepts or theories on environmental gradients in savanna rangelands, vegetation, wildlife, and livestock distributions. Chapter 3 describes the detailed methods, field data collection, and statistical analyses of the data.

Given the above overview and the need to establish the critical determinants regulating the spatial distribution of wild herbivores and carnivores in southern Africa rangelands, a key knowledge gap is understanding the relationship between forage availability and the distribution of wildlife of different body sizes in communally managed rangelands adjacent to CAs. Chapter 4 therefore, aims using the Kalahari community, to describe the spatial variation of forage availability (i.e. quality and quantity) and vegetation heterogeneity relative to pastoral activities disturbance gradient and land use. Subsequently, Chapter 5 relates the distribution of forage availability and vegetation heterogeneity to the distribution of pastoral activities and wild herbivores. The spatial distribution of carnivores in relation to the distribution of livestock, pastoral activities, wild herbivores and vegetation heterogeneity between land use types are established in Chapter 6. Finally, Chapter 7 synthesis the findings from Chapter 4, 5 & 6 and the implications for free-ranging livestock management and wildlife conservation. This chapter also evaluates the possibility of coexistence at different spatial scales of wildlife (>1kg) and free-ranging livestock in CGAs and CAs along a livestock grazing gradient.

Chapter 2: Literature review

The primary emphasis of this chapter is to find out how much has been done or is known concerning critical determinants of the spatial distribution of multiple wildlife species in African savanna ecosystems, regarding pastoral dominated CGAs adjacent to CAs in southern Africa. The chapter also investigates what is known and not known about the effects of pastoral activities on the spatial vegetation heterogeneity relative to the distribution of herbivores and carnivores in African savanna rangelands to identify gaps in knowledge.

i) Spatial forage heterogeneity

The review reveals that land use is considered the primary driver for environmental change in African savanna ecosystems. Therefore, because livestock grazing is a significant land use, it plays an important role in structuring the changes in savanna rangelands, through the effects of herbaceous, woody vegetation and soil properties. Consequently, intensification of anthropogenic activities and livestock grazing in the pastoral areas adjacent to the CAs creates spatial heterogeneity in forage quality and quantity between the CAs and pastoral areas, hence influencing the distribution of wildlife of different body size and feeding style otherwise. Past research has indicated that environmental factors, such as forage quality, quantity play a key role in shaping the distribution of wildlife in East African CAs and pastoral ranches. There is, however, little information available on the recent detailed comparative analysis on forage quality, quantity and vegetation species composition relative to multiple wildlife species' distribution between CAs and communally managed areas supporting free-ranging livestock in southern Africa rangelands. Moreover, previous studies estimating forage availability, particularly for livestock have disregarded forbs and woody plants and concentrated on the grass efficiency, yet, forbs and woody plants make part of the diets of domestic animals and wildlife.

ii) Herbivores

The review indicates that the critical ecological factors and mechanisms shaping herbivores' distribution as identified in CAs and pastoral ranches in East Africa are forage quality, quantity and quality and the influence of these factors vary with wildlife body size, feeding style and environmental gradients within the landscapes. The review also reveals that herbivores should maximise access to forage requirements and reduce the risk of predation depending on the body size. For example, large-sized herbivores are not susceptible to predation than small to medium-sized herbivores and are regulated by forage quantity as they can extra sufficient nutrients from low-quality forage. On the other hand, small to medium-sized herbivores are regulated by forage quality and the risk from the predators. Hence, small to medium-sized herbivores can be facilitated by livestock grazing by maintaining the grass short and actively growing. This raises essential questions about the degree to which these ecological factors and mechanisms identified as influencing the distribution of herbivores in East African CAs and pastoral ranches can be extrapolated to semi-arid CGAs with free-ranging livestock in southern Africa rangelands. Wildlife shares these CGAs with pastoralists, their settlements, cultivation fields, and free-ranging livestock.

However, increase in pastoral activities has invaded what used to be wildlife habitat, therefore shaping their distribution and possibly the restriction in the seasonal movements of different wildlife species depending on the body sizes. Furthermore, there is little information available on the influence of human disturbance (i.e. the pastoralists-induced risk), such illegal hunting pressure, predator control measures, indirect disturbance among others and livestock grazing intensity on the distribution of multiple wildlife species in the Kalahari ecosystem, southern Africa. Nevertheless, a study by Hopcraft, Anderson et al. 2012, suggests that the distribution of wildlife could be influenced by human disturbance because wildlife avoid human-dominated areas even though there is no barrier between the CAs and human-dominated areas, hence the possibility for future research. However, such kind of research may offer fundamental information on the ecological factors influencing the distribution of wild herbivores of different body sizes and feeding styles.

iii) Carnivores

It was also established from the review that changes in land tenure, land use, increase in human population, pastoral activities have resulted in habitat loss, land degradation, and fragmentation; hence competition for forage resource between livestock and wild herbivores is conceivable. Conversion of rangelands into agriculture is the most widespread land use change globally. Therefore, the spatial ecology of wild animals is regulated by land use change and human disturbance. The review also reveals that the decrease in herbivores (i.e. prey biomass) affects the distribution of carnivores because of prey shortage and increase in persecution of carnivores due to livestock depredation. Prey biomass, vegetation cover, water availability, influence many ecological and population parameters of carnivores. Livestock grazing increases visibility against carnivores, hence making it difficult for carnivores to catch their prey, and vulnerable to other predators through the increase of shrubs and reduction of grasses. These conclusions were nevertheless, made on the studies conducted in CAs and pastoral ranches of East Africa. However, few studies in southern Africa rangelands have thoroughly analysed the influence of pastoral activities on the distribution of carnivores in extensive CGAs with free-ranging livestock adjacent to CAs. Consequently, the results from such studies may provide a better understanding of anthropogenic and environmental factors influence the distribution of carnivores in semi-arid rangelands; hence can guide in decision making on management and conservation of wildlife.

Chapter 3: Previous methods used on wildlife distribution

On reviewing the previous research techniques and methodology on wildlife distribution in African savanna rangelands, it was established that most studies commonly used aerial, camera trapping surveys and field observations. However, aerial survey and field observational methods tend to miss the presence of specific animals, usually small, less dense and nocturnal animals, because many terrestrial mammals are secretive in appearance. For instance, when using camera trapping survey in an area with dense vegetation, cameras can be obstructed by vegetation cover, and the number of cameras could be limited; hence the possibility of missing the presence of some animals.

Therefore, in the case where the substrates (soils) are suitable, for example, the sandy soils of the Kalahari rangelands, indirect methods like spoor/tracks and field observations could be the realistic options to explore the distribution of wildlife because several tracks of animals and animals within the vicinity of sample points can be quickly captured. However, very few studies in the Kalahari rangelands have used spoor/truck methods to establish the distribution of multi wildlife species.

On the other hand, the use of GPS and GIS tools can provide researchers with efficient and precise spatial distribution maps on livestock grazing intensity distribution. Nevertheless, few studies if not none on livestock grazing distribution have used these tools in the Kalahari rangelands. The use of both spoor/track information, GPS telemetry and GIS can provide more direct insights into the interactions of pastoralists, wildlife and livestock interactions in savanna rangelands, hence the use of these tools in this study.

Chapter 4: Forage resource availability and vegetation heterogeneity across land use types and along a free-ranging livestock grazing gradient

This Chapter aims to assess forage resource availability and vegetation heterogeneity along a free-ranging livestock grazing and pastoral activities disturbance gradient in Kalahari, as a case study. This is later related to wildlife distribution (chapter 5) starting from human-dominated areas in CGAs and to end in CAs. The relationships between herbaceous and woody plant species parameters, livestock grazing intensity and land use were assessed through a vegetation survey in the dry and wet seasons. The findings from this chapter are related to the spatial distribution of herbivores (Chapter 5) and carnivores (Chapter 6) and used to establish the possibility of coexistence of pastoralists, free-ranging livestock and multi-species wildlife of different body sizes in CGAs and nearby CAs (Chapter 7).

Chapter 5: Factors influencing the interactions between pastoralists, free-ranging livestock and wild herbivores of different body sizes

There are fundamental questions about i) the extent to which the ecological factors and mechanisms identified to influence the distribution of wild herbivores between CAs and pastoral areas in East Africa can be extrapolated to pastoral-dominated, semi-arid community-managed savanna rangelands supporting free-ranging livestock; and ii) how herbivores of different body size respond to the pastoralists-induced risk in CGAs with free-ranging livestock. Given the above overview, this chapter deals with relative effects of anthropogenic and environmental factors, such as forage availability, land use, predation risk and the pastoralists-induced risks on the spatial and temporal distribution of wild herbivores in communally managed rangelands and the adjacent CAs of the Kalahari rangelands of Botswana.

The spatial distribution of eleven wild herbivores in relation to pastoral activities and five free-ranging livestock grazing and pastoral activities disturbance gradients starting from CGAs and ending in CAs was studied for two years based on the gradient of decreasing livestock grazing intensity (pastoral activities disturbance gradient) to determine their interactions. A systematic survey approach combining wildlife and livestock spoor/tracks data, vegetation survey (Chapter 4), road-side field observations along a livestock grazing intensity gradient, cattle fitted with GPS telemetry was applied. This investigation complements and extends knowledge on the current research on the factors influencing the distribution of wildlife in CAs, between CAs and pastoral ranches in East Africa to pastoralists dominated CGAs supporting free-ranging livestock. Accordingly, the findings on herbivore distribution were also related to the spatial and temporal distribution on carnivores (Chapter 6).

Chapter 6: The effects of pastoral activities, free-ranging livestock and environmental factors on the distribution of carnivores of different body sizes

The impacts of the pastoral activities, specifically free-ranging livestock grazing intensity on the distribution of carnivores in semi-arid CGAs near CAs are less documented. Given the above review, there is a need to evaluate the impacts of the pastoralists-induced risk, free-ranging livestock grazing intensity and land use on the distribution of carnivores. This chapter, therefore, addresses the role of anthropogenic activities, land use and prey availability on the distribution of carnivores in CGAS and CAs of the Kalahari rangelands, southern Africa. The predictions of the hypotheses on prey biomass, livestock grazing intensity, vegetation heterogeneity, the pastoralists-induced risk, are tested to establish factors influencing the spatial distribution of twelve wild carnivores in CGAs and adjacent CAs. The spatial distribution of twelve carnivores in relation to pastoral activities and along five free-ranging livestock grazing and pastoral activities disturbance gradients starting from human-dominated areas in CGAs and ending in CAs was studied during the wet and dry seasons for two years. The study was based on a sampling survey using carnivores and livestock spoor/ data, GPS telemetry on livestock, vegetation survey (Chapter 4), road-side field observations along a free-ranging livestock grazing gradient.

Chapter 7

Lastly, this chapter discusses the main findings from Chapters 4, 5, & 6 in relation to the broader literature and the broader debates on conservation and human threats to wildlife to establish the possibility of coexistence of pastoralists, free-ranging livestock and wildlife of different species and body sizes in CGAs and nearby CAs. It also discusses the implications of the findings for wildlife and free-ranging livestock management in Botswana.

Chapter 2

Literature review

2.1: Introduction

Pastoralists, free-ranging livestock and wildlife interactions here will only refer to their overlapping or partitioning in spatial distribution due to either facilitation or competition over resources respectively. Free-ranging livestock refers to domestic animals (cattle, donkey, horse, sheep and goats) that are kraaled at night and released during the day for grazing in CGAs without the herders and the animals come to the watering point when they feel like drinking after few days (Perkins, Stuart-Hill et al. 2002). Pastoralists keep their free-ranging livestock in CGAs at places called cattle posts, which are composed of kraals (bomas) where the livestock is held at night (Perkins, Stuart-Hill et al. 2002), a borehole to supply water and a place (huts) where the herd boys stay (Reed, Dougill et al. 2007).

The aim of the review is to assess the progress that has been made on the environmental factors regulating the distribution of multi-species wildlife (i.e. herbivores and carnivores) in pastoral areas adjacent to CAs and how they interact with livestock and other anthropogenic activities in African rangelands. The review also draws experiences from elsewhere. Pastoralists' or anthropogenic activities include but not limited to cattle posts, arable fields, settlements, harvesting of veldt products and other direct or indirect human disturbances. While the pastoralists-induced risk in this study will refer to all the factors that directly or indirectly interfere with the movements of wildlife, such as illegal hunting, disturbance by the presence of humans, predator control measures among others. Consequently, the review evaluates the progress that has been made in exploring key factors influencing the interactions between livestock, pastoralists and multi-species wildlife in African CGAs near CAs and identify research gaps for the current study.

In African rangelands, increase in human and livestock population near CAs has intensified pastoralists, livestock and wildlife interactions, resulting in competition for resources, conflicts related to predation, crop damage and diseases transformation (de Garine – Wichatitksy et al. 2013). However, studies by (Arsenault and Owen-Smith 2011, Odadi, Karachi et al. 2011), suggest that they could be resource facilitation between some wildlife species and moderate livestock grazing through modification of vegetation. Therefore, reducing contacts between pastoralists, livestock and wildlife to minimise the risk of resources competition and conflicts remains a challenge for biodiversity conservation and livestock production (Larmarque et al. 2009). Consequently, for land use planning and management tools that promote coexistence of pastoralists, livestock and wildlife, it is vital to identify the critical environmental factors influencing their interactions.

Several factors including biophysical and human activities have been linked to the influence of the distribution of wildlife (Hebblewhite and Merrill 2008). For example, in East Africa (e.g. the Mara region, Kenya), forage quality, quantity and predation risk were identified as the critical determinants of wildlife distribution (Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012, McNaughton, Ruess et al. 1988, McNaughton 1990, Anderson, Hopcraft et al. 2010) between CAs and ranches. Nevertheless, the extent to which these ecological factors and mechanisms can be extrapolated to the distribution of multiple wildlife species in human-dominated CGAs, supporting free-ranging livestock like in the Kalahari rangelands of southern Africa has never been tested. Furthermore, the pastoralists-induced risk (i.e. human disturbance) has the potential to influence the distribution of multiple species of wildlife in CGAs adjacent to the CAs; however, the influence of both pastoralists-induced risk and forage availability on the distribution of multi-species herbivores and in turn carnvores in the Kalahari ecosystems is less documented. This chapter, therefore, attempts to engage and identify gaps in knowledge with a wide range of issues on rangelands, vegetation, wildlife ecological theories and human factors influencing the spatial distribution of multi-species of wildlife in African rangelands, comprising southern Africa CGAs adjacent the CAs with the following objectives;

1. To review how livestock grazing intensity affects forage availability (i.e. quantity and quality) and vegetation heterogeneity in semi-arid savannah rangelands
2. To review the possible critical determinants of the distribution of wild herbivores between CGAs and CAs in African rangelands
3. To evaluate the possible critical determinants of the distribution of carnivores between CGAs and CAs in African rangelands
4. The review previous techniques, methods used to establish the distribution of wildlife and their relevance/limitations

5. To review the possibility of coexistence of pastoralists, free-ranging livestock and multi-species of wildlife of different body sizes.

2.2: The effects of livestock grazing intensity on forage availability and vegetation heterogeneity in semi-arid savannah rangelands

The savanna rangelands are described by the concurrence of a continuous layer of herbaceous vegetation and a patchy of woody vegetation (Skarpe, 1992). However, human population growth, expansion of settlements (Lamprey and Reid 2004), cultivation (Serneels et al. 2001; Thompson and Homewood 2002) and changing from semi-nomadic pastoralism to sedentary pastoralism (Western et al. 2009) are gradually altering vegetation composition and the structure of savanna rangelands. Furthermore, soil moisture (Walker, Ludwig et al. 1981), fire and anthropogenic activities (such as livestock grazing intensity) limit the stability of woody plants and herbaceous vegetation (Walker et al 1981, Sternberg et al., 2000; Scholes et al., 2002; van Langevelde et al., 2003). Woody and herbaceous plants compete for soil moisture, which is primarily determined by rainfall and soil parameters. Other factors, such as fire, drought, and herbivory also influence woody and herbaceous biomass changes in both time and space (Jeltsch et al. 1996, 1998, Higgins et al. 2000). Increase in woody plant covers have been documented in southern Africa (Van Vegten 1984, Skarpe 1986, Skarpe 1990, Perkins 1991, Perkins and Thomas 1993, Ringrose et al. 1996, Moleele and Perkins 1998, Dougill, Akanyang et al. 2016) and in other semi-arid rangelands of the world (Archer 1989). This increase in woody plant covers and biomass is severe in CGAs of African rangelands are accompanied by the decrease in herbaceous production (Abel 1997, Dougill, Akanyang et al. 2016). The increase in woody plants and the decrease in herbaceous plants are attributed to the increase in livestock grazing intensity in CGAs (Skarpe 1990) as compared to the private ranches and CAs.

Savanna vegetation in African rangelands are mainly exploited through livestock grazing (Scholes and Archer, 1997; Bilotta et al., 2007), hence influencing the defoliation rate and the sustainability of the forage availability (quality and quantity) and vegetation heterogeneity (Mphinyane et al., 2008). Consequently, rangeland degradation in semi-arid ecosystems is associated with livestock disturbance (Walker, Ludwig et al. 1981, Belsky 1990, Vetter 2005) and have been documented in CGAs of southern Africa (Abel and Blaikie 1989, Skarpe 1986, Moleele and Mainah 2003) as well as other grassland savannahs. Indicators of rangeland degradation such as bush encroachment, reduction of plant species palatability, soil erosion, and reduction of palatable plant species, species composition, canopy cover, plant species diversity and the increase of annual grasses are a concern worldwide. Most herbaceous plants (i.e. grasses and forbs) in African savannas are relatively tolerant to livestock grazing, however, continued heavy livestock grazing intensities lead to shifting in plant species composition (Skarpe, 1992), reduction in grass biomass and an increase in forbs biomass (Moleele and Perkins 1998, Dougill, Akanyang et al. 2016).

Land degradation in the context of southern Africa is understood by discussing the classical succession models such as equilibrium and non-equilibrium theories. Several conceptual models explain the dynamics of savanna rangelands (Belsky 1990), but the most debates have been around the equilibrium and non-equilibrium theories (Westoby, Walker et al. 1989, Vetter 2005, Tefera, Dlamini et al. 2010). The equilibrium theory suggests that if the rangelands are not disturbed by anthropogenic activities, such as herbivory (Westoby, Walker et al. 1989), they will remain in a single state of dynamic equilibrium (climax state) (Cole 1986, Ellis and Swift 1988). Whereby the climax state is dominated by palatable and perennial grasses (Oudtshoorn 2002). Hence this theory predicts that vegetation biomass and cover decline with the increase in herbivore numbers, while species composition changes from being dominated by palatable perennial grasses and forbs to unpalatable forbs and annual grasses. However, the reverse is true if the herbivore numbers are reduced (Fernandez-Gimenez and Allen-Diaz 1999). Still, under the equilibrium theory, other studies have hypothesised that species diversity and richness are highest at intermediate grazing intensities and declines with heavy grazing (Harper 1968, Coppock, Detling et al. 1983, Milchunas, Sala et al. 1988).

However, the equilibrium theory has been widely criticised (Connell and Slatyer 1977, Smith 1988, Westoby, Walker et al. 1989, Friedel 1991) because it could not predict successfully the behaviour of complex natural systems (May 1977, Connell and Sousa 1983). In contrast, the non-equilibrium theory focuses on both effects of abiotic factors and the changes in herbivores populations. According to the non-equilibrium theory, the primary driving force in savanna rangelands is the climate variability, such as rainfall (Ellis and Swift 1988, Behnke, Scoones et al. 1993) as compared to herbivory, which has a minimal effect (Ellis and Swift 1988, Westoby, Walker et al. 1989). Concurrently, influencing livestock and wildlife population and the grazing distribution patterns. Seasonal rainfall also influences vegetation growth, quality, and quantity in the African savanna, hence it is patchy (Deshmukh 1984), therefore influencing the distribution of resident wildlife. Henceforth, in exploring the interactions of pastoralism and wildlife, both the equilibrium and non-equilibrium theories should be taken into considerations to inform the study.

Although there is a contrast between the equilibrium and non-equilibrium theories, the fact remains that land use types play a significant role in the vegetation heterogeneity and forage availability in African savanna rangelands (Scholes and Archer 1997). The savanna rangelands are dominated by the livestock and wildlife grazing (Skarpe 1991), hence the interactions between pastoralists, livestock and wildlife. Wildlife and livestock grazing abilities influence the structure and dynamics of the savanna rangelands, hence their grazing distributions. The presence of both the livestock and wildlife in savanna rangelands has an influence on each other's spatial distribution pattern through the process of competition or facilitation. Therefore, to determine important environmental factors shaping the distribution and interactions of pastoralists, livestock and wildlife, it is critical to first investigate forage availability between land use and along a pastoral activities disturbance gradient during different seasons. According to the non-equilibrium theory (Ellis and Swift 1988, Behnke, Scoones et al. 1993), incorporation of both the abiotic (e.g. rainfall) and biotic factors (e.g. herbivory) is vital to analyse the interactions between the wildlife and livestock in the savanna rangelands. Hence it is important to also analyse the rainfall trends in the study areas during the data collection because cumulatively rainfall influence forage availability of the past, current, and future, hence the grazing distribution for both wildlife and livestock.

Despite the influence of livestock grazing intensity on vegetation heterogeneity and forage availability, and in turn the temporal and spatial distribution of wildlife, little empirical evidence is available pertaining to the comparative analysis of vegetation heterogeneity, forage availability (i.e. quantity and quality) between land use (i.e. CAs and CGAs) and along free-ranging livestock grazing intensity relative to the spatial distribution of different wildlife species in southern Africa rangelands. Furthermore, few studies in East Africa savannah rangelands (Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012) compared forage availability, vegetation heterogeneity to the distribution of multiple wildlife species in private ranches and CAs, but not in communally managed rangelands. Besides, in Southern Africa rangelands, most of the studies on effects of livestock grazing on vegetation heterogeneity, forage availability and plants species composition (Van Vegten 1984, Skarpe 1991, Ringrose et al. 1996, Moleele and Perkins 1998, Nsinamwa, Moleele et al. 2005, Dougill, Akanyang et al. 2016) were done around livestock water points (i.e. boreholes), covering radii of less than 5km ("The piosphere effects"). However, the effects of livestock grazing from the water points extend beyond a distance of 5km, yet documentation on the comparative analysis of vegetation heterogeneity, forage availability livestock grazing intensity and land use is scarce.

Even though previous research from East Africa (Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012), has shown that forage availability (quality and quantity) influences the distribution of wild herbivores between CAs and private ranches the role of these factors in determining the distribution of multiple wildlife species in human-dominated communally managed rangelands in southern Africa (i.e. CGAs), supporting free-ranging livestock is less understood. Furthermore, past studies estimating forage availability for livestock have disregarded forbs and woody plants and focused only on the grass efficiency (Hayes and Holl 2003). However, forbs and woody plants make part of the diets of domestic animals, such as cattle (Moleele 1999), and other wild herbivores (Bergstrom 1992). Besides, browse provides supplements for protein and energy during the dry season (Moleele 1999). Hence the need to incorporate all types of vegetation to establish forage availability and vegetation heterogeneity in this study because different plant species will be uniquely preferred as food by different wildlife species, thus influencing their spatial distributions.

Furthermore, little knowledge is accessible as to how free-ranging livestock grazing and other anthropogenic activities are affecting forage availability (quantity and quality), and in turn, the distribution of multi-species wildlife of different body sizes in CGAs of southern Africa rangelands. The rapid human population growth, expansion of settlements (Lamprey and Reid 2004), cultivation (Serneels et al. 2001; Thompson and Homewood 2002) and transition from semi-nomadic pastoralism to a sedentary lifestyle (Western et al. 2009), are progressively altering the vegetation composition and structure of savanna grasslands. Therefore, information on how free-ranging livestock and other anthropogenic activities in CGAs impact on vegetation heterogeneity, forage availability and in turn the spatial distribution of different wildlife species is needed to understand the environmental factors shaping the distribution of wildlife in southern Africa rangelands.

In savannas and grassland of Africa, the driving factor influencing the shift in vegetation is subject to controversy (Moleele 1999). Nonetheless, in Southern Africa, the shift is associated with anthropogenic activities especially livestock production in CGAs (Van Vegten 1981, Skarpe 1986, 1991, Ringrose et al. 1996). Grazing and trampling at water points by livestock (Ringrose et al. 1996, Moleele and Perkins 1998), selectivity of livestock on the range (Squire 1981, Moleele 1999, Scholte 1992), high nutrients at the cattle posts and water points (Moleele and Perkins 1998, Perkins and Thomas 1993) and fire are some of the factors resulting from anthropogenic activities which are speculated to account for forage availability and vegetation heterogeneity. Grazing and trampling by livestock at water points and cattle posts create bare soil patches through the removal of herbaceous plants. Consequently, making moisture conditions to be available to woody plants seedlings, hence they can grow to maturity (Van Vegten 1981). This process is accounted for by the two-layer soil moisture model (Walker, Ludwig et al. 1981, Knoop and Walker 1985) and it is termed bush encroachment in southern Africa rangelands. Most of the bush encroachment species are thorny, for example, *Dicrostachys cinerea, Acacia erubescens, Senegalia mellifera* (Van Vegten 1981, Skarpe 1990).

Also, the selectivity of livestock on the range responding to the palatability of plants leaves, nutrients levels, the presence of thorns and chemical deterrents will affect the establishment and survival of specific plants species over others (Moleele and Perkins 1998). As a result, the palatable species with high nutrients levels, less chemical deterrents and fewer thorns will not survive livestock browsing and grazing. Around the cattle posts and waters points, there is a high accumulation of nutrients from urine and dung, hence influencing the growth of specific species (Perkins and Thomas 1993, Moleele 1994). The above review shows that livestock grazing intensities and other anthropogenic activities account for the vegetation heterogeneity and forage availability (i.e. quantity and quality) in savannah rangelands, hence might also influence the temporal and spatial distribution of wildlife of different body sizes differently. Hence the need for imperial evidence from a study like this one to see how livestock affects vegetation structure and forage availability and in turn the distribution of wildlife.

Continuous livestock grazing does not only affects herbaceous plants life history strategy (perennial vs. annual grasses) but also increase bush encroachment, and reduce herbaceous canopy cover and biomass, hence affecting forage availability for wildlife species negatively or positively. Previous studies, for example (Skarpe 1992, Dougill, Akanyang et al. 2016) in the Kalahari rangelands have revealed that continuous livestock grazing results into most palatable and nutritious plants consumed over time and being replaced by unpalatable plants, together with annual grasses and forbs. However, annual grasses and forbs might provide nutritious and digestible forage for other wildlife species during the wet than the dry season, hence facilitating the grazing distribution of certain wildlife species. Lack of mobility for livestock like in the past, due to sedentary cattle posts, results in the conversion of rangelands from productive perennial grass dominance to annual-grass dominance because of insufficient recovery periods for perennial grasses (Fynn 2012).

Consequently, the landscape dominated by short, annual grasses will lack adaptive foraging options and exhibit extreme instability as herbivores will have no crucial resource during the dry seasons and drought periods (Illius and O'Connor 2000), hence competition between the livestock and wildlife. Therefore, detailed knowledge of herbaceous species composition and distribution patterns relative to pastoral activities disturbance gradient and land use is essential to determine the influence of environmental factors on wildlife distribution. Hence there is need to account for grass life history strategy, herbaceous species composition in relation to livestock grazing gradient, wildlife distribution between the land use to establish how livestock affects the spatial distribution of different wildlife species. Bush encroachment is a concern worldwide, however, in the semi-arid ecosystem, it is associated with livestock disturbance (Walker, Ludwig et al. 1981, Belsky 1990).

Despite the arguments on bush encroachment and reduction in herbaceous biomass by livestock grazing intensities in CGAs, the relationship between increased woody plant cover and reduced herbaceous cover and biomass with the temporal and spatial distribution of wildlife species of different body sizes is less documented in CGAs of southern Africa rangelands. For example, some of the woody plants' species have been identified as preferred by wildlife species that browse, while the same is true for the wildlife species that prefer the forbs. These imply that woody plants and forbs may not necessarily be indicators of land degradation but could either facilitate or reduce forage availability for specific wildlife species. In addition to bush encroachment, other components of land degradation such as reduction of plant species palatability, herbaceous productivity through shading and competition for resources (Hagos and Smit 2005), soil erosion and compaction, have been reported in CGAs of southern Africa (Abel and Blaikie 1989, Skarpe 1986, Moleele and Mainah 2003). Land degradation increases homogeneous vegetation cover (Skarpe 1990), hence the possibility for shaping the distribution of wildlife species.

Despite the fact that in African rangelands, wildlife and human activities coexisted for centuries (Lamprey and Reid 2004, Galvin et al. 2008), intensification of anthropogenic activities creates strong gradients of spatial heterogeneity in forage quality and quantity, vegetation heterogeneity between the CAs and pastoral areas (Bhola, Ogutu et al. 2012). Subsequently, most of CAs do not contain a full range of functional resource gradients and seasonal habitats essential for the maintenance of the wildlife populations (Fynn and Bonyongo 2011), because forage quality and quantity varies both spatially and temporally (Fryxell, Wilmshurst et al. 2005, Illius and O'Connor 2000, Owen-Smith and Mills 2006). Therefore, forage availability and vegetation heterogeneity are expected to vary with land use types and along livestock grazing intensity and between seasons. Its variation is foreseen to reflect the spatial distribution of livestock numbers, the density of cattle posts and wildlife species (Wallgren, Skarpe et al. 2009).

Therefore, during the wet season, tall dense grasses are expected to be associated with CAs (i.e. CAs) because of less to none-livestock grazing in CAs. However, the quality of these tall and dense grass is low because of high lignin (Georgiadis and McNaughton 1990, Hopcraft, Olff et al. 2010). Hence tall grasses would reflect low digestibility and low quality (Hopcraft, Olff et al. 2010). In contrast, during the dry season, the forage quality and quantity are expected to be low in savanna rangelands (Georgiadis and McNaughton 1990). However, grass height is generally taller in the CAs than pastoral areas because of the absence of livestock grazing; then it is expected that forage quantity would be high in the CAs during the dry season. On the contrary, high quality, short and actively growing herbaceous plants are expected to be related to moderate livestock grazing intensity in CGAs (Augustine and McNaughton 2006) than in areas with increased livestock grazing and CAs during the wet season. Therefore, the density of short palatable perennial grasses, herbaceous diversity is foreseen to increased with moderate livestock grazing, hence high forage quality in the wet season (Gilfedder and Kirkpatrick 1994, Du Plessis, Bredenkamp et al. 1998). Still, moderate livestock grazing is expected to have high forage quality but decreasing herbaceous biomass (Owen-Smith 2004, Hobbs, Galvin et al. 2008). Consequently, the possibility of feeding facilitation with small to medium wildlife.

Also, it is predicted that increased livestock grazing intensity in pastoralists-dominated areas wound be associated with high tree density, cover but less herbaceous biomass (Moleele and Perkins 1998). Similarly, these areas are expected to be associated with high density of unpalatable annual and perennial grass species, increased bare ground and forb cover in the late wet season (Trollope 1990, Fernandez-Gimenez and Allen-Diaz 1999), thus low forage quality. Hence not favouring small to medium herbivores (i.e. because of low forage quality and quantity) and carnivores (i.e. increased visibility) (Ogutu, Bhola & Reid 2005, Bhola, Ogutu et al. 2012), let alone large-sized wildlife. Beside livestock grazing intensity, rainfall seasonality also regulates forage quality, quantity and vegetation heterogeneity in savanna rangelands (Deshmukh 1984). Consequently, in the African savanna, vegetation productivity varies considerably spatially because of the patchiness of rainfall, soil moisture, and nutrients (East 1984). Hence the need to account for rainfall before revealing the effects of other factors on the influence of the distribution of wildlife.

2.3: Critical determinants of the distribution of wild herbivores between CGAs and CAs in African rangelands

Despite the fact that in African rangelands, wildlife and human activities coexisted for centuries (Lamprey and Reid 2004, Galvin et al. 2008), and shared the rangelands, water and forage resource under traditional moderate pastoral activities (Young, Palmer et al. 2005), intensification of anthropogenic activities has interfered with this coexistence. Hence the prevailing conservation paradigm that emphasizes separation of CAs and livestock production areas, such as CGAs and private ranches to protect terrestrial biodiversity against human activities (Terborgh 2002). This conservation paradigm assumes that pastoral activities, such as agriculture and livestock production mostly harm wildlife (Bhola, Ogutu et al. 2012). Although there is some indication that pastoral activities adversely affect the distribution of herbivores (Prins 1992, Cumming 1999), empirical studies from South Africa (Arsenault and Owen-Smith 2011, Odadi, Karachi et al. 2011) suggest that moderate forms of pastoral activities might benefit some wildlife species through habitat modification in tropical ecosystems.

However, intensifying anthropogenic activities, such as livestock grazing, creates strong gradients of spatial heterogeneity in forage resource availability (i.e. quality and quantity), predation risk (Bhola, Ogutu et al. 2012) and the pastoralists-induced risk (de Leeuw, Waweru et al. 2001) between CAs and pastoral areas. Consequently, these strong gradients between CAs and pastoral areas influence the distribution of multi-species herbivores in response to conditions that maximize the net effect of forage availability (quality and quantity) and minimise the risk of predation (McNaughton, Ruess et al. 1988, McNaughton 1990, Anderson, Hopcraft et al. 2010) and possibly the pastoralists-induced risk. Therefore, the protection of multi-species herbivores in these pastoral areas is a significant challenge for to conservationists because several factors such as diet site overlap with livestock and other intensifying anthropogenic activities might lead to resource competition.

The distribution and seasonal movement of herbivores in African savannas have been well studied within CAs and pastoral ranches of East Africa and food availability, quality and predation risk have been identified as the critical determinants for wildlife distribution and abundance. For example, in the CAs of Mara-Serengeti ecosystems, Kenya and Tanzania (McNaughton 1990, Ogutu, Bhola et al. 2005, Anderson, Hopcraft et al. 2010, Hopcraft, Anderson et al. 2012), between CAs and human-dominated pastoral ranches in Mara regions, Kenya (Maddox 2003, Bhola, Ogutu et al. 2012). However, the influence of these critical determinants varies with herbivore body size, feeding style and environmental conditions within the ecosystems (Hopcraft, Anderson et al. 2012, Valeix et al. 2009). Furthermore, the distribution and interactions of multiple herbivores' species of different body sizes and free-ranging livestock in pastoral-dominated, semi-arid, communally managed rangelands near the CAs in the Kalahari ecosystem, southern Africa are less understood. As a result, the extent to which these ecological factors and mechanisms can be extrapolated to multiple herbivores in pastoral-dominated CGAs, supporting free-ranging livestock, such as the Kalahari ecosystem, southern Africa is less understood. Besides in communally managed rangelands, the pastoralists-induced risk could also be one of the major factors influencing the distribution of herbivores of different body sizes because of a variety of pastoral activities (de Leeuw, Waweru et al. 2001) as compared to the pastoral ranches. Hence the need to test whether the theoretical expectations, as reviewed by Hopcraft, Olff et al. 2010 and other empirical studies on the distribution of herbivores in East Africa (Anderson, Hopcraft et al. 2010, Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012, Ogutu, Bhola et al. 2005) are consistent with empirical data from CGAs dominated by free-ranging livestock and pastoralists such the Kalahari ecosystem, southern Africa.

The theory suggests that food availability and predation regulates the spatial distribution of herbivores (Fritz and Duncan 1994, Sinclair, Mduma et al. 2003, Anderson, Hopcraft et al. 2010, Hopcraft, Anderson et al. 2012), which limit the number of herbivores an area can support. Therefore, the choice of habitat by an individual herbivore is controlled by both food availability and predation risk because herbivores should maximise their access to vital feeding resource requirements and at the same time reduce predation risk. Also, the theory suggests that the chose of habitat by an individual herbivore is dependent on the body size because the net effects of food supply and predation risk between large and small-sized herbivores defers (Hopcraft, Olff et al. 2010, Hopcraft, Anderson et al. 2012). The size of herbivore determines the susceptibility of herbivores to the number of predators (Sinclair, Mduma et al. 2003), and forage requirement (Smith 1988). Therefore, body size might limit the herbivores to occupy specific habitats, due to forage quality, quantity and or its safety. Subsequently, that could explain the temporal and spatial distribution of herbivores in African rangelands (Jarman 1974, Bhola, Ogutu et al. 2012).

Nonetheless, in communally managed rangelands supporting free-ranging livestock other factors, such as pastoralist-induced risk, might also influence the temporal and spatial distribution of herbivores. However, information on how the ecological factors such as forage quality and quantity, in combination with other factors like pastoralists-induced risk influence the multiple herbivores and in turn carnivores in communally managed rangelands of southern Africa is lacking. Besides, few studies in southern Africa rangelands (Verlinden 1997, Wallgren, Skarpe et al. 2009) have thoroughly analysed the influence of pastoral activities on the temporal and spatial distribution of herbivores across a landscape in communally managed rangelands adjacent to CAs. Hence the need for an empirical study to explore how different herbivores of different body sizes interact with pastoral activities (i.e. settlements, boreholes, cattle posts, arable fields among others), free-ranging livestock grazing intensity and the possibility for coexistence in southern Africa rangelands. LGI in CGAs near CAs creates strong gradients of spatial heterogeneity of forage availability, predation risk (Bhola, Ogutu et al. 2012) and the pastoralists-induced risk (Bhola, Ogutu et al. 2012). Therefore, habitat occupation of herbivores of different body sizes might be influenced differently by these strong gradients because their forage requirements, predation and the pastoralists-induced risks differ.

Even though there is evidence of resource competition between wildlife species with the same food requirements, there is also a possibility of facilitation between such herbivore species through habitat modification (Arsenault and Owen-Smith 2011, Odadi, Karachi et al. 2011). For example, areas with moderate livestock grazing in pastoral areas could facilitate wildlife distribution through habitat modification. Nevertheless, high LGI may lead to competition for resources with wildlife. Food availability, vegetation heterogeneity and predation risks are expected to vary along a livestock grazing gradient, between land use and seasons (Wallgren, Skarpe et al. 2009). Therefore, influencing the spatial distribution of wildlife of different body sizes differently. High quality, short and actively growing herbaceous plants are expected to be related to moderate livestock grazing in CGAs (Augustine and McNaughton 2006) than in areas with increased LGI and CAs. Hence the density of short palatable perennial grasses, herbaceous diversity is foreseen to increase with moderate livestock grazing in the wet season (Gilfedder and Kirkpatrick 1994, Bredenkamp et al. 1998). Therefore, herbivores preferring short, nutritious grasses could be attracted to moderately grazed areas with short, high-quality grass in CGAs during the wet season, however, they may return to taller-grass regions with less livestock grazing during the dry season when the forage resource are limiting (Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012).

On the contrary, the density of pastoral activities such as cattle posts, arable fields, boreholes, and settlements have a significant effect on functional heterogeneity for wildlife. Therefore, low and high densities of pastoral activities would increase and decrease vegetation heterogeneity respectively, hence determining food availability and the distribution of wildlife in CGAs. Increased tree density/cover, reduced grass cover, which is expected to be associated with high livestock grazing intensity and other pastoral activities in CGAs (Moleele and Perkins 1998) is predicted to be associated with low forage quality and quantity (Owen-Smith 2004, Hobbs, Galvin et al. 2008). Therefore, areas with high LGI in CGAs is predicted to be associated with high density of unpalatable annual and perennial grass species, less grass cover, increased bare ground, but increased forb cover in the late wet season (Trollope 1990, Fernandez-Gimenez and Allen-Diaz 1999), thus low forage quality and quantity. Consequently, high densities of pastoral activities are expected to have a negative association with a variety of wildlife species of different body sizes because of the pastoralists-induced risk and reduced forage availability. Moreover, the pastoralists-induced risk to wildlife could be associated with high densities of pastoral activities in CGAs and decreases with increasing distance (Blaum, Rossmanith et al. 2007c,d, Blaum, Tietjen et al. 2009).

In both seasons, tall, dense grasses are expected to be related to CAs because of less or none-livestock grazing, except during illegal intrusions. However, the quality of these tall and dense grass is low because of high lignin (Georgiadis and McNaughton 1990, Hopcraft, Olff et al. 2010). Nevertheless, the tall grass specialists are expected to concentrate in areas with less livestock grazing intensity in both seasons (Hopcraft, Olff et al. 2010, Hensman, Owen-Smith et al. 2013) because forage quantity constrain their distribution (Hopcraft, Anderson et al. 2012) and are relatively free from predation risk because their body size (Fritz et al. 2002). For example, large-sized adult herbivores are not susceptible to predation than small-sized herbivores because predators have difficulty capturing and handling them (Fritz, Duncan et al. 2002, Sinclair, Mduma et al. 2003,). However, they are regulated by forage quantity as they can extract sufficient nutrients from low-quality forage due to their slow metabolic rate and extra comprehensive fermentation process which extract more energy from low-quality forage (Hopcraft, Anderson et al. 2012). Therefore, large-sized herbivores, such as Eland (*Tragelaphus oryx* – Pallas; 660 kg), are expected to be related to CAs away from the pastoral dominated areas in both seasons (Hopcraft, Olff et al. 2010, Anderson, Hopcraft et al. 2010, Hensman, Owen-Smith et al. 2013,) where the forage quantities are high (Hopcraft, Anderson et al. 2012).

On the contrary, small-sized herbivores, such as Steenbok (*Raphicerus campestris* – Thunberg; 13 kg) and medium-sized herbivores Red Hartebeest (*Alcelaphus bucelaphus* – Hilaire; 150kg) are regulated by forage quality because of their small rumen (i.e. can retain ingesta for a short time) and predation risk (Wilmshurst, Fryxell et al. 2000). Therefore, areas associated with livestock grazing in CGAs have increased visibility against predators due to reduced herbaceous cover (Ogutu, Bhola et al. 2005, Hopcraft, Olff et al. 2010, Bhola, Ogutu et al. 2012, Ogutu, Bhola et al. 2005), hence favouring the distribution of small to medium-sized herbivores. Hence, small to medium-sized herbivores might avoid predation risk in areas with high herbaceous biomass (e.g. CAs) and the pastoralists-induced risk (i.e. high livestock grazing intensity). Therefore, selecting predator-free areas with low herbaceous biomass in moderately grazed areas (Hopcraft, Olff et al. 2010), because their small gastrointestinal tract can extract sufficient energy from these low herbaceous biomass with high nutritious forage resource (Gordon, Illius et al. 1996b, Owen Smith 1992, Demment and Van Soest 1985, Gagnon and Chew 2000, Wilmshurst, Fryxell et al. 2000). Therefore, small-sized herbivores are expected to be associated with moderately grazed areas in CGAs in both seasons.

On the other hand, medium-sized herbivores are predicted to be related to moderately grazed areas in CGAs in the wet season. Consequently, taking advantage of enough grass quantity of appropriate quality and avoiding predation risk and the pastoralists-induced risk from CAs and increased livestock grazing intensity in CGAs respectively (i.e. mixed strategy) (Cromsigt 2006; Wilmshurst, Fryxell & Bergman 2000). However, medium herbivores are also expected to return to taller-grass regions with less livestock grazing (i.e. CAs) during the dry season when the forage resource are limiting (Jarman 1974, Sinclair 1995, Olff, Ritchie et al. 2002, Georgiadis and McNaughton 1990, Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012) regardless of the predation risk.

2.4: Key determinants of the distribution of carnivores between CGAs and CAs in African rangelands

Although CAs are the basis to shield carnivore species from anthropogenic impacts globally, their effectiveness in protecting mammalian carnivores from human conflicts is progressively in question (Burton, Sam et al. 2012). Carnivores move seasonally between CAs and pastoral areas (Maddox 2003). Yet progressive intensification of land use, land fragmentation, conflicts, sedentarisation of pastoral activities (such as livestock grazing, settlements, cattle posts among others) threaten the future of carnivore populations in pastoral areas of African rangelands (Karani 1994, Omondi 1994, Treves & Karanth 2003, Dublin 1995, Homewood, Lambin et al. 2001l). The natural-prey base for carnivores is declining quickly in the pastoral systems of African rangelands and this can amplify the threat of local extinction of carnivores due to human conflict (Woodroffe and

Ginsberg 1998, Woodroffe and Ginsberg 2000). Therefore, large-sized mammalian carnivores might be affected by human conflict; hence a comprehensive understanding on how pastoral activities and land use change affect the temporal and spatial distribution of carnivore population in pastoral areas that are adjacent to the CAs is necessary (Soule et al. 2003, Terborgh 2002).

The distribution of carnivores in African savannas have been well studied within CAs of East Africa (Ogutu and Dublin 2002, Ogutu and Dublin 2004, , Anderson, Hopcraft et al. 2010, Bhola, Ogutu et al. 2012) and between CAs and pastoral ranches of East Africa ranches (Karani 1994, Maddox (2003, Ogutu, Bhola et al. 2005 Mworia, Kinyamario et al. 2008, Bhola, Ogutu et al. 2012). However, in the sub-tropical savanna rangelands, for example, southern Africa, there have been very few studies on carnivores and livestock interactions between extensive communally managed rangelands with free-ranging livestock adjacent to CAs (Verlinden 1997, Verlinden, Perkins et al. 1998, Anthony 2006, Wallgren, Skarpe et al. 2009). These previous studies in southern Africa rangelands, however, were focused on the distribution of carnivores between land uses and did not map out the temporal and spatial distribution of the carnivores relative to the spatial distribution of pastoralists activities such as cattle posts, settlements, boreholes and livestock grazing intensity.

Therefore, knowledge on the impacts of free-ranging livestock grazing intensity, land use and other pastoral activities on the spatial distribution of carnivores of different body sizes in communally managed rangelands of southern Africa is rarely available (Blaum, Tietjen et al. 2009, Wallgren, Skarpe et al. 2009). However, such kind of information is required not only for long-term conservation and management of carnivores but also for the adequate protection of the ecosystems in which they play a significant role (Soule et al. 2003, Terborgh 2002). Besides, there is a possibility of misplacing knowledge on the relevant conservation of carnivores in these rangelands. Moreover, both small and large-sized carnivores have an essential role in structuring the ecosystems by regulating and restricting the populations of prey species (Sinclair, Mduma et al. 2003, Terborgh 2002). Therefore, Knowledge on the temporal and spatial distribution of carnivores CGAs adjacent to CAs in southern Africa is needed for strategic management of carnivores and livestock coexistence or resource partitioning.

Habitat destruction by livestock grazing intensity influences the distribution of different carnivore species. For example, even though the density of Lion *Panthera leo* is in the Mara CAs is among the highest in the African savanna, studies by Ogutu and Dublin 2002, Ogutu and Dublin 2004, have shown that lion density is low in pastoral ranches and on the edge of the Mara CAs. Therefore, indicating the possibility of adverse impacts of the pastoral activities on the spatial distribution of large-sized carnivores in the ranches. Although a study by Maddox (2003), found no significant difference in large-sized carnivores (Cheetah, Lion and Spotted Hyena) on pastoral rangelands of Maasai (Loliondo and Ngorongoro) and the reserves of Serengeti National Park, Tanzania, other study in southern Africa show negative impact by anthropogenic activities on the distribution of small-sized carnivores in the ranches (Blaum, Rossmanith et al. 2007a,c,d). Hence the need for an empirical study to explore how carnivores of different body sizes interact with pastoral activities (i.e. settlements, boreholes, cattle posts, arable fields among others), free-ranging livestock grazing intensity and the possibility for coexistence in southern Africa rangelands. Livestock grazing intensity in CGAs near CAs creates strong gradients of spatial heterogeneity in prey availability, predation risk (Bhola, Ogutu et al. 2012) and the pastoralists-induced risk (Bhola, Ogutu et al. 2012). Therefore, just like herbivores, habitat occupation by carnivores of different body sizes might be influenced uniquely by these strong gradients of vegetation heterogeneity, prey availability, predation by dominant carnivores (Creel and Creel 1996, Mills and Gorman 1997) and the pastoralists-induced risks (Bhola, Ogutu et al. 2012).

Despite the importance of carnivores of different body sizes for ecosystem changes in African rangelands, there is less documentation in management, status of carnivores, research activities (Martinoli et al. 2006), especially in southern Africa CGAs adjacent to CAs. Hence knowledge on the interactions between carnivores and pastoral activities such as free-ranging livestock in the southern Africa rangelands is seldom available. However, the direct and indirect effects of livestock grazing intensity and other anthropogenic activities can affect the distribution carnivore population and carnivore community structure (Blaum, Tietjen et al. 2009, Karaki et al. 2007, Berger and Gese 2007). For example, reduction in the number of medium to large-sized carnivores can increase in the population of small-sized carnivores (i.e. mesopredator release) (Crooks and Soulé 1999, Schmidt 2003, Blaum, Tietjen et al. 2009). For example, in a fragmented landscape in California, small carnivore population increased after the decrease of Coyotes, resulting in a decline in avian prey (Crooks and Soulé 1999).

According to Blaum, Tietjen et al. 2009, heavy grazing by livestock is the primary driving factor of carnivore population declines in southern Africa rangelands. High livestock grazing intensity promotes shrub cover and reduces herbaceous cover, hence improving visibility against carnivores because of less vegetation cover (Schooley and Wiens 2003). However, moderate livestock grazing intensity could improve complex structural habitats, hence providing more environmental resources and niches (i.e. a mixture of grasses and shrubs) (Jeltsch, Milton et al. 1996). Therefore, it might attract medium-sized carnivores because of vegetation heterogeneity (Jeltsch, Milton et al. 1996) in both seasons, indicating facilitation by moderate livestock grazing. However, not all carnivores of different body sizes respond the same way to anthropogenic activities.

For example, large large-sized carnivores are expected to be associated with CAs in both seasons because of high vegetation cover (Ogutu and Dublin 2002, Wallgren, Skarpe et al. 2009, Hopcraft, Anderson et al. 2012) and the pastoralists-induced risk such as predator control measures in CGAs. The fact that certain carnivore species also prey on livestock, pastoralists might use predator control measures to regulate and limit livestock losses. For example, control measures were used in Australia (Glen and Dickman 2005), Europe (Virgos and Travaini 2005), United States (Berger 2006) and African rangelands (Blaum, Tietjen et al. 2009). Therefore, it can be predicted that the distribution of carnivores that prey on livestock such as Lion (*Panthera leo* - Linnaeus), Spotted Hyena (*Crocuta crocuta* - Erxleben), Black back Jackal (*Canis mesomelas* - Linnaeus) would be negatively affected by pastoral activities in both season. However, carnivores respond to anthropogenic activities uniquely (Burton, Sam et al. 2012). For example, some species may prefer pastoral dominated areas by avoiding inter-specific resource competition in areas without pastoral activities (Linnell and Strand 2000) or being influenced by water resources for livestock (Weyde, Mbisana et al. 2018). Therefore, there is the possibility for competition or facilitation with carnivores for resources in CGAs by free-ranging livestock grazing intensities and other anthropogenic activities.

Furthermore, the distribution of carnivores are not only regulated by land use changes and anthropogenic activities but can be influenced by inter-specific resource competition and food requirements (Rosenzweig 1966, Holt 1984). These competitive interactions are common within carnivore's communities (Palomares and Caro 1999, Caro and Stoner 2003), mainly when habitat selection, diet, and body size are similar (Rosenzweig 1966). Hence the possibility of killing potential competitors by the dominant predators is common (e.g. Lion and Hyena) (Donadio and Buskirk 2006), resulting in spatial and temporal resource partitioning among carnivore species. Consequently, the subordinate predators will be regulated by both the food resources and the risk of aggression of the dominant predator, resulting in choosing areas with lower prey biomass (Creel and Creel 1996, Durant 1998) for safety. The distribution of carnivores can also be influenced by kleptoparasitism (i.e. stealing of other carnivores' killings) among large African carnivores (Creel and Creel 1996, Mills and Gorman 1997), hence forcing the subordinate to different occupie habitat from the dominant carnivores. Previous studies in East Africa indicated that prey density (Carbone and Gittleman 2002) and vegetation cover (Pettorelli, Lobora et al. 2005) influence the distribution of carnivores. Therefore, it is expected that the distribution of carnivores of different body sizes would be different between land use and along livestock grazing intensities due to the influence of both prey availability, the pastoralists-induced risk and the resource competition between the carnivores themselves.

2.5: Previous techniques, methods used to establish the distribution of wildlife and livestock

Many terrestrial mammals are nocturnal, secretive in appearance, and for the most part, they avoid being seen, which limits direct observation methods in establishing their distribution (Chiarello 2000, Jachmann 2002). Therefore, limiting the use of direct methods of survey in establishing their spatial distribution. However, indirect methods such as spoor/tracks could be a realistic option to explore their distribution, because they give details of the presence of an animal and can quickly capture several tracks of animals that have been in the area for the past few days. Nevertheless, most studies on wildlife distribution and census in African savanna rangelands commonly relied on wildlife aerial survey, field observations and camera trapping surveys data among others. For example, the following authors used aerial survey to determine the distribution of wildlife in southern Africa (Verlinden, Perkins et al. 1998, Gandiwa 2014), East Africa (Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012) and direct observational methods in southern Africa (Wallgren, Skarpe et al. 2009, Verlinden 1997, Bergström and Skarpe

1999), East Africa (Mworia, Kinyamario et al. 2008, Ogutu and Dublin 2004) to establish the distribution of wildlife. Other studies (Burton, Sam et al. 2012, Carter, Shrestha et al. 2012) relied on camera trapping surveys to determine the distribution of wildlife. However, few studies in the Kalahari rangelands, for example, (Verlinden 1997, Verlinden, Perkins et al. 1998, Blaum, Tietjen et al. 2009) used spoor/truck methods in exploring the distribution of multi-species wildlife.

Nonetheless, in several parts of the world, conservationists relied on wildlife spoor/tracks surveys as an essential tool. For example, wildlife spoor/track studies have been utilised in large-scale biodiversity observations in northern Europe (Linde´n 1996, Danilov, Helle et al. 1996), North America (Alberta Biodiversity Monitoring Institute 2012), and Australia (Southgate and Moseby 2008), impact assessment of habitat and land use (Soutiere 1979), and managing invasive species (Allen, Engeman et al. 1996, Edwards, De Preu et al. 2000). Although aerial survey and observational methods are useful, they often cover a short period which makes it difficult to detect interactions between wildlife species and anthropogenic activities over a long period. Also, these methods tend to miss the presence of specific animals, such as small (e.g. Duiker and Steenbok) and nocturnal wildlife (Verlinden, Perkins et al. 1998, Keeping 2014). The data on the distribution of wildlife based on the spoor/tracks and field observational methods provide more accurate insights into the movements of wildlife within the rangelands, in particular, the small ones. Besides, in areas where the substrates are suitable, for example, sandy soils of the Kalahari ecosystem, spoor/truck surveys are best to use because there are simple, practical, inexpensive and readily expose (i.e. except when wind is blowing and after rains) the presence of different wildlife species, including the ones that are difficult to be detected otherwise (Keeping 2014).

On the other hand, despite the potential of GIS and GPS tools in monitoring and analysing the distribution of animals, few studies if not none on livestock grazing distribution have used these tools in the Kalahari rangelands (Chapter 5). However, previous studies elsewhere have relied on GIS and GPS tools to map rangeland usage, for example in south-east Montana, USA (Beaver and Olson 1997), the spatial distribution of beef cattle in western USA (Wade, Schultz et al. 1998) and spatial overlap between buffalo and livestock in Zimbabwe (Zengeya et al. 2015). Therefore, there is need to explore the use of GIS/GPS on free-ranging livestock to map their grazing distribution relative to the distribution of various multiple wildlife species, forage availability and pastoral activities in the Kalahari rangelands. The use of GIS and GPS telemetry can give researchers efficient and precise quantitative data on livestock movements and grazing distribution and could allow detection of wildlife and livestock overlap patterns (Zengeya et al. 2015) in both wet and dry seasons. Past research relied on tracking animals using information mainly through field observations (Turner, Udal et al. 2000), and VHF Radio signal tracking methods (Rodgers, Rempel et al. 1996). These methods are time-consuming and associated with errors, physical limitations and external factors such as weather (Turner, Udal et al. 2000). Nevertheless, recent advances in GPS telemetry innovation have permitted the development of lightweight receivers appropriate for observing animal position at least 5 minutes in the interval. Information from the GPS telemetry can be transformed into a GIS to evaluate the spatial distribution of wildlife species and utilization of the rangelands through interpolation (Turner, Udal et al. 2000).

Interpolation of the spatial distribution of wildlife (spoor/tracks) and livestock data (GPS telemetry) using GIS techniques can produce valuable detailed maps of multi wildlife species of different body sizes in relation to livestock grazing intensity and other anthropogenic activities and land use. However, these have never been done in the Kalahari rangelands. Consequently, there are potential capabilities and a broad application of spatial analysis tools such as GPS telemetry and GIS in the assessment of animal distribution and the likelihood to contribute to the decision-making process because it provides detailed information on animal movements (Turner, Udal et al. 2000).. In this regard, the present study explores the use GIS/GPS to map free-ranging cattle grazing intensity and distribution relative to various multiple wildlife species of different body sizes, forage availability and pastoral activities in the Kalahari rangelands, to establish the possibility of coexistence between pastoralists, livestock and wildlife.

2.6: The possibility of coexistence of pastoralists, free-ranging livestock and multi-species of wildlife of different body sizes.

Many wildlife species in African rangelands are in danger of extinction because of increasing human population and land use changes, hence the belief that large-sized herbivores and carnivores cannot coexist with pastoralists, livestock and other anthropogenic activities in the same location (Carter, Shrestha et al. 2012). Consequently, coexistence between pastoral activities and wildlife is a central issue concerning conservation policies (Dickman, Macdonald et al. 2011, Woodroffe and Ginsberg 1998). Several conservation models have been proposed and implemented to enable wildlife and pastoral activities coexistence at different spatial scales (i.e. different locations). For example, community based-conservation (Berkes 2007), CAs such as National Parks, Game Reserves, CAs are designed to allow coexistence at a regional scale, where wildlife conservation is in areas surrounding pastoral areas (Dudley 2008, Western, Russell et al. 2009). The reason behind separating CAs and pastoral areas, is that conservationists and policymakers believe that large-sized wildlife cannot coexist with pastoral activities at a finer scale (i.e. sharing the same locations) (Cardillo, Purvis et al 2004, Karanth, Gopalaswamy et al. 2011, Brashares, Arcese et al 2001) due to the conflicts between wildlife and humans. Although the leading cause of biodiversity loss globally has been attributed to agriculture land use, however, the traditional notion that agriculture is not friendly to biodiversity conservation is being challenged (Tsharntke et al. 2005).

Nevertheless, most of the CAs in African rangelands, do not have a full range of functional resource gradients and seasonal habitats essential to maintain different wildlife species (Fynn and Bonyongo 2011), because forage availability varies spatially and temporally (Chapter 4). As a result, wildlife moves seasonally from CAs to pastoral areas (Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012). Hence pastoral areas act as dispersal areas for wildlife during the wet season. Therefore, indicating that these dispersal areas play an important role in wildlife biodiversity conservation, for example, a study in Kenya, (Western, Russell et al. 2009, Estern et al. 2006) found out that pastoral areas often contain more wildlife than the CAs. Dispersal areas outside the CAs are believed to minimise the extinction of local species (Nemark 1996), competition and resource limitation inside the CAs (Ottichilo, De Leeuw et al. 2000). Also, recent studies indicate that moderate livestock grazing are less damaging to rangeland resources as formerly thought (Reid 2012) and may even benefit wildlife species (Gregory and Sensenig 2010; Soderstrom and Reid 2010; Augustine et al. 2011; Woodroffe 2011; Reid 2012, Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012). For example small to medium herbivores and carnivores could benefit from high quality, short grasses maintained by moderate livestock grazing intensity (Augustine and McNaughton 2006, Hopcraft, Olff et al. 2010).

Even so, the maintenance of multi-species wildlife in communally managed pastoral areas (dispersal areas) adjacent to the CAs is a challenge to conservationists. Even though livestock and wildlife share most of the pastoral areas worldwide, little research has been done on how multi wildlife species of different body sizes interact with livestock, pastoralists and the possibility for coexistence during different seasons in southern African rangelands. Consequently, quantitative information on the ability for multiple wildlife species (i.e. herbivores and carnivores of different sizes) to coexist with pastoralists, free-ranging livestock at different spatial scales in southern Africa CGAs near CAs is lacking. Therefore, the need for such information is urgently required because pastoralism pressure (i.e. settlements, livestock grazing, natural resource collection, and hunting) in African rangelands has increased (Western, Russell et al. 2009, Wittemyer et al. 2008). Also, the world human population is increasing, hence compelling human and wildlife to share the same rangelands.

Study on the interactions between multi wildlife species (i.e. both carnivores and herbivores together) and livestock is needed because their relationships are complex as several drivers could influence the distribution and abundance of wildlife (Olff, Ritchie et al. 2002, Cromsigt, Prins and Olff 2009), including the interactions between carnivores and herbivores. Therefore, it is important to relate and map the spatial distribution of wild herbivores and carnivores to the spatial distribution of forage availability, vegetation heterogeneity and pastoral activities. Research on the possibility of coexistence between multi-wildlife species and livestock in southern African rangelands is lacking and limited to small scales. Consequently, knowledge relevant for conservation planning is less understood.

The co-existence of wildlife in pastoral areas could depend on several environmental factors, such a competition or facilitation with livestock, density of human and settlements (i.e. human-induced risk) (, Hoare and Du Toit 1999, Voeten and Prins 1999) and varies with rangelands. The association of pastoralism disturbance regimes, such as grazing intensity, cultivation, settlements, water points and their related effects on plant productivity and diversity might influence the distribution and abundance of wildlife species of different body size differently (Verlinden 1997, Serneels et al. 2001). Predation is also an important factor influencing the distribution of wildlife (both herbivores and carnivores). In African rangelands, large-sized carnivores constitute one of the most noticeable human-wildlife conflicts issues. Hence conservation of predators in pastoral areas can only be possible if people can value predators (Sillero-Zubiri and Laurenson, 2001). However, people can only value and conserve the predators if the benefits resulting from having predators on the pastoral areas are more than the costs. Livestock predation has been a severe challenge to conservation of predators in pastoral areas (Treves and Karanth 2003) due to livestock depredation (Woodroffe and Ginsberg 1998). Hence these raise the fundamental question on the possibility of coexistence between pastoral activities and a variety of carnivore species.

Chapter 3

Materials and methods

3.1: The scope and selection of the study area – The Kalahari Savanna Rangelands

The CGAs which are adjacent to CAs and dominated by free-ranging livestock and other anthropogenic activities in Kalahari ecosystems, Botswana, was selected as the study area. The study area is suitable because it supports pastoralists, free-ranging livestock, and wildlife, hence, the possibility for competition or facilitation (i.e. coexistence) across the landscape in communally managed savanna rangelands adjacent to CAs of the Kalahari ecosystems, during the wet and dry seasons. The study area covers a radius of 60km from the central settlements (Hukuntsi, Lehututu, Tshane and Lokgwabe), comprising of CGAs and CAs (Figure 3.1). The 60km distance was ideal because it covers both the CGAs and CAs to compare the spatial distribution of wildlife and livestock in both land uses. The total population of the study area was 11,340, 16,111, and 20,476 in 1991, 2001 and 2011 respectively, showing an increase of 80 % from 1991 to 2011 (Central Statistics Office of Botswana 2011). The study area is within Kalahari north, which is a sub-district of the Kalahari district. This sub-district covers approximately 44,044 square kilometres, which is 40% of the whole Kalahari district, Botswana. The Kalahari north sub-district is subdivided into four primary land uses, which are CAs, CGAs, private ranches and National Park (Chanda and Totolo 2001).

CGA is where livestock (i.e. cattle, goats, sheep, Donkey and Horse) grazing pasture and other different anthropogenic activities such as settlements, cultivation fields, sedentary cattle posts, ranches, the collection of veld products and firewood are held under communal tenure. It is predominantly used and hold a high number of free-ranging cattle and arable farming (Wallgren, Skarpe et al. 2009). Since 1800, livestock has been present in this area and was nomadic (i.e. continually moving from place to place) (Arntzen, Chanda et al. 1998). However, livestock production had become sedentary (cattle posts not mobile), since borehole drilling technology in the Kalahari rangelands (Moleele and Mainah 2003). Livestock in Kalahari has been increasing (Figure 3.2) for example, between 2008 and 2012.

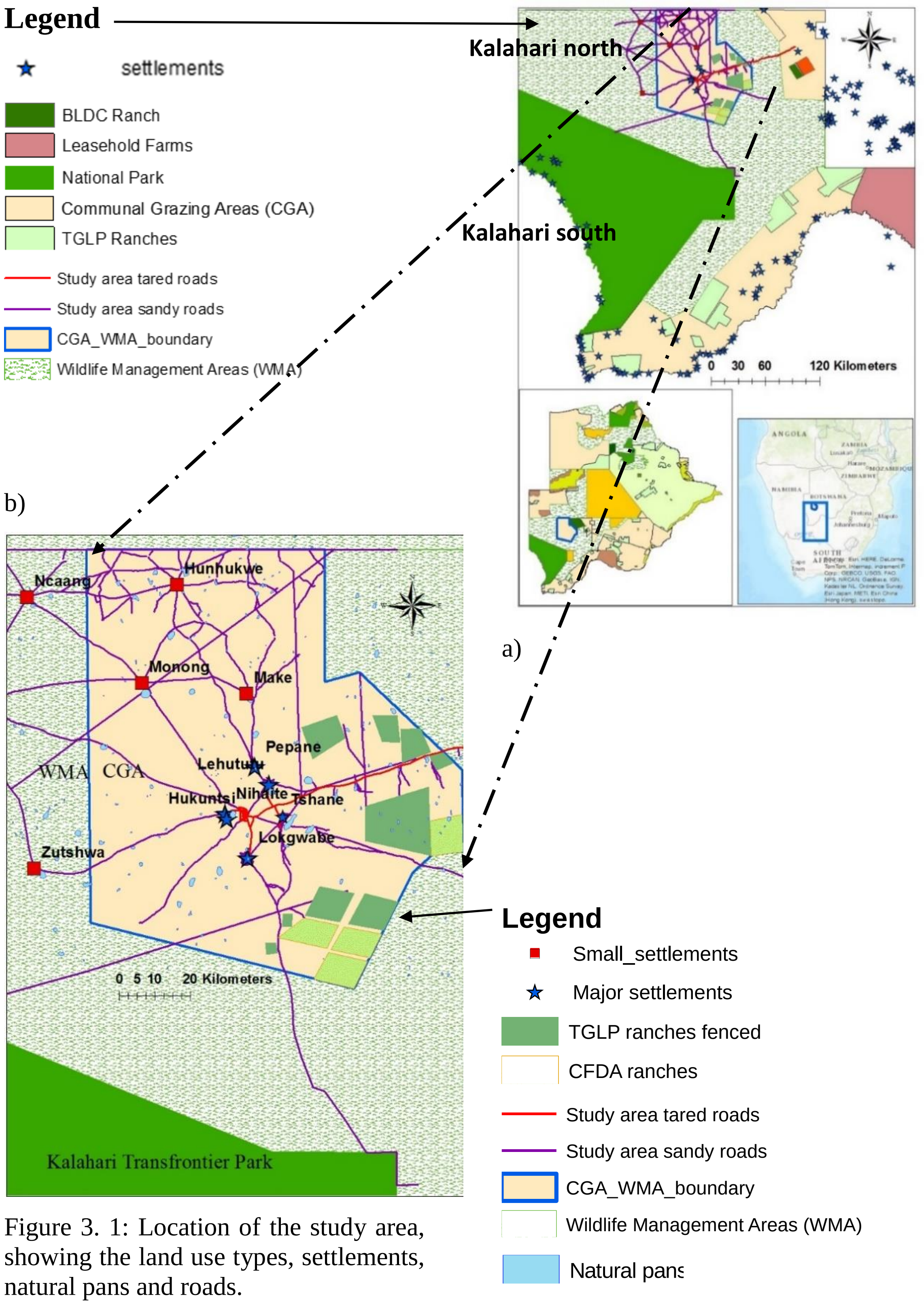


Figure 3. 1: Location of the study area, showing the land use types, settlements, natural pans and roads.
All settlements are represented by a star symbols. TGLP – Tribal Grazing Land Policy ranches, CFDA - Communal First Developemnt Area ranches, BLDC – Botswana Livestock Development Cooperation. Source: Lawrence Akanyang.

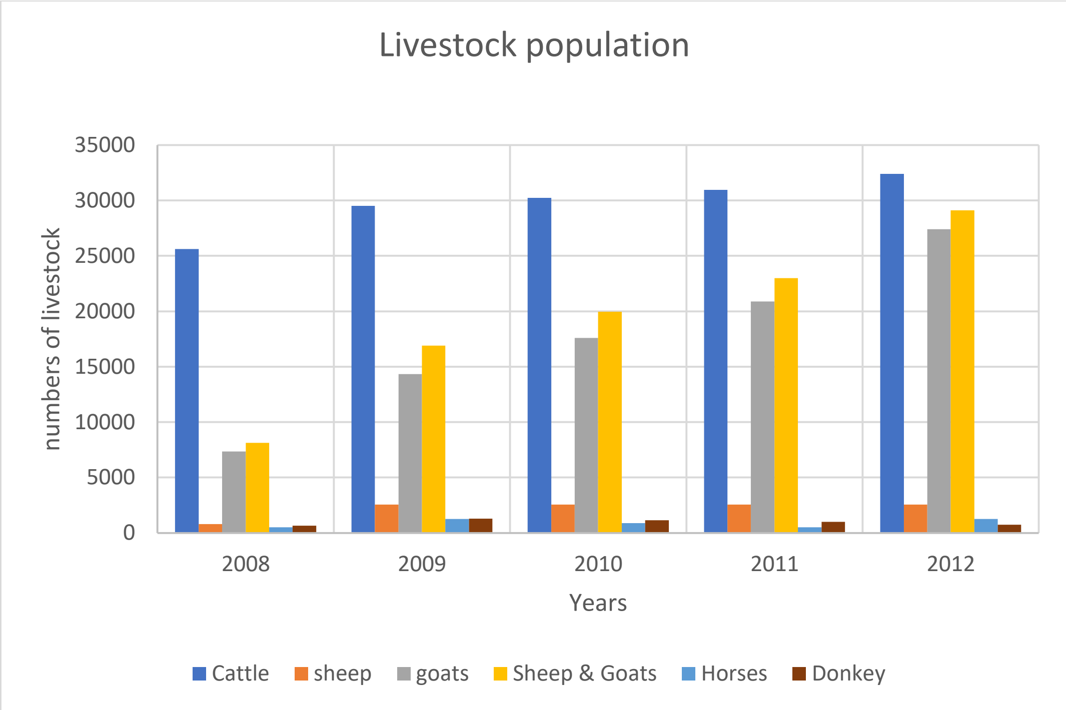


Figure 3. 2: The total population of livestock in the study area from 2008 to 2012 (Source: Ministry of Agriculture 2013 unpublished)

Furthermore, CGAs are experiencing pastoralists' population growth, expansion of sedentary cattle posts and cultivation fields, free-ranging livestock stocking levels, hence these areas are fragmented and degraded (Moleele and Mainah 2003, Dougill, Akanyang et al. 2016, Skarpe 1986, Perkins and Thomas 1993). Livestock fenced ranches are also demarcated in blocks within the CGAs and their sizes are at least 4 x 4 km and are leased from the government. There are three types of ranches in the study area, which are Tribal Grazing Land Policy (TGLP), Botswana Livestock Development Corporation (BLDC) and Communal First Developement Area (CFDA). TGLP ranches are used by individuals or a group of farmers for commercialising cattle rearing, while BLDC ranches are used as communal grazing areas (groups of farmers) (Arntzen, Chanda et al. 1998. Nonetheless, the owners of the TGLP and CFDA ranches, also practice dual grazing (their livestock use both the ranches and the communal areas for grazing), hence exacerbating grazing intensity in CGA. Livestock grazing intensity (LGI) here refers to the proportion of herbaceous biomass or cover removed by livestock (cattle, sheep, goats, Donkey and Horses) grazing and trampling.

Livestock is kept at the cattle posts. These are a traditional livestock management system that involves routine kraaling of animals (Perkins and Ringrose 1996). Cattle posts encompass a watering point, kraals fenced or thorn bush enclosure, where the livestock are routinely kraaled at night and released in the morning depending on the season. Close to the kraals are huts for the owners and herders, watering point (borehole or well) and cultivation fields. In most cases watering points are shared by several pastoralists forming syndicates; hence several kraals and cultivation fields are located within a certain radius from the watering points (Perkins 1991). Cattle posts system displays a uniform rhythm of night kraaling and releases in the morning for grazing (without the herd boys), allowing the livestock to return for water during the day amid the dry season, hence 'the borehole act as the herder' (Jerve 1982). However, in wet season cattle hardly return to cattle posts frequently because of availability of water in the natural pans (Wallgren, Skarpe et al. 2009), resulting in livestock intrusions in the CAs because there is no physical boundary between the CAs and the CGAs.

Therefore, the grazing distribution of the cattle is restricted by the cattle posts and water points (Abel et al. 1989) compared to livestock in East Africa rangelands, where it is constrained through herding (de Leeuw, Waweru et al. 2001, Ogutu, Bhola et al. 2005, Bhola, Ogutu et al. 2012). However, the spatial distribution of pastoral activities such as cattle posts, agriculture fields and LGI relative to the distribution of wildlife species of different body sizes in the Kalahari rangelands has never been documented (Chapter 5). Also, information on the distances travelled by free-ranging livestock for grazing during the wet and dry season in the Kalahari rangelands are seldom available. However, knowing the distances travelled by this livestock can assist in developing land use policies and plans that are wildlife friendly, hence promoting wildlife-livestock coexistence. However, the influence of these pastoral activities and LGI on the distribution of wildlife of different body sizes in the Kalahari ecosystem is less understood. Pastoral activities here refer to all anthropogenic activities in the study area such as cattle posts, LGI, arable fields, settlements and boreholes, the collection of veld products among others.

The CGAs in the study area is surrounded by the CAs covering areas from 40 – 100kms from the main settlements (Figure 3.1). Different wildlife species share these CGAs and CAs with pastoralists, settlements, cultivation fields, sedentary cattle posts and free-ranging livestock. Subsequently, reduced grass cover has been reported in these CGAs especially near settlements (Verlinden 1997, Moleele and Mainah 2003). However, LGI is reduced away from the major settlements, reflecting the "pastoral activities disturbance gradient effect". The CAs in this study area is between two major wildlife sanctuaries, Central Kalahari Game Reserve (CKGR) to the north-east and Kalahari Trans Frontier Park (KTFP) to the south-east. Therefore these CGAs and CAs constitute wildlife dispersal areas or migration corridors (i.e. buffer zones) for wildlife between these CAs during the wet season (Moleele and Mainah 2003). Therefore, indicating that the study area is the critical wet season core area for different wildlife species (also known as the Schwelle). Hence the selection of the study area, to explore the interactions between pastoralists, free-ranging livestock and wildlife of different body sizes within this critical wet season core area.

CAs are utilised for the non-consumptive and consumptive wildlife, tourism and few Rural Area Dwellers (RAD) settlements with the small number of free-ranging livestock (Perkins and Thomas 1993). However, the impact of pastoral activities in CAs is less than in CGAs. Since the study area is the dispersal area for wildlife, the possibility of restriction of seasonal movements of wildlife by pastoral activities to access their traditional wet season resources cannot be ruled out (Fynn and Bonyongo 2011). As a result it might contribute to the decline in size and diversity of wildlife species in pastoral areas (Moleele and Mainah 2003, Bhola, Ogutu et al. 2012). However, areas with moderate livestock grazing in the CGAs might facilitate some wildlife species distribution by maintaining the grass short and actively growing. Nonetheless, information on how different LGI and other pastoral activities influence the distribution of wildlife species of different body sizes in communally managed rangelands is scares. Rainfall and temperatures influence rangelands in Kalahari ecosystems; hence each year moisture shortage is experienced during the dry season (Van Vegten 1984).

The study area is characterized by the semi-arid climate with inconsistent rainfall with mean annual of 300 mm (Botswana department of Metrological Services, unpublished), falling between October and April (Moleele and Mainah 2003). The wet season starts from November to April depending on the start of the rains, while the dry season starts from May to September. The minimum and maximum temperatures are 12°C (May to August) and 41°C (September – April) respectively (Bhalotra 1987). Therefore, vegetation is always under acute moisture because the highest temperature occurs during the months with the highest rainfall. The Kalahari rangelands are massive semi-arid and consist of mainly infertile homogeneous red sandy soil (Bergström and Skarpe 1999) and various calcrete pans (Knight, Knighteloff et al. 1988). Two types of sandy soils are found in the Kalahari rangelands are (i) red, pink and white sandy soils with more than 90 % sandy (0.02 – 2.0 mm in diameter). (ii) Fine soils with less than 90 % sand, mainly sandy loams, sandy silts and sandy clays (Leistner 1967, Leistner & Werger 1973). The red sand is the most common and it is neutral or slightly acidic and weak in most minerals, followed by the pink which occurs on the dunes and close to the pans. The least common and more abundant in minerals than other soils are the white sand and it is mostly found in the pans (Skarpe 1986).

The landscape is flat, and shrub savanna dominates the vegetation with scattered trees with some broad-leaved deciduous woody species. The grass layer consists of tufted perennial and annual grasses (Skarpe 1986). The vegetation of the pans is different from the other savanna with grasses such as *Sporobolus* spp. and *Eragrostis* spp, *Panicurn coloratura* and surrounding the pan is a broad zone of the dwarf shrubs, such as *Eriocephalus* spp. and *Zygophyllum* spp, *Rhigozum trichotomum* and, frequently, patches with Catophractes alexandri (Skarpe 1986). Woody vegetation is a mixture of different species and sizes in most places. However, woody species, such as *Vachellia erioloba* E. Meyer and *Senegalia mellifera* Vahl, *Terminalia sericea*, *Acacia luederitzii* Engler, *Boscia albitrunca* (Burch.) form their stands (Skarpe 1986). Shrubs less than 2 m such as *Grewia flava* DC., *Lycium namaquense* Dammer and *Rhus tenuinervis* Engler are also part of the vegetation (Skarpe 1986). The herbaceous vegetation in areas with less livestock grazing is dominated by perennial grasses such as Schmidia pappophoroides Steudel (palatable species) and *Stipagrostis uniplumis* (Licht.) De Winter (moderately unpalatable) (Skarpe 1990). However, in areas with increased livestock grazing the annual grass *Schimidtia kalaharensis* and forb species dominate. Therefore, indicating that the variation of forage availability and vegetation heterogeneity within the study area. However, the influence of this variation on the distribution of wildlife of different body sizes is less documented.

There is no permanent natural water in the Kalahari rangelands (Engineers 1980), except in the calcrete pans during the wet season. The Kalahari pans are dominated by fine-textured soils and are rounded shallow depressions about 100m to some kilometres in diameter with clayey soils on the bottom (Lancaster 1974). Because of the impenetrable water soils on the bottom of the pans, they hold water for weeks even months (Skarpe 1986), hence supplying livestock and wildlife during the wet season. These natural pans contain mineral licks and more nutrient-rich vegetation; hence they are the key resources for many wildlife species (Bergströn and Skarpe 1999) and have the potential to influence the spatial distribution of wildlife. Larger pans that hold water for a long time are close to the major livestock-keeping villages because historically those were the significant sources of water; as a result, people settled closer to water sources. Thus, most of the livestock is found around the central settlements (Hukuntsi, Lokgwabe, Lehututu and Tshane) because of these significant pans, hence the possibility of restricting wildlife from coming to these big pans. However, livestock also concentrates on different artificial boreholes, mainly to the north of the study area. Consequently, most of the pans, boreholes and areas of the dead river in the Kalahari are heavily grazed by livestock (Campbell & Child, 1971). The artificial boreholes supply water for humans throughout the year and livestock during the dry season (Wallgren, Skarpe et al. 2009). Nonetheless, knowledge on contribution of the pastoral activities towards the distribution of multiple wildlife species in areas sorounding these watering points in human dominated areas is seldom available.

Livestock production (mainly cattle and goats) is the primary significant economic activity and a measure of wealth within the study area followed by small-scale crop production and it is essential for local food security (Arntzen, Chanda et al. 1998). Other non-agricultural activities and collection of veld products including wood resources are also crucial in the study area (Kgabung 1999). There is less livestock in small settlements located within CAs (for example, Zutshwa, Ncaang) and in CGA (Hunhukwe, Make, and Monong) (Wallgren, Skarpe et al. 2009). Livestock and pastoralists population increased and became sedentarised in the Kalahari ecosystem starting from the 1970s (Arntzen, Chanda et al. 1998) due to the spreading of artificial drilled boreholes and wells. Sedentarisation of pastoral activities was influenced by the provision of social services in rural settlements, and changing land use management, allocation of ranches under Tribal Grazing Land Policy (TGLPS) (Thomas 2002) and other support which the livestock sector receives from the Government. Furthermore, expansion of livestock numbers in the previously wildlife dominated areas was influenced by macro-economic assistance from the European Union (EU) trade in beef protocol agreement (Perkins, Stuart-Hill et al. 2002). Despite the possibility of interactions between the livestock and wildlife in the study area, the spatial distribution of the sedentary cattle posts, livestock grazing intensity, arable fields and livestock numbers and how they relate to the distribution of different wildlife species of different body sizes in the Kalahari rangelands is less documented if ever.

Wildlife numbers in the study area used to be abundant (Child and Le Riche, 1969), but have declined intensely since the end of 1970's (Wallgren, Skarpe et al. 2009). The most likely reasons for the declines could be competition with livestock, increasing hunting pressure, declining surface water, drought and erection of veterinary cordon fences across wildlife migration routes (Arntzen, Chanda et al. 1998, Williamson, Williamson et al. 1988). Moreover, cordon fences could have interfered with migratory patterns of wildlife from the Okavango Delta to Kalahari and the other way around (Kgabung, 1999). For example, one notable event was the 90% population die-off of wildebeest (*Connochaetes taurinus*) when their migration routes were blocked by the cordon fences (Spinage, 1992). Therefore, the need to establish the key ecological factors influencing the distribution multiple wildlife species in the Kalahari ecosystem. The Kalahari wildlife is mostly water independent because they are mobile and can dig for roots and tubers and utilize Tsamma melon crop (Engineers 1980).

Therefore, wild herbivores commonly found in the Kalahari north rangelands are, 1) water independent species such as Eland (*Tragelaphus oryx* Pallas), Gemsbok (*Oryx gazella* Linnaeus), Duiker *(Sylvicapra grimmea* Linnaeus), Kudu (*Tragelaphus strepsiceros* Pallas), Springbok (*Antidorcas marsupialis* Zimmermann), Steenbok *(Raphicerus campestris* Thunberg*)* and Ostrich (*Struthio camelus* Linnaeus). 2) Semi-water independent such as Wildebeest (*Connochaetes taurinus* Burchell), Hartebeest (*Alcelaphus bucelaphus* Hilaire) and Warthog (*Phacochoerus africanus* Gmelin) (Arntzen and Veenendaal 1986, Ecosurv 1998). Carnivorous mammals commonly found within the study areas are Honey badger (*Melivora capensis* (Schreber), Cheetah (*Acinonyx jubatus* Schreber*),* Striped hyena (*Hyaena hyaena* Linnaeus), African wild dog (*Lycaon pictus* Temminck), Brown hyena (*Parahyaena brunnea* Thunberg), Spotted hyena (*Crocuta crocuta* Erxleben*),* Leopard (*Panthera pardus* Linnaeus), Caracal (*Caracal caracal* Schreber), Black back Jackal *Canis mesomelas* Linnaeus and Lion (*Panthera leo* Linnaeus) (Wallgren, Skarpe et al. 2009, Moleele and Mainah 2003).

3.2: Research design

This study was a sampling survey with the aim of analysing the interactions between pastoralists, wildlife and free-ranging livestock across the different land use types, along a livestock grazing gradients and forage resource availability of Kalahari savanna rangelands. Due to the time limitation, an experimental approach was not achievable. Hence a sampling survey was carried out in two dry seasons (August to October 2014 & 2015) and two wet seasons (March to May 2015 & 2016) to also capture the influence of climate (i.e. rainfall and seasonal variation) in addition to other factors, on the distribution of wildlife and livestock (i.e. cattle, Sheep and Goats, Donkey and Horse) grazing. The study design was based on the quantitative correlational research looking at the relationships or association between the spatial distribution of pastoralists activities, wildlife and livestock along the gradient of the pastoral activities such settlements, livestock grazing intensity, the density of cattle posts among others. Previous studies (Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012) have shown that wildlife of different body sizes is influenced differently by forage availability (quality and quantity) and predation risk. However, the influence of pastoralists-induced risk in addition to forage availability and predation risk on the distribution of wildlife of different body sizes is less documented. Thus the study was designed to explore how wildlife of varying body sizes relates to the pastoral activities in CGAs adjacent to the CAs in Kalahari rangelands; consequently, the sampling survey along the decreasing gradient of the pastoral activities was appropriate.

The sampling survey was based on “pastoral activities disturbance gradient effect” (Lange 1969) (i.e. a gradient of livestock grazing intensity and concentration of pastoral activities). Pastoral activities here refer to all pastoralism impacts within the study area. For example, cattle posts, settlements, cultivation fields, boreholes, wells, firewood collections, cutting poles, livestock grazing intensity (LGI) and the presence of humans among others. Therefore, transects starting from the main settlements (from the outskirt) in CGAs (i.e. where there is increased LGI and human disturbance, due to the high density of cattle posts and other pastoral activities such as cultivation fields, watering points and settlements) were deemed appropriate for the sampling survey. The impacts of pastoral activities disturbance were expected to decrease with the distance from the main settlements (Andrew & Lange 1986). In the study area, most of the livestock watering points and cattle posts are located near the major settlements in the major pans hence LGI is high near settlements and less when moving away from the settlements. In view of this, and limited time for data collection, only five 60 km transects starting from the outskirt (3 km) of the four main settlements (Lehututu, Hukuntsi, Lokgwabe, and Tshane) in CGA and ending in CAs were reckoned appropriate for sampling purposes (Figure 3.1). Five transects were chosen because it was economical to do so and at the same time covering most of the study area (i.e. CGAs and CAs). Nevertheless, more than five transects could have produced more detailed data, but it was not feasible because of the time limitation and the costs involved. However, the sampling survey was repeatedly conducted during the wet and the dry season for two years, thus somehow minimizing the limitation of only having five transects.

Each transect was limited to 60km distance so that it can cut across both land uses and at the same time being economically pragmatic to conduct sampling activities. For example, approximately the first 40km distance covers CGAs (i.e. where most of the pastoral activities are found), while the last 20km is approximately covering the CAs, except along one transect (Lehututu/hunhukwe), where the CAs boundary was more than 60km. The distance from the main settlements was used to reflect relative LGI and pastoralists-induced risk. LGI and pastoralists-induced risk decrease with distance from major settlements because of the increased pastoral activities near the main settlements. However, it should be noted that there are cattle posts and artificial boreholes along the demarcated transects, hence LGI is not only decreasing along transects but also increasing close to these cattle posts and boreholes that are along transects.

Nevertheless, the LGI and the impacts of pastoral activities close to the cattle posts that are far from the settlements is less than near the main settlements. Furthermore, it should be noted that in CGAs it was not possible to not have the existence of the cattle posts and boreholes along the transects because of they are located in different locations with the CGAs in the study area. Nonetheless, when moving away from the settlements, there are few cattle posts and boreholes; hence the grazing intensity decreases with distance from the settlements. Besides, the sample points were located at least two (2) km away from the encountered cattle posts or artificial borehole, and the effects of the cattle posts at each sample point were noted as the environmental variables. For example, the distance from the nearest cattle posts and boreholes and LGI at each sample point were recorded and used during the analysis of wildlife distribution.

The spatial distribution of wildlife and livestock was established along livestock grazing and pastoral activities gradients to determine how pastoral activities influence the distribution of wildlife of different body sizes. Hence, five transects reflecting a decrease in pastoral activities were established in the direction of a high density of cattle posts within the CGAs and using existing sandy roads for easy accessibility (Verlinden 1997, Wallgren, Skarpe et al. 2009). Thus, to explore the influence of the pastoral activities, the orientation of each transect was based on what was anticipated as the main direction of grazing activity (i.e. towards high cattle post density, evidence of cattle trails) and also following sandy roads for easy access. It was challenging to drive a vehicle for a long distance (e.g. 60km) in areas without tracks or sandy roads. Hence the limitation because of the edge effects of roads to the distribution of wildlife.

Nevertheless, sample points were located at least 200m away from the access road (Moleele and Mainah 2003) to minimise possible edge effect of the road on the distribution of wildlife (Verlinden, Perkins et al. 1998). The first transect starts from Lehututu towards Hunhukwe (Lehututu/Hunhukwe) because of the high density of cattle posts and artificial water points in that direction and also because the grazing areas for cattle using watering points located in Lehututu settlement is towards that direction. On the other hand, the grazing area for most of the cattle using watering points in Hukuntsi pan is towards the directions of Zutshwa and Ngwatle. Hence, the second and third transects were created from Hukuntsi towards Zutshwa (Hukuntsi/Zutshwa) and Hukuntsi towards Ngwatle (Hukuntsi/Ngwatle) respectively. The fourth and fifth transects were from Lokgwabe towards Mabuasehube National Park (Lokgwabe/Mabuasehube) and from Tshane towards Kang (Tshane/Kang) to capture the grazing areas for the cattle using water points from Lokgwabe and Tshane respectively (Figure 3.3).

Lehututu/Hunhukwe transect did not cut across the CGAs/CAs boundary because the boundary was more than 60km in that direction (Figure 3.3). Nevertheless, it was essential to include Lehututu/Hunhukwe transect because it is in the direction of the high density of artificial boreholes and cattle posts to capture their effects on the distribution of wildlife. It should be noted that transects were delineated in such a way that they did not cut across the private ranches because ranches have different management systems from CGAs and also there are few fenced ranches in the study area, therefore their influence to the distribution of wildlife is minimal. Transect delineation was done using google earth images (2014) for easy identification of access roads and cattle posts densities on the images.

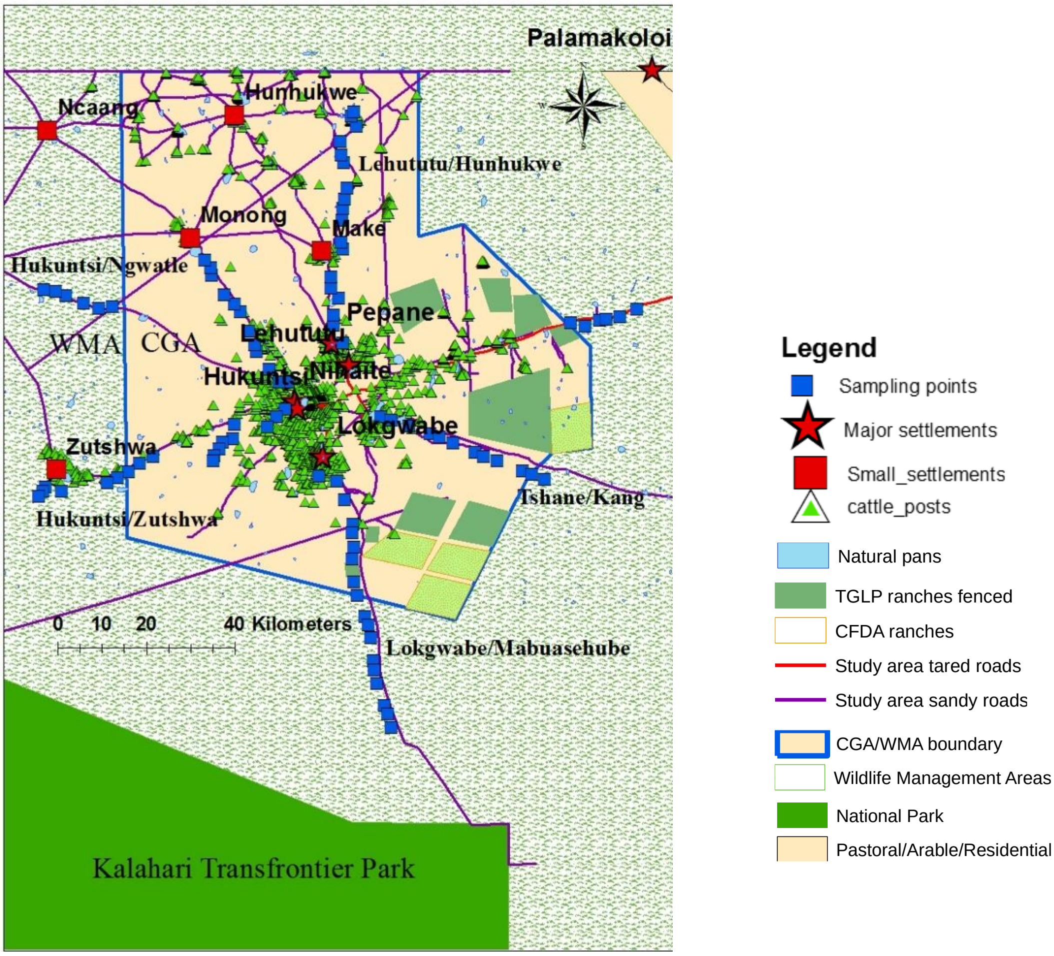


Figure 3. 3: The location of five 60 km transects and sample points
Map shows five transects (Lehututu/Hunhukwe, Hukuntsi/Ngwatle, Hukuntsi/Zutshwa, Lokgwabe/Mabuasehube and Tshane/Kang) and sample points (blue squares) radiating from the main settlements (Lehututu, Hukuntsi, Lokgwabe and Tshane). Transects start from the main settlements and passing through some cattle posts in Communal Grazing Area and Wildlife Management Area. It was not possible to have no existence of the cattle posts and boreholes along the transects because of they are located in different locations with the CGAs in the study area. However, high density of cattle posts is closer to the major settlements, hence the LGI was expected to decrease with distance from settlements. Lehututu/Hunhukwe transect did not reach the Wildlife Management Area because the boundary was more than 60km. Existing sandy roads, density of cattle posts and the angles between transects were used to guide transects. TGLP ranches – Tribal Grazing Land Policy ranches, CFDA ranches = Communal First Developemnt Area ranches.

The coordinates of each sample point were collected from the google earth image and stored in the GPS receiver for the location of the sample point in the field. However, during the fieldwork, some sample points locations were adjusted and located within a representative stand of vegetation to include as much heterogeneity of floristic composition and habitat structure as possible (Bonham 2013). For example, when the sample point is located in a stand of *Senegalia mellifera*, but not including the nearby open grassland, the sample point was re-located in such a way that it covers both stands of *Senegalia mellifera* and open grassland following the requirements for Braun-Blanquet surveys (Lamarque, Anderson et al. 2009).

Each transect was divided into sub-transects (Tefera, Snyman et al. 2007), such that each sub-transect was 10km long (Figure 3.2) for reference purposes only in the analysis. For example, the sub-transects were classified as Near (< 10 km), Middle (10 – 20 km), Far (20 – 30 km), Very far (30 – 40 km), Near CA (40 – 50 km) and Far CA (50 – 60 km) starting from the outskirts of the main settlements. Sub-transects were used as reference points in the analysis of wildlife and livestock distribution and other ecological variables. However, for statistical analysis, the average for the sample points (i.e. distances sampled) within the sub-transects were used. For example, sub-transects were meant to reflect the zones, so that the spatial distribution of wildlife could be described per zone such as near major settlements (i.e. <10km), midway (i.e. between 10km and 20km) and so forth (Figure 3.4). Each sub-transect had three sample points, for < 10km, sample points were located at 3km, 5km and 8km while between 10km and 20km (13km, 15km and 18km), between 20 and 30km (23km, 25km & 28km), between 30 and 40km (33 km, 35km & 38km), between 40 & 50km (43km, 45km & 48km) and lastly between 50 and 60km (53km, 55km & 58km) along all transects.

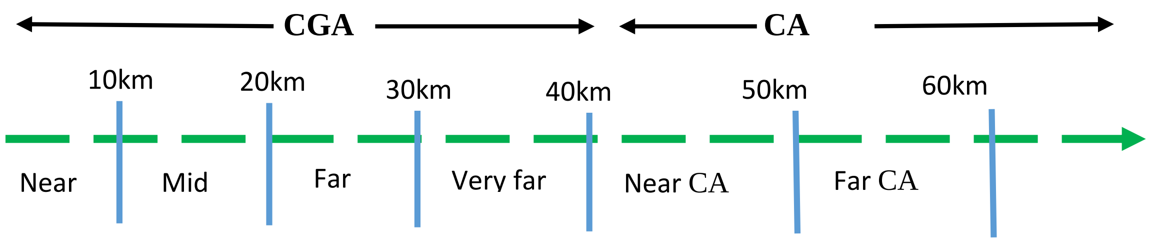


Figure 3. 4: Sub-transects along each transect from the outskirts of the main settlements. Even though the distance to CAs from the main settlements varied along the selected transects, sub-transects were divided equally and used as reference point in terms of distance from the settlements (i.e. from the increased pastoral activities). Novertheless, the distance to CA from settlements was about 40km except Hukuntsi/Ngwatle (30km) and Lehututu/Hunhukwe, which was >60km.

At each sample point, woody and herbaceous plants variables, such density, canopy cover, biomass and species diversity, livestock and wildlife spoor/tracks data survey were identified and recorded to the species level (Table 3.1) to explore their distributions. Woody plant and wildlife variables were measured from two plots of 30m x 30m (900m^2), an area found to be suitable for woody plants (Skarpe 1986) and wildlife surveys (Moleele and Mainah 2003) in the Kalahari ecosystem. The distance between the 30m x 30m plots was 30m to encompass variability in biodiversity at each sample point. A total of 36 plots per transect and totalling to 180 plots in all transects per season were surveyed. Besides, at every sample point, herbaceous plant variables (Table 3.1) were identified and recorded to species level from a total of 216 (1m x 1m) quadrats per transect, and a total of 1080 (1m x 1m) quadrats for all the five transects. Other environmental variables (i.e. independent variables) such as Distances from main settlements, cattle posts and boreholes, LGI were also recorded at each sample point (Table 3.1).

Table 3. 1: The plant, wildlife species and environmental variables measured at each sample point. NDVI = Normalised Difference Vegetation Index

Lifeform/ variables	Variables measured
Trees & shrubs	Tree density Total canopy cover Diversity of bush encroachment Density of bush encroachment Diversity of non-bush encroachment Density of non-bush encroachment
Grasses	Density of decreasers Species richness of decreasers Density of increasers Species richness of increasers Total grass biomass Density palatable perennial grasses Density unpalatable perennial grasses Density unpalatable annual grasses Density palatable annual grasses Grass diversity, cover, height
Forbs	Total Forb biomass Density of Tsamma melons Forb density, cover, & diversity
Ground cover	% Bare ground
Wildlife & livestock	Density of pellets & tracks
Environmental variables	NDVI, land use types Livestock Grazing intensity (LGI) Annual rainfall, Habitat type Distances from settlements & cattle posts, boreholes

3.3: Sampling frame and data collection procedures

Sampling procedures are discussed below according to the main objectives to show how the data for each objective was collected. First, the sampling procedures on forage resource availability and vegetation heterogeneity are discussed, followed by procedures on how the data on pastoralists, free-ranging livestock and wild herbivores was collected. Lastly, the sampling frame and data collection procedures on pastoralists, free-ranging livestock and carnivorous mammals are deliberated.

3.3.1: Forage resource availability and vegetation heterogeneity in relation to the distribution of wildlife and along a pastoral activities disturbance gradient

The vegetation characteristics were assessed at two levels, concentrating on woody and herbaceous layers at each sample point. For woody vegetation (trees and shrubs), canopy cover, species composition, and density were determined from the two 30m x 30m plots, a plot size shown to be suitable for vegetation surveys in the Kalahari ecosystem (Skarpe, 1986; Moleele & Mainah, 2003). For the herbaceous layer (grasses and forbs), canopy cover, density, diversity, biomass, species composition and height and bare ground were recorded in six systematically placed (10m apart) 1m x 1m quadrats within the 30m x 30m plots at each sample point (Dougill, Akanyang et al. 2016) (Figure 3.3). Plant density, which is a commonly measured attribute used to quantify and describe vegetation, was recorded because it indicates the abundance of plants, hence reflecting forage availability. Canopy cover was measured because it is an essential indicator of ecological (i.e. species dominance and importance, ecological process) and management (forage availability and wildlife habitats) principles (Bonham 2013), while plant species composition, species diversity (richness and evenness) reflected vegetation heterogeneity. The plant canopy cover was selected among other types of vegetation covers, such as foliar cover, basal cover because it is cost effective when sampling a large area (Bonham 2013) and provides good indication of both forage and habitat.

Square plot or quadrat was selected among other shapes because it is suitable for measuring dense vegetation (Skarpe 1986) since the observer could easily see all plot corners (especially for bigger plots) as compared to rectangular plots with longer sides. Besides vegetation in the study area was not primarily dispersed. The density of vegetation (i.e. both woody and herbaceous layers) was estimated using counting methods (Bonham and Ahmed 1989). Other plant density methods such as abundance class (which is difficult to ensure consistency when using different observers) and distance methods (which is not cost effective when dealing with a large study area) (Bonham and Ahmed 1989) were deemed not appropriate because there are not cost-effective concerning time and money. Therefore, all the trees/shrubs, grasses and forbs rooted within and on the boundary of the plots (i.e. 30m x30m and 1m x 1m respectively) were counted to species level to estimate plant density and species composition (Moleele and Mainah 2003).

Plant species composition

The plant species composition data was derived from the plant density data using counting methods (Bonham and Ahmed 1989) because individual woody and herbaceous plants were recorded at each sample point. Counting method has its own limitations. For example, even though counting methods perhaps is the easiest analytical concept to understand; however, it often causes difficulties in the application in the field. For example, the identification of an individual plant (Mueller-Dombois and Ellenberg 1974) where it is difficult to identify an individual when the plants are rhizomatous. Besides, plants may be located on the boundary; hence, a decision has to be made whether to count it in or out. However, for this study plants on the boundary were counted in and the rhizomatous shrubs and grasses or bunch grasses were counted as one unit and not counted as individual stems. Furthermore, stoloniferous grasses rooted within the quadrats were also counted as individuals which are in. Counting process may be slow and tedious when counting herbaceous plants, seedlings and shrubs (Bonham and Ahmed 1989). Even though counting methods have the potential for errors at the boundaries because of the " the edge effects" or difficult decisions to make when the plant is on the plot boundary, it was deemed appropriate method because of its cost-effectiveness. For example, the density and species composition of plants data from a large study area could be collected within a short time.

Woody plants attributes

Trees and shrubs were quantified to species level because they provide browse to both livestock and wildlife, hence an indicator of forage availability and vegetation heterogeneity. According to a study by (Moleele and Perkins 1998), browsing by livestock is superior throughout the season as compared to grasses and forbs which are only nutritious at the beginning of the growing season. Woody vegetation (trees/shrubs) survey was only conducted in one season because it was expected to remain constant for a two-years of study. Woody plant canopy cover (i.e. not distinguishing the gaps between the leaves but the entire canopy, including leaves and branches), which is essential as forage resource and also as shade in hot climate was also estimated using the line intercept method (i.e. 30m measuring tape) at each sample point (Figure 3.5) (Mueller-Dombois and Ellenberg 1974, Kercher, Frieswyk et al. 2003, Krebs 1989).

The line intercept method was developed in the USA by Canfield in the 1940s to estimate cover and has been widely adopted in rangeland inventory and monitoring applications. Within the 30m x 30m plot, two measuring tapes (30m long), 10m apart were extended to create a transect to measure woody plant canopy cover (Figure 3.5). The observer identified plants intercepted by the tape and recorded the intercepted distances. Even though line –intercept method is simple to use, and provides an accurate estimate of cover, its limitation is that the sampling can be time-consuming, mainly when vegetation is dense, or when intercept distances are difficult to define because of many gaps or irregular edges within the canopy. Nevertheless, vegetation in the study area was not dense except closer to the settlements, hence it was appropriate to use the line-intercept method.

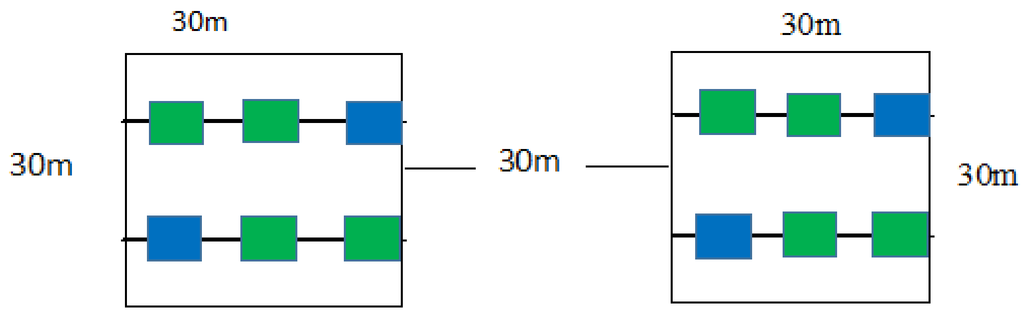


Figure 3. 5: Sampling plots for woody, herbaceous plants, livestock & wildlife

Woody plant parameters, (density, diversity, species composition and canopy cover), livestock (i.e. cattle, sheep, goats, donky and horse) and wildlife spoor data were recorded from the 30m x 30m plots. Woody plant density and diversity were measured using counting methods within the quadrats, while herbaceous characteristics (see Table 3.1) were recorded from the 1m x 1m quadrats (green and blue blocks) at every sample point along transects. Herbaceous biomass was measured only in first and last 1m x 1m quadrats (blue squares) using estimation methods, while all other herbaceous parameters were recorded in every 1m x 1m quadrats.

Herbaceous plants attributes

Moreover, the herbaceous attributes such as biomass, cover, density, palatability, lifespan and height and bare ground (%) were also estimated and recorded at each sample point to evaluate forage quality and quantity along a livestock grazing gradient. Forage quality was inferred from the grass height, palatability, plant lifespan (perennial vs annual), and species diversity. Therefore, areas with short growing, palatable, perennial grass with high species diversity were considered to provide high-quality forage. On the other hand, forage quantity was inferred from herbaceous biomass, cover, and tall herbaceous plants. Hence, areas with tall, high herbaceous biomass/canopy cover would provide high forage quantity but low quality (Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012). Similarly, areas with the high bare ground would be considered to provide both low forage quality and quantity, less vegetation heterogeneity. Forbs were classified as all those plants which were non-woody plants and non-grasses (Jacobs and Naiman 2008, Kgosikoma 2012). In addition, forb species were not classified regarding palatability, life forms and ecological status like grasses. Just like the woody plants, herbaceous density was measured using counting methods (Bonham and Ahmed 1989).

All the herbaceous plant species rooted within and on the boundary of the 1m x 1m plots were counted to species level to estimate herbaceous density (Moleele and Mainah 2003) covering a total of 1080 (1m x 1m) quadrats for all the five transects. The herbaceous plant species (grasses and forbs) were classified through relative density (%), as dominant (≥15%), common (<15 – 5%), less common (<5 – 1%) and rare (<1%) (Tefera, Dlamini et al. 2010). The grass species was also classified based on the succession theory (Dyksterhuis 1949) and the ecological information (decreasers, and increasers) for the arid and semi-arid regions of Southern Africa (Trollope, Potgieter et al. 1989, Du Plessis, Bredenkamp et al. 1998) depending on how they ecological respond to grazing. The grass species were classified into lifespan (annuals and perennials) and according to their desirability.

Herbaceous canopy cover

On the other hand, herbaceous canopy cover (%), bare ground (%) was estimated using ocular estimate methods in quadrats (i.e. estimation as perceived by the eye). (Bonham and Ahmed 1989). Canopy cover is the vertical projection of the crown area of the species expressed as a proportion of plot covered by the plant (i.e. not distinguishing the gaps between the leaves but the entire canopy, including leaves and branches) (Mueller-Dombois and Ellenberg 1974). Herbaceous canopy cover is of greater ecological importance than density because it can be used to predict herbaceous biomass than density (Rice 1967). Therefore, in this study, herbaceous canopy cover (i.e. canopy cover recorded not to species) was conducted to estimate forage availability (quantity and quality). High herbaceous canopy cover was expected to be associated with high forage quantity, while moderate canopy cover was expected to be related to forage quality.

There are other methods used to measure canopy cover, such as line point intercept (Cook & Stubbendieck, 1986,Bonham and Ahmed 2013); however, ocular estimate methods in quadrats have the advantage to detect rare and uncommon plant species compared to these other methods. The limitations of the ocular estimate method are; it needs more training and practice before the actual data collection; hence there is always some level of uncertainty about the precision of the observer estimates (Bonham and Ahmed 2013). Even though there are other approaches to measure cover ocularly in the plot, such as the Daubenmire cover class methods, these methods are time-consuming. Consequently, in this study, it was deemed appropriate to use ocular estimate methods in plots rather than other cover methods (e.g. Daubenmire cover class method), because it is cost effective when dealing with a large study area.

Herbaceous biomass

Herbaceous biomass (i.e. dry matter content) was estimated using estimates methods in quadrats (Bonham and Ahmed 2013). The total herbaceous (grass and forb aboveground) biomass was estimated (i.e to the nearest 2%) only in the first and last 1m x 1m quadrats using estimation methods (i.e. those small quadrats shaded in blue in Figure 3.3). Herbaceous biomass refers to the weight of aboveground plant materials of any herbaceous plants (grasses and forbs), it includes both dead and living standing materials (Bonham and Ahmed 2013) and it is valued as an indicator of ecological processes and management effectiveness. Hence it is conducted to determine forage availability for herbivores and to evaluate habitat conditions for both wildlife and livestock (Bonham and Ahmed 2013). The most widely used techniques for estimating herbaceous biomass are direct, indirect methods or a combination of direct and indirect methods. However, the direct method (clipping) is probably the most common methods used to measure herbaceous biomass. Nonetheless, the clipping method is time-consuming (Bonham and Ahmed 2013). Furthermore, the direct methods for herbaceous biomass measurements are associated with boundary error deciding which one is in or out and separation of harvested materials into species as also time-consuming (Mueller-Dombois and Ellenberg 1974). Therefore, Therefore, in this study, indirect methods (i.e. estimation methods) were used to evaluation herbaceous biomass.

To estimate the herbaceous biomass, grass and forb samples (i.e. a combination of different grass and forb species) were harvested at 2cm above the ground during the wet and dry seasons and oven dried for 72 hours at 50 degrees Celsius to standardise the estimation procedures. Both the herbaceous biomass and cover were not recorded to species level or palatable and unpalatable species but only the combined biomass and cover was estimated as it was deemed cost-effective when dealing with a large number of 1m x1m quadrats (i.e. a total of 1080). Nonetheless, palatability and abundance to species level were reflected from other measured herbaceous variables such as densities of palatable perennial grasses, unpalatable perennial grasses, unpalatable annual grasses, palatable annual grasses, forbs and herbaceous species composition (Table 3.1).

Herbaceous height

The average grass and forb heights were estimated and recorded within each 1m x 1m quadrat to evaluate forage quality. Short grasses and forbs were associated with forage quality, while tall herbaceous plants were associated with low forage quality but high quantity. Grass and forb heights were determined by estimating average grass leaf-table height above the solid surface in each 1m x 1m quadrat. Also within the 30m x 30m plot the presence of wild watermelons, herbaceous species composition and fire occurrence (Moleele and Mainah 2003) were recorded.

Other information collected at the sample point

Other trees, shrubs, grasses and forbs which were present at sample point but not within the quadrats or plot were recorded for species composition only. Wild watermelons are important as dry season moisture source (Williamson 1987, Knight 1995); hence it is a good indicator for forage availability, and therefore wild watermelon fruits (dry season) and plant (wet season) densities were estimated within the two 30m x 30m quadrats at each sample point. The density of wild watermelons plants were classified on a 3-point scale; sparse (0.026 plants/m^2), moderate (0.102 plants/m^2) and dense (0.250 plants/m^2) (Knight 1995).

Fire occurence

Fire occurrence at each sample point was likewise recorded because it influences forage accessibility and may impact the grazing distribution of both wildlife and livestock (Laris 2005). The frequency of fire was characterised according to relative age (0 = no signs of fire, 1 = old signs of fire on trees, 2 = few months on trees and grasses; 3 freshly burnt evident on the herbaceous layer).

Livestock grazing intensity (LGI)

LGI within the 30m x 30m plots was subjectively determined by observing how much the herbaceous layer (i.e. in terms of herbaceous cover) was damaged by livestock grazing or trempling then classified into three categories (0 = no signs; 1 = low; 2 = moderate; 3 = high (Moleele and Mainah 2003). Free-ranging livestock are the main grazers in CGAs; hence influencing the spatial distribution of wildlife of didfferent body sizes.

Rainfall distribution

Rainfall is the primary climatic factor influencing the dynamics (abundance, diversity and distribution) of African wildlife (Georgiadis, Hack et al. 2003, Ogutu, Piepho et al. 2008). Therefore, monthly rainfall data were obtained from all the network of rain gauges distributed within the study area from the Metrology Department (15 rain gauges) and others operated by the researcher within different cattle posts (10 rain gauges). Ten rain gauges were placed across different cattle posts depending on the agreement with pastoralists and the availability of a person who could take the readings after it had rained. In some cattle posts the herd boys could not read and write; hence no rain gauge was left in such cattle posts. However, it should be noted that the rain gauges were put in such a way that many cattle posts at different locations were covered. At each sample point, the annual rainfall of the nearest rain gauge was used as an environmental variable to assess its influence on the distribution of wildlife and livestock. Nevertheless, the number of the rain gauge was not enough; hence a limitation to adequately capture the influence of the rainfall on the distribution of wildlife. Monthly rainfall per station were recorded all year round and the quarterly rainfall were calculated as early wet season (November to February), late wet season (March to June), early dry season (July to August) and late dry season (September to October) (Ogutu, Piepho et al. 2009). Henceforth, the wet season rainfall was from February to May and the dry season was from August to October.

3.3.2: Interactions between Pastoralists, free-ranging livestock and wild herbivores along a pastoral activities disturbance gradient

Data collection involved thirteen wild herbivores (i.e. Common eland, Gemsbok, Red Hartebeest, Blue Wildebeest, Greater Kudu, Springbok, Common Warthog, Common Duiker, Steenbok, Savanna hare, Cape Porcupine, Springhare and Common Ostrich) and four domestic herbivore species (>1kg) (i.e. cattle, donkey, horse, small stock) (Appendix 5A) using sampling surveys of spoor data (tracks, pellets). Road-side field observations were also used to explore the presence and absence of wild herbivores along the transects. For example, wild herbivores detections and tracks were also observed and recorded while driving to sample points along access roads, however, these recordings were not included in the quadrats counts but were recorded for species composition (i.e. to show the presence and absence of the species at different sample points). However, at every sample point, wild herbivore and livestock densities within 30m x 30m plot were assessed to the species level to capture for the habitat overlaps between wild herbivore species with free-ranging livestock during the wet and dry seasons. The densities of different wild herbivores and livestock species (dependent variables) were estimated using spoor data (tracks and pellets) (Appendix 3A) present in the plot (Verlinden, Perkins et al. 1998, Moleele and Mainah 2003). Reference books (Liebenberg 1990, Stuart and Stuart 2013) and indigenous knowledge of local people were used to identify wildlife spoor.

The assumption was that the area with less population of wild herbivores and livestock species would have fewer tracks, dung or pellets and vice versa. The density of livestock and wild herbivores' tracks and pellets at each sample point was used to classify their abundance at a 4-point scale (zero = 1, low = 2, moderate = 3, and high = 4) (Moleele and Mainah 2003). In view that the theory suggests that the distribution of wild herbivores is depended on the body size (Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012); hence the wild herbivores were classified by average body size as small (12 – 35kg), medium (80 – 135kg) and large (210 – 690kg) and by feeding styles. For example, pure browsers, grazers and mixed feeders (i.e. those that switch between browsing and grazing seasonally). At each sample point, human disturbance (i.e. pastoralists-induced risk) to wildlife was inferred from the distance from the settlements, cattle posts, and boreholes assuming that there is more human disturbance close to the settlement, cattle posts and boreholes than further away. Consequently, areas near densely populated settlements were expected to have the highest pastoralists-induced risk but getting reduced with increasing the distance from the settlements. It was difficult to infer human disturbance from other human signs like grass cutting, poles cutting, and hunting because such signs were scarce and most of the time not visible.

Most studies on the distribution of wildlife in African savanna rangelands commonly relied on aerial survey data, for example, southern Afrcia (Verlinden 1997, Verlinden, Perkins et al. 1998, Bergström and Skarpe 1999, Gandiwa 2014) and East Africa (Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012,). While other studies in southern Africa (Verlinden 1997, Bergström and Skarpe 1999, Wallgren, Skarpe et al. 2009,) and East Afrcia (Ogutu and Dublin 2004, Mworia, Kinyamario et al. 2008) relied on road-side field observations. Camera trapping surveys have also been used to explore the distribution of wildlife in West Africa (Burton, Sam et al. 2012) and Asia (Carter, Shrestha et al. 2012).

Therefore, for this study, a survey of wild herbivores spoor/tracks was deemed appropriate to explore their distribution because it is cost effective and gives details of the presence and absence of wildlife. Furthermore, few studies in southern Africa (Verlinden, Perkins et al. 1998, Blaum, Tietjen et al. 2009) used the spoor/truck methods in exploring the distribution multi-species wildlife distribution. Nonetheless, there are some limitations to the spoor/tack method, for example, during the rainy seasons it was difficult to find and identify the wildlife tracks that have passed before the rains. Therefore, to mitigate this limitation, spoor/tracks data on the distribution of wildlife was in this study were not collected when it was raining. Conversely, the tracks of the wildlife after the rains were more visible, which was an added advantage.

3.3.3: Pastoral activities and free-ranging livestock grazing distribution

Cattle watering points and cattle posts are the main foci of pastoral activities in the Kalahari region (Verlinden 1997). Hence, information on the pastoral activities, such as boreholes, wells, cattle posts, number of cattle posts, private ranches, arable farms, settlements, roads, and fences were identified through the interpretation of a complete coverage of the most recent google earth satellite images (2014) (Lamprey and Reid 2004) and verified with the help of the pastoralists (Bond 2002, Laituri 2002) and ground truthing during field work. The cattle bomas/kraals were differentiated from other environmental features on the satellite image because livestock manure in the kraals reflects differently than the surrounding soils. Hence the locations of the kraals, arable farms, settlements, roads, were digitized from these google earth satellite images. Calcrete natural pans and livestock ranches were mapped using the Botswana geographical data. Information on the spatial distribution of livestock number in the study area and location of boreholes used for watering catle was collected from the Ministry of Agriculture Offices in Hukuntsi as secondary data.

At each sample point data on the spoor/tracks of livestock were recorded from the 30m x 30m plots. Besides, information on the LGI within the 30m x 30m plots was recorded by observing how much the herbaceous cover was damaged by livestock grazing at a four-point scale (0 = no signs; 1 = low; 2 = moderate; 3 = high (Moleele and Mainah 2003). In the study area livestock grazing is the main factor responsible for herbaceous defoliation, hence the damage or removal of herbaceous cover in CGAs was attributed to livetock. In addition to assessing the spoor data of livestock and LGI, water-resistant GL300 GPS telemetry (Figure 3.4a) weighing 60grams with position accuracy of about 2.5m, were used to understand the fine-scale movements of free-ranging cattle (i.e. the grazing distribution of cattle) (Appendix 3A) and how they overlap with wildlife. Cattle travel long distance for grazing than small stock and equines, hence knowing the distance they travel for grazing could be used to map the maximum grazing distribution of livestock from each cattle posts and in turn the livestock grazing distribution in the study area. The livestock grazing distribution was later related to the spatial distribution of wildlife of different body sizes to explore the possibility for competition or facilitation.

None of the previous studies in Kalahari rangelands have used GPS telemetry and GIS in monitoring the movements of cattle relative to wildlife to help in understanding how they interact with wildlife. Therefore, the use of GPS telemetry in this study was used to help in monitoring the grazing distribution of cattle. GPS telemetry were not used in wildlife because it was deemed costly to capture and insert the telemetry on different wildlife species. For example, it would require the veterinary Doctor for such kind of exercise to tranquilize the wildl animal. The GPS telemetries were connected to the Global Telesat Communications online, and the information on the movement of the cattle was also accessed in real time online to monitor whether the GPS telemetries were functioning well during data collection.

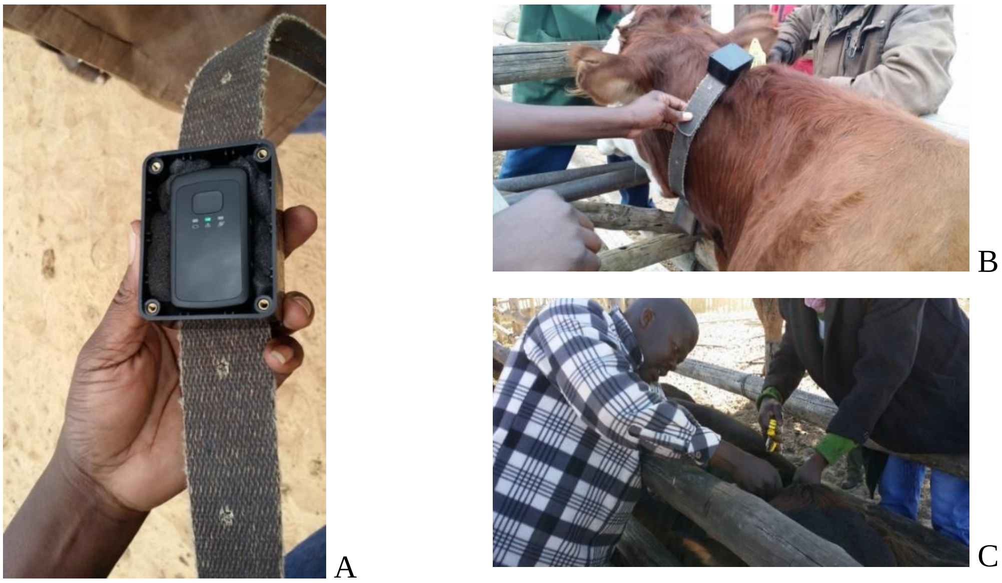


Figure 3. 6: Example of GL300 GPS telemetry fitted on cattle
(A) Shows GPS telemetry inside the plastic container, which is attached to the handmade collar, (B & C) GPS telemetry being fitted on cows with the help of the herd boys at Makgarijwana and Namogosisi cattle posts respectively. Each cow fitted with GPS telemetry was monitored for 14 days and its’ position recorded every 20 minutes during the wet and dry seasons.

The GPS telemetry recorded the position of the fitted cows at every 20 minutes’ intervals to conserve the battery power and at the same time collect the cattle positions frequently. One adult lead cow as perceived by the herders and the cattle owners was selected to represent each cattle heard and fitted with GPS telemetry (Zengeya et al. 2015), with the assumption that other cattle would follow the lead cow during grazing. The cows were held in a crush and the GPS telemetry fitted around their necks (Figure 3.6b & c). To allow a larger coverage of the cattle posts in the study area, different cattle posts in the different locality were selected depending on the agreements with the cattle owners, availability of local mobile network coverage and availability of cows at different seasons. However, mobile network was not available at some cattle posts; hence there were not included because GPS tracker could not function in the absence of the coverage of the mobile network. Therefore, thirteen cattle posts within the study area were selected as follows: Ngwamaripe, Makwankwang, Hukuntsi, Namogosisi, Phephane, Lokgwabe, Tshane, Marang, Nxasape, Matekane, Lehututu, Bohise and Lekojwana (Figure 3.7).

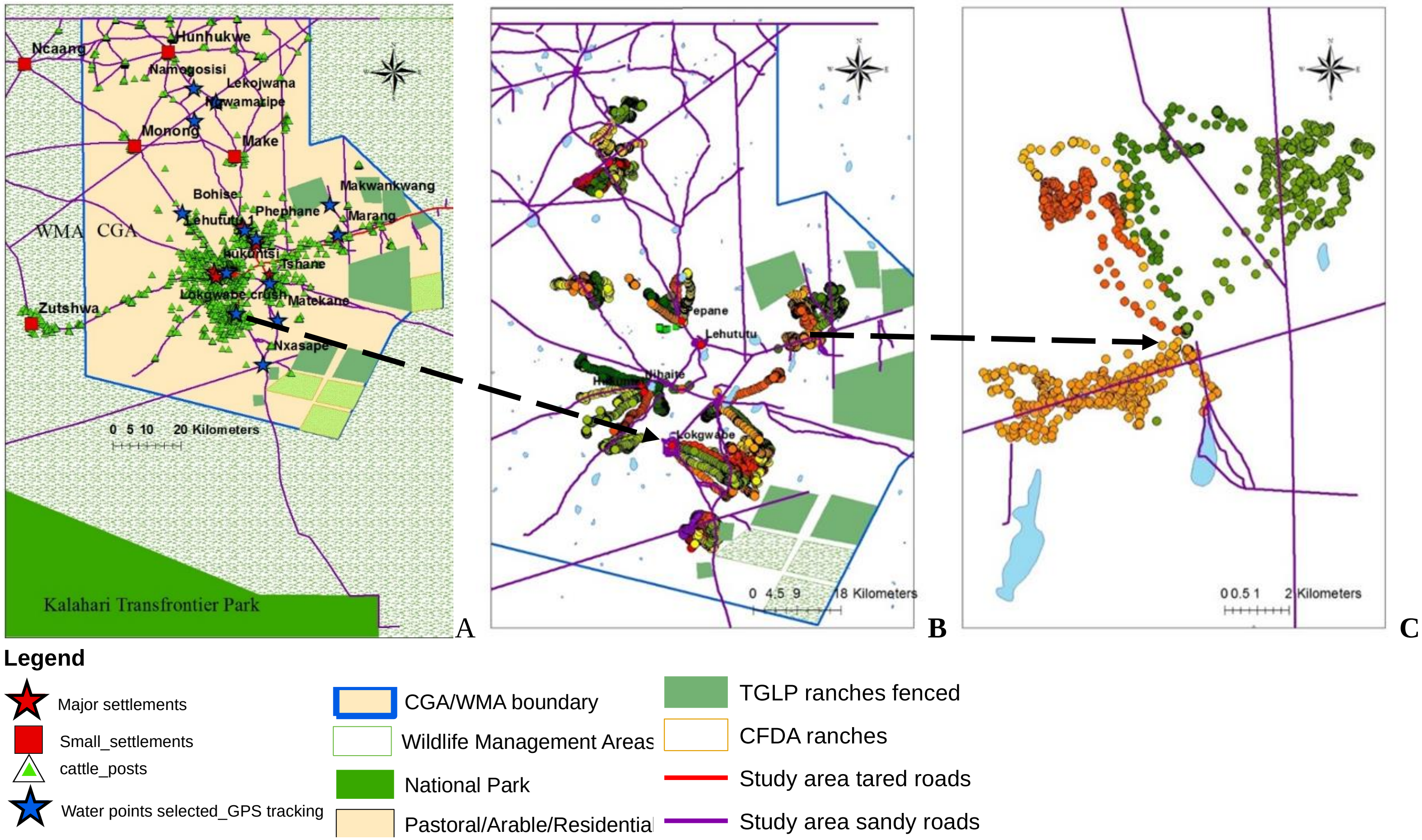


Figure 3. 7: Location of watering points where the cattle fitted with GPS telemetry were selected (A) Location of watering points selected for GPS telemetry (blue star) relative to spatial distribution of cattle posts. (B) Movement of cattle fitted with GPS telemetry during the dry 2014 & 2015 and wet season 2015 & 2016. Different colors show movement of individual cow fitted with GPS telemetry. (C) Detailed example of movement of cattle fitted with GPS telemetry at Marang watering point.

Consequently, during the dry season 2014 and 2015 twenty (20) and twenty-two (22) cows were fitted with GPS telemetry respectively. While in wet season 2015 and 2016, twenty (20) and fourteen (14) cows were also fitted with GPS telemetry respectively (Figure 3.5, Appendix 3A) and each cow monitored for 14 days because the battery power for GPS telemetry could last for only fourteen (14) days when recording the positions of cattle every 20 minutes. Selection of cattle posts was made to cover different spatial distribution of cattle posts to detect the variation in the grazing distribution of cattle from different locations. The GPS telemetries were removed when cattle came for drinking water after 14 days so that the batteries could be charged overnight and taken to other different cattle posts. However, at first in some cattle posts, it took more than 14 days to remove the GPS telemetry because the cattle were not returning to watering points in time or sometimes no one was available to remove the telemetry. Nevertheless, the herd boys were engaged to remove the telemetry after 14 days at a minimum fee. The cattle fitted with GPS telemetry were monitored for two months during the dry and two wet seasons because that was the maximum time available for the researcher for the field work. The data from GPS telemetry was downloaded at the end of each monitoring period and mapped with ArcGIS (Figure 3.6).

3.3.4: Effects of Pastoralists, free-ranging livestock on carnivorous mammals

Data on the distribution of carnivore species were collected the same way as that of the wild herbivores (see section 3.3.2 above.). However, the carnivore pellets were scares hence their tracks were most useful to explore their spatial distribution. Nonetheless, their scares pellets were counted and recorded at each sample point. The body sizes for carnivores were classified as follows; small-sized (1 – 11kg), medium-sized (12 – 30kg) and large-sized (31 – 150kg). Data collection procedures involved the distribution of twelve carnivores (>1kg) (i.e. Lion, Black-backed jackal, Spotted Hyena, Honeybadger, Cheetah, Striped Hyena, African Wild dog, Brown Hyena, Blanford's fox, Leopard, African wild cat, Caracal, one Formivore Aardvark) and insectivore (Bat-eared Fox) (Appendix 6A) and four domestic herbivore species (cattle, donkey, horses and small stock) using surveys of spoor (tracks, pellets).

Road-side field observations (i.e. tracks and carnivore's sightings along the access roads) were also used to inform the presence and absence of the carnivores at different sample points. For example, the detection of carnivores and their tracks along the roads were also observed and recorded as present/absent when driving to other sample points, however, these recordings were not included in the quadrats counts but were recorded for species composition. The fact that the droppings for carnivores at each sample point were scares, as compared to the wild herbivores, hence the limitation in using pellets to establish the distribution of carnivores. Other methods, such as camera trappings and night drives could have revealed more information about the distribution of carnivores. Conversely, these methods were not used because there are expensive to use. For example, putting the camera at each sample point would be costly, furthermore driving at night along a 60km transect would be costly and time-consuming. The detailed procedure is the same as for the wild herbivores and it is specified in section 3.3.2 above.

3.3.5: Possibility of coexistence of wild herbivores, carnivores and free-ranging livestock

The synthesis of all the findings from the interactions between pastoralists, free-ranging livestock, wild herbivores, and carnivore species in relation to livestock grazing intensity (Objectives 4 to 6) was used to evaluate the possibility of their coexistence in the Kalahari rangelands. Theoretical and empirical evidence from studies in East Africa (Bhola, Ogutu et al. 2012, Hopcraft, Olff et al. 2010, Hopcraft, Anderson et al. 2012) was also used in the evaluation of the possibility of coexistence of wildlife and free-ranging livestock.

3.4: Data processing and multivariate data analysis

3.4.1: Forage resource availability in relation to the distribution of wildlife and along livestock grazing intensity

The data was collated using Excel software and also used to calculate vegetation attributes such as plant species diversity, abundance, density, frequency, biomass and canopy cover. Statistical Package for Social Sciences (SPSS) 22.0 was used to conduct Principal Component Analysis (PCA) (Bayo and López-Castellanos 2016), while Canonical Community Ordination (CANOCO) version 4.5 software was used to carry out other multivariate analysis. PCA was used as a data reduction technique, to lessen the number of variables into a manageable number, while CANOCO was used to relate community composition (Plant species data) to environmental variables extracted from PCA (Table 3.2). All tests were conducted at 95% confidence level, therefore results with $P < 0.05$ was considered statistically significant. The vegetation data was also analysed using scatter plots fitted with natural cubic splines interpolation to show the trends and the variation in distribution of the density plant pecies (woody plants, grasses) plotted against distance from the settlements (km) (less livestock grazing intensity gradient). Forbs species were not analysed with the spline interpolation because the number of forbs were too high to come up with graphs for all the forb species, however, forb plants species were related to environmental variables using CANOCO.

Plant species diversity, abundance, density, frequency, biomass and canopy cover

Plant species diversity along transects was calculated using Simpson's index of diversity (D') (1) (Begon et al., 2000), which represents for species richness (R) and evenness. Species richness is the aggregate number species at a specific area, while evenness is a measure of relative abundance of various species making up the richness of the habitat (Waite 2000). The more species exhibit in a range, then the range has high species richness but it does not represent the number of individuals of each species. On the other hand, evenness compares the similarities of the population size of each of the individual species present. Hence as species richness and evenness increase, diversity also increases. The Simpson's index of diversity was calculated as per the following equation:

$$(D') = 1\text{-}D,\ D = \sum (P_i)^2,\ P_i = \frac{ni}{N} \qquad (1)$$

Where D is Simpson's index and it measures the probability that two individuals from a sample belong to the same species or group of species, n_i is the number of species (i) in the sample, while N is the total number of individuals in that sample (Waite 2000). The values for D ranges from 0 and 1, where 0 and 1 represent infinite diversity and no diversity respectively. The higher the value of Simpson's Index of diversity (D'), the higher the sample diversity. Other indexes of diversity have been proposed and used to study species distribution, for example, the Shannon-Winner index (Pielou, 1975); McIntosh index of Diversity (McIntosh, 1967) and Similarity index (Odum, 1971), However, Simpson's Index of diversity (D') was deemed fit for this study because it is easier to calculate compared to others.

Abundance of plant species was determined by summing the total number of individuals of the plant species recorded in all the quadrats having the plant species. Densities of the different plant species, i.e. their number of individuals per ha, was determined from the total number of individuals recorded in all the quadrats. Frequencies of the plant species was determined from the number of times a species is recorded in all the quadrats. Herbaceous canopy cover (%), bare ground (%) was species expressed or determined as the average proportion of plots covered by the herbaceous plants. While the woody plants canopy cover was determined from all the added intercepted distances for each species and expressed as a proportion of the total length of the tape at each sample point. Herbaceous biomas was calculated as the dry matter content per ha.

Principal Components Analysis

Principal components analysis (PCA) was used to quantify the significance of different variables in the data set (Zhang, Tao et al. 2010). PCA is a multivariate statistical technique (Hotelling 1933), and it is a widely used method in natural sciences as data reduction technique of highly correlated data into a few uncorrelated components. Its main aim was to reduce the number of variables to a small number of elements with high variance in the observed variables (Vialle, Sablayrolles et al. 2011, Jiang, Guo et al. 2015). The initial variables were reduced to new uncorrelated broad components (using regression-based matrix) without losing the relevant information from the initial parameters (Brown 1998). The sample size n = 4314, was more than the required minimum (n = 200) to conduct PCA. The PCA depended on the correlation matrix (orthogonal varimax rotation), and extraction depended on the eigenvalue greater than one criterion (Kaiser 1960). The correlation coefficients between variables stronger than 0.9 were taken as highly correlated hence multicollinearity and were removed.

Kaiser-Meyer-Olkin (KMO), a test of sampling adequacy, was used to check the degree of fitness of the data for component analysis (its value >0.5). Bartlett's test of sphericity (Snedecor and Cochran 1989) was used to measure the significant ($P < 0.05$) correlation of environmental variables, hence it scrutinizes the null hypothesis that the resulting correlation matrix was an identity matrix. Therefore, only the principal components with an eigenvalue greater than one were retained. The first component explained most of the variance in the observed variables, while the last component accounted for the least variance (Quinn and Keough 2002).

There are two types of factor analysis rotation, namely orthogonal (Varimax, Quartimax, Equamax) and Oblique (Direct oblimin and promax). Orthogonal rotation is used when the components are uncorrelated while the oblique is used when the components are correlated. Factor analysis rotation is a mathematical procedure that rotates the components axis to produce a simple structure for easy interpretation. Therefore, in choosing the most useful factor rotation, it was first determined whether one of the two components correlate (component correlation matrix for values -0.32 < r > +0.32) by choosing the oblique rotation (Direct oblimin) first. If at least one of the two components are correlated then the oblique rotation (Direct oblimin, promax) was used, or else orthogonal ration was chosen (Statistics 2015).

Subsequently, the orthogonal (Varimax) was chosen for the present study for both vegetation and animals' variables, because it produced a simple structure and the components were not correlated. A simple structure is when one variable is loading significantly in one component (>0.3), and the same variable was having as many zero loading (between -0.1 and +0.1) in other components and few complex variables. Therefore, to test for the quality of the PCA result, a rotation that produces simple structure was preferred, every single component to explain at least 4% of the variance, and the total proportion of the cumulative explained variance by the components be >30 % (Bayo and López-Castellanos 2016). The variables measurements were standardized to ensure equal weights during the analysis because their scales were different.

Table 3. 2: Environmental variables extracted from PCA and used in the multivariate analysis of vegetation species data.
Land use; CGA = communal grazing area. CA = wildlife management area. Grazing intensity; NLG = grazing absent, LLGI = low grazing intensity, MLGI = medium grazing intensity, HLGI = high livestock grazing intensity. Habitat type (AAF = Arable Fields, WC = Woody cover)

Variables	Abbreviations	Variable type
Density palatable perennial grasses	Palpere	Quantitative
Density unpalatable perennial grasses	unpalper	Quantitative
Density unpalatable annual grasses	unpalann	Quantitative
Density palatable annual grasses	palann	Quantitative
Grass diversity	grdiveri	Quantitative
Total tree cover	Treecove	Quantitative
Grass cover	Grasscov	Quantitative
Grass height	Grasht	Quantitative
Forb density	Forbdens	Quantitative
Forb cover	Forbcove	Quantitative
Forb diversity	Forbdive	Quantitative
Land use	CGA/CA	Nominal
Grazing intensity	NLG, LLGI, MLGI, HLGI	Nominal
Annual rainfall	anurain	Quantitative
Habitat Type	AAF/WC	Nominal
Distances from settlements	Distsett	Quantitative
Distances from cattle posts	Distcpot	Quantitative

Canonical Community Ordination

The original environmental variables (Table 3.2), which showed high loadings on the extracted PCA components, but not the component scores, were used in CANOCO analysis (Palmer 1993). Multivariate analysis technique through CANOCO version 4.5 (Ter Braak and Smilauer 2002) software was used to determine the variation of vegetation communities across different environmental variables. Vegetation species data and environmental variables (Table 3.2) at each of the 90 sample points during the wet and dry season respectively were exposed to a direct gradient analysis (Canonical Correspondence Analysis – CCA) technique using a CANOCO program package of (Ter Braak 1986, Ter Braak 1988, Ter Braak 1990). This package is used to relate community composition (plant species data) to environmental variables through ordination and multiple regression (Lepš and Šmilauer 2003). Hence resulting in axes which are constrained to produce linear combinations of the supplied environmental variables (Ter Braak 1988).

There are different types of ordination methods under this package, namely indirect gradient analysis (e.g. principal component analysis – PCA, correspondence analysis – CA, detrended correspondence analysis – DCA) and direct analysis (redundancy analysis – RDA and canonical correspondence analysis – CCA) (Lepš and Šmilauer 2003). Therefore, for the present study direct analysis methods (CCA) was used because initially DCA, revealed that largest value for the length of the gradient for all response variables was greater than three (3) (Lepš and Šmilauer 2003). Also, CCA is designed to relate community data to environmental variables (Ter Braak 1986, Palmer 1993) to predict the distribution of species data (response variables). Manual stepwise forward selection of the environmental variables was performed (Lepš and Šmilauer 2003) to select environmental variables explaining most of the variance in the vegetation species data. Consequently, to determine which environmental variables had a significant effect on the distribution of the animal species data (Van Rooyen, Bredenkamp et al. 1994), and also indicate significance on the first canonical axes, the Monte Carlo permutation test (499 permutations) under full model was performed.

Scatter plots fitted with natural cubic splines interpolation

Spline interpolation is the type of interpolation which produces a particular type of piecewise polynomial called a spline. The spline is often preferred when drawing trends because the interpolation error is small. Cubic spline interpolation is a unique case for spline interpolation, which gives a smoother interpolation polynomial. Therefore, the purpose of the spline interpolation for this study was to show the trends or the variation in the distribution of plants species (individuals/ha) along the livestock grazing gradient.

3.4.2: Interactions between Pastoralists, free-ranging livestock and wild herbivores

The data was collated using Excel software. Statistical Package for Social Sciences (SPSS) 22.0 was used to conduct the Principal Component Analysis (PCA) (Bayo and López-Castellanos 2016), and the General Linear Model (GLM). Canonical Community Ordination (CANOCO) version 4.5 software was used to carry out other multivariate analysis. CANOCO was used to relate community composition (animal species data) to environmental variables. Scatter plots fitted with natural cubic splines interpolation to show the trends and the variation in distribution of the wild herbivores. A Mann-Whitney U test was performed to determine if there were differences in distances travelled by cattle between dry and wet seasons, also between cattle posts closer and far from settlements. The geographical information System (GIS) program, ArcGIS 10.1, was also used for the spatial analysis of the wildlife and livestock distribution in relation to the pastoral activities using Inverse Distance Weighted (IDW) interpolation. All tests were conducted at 95% confidence level, therefore results with $P < 0.05$ was considered statistically significant.

Principal Components Analysis

PCA was also used as a data reduction technique in the wild herbivores and livestock species data during the wet and dry seasons separately (see details on PCA procedures on section 3.4.1**).**

Canonical Community Ordination

Like vegetation species data, animal species data and environmental variables (see Table 3.2) were also subjected to CANOCO for correlation (see details on CANOCO procedures on section 3.4.1). Animal species data and environmental variables at each of the 90 sample points during the wet and dry season respectively were exposed to a direct gradient analysis (Canonical Correspondence Analysis – CCA) technique using a CANOCO program package of (Ter Braak 1986, Ter Braak 1988, Ter Braak 1990).

The CCA biplot ordination diagrams, in which the quantitative environmental variables are presented by arrows radiating from the origin of the graphs. The length of the arrows of the ecological variable signifies its importance, while the arrow points its greatest power and the beginning of the arrow shows its average intensity (Ter Braak 1988). Therefore, species projecting from the inception of the diagram toward the environmental variable arrow are anticipated to have above average abundances, and those emanating the inverse are anticipated to have beneath normal values (Ter Braak 1994). Orthogonal projection of each species from origin with the environmental variable arrow, are predicted to have a little correlation (near zero) (Lepš and Šmilauer 2003). The directions of the arrows show how environmental variables relate to species composition axes, while the angle between the environmental variables indicates their correlations. The nominal and species variables are presented as points. The location of the species about the orthogonal projection from the environmental variable arrow (quantitative) or distance from the nominal environmental variables positions to species data provides an inferred ranking of the species relationship to that variable (Palmer 1993, Lepš and Šmilauer 2003).

General Linear Model

A General Linear Model (GLM) (Gaussian) was used to analyse the relationship between the estimated and measured environmental variables on the wildlife and livestock distribution and abundance (Statistics 2015). To avoid the larger number of environmental variables the extracted vegetation principal components scores were used in the GLM as covariates and the categorical environmental variables were used as fixed factors. The aim was to determine how much variation in wildlife and livestock densities (observed pellet densities) could be explained by the environmental variables together and find out their unique contribution towards the variation. The assumptions of homogeneity of variance, the normality of residuals, linearity, homogeneity of regression slopes and outliers were checked using Levene's Test, Shapiro-Wilk's test ($p > .05$), scatter plots, p-value and box plots respectively before the GLM was performed (Field 2013). The original wildlife spoor distribution data did not meet equal variance and normality of residuals; hence the data were log-transformed. The variables used were seven (7) categorical variables (i.e. fixed factors) and six vegetation principal components (continuous variables) as covariates, hence an analysis of covariance (ANCOVA) (Statistics 2015).

ANCOVA was run to reduce the within-group error variance and also eliminate the variables that could affect the dependent variable (Field 2013). Categorical variables were; season, sub transect, transects, average grass height, LGI, land use, and distances from cattle posts and boreholes. The following vegetation components extracted from PCA; forb density, palatable perennial grasses, unpalatable annual grasses, unpalatable perennial grasses, tree density and palatable annual grasses were used as covariates. Initial all the categorical variables or fixed factors, their interactions and covariates were included in the model. Then the terms which were non-significant ($P > 0.05$) were removed step by step until all were significant. To decrease the likelihood of Type I error, Post Hoc Test, using Bonferroni correction was run to test the levels of the individual significant categorical variables (Field 2013).

Scatter plots fitted with natural cubic splines interpolation

The wild herbivores spoor data was also analysed using scatter plots fitted with natural cubic splines interpolation to show the trends and the variation in distribution of the wild herbivores long the livestock grazing intensity gradient and land use.

Spatial analysis of pastoral activities, wildlife and livestock distribution

The Geographical Information System (GIS) program (ArcGIS 10.1) was used for the spatial analysis of the distribution wildlife and livestock in relation to the pastoral activities. Data on wells, cattle posts, fenced private ranches, arable farms, and access roads were digitized from the recent google earth satellite images (2014), with the help of the local pastoralists and government Officers. The participatory approach using local knowledge have the potential to improve simple spatial models (Carver 2003, Irvine, Fiorini et al. 2009). However, boreholes, calcrete natural pans, unfenced ranches and settlements were mapped using the Botswana geographical data. The average 90th percentile maximum distances travelled by cattle fitted with GPS telemetry were used to map out the livestock grazing distribution from all the identified cattle posts through buffering. Buffering is the production of zones of interests around an element. Furthermore, spatial distribution patterns for free-ranging livestock and wildlife were mapped using Inverse Distance Weighted (IDW) interpolation based on their abundance at each sample point.

Spatial interpolation is the procedure of evaluating the estimations of data at areas not sampled with the regions secured by real observation (Waters 1989). The role of interpolation is to fill the un-observed data points; therefore, the information inferred to address the gaps are estimates. Consequently, the nature of any data interpolation analysis has some level of uncertainty, thus the limitations (Ian 2010). IDW expect that each measured point has a neighbourhood impact that reduces with distance. Therefore, the closest observations to the un-sampled areas are given the bigger weights while exceptionally far off observations have a relatively low impact on the prediction of the un-sampled areas (Luo, Taylor et al. 2008). Consequently, when the observed data is unevenly distributed, IDW spatial analysis will have a significant uncertainty. For example, in the present study, moving away from the settlements, the distance between transects increases, subsequently the observed data between transects get far off.

Therefore, the impact on the estimates of un-sampled areas resulting in significant uncertainty on the edge of the interpolation maps (especially in the CAs). However, IDW has an advantage, because it can also be useful when applied to datasets of small size. The other advantage of IDW over other interpolation methods (e.g., Triangular Interpolation Network) is that it involves more observation into the forecast of un-sampled areas, which is probably more likely to be helpful for its accuracy (Rhodes and Myers 1993) and it is flexible to measure variables with trends (Tomczak 1998). Subsequently, it is crucial for the reader to welcome the confinements of interpolated data when analysing the spatial interpolated maps (Ian 2010), particularly on the map edges, where the sampled points are far apart.

3.4.3: Effects of Pastoralists, free-ranging livestock on carnivores

The data on the distribution of eleven carnivore species and four livestock species along free-ranging livestock intensity was analysed the same as for wild herbivores above using Principal Component Analysis (PCA) (see the details in section 3.4.2), and Canonical Community Ordination (CANOCO) version 4.5 software. In addition, Hierarchical Cluster Analysis (HCA) and Generalized Linear Model (GLM) (Poisson regression) and spline interpolation were also used to establish the distribution of carnivores. The spoor data of eleven carnivores and four livestock species were subjected to PCA, HCA and GLM (Poisson regression) in both seasons combined to establish their distribution. Hierarchical Cluster Analysis (HCA), was used to quantify the similarities and dissimilarities of the animal variables. Conversely, to analyse the relationship of the estimated and measured environmental variables on the carnivores and livestock distribution, the Generalized Linear Model (GLM) (Poisson regression) was used (Statistics 2015). The Poisson regression was performed on the spoor data of carnivores to ascertain the effects of pastoral activities on the spatial distribution of carnivores

The assumptions of Poisson regression were checked and met before the GLM was performed. The observations were independent, the dependent variable contained count data, while the independent variables contained categorical and scale data. The distribution of dependent variables followed Poisson distribution ($P > 0.05$) as it was assessed via one sample Kolmogorov-Simirnov test. The mean and variance for the dependent variables (counts for each carnivorous mammals) were checked using the descriptive statistics and were similar. Spatial analysis of pastoral activities in relation to the distribution of free-ranging livestock grazing intensity, and carnivore species were also performed the same as wild herbivores above. Nevertheless, a lot of the data on the pellets of carnivores was largely 0s and 1s but there were also 2s and 3s (especially pellets of small to medium-sized carnivores). This was because pellets or droppings of carnivores were not many, hence a few number of droppings were encountered at each sample point. Therefore, it was deemed fit to analyse the data using Poisson regression instead of Binomial Logistic regression so that some data (2s and 3s) are not wasted by replacing it with 0s and 1s (i.e. present and absent). Similar to the analsysis of wild herbivores the use of spline interpolation on the spoor data for carnivores was also perfomed to establish the trends or variation on the distribution of carnivores along livestock grazing gradient.

Hierarchical Cluster Analysis

HCA was performed based on the output from the principal component analysis (PCA). The component scores obtained in PCA were variables for statistical grouping. Therefore, HCA supplemented PCA. Cluster analysis tried to identify homogenous natural structures or groups within cases or variables (Ketchen and Shook 1996), which were previously unknown. Therefore, before running cluster analysis, a number animal variables were subjected to factor analysis separately (Principal Component Analysis – PCA) with orthogonal rotation to reduce the number of variables and also to minimise multicollinearity (r >=0.9) effects between variables. Then using the resultant fewer uncorrelated component scores for each observation as the basis for clustering (Punj and Stewart 1983, Hair, Anderson et al. 1992). Even though some experts believe that standardizing variables have no effects (Edelbrock 1979, Milligan 1980), for this study, variables were normalized to the Z scores to eliminate the potential impact of scale differences among them (Harrigan 1985, Hair, Anderson et al. 1992). The validity of each classification, before and after standardizing the variables was checked and the solution which provided the highest efficacy was adopted.

There are two basic types of methods or algorithms: 1) hierarchical and non-hierarchical cluster analysis. Therefore, the selection of appropriate clustering methods was necessary for cluster analysis (Punj and Stewart 1983). There are different types of agglomerative methods (Hair, Anderson et al. 1992), for example in SPSS, there is between groups linkage, within-groups linkage, nearest neighbor, furthest neighbor, centroid clustering, median clustering and Ward's method. HCA is the most common method used. Hence it was selected for this study, as opposed to the two-step cluster (nonhierarchical & Hierarchical) and K-means cluster (nonhierarchical) analysis. The other reason for choosing it was that it could also group variables together as opposed to cases or respondents. When running the HCA, first the between groups linkages cluster method and square Euclidean distance measure for interval data was used to help identify outliers. Finally, Ward's method was chosen among others because, like ANOVA, Ward's method uses the F value to maximize the significance of cluster group differences. Therefore it has the statistical power over all other methods. Ward's method produces clusters with more or less the same number of groupings (Hair, Anderson et al. 1992). However, Ward's method limitation is that it is prone to outliers and creates small clusters if the outliers are present. To determine the number of clusters the use of scree plot (Hair, Anderson et al. 1992) and inspecting a dendrogram (Aldenderfer and Blashfield 1984) was efficient. The summary of methods and data analysis for each individual objectives are shown in Table 3.3 below.

Scatter plots fitted with natural cubic splines interpolation

The carnivores spoor data was also analysed using scatter plots fitted with natural cubic splines interpolation to show the trends and the variation in distribution of the carnivores long the livestock grazing intensity gradient and land use.

3.4.4: Possibility of coexistence of wild life and free-ranging livestock

The findings from all the objectives 1 to 3 (Chapter 4, 5, & 6) and empirical data from the past studies, for example, among others (Arsenault and Owen-Smith 2011, Odadi, Karachi et al. 2011, Reid 2012, Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012) were used to evaluate the possibility for coexistence of wild and free-ranging livestock.

Table 3. 3: Summary of objectives, rational, methods and how the data was analysed

Overall objectives	Justification	Methods	Data analysis
1) Determine forage resource availability and vegetation heterogeneity in relation to the distribution of free-ranging livestock along a pastoral activities disturbance gradient in CGAs and CAs (i.e. CAs) during the wet and dry seasons (Chapter 4)	Firstly, to establish the Forage availability (quantity and quality) and vegetation heterogeneity relative to the pastoral activities disturbance gradient and land use. Secondly, associate the distribution of different wildlife species with forage availability and vegetation heterogeneity.	Woody plants density and cover determined from counting methods in 30m x 30m plots and 30m line intercept respectively Herbaceous density (counting methods in 1m x 1m quadrats), Herbaceous canopy cover (Ocular methods in 1m x 1m quadrats), Herbaceous biomass (Estimation methods in 1m x 1m quadrats), Herbaceous heights (estimation methods in 1m x 1m quadrats) Wildlife (spoor/tracks in 30m x 30m plots, roads-side field observations) and livestock (spoor/tracks in 30m x 30m plots, GPS telemetry) grazing distribution survey.	1) Abundance of plant species = the summing the total number of individuals of the plant species recorded in all the quadrats having the plant species. Densities of the different plant species = the number of individuals per ha. Frequencies of the plant species = the number of times a species is recorded in all the quadrats. Herbaceous canopy cover (%), bare ground (%) determined as the average proportion of plots covered by the herbaceous plants. While the woody plants canopy cover was determined from all the added intercepted distances for each species and expressed as a proportion of the total length of the tape. Biomas was calculated as the dry matter content per ha. 2) Canonical Correspondence Analysis – CCA to relate community composition with environmental variables to determine the variation of vegetation communities across different environmental variables. 3) Principal Component Analysis (PCA) –Used to reduce highly correlated data into a few uncorrelated components.

			4) Vegetation heterogeneity – used Simpson's index of diversity and species composition 4) Scatter plots fitted with natural cubic splines interpolation to show the trends and the variation in the distribution of vegetation heterogeneity and forage availability along the livestock grazing intensity gradient and land use.
2) Explore the interactions between wild herbivores (>1kg), pastoralists and free-ranging livestock in CGAs and CAs along a pastoral activities disturbance gradient and land use types during the wet and dry seasons (Chapter 5) 3) Explore the interactions between carnivores (>1kg), pastoralists and free-ranging livestock grazing intensity in CGAs and CAs along a pastoral activities disturbance gradient and land use types during the wet and dry seasons (Chapter 6)	Determine whether there is competition or facilitation between Wild herbivores, carnivores, free-ranging livestock and other pastoral activities (e.g. settlements, cultivation). Determine the spatial and temporal distribution of wildlife species of different body sizes and free-ranging livestock	Monitoring and mapping cattle grazing distribution using GPS telemetry in every 20 minutes for 14 days each cow for two months. Wild herbivore, carnivores and livestock survey of spoor (tracks and pellets) within the 30m x 30m plots and road-side field observations along five 60km transects. .	1) Spatial interpolation using Inverse Distance Weighted (IDW) – was used to analyse and map the spatial distribution of pastoral activities, wildlife and livestock distribution 2) Canonical Correspondence Analysis (CCA) – was used to relate the distribution of wildlife (herbivores and carnivores) and livestock in relation to environmental variables (season, sub transect, transects, average grass height, LGI, land use, and distances from cattle posts and boreholes). 3) Principal Component Analysis (PCA) –used for data reduction of highly correlated wildlife and livestock data into a few uncorrelated components. 4) A General Linear Model (GLM) (Gaussian) with covariates (forb density, palatable perennial grasses, unpalatable annual grasses, unpalatable perennial grasses, tree density and palatable annual grasses) was used to analyse the independent effects of estimated variables and

			measured environmental variables (season, sub transect, transects, average grass height, LGI, land use, and distances from cattle posts and boreholes) on the spatial distribution of herbivores, livestock (i.e. response variables). However, Poisson Regression was used to explore the distribution of carnivores instead. 5) Hierarchical Cluster Analysis (HCA) – was used to cluster or to identify homogenous natural structures or groups within data of carnivores and livestock. 6) Mann-Whitney U test - was performed to determine if there were differences in distances travelled by cattle between dry and wet seasons, and between cattle posts closer and far from settlements. 7) Scatter plots fitted with natural cubic splines interpolation to show the trends and the variation in the distribution of the wild herbivores and carnivores long the livestock grazing intensity gradient and land use.
4) To evaluate the possibility of coexistence of wildlife and free-ranging livestock across landscape along a pastoral activities disturbance gradient in CGAs and CAs in the Kalahari savanna rangelands (Chapter 7)	Possibility of coexistence between wildlife & pastoralism	All the above methods	The results form forage availability (quality and quantity) and vegetation heterogeneity relative to land use (objective 1), livestock, pastoral activities and wild herbivores distribution (objective 2) and in turn, the distribution of carnivores (objective 3) is used to evaluate the possibility for coexistence.

Chapter 4

Forage resource availability and vegetation heterogeneity across land use types, along a free-ranging livestock grazing and other pastoralists activities disturbance gradients

Abstract

Forage resource availability (i.e. quality and quantity) and vegetation heterogeneity in African rangelands differ spatially and temporally across land use type and along a livestock grazing gradient. The theory predicts that the distribution of small and large-sized herbivores is controlled by forage quality and quantity respectively, while the distribution of carnivores is regulated by vegetation heterogeneity and prey availability. However, there have been few studies on the detailed comparative analysis on vegetation heterogeneity, forage quality and quantity in relation to the distribution of multiple wildlife species across a landscape between Conservation Areas (CAs) and communally managed pastoral areas supporting free-ranging livestock in the southern African rangelands. This chapter, therefore, analysed forage resource availability and vegetation heterogeneity in relation to a free-ranging livestock grazing and pastoral activities disturbance gradients and land use through a vegetation sampling survey data collected in two years during the wet and dry seasons. The results are later associated with the distribution of livestock, herbivores (Chapter 5) and carnivores (Chapter 6). The results reveal the difference in spatial distribution of vegetation heterogeneity and forage availability along livestock grazing gradients and across land use types (X^2 = 38526.955, df = 1325, $p < 0.001$). Palatable perennial and annual grasses, grass cover, grass diversity are associated with moderate to less livestock grazing intensity (LGI) in CGAs and within CAs in both seasons. Forb density, diversity was associated with moderate LGI during the dry season. Unpalatable perennial grasses were related to moderate LGI, while increased woody plant density/cover and bare ground were associated with high LGI in both seasons. Nevertheless, during the wet season unpalatable annual grasses, forb species richness and density are associated with increased LGI in CGAs. Grass cover is negatively associated with woody plant density in both seasons, while forb cover is positively related to woody plant density in the wet season. The primary factors influencing the distribution of forage availability and vegetation heterogeneity are LGI and land use types. Hence findings show that high forage quality in moderately grazed areas and low forage quality and quantity in areas with increased LGI, while areas in CAs had high forage quantity during both seasons.

4.1: Introduction

Livestock and wildlife share land, water and forage resource in African savanna rangelands and their interactions are complex (Young, Palmer et al. 2005). Consequently, there is the possibility for resource competition (Parris and Child 1973, Coe, Cumming et al. 1976) or facilitation (Arsenault and Owen-Smith 2011, Odadi, Karachi et al. 2011) for forage resource by livestock through habitat modification. (Young, Palmer et al. 2005). Overgrazing by livestock, result in the reduction of palatable and nutritious plants over time (Mphinyane, Tacheba et al. 2008, Tefera, Dlamini et al. 2010) and replaced by unpalatable plants (Adler, Milchunas et al. 2005). Overgrazing also leads to an increase in the bare ground (Diaz, Lavorel et al. 2007), hence promoting annual grasses and forbs (Hayes and Holl 2003), woody plants (Moleele and Perkins 1998) and loss of vegetation diversity (Oba, Vetaas et al. 2001). Increasing grazing intensity affect species composition (Skarpe 1992) by reducing the dominant species and influencing the less competitive and grazing tolerant plant species (Sternberg, Gutman et al. 2000). Therefore, rangelands with an increase in annual grasses and forbs indicate rangeland degradation (Smet and Ward 2005). Similarly, selective grazing can lead to the qualitative and quantitative change in species composition, shifting from palatable or sweet to unpalatable or sour species. Increaser species deteriorate significantly in nutritive value as they mature compared to the palatable species. Therefore most of the heavily grazed rangelands are dominated by unpalatable plant species (Trollope 1990).

The rangelands with moderate grazing effects are dominated by grass species which tend to decrease under heavy grazing (i.e. decreasers), while the rangelands which are underutilized are dominated by those grass species that increase when under or over utilised (i.e. increasers) (Du Plessis, Bredenkamp et al. 1998). Moderate livestock grazing keeps the grass short and actively growing hence providing high quality and digestible forage (Owen-Smith and Mills 2008, Fynn and Bonyongo 2011). Even though livestock grazing reduces forage quantity, it can increase quality (DuToit, Bryant et al. 1990, Jefferies, Klein et al. 1994) through the process of compensatory growth, hence grazing facilitation by livestock. The biomass produced after grazing is rich in nutrients than the ones not utilized (Skarpe 1991). Hence Forage availability (quantity and quality) in African rangelands differ both spatially, temporally (Ellis and Swift 1988, Illius and O'Connor 2000, Fryxell, Wilmshurst et al. 2005, Owen-Smith and Mills 2008) and across land use types.

For example, between CGAs, and CAs, the forage resources are different. In the CAs, tall, dense grasses, high herbaceous biomass and cover, are expected while in CGAs it is predicted to dominate short and low herbaceous biomass as maintained by livestock grazing. Therefore, indicating that the CAs do not provide a full range of useful resource gradients and seasonal habitats essential for the maintenance of different wildlife species (Fynn and Bonyongo 2011). Thus, different wildlife species track this spatial and temporal variability in forage availability between land use during the different seasons (Owen-Smith 2002, Owen-Smith 2004, Fryxell, Wilmshurst et al. 2005, Hopcraft, Olff et al. 2010). Forage quality and digestibility are highest in the short growing grass maintained by moderate livestock grazing compared to high grass biomass (Murray 1995) in areas without livestock grazing. Grass height determines digestibility, quality and influences predation risk (Bhola, Ogutu et al. 2012); hence tall grasses are favoured by large-sized herbivores (Olff, Ritchie et al. 2002). In the Kalahari rangelands most of the free-ranging livestock graze in the CGAs, hence the growing concern that expansion of pastoral activities could influence the movement of wild animals through competition or facilitation (Verlinden 1997).

Previous studies from East Africa and southern Africa have shown that the key determinants for the distribution of herbivores (Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012) and carnivores (Blaum, Rossmanith et al. 2007c,d) are forage availability (i.e. quality and quantity) and vegetation heterogeneity respectively. However, some studies indicate that pastoral activities in Africa rangelands limit the distribution and diversity of wildlife through the reduction of forage availability (Prins 1992, Cumming 1999). Nonetheless, recent studies elsewhere, also indicate that moderate livestock grazing are less damaging to rangeland resources as traditionally thought (Reid 2012) and may even benefit wildlife species through modification of vegetation (Gregory and Sensenig 2010; Soderstrom and Reid 2010; Augustine et al. 2011; Woodroffe 2011; Arsenault and Owen-Smith 2011, Odadi, Karachi et al. 2011, Reid 2012, Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012), hence improving the quality of forage.

Despite the above review, there are few studies on comparative analysis on the effects of free-ranging livestock on forage availability and vegetation heterogeneity along a grazing gradient at a large scale and between the CGAs and CAs. Also, the role of forage availability and vegetation heterogeneity in determining the distribution of multiple wildlife species of different sizes in communally managed rangelands (supporting free-ranging livestock) adjacent to CAs is less understood. Thus, there have been few studies on the detailed comparative analysis on the relationship between vegetation heterogeneity and forage availability with the spatial distribution of multiple wildlife species of different body sizes across the landscape of these communally managed rangelands adjacent to CAs in the southern Africa rangelands.

However, few studies in southern Africa savannah (Verlinden 1997, Verlinden, Perkins et al. 1998, Wallgren, Skarpe et al. 2009) determined the influence of forage availability, vegetation heterogeneity on the distribution of multiple wildlife species in private ranches and CAs. Furthermore, the above previous studies on wildlife distribution in southern Africa did not explore or measure in detail the forage availability (to species level), and did not compare the influence of seasons on forage availability and vegetation heterogeneity. Also a study from East Africa by (Bhola et. al. 2012), only estimated vegetation biomass and quality using Normalized Difference Vegetation Index (NDVI), yet NDVI does not give the details to plant species level.

Rainfall seasonality exerts essential controls on the growth, quality and quantity of vegetation in savanna rangelands (Deshmukh 1984), consequently influencing the distribution of resident wildlife. Vegetation quantity increases with the increase in rainfall. Nonetheless, forage quality increases with lower productivity regions, such as low rainfall, shallow upland soils because high rainfall dilutes the minerals, protein and energy; hence the decreasing and increasing the grass digestibility and biomass respectively (McNaughton and Banyikwa 1995, Murray 1995). Thus, in the regions of lower production, the grasses are predominately short resulting in higher rates of nutrients and energy intake by most of the ungulate species (Wilmshurst, Fryxell et al. 2000, Owen-Smith 2002). Therefore, the lower production regions supply sufficient protein, energy, and minerals during the wet season when the wild herbivores are lactating and building body stores for the dry season (McNaughton and Banyikwa 1995, Hopcraft, Olff et al. 2010). In contrast, however, high rainfall regions with low-quality forage during the wet season, provide green forage in the dry seasons (McNaughton 1985).

As a result, vegetation heterogeneity and availability also vary spatially and temporal due to the patchiness of rainfall, soil moisture and nutrients ((East 1984, Ellis and Swift 1988, Behnke, Scoones et al. 1993). In the late wet season, herbaceous plants (grasses and forbs) are tall and dense in CAs, hence the grasses will have crude protein and high in lignin, resulting in low digestibility (Georgiadis and McNaughton 1990). However, in CGAs, moderate livestock grazing intensity keeps grass short and actively growing during the wet season, therefore, increasing the quality but decreasing the quantity (Augustine and McNaughton 2006). Novertheless, forage quality and quantity are expected to be low in savanna rangelands during the dry season (Georgiadis and McNaughton 1990) but forage quantity is predicted to be high in CAs. Therefore, it is important to account for land use, livestock grazing and pastoral activities disturbance gradients and rainfall seasonality when determing forage availability and heterogeneity.

Other factors, such as fire, drought, and herbivory also influence woody and herbaceous biomass changes in both time and space (Jeltsch et al. 1996, 1998, Higgins et al. 2000). Livestock grazing can change spatial pattern of vegetation (Adler, Raff et al. 2001, du Toit 2003) and influence plant diversity (Milchunas and Lauenroth 1993). Therefore, influencing the grazing distribution of wildlife species (Bailey, Gross et al. 1996, Dennis, Young et al. 1998, Hobbs 1999). Moderate livestock grazing can result into the uneven utilisation of rangelands (Bailey, Dumont et al. 1998), leading to vegetation heterogeneity, which can either benefit (WallisDeVries 1998), or negatively affect biodiversity. In communally manged rangelands of Kalahari, Botswana, there is increased livestock grazing intensity on vegetation near the water points and cattle posts compared to greater distances from water points, consequently resulting into a large-scale vegetation heterogeneity near the borehole and further away (Fuhlendorf and Engle 2001). Intensive livestock grazing can results in a decrease in perennial palatable grasses and an increase in annual grasses and forbs, while moderate grazing increase herbaceous diversity and palatability (Skarpe 1991).

Besides rainfall and livestock grazing, vegetation heterogeneity in savanna rangelands is also determined by the variation in topography, soil conditions, spatial and temporal distribution of surface water (Frost et al. 1986). Thus, the availability of water in the semi-arid savannas affects food availability (i.e. the distribution, quality and quantity) for wildlife (Skarpe 1986). Vegetation heterogeneity which is expressed as the diversity of plant community (i.e. vegetation structure, species composition, density, cover and biomass and habitat types) in this study (Fuhlendorf and Engle 2001), influences the distribution of wildlife (Dunham, 1994; Ben-Shahar, 1995). The Kalahari rangelands are massive semi-arid and consist of mainly infertile homogeneous red sandy soil (Bergström and Skarpe 1999) and various natural calcrete pans (Knight, Knighteloff et al. 1988). These natural pans contain mineral licks and more nutrient-rich vegetation; hence they provide food resources for many wildlife species and livestock (Bergström and Skarpe 1999). Besides, even though there is no permanent natural water in the Kalahari rangelands (Engineers 1980), during the wet season these calcrete pans hold water for weeks even months (Skarpe 1986), hence supplying livestock and wildlife with water. Therefore, in addition to livestock grazing and other anthropogenic activities, natural pans have the potential to influence the distribution of wild herbivores and their associated predators (Parris and Child 1973; Milton, Dean & Siegfried, 1994).

Moreover, livestock grazing intensity in human dominating communally managed rangelands in Kalahari, southern Africa has the potential to compete with wildlife for grazing resources or facilitate grazing for other wildlife species depending on the body size. However, there are few studies relating the effect of livestock grazing to forage availability and vegetation heterogeneity and in turn how they influence the distribution of wild herbivores and carnivores of different body sizes. Spatial distribution of forage availability relative to the distribution of wildlife species could give indicators on whether there is competition or facilitation for grazing resources between livestock and wildlife species. The aim of this study, therefore, is to evaluate forage resource availability and vegetation heterogeneity along a free-ranging livestock grazing and pastoral activities disturbance gradients and across the land use types during the wet and dry seasons in Kalahari, southern Africa, as a case study. Forage resource availability and vegetation heterogeneity is later associated with the wildlife distribution in chapter 5 & 6. Consequently, this study tested the following hypotheses relating to the forage availability and vegetation heterogeneity;

i. Objective 1: Characterized spatial and temporal vegetation heterogeneity along a livestock grazing and pastoral activities disturbance gradients and across land use types during the wet and dry seasons.

   (H1a) The Vegetation heterogeneity (i.e. a mixture of herbaceous and woody plants) was expected to increase in the intermediate livestock grazing intensity and less pastoral activities disturbance (i.e. in areas with moderate livestock grazing) and decrease in areas with high livestock grazing intensity and pastoral activities disturbance in CGAs and in CAs. Moderate livestock grazing can result into the uneven utilisation of rangelands (Bailey, Dumont et al. 1998), leading to vegetation heterogeneity, while increased livestock grazing facilitate even utilisation of rangelands.

ii. Objective 2: To determined herbaceous species distribution (grasses & forbs) and their relationship with other environmental variables along a livestock grazing and pastoral activities disturbance gradients in communal grazing and wildlife management areas during the wet and dry seasons.

(H1b) Short palatable perennial and annual grasses, high grass and forb species richness and diversity were predicted to be related to intermediate livestock grazing intensity and less pastoral activities disturbance in the wet season and declines with heavy livestock grazing (Harper 1968, Coppock, Detling et al. 1983, Milchunas, Sala et al. 1988). Less livestock grazing intensity maintain grasses in short and at an active growth stage during wet season (Fryxell 1995). Therefore, high quality forage resources are expected to be associated with intermediate livestock grazing intensity (Hopcraft, Anderson et al. 2012, Augustine and McNaughton 2006) and less pastoralists activities away from the settlements and cattle posts. Hence, during the wet seasons, forage quality and digestibility are expected to be highest in the short growing grass maintained by moderate livestock grazing compared to high grass biomass (Murray 1995) in areas without livestock grazing.

(H1c) Unpalatable perennial and annual grasses, forbs and reduced grass cover were predicted to increase in areas with increased livestock grazing intensity closer to cattle posts and settlements (Fernandez-Gimenez and Allen-Diaz 1999). Intensive livestock grazing can results in a decrease in perennial palatable grasses and an increase in annual grasses and forbs, while moderate grazing increase herbaceous diversity and palatability (Skarpe 1991). Consequently, low forage quality and quantity are expected to be in these areas because of increased livestock grazing intensity closer to the settlements and cattle posts.

(H1d) Tall, dense grasses, high grass biomass and cover were expected to be related to areas with no livestock grazing in CAs in both seasons, because of less or no livestock grazing, except during illegal intrusions. However, the quality of these tall and dense grasses is low because of high lignin accumulation, hence low in digestibility (Georgiadis and McNaughton 1990, Hopcraft, Olff et al. 2010). Accordingly, low forage quality, but high forage quantity was expected to be related to the CAs, in both seasons. Though forage quality and quantity are expected to be low in savanna rangelands during the dry season (Georgiadis and McNaughton 1990), but in CAs forage quantity is predicted to be higher than CGAs in both seasons, due to less livestock grazing intensity.

iii. Objective 3: To compared the distribution of woody plant species and their relationship with other environmental variables along a pastoral activities disturbance gradient and land use types.

(H1e) The high density and canopy cover of woody plants were predicted to be associated with increased density of cattle posts, increased livestock grazing intensity near settlements in CGAs (Moleele and Perkins 1998, Dougill, Akanyang et al. 2016). The increase in woody plants and the decrease in herbaceous plants have been attributed to the increase in livestock grazing intensity in CGAs (Skarpe 1990). Besides, the density of bush encroachment woody plants species is expected to be closer to cattle posts and settlements, and for the density of non-bush encroachers is expected to increase with distance from settlements and high cattle post density (Moleele 1999).

4.2: Materials and methods

The quantities and qualities of forage resource (herbaceous and woody plants species) were evaluated within CGAs and CAs along a pastoral activities disturbance gradient in two dry seasons (August to October 2014 & 2015) and two wet seasons (March to May 2015 & 2016). This was achieved through a vegetation survey from a total of 180 plots (woody plants) and 1080 quadrats per season (herbaceous plants) along five transects radiating from the major settlements, cutting across CGAs and CAs. Principal Component Analysis (PCA), Canonical Correspondence Analysis – CCA technique using a CANOCO program package of (Ter Braak 1986, Ter Braak 1988, Ter Braak 1990) and Statistical Package for Social Sciences (SPSS) were used for the data analyses. PCA was used to reduce the number of measured vegetation variables from the original 27 to a more manageable small set of variables (also called components) which still account for the larger part of the total variation in the original vegetation variables, PCA was conducted for wet and dry season separately. The original variables are highly correlated to the resulting components (i.e. high factor loadings), hence the components could be interpreted in ecological term showing vegetation spatial heterogeneity during different seasons. CCA was used to relate community composition (Plant species data) to environmental variables.

The detailed description of the study site transects, data collection and statistical analysis are discussed under sections 3.1, 3.2, 3.3.1, 3.4.1 respectively. The results in this chapter are presented as follows; first is the vegetation heterogeneity, followed by the distribution of herbaceous layers (grasses and forb species) and the woody plant species respectively along livestock grazing intensity and pastoral activities disturbance gradients.

4.3 Results

The results reveal the difference in vegetation heterogeneity and forage availability along pastoral activities disturbance gradient from the settlements, across land use types and between seasons. CAs were associated with tall palatable perennial grasses with the increased herbaceous cover in both seasons. Forage quantity was high in the CAs but low-quality CGAs. On the contrary increased LGI in CGAs was related to increased woody plant density and cover, forb cover, unpalatable annual grasses, less grass cover, in both seasons. Therefore, increased LGI reduced grass cover & diversity, forb diversity, palatable perennial and annual grasses in both seasons. There was a decrease in forage quality and quantity in CGAs in areas with increased LGI closer to settlements and cattle posts. Nonetheless, moderate LGI influenced diversity & species richness of forbs, density & species richness of palatable perennial and annual grasses in both seasons. Hence moderate LGI facilitated vegetation heterogeneity (i.e. a mixture of different types of grasses, forbs, shrubs and trees), while increased LGI reduced vegetation heterogeneity.

4.3.1. Vegetation spatial heterogeneity along livestock grazing and pastoral activities disturbance gradients

From the PCA analysis, twenty-five (25) out of the twenty-seven vegetation variables satisfied the 0.3 cross-factor loading minimum limit in the varimax rotated matrix during both seasons, with Kaiser-Meyer-Olkin (KMO) test of 0.594 indicating the average sampling adequacy (Kaizer, 1974). Moreover, the Bartlett's test of sphericity was also significant (X^2 = 58526.95, $p < 0.001$, df = 325), hence accepting the correctness of the selected PCA model as appropriate for the data set. The following vegetation variables; bare ground cover, density and species richness of decreaser grasses, density and species richness of increaser grasses, were removed from PCA analysis because of multicollinearity ($r > 0.9$), while, Normalised Difference Vegetation Index (NDVI), and density of tsamma melons did not have significant loadings (>0.3) in all the extracted components. Therefore, PCA extracted six uncorrelated components which are interpreted or inferred as showing spatial vegetation heterogeneity along a livestock grazing gradient.

PCA extracted six distinct components with eigenvalues greater than 1 and describing 58.3 % and 56.96 % of the total variance of the dataset during the dry and wet season respectively (Table 4.1 & 4.2). Even though each component comprised of a linear combination of different variables, each component represents a variable in the model and the components were displayed in descending order of their corresponding variance. For example, during the dry season, the six components accounted for the following total variance (%) of the data from highest to low: 12.25, 11.02, 9.92, 8.89, 8.8, and 7.4 respectively (Table 4.1). Contrary, during the wet season, the six components extracted from PCA accounted for the following variance (%) in descending order: 11.7, 10.81, 9.77, 9.05, 7.82, and 7.8 respectively. Consequently, the reduction of data set dimensionally was from twenty-five (25) to six (6) components, for both dry and wet seasons respectively. For example, during the dry season 41.7% of the information was lost (accounting for 58.3 %) and while in the wet season only 43 % of the information was lost (accounting for 56.96 %). The data shown in bold in Table 4.1 & 4.2, show relatively higher loadings of each original vegetation variables and contribution to the corresponding extracted components.

Table 4. 1: Rotated Component Matrix and variance explained for vegetation variables during the dry season.
Pala = palatable grasses, Unpala = unpalatable grasses, perennial & annual = grass life form as identified by Oudtshoon 2002, encroachers = woody plants, Spp = species. Bold numbers show higher loadings of each original vegetation variables and contribution to the corresponding components.

	Vegetation spatial heterogeneity					
	Tall/Pala/Perennial	**Bush encroachers**	**Forbs/Pala annual**	**Unpala/Perennial**	**Non-encroachers**	**Unpala/annual**
Spp richness palatable perennial	**0.764**					
Grass total cover	**0.744**					
Density palatable perennial	**0.684**					
Grasss height	**0.682**					
Grass total biomass	**0.668**					
Grass Simpson index diversity	**0.646**			0.412		0.335
Total cover encroachers		**0.878**				
Total cover		**0.828**				
Density encroachers		**0.792**				
Species richness encroachers		**0.639**				
Forb total cover			**0.774**			
Forb total biomass			**0.748**			
Forb density			**0.679**	0.317		
Density palatable annuals			**0.467**			0.311
Spp richness unpalatable perennials				**0.771**		
Density unpalatable perennials				**0.718**		
Forb species richness			0.539	**0.571**		
Forb Simpson index diversity			0.421	**0.548**		
Density non-encroachers					**0.834**	
Spp richness non-encroachers					**0.805**	
Total cover non-encroachers					**0.59**	
Trees Simpson index diversity					**0.564**	
Spp richness unpalatable annuals						**0.843**
Density unpalatable annuals						**0.836**
spp richness palatable annuals			0.452			**0.459**
Eigen Value	**3.186**	**2.866**	**2.58**	**2.312**	**2.279**	**1.925**
Initial variance (%)	**12.26**	**11.02**	**9.922**	**8.892**	**8.764**	**7.405**
Cumulative variance (%)	**12.26**	**23.28**	**33.2**	**42.09**	**50.86**	**58.26**

Extraction Method: Principal Component Analysis, Rotation Method: Varimax with Kaiser Normalization, a Rotation converged in 6 iterations and six components were produced. KMO = 0.594, X^2 = 38526.955, df = 1325, $p < 0.001$. Factor loadings (>0.3).

Table 4. 2: Rotated Component Matrix and variance explained for vegetation variables during the wet season.
Pala = palatable grasses, Unpala = unpalatable grasses, perennial & annual = grass life form as identified by Oudtshoon 2002, encroachers = woody plants, Spp = species. Bold numbers show higher loadings of each original vegetation variables and contribution to the corresponding components.

	Vegetation spatial heterogeneity					
	Tall/Pala/Perennial	**Bush encroachers**	**Forbs/Pala annual**	**Non-encroachers**	**Pala/Unpala/annual**	**Unpala/Perennial**
Spp richness palatable perennial	0.802					
Density palatable perennial	**0.751**					
Grass total cover	**0.675**					
Grass total biomass	**0.664**					
Grasss height	**0.656**					
Grass Simpson index diversity	**0.544**					0.328
Total cover encroachers		**0.86**				
Total cover		**0.801**				
Density encroachers		**0.795**				
Spp richness encroachers		**0.702**				
Forb total cover			**0.83**			
Forb total biomass			**0.82**			
Forb density			**0.754**			
Forb species richness			**0.546**		0.346	
Density non-encroachers				**0.838**		
Spp richness non-encroachers				**0.827**		
Trees Simpson index diversity				**0.654**		
Total cover non-encroachers				**0.554**		
spp richness palatable annuals					**0.716**	
Density palatable annuals					**0.702**	
Forb Simpson index diversity					**0.469**	
Density unpalatable annuals					**0.431**	0.39
Density unpalatable perennials						**0.84**
Spp richness unpalatable perennials						**0.838**
Spp richness unpalatable annuals					0.438	**0.452**
Eigen Value	**3.042**	**2.813**	**2.54**	**2.353**	**2.034**	**2.029**
Initial variance	**11.7**	**10.82**	**9.768**	**9.051**	**7.822**	**7.803**
Cumulative variance	**11.7**	**22.52**	**32.29**	**41.34**	**49.16**	**56.96**

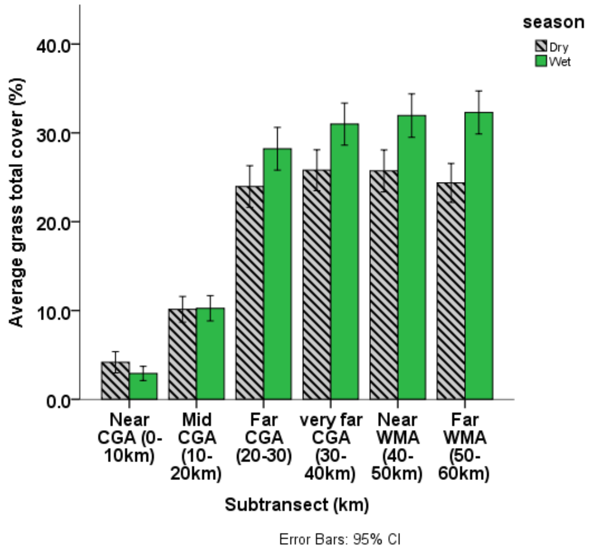
Extraction Method: Principal Component Analysis, Rotation Method: Varimax with Kaiser Normalization, a Rotation converged in 6 iterations and six components were produced. KMO = 0.594, X^2 = 38526.955, df = 1325, $p < 0.001$. Factor loadings (>0.3).

Overall the six components extracted from the PCA (Table 4.1) reflected the following vegetation spatial heterogeneity along a pastoral activities disturbance gradient within the study area: “palatable perennial grasses”, “Bush encroachment”, “Forbs/palatable annual grasses’, ‘unpalatable perennial’, ‘non-encroachment’ and unpalatable annual grasses’ during the dry season. Similarly, during the wet season, six components reflected the same vegetation spatial heterogeneity except one (Palatable and unpalatable grasses species) (Table 4.2). During the dry season, the first component (Tall/Para/perennial) accounts for 12.25 % of the variance and it is characterized by the highest number of original measured vegetation variables (six) (Table 4.1).

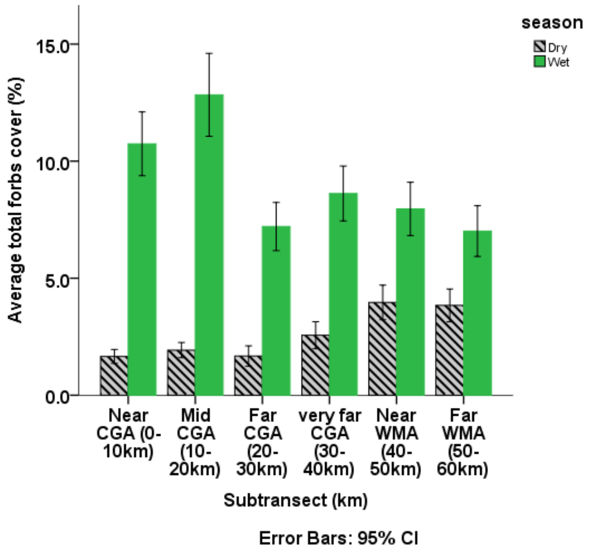
The variables loading on the first component are all grass parameters; species richness of palatable perennial, high grass cover, the density of palatable perennial, high grass height, biomass, diversity (0.764, 0.744, 0.684, 0.682, 0.668, 0.646 respectively). Hence this component was labelled (tall palatable perennial grasses–Tall/para/perennial'). Therefore, it was inferred that the first component reflects a gradient of "palatable perennial grasses" in areas with high grass height, biomass and diversity (Figure 4.1 g & h) mainly in the CAs and at a greater distance from the settlements (>30km) in areas with less grazing intensity. The same grass parameters loaded highly on the first component during the wet season data (Table 4.2). Therefore, showing that grass cover (Figure 4.2A), biomass, the density of palatable perennials, grass diversity and species richness of palatable perennial grasses were increasing with increasing distance from the settlements in both seasons. However, the grass diversity also significantly loaded on other component during the dry season (Table 4.1) (Unpala/Perennial (0.412) & Unpala/annual – 0.335) and wet season (Table 4.1b) (Unpala/perennial – 0.328), showing that moderate livestock grazing facilitates grass diversity (Figure 4.1 E & F). Therefore, indicating that forage quantity was associated with CAs in both seasons, while forage quality was related to moderate livestock grazing in CGAs.

The second component represents 'bush encroachment' in both seasons, accounting for 11.02 % and 10.82 % variance of the dataset during the dry and wet season respectively. The component comprises all woody plants parameters; high total tree cover, high cover, density and species richness for bush encroachment species (0.878, 0.828, 0.792, 0.639 respectively) in the dry season (Table 4.1) and (0.801, 0.86, 0.795, 0.702 respectively) in wet season (Table 4.2). Hence it was inferred that this component characterises a gradient of "bush encroachment woody plants' mainly in intensively grazed areas near settlements (<15km) in areas with less grass biomass and cover. Henceforth, indicating that increasing livestock grazing intensity was associated with bush encroachment plant species (Figure 4.1a -d, Figure 4.2a & e).

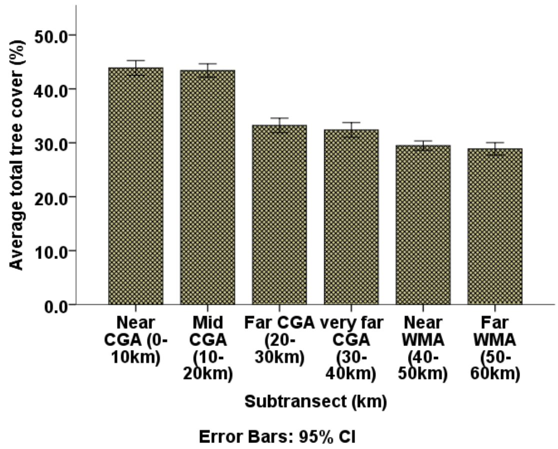
Figure 4. 1: Examples of vegetation heterogeneity along livestock grazing gradient (A & B) intensively grazed areas (< 10km CGAs) showing high tree density and bare ground in dry and wet season respectively. (C & D) intensively grazed areas (10 – 20km CGAs) showing bare ground during the dry season and high forb cover during the wet seasons respectively. (E & F) moderately grazed areas (20 – 30km CGAs) showing unpalatable perennial grasses during the dry season and a variety of short herbaceous plants in wet season respectively. (G & F) non-livestock grazing (>30km & CAs) showing taller, high grass cover/biomass in both the dry and wet season respectively. Photos: L. Akanyang.



A



B



C

Figure 4. 2: Grass, forbs and woody cover along livestock grazing gradient
Average grass cover (A), forb cover (B) during the dry and wet seasons respectively and woody cover in the dry season (C) along sub-transects radiating from the main settlements in Kalahari north, Botswana. It should be noted that the distance to CAs from the main settlements varied along different transects, however, it was about 40km except Hukuntsi/Ngwatle (30km) and Lehututu/Hunhukwe, which was >60km. The plants cover was calculated as the averages of the sample points within the sub-transects.

The third component reflects 'Forbs/palatable annual grasses' in both seasons and accounting for 9.92 % variance of the dataset during the dry and wet season respectively. This component is characterized by forbs biomass, cover, density and density of palatable annual grasses (i.e. mainly *Schmidtia kalihariensis*) during the wet seasons (Table 4.1). However, during the dry seasons, this component highly loaded on the same variables except for annual grasses but forb species richness (Table 4.2). Therefore, reflecting intensively grazed areas between 10 – 20km from the settlements in CGAs (Figure 4.1c & D, Figure 4.2B). Hence, indicating that these areas were dominated with high forb cover, density and species richness.

The fourth component represents 'unpalatable perennial grasses' during the dry season and highly loading on density and species richness of unpalatable perennial grasses, forb species richness and diversity. Therefore, indicating low herbaceous quality but moderate quantity during the dry season (Table 4.1, Figure 4.1e). These areas represent moderate grazed areas between 20 - 30kms. However, these areas were associated with non-bush encroachment species during the wet season (i.e. component 'non-encroachers) (Table 4.2, Figure 4.1F). Consequently, suggesting forage quality and moderate quantity in moderate livestock grazed areas between 20 to 30kms from the village.

The fifth component (C5) and the six components explained only 8.8% and 7.4% of the variance respectively. Hence, reflecting non-bush encroachers and unpalatable annual grasses respectively during the dry season (Table 4.1). However, the results for the wet season show that the fifth and the six components explained 7.8% and 7.8% of the variance respectively. Therefore, the fifth component reflecting palatable and unpalatable annual grasses ("pala/unpala/annual"), while the six component indicates unpalatable perennial grasses (Table 4.2).

4.3.2: The distribution of herbaceous species

Grass species composition

A total of 29 grass species were recorded in the present study, 14 were perennials, four weak perennials, and 11 annuals. Furthermore, 13 were highly desirable, seven moderate desirables and nine less desirable grass species. Thirteen (13) grass species were decreasers (species decreasing in abundance when grazing intensity increases) and 16 as increaser species (species increasing when grazing intensity increases) (Appendix 4A). During the dry season, the dominant (relative density >15%) grasses were *Eragrostis* *lehmannian* Nees, *Eragrostis pallens* Hack and *Schmidtia pappophoroides* Steud, while in wet season only *Schmidtia kalihariensis* Stent was dominant. These dominant grasses were mainly perennial grasses except *Schmidtia kalihariensis,* which is an annual (increaser). During the dry season, common grass species (relative density 5 – 15%) included *Stipagrostis uniplumis* Lincht, *Schmidtia kalihariensis* Stent and *Urochloa trichopus* Hochst. However, *Melinis repens* Willd, *Aristida stipitata* Hack, *Digitaria sanguinalis* L., *Digitaria eriantha* Steud and *Aristida congesta* Roem & Schult were less common (1-5%), while the rest of the grasses were rare (<1%) during the dry season. On the contrary, *Stipagrostis uniplumis, Eragrostis lehmannian*, *Schmidtia pappophoroides* and *Urochloa trichopus* were common in wet season, while *Melinis repens*, *Digitaria sanguinalis*, *Digitaria eriantha* were less common and the rest were rare.

Grass species distribution and relationships with other environmental variables

Forward selection of 17 environmental variables (i.e. extracted from PCA) (Table 3.2) using CANOCO program indicated that ten and nine variables (Table 4.3B) statistically significantly influenced grass species composition in dry and wet season respectively. Consequently, explaining a variance of 42.4% (1.35/3.182) and 45.4% (1.662/3.664) in the grass species data in dry and wet season respectively ($p < 0.05$) (Table 4.3A), omitting seven (dry) and eight (wet) environmental variables ($p > 0.05$) due to small variation. Regardless of the omission of these environmental variables, the eigenvalues of the first two axes continued to be reasonably high for dry (AX1 = 0.461, AX2 = 0.299) (Table 4.3 A) and wet seasons (AX1 = 0.755, AX2 = 0.309) (Table 4.3A), demonstrating that the first two axes explained the most variance (i.e. cumulative % variance) in dry (23.9%) and wet (29.1%) seasons (Table 4.3A). Most of the retained environmental variables were not highly correlated; hence no multicollinearity between the variables (Appendix 4B).

Table 4. 3: Summary for forward selection and inter correlation of coefficients of environmental variables with species axis grass species Data for dry and wet season. Bold figures in Table 4.3B, show variables with the highest correlation coefficients (- or +)

A) Summary of the forward

	Dry season				Wet season			
Axes	**AX1**	**AX2**	**AX3**	**Total Inertia**	**AX1**	**AX2**	**AX3**	**Total inertia**
Eigenvalues	0.461	0.299	0.201	3.182	0.755	0.309	0.259	3.664
Species-environment correlations	0.92	0.882	0.849		0.951	0.807	0.844	
Cumulative percentage variance								
of species data	14.5	23.9	30.2		20.6	29.1	36.1	
of species-environment relation	34.2	56.3	71.2		45.4	64	79.6	
Sum of all eigenvalues				3.182				3.664
Sum of all canonical eigenvalue				1.35				1.662

B) inter-set correlation of coefficients

	Dry season			Wet season		
Variables	**AX1**	**AX2**	**AX3**	**AX1**	**AX2**	**AX3**
Livestock grazing absent				**0.5358**	**0.3009**	-0.3197
Land use (CA/CCA)	**0.5583**	0.0306	0.2432	**0.519**	-0.1199	0.3113
Habitat type (WC/AAF)	**0.531**	0.2014	0.0419			
Annual rainfall	**0.5386**	-0.0816	0.1133			
Distance from cattle posts				**0.5526**	0.0691	-0.3091
Distance from settlements	-0.0922	-0.1883	-0.3	**-0.5167**	-0.1199	-0.1676
Grass height	**-0.6641**	-0.277	-0.1608			
Grass cover				-0.1526	**-0.3545**	**-0.4014**
Palatable perennial grasses	-0.1098	**-0.6752**	0.019	**0.7758**	**-0.366**	-0.1857

Unpalatable annual grasses	-0.185	-0.1301	0.1469	-0.0228	-0.0795	**0.7679**
Unpalatable perennial grasses	0.0331	**0.4251**	**0.671**	0.1915	**0.33**	**0.3448**
Palatable annual grasses	-0.1463	**0.4606**	**-0.3966**	**-0.8863**	-0.0951	-0.0182
Grass diversity	-0.1661	**-0.5677**	0.1949			

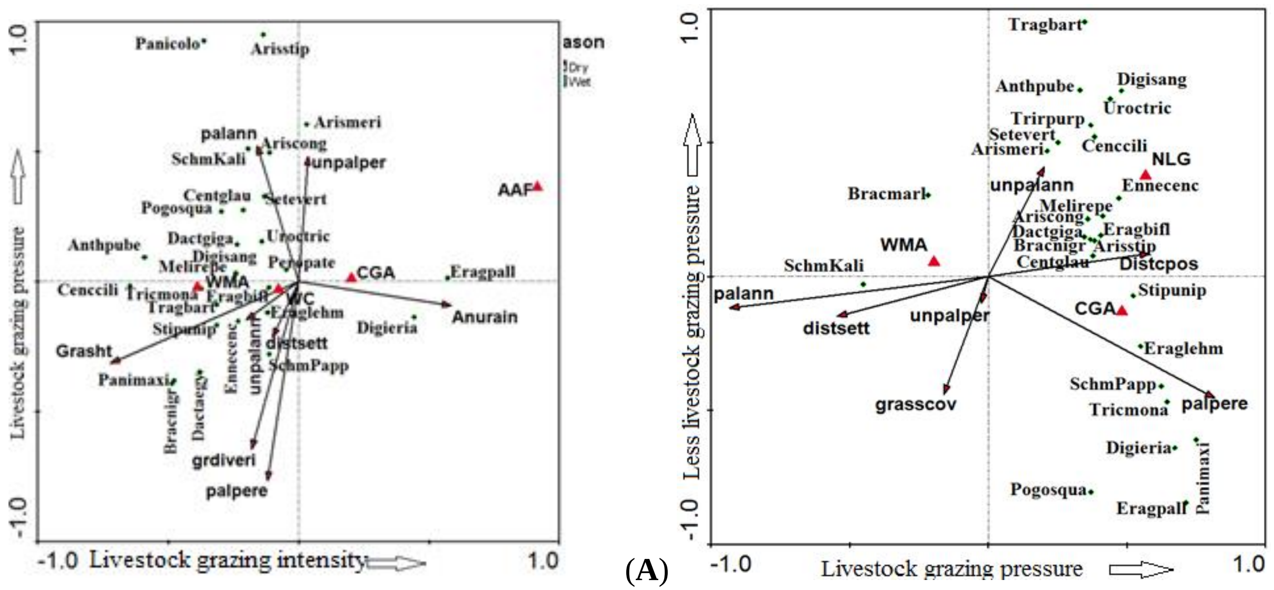


Figure 4. 3: Grass species ordination diagram based on canonical correspondence analysis - CCA

Grass species densities with respect to environmental variables during the dry season and wet season respectively **(**A shows dry season & B shows wet season). Quantitative and qualitative environmental variables are indicated by arrows and triangles respectively. Grass species variables are shown as green dots. The species – environmental correlation for the first two axes are 0.92 and 0.882 (**A**), 0.951 and 0.807 (**B**) respectively (eigenvalue 1 = 0.461, eigenvalue 2 = 0.299; scaling = 2, sum of all canonical eigenvalues is 1.35) (**A**) and eigenvalue 1 = 0.755, eigenvalue 2 = 0.309; scaling = 2, sum of all canonical eigenvalues is 1.662 (**B**). Distsett, Distcpos = distance from settlements, cattle post respectively, palpere = palatable perennial grasses, unpalann = unpalatable annual grasses, palann = palatable annual grasses, unpalper = unpalatable annual grasses, annurain = annual rainfall, grasht = grass height, grdiverl = grass diversity, grasscov = grass cover, Livestock grazing intensity (NLG = no livestock grazing), Land use types, (CGA & CA), WC = woody cover, AAF = arable agriculture fields. Arisstip = *Aristida stipitata*, Arismeri = *Aristida meridionalis*, Ariscong = *Aristida congesta*, Schmkali = *Schmidtia kalihariensis*, Setevert = *Seteria verticillata*, Centglau = *Centropodia glauca*, Pogosqua = *Pogonathria squarrosa*, Dactgiga = *Dactyloctenium giganteum*, Anthpube = *Anthephora pubescens*, Urotric = *Urochloa trichopus*, Peropate = *Perotis petens*, Digisang = *Digitaria sanguinalis*, Melirepe = *Melinis repens*, Cenccili = *Cenchrus ciliaris*, Tricmona = *Tricholaena monachne*, Eragbifl = *Eragrostis biflora*, Eraglehm = *Eragrostis lehmannian*, Tragbart = *Tragus barteronianus*, Stipunip = *Stipagrostis uniplumis*, Ennecenc = *Enneapogon cenchroides*, Schmpapp = *Schmidtia pappophoroides*, Digieria = *Digitaria eriantha*, Erapall = *Eragrostis pallens*, Panimaxi = *Panicum maximum*, Bracnigr = *Brachiaria nigropedata*

Forward selection of the environmental variables showed that Grass height (18.59%) explained most of the variations in the species data, followed by unpalatable perennial (12.46) and palatable annualgrasses (12.00%) in dry season. On the contrary, during the wet season palatable annual grasses (34%) explained most of the variations in the species data, followed by unpalatable annuals (18.8%) and unpalatable perennial grasses (12.4%) respectively. The Monte Carlo test of significance showed that there was a significant fit between the ten (dry) and nine (wet) retained environmental variables and species composition along the first and second axes in both seasons ($P < 0.001$).

During the dry season land use (CGA) (0.558), annual rainfall (0.538), habitat type (0.531), which had the highest positive correlations with the first axis respectively and grass height (-0.664) were the most important variables influencing grass species distribution (Table 4.3B). The other important environmental variables were palatable annual (0.460), unpalatable perennials (0.425) palatable perennial (-0.675) and grass diversity (-0.567), which had the highest correlation coefficients in the second axis (Table 4.3 B). Therefore, the first and the second axes reflect livestock grazing gradients increasing from left to right and the bottom – up respectively (see Figure 4.3 A).

On the other hand, during the wet season palatable perennial (0.776), distance from the cattle posts (0.553), areas without livestock grazing (0.536), in CGAs (0.519) had the highest positive correlations with the first axis respectively. However, palatable annual (-0.886) and distance from the settlements (-0.517) have the highest negative correlation along the first axis. Therefore, indicating the most important environmental variables influencing the distribution of grass species. The other important variables were unpalatable annual grasses (0.33), areas without livestock grazing (0.301), which had the highest positive correlation respectively, and palatable perennial (-0.366) and grass cover (-0.355) with highest negative correlation with the second axis (Table 4.3B). Therefore, the first and second axes represent the gradients of livestock grazing intensity increasing from left to right and decreasing from the bottom up respectively (Figure 4.3B). The quantitative and nominal environmental variables are presented by arrows and triangles (red) respectively (Figure 4.3A & B).

Therefore species projecting from the origin of the graph in the direction of the environmental variable arrow are predicted to have above average abundances relative to that variable, and those radiating the opposite are predicted to have below average values

(Ter Braak 1994). Orthogonal projection of each species from origin with the environmental variable arrow, are predicted to have a little correlation (near zero) (Lepš and Šmilauer 2003). The directions of the arrows show how environmental variables relates to species composition axes, while the angle between the environmental variables indicates their correlations. The location of the species about the orthogonal projection from the quantitative environmental variable arrow or distance from the nominal environmental variables (qualitative) positions to species data provides an inferred ranking of the species relationship to that variable (Palmer 1993, Lepš and Šmilauer 2003).

The number of grass species (grass species richness) was decreasing with increasing livestock grazing intensity in CGAs in both seasons. However, in dry season most of the grass species were associated with areas with taller grasses in the CAs, while in wet season they were related to moderately grazed areas in CGAs. Grass species richness for decreasers (species decreasing in abundance when grazing intensity increases) and increasers (species increasing when grazing intensity increases) increased and decreased with distance (less grazing intensity) respectively in both seasons. During the dry season, however, some few grass species such *Digitaria eriantha* Steud, *Eragrostis pallens* Hack, *Aristida meridionalis* Stapf and *Aristida stipitata* Hack were negatively correlated with grass height and associated livestock grazing intensity in CGAs (Figure 4.3 A).

The above grass species are low to medium desirable perennials except *Digitaria eriantha,* which is highly desirable perennial grass. Most of the palatable perennial grass species, for example *Brachiaria nigropedata* Munro, *Dactyloctenium giganteum* B.S., *Panicum maximum* Jacq, *Stipagrostis uniplumis* Lincht, *Schmidtia pappophoroides* Steud, *Eragrostis lehmannian* Nees, *Cenchrus cilliaris* L., *Schmidtia kalihariensis* Stent, and *Anthephora pubescens* Nees were positively associated with increasing distance from settlements in areas with medium to no livestock grazing. These grass species are mostly palatable species and classified as decreasers, except *Eragrostis lehmannian* Nees which is an increaser.

Grass diversity, palatable perennial grasses and annual grasses increased with less livestock grazing and positively associated with CAs than CGAs. Therefore, indicating that during the dry season within 20km from the settlement in CGAs, the palatable perennial grass species have been depleted by livestock grazing intensity. Nonetheless, grass diversity tends to be high in moderately grazed areas (20 – 40km). There was an increase in unpalatable perennial grass species, such as *Aristida stipitata* Hack, *Eragrostis pallens* Hack, *Aristida meridionalis* Stapf in areas with high livestock grazing during the dry season. Grass species such as *Urochloa trichopus Hochst*, *Seteria verticillata L.*, *Pogonathria squarrosa* Roem & Schult, *Schmidtia kalihariensis Stent*, *Aristida stipitata* Hack, *Aristida congesta* Roem & Schult were found in areas with less grass diversity and palatable perennial grasses (Figure 4.3A). Therefore, indicating the negative effects of livestock grazing intensity, hence the possibility for competition for grazing resources with other herbivores during the dry season.

The densities of most of palatable perennial grasses, such as *Schmidtia pappophoroides* Steud *Eragrostis lehmannian* Nees, *Digitaria eriantha* Steud *Stipagrostis uniplumis* Lincht, *Aristida stipitata* Hack, were associated with CGAs at greater distances from the cattle posts, in areas with moderate livestock grazing intensity (Figure 4.3B). However, high grass cover was still interrelated with CAs and no correlation with the CGAs, like dry season. Therefore, implying that even though there are high densities of grasses in moderately grazed areas in CGAs, large crown grasses were found in areas with no livestock grazing (CAs), while small growing grasses were in areas where there is livestock grazing. Therefore, indicating that moderate livestock grazing reduces grass cover and facilitates individual grass regeneration in wet season.

The following grass species were related to the CAs; *Aristida meridionalis* Stapf, *Schmidtia kalihariensis* Stent, *Brachiaria marlothii* Hack, *Seteria verticillata* L., and *Anthephora pubescens* Nees (Figure 4.3B). Palatable annual grasses were associated with CAs and negatively correlated to CGAs. Like dry season, the density of palatable perennial and annual grasses increased with less livestock grazing intensity and tends to be high in areas with moderate livestock grazing. *Schmidtia kalihariensis* Stent was negatively correlated with high distances from the cattle post, indicating that during the wet season this low to medium desirable annual grass was also found closer to the cattle posts.

Most of the decreaser grass species which were dominant in both seasons were *Schmidtia pappophoroides* Steud, *Digitaria eriantha* Steud, Stipagrostis uniplumis Lincht (Figure 4.4). The densities of these decreaser grass species were decreasing with increasing livestock grazing intensity and these grasses were rare within 15km distance from the settlements in both seasons. Similarly, increasers' grass species such as (*Eragrostis lehmannian* Nees, *Urochloa trichopus* Hochst, *Tricholaena monachne* Trin, *Enneapogon cenchroides* Lincht, *Digitaria sanguinalis* L., *Eragrostis biflora* Hack, *Schmidtia kalihariensis* Stent) decreased with increasing livestock grazing intensity (distances <15km) in both seasons (Figure 4.5).

However, the density of three increasers' grass species (unpalatable annuals) (*Aristida congesta* Roem & Schult, *Aristida stipitata* Hack and *Tragus barteronianus* Schult showed an increasing trend with increasing livestock grazing intensity (Figure 4.5). Therefore, showing overgrazing by livestock within 15km radius from the main settlements in both seasons. The density of palatable annual grasses (*Urochloa trichopus* Hochst, *Schmidtia kalihariensis* Stent decreased and *Eragrostis lehmannian* Nees) decreased and increased with increasing livestock and moderate grazing intensity respectively.

Forb species composition

A total of 53 forb species were recorded in the present study (Appendix 4C). However, most of the forbs were annuals; hence few were encountered during the dry season. During the dry season, the dominant (relative density >15%) forbs were *Helichrysum argyrosphaerum* DC. (36%), *Indigofera daleioides* Harv (22%), *Indigofera flavicans* Baker (15), while *Phylanthus angolensis* Mull. Arg was common (5%). During the wet season, the same species were dominant except *Helichrysum argyrosphaerum* DC.

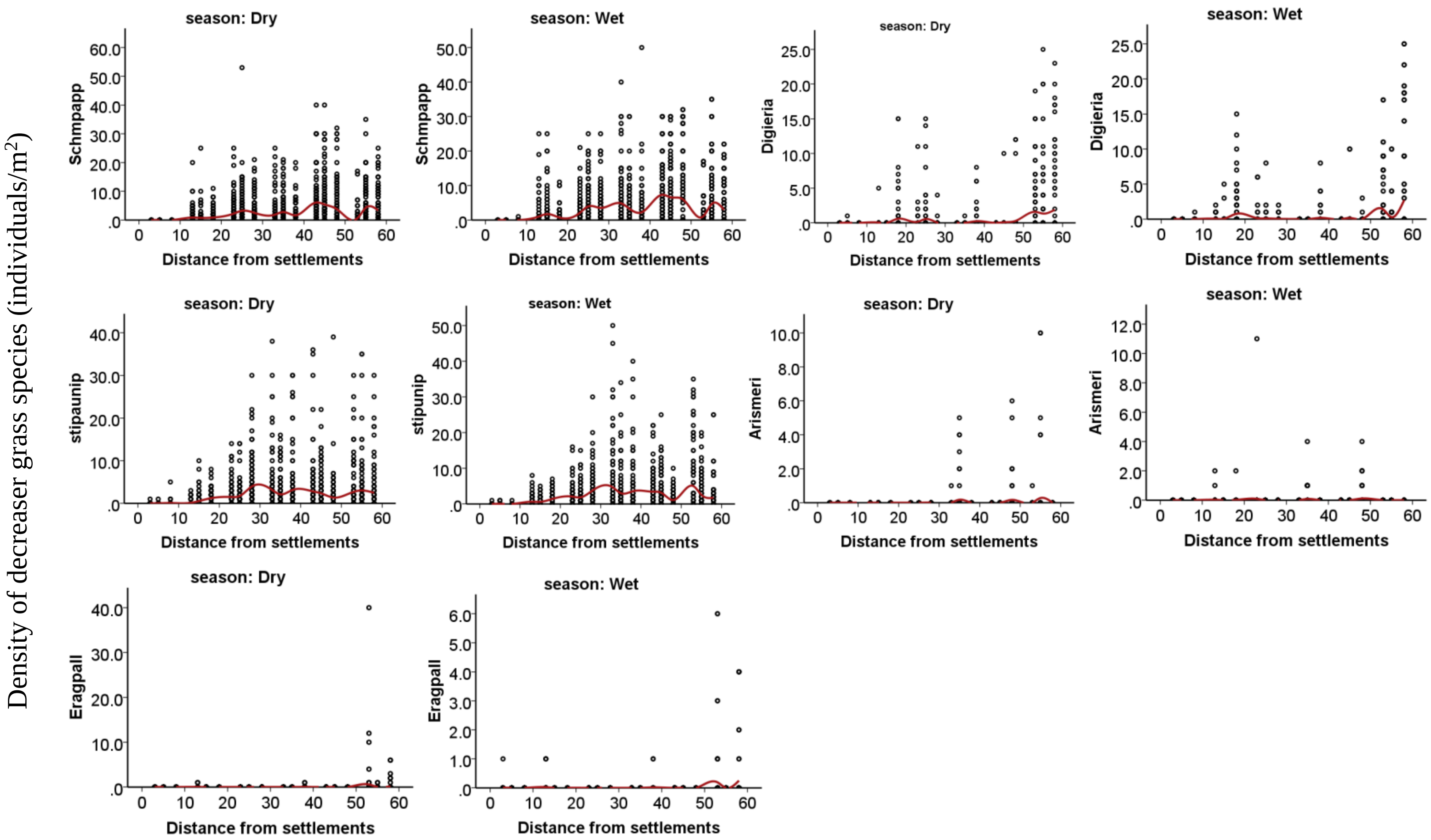


Figure 4. 4: Scatter plots showing variation in the density (individual/m^2) of grass species (decreasers) relataive to distance from settlements. The y axis shows the density of grass species. Fitted with natural cubic splines interpolation (red line) in Kalahari, Botswana, plotted against distance from the settlements (km) in dry and wet season respectively. Schmpapp = *Schmidtia pappophoroides* Steud, Digieria = *Digitaria eriantha* Steud, Stipaunip = *Stipagrostis uniplumis* Lincht, Arismeri = *Aristida meridionalis* Stapf, Eragpall = *Eragrostis pallens* Hack, Melirepe = *Melinis repens* Willd.

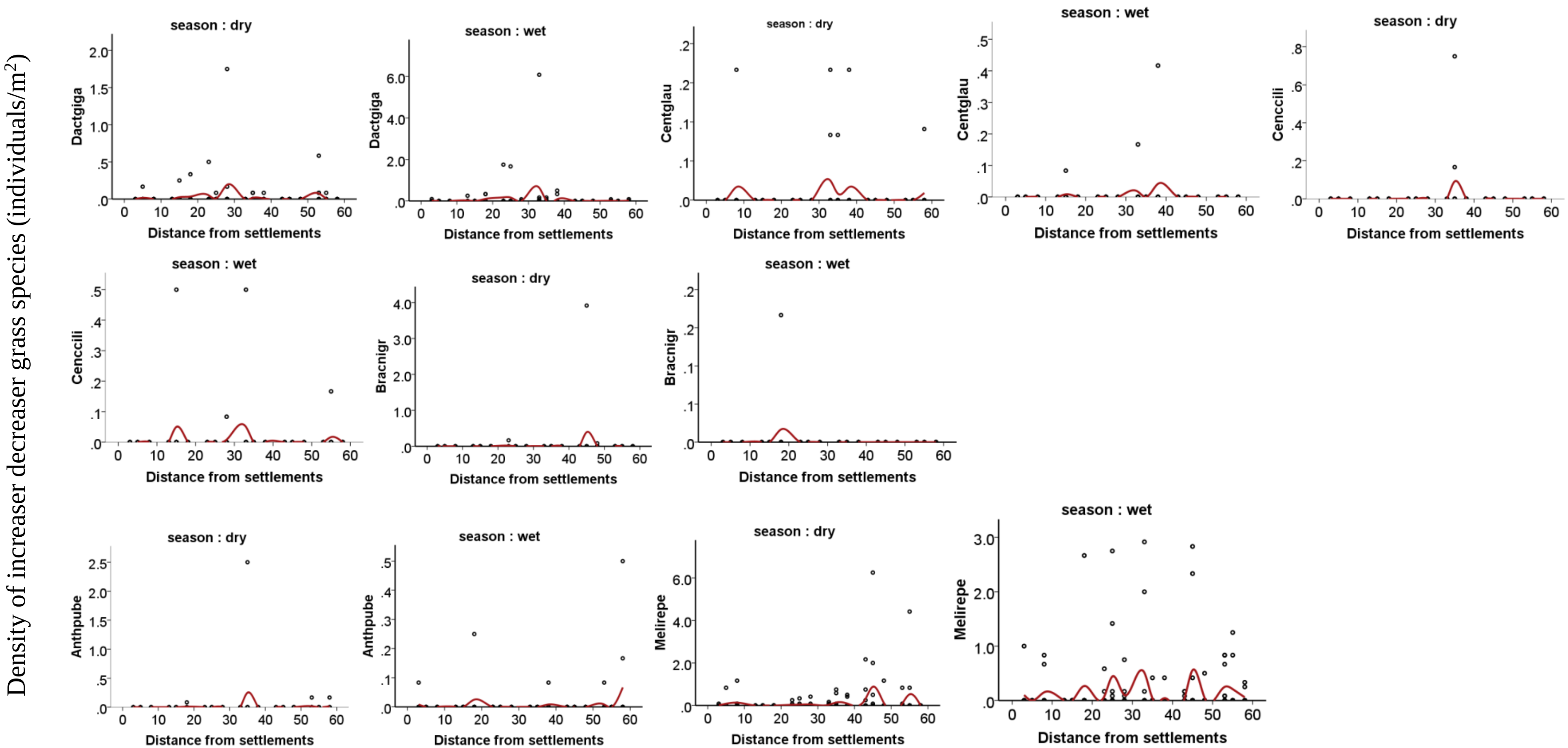


Figure 4.4 continues: Scatter plots fitted with natural cubic splines interpolation to show the variation in density of grass species (decreasers) (individual/m^2) (red line) in Kalahari, Botswana, plotted against distance from the settlements (km) (livestock grazing intensity gradient) in dry and wet season respectively. The y axis shows the density of grass species. Dactgiga = *Dactyloctenium giganteum* B.S., Cectglau = *Centropodia glauca* Nees, Cenccili = *Cenchrus cilliaris* L., Bracnigr = *Brachiaria nigropedata* Munro, Digieria = *Digitaria eriantha* Steud, Anthpube = *Anthephora pubescens* Nees.

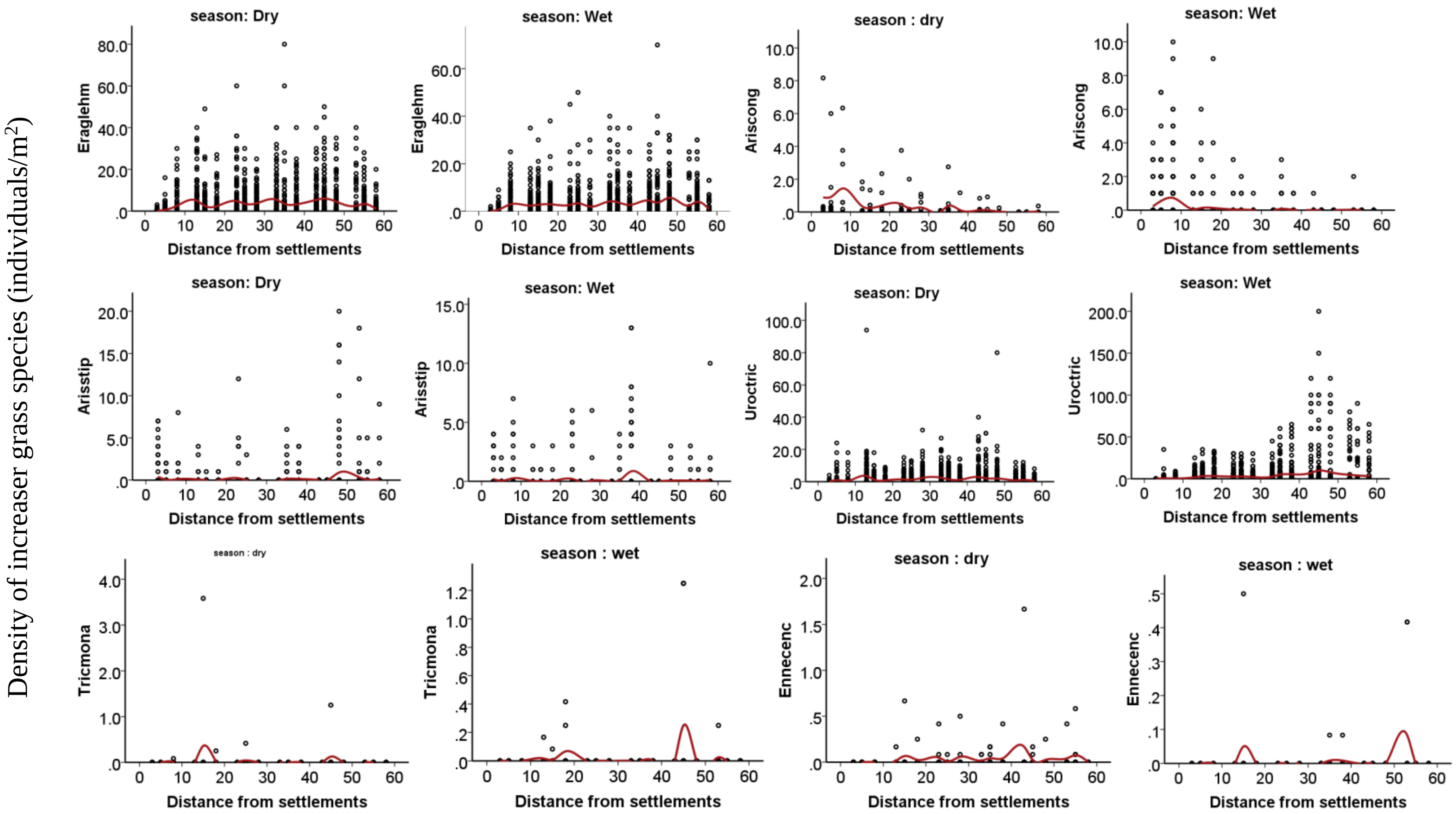


Figure 4. 5: Scatter plots showing variation in the distribution of density (individual/m^2) of grass species (increasers) Iitted with natural cubic splines interpolation (red line) in Kalahari, Botswana, plotted against distance from the settlements (km) (livestock grazing intensity gradient) in dry and wet season respectively. The y axis shows the density of grass species. Eraglehm = *Eragrostis lehmannian* Nees, Ariscong = *Aristida congesta* Roem & Schult, Arisstip = *Aristida stipitata* Hack, Uroctric = *Urochloa trichopus* Hochst, Tricmona = *Tricholaena monachne* Trin, Eneacenc = *Enneapogon cenchroides* Lincht.

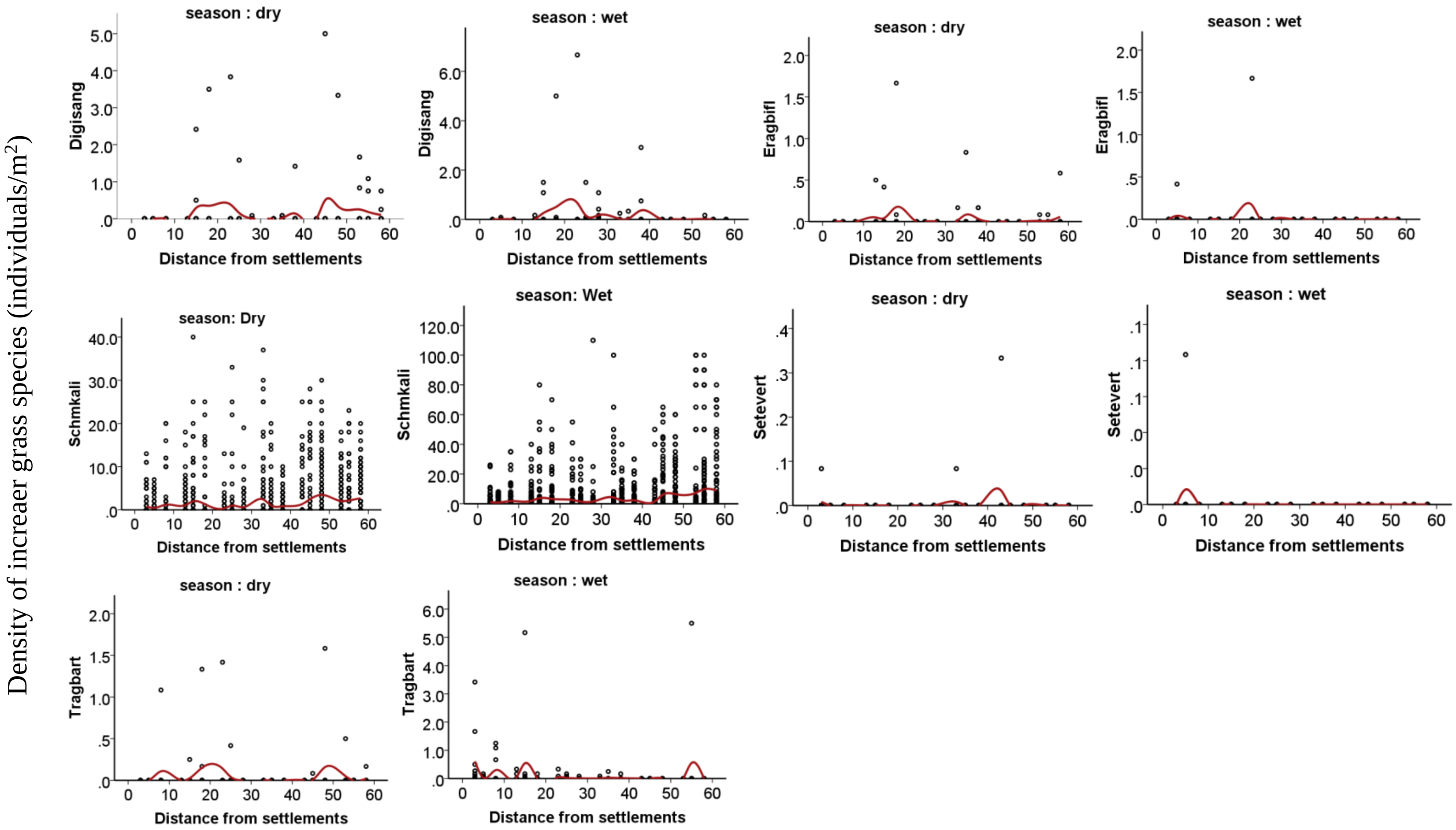


Figure 4.5 continues: Scatter plots fitted with natural cubic splines interpolation to show the variation in distribution of abundance (M^{-2}) of grass species (increasers) (red line) in Kalahari, Botswana, plotted against distance from the settlements (km) in dry and wet season respectively. The y axis shows the density of grass species. Digisang = *Digitaria sanguinalis* L., Eragbifl = *Eragrostis biflora* (Hack*),* Schmkali = *Schmidtia kalihariensis* (Stent), Setevert = *Seteria verticillata* (L.), Tragbart = *Tragus barteronianus* (Schult).

The distribution of forb species in relation to other environmental variables

A total of eight and five environmental variables (Table 4.4B) statistically significantly influenced the distribution of forb species in the dry and wet season respectively. These variables explained variances of 23% (dry) and 15.2% (wet) in the forb species data ($p < 0.05$) (Table 4.3A), while thirteen and sixteen environmental variables were omitted ($p > 0.05$) due negligent variance in dry and wet season respectively. The omission of these environmental variables resulted into the eigenvalues of the first two axes explaining 13% (dry) and 9.9% (wet) of the total variation in forb species data set (Table 4.3A). The retained environmental variables were not highly correlated; hence no multicollinearity between the variables as evident through the correlation coefficients and all their variance inflation factors (VIF) values are less than 10 (Appendix 4D). The Monte Carlo test of significance showed that there was a significant fit between the retained environmental variables and species composition along the first and second canonical axes at 1% and 5% significance level respectively. Land use (16.4%) explained most of the variations in forb species data, followed by Forb density (11.6%) and Habitat type (7.18%) in a dry season, while in wet season forb density (17.4%) explained most of the variations followed by grass height (12.6%) (Appendix 4D).

Land use (CGAs = 0.670), unpalatable perennial grasses (0.460) and arable agriculture fields (0.2916) have the highest positive correlations along the first axis respectively. However, distance from the settlements (-0.635), grass height (-0.5567) and grass cover (-0.415) have the negative association with the first axis (Table 4.3B). Therefore, showing the most significant environmental variables influencing distribution of forb species. The other important variables influencing the distribution of forbs were Grass cover (0.333) and grass height (0.2346), which had the highest positive correlation respectively, and forb density (-0.4997), unpalatable perennial (-0.156) having the highest negative correlation with the second axis (Table 4.3B). Therefore, the first axis represents livestock grazing intensity increasing from the left to right, while the second axis reflects livestock grazing intensity was increasing from the top to bottom during the dry season (Figure 4.6A).

Table 4. 4: Summary of the forward selection and the inter-set correlation of coefficients of the environmental variables with species axis for forbs. Bold figures in Table 4.4B, show variables with the highest correlation coefficients (- or +)

Data is for dry and wet seasons. A) **Summary of the forward selection**

	Dry season				**Wet season**			
Axes	**AX1**	**AX2**	**AX3**	**Total Inertia**	**AX1**	**AX2**	**AX3**	**Total inertia**
Eigenvalues	0.293	0.221	0.106	3.918	0.28	0.182	0.147	4.676
Species-environment correlations	0.797	0.684	0.679		0.806	0.729	0.686	
Cumulative percentage variance								
of species data	7.5	13.1	15.8		6	9.9	13	
of species-environment relation	32.5	56.9	68.6		39.3	64.8	85.4	
Sum of all eigenvalues				3.918				4.676
Sum of all canonical eigenvalue				0.903				0.713

B) **Inter-set correlation of coefficients**

	Dry season			**Wet season**		
Variables	**AX1**	**AX2**	**AX3**	**AX1**	**AX2**	**AX3**
Land use (CGA)	**0.6709**	0.077	0.0847			
High livestock grazing intensity				**0.546**	**0.4312**	0.0503
Habitat type (AAF)	**0.2916**	-0.0779	-0.4444	0.1517	**0.3389**	0.4719
Grass height				**-0.4022**	**-0.6072**	0.0266
Annual rainfall	**0.3387**	**0.3013**	0.1561			
Distance from settlements	**-0.635**	-0.1051	0.2133			
Grass cover	**-0.4151**	**0.3333**	-0.1699			
Grass height	**-0.5567**	0.2346	0.0253			
Un Palatable perennial	**0.4601**	-0.156	-0.0121			
Forb density	-0.1015	**-0.4997**	0.0155	**0.7254**	-0.0127	-0.1697
Grass diversity				-0.2108	-0.0239	-0.2673

During the wet season, the most significant environmental variables were forb density (0.7254), livestock grazing intensity (0.546), grass height (-0.4022) and grass diversity (-0.2108), which had the highest positive and negative correlation with the first axis (Table 4.3B). Hence it was inferred that the first axis was mainly a gradient of livestock grazing and high forb density increasing from the left to right. The other relevant variables were high livestock grazing intensity (0.4312) and arable Fields (0.3389), grass height (-0.6072) and grass diversity (-0.0239) showing the strong correlation with the second axis, consequently showing livestock grazing gradient increasing from the bottom upwards (Figure 4.6B). Therefore, implying that high forb density is associated with livestock grazing intensity and negatively correlated with grass diversity and tall grasses further away from the settlements.

During the dry season forb density was negatively correlated with livestock grazing intensity and also negatively correlated with grass cover and height, but associated more with CAs than CGAs (Figure 4.6A). Showing that high density of forbs was found in moderately grazed areas in dry season. Most of the forb species were related to CGAs (22) than CAs (10). During the dry season most of the forb species, for example, *Evolvulus alsinoides*, *Hermbstaedtia fleckii*, *Malhania prostrata*, *Indigofera alternans*, *Indigofera flavicans*, *Sida chrysantha*, *Requienia sphaerosperma*, *Gisekia africana*, *Aptosimum elongatum*, were negatively correlated with grass cover, height and associated with increasing grazing intensity in the CGAs (Figure 4.6A).

Forb species positively associated with forb density in CGA (in moderately grazed areas) were *Indigofera alternans*, *Indigofera flavicans*, *Gisekia africana*, *Aptosimum elongatum, Cyamopsis serrata, Sida cordifolia, Athrixia elata, Chamaesyce protrata*, *Acrotome inflate* (blue circle). However, some of the forb species were negatively associated with forb density and related to CGAs (in highly livestock grazing intensity) were *Limeum fenestratum, Gisekia pharnacoides, Crotalaria sphaerocarpa, Macrotyloma axillare, Sida chrysantha, Evolvulus alsinoides Requienia sphaerosperma, Senna italica*, and *Hermbstaedtia fleckii* (Figure 4.6A). Other forb species were associated high grass cover and tall grasses in CAs. Most of the forb species were associated less grass cover in CGAs, while few others were found in areas with high grass cover. It is worth noting that, despite that most of the forb species were associated with the CGAs, forbs were rare closer to the settlements during the dry season.

Unlike the dry season, forb density was positively correlated with livestock grazing intensity and arable fields in CGAs and negatively associated with grass diversity and tall grasses during the wet season (Figure 4.6B). However, forb diversity tends to increase with less grazing intensity. High forb density, low grass diversity and less forb diversity were related to livestock grazing intensity in wet season. Forb species such as *Striga gesneriodes, Indigofera flavicans, Indigofera alternans, Ocimum americanum, Chamaecrista mimosoides, Geigeria burkei, Gisekia pharnacoides*, *Sida cordifolia, Evolvulus alsinoides, Athrixia elata, solanum supinum,* (Figure 4.6B) favoured areas with high livestock grazing intensity, short grasses and around arable fields.

However, some of the forb species such as *Striga gesneriodes, Athrixia elata, Indigofera alternans, Indigofera flavicans, Chamaecrista mimosoides* were related to forb density and weakly associated with grass height. The rest of the forb species were not associated with grazing intensity, forb density and arable fields, but correlated with high grass diversity and tall grasses in areas with less livestock grazing intensity (Figure 4.6B). Most of the annual forbs such as *Chamaesyce protrata, Crotalaria sphaerocarpa, Cyamopsis serrata*, *Helichrysum argyrosphaerum*, *Limeum fenestratum, Oxygonum alatum* were associated with grass height and negatively associated with increasing grazing intensity during the wet season.

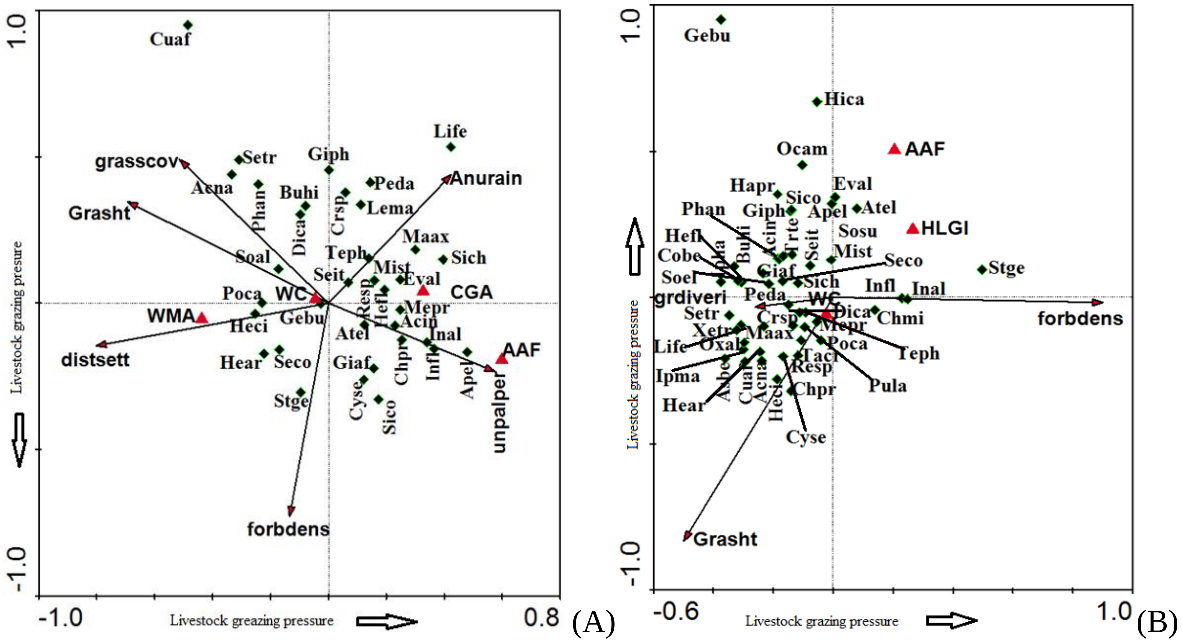


Figure 4. 6: Forb species ordination diagram based on canonical correspondence analysis - CCA

The forb densities with respect to environmental variables during the dry season (A) and wet (B) season respectively. Quantitative and qualitative environmental variables are indicated by arrows and triangles respectively. Forb species variables are shown as green dots. The species – environmental correlation for the first two axes are 0.797 and 0.684 (A) and 0.806 and 0.729 (B) respectively (eigenvalue 1 = 0.293, eigenvalue 2 = 0.221; scaling = 2, sum of all canonical eigenvalues is 0.903) (**A**) and (eigenvalue 1 = 0.28, eigenvalue 2 = 0.182; scaling = 2, sum of all canonical eigenvalues is 0.713) (B). Distsett, = distance from settlements, grasscov = grass cover, unpalpere =un-palatable perennial grasses, Anurain = annual rainfall and grasht = grass height. Land use (CGA = communal grazing area, CA = wildlife management areas) and habitat type (AAF = arable agriculture fields, WC = woody cover), grazing intensity (HLGI = high livestock grazing intensity). Cuaf - *Cucumis africanus*, Life - *Limeum fenestratum*, Peda - *Pergularia daemia*, Maax - *Macrotyloma axillare*, Crsp - *Crotalaria sphaerocarpa*, Tepu - *Tephrosia purpurea* , Seit - *Senna italica*, Eval - *Evolvulus alsinoides*, Sico - *Sida cordifolia* , Hefl - *Hermbstaedtia fleckii*, Resp - *Requienia sphaerosperma*, Atel - *Athrixia elata*, Chpr - *Chamaesyce protrata*, Infl - *Indigofera flavicans*, Apel - *Aptosimum elongatum*, Cyse - *Cyamopsis serrata*, Giaf - *Gisekia africana*, Sich - *Sida chrysantha* , Stge - *Striga gesneriodes*, Seco - *Senecio consanquineus*, Hear - *Helichrysum argyrosphaerum*, Heci - *Hellotropium ciliatum*, Gebu - *Geigeria burkei*, Dica - *Dicoma capensis*, (also refer to Appendix C for ACRONYM).

4.3.3: Woody plant species distribution

Species composition

A total of 23 woody plant species were recorded in the present study, seven were classified as bush encroachment species, while 16 were non-bush encroachers. Twelve of the woody plant species (*Rhigozum brevispinosum, Cadaba termitaria, Diospyros lysioides, Ehretia rigida, Terminalia sericea, Acacia fleckii, Asparagus nelsii, Acacia hebeclada, Acacia karroo, Senegalia mellifera, Grewia flava, Ziziphus* mucronata) were positively associated with increasing livestock grazing intensity in CGAs, while the other woody plant species were not (Appendix 4E).

Woody plant species distribution and relationships with other environmental variables

Forward selection of the 21 environmental variables showed that only six (dry season) (Table 4.4B) and seven (wet season) (Table 4.4B) environmental variables statistically significantly explained the variance in the woody plant species data ($p < 0.05$), while the rest were omitted ($p > 0.05$). The omission of other environmental variables resulted into the eigenvalues of the first two axes remaining relatively low, showing the first and the second axes explaining only 16.7 % (dry season) (Table 4.4A) and 14.5% (wet season) (Table 4.4A) of the total variation in woody plant species data set. The retained environmental variables were not highly correlated, and there was no multicellularity between the variables. Annual rainfall (22%), tree canopy cover (11.2%), distance from the settlements (10.2%) and Land use (CA/CGA) (8.4%) explaining most of the variations respectively during the dry season. On the contrary, tree canopy cover (15%), moderate livestock grazing (12.5%) and distance from the settlements (9.8%) explaining most of the woody plant species variations respectively in the wet season. The environmental variables significantly influencing woody plant species composition along a livestock grazing gradient were land use, distance from the settlements and livestock grazing intensity.

Examining the inter-set correlation coefficients of the retained environmental variables in relation to species axes (Table 4.4B), indicate that annual rainfall (0.556), tree canopy cover (0.3311) and land use (CGAs) (0.199) were the most significant environmental variables. Hence, reflecting livestock grazing intensity gradient from left to right. However, the second axis shows that habitat type (arable agriculture fields) (0.513), tree canopy cover (0.439) and land use (CGA) (0.215) have the positive correlation. While the distance from the settlement (-0.571) and palatable perennial grasses (-0.232) have the negative correlation, indicating other relevant variables. Therefore, indicating livestock grazing intensity from the bottom up (Figure 4.7A) during the dry season. The same gradients apply in the wet season (Table 4.4B).

Tree canopy cover was negatively correlated with increasing distances from the settlements and CAs but positively related to CGAs (Figure 4.7). It was also negatively related to palatable perennial and positively associated unpalatable perennial grasses during the dry and wet seasons respectively. Palatable perennial grasses were highly correlated with distance from settlements and negatively with tree cover in the dry season, while in the wet season the unpalatable perennial grasses were associated with medium livestock grazing intensity. Suggesting that high tree canopy cover and unpalatable perennial grasses were associated with livestock grazing intensity in CGAs. However, palatable grasses were negatively associated with increasing grazing intensity. Tree species such as *Acacia hebeclada*, *Diospyros lysioide*, *Acacia karroo, Senegalia mellifera*, *Ziziphus mucronata*, were positively associated with high tree canopy cover in CGAs and negatively associated with distance from the village. The woody plants mentioned above are mainly bush encroachment species. The density of *Acacia karroo, Senegalia mellifera*, *Grewia flava, Acacia hebeclada,* tend to be high closer to the settlements and decrease with less livestock grazing intensity (Figure 4.7 & 4.8).

On the other hand, non-bush-encroachment plant species such as *Acacia luederitzii*, *Rhus tenuinervis*, *Vachellia haematoxylon*, *Dichrostachys cinerea*, *Bauhinia. Petersiana, Lonchocarpus nelsii*, *Rhus tenuinervis, Grewia retinervis, and Acacia fleckii* were positively related to increasing distances from settlements (less livestock grazing) (Figure 4.7 & 4.8). Other tree species, such as *Lycium bosciifolium, Asparagus nelsii*, *Kleinia longiflora*, *Cadaba termitaria, Rhigozum brevispinosum*, *Grewia flava* tend to show weakly to no association with distance from settlements. The densities of *Vachellia erioloba, Boscia albitrunca*, *Dichrostachys cinerea, Rhus tenuinervis and Lycium bosciifolium* showed an increasing trend with increasing distance from settlements. Areas with higher livestock grazing intensity were related to high tree canopy cover of mainly bush encroachment woody plant species, while none–bush encroachment woody species were negatively associated with livestock grazing intensity.

The results show that there is high bare ground and tree cover canopy closer to settlements and decrease with less livestock grazing intensity in both seasons. On the contrary, grass cover increases with increasing distances from settlements in both seasons, while forb cover increases and decreases with distance from settlements during the dry and wet season respectively. Even though total woody density is high closer to the settlements, averagely the highest total density (1333 plants/ha) of woody plant species was less than the critical value for bush encroachment (2400 plants/ha).

Table 4. 5: Summary of the forward selection and the inter-set correlation of coefficients of the environmental variables with species axis for woody plants.

Bold figures in Table 4.5B, show variables with the highest correlation coefficients (- or +). Data in dry and wet season

A) **Summary of the forward selection**

	Dry season				**Wet season**			
Axes	**AX1**	**AX2**	**AX3**	**Total inertia**	**AX1**	**AX2**	**AX3**	**Total inertia**
Eigenvalues	0.212	0.09	0.049	1.812	0.178	0.084	0.045	1.812
Species-environment correlations	0.733	0.78	0.543		0.695	0.749	0.548	
Cumulative percentage variance								
of species data	11.7	16.7	19.4		9.8	14.5	16.9	
of species-environment relation:	51.7	73.6	85.4		47.1	69.5	81.4	
Sum of all eigenvalues				1.812				1.812
Sum of all canonical eigenvalues				0.411				0.377

B) **Inter-set correlation of coefficients**

	Dry season			**Wet season**		
Variables	**AX1**	**AX2**	**AX3**	**AX1**	**AX2**	**AX3**
Livestock grazing intensity				**0.4334**	-0.1189	0.0116
Land use (CA/CGA)	0.1988	0.2152	-0.1553	0.1963	**0.2998**	-0.1176
Habitat type (WC/AAF)	-0.1291	**0.5127**	-0.0785	-0.1963	**0.4563**	-0.0807
Annual rainfall	**0.5556**	0.2562	0.2424	0.1604	0.277	0.4814
Distance from settlements	0.1667	**-0.5706**	0.0672	0.228	**-0.5096**	0.04
Palatable perennial grasses	0.0901	-0.2322	0.3555	**0.3318**	0.1233	0.0191
Total tree cover	**0.3311**	**0.4398**	-0.2579	**0.299**	0.58	-0.0795

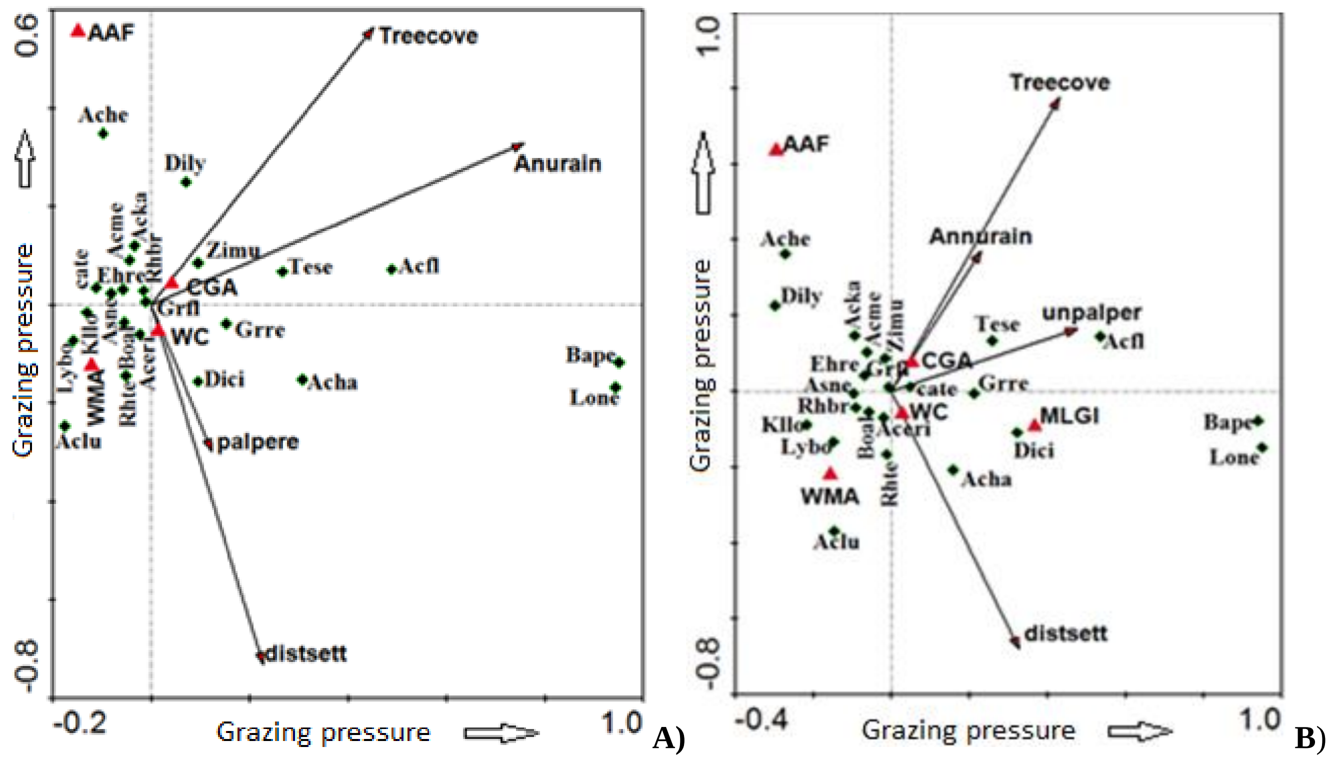


Figure 4. 7: Woody plants ordination diagram based on canonical correspondence analysis - CCA

(A & B) Woody plant densities with respect to environmental variables during the dry and wet seasons respectively. Quantitative and qualitative environmental variables are indicated by arrows and triangles respectively. Tree species variables are shown as green dots. The species – environmental correlation for the first two axes are 0.733 & 0.78 (dry), 0.695 & 0.749 (wet), respectively (eigenvalue 1 = 0.212 (dry), 0.178 (wet), eigenvalue 2 = 0.09 (dry), 0.084 (wet); scaling = 2, sum of all canonical eigenvalues is 0.411 & 0.377 respectively). distsett = distance from settlements, palpere = palatable perennial grasses, Anurain = annual rainfall, Treecove = total tree cover. Habitat type (AAF = arable agriculture fields, WC = woody cover) and land use (CA = Wildlife Management Areas, CGA = Communal Grazing Areas). Livestock grazing intensity (MLGI = medium livestock grazing intensity). *Vachellia hebeclada* (Ache), *Acacia eriloba* (ACeri), *Vachellia haematoxylon* (Acha), *Acacia karroo* (Acka), *Acacia luederitzii* (Aclu), *Senegalia mellifera* (Acme), *Boscia albitrunca (Boal)*, *Cadaba termitaria (Cate)*, *Dichrostachys cinerea* (Dici), *Diospyros lysioides* (Dily), *Ehretia rigida* (Ehre), *Grewia. Flava (Grfl)*, *Grewia retinervis* (Grre), *Lycium bosciifolium* (Lybo), *Rhus tenuinervis (*Rhte), *Terminalia sericea* (Tese), *Ziziphus mucronata (*Zimu), *Acacia fleckii* (Acfl), *Asparagus nelsii* (Asne), *Kleinia longiflora (Kllo)*, *Lonchocarpus nelsii (*Lone*)*, *Bauhinia. Petersiana* (Bape), Rhigozum brevispinosum (Rhbr). Tree species negatively associated with distance and closely related to the CGAs).

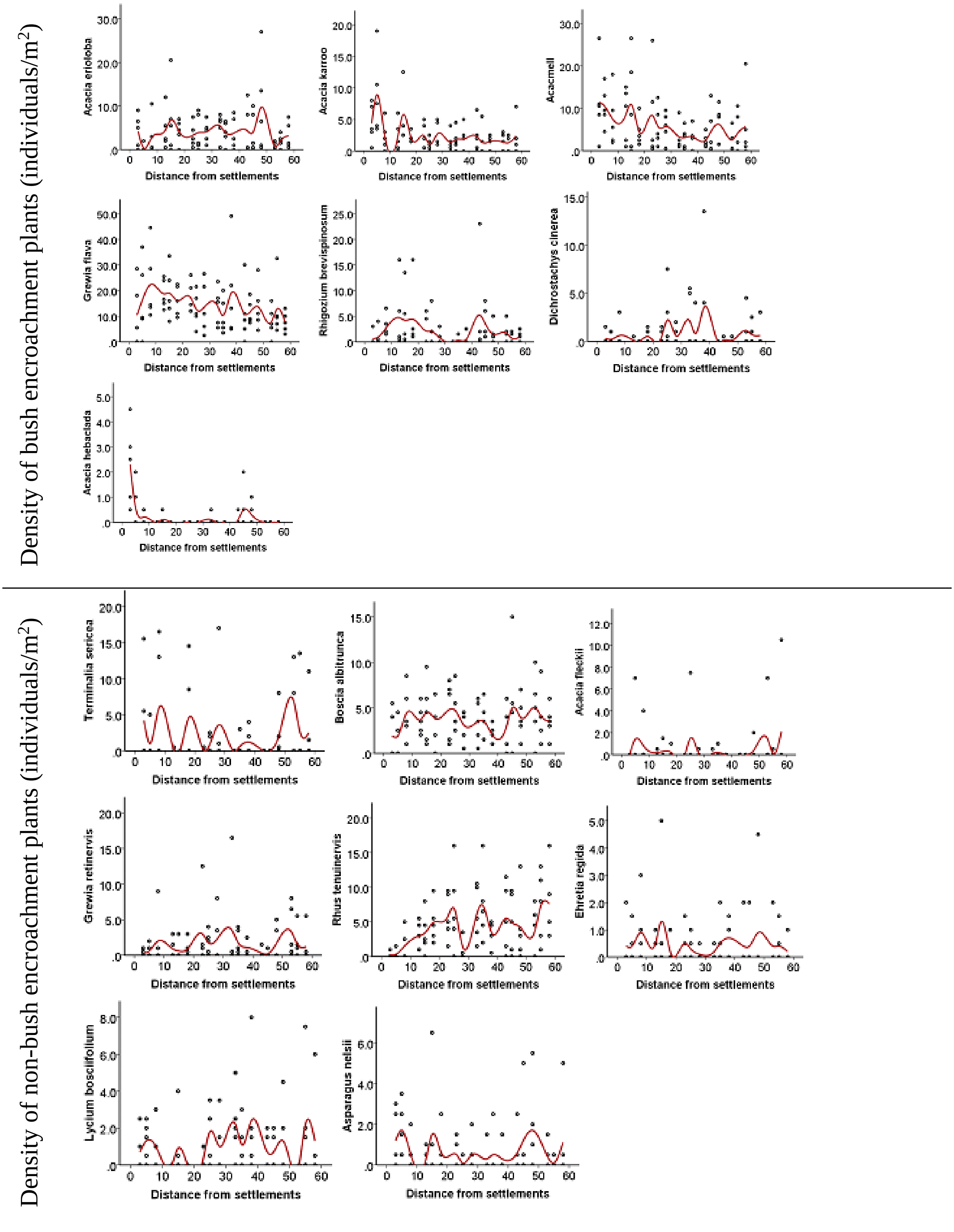


Figure 4. 8: Scatter plots showing the variation in distribution of dominant bush encroachment (top) and non-bush encroachment (bottom) woody plants pecies.

Scatter plots are fitted with natural cubic splines interpolation to show the trend in the variation in the distribution of the density ($900M^{-2}$) of the dominant woody plant species (red line) in Kalahari, plotted against distance from the settlements (km) (less livestock grazing intensity gradient). Bush encroachment species are *Vachellia hebeclada (Accia hebeclada), Vachellia karroo (Acacia eriloba), Vachellia karroo (Acacia karroo), Senegalia mellifera (Acacia mellifera), Grewia flava, Rhigozium brevispinosum .*

4.4: Discussion

Livestock grazing intensity in human-dominated communally managed rangelands in Kalahari rangelands has the potential to compete with wildlife for grazing resources or facilitate grazing for other wildlife species depending on the body size. Conversely, there are few studies relating the effect of livestock grazing to forage availability and vegetation heterogeneity and in turn how they influence the distribution of wild herbivores and carnivores of different body sizes. Therefore, this Chapter evaluated forage resource availability and vegetation heterogeneity along a free-ranging livestock grazing and pastoral activities disturbance gradients and across the land use types during the wet and dry seasons in the Kalahari rangelands.

The results revealed the difference in spatial vegetation heterogeneity with livestock grazing and pastoral activities disturbance gradients from the settlements and across land-use types. As expected (H1a), vegetation heterogeneity (i.e. a mixture of herbaceous and woody plants) was increasing with moderate livestock grazing and decreasing in areas with increased livestock grazing intensity in CGAs and in CAs. The CAs were associated with palatable tall perennial grasses, which is consistent with (H1d), while areas with increased LGI in CGAs had increased woody plant density, less grass cover and bare ground in both seasons, which agrees with the hypotheses (H1c & e). Therefore, confirming that areas with increased LGI in CGAs (i.e. closer to cattle posts and settlements) had low forage quality and quantity (i.e. unpalatable perennial and annual grasses, forbs and reduced grass cover), which is consistent with hypothesis (H1c), while areas in CAs had high quantity during both seasons, which is consistent with (H1d). As expected (H1c & c), increased LGI in CGAs promoted forb density & cover, woody plant density & cover and unpalatable annual grasses (increasers); hence, during the wet season unpalatable annual grasses, forb species richness and density were associated with increased LGI in CGAs.

Furthermore, as expected (H1e), increased LGI was associated with a high density of woody plant species, reduced grass diversity, forb diversity, palatable perennial and annual grasses in both seasons. Therefore, Grass cover was negatively associated with woody plant density in both seasons, while forb cover was positively related to woody plant density in the wet season. Additionally, the density of bush encroachment woody plants species was related to the density of cattle posts and closer to settlements, while the density of non-bush encroachers was associated with increasing distance from settlements and cattle posts, which is consistent with (H1e). Nonetheless, moderate LGI in CGAs increased diversity & species richness of forbs, density, diversity & species richness of palatable perennial and annual grasses in both seasons. Hence, palatable perennial and annual grasses, unpalatable perennial grasses, herbaceous (grasses and forbs) cover, and diversity species richness were associated with moderate to less livestock grazing intensity (LGI) in CGAs and within CAs in both seasons. Therefore, indicating that moderately grazed areas were associated with high forage quality, which agrees with hypothesis (H1b). The following sections give a detailed discussion of vegetation heterogeneity concerning grass, forb and woody plants species in relation to previous studies.

4.4.1: Vegetation heterogeneity

Only the general spatial pattern of vegetation heterogeneity is discussed in this section and details of grasses, forbs and woody plant species in the other sections to follow. The composition of vegetation parameters varied with LGI and pastoral activities gradients (i.e. distance from the settlements), which agrees with a study from Kruger (South Africa) and Serengeti (Tanzania) National Parks by (Arnold, Anderson et al. 2014) who stated that livestock grazing generates functional heterogeneity through foraging activities, such as consumption of plants parts, trampling and deposit of dung and urine to the soil. Spatial variations of vegetation parameters are attributed to how each species respond to climatic conditions (Carr, Robertson et al. 2009, Muhumuza and Byarugaba 2009) and herbivory (Turner 1999). There were six general vegetation components that describe the vegetation heterogeneity along LGI and pastoral activities disturbance gradients within the study area; 1) Palatable perennial grasses, 2) increased tree density, 3) increased forb density/cover, 4) unpalatable perennials, 5) unpalatable annual grasses, 6) palatable annual grasses with forb diversity. Vegetation heterogeneity (a mixture of grasses and woody plants) was high in areas with moderate livestock grazing (between 15 to 25km from settlements), and less in areas closer to the settlements, which is consistent with hypothesis (H1a).

Areas characterized by palatable perennial grasses had high species richness of palatable perennials grasses, the density of palatable perennials, and grass cover/biomass and diversity. These areas had little to zero livestock grazing and mainly within CAs and areas further away from the settlements (Approximately >30km from settlements). Standing herbaceous grass biomass/cover and diversity was significantly high in CAs than CGAs; consequently, there were more palatable perennial grasses in CAs than CGAs in both seasons, which is consistent with (H1d). The variation of palatable perennial grass across land-use types is due to livestock grazing intensity (Weber, Jeltsch et al. 1998, Lin, Hong et al. 2010, Mbatha and Ward 2010, Kgosikoma 2012). Continuous grazing resulted in most palatable perennial grasses consumed over time (Sarmiento 1992) and being replaced by unpalatable plants, together with annual grasses and eventually forbs (Skarpe 1992). Besides, one study from Southern Botswana (Mphinyane, Tacheba et al. 2008) reported decreasing standing biomass as a reult of high livestock grazing intensity, which agrees with the present study because it shows the high per cent bare ground (i.e. overgrazing) within 15km from the main settlements.

The present study shows that areas near settlements and in areas with increasing livestock grazing intensity had the high woody plants density, which agrees with a study by (Moleele and Perkins 1998) and hypothesis (H1e). As a result, confirming rangeland degradation (Van Vegten 1984, Van Auken 2009). Historically high stocking rates have been distinguished as the main source of rangeland degradation (Heitschmidt and Taylor Jr 1991). The present study shows that areas near settlements had less total grass biomass and cover in both seasons, most likely because of overgrazing by livestock. Savanna vegetation is mainly exploited through livestock (Bilotta, Brazier et al. 2007) and bush encroachment is frequently associated with livestock disturbance (Walker, Ludwig et al. 1981) through their effect on fire frequency (Roques, O'connor et al. 2001). Overgrazing removes fuel load from rangelands, resulting in fewer fire frequencies (Heinl, Sliva et al. 2008, Lehmann, Prior et al. 2008); hence promoting woody plants regenerations.

Different studies have documented the presence of bush encroachment in Southern Africa (Acocks 1975). For example eastern Botswana (Van Vegten 1981, Abel and Blaikie 1989), western Kalahari (Skarpe 1986, Skarpe 1990), southern Kalahari (Blair Rains and Yalala 1972, Dougill, Akanyang et al. 2016), southern Botswana (Kgosikoma 2012) and northern Kalahari, which is also confirmed by this study. However, areas with high tree density do not reflect declining forage availability for all wildlife species, because woody species could benefit some wildlife species which browses or mixed feeders. For example, Steenbok, Duiker, and Springbok could take advantage of the palatable leaf browsing (TOIT 1993, Nagy and Knight 1994). Consequently, implying that rangelands closer to settlements are overgrazed, and have high tree density, hence resource competition with wild herbivores which are grazers and possibly facilitation to the browsers.

Rangeland areas with increased forb density/cover were characterized by high forb density, cover, and diversity during the wet season and these were intensively grazed areas but not near the settlements (approximately 10 – 20km from settlements). However, amid the dry season, these regions had increased bare ground possibly linked to livestock and wildlife grazing the forbs and dieback of annual forbs. Likewise, rangelands with high forb densities had less grass cover amid the dry season, but in the wet season, they are secured with unpalatable annual grasses, mainly *Schimidtia kalaharensis* Stent. Areas with high forbs are favourable to small-sized wild herbivores like Steenbok, Duiker, and Springbok because these animals feed on dicotyledonous plants (forbs and woody) (Owen-Smith 1982) (see Chapter 5). As a result, there is competition for grazing resources with bulk grasses (medium to large-sized wild herbivores) in the areas with high forb (see Chapter 5). On the contrary, areas with unpalatable perennials had high species richness and density of unpalatable perennial. Therefore, these were areas with moderate livestock grazing, further away from the settlements (about 20 – 30km from settlements), whereby selective grazing by livestock has exploited the palatable grass species. These areas are also composed of short palatable perennial and annual grasses with a diversity of forbs during the wet season, which is agrees with (H1b); hence these areas could attract wildlife species which are short grass specialist, such as Blue Wildebeest (Fynn and Bonyongo 2011).

Most of the areas within 15km from the settlements were dominated by medium palatable annual grasses, mainly *Schimidtia kalaharensis* Stent, which is in consistent with studies regionally (Skarpe 2000, Dougill, Akanyang et al. 2016). *Schimidtia kalaharensis* was classified as medium palatable annual because it is an essential pioneer grass, which occurs in overgrazed rangelands and despite its sour smell, it is grazed either green or dry by livestock (Oudtshoorn 2002). Other grass species occurred within 15km from the settlements (increased livestock grazing intensity), was unpalatable annual grasses such as *Aristida congesta* and *Tragus berteronianus* during the wet seasons. Therefore, as expected (H1c), suggesting low forage quality and quantity, thus resource competition between livestock and other wild herbivores within a radius of 15km from the settlements, more especially during the dry season.

4.4.2: Grass species distribution and relationships with other environmental variables

Plant species are more common unit used in the vegetation studies than plant functional types (Skarpe 2000). However, in the current study, plant functional types were also used to understand how plants adapt to environmental conditions such as herbivory (Landsberg, Lavorel et al. 1999). During the dry season, the most dominant perennial grass species (i.e. relative density) were *Eragrostis lehmannian*, *Eragrostis pallens*, *Schmidtia pappophoroides*, and *Stipagrostis uniplumis* respectively. The above mentioned perennial grasses, except *Eragrostis pallens*, were positively associated with less livestock grazing intensity and related to CAs in the dry season, which accords with (H1a & d), indicating that these rangelands were in good condition than areas within 15km from settlements. However, *Eragrostis pallens*, which has low desirability, was positively related to moderate livestock grazing intensity and associated with CGAs during the dry season, which agrees with other studies from Kalahari rangelands (Skarpe 1986, Perkins and Thomas 1993, Skarpe 2000).

The grass species mentioned above are tufted and perennial, therefore could be expected to be available in good rangelands in the dry season; consequently, their absence closer to settlements indicate overgrazing by livestock. Also, *Schmidtia pappophoroides* is stoloniferous, drought resistant grass (Oudtshoorn 2002); hence it is expected to be tolerant to grazing (Landsberg, Lavorel et al. 1999). However, it is more palatable than other perennial grasses, and it is extremely utilized. Hence it was related to less livestock grazing intensity in the dry season. On the other hand, annual grasses were dominated by *Schmidtia kalihariensis* and *Urochloa trichopus* and both were also positively associated with less livestock grazing intensity and weakly related to CAs during the dry season, while other grasses were less common. *Schmidtia kalihariensis* and *Urochloa trichopus* are great pioneer grasses and occur in overgrazed rangelands (Oudtshoorn 2002, Dougill, Akanyang et al. 2016); hence there are expected to be available near the settlements. However, their association with increasing distance from the settlement and cattle post during the dry season, also further indicate overgrazing and the potential for competition for forage resource between livestock and some wild herbivores near the settlements.

On the contrary, during the wet season most dominant perennial grass species were *Stipagrostis uniplumis, Eragrostis lehmannian, Schmidtia pappophoroides* and were all associated with less livestock grazing intensity in CGAs, which is an agreement with the hypotheses (H1 & b). Grass species richness (the number of grass species) increase in response to moderate livestock grazing (Cheng, Tsubo et al. 2011) due to the establishment of less dominant grasses and a variety of forbs. In the present study grass species richness decreased with increasing livestock grazing intensity, which agrees with previous research (Landsberg, Lavorel et al. 1999), hence indicating low-quality forage due to overgrazing by livestock. As expected (H1d), although the density of the dominant perennial grasses was related to moderately grazed rangelands in CGAs, high grass cover was positively related to CAs in the wet season, showing high forage quantity in the CAs. Grass species diversity tends to be high in moderately grazed areas in both seasons, which is consistent with hypothesis (H1b) and the previous study (Gilfedder and Kirkpatrick 1994), who argued that moderate levels of disturbance is needed to conserve native plant species. Therefore, suggesting high forage quality and facilitation for both wildlife and livestock (Owen-Smith 2002) in moderately grazed areas.

As predicted (H1b), moderate livestock grazing promoted regrowth of the dominant perennial grasses, compared to areas without livestock grazing; hence grazing facilitating to short-grass specialists wild herbivores such as wildebeest, impala, and gazelles (Owen-Smith 2004, Fynn 2012). Short grass, maintained by moderate livestock grazing in CGAs, provides forage quality, while taller grasses (e.g. CAs) provide forage reserve in the dry season and during drought (Owen-Smith 2004, Hobbs, Galvin et al. 2008, Hopcraft, Olff et al. 2010). Like the dry season, the dominant annual grass species *Schmidtia kalihariensis* was associated with less livestock grazing intensity and positively related to CAs, while *Urochloa trichopus* was negatively correlated with distance from settlements and grass cover and related to moderate livestock grazing intensity.

The increase in annual grasses in livestock dominated areas have been reported Kalahari rangelands (Skarpe 2000, Dougill, Akanyang et al. 2016); nonetheless, it was not in agreement with (H1c). However, in the present study, these dominant annual grasses decreased with increasing livestock grazing intensity (within 15km), in both seasons, which further suggests prevailing low forage quality and quantity due to overgrazing in rangelands within 15km from settlements. Consequently, indicating the possibility of competition for grazing resources between livestock and other wild herbivores. In developing countries, overgrazing and encroachment of arable fields into rangelands are considered the most prominent factors that are linked to rangelands degradation (Lipper, Dutilly-Diane et al. 2010). In the present study, within a radius of 10km from the settlements there was a high density of arable fields and cattle posts (Chapter 5); consequently, these areas have reduced grass cover, less perennial and palatable annual grasses in both seasons. The most likely explanation is that in CGAs, livestock is often overstocked, resulting in overusing the grazing resources mainly near the water points, arable fields, settlements and cattle posts (Moleele, Ringrose et al. 2002). In the study area most of the permanent water points for cattle were near the main settlements (Hukuntsi, Lokgwabe, Tshane and Lehututu); hence there is intensive grazing within 15km radius. Consequently, within a 15km, palatable perennial grasses, which are mainly decreasers, and palatable annuals were overused by livestock.

During the dry season, low to medium desirable perennial grass species such *Digitaria eriantha*, *Eragrostis pallens*, *Aristida meridionalis* and *Aristida stipitata* were negatively correlated with distance from settlements and associated with moderate livestock grazing in CGAs, possibly linked to selective livestock grazing. Continuous grazing leads to most palatable and nutritious plants consumed over time and being replaced by unpalatable plants, together with annual grasses (Skarpe 1992). For that reason, most of the palatable perennial grass species (decreasers) such as *Brachiaria nigropedata*, *Panicum maximum*, *Stipagrostis uniplumis*, *Schmidtia pappophoroides*, *Eragrostis lehmannian*, *Cenchrus cilliaris*, and *Anthephora pubescens* were positively associated with increasing distance from settlements and related to less livestock grazing intensity and in CAs in both seasons.

The increase of palatable perennial grass with less livestock grazing intensity has been reported in Kalahari rangelands (Skarpe 1986). Grass species differ along a livestock grazing gradient not only because of their palatability but also because they differ phenologically, for example, some grasses have rhizomes, tufted, stoloniferous, shade and not shade intolerant (Smit 1994, Snyman 1998). Although *Digitaria eriantha* is a palatable grass species, it was sparsely associated with moderately grazed areas in both seasons, possibly because it is drought and grazing tolerant (Oudtshoorn 2002) and also because it is stoloniferous. Hence it can escape moderate livestock grazing (Strohbach

1992, Landsberg, Lavorel et al. 1999). *Eragrostis pallens* is a tough grass which is barely grazed; however, its inflorescence utilised by livestock, while *Aristida meridionalis* is also a tough grass and it is slightly grazed in the early wet season. *Aristida stipitata* is a tough grass with low leaf production and it was sparsely distributed along the entire livestock grazing gradient, and in most cases, its common occurrence is an indicator of overgrazing (Oudtshoorn 2002). Hence the grass species mentioned above were associated with moderately grazed rangelands.

Perennial grasses, such as *Brachiaria nigropedata Panicum maximum Anthephora pubescens Cenchrus cilliaris* are highly palatable with high leaf production, and there are easily overused by livestock. Their presence is an indication of good veld conditions. Similarly, *Stipagrostis uniplumis*, *Schmidtia pappophoroides*, *Eragrostis lehmannian* are relatively palatable perennial grasses with limited leaf production and because they are the most dominant grasses in the semi-arid rangelands; hence there are important grasses in the Kalahari rangelands. *Schmidtia pappophoroides* and *Eragrostis lehmannian* are drought resistant, and grazing tolerant grasses and *Eragrostis lehmannian* is one of the grass that starts growing in the early rains, hence valuable for livestock grazing (Oudtshoorn 2002). Consequently, these perennial grasses are being overused in areas with high livestock grazing intensity and were associated with less livestock grazing intensity because. Strohbach, 1992 also report the decline of *Brachiaria nigropedata, Anthephora, pubescens Stipagrostis uniplumis*, *Schmidtia pappophoroides*, *Eragrostis* with overgrazing in Grootfontein District, Namibia.

Most of the annual grasses (increaser species), such as *Schmidtia kalihariensis* and *Urochloa trichopus, Seteria verticillata* were associated with moderate livestock grazing intensity in both seasons. However, unpalatable annuals, such as *Aristida congesta, Aristida stipitata* and *Tragus barteronianus* showed an increasing trend with increasing livestock grazing intensity closer to settlements is an indicator of overgrazing (Trollope, Trollope et al. 1990) and rangeland degradation. Nonetheless, *Schmidtia kalihariensis* was negatively correlated with high distances from the cattle post in wet, indicating that during the wet season this low to medium desirable annual grass also occurred closer to the cattle posts (Dougill, Akanyang et al. 2016) located further away from the settlements. CGAs had high and lower density of annuals and unpalatable perennials grass respectively, a pattern which is consistent with other studies elsewhere (Friedel, Bastin et al. 1988, Noy-Meir, Gutman et al. 1989, Whitford, De Soyza et al. 1998, Skarpe 2000, Tefera, Snyman et al. 2007, Kgosikoma 2012). Therefore, suggesting that perennial grasses, has been replaced by annuals due to continuous livestock grazing intensity. Plant species with above-ground meristems have been reported to decrease under grazing in Australia (Tremont 1994), South Africa (Danckwerts and Stuart-Hill 1987) and South America (Sarmiento 1992).

The high density of annuals, bare ground, and forbs is an indicator that the rangeland is overgrazed (Du Plessis, Bredenkamp et al. 1998, Skarpe 2000), therefore, suggesting that closer to settlements, there is overgrazing. A Similar pattern has also been documented in areas that are overgrazed in arid and semi-arid rangelands for example Botswana (Mphinyane and Rethman 2006) and elsewhere (O'Connor 1991). Nonetheless, rangelands with a high density of annual grasses do not mean that the herbaceous productivity declines (Shackleton 1993), because some annual grasses have medium to high palatability; however, there is reduced forage availability for the dry season. For example, in the present study the following annual grasses were classified as palatable *Urochloa trichopus, Schmidtia kalihariensis, Seteria verticillata, Schmidtia kalihariensis, Dactyloctenium aegyptium, Dactyloctenium giganteum, Eragrostis biflora*.

4.4.3: Forb species distribution and relationships with other environmental variables

In the present study, in terms of species richness, there were more forb species (53), followed by grasses (29) and woody plants (23) species. Though the majority of the rangelands have more forb species than other vegetation, past investigations on forage availability have disregarded forbs as a potential for forage accessibility and concentrated on grass efficiency (Hayes and Holl 2003). However, forbs make part of the diets of domestic (e.g. sheep, donkey) and wild herbivores (e.g. Springbok, Steenbok). Therefore, in the present study forbs were included in the determination of forage availability in relation to livestock grazing gradient. Most of the variation in forb species was influenced by land use types, forb density, and habitat type; consequently, the number (forb species richness) and density of forbs were associated with livestock grazing intensity in CGAs compared to the CAs in both seasons. Therefore, implying facilitation of forb production by livestock grazing.

Supprisingly, during the dry season, high forb density was found in moderately grazed areas, which is not in agreement with hypothesis (H1c), most likely due to livestock utilizing and trampling of the forbs closer to the settlements because of the shortage of grass. How it is consistentwith (du Toit 2003), who reported that savanna grazers utilize forbs significantly during the dry season. However, as expected (H1c), in wet season forb density was positively correlated with livestock grazing intensity near settlements. Rangelands with a large bare ground in CGAs were also associated with high forb cover, a pattern similar to studies in Botswana (Skarpe 2000, Kgosikoma 2012), South Africa (Smet and Ward 2005), and southern Ethiopia (Tefera, Snyman et al. 2007). Forb diversity was positively related to moderately grazed areas in both seasons, which is consistent with hypothesis (H1c). Therefore, implying that increasing livestock grazing does not only influences high forb density and cover, but reduces forb diversity, grass diversity and cover, which is consistent with the previous study (Dorrough, Ash et al. 2004). The results show that most of the forb species prefer less grass cover in CGAs, while few forb species prefer high grass cover, mainly in CAs. The possible explanation could be linked to herbaceous cover, height and litter depth, which reduces forb species richness and density (Hayes and Holl 2003). As a result minimizing light reaching the understory (Tilman 1993) and increase in competition for moisture and nutrients. Kgosikoma (2012) also found out that communal land had high forb cover than ranches, which is an indicator of rangeland degradation (Whitford, De Soyza et al. 1998).

Continuous grazing promoted forb species production by reducing grass cover, hence less competition for nutrients, sunlight, and moisture (Sternberg, Gutman et al. 2000, Jacobs and Naiman 2008). These findings agrees with studies in Australia (Fensham, Holman et al. 1999) and the USA (Knapp, Blair et al. 1999, Hayes and Holl 2003). Sternberg et al. (2000) found out that reduction in tall grass cover, correlated with prostrate annual legumes and less palatable forbs. Jacobs and Neiman (2008) also reported that in the absence of livestock grazing, fast growing grasses shaded the forbs in the understory and the forb species richness declined. In the present study, the number of forb species was also high in CGAs than CAs in both seasons. Hence, implying that continuous heavy grazing by livestock promotes forb production through reduction of grass cover. Resulting in competition for forage resource (mainly grasses) with wild herbivores and possibly facilitation to other wild herbivores preferring dicotyledonous plants (forbs) (e.g. Springbok, Steenbok).

Forb species such as *Striga gesneriodes, Indigofera flavicans, Indigofera alternans, Ocimum americanum, Chamaecrista mimosoides, Geigeria burkei, Gisekia pharnacoides, Sida cordifolia, Evolvulus alsinoides, Athrixia elata, solanum supinum,* favoured areas with increasing livestock grazing intensity, short grasses and around arable fields in wet season. However, in dry season, forb species, such as *Evolvulus alsinoides*, *Hermbstaedtia fleckii*, *Malhania prostrata*, *Indigofera alternans*, *Indigofera flavicans*, *Sida chrysantha*, *Requienia sphaerosperma*, *Gisekia africana*, *Aptosimum elongatum*, *Cyamopsis serrata*, *Sida cordifolia*, *Athrixia elata*, *Chamaesyce protrata*, *Acrotome inflate*, *Macrotyloma axillare, Senna italica,* and *Hermbstaedtia fleckii* were found to be associated with increasing livestock grazing but not closer to settlements. Most of the above-mentioned species are perennial forbs except *Striga gesneriodes. Cyamopsis serrata*, *Chamaesyce protrata*, *Acrotome inflate*. Suggesting that perennial forbs prefer less grass cover and possibly there are tolerant to grazing or maybe an indication that there may be not palatable (Nsinamwa, Moleele et al. 2005).

Perennial forbs in heavily grazed areas establish themselves faster in the early rains, and possibly over-shadowing the annual forbs and grasses germinating from seeds, through high cover. Landsberg et al., (1999) also reported an increase in forbs abundance in relation to heavy grazing, a pattern which is also similar to the present study and some studies elsewhere (Friedel, Bastin et al. 1988, Noy-Meir, Gutman et al. 1989). Tall perennial and palatable forb species decline with increasing grazing intensity (Wahren, Papst et al. 1994); nonetheless, creeping forb species increase with high grazing intensity possibly because they can escape grazing by livestock (e.g. cattle) because of their growth form, as evidenced in the present study. Conversely, some of these creeping forbs, which are not palatable to cattle could be palatable to other small-sized wild herbivores, such as Springbok, Duiker and Steenbok (Toit 1993, Nagy and Knight 1994), as a result, implying grazing facilitation.

However, most of the annual forbs such as *Chamaesyce protrata*, *Crotalaria sphaerocarpa*, *Cyamopsis serrata*, *Helichrysum argyrosphaerum*, *Limeum fenestratum*, *Oxygonum alatum* were associated with grass height in moderately grazed areas and negatively associated with increasing grazing intensity. Therefore, implying that annual forbs prefer some partial cover from grasses in moderately grazed areas but does not prefer high density and cover of perennial forbs in heavily grazed areas. This distribution pattern agrees with other studies elsewhere (Foster and Gross 1998), which reported that in the desert environment, the herbaceous cover might help in establishment and growth of annual forbs through improving the hash micro-climate of the bare soils. Hence in the moderately grazed areas, the annual forbs receive both light and shade from the sparsely distributed herbaceous plants. Skarpe (2000) also reported that most of the unpalatable perennial forbs such as *Senna italica* (Mill.) increased with increasing livestock grazing, while the annual palatable forbs were positively associated with less livestock grazing intensity.

Most of the prostrate forb species were found in areas with increasing livestock grazing intensity possibly because of the reduced herbaceous cover due to openings created by intensive grazing. (Noy-Meir, Gutman et al. 1989, Fernández Alés, Laffarga et al. 1993, McIntyre, Lavorel et al. 1995). Both annual and perennial forbs decreased with increasing distance, mainly in CAs, possibly due to cover of perennial grasses. Perennial grasses allocate most of their resources to vegetation spread and underground structures, therefore, in the absence of livestock grazing they can out-compete the annual plant species through shading the understory (Oba, Vetaas et al. 2001). As a result, preventing the seeds of many annual plant species from germinating and establishing. However, in the presence of moderate grazing, openings are created which favours the germination and establishment of forbs (Dorrough, Ash et al. 2004), thus enabling more plant species to coexist (Olff and Ritchie 1998).

4.4.4: Woody plant species distribution and relationships with other environmental variables

Like forb species, studies estimating carrying capacity for grazing pastures have overlooked the importance of woody plants. However, some bush encroachment species are important in livestock diets than non-bush encroachers (Moleele 1998) and some wildlife species are mainly browsers; hence benefit from woody plants. In terms of species richness, there were more non-bush encroachers in the study area than bush encroachers. As expected (H1e), twelve of the bushecroachment woody plant species (*Rhigozum brevispinosum, Cadaba termitaria, Diospyros lysioides, Ehretia rigida, Terminalia sericea, Acacia fleckii, Asparagus nelsii, Vachellia hebeclada, Vachellia* *karroo*, *Senegalia mellifera*, *Grewia flava*, *Ziziphus mucronata*) were positively associated with increased livestock grazing intensity in CGAs.

Tree canopy cover, livestock grazing intensity and distance from the settlements explained most of the variation in woody plant species distribution. Tree canopy cover and density were positively associated with increased livestock grazing intensity near settlements and negatively related to palatable perennial grasses in both seasons. Implying that livestock grazing influences woody plant recruitment. Different types of soils could also influence woody plants distribution, however, for this study soil parameters were not measured. The findings of the present study provide additional evidence towards bush encroachment in semi-arid rangelands of Kalahari, which is consistent with the previous studies (Skarpe 1990, Jeltsch, Milton et al. 1996, Chanda, Totolo et al. 2003, Thomas and Twyman 2004, Reed, Dougill et al. 2007, Dougill, Akanyang et al. 2016). Grazing changes the balance between herbaceous and woody vegetation by reducing the amount of grass and promoting water and nutrients (from herbivore dung and urine) movement to the subsoil (tree roots zone), hence promoting also the deep-rooted woody vegetation growth (Prins 1996, Hopcraft 2000).

Savanna vegetation is mainly exploited through livestock grazing (Bilotta, Brazier et al. 2007) and increase in densities of bushes/trees is frequently associated with livestock disturbance into the semi-arid savannas (Walker, Ludwig et al. 1981), as also confirmed by the present study. However, the difference between the current study and other studies which reported bush encroachment is that transects in the current study were located starting from 3km away from the water points, and sample points were not located near boreholes. Hence the woody plant densities recorded were below the critical threshold of bush encroachment (2400 plantsha-1) (Roques, O'connor et al. 2001). Therefore, suggesting no indication of bush encroachment beyond 3km from settlements along with all the five transects. However, woody plant densities were increasing with increasing livestock grazing intensity in CGAs (highest 1333 plantsha^{-1}). Previous studies reported bush encroachment within 3 km from the water points or kraals (Moleele and Perkins 1998). Consequently, in the present study, it is also postulated that bush encroachment could be associated with boreholes, kraals and other natural water sources such as pans, as evidenced by the increase in tree densities in association with livestock grazing intensity compared to increasing distance from the village.

On the other hand, the present study shows that tree canopy cover and density were negatively associated with increasing distance from the settlements and in CAs. Unpalatable perennial grasses were associated with moderate livestock grazing intensity (high tree cover) in the wet season, while the palatable perennial grasses were related to less tree canopy cover in relation to increasing distance and CAs in both seasons. In the CAs, there is less livestock grazing; hence herbaceous biomass has accumulated at a high rate as compared to CGAs because wild herbivores are not good grazers resulting into some interactions between woody and herbaceous plants (Scholes and Archer 1997). Grass cover may influence woody plant recruitment directly (rivalry for light, water, and supplements), or indirectly (fire frequencies), when the trees are still sufficiently little to be in the grass layer (Caron, Miguel et al. 2013). Tree/hedge recruitment in regions with less livestock grazing, for example, CAs may happen during the period of moisture availability when resource competition from grsses is negligible. However, fuel load might make the savanna susceptible to fires (Joppa and Pfaff 2009), and hence limit the tree recruitment (Perkins and Thomas 1993). Therefore, resulting in less tree canopy cover or density, as confirmed by the present study.

On the contrary, in CGAs, increased livestock grazing reduces herbaceous biomass fuel loads in the dry seasons, therefore reducing the frequency, intensity and spatial extent of fires, hence promoting bush recruitment or increased tree densities (Dougill 2002). If the soil moisture is increased due to factors such as reduced grass biomass through grazing and suppressed frequent fires, then the shallow rooted woody vegetation, can increase in abundance (Cole and Brown 1976, Cole 1986, (Skarpe 1990, Scholes and Archer 1997), due to less resource competition. The high density of thorny shrubs limits the amount of light reaching the grass layer underneath (Belsky and Canham 1994). For example, *Senegalia mellifera* canopies intercept about 50% of the rainfall drops with their leaves and stems, hence limit the amount of rainfall that can be received by the grass under their canopies, thus facilitating bush encroachment (Donaldson 1969).

A change from grass-dominated savanna vegetation to bush-dominated vegetation has been attributed to overgrazing (Moleele and Perkins 1998) and lack of fire (Heinl, Sliva et al. 2008, Lehmann, Prior et al. 2008) and it is intensified by drought (Smith and Smith 2001). In the present study, increasing livestock grazing intensity was associated with high bare ground and tree cover canopy closer to settlements, and they decrease with increasing distance from settlements in both seasons. Grass cover was negatively associated with tree canopy cover in both seasons, while and forb cover was positively related to tree cover in the wet season. The high density of woody plants results into less grass cover (Oba, Post et al. 2000); hence less forage availability for both domestic and wild herbivores. However woody plants can be useful as browse (Moleele 1998) to domestic and other wild herbivores.

Pastoralism influences the structure and functioning of savanna landscapes through many ways, including fire suppression and livestock grazing, which have caused herbaceous degradation and increased woody plant (Sarmiento 1992, Moleele and Mainah 2003). Woody plant can positively or negatively change species composition, spatial distribution and productivity of grasses in savanna landscapes (Scholes and Archer 1997). However, trees and grasses can benefit from each other through improvement of harsh environmental conditions (Weltzin and Coughenour 1990, Vetaas 1992). Young and small trees facilitate the growth of grasses as compared to old and densely populated trees (Schuette, Leslie Jr et al. 1998, Kassa, Libois et al. 2008). Hence herbaceous diversity and production are facilitated more when there are few trees as compared when there are no trees (Scholes 1990, de Leeuw, Waweru et al. 2001, Hensman, Owen-Smith et al. 2013). Therefore, indicating that in the present study, high density and cover of woody plants is associated with increasing livestock grazing intensity near the settlements, resulting in reduced herbaceous production. However, less woody density and cover is associated with moderately grazed areas, hence influencing herbaceous diversity and production.

Bush encroachment species such as *Vachellia hebeclada, Diospyros lysioide, Vachellia karroo, Senegalia mellifera, Ziziphus mucronata*, were positively associated with increasing tree canopy cover (increasing livestock grazing intensity) in CGAs and negatively associated with distance from the village. Previous studies have shown *Senegalia mellifera* as one of the largest encroacher species in the semi-arid rangelands of the southern Kalahari (Moleele and Mainah 2003, Reed, Dougill et al. 2007). It is also a problem nationally (Perkins, Reed et al. 2013), in south Africa (O'Connor, Puttick et al. 2014) and Namibia (Joubert, Smit et al. 2013). On the other hand, non-bush-encroachment plant species such as *Vachellia luederitzii, Rhus tenuinervis, Vachellia* *haematoxylon, Dichrostachys cinerea, Bauhinia petersiana, Lonchocarpus nelsii, Rhus tenuinervis, Grewia retinervis*, and *Acacia fleckii* were positively related to less livestock grazing intensity with increasing distances from settlements. The densities of *Vachellia erioloba, Boscia albitrunca, Dichrostachys cinerea, Rhus tenuinervis and Lycium bosciifolium* showed an increasing trend with increasing distance, possibly because of the cutting for construction by the pastoralists.

Bush encroachment species distribution pattern is consistent with studies in Kalahari rangelands (Vegten 1984, Skarpe 1990, Skarpe 2000), who found out that *Vachellia hebeclada, Senegalia mellifera* increased with livestock grazing intensity. Therefore, the high density of bush encroachment woody species near the settlement further indicates overgrazing by livestock (Landsberg, O'Connor et al. 1999), hence competition for grazing resources with wild herbivores. *Grewia flava* may sometimes behave as an encroacher (Skarpe 1990), however, in the present study, it was weakly associated with distance, possibly linked to livestock browsing. Palatable woody species without protection from thorns, such as *Grewia flava*, are probably browsed by livestock than those with thorns (Moleele 1994); hence not associated with increased grazing intensity.

Even though cattle are grazers, they do browse during the dry season when the grazing resources are limited (Moleele 1998, Mphinyane, Tacheba et al. 2015). Consequently, the possibility for resource competition between cattle and other wildlife species which are browsers. Despite the fact that leaves of *Vachellia hebeclada, Vachellia karroo, Senegalia mellifera, Ziziphus mucronata* are nutritious, their thorns protect them from being browsed by cattle, and as a result, they increase with increasing livestock grazing intensity (Moleele and Perkins 1998). However, goats do benefit from the growing woody plant density because they are selective browsers all year around (Omphile 1997, Mkhize, Scogings et al. 2014). As a result, goats can withstand overgrazing better than cattle; however, there is a possibility for goats to also compete for browsing resources with small-sized herbivores such as duiker and steenbok. Steenbok and Duiker are browsers hence they also benefit from the same woody plants that are used by the small stock.

4.4.5: Limitations

Initially it was difficult to identify herbaceous plants during the dry season in the absence of inflorescence, however, through experience gained by the researcher, season after season, the identification became accurate over time. During the wet season, herbaceous identification was easier because the survey was conducted near end of the rainy season when most of the plants have produced inflorescence (Abule, Snyman et al. 2007). Vegetation survey methods have been used in the past to establish forage availability (Dougill, Akanyang et al. 2016), therefore it is an effective method to use.

4.5: Conclusions

Vegetation heterogeneity (i.e. a mixture of grasses, forbs and woody plants) was increasing with moderate livestock grazing and decreasing in areas with increased LGI in CGAs and CAs (CAs) in both seasons. Herbaceous species (grasses and forbs) distribution (i.e. short, palatable perennial and annual grasses, high grass and forb species richness and diversity) of high forage quality were associated with moderately grazed areas, while areas closer to settlements and cattle posts in the wet season had low forage quality and quantity due to high LGI. CAs were associated with high forage quantity during both seasons, but low quality during the wet season. Unpalatable perennial and annual grasses, forbs and reduced grass cover were associated with the increased livestock grazing intensity closer to cattle posts and settlements, showing overgrazing by livestock and low forage quality and quantity closer (< 15km) to the settlements and cattle posts. Areas with increased LGI in CGAs had increased woody plant density, less grass cover, increased forb density, and high percentage bare ground. On the contrary, CAs were associated with increased herbaceous cover, tall perennial grasses, and less woody plants in both seasons, indicating that livestock grazing influenced woody plant recruitment and the reduction palatable perennial grasses closer to cattle posts and settlements.

4.6: Recommendations

It is recommended that to reduce overgrazing by livestock within 15km from the settlements, livestock numbers at the watering points located in the main settlements, should be regulated through water reticulation to the areas where there are no boreholes in CGAs. Consequently, LGI will spread over a larger area, to promote moderate grazing, hence keeping the grass short and high quality, consequently, grazing facilitation for small to medium-sized herbivores. Water reticulation could be expensive, however, if farmers group themselves, possibly the government could assist. The recommended distance between the artificial boreholes should be maintained at least at the current status (8 x 8 km apart), to reduce grazing intensity between the boreholes. Allocation of commercial ranches within the CGAs should be discouraged because ranches will increase grazing intensity through “dual grazing rights” (Sallu, Twyman et al. 2009, Sebego, Atlhopheng et al. 2017) and reduce CGAs. Livestock in CGAs should be managed strategically to improve livestock husbandry (Ogada, Woodroffe et al. 2003), to minimise continuous livestock grazing throughout the year.

Chapter 5

Factors influencing the interactions between pastoralists, free-ranging livestock and wild herbivores of different body sizes

Abstract

Wildlife habitats in pastoral areas which are dominated by pastoral activities such as free-ranging livestock grazing, settlements, and other anthropogenic activities adjacent to conservation areas (CAs) are fragmented and degraded. Consequently, the possibility for the restriction in the distribution and seasonal movements of wild herbivores between CAs and these pastoral areas. Theory predicts that forage quantity influences the distribution of large-sized herbivores, while the digestive quality of grass and predation risk regulate small to medium-sized herbivores. However, this raises fundamental questions as to whether these ecological factors and mechanisms can be extrapolated to multiple herbivores in pastoral-dominated Communal Grazing Areas (CGAs), supporting free-ranging livestock in Kalahari. This study therefore, investigates interaction – specifically the levels of competition and facilitation – between livestock and wild herbivores and how this varies between the wet and dry season and wild herbivors' body size functional grouping and predation risk in the Kalahari. Sampling survey based on the use of wildlife and livestock spoor data, road-side field observations, cattle fitted with Global Positioning System telemetry is analysed. The major pastoral activities such as sedentary cattle posts, artificial boreholes for watering livestock, settlements and arable fields among others are mainly within the CGAs, near the four main settlements. Cattle travelled longer distances from the cattle posts for grazing during the dry (average 10.81 ± 0.77383 km) than wet (average 5.69 ± 0.3153 km) season. Large-sized herbivores, which suffer less predation, but require forage quantity, concentrated in CAs and avoided pastoral dominated areas in CGAs in both seasons, suggesting their preference for CAs in both seasons. Medium-sized herbivores, except Ostrich, that are susceptible to predation and the pastoralists-induced risks, but require quality forage avoided increasing livestock grazing intensity, pastoral dominated areas and were related to moderately grazed areas on CGAs, CAs boundary and in CAs in both seasons. Small-sized wild herbivores, except Springbok, which depend on high-quality forage but susceptible to predation risk, were associated with CGAs even in areas with increased livestock grazing intensity in both seasons, denoting facilitation. The results illustrate how the distribution of wild herbivores of different body sizes is influenced differentially by free-ranging livestock, forage availability, predation and pastoralists-induced risk in CGAs and adjacent CAs.

5.1: Introduction

In African rangelands, wildlife and pastoralists have lived together for more than 2000 years, and pastoralism is the economic backbone of most people in these rangelands. However, the increase in human population and land use pressure such as settlements (Lamprey and Reid 2004), cultivation (Serneels et al. 2001; Thompson and Homewood 2002), shifting from nomadic to sedentary pastoralism (Western et al. 2009), threaten this co-existence by changing vegetation structure. Before European hunters, indigenous trophy hunters and meat poachers, livestock and wild animals have co-existed successfully in most of the African rangelands (Parkipuny 1989), indicating that the pastoralists were capable of sustainable management of livestock, wildlife and their habitats (Osemeobo 1988). Also, livestock population density was small, and they had little impact on the environment compared to the current situation. Therefore, the interaction between pastoralism and wild herbivores is now a contested space (Kock 2005, Anthony 2006). Pastoral activities such as settlements and cattle posts among others are increasing closer to the CAs, for example, ranches near Masai Mara National Reserve (MMNR) in Kenya (Norton-Griffiths 2007) and the Kalahari rangelands, southern Africa (Perkins et al. 1998). The intensification of land use pressure is associated with the declining of wildlife in East Africa, for example in Mara (Broten and Said 1995, Ottichilo et al. 2001, Ogutu et al. 2009), Athi-Kaputiei (Reid et al. 2008b) and Laikipia (Georgiadis et al. 2007a). Hence the dominant traditional conservation paradigm emphasizes the importance of CAs in protecting wildlife from anthropogenic activities (Terborgh et al. 2002).

Although the traditional conservation paradigm assumes that pastoral activities are detrimental to wildlife, some studies suggest that moderate pastoral activities could benefit wild herbivores through long-term habitat modifications (Augustine, Veblen et al. 2011) and the effects on the forage resource base (Arsenault and Owen-Smith 2011, Odadi, Karachi et al. 2011). Wild herbivore species respond differently to pastoral activities depending on their body size, the type of feeding, nutritional quality, the quantity of forage and predation risk. In particular, the body size of herbivores influences the predation risk and forage requirements (Bhola, Ogutu et al. 2012), consequently, the grazing distribution. Intensification of anthropogenic activities in pastoral areas creates strong gradients of spatial heterogeneity in forage quality, quantity, vegetation heterogeneity (chapter 4), predation (chapter 6) and the pastoralists-induced risks between the CAs and pastoral areas (Bhola, Ogutu et al. 2012). Subsequently, locations with conditions that minimise predation and pastoralists-induced risk and maximises net effects of forage availability will influence the distribution and abundance of wild herbivores (McNaughton, Ruess et al. 1988, McNaughton 1990, Anderson, Hopcraft et al. 2010). These resource gradients vary both spatially and temporally between the CAs and the pastoral areas and temporally (Fryxell, Wilmshurst et al. 2005, Illius and O'Connor 2000, Owen-Smith and Mills 2006), hence contributing to the seasonal movements of wildlife (Fynn and Bonyongo 2011).

In general, predation risk is more significant in CAs than in CGAs due to vegetation cover in both the wet (Ogutu, Bhola et al. 2005) and dry seasons (Reid, Rainy et al. 2003). Subsequently, large predators, for example, Lion and Hyena, avoid pastoral activities in CGAs and concentrate in conservation areas (Ogutu, Bhola et al. 2005). As a result influences the distribution of small to medium-sized herbivores as they prefer areas with lower predation risk (Sinclair, Mduma et al. 2003). Large-sized herbivores prefer taller grasses to meet their more substantial requirements for biomass intake (Owen-Smith 1992) and are not as susceptible to predation as small-sized herbivores because they are more difficult to catch (Sinclair, Mduma et al. 2003). Wildlife habitats in CGAs near conservation areas are fragmented and degraded (Bhola, Ogutu et al. 2012), due to pastoralism, hence the possibility of restricting seasonal movements between conservation areas and CGAs. The expansion of settlements, population growth (Lamprey and Reid 2004), arable farming, and sedentary cattle posts (Western, Russell et al. 2009) alter vegetation composition and structure (Chapter 4) in African rangelands, hence influencing the grazing distribution of herbivores.

Despite the previous research on wildlife and livestock interactions, there is still controversy surrounding the relationship between free-ranging livestock, pastoralists, and wild herbivores. Studies in Tanzania (Voeten and Prins 1999) and Kenya (Young, Palmer et al. 2005) suggest that livestock either compete with wild herbivores for forage resource, or facilitates wild herbivore grazing (Gordon 1988), while other a study in Serengeti-Mara, suggests that wildlife and livestock can coexist and do not compete with wild herbivores (e.g., Homewood, Lambin et al. 2001). Also, some think that livestock can either facilitate or compete with wild herbivores depending on the season (Odadi, Karachi et al. 2011). Resource competition between two species happens if there is habitat overlap, a common diet, and the resources are limiting (De Boer and Prins 1990), also between prey and predator. Hence in the present study, to evaluate resource competition between free-ranging livestock and wild herbivores, the above definition is adopted.

In African tropical savannas, most studies on the distribution of wild herbivores have occurred in East Africa (McNaughton 1990, Ogutu, Bhola et al. 2005, Anderson, Hopcraft et al. 2010, Bhola, Ogutu et al. 2012), in protected areas and pastoral ranches (Mworia, Kinyamario et al. 2008, Bhola, Ogutu et al. 2012), where the herders actively control their livestock during the day. However, in southern Africa, there have been few studies (Verlinden 1997, Verlinden, Perkins et al. 1998, Anthony 2006, Wallgren, Skarpe et al. 2009) on the distribution of wild herbivores and free-ranging livestock and how they interact between extensive communal grazing rangelands surrounded by protected areas. Therefore, the distribution of wild herbivores between CGAs dominated by free-ranging livestock (not herded) and other pastoral activities, such as sedentary cattle posts, arable fields and free-ranging livestock in CGAs and CAs is less understood. In Kalahari, Botswana, livestock is free-ranging in CGAs during the day and controlled by the boreholes rather than the herders. However, little is known about cattle grazing distribution and how they interact with wild herbivores during different seasons.

The Kalahari rangelands are massive, semi-arid and consist of mainly infertile red sandy soil and several calcrete pans (Knight, Knighteloff et al. 1988) (section 3.1). The resident herbivores move seasonally between the CAs and the CGAs responding to variation in forage quality, quantity and predation risk (Ogutu, Piepho et al. 2008, Fynn and Bonyongo 2011). Therefore, the increase of sedentary cattle posts and other pastoral activities may interfere with the wild herbivores' grazing distribution across the Kalahari ecosystem (Verlinden 1997, Mbaiwa and Mbaiwa 2006). Human settlements and other pastoral activities in CGAs may interfere with the movement of wild herbivores to access the wet season (in CGAs) and dry season (CAs) grazing resources (Williamson, Williamson et al. 1988, Verlinden 1997). Therefore, there is a potential for herbivores exclusion from accessing nutritious grazing (e.g. moderately grazed areas) in CGAs, resulting in adverse impacts on the productivity and sustainability of wild herbivores (Hopcraft, Olff et al. 2010). Consequently, the aim of this Chapter was to use spatial data collection (using GPS telemetry) and spatial analysis tools (GIS) to investigate pastoralists, free-ranging livestock and wild herbivores interactions in extensive communal grazing rangelands, in northern Kalahari, Botswana.

Many terrestrial mammals are nocturnal, secretive in appearance, and they avoid being seen; therefore, it limits the direct observation methods, such as camera trapping, aerial survey and field observations among others in establishing distribution the distribution of herbivores (Chiarello 2000, Jachmann 2002). Nevertheless, most studies on the distribution of wildlife in African savanna rangelands commonly relied on aerial survey data (Verlinden, Perkins et al. 1998, Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012, Gandiwa 2014), field observations (Verlinden 1997, Bergström and Skarpe 1999, Ogutu and Dublin 2004, Mworia, Kinyamario et al. 2008, Wallgren, Skarpe et al. 2009) and camera trapping surveys (Burton, Sam et al. 2012, Carter, Shrestha et al. 2012) among others. However, indirect methods such as spoor/tracks could be a realistic option to explore information on the distribution of wild herbivores, because they give details of the presence of an animal and can quickly capture several tracks of animals that have been in the area for the past few days. Besides, few studies in the Kalahari rangelands, for example, (Verlinden, Perkins et al. 1998, Blaum, Tietjen et al. 2009) used spoor/truck methods in exploring free-ranging livestock and multi-species wildlife distribution. Despite the potential of GIS and GPS telemetry tools in monitoring the distribution of animals, none of the previous studies in the Kalahari rangelands have used these tools in determining the distribution of free-ranging livestock grazing and mapping the expansion of cattle posts and other anthropogenic activities influencing the distribution of wild herbivores.

The distribution and seasonal movement of herbivores in African savannas have been well studied within CAs and pastoral ranches of East Africa and these studies suggests forage quality, quantity and predation risk are the critical ecological factors controlling the distribution of wild herbivores (McNaughton 1990, Ogutu, Bhola et al. 2005, Anderson, Hopcraft et al. 2010, Hopcraft, Anderson et al. 2012). However, the role of these ecological factors and mechanisms in determining the distribution of multiple wild herbivores across a communally managed pastoral areas supporting free-ranging livestock adjacent to CAs of southern Africa has never been tested. Furthermore, information on the effects of the pastoralists-induced risk (i.e. direct or indirect human disturbance) on the distribution of herbivores species of different body size in Kalahari rangeland is seldom available. This study therefore, address this information gap by testing whether the theoretical expectation of the distribution of herbivores as influenced by body size-resources, predation relationships (as reviewed by Hopcraft, Olff et al. 2010, Hopcraft, Anderson et al. 2012) are consistent with empirical data on the distribution of multiple herbivore species across a landscape that differs in vegetation heterogeneity, forage availability (quality and quantity) (chapter 4) and the pastoralists-induced risk.

The hypotheses for this chapter were based on the forage availability (i.e. quality and quantity), predation and pastoralists-induced risk between the CAs and CGAs. Grass height influences predation risk, forage quality and quantity, while the pastoralists-induced risk is influenced by land use. In the wet season grasses in the CAs are tall due to the absence of livestock grazing in the reserve. Hence, they allocate more energy to structural fibre development with high carbon to nitrogen ratios, therefore, resulting in less nitrogen and phosphorous concentration available to herbivores (Anderson, et al. 2007). Consequently, digestibility and nutritional quality of grasses are inversely related to tall grasses (Hopcraft et al. 2012). Therefore, mature tall grasses are not favoured by small to medium herbivores (Fritz and Duncan, 1994; Olff, Ritchie and Prins, 2002). On the other hand, short grasses maintained by moderate livestock in the pastoral areas have high digestibility and nutritional quality (Bhola, Ogutu et al. 2012). Moderate livestock grazing promote more nutritional grasses, which attracts herbivores requiring quality forage (McNaughton, 1976), such as small to medium-sized herbivores (Fryxell, 1995) because of their smaller gastrointestinal tract which cannot digest more efficiently mature tall vegetation (Gagnon and Chew 2000, Wilmshurst, Fryxell et al. 2000). Therefore, small to medium herbivores should be getting higher protein consumption on moderately grazed areas in pastoral areas than from the CAs in the wet season.

Because of taller grass cover in the CAs than in CGAs (Chapter4, Reid et al. 2003), and increased human and livestock activities in CGAs (Ogutu et al. 2005), it is likely that predators are more plentiful in the CAs during the wet and dry seasons. Previous studies in Mara region (Kanga et al., 2011) and Serengeti (Hopcraft et al. 2005) have shown that predation increases with grass height. Moreover, in areas with short grasses in CGAs, predation is expected to be lower than CAs (Sinclair et al. 2003) because of the improved visibility against the predators (Hopcraft, Anderson et al. 2012), hence favouring the predation susceptible small to medium-sized herbivores. Therefore, the medium herbivores are likely to experience lower predation risk on the CGAs than CAs. Increased pastoral activities such as livestock grazing, cultivation, water points (Voeten and Prins

1999, Verlinden 1997, Serneels and Lambin 2001), human-induced risk such illegal hunting (Mfunda and Roskaft 2010) or human-wildlife conflict in pastoral areas also have a negative impact in the distribution of wild herbivores. In the dry season, forage availability is reduced in CGAs due to heavy grazing by livestock hence competition with wildlife, thus, forcing the small to medium herbivore to disperse into the CAs, where there is less grazing (Ogutu et al. 2008). Given the above views, the following four hypotheses were formulated based on herbivore body size, forage resources, prey availability, predation and pastoralists-induced risk relationships.

i) (H2a) The high density of pastoral activities such as cattle posts, arable fields, boreholes, livestock grazing intensity, livestock density would be higher closer to settlements. Therefore, free-ranging livestock will travel long distances from the settlements and cattle posts during the dry season than during wet seasons because of the shortage of forage resource in the dry season; hence, resource competition with wildlife is expected to be high in the dry season. Consequently, the distribution of the variety of wildlife species would be lower closer to settlements and cattle posts in CGAs because of direct and indirect disturbances (i.e. the pastoralists-induced risk) but increasing with distance from settlement and cattle posts in dry seasons.

ii) (H2b) The distribution of small-sized wild herbivores, such as Steenbok (*Raphicerus campestris* – Thunberg; 13 kg), would be higher in the moderately grazed areas in CGAs but increasing with distances from pastoral activities in both seasons ‘to benefit from short nutritious grasses maintained by moderate livestock grazing. Small-sized herbivores will also benefit from the improved visibility in the CGAs in both seasons (Fritz and Duncan 1994; Olff et al. 2002, Bhola, Ogutu et al. 2012), but negatively impacted by the pastoralists-induced risk in human-dominated areas, and predation risk (Sinclair and Arcese 1995b) in CAs.

iii) (H2c) On the contrary, the distribution of medium herbivores, such as Red Hartebeest (*Alcelaphus bucelaphus* – Hilaire; 150kg), would be higher in areas with moderate livestock grazing intensity in CGAs in the wet season to benefit from short grass (i.e. improved visibility) of satisfactory quality. Besides, they will be avoiding predation risk (Cromsigt 2006; Wilmshurst, Fryxell & Bergman

2000, Bhola et al. 2005) in CAs and the pastoralists-induced risk in human-dominated areas. However, the distribution of medium-sized herbivores would be higher in the CAs with higher quantities of grass in the dry season when the grass dries out and becomes too short in the CGAs (Bhola, Ogutu et al. 2012) due to heavy grazing by livestock, hence competition with livestock during the dry season.

iv) (H2d) The distribution of Large-sized herbivores, like Eland (*Tragelaphus oryx* – Pallas; 660 kg) would remain higher in CAs in both seasons because their energy demand can be satisfied by ingesting large quantities of low-quality forage (Demment and Van Soest 1985). Besides, they are not susceptible to predation risk (Fritz et al. 2002, Bhola, Ogutu et al. 2012) like small to medium sized wild herbivores, but there are prone to pastoralists-induced risk in CGAs, hence they would avoid human-dominated areas and concentrate in areas with high vegetation cover.

5.2: Materials and methods

5.2.1: Study area and data collection

This study was conducted at Kalahari north, Botswana, a radius of 60km from Hukuntsi, Lehututu, Tshane, and Lokgwabe. A comprehensive description of the study area is specified in Chapter 1.3. The methods involved eleven wild and four domestic herbivore species (>1kg) using surveys of spoor (tracks, pellets) and road-side field observations. Surveys were performed along five 60km transects radiating from the main settlements in two dry seasons (August to October 2014 & 2015) and two wet seasons (March to May 2015 & 2016). The richness of livestock and wild herbivores' tracks and pellets at each sample point were used to classify their abundance at each sample point on a 4-point scale (zero, low, moderate, and high). The grazing distribution of free-ranging livestock from the watering points and cattle posts were determined through monitoring twenty and twenty-two cattle during the dry seasons of 2014 and 2015 respectively. While during the wet season of 2015 and 2016, twenty and twenty-four cattle were monitored respectively using the GPS telemetry. The details of the methods are given in Chapter 3.

5.2.2: Data analysis

Spatial distribution of the pastoral activities, such as boreholes, wells, cattle posts, within the study area was mapped using Google Earth images (2014) and ArcGIS 10.1 software, with the help of pastoralists and government Officers to establish the free-ranging livestock grazing distribution in relation to land use types. A Mann-Whitney U test was (Statistics 2015) performed to determine if there were differences in distances travelled by cattle between dry and wet seasons, also between cattle posts closer and far from settlements. Principal Components Analysis (PCA) and General Linear Model (GLM) were applied on the wild herbivores' spoor data to explore the distribution of different wild herbivores in relation to free-ranging livestock grazing gradient and pastoral activities in CGAs and CAs. PCA was used to quantify the significance of different variables in the data set(Zhang, Tao et al. 2010).

To assess the variation of wild herbivores' distribution along livestock grazing gradient and across land use typess as influenced by the environmental variables, Canonical Correspondence Analysis – CCA technique on the spoor data of wild herbivores and livestock using a CANOCO program package of (Ter Braak 1986, Ter Braak 1988, Ter

Braak 1990) was applied on the spoor data of wild herbivores. Spatial distribution patterns for free-ranging livestock and wild herbivores were mapped using Inverse Distance Weighted (IDW) interpolation and buffering. The wild herbivores spoor data was also analysed using scatter plots fitted with natural cubic splines interpolation to show the trends and the variation in distribution of the wild herbivores long t distance livestock grazing intensity gradient and land use. The details of the data analysis are given in Chapter 3.3.2

5.3: Results

The details of differences in the distribution of wild herbivores between land use, seasons and along pastoral activities disturbance gradient were complex and varied with wildlife species and season, but some regular overall patterns were, however, evident. Clusters of wildlife of different body sizes and livestock were persistent in different spatially areas along the pastoral activities disturbance gradient, between land use and seasons. Six (6) general patterns were apparent. 1) Pastoral activities such as sedentary cattle posts, wells and boreholes for watering cattle, settlements, arable fields, sandy roads are near the four main settlements (Hukuntsi, Lokgwabe, Lehututu and Tshane) (Figure 5.1). Therefore, high density and the distribution of livestock (cattle, small stock, donkey and horse) near these settlements leading to increased LGI and pastoralists-induce risk within a radius of 18km. 2) The variety of the wild herbivores in human-dominated areas was reduced except for small-sized wild herbivores. 3) Cattle travelled longer distances from the cattle posts for grazing during the dry (average 10km) than the wet (average 5km) seasons (Table 5.1); however, the grazing distribution of Livestock was significantly dominant in CGAs than CAs. Cattle from the cattle posts that are near the settlements travelled longer distances compared to those from the cattle posts that are far from the settlements during the dry season, however, during the wet season, there was no significant difference in the distances travelled by cattle for grazing.

4) Large-sized herbivores (Gemsbok, Eland and Blue wildebeest), which are susceptible to the pastoralists-induced risks but suffer less predation and require forage abundance, were consistently highly distributed in the CAs and avoided pastoral dominated and moderately grazed areas in CGAs in both seasons. 5) Medium-sized herbivores (The Greater Kudu, Red Hartebeest, Warthog), except Ostrich, that are susceptible to predation and the pastoralists-induced risks, but require quality forage avoided increased LGI, pastoral dominated areas and remained in moderately grazed areas in CGAs and CAs in the wet and the dry season

respectively. Ostrich was also highly distributed in areas with high density of cattle posts and LGI. 6) Small-sized wild herbivores (Duiker, Steenbok, and Porcupine), except Springbok, which depend on high-quality forage but susceptible to predation and pastoralists-induced risks were not negatively impacted by increasing LGI and other pastoral activities in both seasons, hence were associated with increased LGI within CGAs, even in areas closer to the settlements in both seasons. The following sections; 5.3.1, 5.3.2 show the detailed results of the spatial distribution of pastoral activities and different wild herbivores of varying body sizes along a livestock grazing and pastoral activities disturbance gradients and land use types respectively.

5.3.1: Spatial distribution of various pastoral activities and free-ranging livestock grazing

Spatial distribution of Pastoral activities in CGAs and CAs

The major pastoral activities within the study area were, settlements, artificial boreholes and hand dug wells for watering livestock, sedentary cattle posts, and few fenced TGLP ranches, arable fields, and sandy roads. There are four major settlements (Hukuntsi, Lehututu, Tshane and Lokgwabe) and five small settlements (Make, Hunhukwe, Ncaang, Monong and Zutshwa). Most of the settlements are in CGAs, except Ncaang and Zutshwa, which are in the CAs (Figure 5.1). The main settlements are found roughly in the focal point of the CGAs around 40 – 60 km from the CA boundary and couple of small settlements in the north of the CGA (Make, Monong, and Hunhukwe) (Figure 5.1).

There are several hands dug wells for watering cattle within major pans in Hukuntsi, Lokgwabe, Lehututu, and Make, consequently, the high density of cattle posts closer to the main settlements. Water for livestock and human is mainly from the artificial boreholes in areas that are far from the main settlements. These boreholes are in the north of the CGA, for example in Make, Lesedi, Kgamatholo, Makhubung, Ikhutseng, Thupa ya mokala, Ngwamaripe, Lekojwane cattle posts (Figure 5.1A). There are no boreholes used for watering livestock towards the south of the main settlements, consequently less cattle posts in that direction. Most of the boreholes are shared by several pastoralists and there are several cattle posts surrounding each borehole.

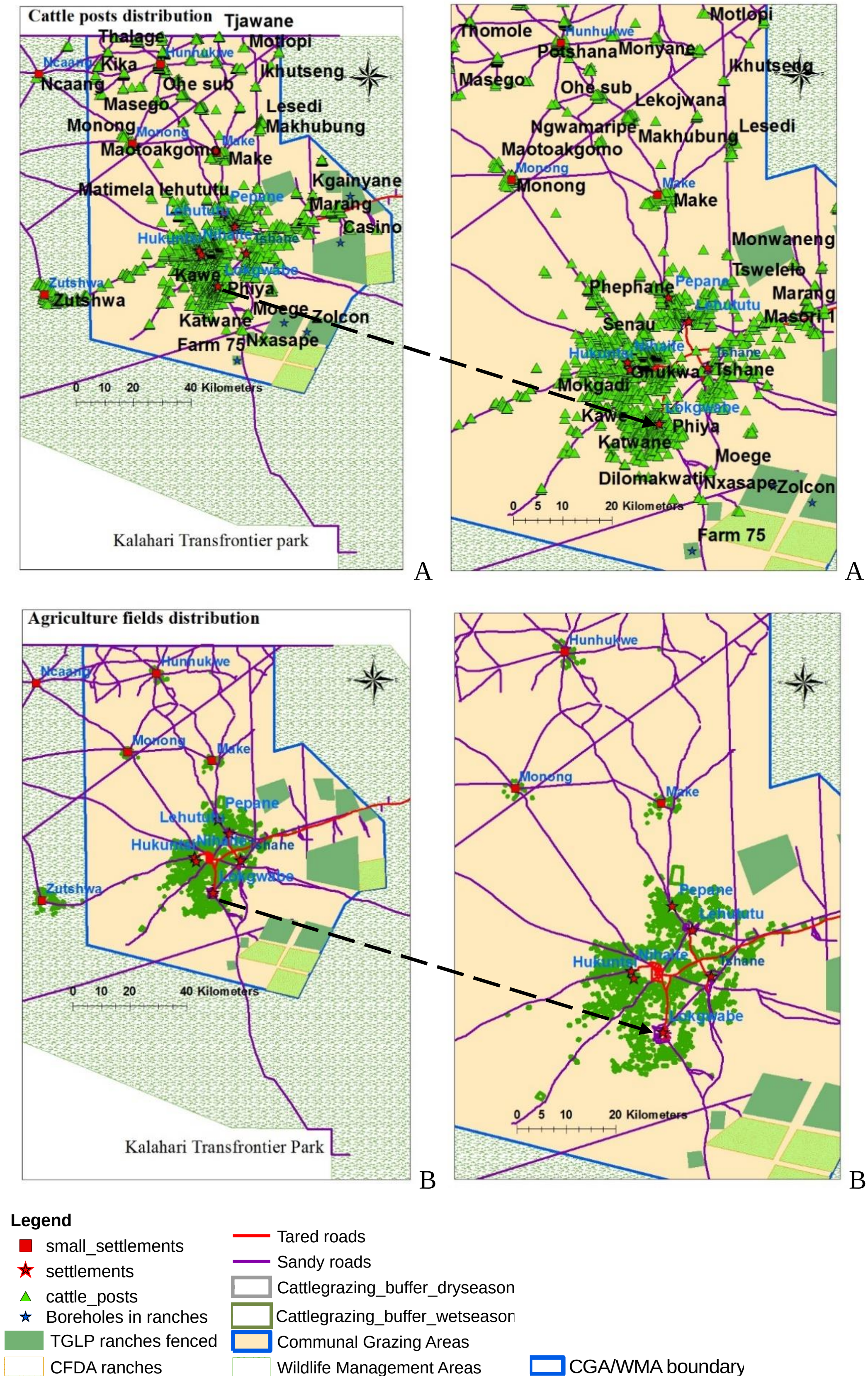


Figure 5. 1: Spatial distribution of pastoral activities (cattle posts and arable fields) Cattle posts (green triangles) (A), arable fields (green polygons) and sandy roads (B). Most cattle posts and arable fields were located closer to the main settlements (Hukuntsi, Lehututu, Tshane & Lokgwabe). Cattle posts in the north of the study area were near the artificial borehole for watering cattle.

More than 3000 sedentary cattle posts were recorded in the study area, and most of them were closer to the four main settlements (Hukuntsi, Lehututu, Tshane and Lokgwabe) (Figure 5.1A). However, most of the cattle posts in the north of the CGAs are near the boreholes. Even though all cattle posts are supposed to be in the CGA, there were few in or near the CA, resulting in livestock grazing in the CAs. For example, the following cattle posts were located near the CAs boundary; Kgamatholo, Thupa ya Mokala, Tjawane, Itereleng, Qamaque, while Zutshwa and Ncaang cattle posts were in the CAs. There are few fenced Tribal Grazing Land Policy ranches mainly towards the East and South East of the CGA (Figure 5.1A). Most of the arable fields ($P < 0.001$) were located closer to the main settlements within a radius of 10km and few in small settlements in CGA and CAs (Figure 5.1BD). Cultivation intensity was highest near the settlements. Several access roads connecting settlements and the cattle posts also do exist, however, small access roads are not shown on the maps because there were not easily visible on the satellite images.

Free-ranging livestock grazing distribution in relation to land use types and cattle posts

Free-ranging livestock included Cattle *Bos taurus* Linnaeus, Goats *Capra aegagrus hircus* Linnaeus, Sheep *Ovis aries* Linnaeus, donkey *Equus asinus* Linnaeus, and horse *Equus caballus* Linnaeus. The average distances travelled by cattle were statistically significantly greater in the dry (mean rank = 48.52) vs wet season (mean rank = 26.12) (dry 10.81 ± 0.77383 km, n = 42, wet 5.62 ± 0.3153 km, n = 34, Mann-Whitney U = 293, $P < 0.001$) (Figure 5.2A & Figure 5.3). However, average 90th percentile maximum distances travelled by cattle were 15.5km and 8.15km during the dry and wet season, respectively. While the average minimum distances travelled by cattle were 2.5km and 2.85km in the dry and wet season, respectively (Table 5.1). In mapping the cattle grazing distribution around the cattle posts, these average 90th percentile for the dry (15.5km) and wet (8.15km) seasons were used respectively. Hence for every cattle post, a buffer zone was created to show the cattle grazing distribution in both seasons (Figure 5.4A & B).

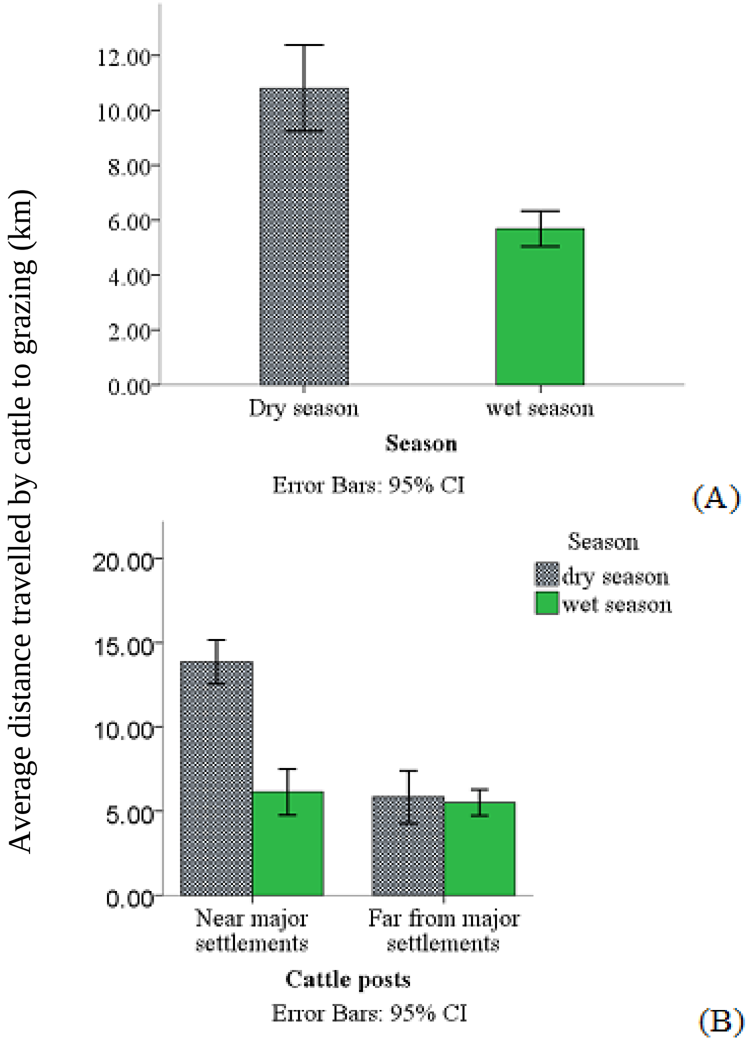


Figure 5. 2: Average distances travelled by cattle for grazing
(A) Average distances (km) travelled by cattle for grazing during the wet and dry seasons. Cattle travelled longer distances from the cattle posts during the dry season because of shortage of forage resources. (B) Average distances travelled by cattle for grazing from cattle posts near and far the major settlements. Cattle near the major settlements travelled longer distances during the dry season because of shortage of forage resources due to high and low cattle density far from settlements and cattle posts respectively.

Table 5. 1: Distances travelled by cattle fitted with GPS telemetry

	Dry season		Wet season	
	2014	**2015**	**2015**	**2016**
Minimum distance	2.5	2.5	1.7	4
Max distance	16.6	22	8.9	9.2
Average distance	11.1	10.5	5.4	6.1
90th percentile	**15**	**16**	**7.6**	**8.7**
Average 90th percentile	**15.5**		**8.15**	

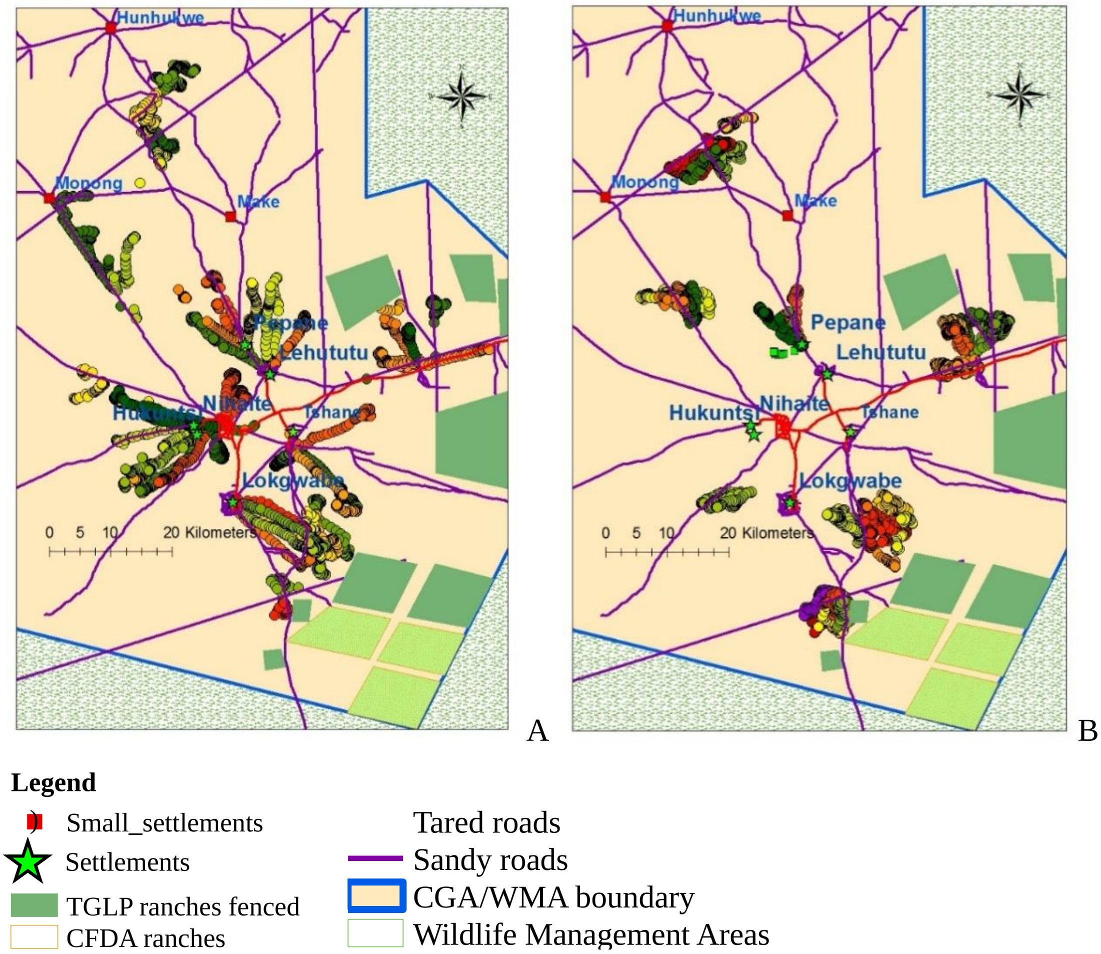


Figure 5. 3: Movements of selected cattle fitted with GPS telemetry
Movement during the dry (2014 & 2015) (A) and wet seasons (2015 & 2016) (B). Different colors show movement of individual cow fitted with GPS telemetry.

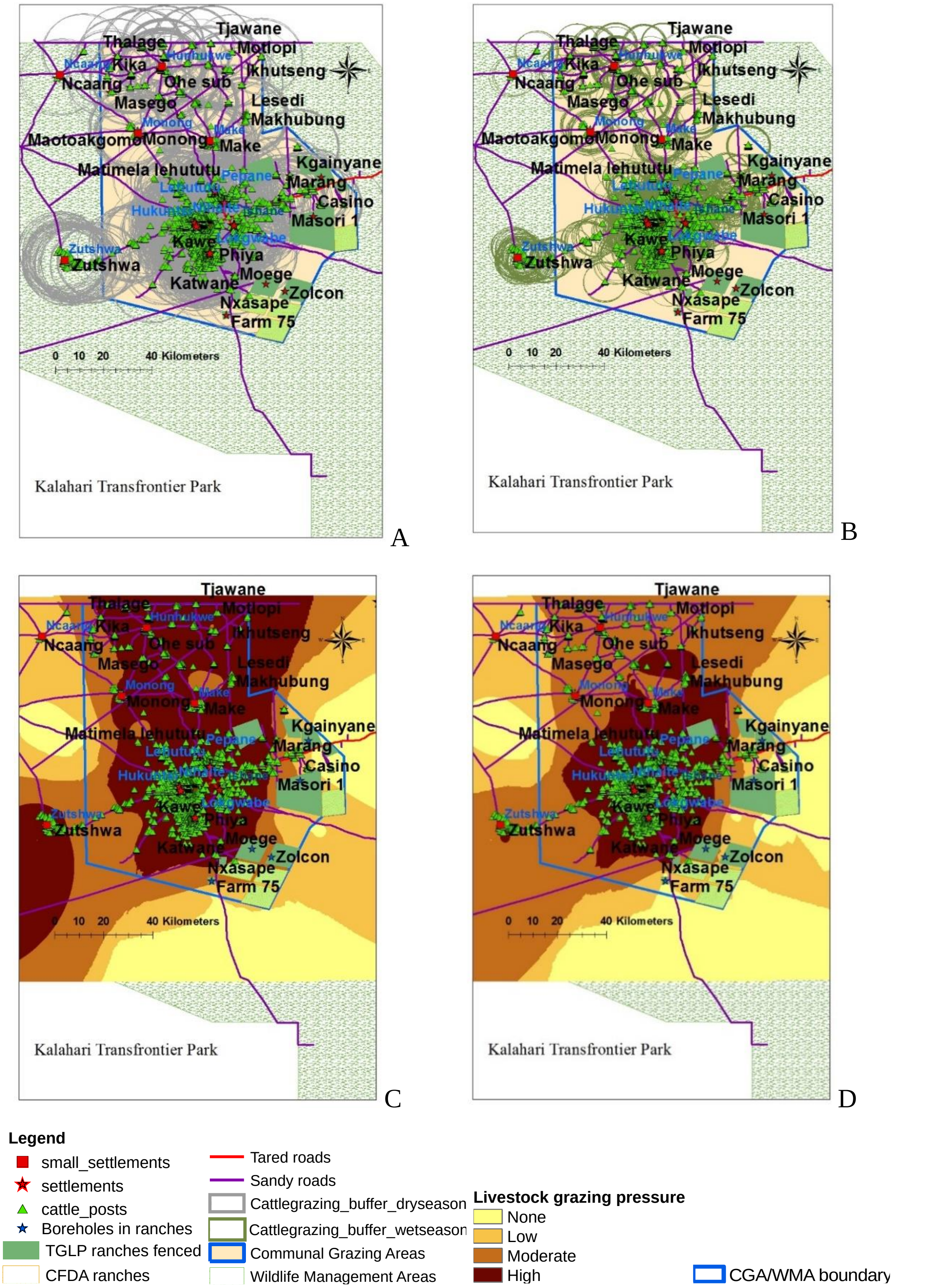


Figure 5. 4: Livestock grazing distribution amid the dry and wet seasons

The average 90th percentile maximum distance travelled by cattle was used in buffering the grazing area for every cattle post. Livestock grazing intensity along the grazing gradient during the dry (A) and wet (B) seasons respectively in CGAS and CAs. Inverse Distance Weighted interpolation based on sample points in relation to cattle posts and land use in dry (C) and wet (D) season as revealed by the cattle fitted with GPS telemetry.

The average distances travelled by cattle near the major settlements (mean rank = 28.90) were statistically significantly greater than those which are far from the major settlements (mean rank = 9.47) in the dry season (near 13.87 ± 0.6352 km, n = 26, far 5.84 ± 0.7364 km, n = 16, Mann-Whitney U = 15.5, P < 0.001) (Figure 5.3). However, during the wet season the average distances were not statistical significantly difference between near (mean rank = 19.35) and far (mean rank 16.73) (near 6.14 ± 0.6058 km, n = 10, far 5.51 ± 0.3703 km, n = 24, Mann-Whitney U = 101.5, P = 0.491) (Figure 5.2B). Therefore, showing that cattle from the cattle posts that are near the major settlements (e.g. Hukuntsi, Lokgwabe, Lehututu, Tshane Phephane) travel longer distances for grazing than those from cattle posts that are far (e.g. Ngwamaripe, Makwankwang, Namogosisi) during the dry season. However, during the wet season, the distances travelled for grazing were the same (P > 0.05).

The grazing distribution of Cattle, donkey, and small stock (P< 0.001), except horses (P = 285) was high within the CGAs than CAs in both seasons (Table 5.2). However, there was less livestock grazing in CAs due to the cattle posts within the CAs (e.g. Zutshwa, Ncaang) and near the CAs (e.g. Kgamatholo, Lesedi Makgubung, Ikhutseng, Thupa ya mokala, Motlopi, Tjawe, Itereleng, Qamaque, Thalage, Thomole, and Kika). Cattle distribution concentrated within a radius of 15.5 km and 8.2 km from the main settlements during the dry season and wet season respectively (Figure 5.4). The GLM (Gaussian) show that cattle distribution was statistically significantly associated with medium to high Livestock grazing intensity, forb density, and unpalatable annual grasses, closer to boreholes, and cattle posts (P < 0.001) (Table 5.2). Livestock grazing distribution was associated with high density of cattle posts, watering points, near the main settlements (P < 0.001) (Figure 5.4C & D). As expected, livestock grazing intensity decreased with increasing distance from settlements and cattle posts (P < 0.001).

The grazing intensity was only high in the dry but moderate in the wet season, as compared to near the settlement, where there is increasing livestock grazing intensity in both seasons (Figure 5.4C & D). Most of the distribution of the cattle, donkey and horse were recorded along Lehututu/Hunhukwe, followed by Hukuntsi/Zutshwa & Hukuntsi/Ngwatle transects (P < 0.001). However, the small stock was highly distributed along Hukuntsi/Zutshwa & Hukuntsi/Ngwatle transects (P < 0.001) (Table 5.2). On the other hand, horse and donkey were attracted within the distances of 15 and 10km from settlements respectively ($P < 0.001$), while the small stock was mainly within 10km ($P < 0.001$) (Figure 5.5). Overall the GLM shows that cattle ($P = 0.015$), donkey ($P = 0.053$), horse ($P = 0.014$) and the small stock ($P = 0.003$) were associated with high tree density (Table 5.2).

5.3.2: Spatial distribution of different wild herbivores along a livestock grazing and pastoral activities disturbance gradients and land use types

Wild herbivore species composition

A total of thirteen (11) wild herbivore species (> 3 kg) including Ostrich were recorded in the study area and all were of Least Concern according to the IUCN 3.1 conservation status (Appendix 5A). The wild herbivore species include three large (Common Eland *Tragelaphus oryx* Pallas, Gemsbok *Oryx gazella* Linnaeus, Blue Wildebeest *Connochaetes taurinus* Burchel), four medium (Red Hartebeest *Alcelaphus bucelaphus* Hilaire, Greater Kudu *Tragelaphus strepsiceros* Pallas, Common Warthog *Phacochoerus africanus* Gmelin, Common Ostrich *Struthio camelus* Linnaeus), and four small (Springbok *Antidorcas marsupialis* Zimmermann, Common Duiker *Sylvicapra grimmea* Linnaeus, Steenbok *Raphicerus campestris* Thunberg, Cape Porcupine *Hystrix africaeaustralis*) herbivores (Appendix 5A).

The wild herbivores feeding style includes four browsers, three grazers, five mixed feeders, and one omnivore. Most of these wild herbivore species were recorded along with all transects, except the two large antelopes; Common Eland and Gemsbok, which were mainly recorded along Lokgwabe/Mabuasehube and Hukuntsi/Zutshwa transects. The frequency of appearance at each sample point was used to classify wild herbivores on a 4-point scale (rare, moderate, frequent and very frequent). Two wild herbivores (Eland & Warthog) were uncommon in the study area (frequency between 0 to 20%) during both seasons. However, Blue Wildebeest was rare only in dry season but average (20 to 40%) in the wet season, while Springbok remained moderate in both seasons. Nonetheless, Gemsbok (Oryx gazelle) was rare only in the wet season but moderate in the dry season. Hence indicating that larger herbivores were uncommon in the study area while the rest of the wild herbivores were common (40 to 60%) and very common (>60%) in both seasons. Nevertheless, only Eland, Gemsbok, Wildebeest, Warthog were rare in CGA but frequent in CAs in both seasons (Appendix 5C).

Table 5. 2: General Linear Model (Gaussian) coefficients, p-values and variance accounted for on livestock
For the relationship of the estimated and measured environmental variables on the distribution of livestock (the dependent variables were log-transformed) in both seasons combined. P-value computed using alpha = .05, hence P < 0.05 shows statistically significant variables at the 0.05 level (2-tailed) (bold P-values). LGI = Livestock Grazing intensity

		Cattle			**Donkey**			**Horse**			**Small Stock**		
Variables	**df**	**Sum of Squares**	**F**	**P-value**	**Sum of Squares**	**F**	**P-value**	**Sum of Squares**	**F**	**P-value**	**Sum of Squares**	**F**	**P-value**
Intercept	1	11.06	317.8	< **0.001**	2.341	115.5	< **0.001**	1.78	143.41	< **0.001**	1.07	26.72	< **0.001**
Sub transect	5	1.54	8.8	< **0.001**	2.853	28.16	< **0.001**	0.44	7.12	< **0.001**	2.51	12.58	< **0.001**
Transects	4	1.61	11.5	< **0.001**	1.292	15.94	< **0.001**	0.51	10.24	< **0.001**	11.86	74.17	< **0.001**
Grass height	4	1.84	13.21	< **0.001**	2.274	28.07	< **0.001**	0.27	5.41	< **0.001**	0.43	2.71	**0.028**
LGI	3	3.23	30.96	< **0.001**	0.466	7.67	< **0.001**	0.98	26.34	< **0.001**	3.28	27.32	< **0.001**
Distance boreholes	4	1.57	11.26	< **0.001**	0.631	7.79	< **0.001**	1.20	24.05	< **0.001**	11.73	73.35	< **0.001**
Distance cattle posts	4	1.82	13.04	< **0.001**	0.34	4.20	**0.002**	0.21	4.29	**0.002**	7.25	45.35	< **0.001**
Land use type	1	0.56	16.04	< **0.001**	0.282	13.94	< **0.001**	0.01	1.14	0.285	9.99	249.8	< **0.001**
Palatable perennials	1	0.20	5.67	**0.017**	0.01	0.50	0.479	0.02	1.47	0.226	0.00	0.02	0.898
Tree density	1	0.21	5.89	**0.015**	0.076	3.73	**0.053**	0.08	6.03	**0.014**	0.36	9.07	**0.003**
Forbs	1	2.21	63.52	< **0.001**	0.115	5.68	**0.017**	0.03	2.08	0.149	1.81	45.28	< **0.001**
Unpalatable perennial	1	0.03	0.76	0.383	0.716	35.35	< **0.001**	0.07	5.63	**0.018**	0.08	1.97	0.16
Unpalatable annuals	1	0.53	15.24	< **0.001**	0.26	12.85	< **0.001**	0.06	4.55	**0.033**	0.10	2.55	0.111
Palatable annuals	1	0.00	0.06	0.807	0.02	1.00	0.318	0.74	59.61	< **0.001**	0.57	14.36	< **0.001**
Sub-transect * LGI	14	3.37	6.91	< **0.001**	3.309	11.67	< **0.001**	1.67	9.61	< **0.001**	9.20	16.44	< **0.001**
Transect * LGI	11	3.16	8.25	< **0.001**	3.973	17.83	< **0.001**	1.10	8.06	< **0.001**	29.21	66.45	< **0.001**
R squared adjusted		**0.482**			**0.363**			**0.159**			**0.496**		

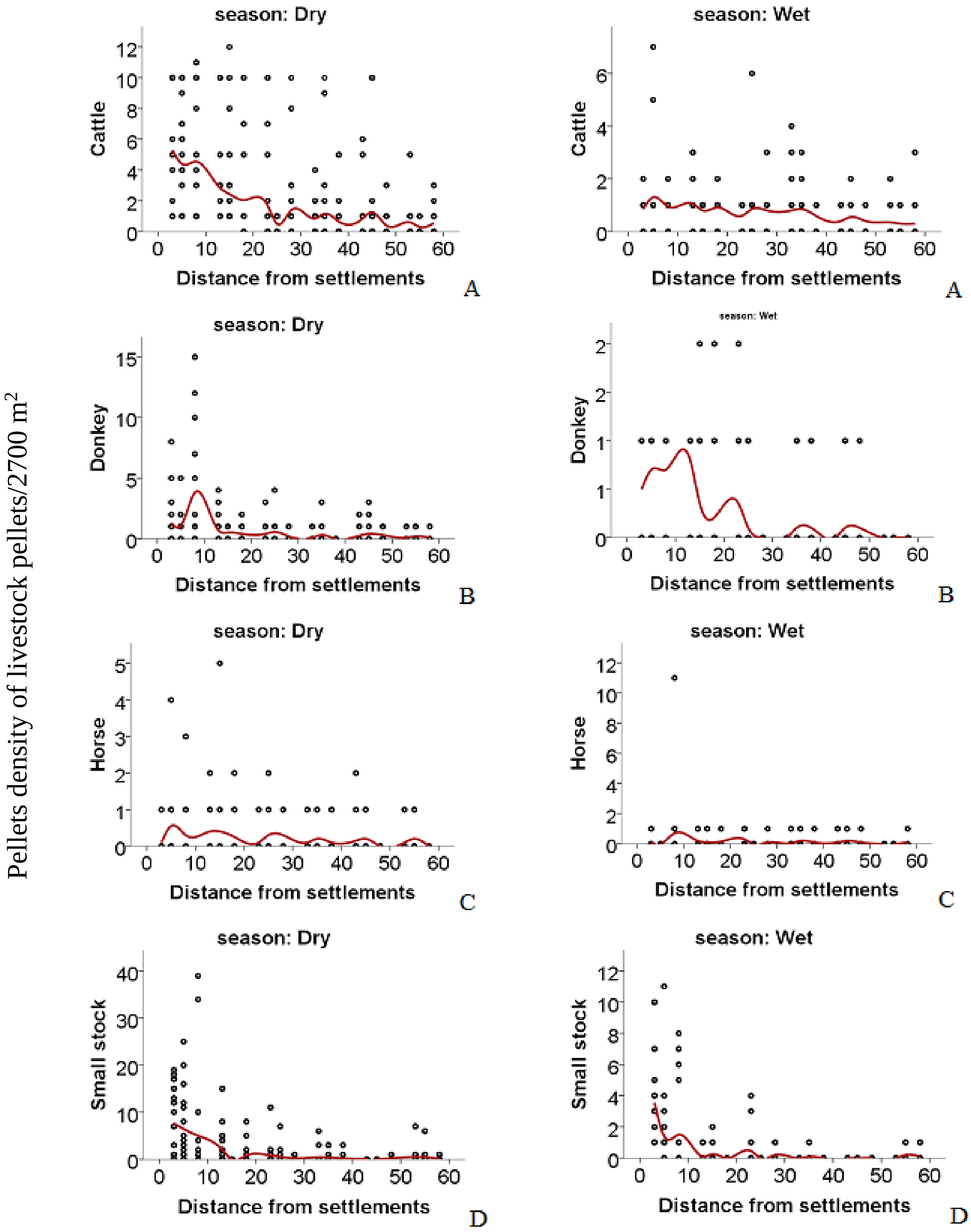


Figure 5. 5: Scatter plots showing distribution of livestock along grazing gradient Scattered plots are fitted with natural cubic spline interpolation to show the variation in distribution of livestock pellets (red line): (A) cattle - *Bos taurus* (Linnaeus), (B) donkey *Equus asinus* (Linnaeus), (C) horse *Equus caballus* (Linnaeus), and (D) Small stock (sheep/goats) *Ovis aries/Capra aegagrus hircus* (Linnaeus) distribution along pastoral activities disturbance gradient (in km) in Kalahari North, Botswana, during the dry and wet seasons respectively. The y-axis represent the density of livestock pellets per 2700m^2 plot within each sample poin and the x-axis if the distance from cattle settlements in km.

The distribution of different wild herbivores in relation to livestock grazing gradient

Spoor data of eleven and four domestic wild herbivores were subjected to Principal Component Analysis (PCA) in both seasons combined. Fourteen herbivore species, excluding Springbok, satisfied the 0.3 cross-factor loading minimum limit in the varimax rotated matrix, with Kaiser-Meyer-Olkin (KMO) test of 0.578. The Bartlett's test of sphericity was also significant ($X^2 = 7617.135$, $p < 0.001$, df = 105) (Table 5.3). Consequently, PCA extracted three distinct components with eigenvalues greater than 1 and explained 35.626% of the total variance of the dataset during the wet and dry season combined, hence each component representing a variable in the model (Table 5.3). The first component explained 14.47% of the variance and highly loaded on the following four wildlife species; Gemsbok, Eland, Warthog, and Blue wildebeest respectively, therefore reflecting large-sized herbivores distribution. The second component accounts for 11.31 % of the variance characterized by the following five herbivore species, Steenbok, Duiker, Kudu, Red Hartebeest, Porcupine, hence reflecting small to medium-sized herbivores distribution. Lastly, the third component highly loaded on livestock species (donkey, cattle, horse) and Ostrich accounted for 9.834%, therefore representing livestock and Ostrich distribution. Therefore, PCA determined a pattern of herbivores' distribution of different body sizes along a livestock grazing and pastoral activities disturbance gradients in Kalahari north.

The General Linear Model (GLM) was conducted on the spoor data of each herbivore species to determine the uniquely, and combined variance explained by the estimated and measured. The PCA extracted vegetation principal components scores (see Chapter 4) were used in the GLM as covariance and the categorical environmental variables (season, sub transect, transects, grass height, livestock grazing intensity, land use, and distances from cattle posts and boreholes) were used as fixed factors. Spatial distribution patterns using Inverse Distance Weighted (IDW) interpolation based on herbivores spoor information at each sample point. Hence the following results on large, medium and small herbivore distribution.

Table 5. 3: Rotated Component Matrix on wild herbivores and livestock during the wet and the dry seasons combined.
The matrix with factor loadings (>0.3). PCA showed that even though Common warthog, is a medium sized herbivore, it was classified with the large herbivores.

Species	**Scientific Name**	**large-sized herbivor**	**small to medium -sized**	**livestock and Ostrich**
Gemsbok	*Oryx gazella*	**0.859**		
Eland	*Tragelaphus oryx*	**0.783**		
Warthog	*Phacochoerus africanus*	**0.546**		
Blue wildebeest	*Connochaetes taurinus*	**0.352**		
Steenbok	*Raphicerus campestris*		**0.669**	
Duiker	*Sylvicapra grimmea*		**0.65**	
Kudu	*Tragelaphus strepsiceros*	0.386	**0.457**	
Red Hartebeest	*Alcelaphus bucelaphus*		**0.423**	
Porcupine	*Hystrix africaeaustralis*		**0.411**	
Goats & Sheep	*Ovis aries & Capra aegagrus hircus*		**-0.333**	
Donkey	*Equus asinus*			**0.76**
Cattle	*Bos taurus*			**0.628**
Ostrich	*Struthio camelus*			**0.513**
Horse	*Equus caballus*			**0.373**
Springbok	*Antidorcas marsupialis*			
	Eigenvalue	**2.172**	**1.697**	**1.475**
	Initial variance	**14.478**	**11.314**	**9.834**
	Cumulative variance	**14.478**	**25.792**	**35.626**

*Extraction Method: Principal Component Analysis, Rotation Method: Varimax with Kaiser Normalization, a Rotation converged in 4 iterations and three components were produced. KMO = 0.578, $X^2 = 7617.135$, df = 105, $p < 0.001$

Large-sized herbivore distribution

Large-sized wild herbivores included Gemsbok, Eland and Blue wildebeest. Their distribution was analysed using the GLM and it showed that Gemsbok and Eland were highly distributed along Lokgwabe/Mabuasehube transect and rare along other transects ($P < 0.001$) (Table 5.4) (Figure 5.7A – B). Gemsbok was recorded from minimum distance 23km (dry) and 18km (wet), while Eland was recorded from the minimum distance of 28km (dry), and 23km (wet) (Figure 5.6). Gemsbok and Eland avoided pastoralists’ impacted areas and high densities of cattle posts along other transects ($P < 0.001$). However, most of the Blue Wildebeest distribution was high along Hukuntsi/Zutshwa & Tshane/Kang transect ($P < 0.001$). The distribution of large-sized herbivore (i.e. Eland, Gemsbok, and Wildebeest) increased with distance from settlements, cattle posts, and boreholes ($P < 0.001$) (as shown in Table 5.4).

Large-sized herbivores were attracted to and remained in areas that had less livestock grazing intensity and less pastoralists' disturbance in both seasons ($P<0.001$). However, there was no statistical difference in the distribution of Blue Wildebeest between CAs and CGAs in both seasons combined ($P = 0.371$) (Table 5.4) (Figure 5.7). Blue Wildebeest was also recorded in CGAs from minimum distance of 13km (dry) and 23km (wet) seasons (Figure 5.6) but avoiding highly grazed areas with high densities of cattle posts and arable fields (Figure 5.7C). Thus, Blue Wildebeest was associated with high densities of trees ($P =0.02$), forbs ($P < 0.001$), unpalatable perennial grasses ($P =0.008$), and unpalatable annual grasses ($P = 0.013$) (Table 5.4).

The distribution of medium-sized wild herbivore

Medium-sized herbivores (The Greater Kudu, Red Hartebeest, Warthog, and Ostrich) were recorded in all transects, indicating that they were common in the study area (Figure 5.7 D-G). The GLM showed that the greater Kudu, Warthog, and Ostrich ($P < 0.001$), except Red hartebeest, ($P = 0.063$) were mostly distributed along Lokgwabe/Mabuasehube, Hukuntsi/Zutshwa and Tshane/Kang (Table 5.5). Therefore, showing that these medium-sized herbivores avoided pastoral activities along with other transects ($P<0.001$). However, Ostrich was also highly distributed in areas wit high density of cattle posts along Hukuntsi/Ngwatle ($P < 0.001$). All medium-sized herbivores (Red Hartebeest, Warthog, Ostrich) ($P < 0.001$) and Kudu ($P = 0.057$) avoided areas with high LGI, cattle post densities and arable agriculture fields ($P < 0.001$) (Figure 5.7d -g).

Consequently, the distribution of medium-sized herbivores was increasing with increasing distance from the settlement, cattle post and boreholes, subsequently they were also associated with moderate livestock grazing intensity ($P < 0.001$) (Table 5.5). Medium-sized herbivores spoors were recorded from minimum distances of 13km (Kudu) and 8km (Red Hartebeest), however, Ostrich and Warthog were recorded from 3km distance from the settlements (Figure 5.6). The GLM showed that the distribution of Ostrich was associated with increasing livestock grazing intensity, ($P < 0.001$), and cattle posts, ($P < 0.001$) in CGAs ($P = 0.007$) and decreasing with increasing distance from settlements ($P < 0.001$). However, it was avoiding areas closer to the settlements during in both seasons (Figure 5.7 G). On the other hand, Red hartebeest ($P = 0.002$), Kudu, ($P = 0.024$), were associated with CGAs in moderately grazed areas ($P < 0.001$) in both seasons combined (Table 5.5).

Table 5. 4: General Linear Model (Gaussian) coefficients, p-values and variance accounted for on large-sized wild herbivores
For the relationship of the estimated and measured environmental variables on the distribution of wild herbivores (the dependent variables were log-transformed) in both seasons combined. P-value computed using alpha = .05, hence P < 0.05 shows statistically significant variables at the 0.05 level (2-tailed). LGI = Livestock Grazing intensity. Bold P-values show significance.

		Eland			Gemsbok			Blue Wildebeest		
Source	**df**	**Sum of Squares**	**F**	**P-value**	**Sum of Squares**	**F**	**P-value**	**Sum of Squares**	**F**	**P-value**
Sub-transect	5	1.712	43.95	< **.001**	1.338	53.032	< **.001**	0.998	35.34	< **.001**
Transect	4	15.818	507.492	< **.001**	14.886	737.391	< **.001**	0.431	19.094	< **.001**
Grass height	4	0.186	5.967	< **.001**	0.108	5.375	< **.001**	0.04	1.77	0.132
LGI	3	0.593	25.384	< **.001**	0.424	28.005	< **.001**	0.353	20.854	< **.001**
Land use types	1	0.169	21.645	< **.001**	0.122	24.161	< **.001**	0.005	0.799	0.371
Distance boreholes	4	0.248	7.958	< **.001**	0.12	5.94	< **.001**	0.17	7.546	< **.001**
Distance cattle post	4	5.011	160.779	< **.001**	1.165	57.728	< **.001**	0.632	27.994	< **.001**
Palatable perennials	1	0.007	0.902	0.342	0.004	0.862	0.353	0.007	1.185	0.276
Tree density	1	0.002	0.204	0.651	0.033	6.44	**0.011**	0.031	5.404	**0.02**
Forbs	1	0.145	18.655	< **.001**	0.001	0.107	0.743	0.089	15.771	< **.001**
Unpalatable perennials	1	0.003	0.437	0.509	0.03	5.917	**0.015**	0.04	7.055	**0.008**
Unpalatable annuals	1	0.023	2.952	0.086	0.001	0.131	0.718	0.035	6.128	**0.013**
Palatable annuals	1	0.008	0.963	0.326	0.012	2.441	0.118	0.004	0.725	0.395
Sub-transect * LGI	14	6.174	56.598	< **.001**	3.962	56.073	< **.001**	2.893	36.586	< **.001**
Transect * LGI	11	21.247	247.884	< **.001**	17.446	314.255	< **.001**	2.11	33.973	< **.001**
R squared adjusted		0.715			0.801			0.331		

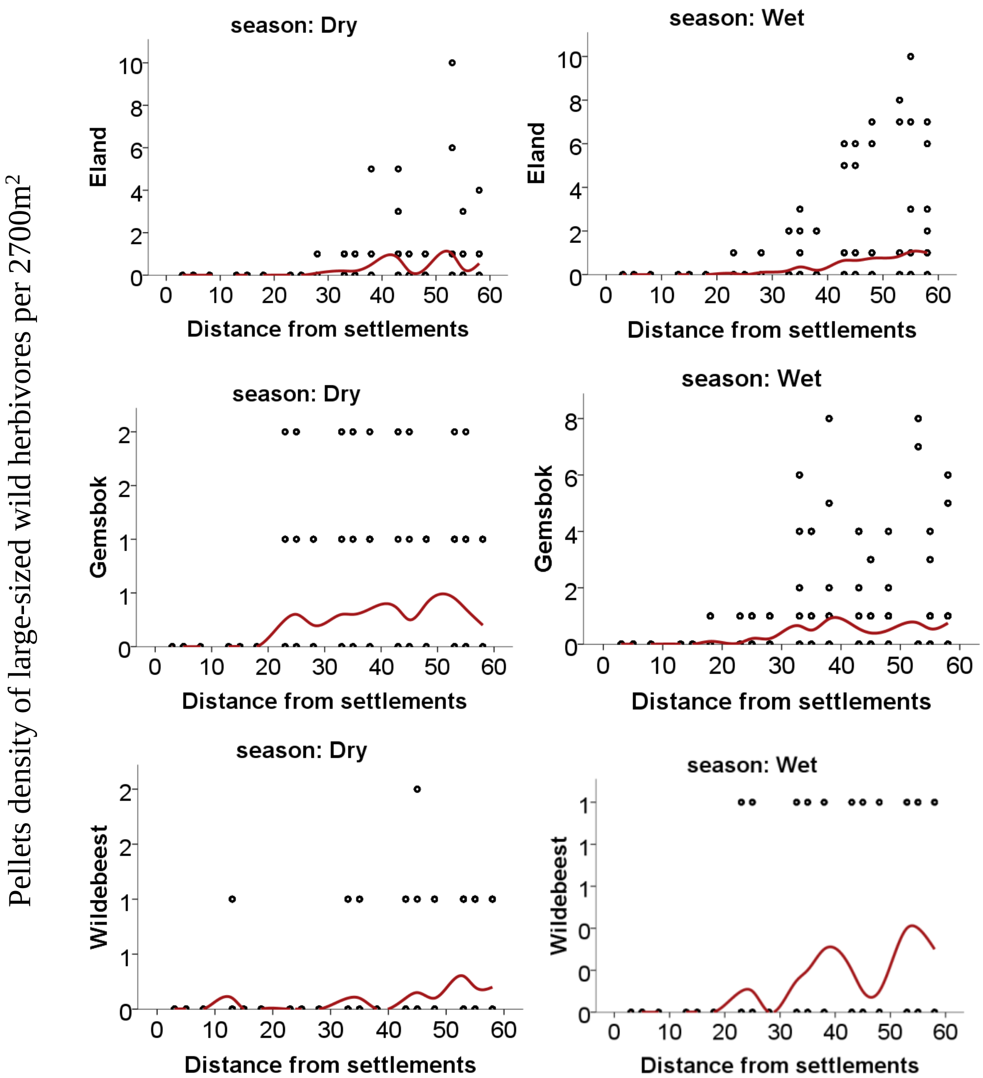


Figure 5. 6: Scatter plots showing the variation in distribution of wild herbivores Scattered plots are fitted with natural cubic spline interpolation to show the trend (red line) in the variation in the distribution of the larger-sized wild herbivores (i.e. density of pellets/2700m^2) (Eland *Tragelaphus oryx* (Pallas), Gemsbok *Oryx gazella* (Linnaeus), and Blue Wildebeest *Connochaetes taurinus* (Burchell). The y-axis represent the density of wildlife pellets per 2700m^2 plot within each sample poin and the x-axis if the distance from cattle settlements in km.

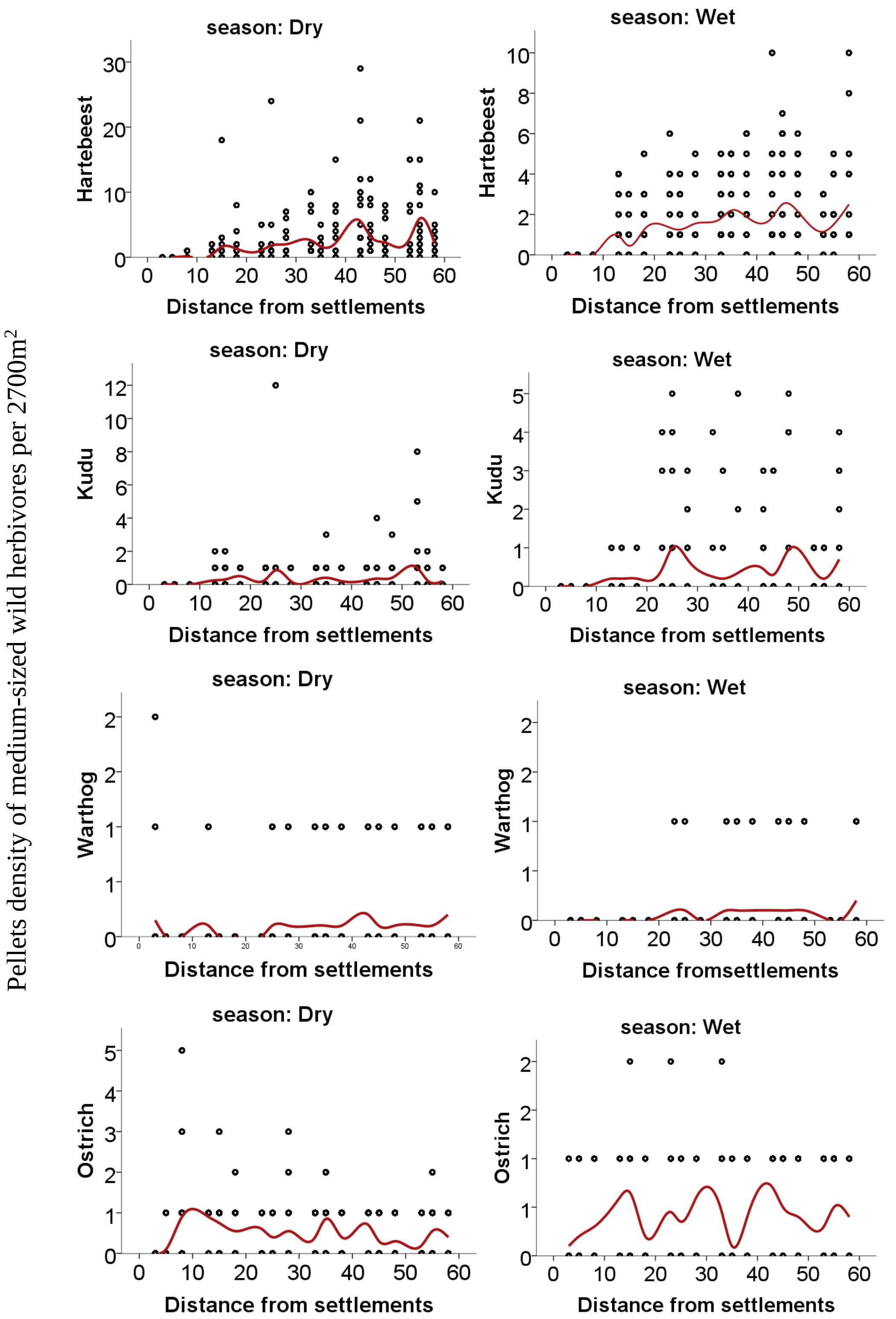


Figure 5. 6: continues: Scatter plots fitted with natural cubic spline interpolation showing the trend in variation (red line) in the distribution of medium-sized wild herbivores (i.e. density of pellets/2700m^2): (Red Hartebeest *Alcelaphus bucelaphus* (Hilaire), The Greater Kudu *Tragelaphus strepsiceros* (Pallas), Warthog - *Phacochoerus africanus* (Gmelin) along pastoral activities disturbance gradient (distance in km) in northern Kalahari, Botswana, during the dry and wet seasons respectively. The y-axis represents the density of wildlife pellets per 2700m^2 plot within each sample poin and the x-axis if the distance from cattle settlements in km.

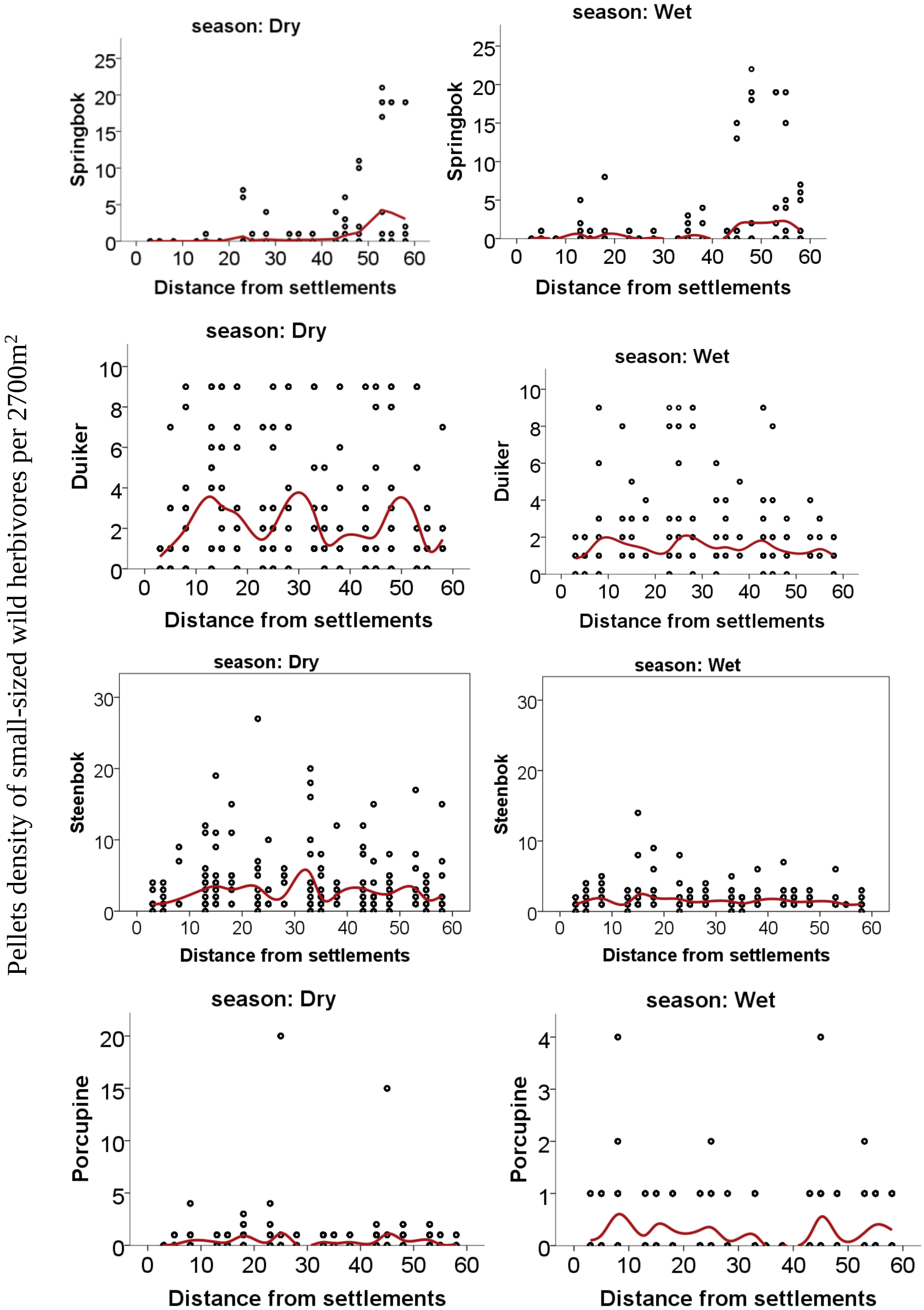


Figure 5.6 continues: Scatter plots fitted with natural cubic spline interpolation to show the trend in variation (red line) in the distribution of the small-sized wild herbivores (i.e. density of pellets/2700m^2): Springbok *Antidorcas marsupialis* (Zimmermann), Common Duiker *Sylvicapra grimmea* (Linnaeus), Steenbok *Raphicerus campestris* (Thunberg), Porcupine *Hystrix africaeaustralis* (Peters) pastoral activities disturbance gradient (distance is in km) in northern Kalahari, Botswana, during the dry and wet seasons respectively. The y-axis represents the density of wildlife pellets per 2700m^2 plot within each sample poin and the x-axis if the distance from cattle settlements in km.

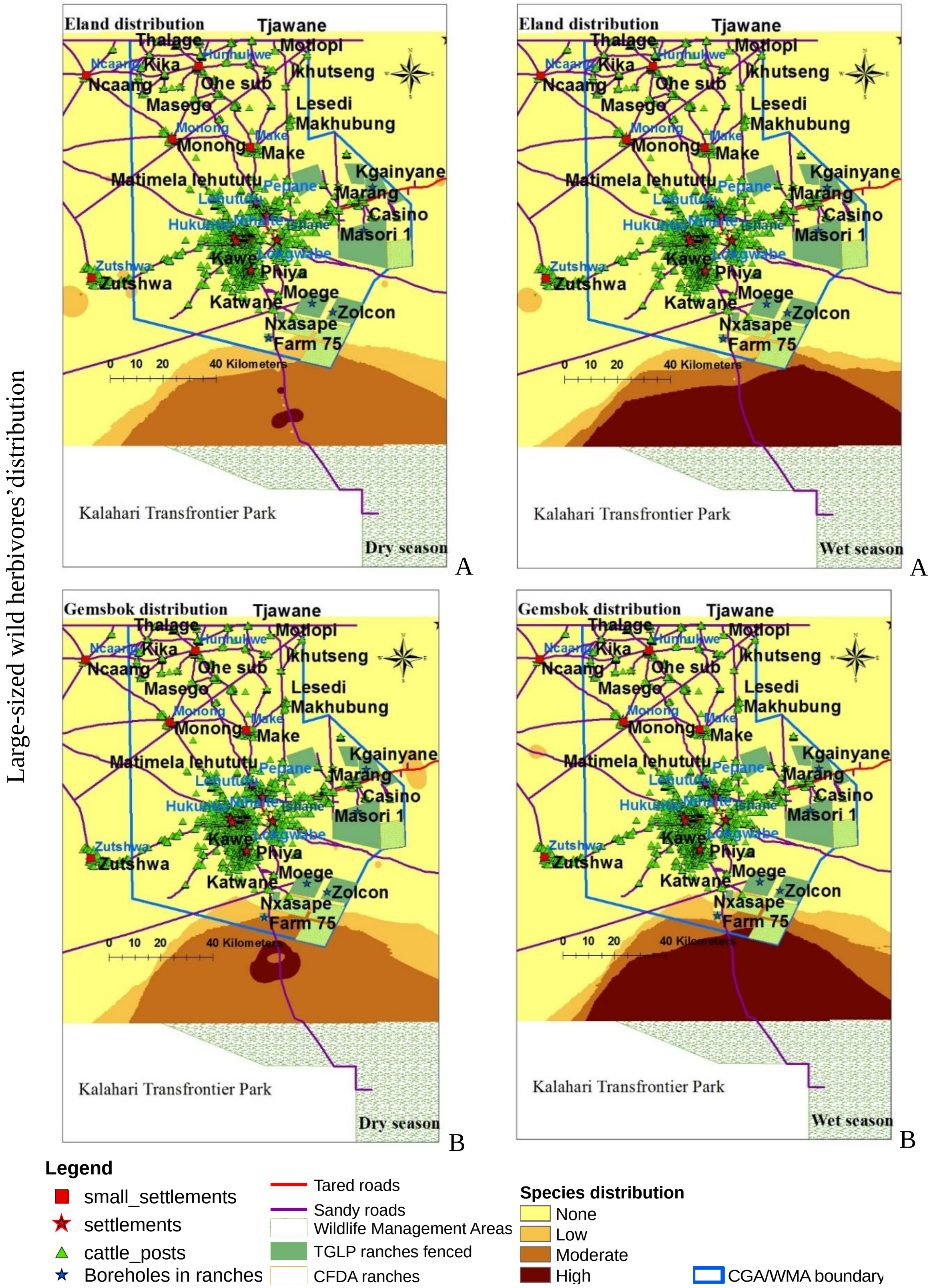


Figure 5. 7: Spatial distribution of herbivores in relation to land use, Pastoral activities and livestock grazing gradient

Inverse Distance Weighted (IDW) interpolation based on spoor data at each sample points of larger herbivores; Eland *Tragelaphus oryx* Pallas (A), Gemsbok *Oryx gazella* Linnaeus (B) during the dry and wet seasons respectively. The green triangles represent individual cattle posts.

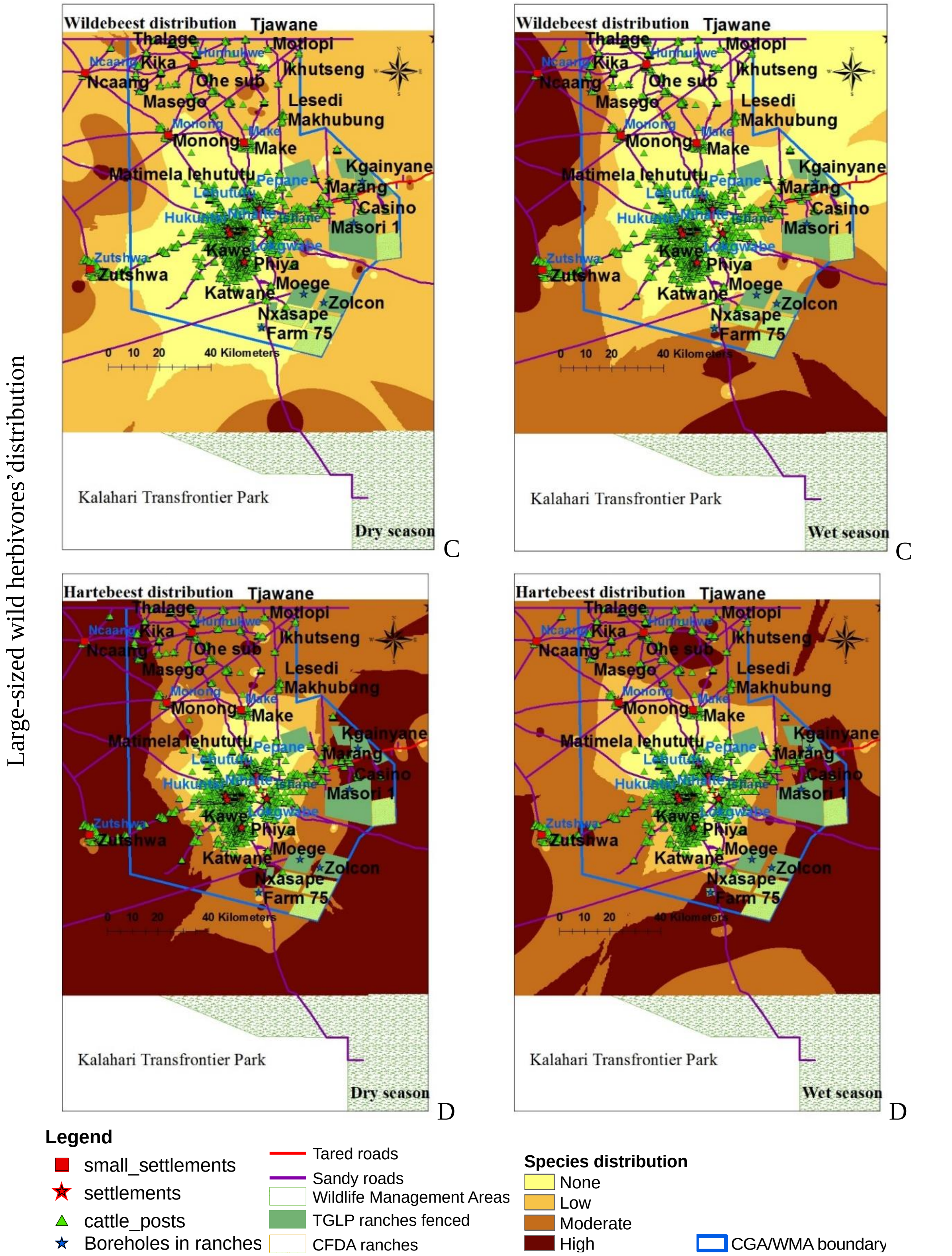


Figure 5.7 continued: Spatial distribution large and medium-sized herbivores in relation to land use, Pastoral activities and livestock grazing gradient

Inverse Distance Weighted (IDW) interpolation based on spoor data at each sample point of larger herbivores; Blue Wildebeest *Connochaetes taurinus* Burchell (C), Medium herbivore; Red Hartebeest *Alcelaphus bucelaphus* (D) in northern Kalahari, Botswana, during the dry and wet seasons respectively. The green triangles represent individual cattle posts.

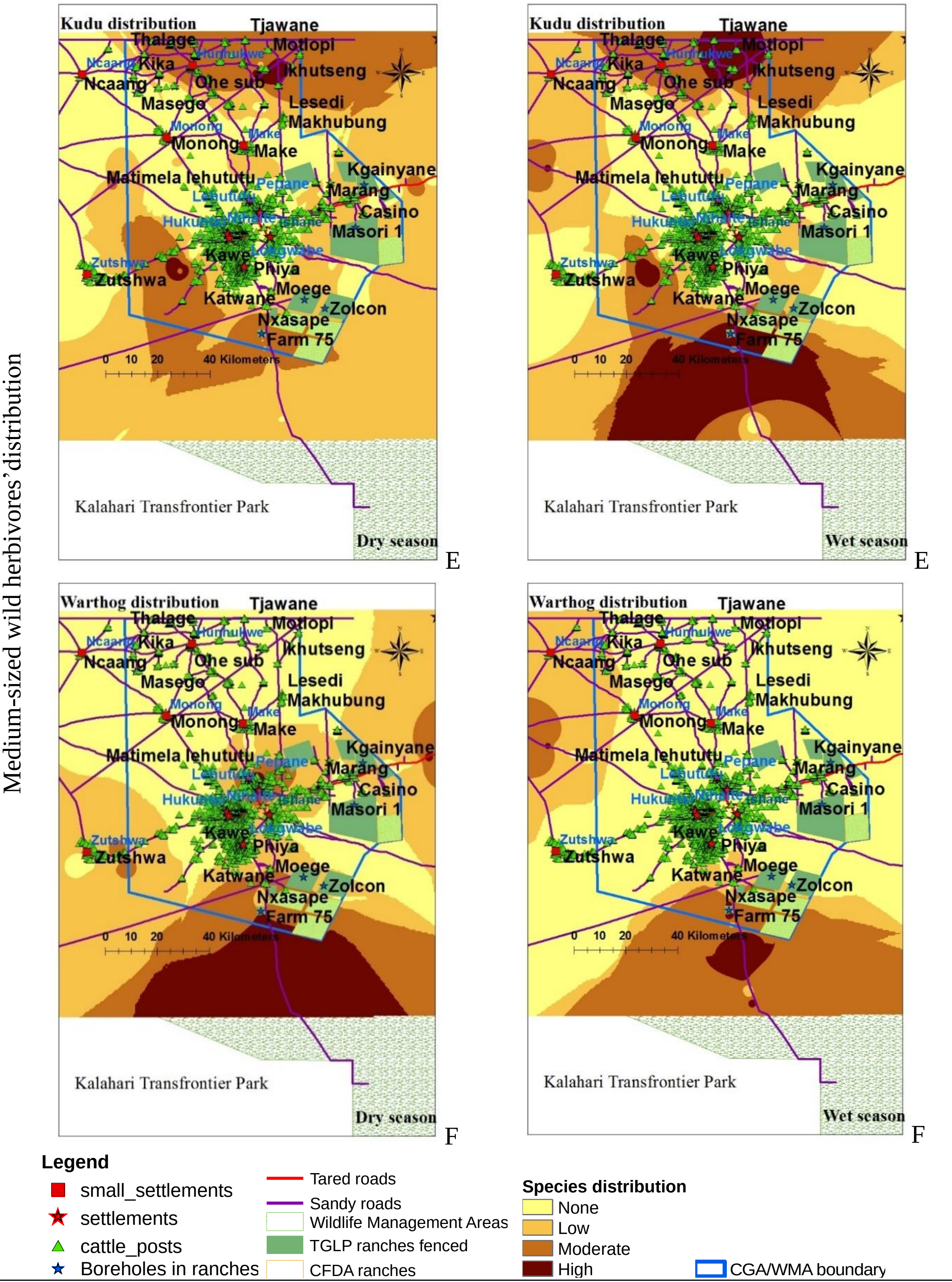


Figure 5.7 continued: Spatial distribution medium-sized herbivores in relation to land use, Pastoral activities and livestock grazing gradient

Inverse Distance Weighted (IDW) interpolation based on spoor data at each sample point of Medium-sized herbivores; The Greater Kudu *Tragelaphus strepsiceros* Pallas (E), Warthog - *Phacochoerus africanus* Gmelin (F) in northern Kalahari, Botswana, during the dry and wet seasons respectively. The green triangles represent individual cattle post

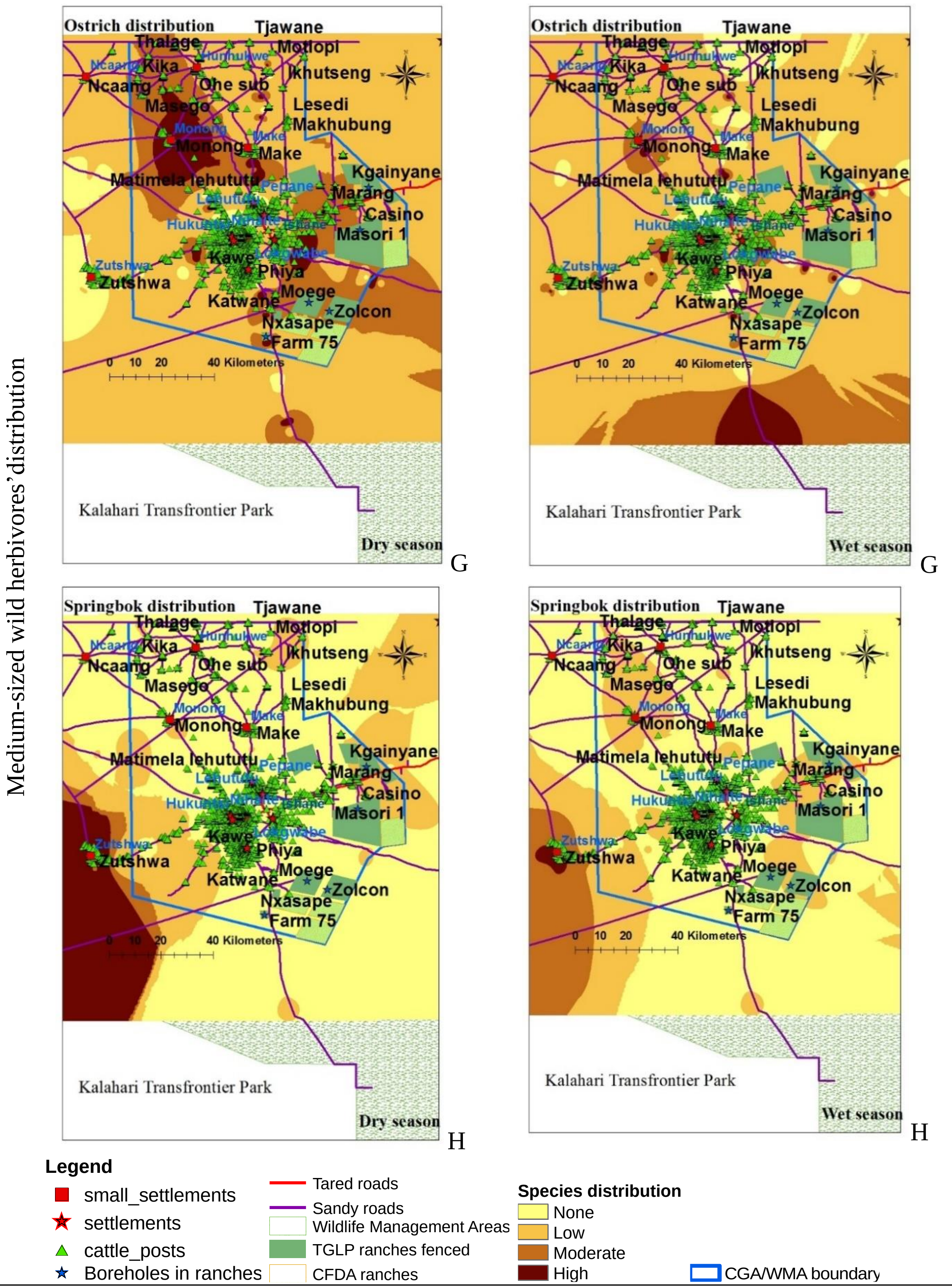
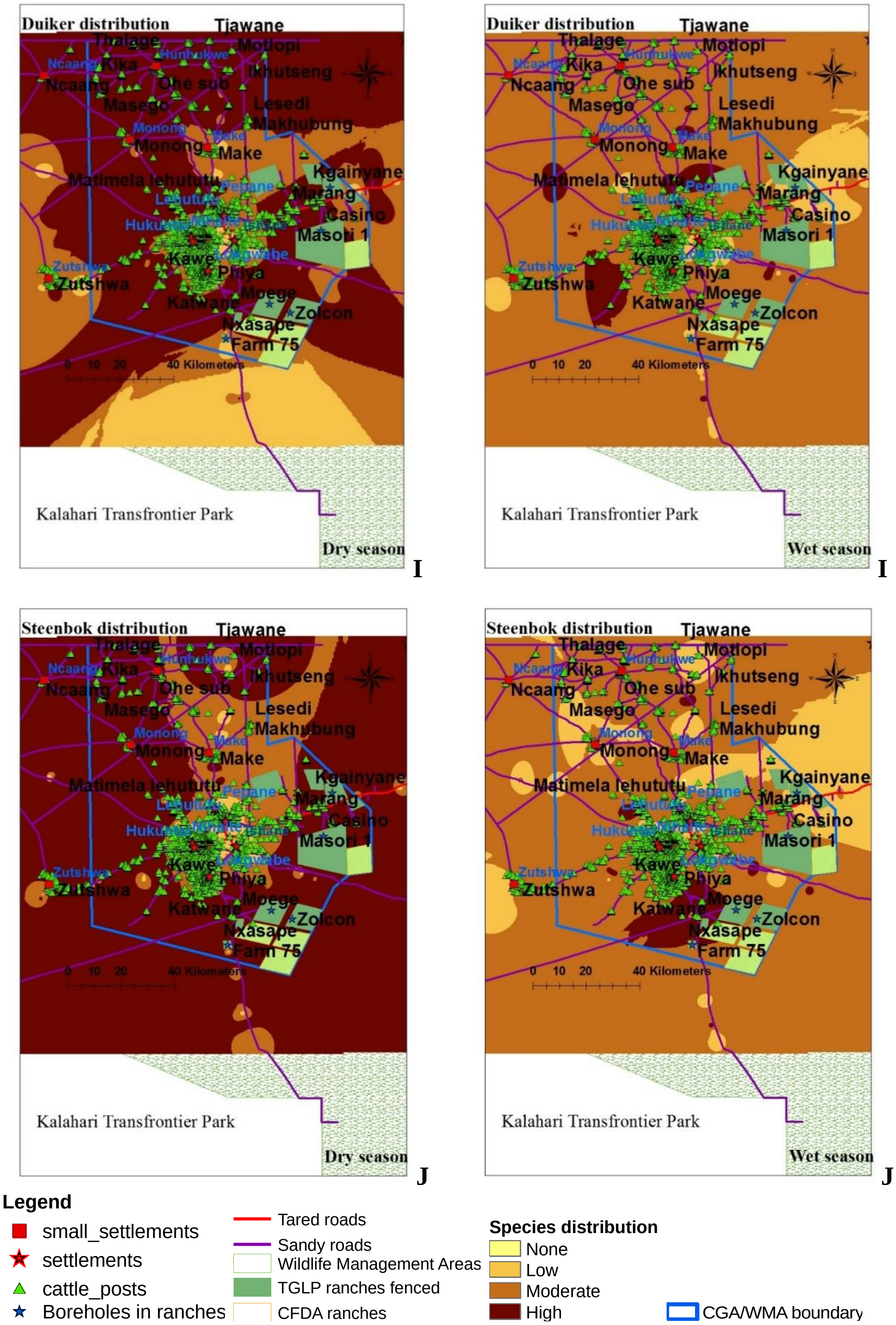


Figure 5.7 continued: Spatial distribution small and medium-sized herbivores in relation to land use, Pastoral activities and livestock grazing gradient

Inverse Distance Weighted (IDW) interpolation based on spoor data at each sample point of Medium-sized herbivores; strich *Struthio camelus* Linnaeus (G) and small-sized wild herbivores; Springbok *Antidorcas marsupialis* Zimmermann (H) in northern Kalahari, Botswana, during the dry and wet seasons respectively. The green triangles represent individual cattle posts

Small-sized wild herbivores' distribution



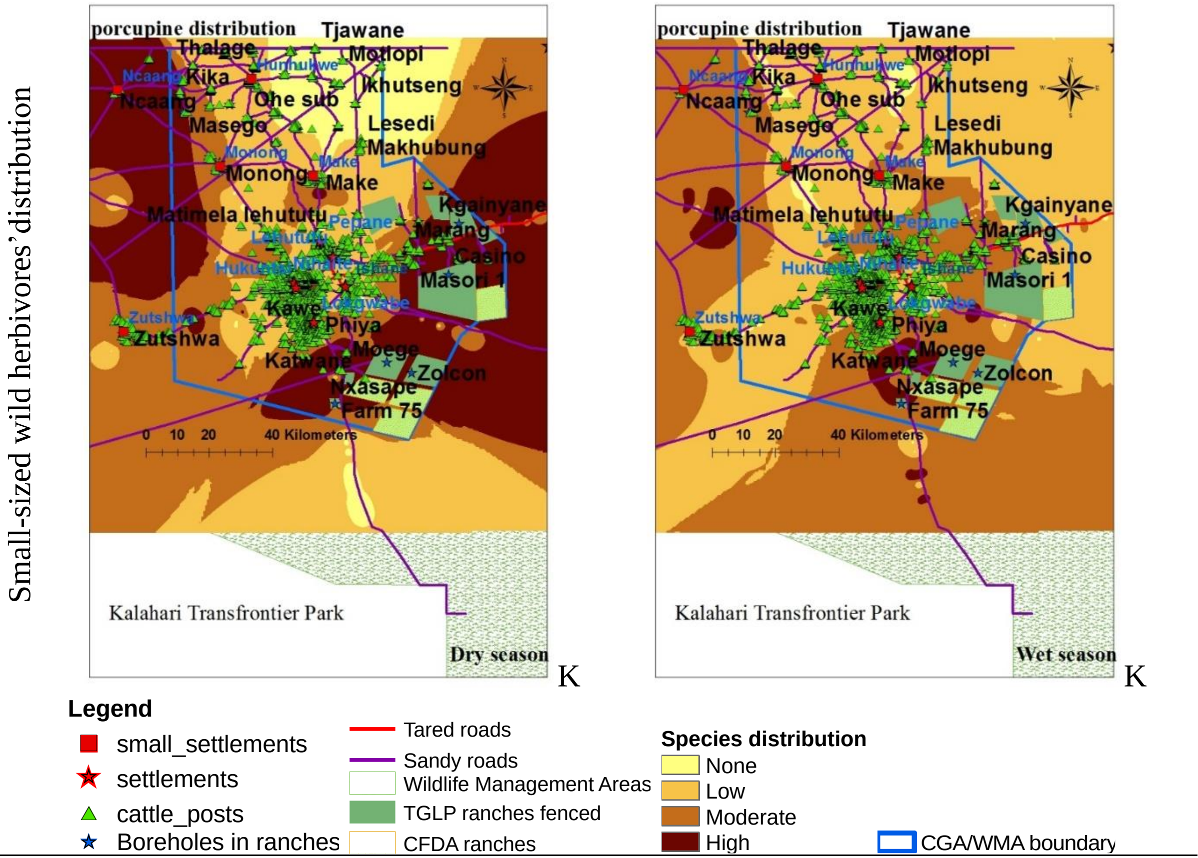


Figure 5.7 continued: Spatial distribution small-sized wild herbivores in relation to land use, Pastoral activities and livestock grazing gradient
Inverse Distance Weighted (IDW) interpolation based on spoor data at each sample point of small-sized wild herbivores; Common Duiker *Sylvicapra grimmea* Linnaeus (I), Steenbok *Raphicerus campestris* Thunberg (J), Porcupine *Hystrix africaeaustralis* Peters (K) in northern Kalahari, Botswana, during the dry and wet seasons respectively. The green triangles represent individual cattle posts.

The distribution of Red Hartebeest was the same in both land use types during the dry season (P = 0.389), but associated with CGAs in wet season (P < .001). Warthog distribution was increasing with distance from the settlements (P < 0.001) and was associated with both land use in dry season (P = 0.59), but related to CAs in wet season, (P = 0.002) (Figure 5.7 F). Therefore, showing that warthog was avoiding areas with high livestock grazing intensity, cattle posts, boreholes, and arable agriculture fields, hence there are adversely affected by pastoral impacted areas.

Table 5. 5: General Linear Model (Gaussian) coefficients, p-values and variance accounted for on medium wild herbivores
For the relationship of the estimated and measured environmental variables on the distribution of wild herbivores (the dependent variables were log-transformed) in both seasons combined. P-value computed using alpha = .05, hence P < 0.05 shows statistically significant variables at the 0.05 level (2-tailed). LGI = Livestock Grazing intensity. Bold P-values show significance.

		Red Hartebeest			**Kudu**			**Warthog**			**Ostrich**		
Source	**df**	**Sum of Squares**	**F**	**P-value**	**Sum of Squares**	**F**	**P-value**	**Sum of Squares**	**F**	**P-value**	**Sum of Squares**	**F**	**P-value**
sub transect	5	7.17	29.30	**<.001**	0.99	11.48	**<.001**	0.38	19.19	**<.001**	3.50	38.29	**<.001**
Transects	4	0.44	2.24	0.063	7.76	112.71	**<.001**	0.81	51.54	**<.001**	1.28	17.57	**<.001**
Grass height	4	0.90	4.59	**0.001**	0.20	2.90	**0.021**	0.07	4.38	**0.002**	0.89	12.13	**<.001**
LGI	3	2.30	15.63	**<.001**	0.13	2.51	0.057	0.13	10.90	**<.001**	0.78	14.22	**<.001**
Land use types	1	0.49	10.04	**0.002**	0.09	5.07	**0.024**	0.00	0.28	0.596	0.13	7.34	**0.007**
Distance boreholes	4	6.01	30.68	**<.001**	3.55	51.58	**<.001**	0.03	1.72	0.143	3.39	46.41	**<.001**
Distance cattle posts	4	4.38	22.37	**<.001**	1.25	18.19	**<.001**	0.09	5.66	**<.001**	2.81	38.43	**<.001**
Palatable perennials grasses	1	0.68	13.92	**<.001**	0.02	1.42	0.233	0.02	6.06	**0.014**	0.18	9.96	**0.002**
Tree density	1	1.08	21.99	**<.001**	0.04	2.38	0.123	0.01	2.57	0.109	0.00	0.05	0.832
Forbs	1	0.01	0.15	0.703	0.15	8.68	**0.003**	0.01	3.71	**0.054**	0.19	10.22	**0.001**
Unpalatable perennials grasses	1	0.05	1.11	0.293	0.30	17.55	**<.001**	0.11	28.42	**<.001**	0.04	2.07	0.15
Unpalatable annuals grasses	1	0.46	9.30	**0.002**	0.02	1.12	0.289	0.04	8.99	**0.003**	0.19	10.42	**0.001**
Palatable annuals grasses	1	0.35	7.08	**0.008**	0.00	0.03	0.875	0.04	9.56	**0.002**	0.07	3.89	**0.049**
Sub transect * LGI	14	10.06	14.67	**<.001**	10.21	42.37	**<.001**	1.84	33.56	**<.001**	3.84	15.03	**<.001**
Transect * LGI	11	8.61	15.98	**<.001**	17.28	91.28	**<.001**	1.15	26.84	**<.001**	7.80	38.85	**<.001**
R squared adjusted		0.463			0.413			0.353			0.257		

The distribution of small-sized wild herbivores

Small-sized wild herbivores (Duiker, Steenbok, and Porcupine), except Springbok, were abundant in the study areas as they were recorded in almost at all sample points. Hence, there was no statistically significant difference in the distribution of Duiker ($P = 0.273$), and Steenbok ($P = 0.835$) between CAs and CGAs. Nonetheless, Springbok, and Porcupine were associated with the CAs in both seasons combined ($P <0.001$) (Table 5.6). In the exception of Springbok, most of the distribution of small-sized wild herbivores were along Lehututu/Hunhukwe, Lokgwabe/Mabuasehube and Hukuntsi/Ngwatle transects ($P < 0.001$) (Figure 5.7 I – K), hence indicating that they were associated with livestock grazing. The distribution of Duiker and Steenbok were decreasing with increasing distances from the cattle posts and livestock grazing intensity ($P < 0.001$) (Table 5.6 & Figure 5.7 I - J). However, their distribution was not associated with high forbs and unpalatable annual grasses ($P > 0.05$). Therefore, showing that they were related to moderate livestock grazing and avoided increased pastoral impacted areas, such as settlements and arable fields. Nevertheless, their spoor observation was also recorded closer to settlements, from minimum distance of 3km (Duiker, porcupine and steenbok) (Figure 5.6).

On the contrary, Springbok, and Porcupine, were associated with CAs than CGAs. Springbok was highly distributed along Hukuntsi/Zutshwa transect and ($P < 0.001$) (Figure 5.7 H), but Porcupine was distributed along all transects (Figure 5.7 K). The distribution of Springbok was increasing with distance from the major settlements, and it was associated with medium to high livestock grazing intensity, ($P < 0.001$). Consequently, Springbok was related to high densities of unpalatable annual grasses ($P = 0.002$), forbs ($P = 0.021$), near Zutshwa settlements (as shown in Table 5.6). Springbok distribution was also recorded within less than 1km from the settlement and grazing with small stock. Nonetheless, Springboks were avoiding high densities of cattle posts and arable fields near the four major settlements in CGAs.

Table 5. 6: General Linear Model (Gaussian) coefficients, p-values and variance accounted for on small-sized wild herbivores
For the relationship of the estimated and measured environmental variables on the distribution of wild herbivores (the dependent variables were log-transformed) in both seasons combined. P-value computed using alpha = .05, hence P < 0.05 shows statistically significant variables at the 0.05 level (2-tailed). LGI = Livestock Grazing intensity. Bold P-values show significance.

		Springbok			**Duiker**			**Steenbok**			**Porcupine**		
Source	**df**	**Sum of Squares**	**F**	**P-value**	**Sum of Squares**	**F**	**P-value**	**Sum of Squares**	**F**	**P-value**	**Sum of Squares**	**F**	**P-value**
sub transect	5	8.42	66.35	**<.001**	1.77	7.30	**<.001**	2.31	9.52	**<.001**	1.04	11.20	**<.001**
Transect	4	2.35	23.18	**<.001**	1.78	9.18	**<.001**	5.93	30.63	**<.001**	1.99	26.86	**<.001**
Grass height	4	0.31	3.08	**0.015**	0.58	2.97	**0.019**	0.38	1.96	0.099	0.13	1.78	0.13
LGI	3	1.55	20.31	**<.001**	2.10	14.43	**<.001**	3.13	21.52	**<.001**	1.54	27.82	**<.001**
Land use types	1	18.88	743.83	**<.001**	0.06	1.20	0.273	0.00	0.04	0.835	0.50	27.01	**<.001**
Distance borehole	4	6.67	65.64	**<.001**	6.16	31.73	**<.001**	1.84	9.48	**<.001**	1.00	13.53	**<.001**
Distance cattle post	4	5.09	50.12	**<.001**	1.16	5.96	**<.001**	2.42	12.47	**<.001**	0.81	10.91	**<.001**
Palatable perennials	1	0.01	0.24	0.623	0.66	13.64	**<.001**	0.16	3.32	0.069	0.07	3.75	0.053
Tree density	1	0.12	4.90	**0.027**	0.08	1.72	0.19	0.57	11.78	**0.001**	1.08	58.30	**<.001**
Forbs	1	0.14	5.33	**0.021**	0.04	0.79	0.374	0.04	0.85	0.355	0.08	4.14	**0.042**
Unpalatable perennials grasses	1	0.09	3.33	0.068	0.04	0.78	0.377	0.00	0.00	0.971	0.12	6.68	**0.01**
Unpalatable annuals grasses	1	0.24	9.31	**0.002**	0.08	1.58	0.209	0.11	2.22	0.136	0.19	10.31	**0.001**
Palatable annuals grasses	1	0.05	1.88	0.171	1.36	28.09	**<.001**	0.04	0.74	0.389	0.01	0.25	0.615
sub transect * LGI	14	12.23	34.42	**<.001**	6.44	9.48	**<.001**	4.03	5.95	**<.001**	4.38	16.91	**<.001**
Transect * LGI	11	0.86	3.07	**<.001**	0.94	1.75	0.057	4.79	9.00	**<.001**	9.61	47.23	**<.001**
R squared adjusted		0.607			0.147			0.10			0.246		

5.3.3: Wild herbivores and livestock species distribution in relation to environmental factors and pastoral activities

Forward selection of seventeen original environmental variables, which showed high loadings on the PCA components, but not the component scores, were used in CANOCO analysis (Palmer 1993) to determine the variation of wild herbivore species through ordination and multiple regression. Hence resulting into axes which are constrained to produce linear combinations of the supplied environmental variables (Ter Braak 1988).. These variables were as follows; densities of palatable perennial, unpalatable perennial, unpalatable annual, palatable annual grasses, total tree cover, grass cover, diversity, & height, forb density & cover, land use, livestock grazing intensity, rainfall, habitat type, distances from cattle posts & settlements.

The distribution of wild herbivores during the dry and wet season

Nine and eight environmental variables statistically significantly explained the variance in the wild herbivores and livestock spoor data in dry (57%) and wet (56.7%) season respectively ($p < 0.05$) (Table 5.7 & 5.8). Despite the omission of other environmental variables, the eigenvalues of the first two axes remained reasonable high in dry (AX1 = 0.602, AX2 = 0.446) and wet season (AX1 = 0.436, AX2 = 0.418). Therefore, indicating that the first two axes for dry and wet seasons, represented the effective gradients, explaining 43.4 & 42.2% of the total variance in the species data respectively (Table 5.7). Most of the retained environmental variables were not highly correlated in both seasons. Hence no multicollinearity between the variables as evident through the correlation coefficients and all their variance inflation factors (VIF) values are less than 10 (using a Tolerance level of 0.10) (Tabachnick, Fidell et al. 2001) (Appendix 5D).

During the dry season, along with the first axis, distance from settlements had the highest positive correlation (0.7101) followed by land use (CA) (0.6879), and forb cover (0.6175) (Table 5.8). Hence, this first axis is a gradient of increasing distance from settlements towards CA, together with forb cover, hence reflecting less livestock grazing intensity (Figure 5.8A). Therefore, indicating that less livestock grazing intensity and less pastoral activities were the most important environmental variables influencing the distribution of wild herbivores and livestock during the dry season. Other relevant environmental variables during the dry seasons were grass height (0.7) and grass diversity (0.6891), distance from cattle posts (0.6521), and woody cover (0.6013), which had the highest correlation with the second axis respectively (Table 5.8). Consequently, in the dry season, the first CCA biplot axis is a gradient of increasing distance from settlements (less livestock grazing intensity), towards the CAs, where there are fewer pastoral activities from left to right. While the second axis is a gradient of grass height, diversity and increasing distance from the cattle posts, hence also reflecting less livestock grazing intensity from bottom up (Figure 5.8A).

On the contrary, during the wet season, Palatable annual grasses (0.6596) have the highest positive correlation with the first axis, followed by grass diversity (-0.6249), distance from cattle posts (-0.6113) and areas without livestock grazing (-0.5569) with negative correlation with the first axis (Table 5.8). Consequently, in the wet season, the first CCA biplot axis is a gradient of less grass diversity, decreasing distance from cattle posts (increasing livestock grazing intensity), together with increasing palatable annual grasses, mainly *Schmidtia kaliharensis* from left to right (Figure 5.8B). Therefore, indicating that palatable annual grasses, grass diversity, and distance from the cattle posts are the most significant environmental variables persuading the distribution of wild herbivores and livestock during the wet season. Other relevant environmental variables in wet season were the distance from settlements (-0.7466), land use (CGA) (0.6864) and arable fields (+0.672) which had the highest correlation with the second axis respectively (Table 5.8). Therefore, the second axis is a gradient of decreasing distance from the settlements (increasing livestock grazing intensity), with increasing pastoral activities, such as arable fields and disturbance in CGAs (Figure 5.8B). The CCA biplot ordination diagrams, in which the quantitative environmental variables are presented by arrows radiating from the origin of the graphs (Figure 5.8).

Table 5. 7: Summary of the forward selection on the retained environmental variables in dry and wet seasons

	Dry season				Wet season			
Axes	**AX1**	**AX2**	**AX3**	**Total inertia**	**AX1**	**AX2**	**AX3**	**Total inertia**
Eigenvalues	0.602	0.446	0.184	2.413	0.436	0.418	0.19	2.025
Species-environment correlations:	**0.918**	**0.883**	0.791		**0.932**	**0.897**	0.762	
Cumulative percentage variance								
of species data:	**24.9**	**43.4**	51		**21.6**	**42.2**	51.5	
of species-environment relation:	43.7	76	89.3		38	74.4	90.9	
Sum of all eigenvalues				**2.413**				**2.025**
Sum of all canonical eigenvalues:				**1.378**				**1.149**

Table 5. 8: The inter-set correlation coefficients of the environmental variables on wild herbivores
The first three ordination species axes showing their influence on wildlife and livestock distribution, in northern Kalahari, Botswana in dry and wet seasons. The **bold** correlation coefficients are the highest in each axis.

	Dry season			Wet season		
Environmental variables	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 1**	**Axis 2**	**Axis 3**
Non-livestock grazing, (NLG)	0.0613	**0.5952**	-0.4415	**-0.5569**	-0.439	0.3137
Less livestock grazing intensity (LLGI)				0.1453	-0.1676	-0.1862
Land use (CGA)	**-0.6879**	-0.2379	0.4077	-0.0169	**0.6864**	-0.3945
Land use (CA)	**0.6879**	0.2379	-0.4077	0.0169	**-0.6864**	0.3945
Arable fields (AAF)	-0.4443	-0.6013	-0.3924	0.1272	**0.672**	0.4714
Woody cover (WC)	0.4443	**0.6013**	0.3924	-0.1272	**-0.672**	-0.4714
Distance from cattle posts	0.0759	**0.6521**	-0.4129	**-0.6113**	-0.4875	0.352
Distance from settlements	**0.7101**	0.3727	-0.0874	0.0069	**-0.7466**	0.0746
Grass height (Grasht)	0.2936	**0.7**	-0.146			
Unpalatable perennial grasses	0.0731	-0.1633	0.3068			
Grass diversity	-0.0698	**0.6891**	0.1796	**-0.6249**	-0.0755	-0.0002
Forb cover	**0.6175**	-0.074	0.0973			
Palatable annual grasses				**0.6596**	-0.3613	0.1347

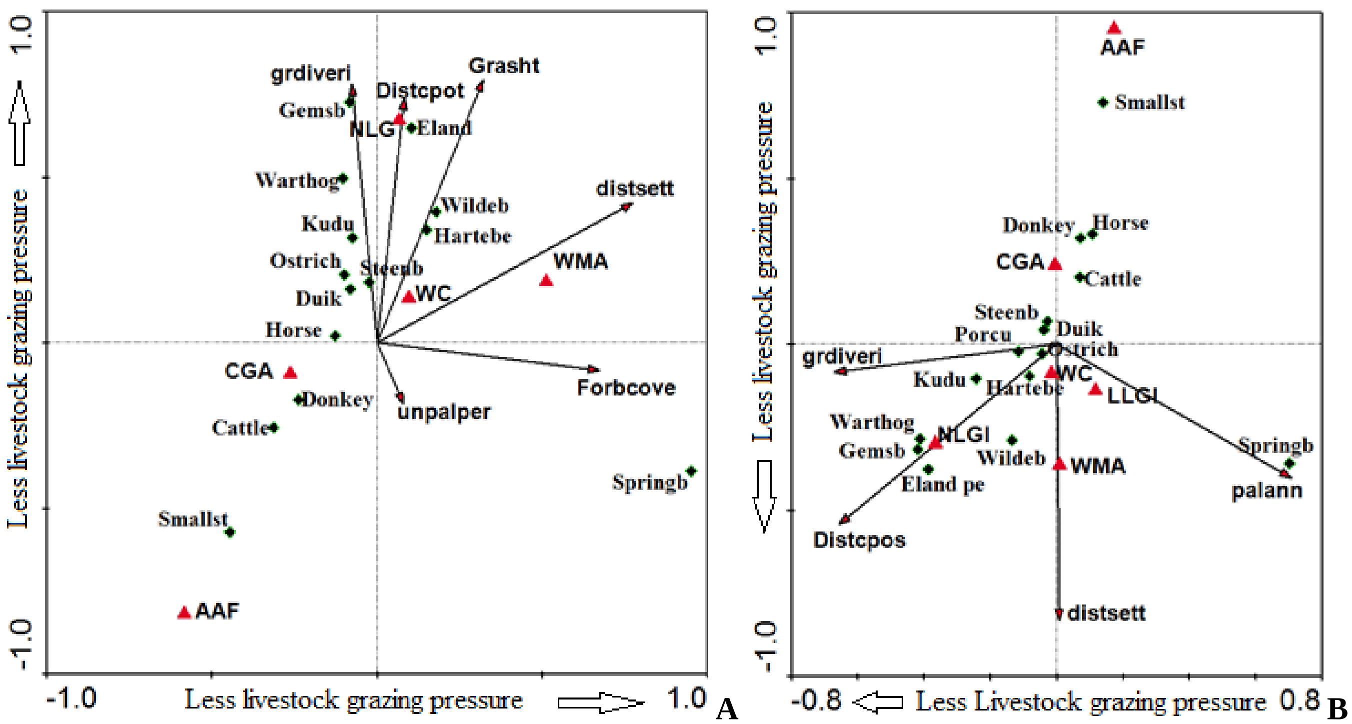


Figure 5. 8: Ordination diagram based on canonical correspondence analysis – CCA for the wild herbivores and livestock Distribution with respect to quantitative (shown by arrows) and nominal (red triangles) environmental variables in northern Kalahari, Botswana, during the dry (A) and Wet (B) seasons.). Wild herbivores and livestock species are shown as green dots. For dry season, the species – environmental correlation for the first two axes are 0.918 and 0.883, respectively (eigenvalue 1 = 0.602, eigenvalue 2 = 0.446; scaling = 2, sum of all canonical eigenvalues is 1.378), while for wet season are 0.932 and 0.897 respectively (eigenvalue 1 = 0.436, eigenvalue 2 = 0.418; scaling = 2, sum of all canonical eigenvalues is 1.149). Distsett, Distcpot, = distance from settlements, cattle posts, respectively, Grasht = grass height, grasscov = grass cover, grdiveri = grass diversity, forbcove = Forb cover, unpalper = unpalatable perennial grasses, palann = palatable annual grasses. Land use (CGA = communal grazing area, CA = wildlife management areas); habitat type (AAF = arable agriculture fields, WC = woody cover), Livestock grazing intensity (NLG = livestock grazing absent, LLGI = less livestock grazing intensity). Duik = Duiker, Steenb = Steenbok, Porcu = Porcupine, Hartebe = Hartebeest, Wildb = Wildebeest, Gemsb = Gemsbok, Springb = Springbok.

There was a clear separation between the distribution of wild herbivores and free-ranging livestock in both seasons. Most of the wild herbivores, except Springbok, were positively correlated with less livestock grazing intensity. However, cattle, donkey, horse and small stock were positively correlated with increasing livestock grazing intensity and arable fields in CGAs during the dry season (Figure 5.8A). Conversely, in the wet season, most of the wild herbivores were positively related to less livestock grazing intensity, except Steenbok, Duiker, and Porcupine which showed no correlation. All large-sized herbivores (Eland, Gemsbok, and Blue Wildebeest) were associated more with the CAs than CGAs, in areas far from the cattle posts, settlements, with high grass height and grass diversity and without livestock grazing in both seasons (Figure 5.8). Therefore, indicating that the large-sized herbivore distribution was influenced by land use, pastoral activities, forage availability and less livestock grazing intensity in both seasons. Hence large-sized herbivores concentrated in CAs and avoided CGAs.

On the contrary, most of the medium-sized herbivores (Warthog, the greater Kudu, and Ostrich), except Red Hartebeest were associated with CGAs than CAs during the dry season. Nonetheless, during the wet season, medium-sized herbivores were related to CA than CGA, except Ostrich which showed close relations with CGA in both seasons. Medium-sized herbivores, except Ostrich, were positively correlated with grass height, grass diversity and increasing distance from cattle posts and settlements, however, negatively associated with unpalatable perennial grasses in both seasons (Figure 5.8B). Therefore, indicating that they avoided increasing livestock grazing intensity and pastoral dominated areas closer to the cattle posts and settlements and remained in moderately grazed areas. Ostrich was not impacted by increasing livestock grazing intensity and other pastoral activities, however, avoided being closer to the settlements.

Small-sized wild herbivores (Duiker, Porcupine, and steenbok) were associated with CGAs. Nonetheless, Springbok was related to CAs, mainly near Zutshwa settlements in both seasons (Figure 5.8). Small-sized wild herbivores (Duiker and Steenbok) showed no correlation with distance from settlements. However, they were weakly positively correlated with grass height, diversity and distance from cattle posts. Duiker and Steenbok were also negatively associated with forb cover in the dry season. In wet season Steenbok, Duiker, Porcupine showed no correlation with distances from the settlements and cattle posts and grass grass diversity. Therefore, showing that Steenbok, Duiker, and Porcupine were not impacted by increasing livestock grazing intensity and other pastoral activities in both seasons. On the other hand, Springbok had a different distribution compared to other small-sized wild herbivores because it was positively associated with increasing distance from the major settlements and found mainly near Zutshwa settlements in CAs in both seasons. It was also positively related to forb cover, negatively related to distance from cattle posts, grass diversity but no correlation with grass height in both seasons. Hence indicating that Springbok was not negatively impacted by Livestock grazing intensity, but pastoralists' disturbance in CGAs.

5.4: Discussion

The theory on the distribution of wildlife (Hopcraft, Anderson et al. 2012, Hopcraft, Olff et al. 2010) and empirical data (e.g. Bhola, Ogutu et al. 2012) from the previous studies in east Africa have identified forage quantity, quality and predation risk as the critical determinants of the distribution of resident herbivores in CAs and pastoral ranches. However, the fundamental questions are (i) to what extent do these ecological factors and mechanisms can be extrapolated to pastoral-dominated, semi-arid communally managed savannah rangelands supporting free-ranging livestock. ii) In addition to forage availability and predation, how does the pastoralists-induced risk (i.e. human disturbance) in communally managed rangeland with free-ranging livestock influence the distribution of wild herbivores of different body sizes and feeding styles? The current study explored factors influencing the distribution of herbivores in CGAs supporting free-ranging livestock near CAs.

The current study revealed six distinct general patterns in the distribution of pastoralists', LGI and wild herbivore, showing groups of herbivores of different body sizes being persistent in separate spatial localities along livestock grazing gradient and land use. (i) As predicted (H2a), most of the pastoral activities were within the CGAs, closer to the four main settlements, hence the increased LGI and the decreasing distribution of the variety of wild herbivores within a radius of 15km from these settlements. (ii) Cattle travelled longer distances from the cattle posts for grazing during the dry than the wet season, due to limited forage resource, which agrees with hypothesis (H2a). Nonetheless, their grazing distribution was mainly in CGAs. (iii) Contrary to hypothesis (H2b), small-sized wild herbivores (e.g. Duiker, Steenbok) tended to concentrate in CGAs, in areas with increased LGI in both seasons, suggesting grazing facilitation by livestock grazing and other anthropogenic activities. iv) The medium-sized herbivores (e.g. Red hartebeest, Kudu and Warthog) avoided increased LGI and human-dominated areas and were related to moderately grazed areas on CGAs, CGA/CA boundary and in CAs in both seasons. This pattern partly agrees with hypothesis (H2c), however, the tendency for medium herbivores to move into CA during the dry season was not noticeable, hence not in agreement with studies by Bhola, Ogutu et al. (2012), Hopcraft, Anderson et al. 2012, and Hopcraft, Olff et al. 2010 in East Africa. v) On the other hand, as predicted (H2d), large-sized wild herbivores (e.g. Eland, Gemsbok, and Wildebeest) concentrated in CAs in both seasons and avoided CGAs. (vi) Lastly, the study reveals that LGI (i.e. forage availability), predation, pastoralist-induced risk and land use were significant factors influencing the distribution of wild herbivores and livestock during both seasons.

Therefore, it can be concluded that environmental factors and mechanisms (i.e. forage quantity, quality and predation risk) identified as the critical determinants for the distribution of wild herbivores of different sizes in between CAs and ranches in East Africa (Hopcraft, Olff et al. 2010, Hopcraft, Anderson et al. 2012, Bhola, Ogutu et al. 2012) can be extrapolated to the pastoral-dominated, semi-arid communally managed savannah rangelands supporting free-ranging livestock. However, pastoralists-induced risk and increased livestock grazing intensity in CGAs supporting free-ranging livestock play a more prominent role in the distribution of wild herbivores of different sizes. These six distinct general patterns in the distribution of herbivores of different body sizes interacting with the effects of livestock and pastoralism are in agreement with the ecological theory that suggests that wild herbivores should maximize access to forage resources and minimise exposure to risk (McNaughton, Ruess et al. 1988, McNaughton 1990, Olff, Ritchie et al. 2002, Anderson, Hopcraft et al. 2010, Hopcraft, Olff et al. 2010). The current study revealed that the spatial distribution of the wild herbivores reflected differences in their body sizes and feeding styles, hence the differences in the distribution of small, medium and large herbivores between land use and LGI.

5.4.1: Spatial distribution of pastoral activities and free-ranging Livestock grazing

The major pastoral activities such as sedentary cattle posts, artificial boreholes for watering livestock, settlements, few fenced ranches, and arable fields were located near the four main settlements. Hence, indicating resource competition with wildlife because of the reduced and increased herbaceous and woody plants, respectively within a radius of 15km (Chapter 4). As expected, cattle travelled longer distances from the cattle posts for grazing during the dry (10.81 ± 0.77 km) than the wet (5.69 ± 0.31 km) season. Hence most wild herbivores were positively correlated with less livestock grazing intensity in CGAs and CAs, supporting (H2a). This pattern accord with and reinforce similar findings by previous studies in East Africa (Hopcraft, Anderson et al. 2012, Bhola, Ogutu et al. 2012, Hopcraft, Olff et al. 2010).

Pastoral activities such as cattle posts, watering posts and arable fields were situated in the periphery of the four main settlements (within 15km) within the CGAs, resulting in an increased LGI within a radius of 15km. Other pastoral activities were associated with sparsely located artificial boreholes in the northern part of the study area and few ranches resulting in moderate LGI. All livestock grazing distribution was restricted to the water points and high density of cattle posts and arable fields near main settlements and in CGAs in both seasons. There was less livestock grazing within the CAs, except in areas where cattle posts were within or near the CAs, therefore, indicating that the distribution of livestock was mainly in CGAs. As predicted (H2a), cattle travelled longer distances from the cattle posts for grazing during the dry than the wet season; hence, the possibility of resource competition within the dry season.

There was a clear separation between livestock and most of the wild herbivores grazing distribution. The results show that within the 15km radius from the main settlements, livestock has reduced the grass cover to the bare ground during the dry season. However, in the wet season, annual grasses like *Schimidtia kalaharensis* Stent and forb species dominant the intensively grazed areas, while *Eragrostis lehmanniana* Nees dominates the moderately grazed areas. Palatable perennial grasses were negatively associated with increasing LGI in both seasons (chapter 4). Therefore, suggesting competition for the grazing resources between livestock and wildlife within these intensively grazed areas. Moderate livestock grazing was observed from a minimum distance of about 15km from the main settlements (chapter 4), suggesting grazing facilitation could occur within 15km from the settlements.

The concentration of cattle posts closer to water points, arable fields and settlements have been documented in other places like Kenya (Lamprey and Reid 2004, Mworia, Kinyamario et al. 2008). The possible explanation for this pattern of pastoralism could be due to the better amenities from the settlements, also as a way of reducing travel costs by managing livestock and arable fields in one place near the settlements. Consequently, areas surrounding the settlements are continually grazed by small stock and donkey because pastoralists restrict their movements as they are kraaled at night. The effects of increasing cattle post density (Reid, Rainy et al. 2003) and cultivation activities (Mworia, Kinyamario et al. 2008) near settlements might adversely affect wild herbivore distribution, such as medium to large herbivores. Arable fields are fenced off separately, possibly allowing the wild animals to move in between them. Hence, suggesting that the arable fields might not harm restricting wild herbivore movements but reduces the grazing areas.

Nonetheless, the frequent presence of the pastoralists and overgrazing by livestock around the arable fields near the settlements (pastoralists-induced risk) have an undesirable impact on the distribution of the wild herbivores. Particularly during the cropping season, when activities at the fields have increased and dry season when the grazing resources are limited (Odadi, Karachi et al. 2011). Sallu et al. (2009) also found out that vegetation near Khawa settlement, Botswana, was adversely impacted by livestock grazing and extraction. Similarly, the current study shows that the cattle distribution was regulated by the centralized water sources in main settlements; hence overgrazing by livestock within a radius of 15 km from these main settlements was prominent. The current study shows that there is less livestock grazing in CAs especially during the wet season, which is in agreement to others studies in Kalahari (Verlinden 1997, Verlinden, Perkins et al. 1998) and Kenya (de Leeuw, Waweru et al. 2001). The possible explanation for some livestock grazing in CAs could be because in the wet season there is the availability of temporary surface water in the natural pans and the wild melons. Hence cattle travel longer distances because they do not return to artificial water points in CGAs. It might also be linked to the few cattle posts near and within the CAs. Cattle travelled longer distances from the cattle posts for grazing during the dry than wet season, possibly because of the shortage of grazing sources (Odadi, Karachi et al. 2011).

5.4.2: Distribution of different wild herbivores in relation to livestock grazing gradient and land use

Factors influencing the distribution of large-sized wild herbivores

As expected (H2d), large-sized herbivores (Eland, Gemsbok, wildebeest), which are not susceptible to predation risk (Sinclair et al. 2003) and depend on bulk grasses because of their ability to digest low-quality forage, were associated with high vegetation cover in CAs (Fritz et al. 2002, Bhola, Ogutu et al. 2012) and avoided CGAs in both seasons. Therefore, suggesting that the distribution of large wild herbivores is influenced by mainly by forage quantity, and the pastoralists-induced risk in communally managed rangelands near CAs in both seasons. Large herbivores can risk predation by concentrating on CAs in areas of relatively high predation risk (Owen-Smith 1988). Predation is generally associated with wildlife body size and vegetation height and cover in savannas (Hopcraft et al. 2005).

The distribution of large-sized wild herbivores agrees with ecological theory (Anderson, Hopcraft et al. 2010, Hopcraft, Anderson et al. 2012) and the emperical studies in East Africa (Bhola, Ogutu et al. 2012) and Southern Africa (Verlinden 1997, Verlinden, Perkins et al. 1998). These spatial distribution of large-sized herbivores are concordant with the ecological theory that suggests that wild herbivores should maximize access to forage resources and minimize exposure to risk (Anderson, Hopcraft et al. 2010, Hopcraft, Olff et al. 2010). Consequently, the findings show that large herbivores avoided pastoralists-induced risk in CGAs and associate themselves with the predation in the CAs, where the forage quantity is high in both seasons (Chapter 4).

The current study revealed that competition for forage resource by livestock, habitat modification and the pastoralists-induced risk together influenced the distribution of large-sized herbivore in Kalahari semi-arid rangelands. However, the pastoralists-induced risk plays a significant role in influencing the distribution of large-sized wild herbivores than the predators, hence their preference to remain in CAs in both seasons, regardless of the presence of large predators (Chapter 6, Hopcraft et al. 2005). Therefore, as the pressure for land use and pastoral activities in CGAs continues to increase, and the areas occupied by pastoral activities increase towards and into the CAs, large-sized herbivores will be pushed further and further away into the CAs.

Nonetheless, one of the large-sized herbivores, Blue Wildebeest was associated with CGAs in the wet season, but, still avoiding areas of high livestock grazing intensity and closer to settlements. Consequently, suggesting that Blue wildebeest benefits from short, high-quality grasses in areas with moderate livestock grazing, hence grazing facilitation but negatively affected by pastoralist-induced risk. Nevertheless, in the dry season, Blue wildebeest was associated with CAs, which is probably linked to competition for grazing resources by livestock in CGAs during the dry season (Fynn and Bonyongo 2011). Bhola, Ogutu et al. (2012) reported a similar pattern for Blue Wildebeest distribution near Masai-Mara Game Reserve, Kenya, where Blue Wildebeest favoured livestock grazed short grasslands (Selebatso, Bennitt et al. 2017). However, the present study findings on the distribution of Blue Wildebeest was not consistent with Wallgren, Skarpe et al. (2009), who reported that Blue wildebeest was attracted to CAs than CGAs. The differences could be linked to the research methods used. Roadside counts alone (Wallgren, Skarpe et al. 2009) has the possibility of missing indicators (e,g, spoor) that show the presence of the wild animal, hence the possibility that the study by Wallgren, Skarpe et al. 2009, did not capture these indicators for Blue Wildebeest in CGAs.

The current study findings on the distribution of large-sized herbivores patterns in relation to free-ranging livestock also add further evidence to a body of literature on the ecological theory, for example (Anderson, Hopcraft et al. 2010, Hopcraft, Olff et al. 2010) and empirica study (Bhola, Ogutu et al. 2012). The human population on the adjacent human-dominated areas is growing, hence expansion of livestock numbers, settlements, arable agriculture, sedentarization of cattle posts, intensification of land use and diversification of livelihood options (Homewood et al. 2001, Ogutu et al. 2011). Consequently, the negative impacts on the movement of the large-sized herbivore between the CAs and CGAs (Fynn and Bonyongo 2011). This pattern is similar and has been documented for other East African ecosystems, for example, Kenya's Amboseli (Western et al. 2009) and Tanzania's Tarangire-Simanjiro (Msoffe et al. 2010).

Pastoralists-induced risk, such as illegal hunting could also be restricting the distribution of large-sized herbivores in the CGA. De Leeuw et al. (2001), attributed negative interactions between livestock and wildlife to poaching and harassment by pastoralists, rather than competition for forage only. Also, Verlinden (1998), reported that poaching was more important in the spatial distribution of large-sized herbivores than the competition for grazing resources by livestock. Similarly, the present study found out that illegal hunting is an ongoing activity in Kalahari rangelands, as confirmed by the wildlife poaching statistics in Kalahari North. The most illegal hunted wild animals from 2007 to 2014 were Gemsbok, followed by Eland, Springbok and Red Hartebeest; however, blue wildebeest was the least hunted large herbivore (DWNP report).

Factors influencing the distributon of medium-sized herbivores

In contrast to large-sized herbivores, medium-sized herbivores (e.g. Red hartebeest, Kudu and Warthog), except Ostrich, avoided increased LGI and pastoral dominated areas near the cattle posts and settlements and were related to moderately grazed areas on CGAs and CAs boundary and in CAs in both seasons. Thus, partially supporting the expectation (H2c). Areas with increased LGI in CGAs (within a radius of 15km from settlements) had fewer forage resources (i.e. quality and quantity) and are likely to have increased pastoralists-induced risk in both seasons. Hence suggesting facilitation by moderate livestock grazing, yet competition for resources with livestock and most likely the negative impacts by pastoral-induced risk. Nonetheless, the medium-sized herbivores tend not to move into the CAs during the dry season, which does not support (H2c), hence the findings in the distribution of medium-sized herbivores do not accord with findings from a study in East Africa by Bhola, Ogutu et al. 2012, who reported that medium herbivores move seasonally between the CAs, and the ranches and they tend to concentrate on the CAs in the dry season because of competition for grazing resources by livestock, but move into the ranches in the wet season.

The most likely explanation as to why the medium-sized herbivores were associated with the CGA/CA boundary in both seasons could be because, in these areas, they apparently benefit from less predation, experience less competition from livestock, and at the same time avoiding pastoralists-induced risk (Ogutu et al. 2011). In these areas, the grasses are kept short by moderate livestock grazing, hence improving visibility against the predators and forage quality (Fryxell 1995), while near the settlements, there is human disturbance because of human activities (de Leeuw, Waweru et al. 2001). Consequently, the observations show that the distribution of medium-sized wild herbivores was influenced by forage quality, predation and pastoralists- induced risk. The medium herbivores probably avoided the CAs because these are associated with poor quality, tall grasses (Chapter4, Georgiadis and McNaughton 1990) and have a high risk of predation (Chapter

6) due to high vegetation cover (Hopcraft et al. 2005). Therefore, the distribution pattern of medium herbivores suggests that they select moderately grazed areas in the CGAs because they are either very much productive or consist of high-quality forage (Bhola, Ogutu et al. 2012) due to moderate grazing, or have lower predation risk pastoralists-induced risk, or all of the above. These patterns partially accord with (H2c).

The distribution of medium herbivores not being associated with the settlements and cattle posts was not surprising because of the possibility of pastoralists-induced risk and overgrazing by livestock within a radius of 15km from the settlements (Chapter 4) which is consistent with (H2c). Therefore, the distribution pattern of medium herbivores reflects both displacement from areas with increased LGI (i.e. < 15km from settlements) due to overgrazing by livestock and pastoralist-induced risk, but facilitation by moderate livestock grazing in areas higher than 15km from the settlements in CGAs. In both seasons, these patterns are partly consistent with H2c and partly not in agreement with H2c and the findings of Bhola, Ogutu et al. 2012, because the dry season movement of medium herbivores into the CAs was not noticeable, maybe because of predation in the CAs.

These observations provide indirect evidence that not only forage quality and predation determine the distribution of medium herbivores (Hopcraft et al. 2005, Anderson et al. 2010, Bhola, Ogutu et al. 2012), but pastoralists-induced risk in CGAs also play a significant role, hence the displacement of medium herbivores within the radius of 15km from the settlements. Besides, they tend to prefer the furthest moderately grazed areas by livestock (Fryxell 1991, Illius and Gordon 1992); hence, their distribution was high in CGAs/CAs boundary. Furthermore, in CGAs in the present study, there is increased human population density, expansion of settlements (Lamprey and Reid 2004), and sedentary cattle posts (Homewood, Lambin et al. 2001, Ogutu, Piepho et al. 2009), which also restricted the distribution of medium-sized herbivore.

The observed spatial distribution of medium-sized herbivores in Kalahari rangelands, therefore supports, or add further evidence, to the argument that most African CAs are not sufficiently large enough to satisfy all season forage requirements because they contained mostly the dry season forage resources (Fynn and Bonyongo 2010). On the contrary, the distribution of Ostrich was influenced by food quality in CGAs (i.e. annual grasses, preferable Schmidtia kalihariensis, climbers, sedges, and prostrate forbs) (Milton, Dean et al. 1994, Kok 1980), and less the pastoralists-induced and predation risks, thus facilitation. Only Ostrich was associated with LGI in areas with high tree density, short, and unpalatable perennial grasses in both seasons, however, it avoided areas closer to the settlements.

The spatial distribution of Ostrich agrees with other studies Kalahari rangelands (Verlinden 1997, Wallgren, Skarpe et al. 2009). Nonetheless, it is in contrast with a study by de Leew, Waweru et al. (2001), who reported that Ostrich avoided areas within less than 10km from water points and cattle posts. It is possible that in the present study, Ostrich was not hunted, as no illegal Ostrich killings were reported from 2007 to 2014 DNWP report. Another possible explanation for Ostrich being associated with increased LGI in this study could be that it prefers to feeds on annual grasses, preferable *Schmidtia kalihariensis*, climbers, sedges, and prostrate forbs when available (Milton, Dean et al. 1994), which are found in areas with increased LGI (Chapter 4, Dougill, Akanyang et al. 2016). Ostrich also feeds on flowers of shrubs, and occasionally eat pods, leaves of trees (e.g. *Vachellia karroo*) (Kok 1980). Consequently, in the present study, *Schmidtia kalihariensis, Vachellia karroo*, prostrate forbs, sedges, shrubs were available within 15km and related to increased LGI (Chapter 4), hence grazing facilitation for the distribution of Ostrich.

Factors influencing the distribution of small-sized wild herbivores

Small-sized wild herbivores (Duiker, Steenbok), except Springbok, that are the most susceptible to predation and dependent on high-quality forage, were associated with CGAs, even in areas with increased livestock grazing in both seasons. Therefore, suggesting that LGI and other pastoral activities did not negatively restrict their distribution. Nonetheless, the distribution of small-sized herbivores is contrary to the expectation (H2b), which states that their distribution will be associated with moderately grazed areas with increasing distance from the settlements in both seasons and negatively impacted by pastoralists-induced risks. Consequently, indicating that small-sized wild herbivores are tolerant of LGI and pastoralists-induced risk, implying facilitation. The pattern agrees with findings of Bhola, Ogutu et al. 2012, who reported that livestock grazing creates conditions favouring small herbivores (i.e. high-quality short grasses and better visibility) in both seasons, hence facilitating the distribution of small-sized herbivores.

The distribution of small herbivores suggests that areas selected by small-sized wild herbivores provided high-quality forage regarding actively growing short grasses (Cromsigt and Olff 2006, Bhola, Ogutu et al. 2012), forbs and shrubs in the wet season as maintained by livestock. In CGAs there is low predation (due to reduced vegetation cover) but increased pastoralists-induced risks, however, the findings indicate that small-sized herbivores were not adversely affected by pastoralists-induced risk; thus, they also concentrated in areas near the settlements and cattle posts. On the other hand, the distribution of Springbok was not similar to other small-sized herbivores, suggesting that either the LGI or pastoralist-induced risk negatively impact on the distribution of Springbok. Besides, in CAs, Springbok was recorded within a minimum distance of 1km distance from Zutshwa settlement grazing with small stock and cattle, suggesting facilitation by moderate livestock grazing.

On the contrary, Springbok showed a different distribution pattern because it concentrated in CAs, but near Zutshwa settlements than in CGAs. It was associated with the borehole, cattle posts, and settlements in CAs, suggesting tolerance to livestock grazing intensity. However, Springbok was sensitive to the pastoralists-induced risk in CGA hence concentrated only in CAs. Therefore, suggesting grazing facilitation by moderate livestock grazing in the CAs, but negatively affected by the pastoralists-induced risk in

CGAs. Springbok concentrates in patches at the same time throughout the year; hence it could be quickly exhausted by illegal hunting, more so that the meat is sought, therefore, the need for it to be protected. Thus, it was not associated with CGAs. Springbok distribution pattern was similar to studies regionally (Verlinden 1997, Verlinden, Perkins et al. 1998), nonetheless, its distribution was not in agreement with the findings by Sallu et al. (2009), who reported Springbok as one of the most abundant wild herbivores within CGAs during the dry season in 2002 in Khawa.

The distribution of small-sized wild herbivores except for Springbok showed a pattern similar to other studies in southern Africa rangelands (Verlinden 1997, Verlinden, Perkins et al. 1998, Wallgren, Skarpe et al. 2009) and East Africa (Bhola, Ogutu et al. 2012). Consequently, showing tolerance to livestock grazing and pastoralists-impacted areas, therefore grazing facilitation (Arsenault and Owen-Smith 2002). Both Steenbok, and Duiker could be benefiting from the increased bushes as a result of livestock grazing, by providing palatable leaf browsing (Toit 1993, Nagy and Knight 1994). Also, areas grazed by livestock have a high density of forb species abundance (Chapter 4), which is preferred by Steenbok (Toit 1993, Nagy and Knight 1994). Therefore, small-sized wild herbivores maximise the net effect of forage quality and importantly minimise the predation risk effect (Anderson, Hopcraft et al. 2010, Bhola, Ogutu et al. 2012) by remaining in the CGAs.

Nevertheless, Duiker and Steenbok also thrived in CAs as in CGAs regardless of the high risk of predation. A likely explanation for this is that these small-sized wild herbivores are less mobile and do not travel long distances. Hence they maintain their home ranges (less than 0.7km^2) (Toit 1993), either in CAs or CGAs. However, because there are fewer predators and less pastoralists-induced risk in CGAs for these small-sized wild herbivores; they reproduce and multiply more in CGAs than CAs. Porcupine was associated with CAs and decreasing with high livestock grazing intensity and around settlements. However, it was also recorded closer to settlements and cattle posts, therefore, suggesting that it is tolerant to livestock grazing and human disturbance. The distribution of Porcupine could be explained by the fact that Porcupine is a nocturnal rodent which feeds on a variety of food such as underground plants parts (roots and tubers) and also consumes shoots of herbaceous plants and stem tissues of trees (De Villiers 1992). Porcupine also uses burrows to hide from the pastoralists during the day and feed at night. When livestock reduces grass cover, they also make it easier for the Porcupine to locate the forbs, tubers and young trees, hence, implying grazing facilitation.

5.4.4: Limitations

Most of the information on the distribution of the wild herbivores and livestock were obtained from surveys of spoor data (tracks, pellets) and road-side observation; however, it was not easy to locate some small-sized wild herbivores tracks on dry sandy soils. Nonetheless, in the wet season when the sandy soil was moist, it was easy to find and identify them, therefore augmenting information from the dry season. Moreover, the investigation was carried out in two dry and wet seasons individually, thus idealizing on the identification of small-sized wild herbivores tracks on dry sandy. On the other hand, it was easy to find the spoor for most of the herbivore species. Spoor data and observations methods have been used in the past to establish the distribution of wildlife (Parris and Child 1973, Verlinden 1997, Verlinden, Perkins et al. 1998); therefore these methods are valid to use in determining the distribution of wild herbivores and livestock. Other methods like night drives (Wallgren, Skarpe et al. 2009, Wallgren, Skarpe et al. 2009) could have augmented the surveys of spoor data. Nonetheless, night drives observations were not performed because of limited time and greater spatial distance of the study area.

5.5: Conclusion

This Chapter aimed to evaluate how different wild herbivore species interact with free-ranging livestock and pastoral activities in CGAs and adjacent CAs. The major pastoral activities were mainly within the CGAs, closer to the four main settlements, hence the increased livestock grazing intensity within a radius of 15km. Cattle travelled longer distances from the cattle posts for grazing during the dry than a wet season due to limited grazing resources. The distribution of wild herbivores was positively correlated with less livestock grazing intensity; consequently, large-sized herbivores concentrated in CAs and avoided pastoral impacted areas in CGAs in both seasons. However, medium-sized herbivores, except Ostrich, avoided increasing livestock grazing intensity and pastoral dominated areas and remained in moderately grazed areas on CGA/CA boundaries and in CAs in both seasons. The distribution of small-sized wild herbivores, except Springbok, was associated with CGAs in both seasons, suggesting no adverse impacts by increasing LGI, but other pastoral activities in both seasons. Livestock grazing did not impact Springbok; nonetheless, it was attracted to livestock grazing in CAs in both season, suggesting that the pastoralists-induced risk rather than livestock grazing intensity was influencing its distribution. The most significant gradients influencing the distribution of wild herbivores were livestock grazing intensity, pastoral activities, and forage availability. The results reveal how the distribution of wild herbivores of different body sizes was influenced differentially (facilitation or competition for resources) by free-ranging livestock grazing, forage availability and pastoral activities in CGAs (i.e. pastoralists – induced risk) and adjacent CAs depending on the season.

5.6: Recommendations

If the areas occupied by pastoral activities increase towards and into the CAs, medium to large-sized herbivores will be pushed further and further away into the CAs, due to the LGI and pastoral activities. Therefore, to retain medium to large-sized herbivores in the Kalahari rangelands, it is imperative to prevent pastoral activities from encroaching the CAs. The study reveals that uncontrolled movement of free-ranging livestock and other pastoral activities into the CAs could threaten medium to large-sized herbivore biodiversity, which also agrees with a study in Kalahari rangelands (Fynn, Augustine et al. 2016). Therefore, the location of settlements, cattle posts and boreholes in CAs and closer to the CGA/CA boundaries should be discouraged, because livestock and other pastoral activities will end up intruding into the CAs, consequently pushing the medium to large-sized herbivores away. Livestock in CGAs should be managed strategically to improve livestock husbandry (Ogada, Woodroffe et al. 2003, Fynn, Augustine et al. 2016) and reduce overgrazing, and promote moderate livestock grazing. For example, the Ministry of Agriculture should calculate and maintain the stocking rate of CGA through the reduction of the livestock numbers.

Stocking rate should be regulated, supplement feeding and the reduction of animal number where possible, mainly in areas where the boreholes are close together should be encouraged. Water reticulation might help to spread the grazing intensity across a large area to promote moderate livestock grazing, hence attracting small to medium-sized herbivores in such areas. Thus, promoting herbaceous heterogeneity and maintaining short-high quality grasses in the wet season. Therefore, leading to less competition for forage resource between wildlife and livestock. Conservation and management efforts in CAs should simulate moderate livestock grazing by creating and maintaining vegetation heterogeneity, with some areas in CAs having short grasses and improved visibility to attract small to medium-sized herbivores. Therefore, activities such as prescribed fires could also be recommended in certain areas in the CAs to reduce the grass biomass, hence attracting the small to medium-sized herbivores. In these areas small to medium-sized carnivores can also be attracted because of availability of small to medium the prey availability. Dispersal areas (i.e. CGAs), should be secured in such a way that it allows continued seasonal movements of wildlife between CAs and the pastoral areas, for example, enforcement of policies and laws to avoid wildlife disturbance (i.e. pastoralists-induced risk) in CGAs.

Enforcement of policies and laws on illegal hunting of wildlife should be encouraged and could reduce local extinction of wildlife. This could be possible because nowadays, people in the Kalahari rangelands rely less on biodiversity for subsistence and depend on different types of livelihood (Sallu, Twyman et al. 2009). For example, Government drought relief projects. "Existence of effective wildlife management structures is more important than human density per se" (Linnell, Swenson et al. 2001). Therefore, policies and legislations towards promoting co-existence of pastoralists, livestock and wildlife should be promoted by empowering local communities on ecotourism projects and maintenance of sustainable livestock stocking rates to reduce overgrazing. Consequently, there is a need for collaboration among the different stakeholders to identify conflicts and opportunities (Austin, Smart et al. 2011). Given the new information on the distribution of wild herbivores, both the stakeholders (pastoralists and government) should use the present study findings to determine wild herbivore and livestock management goals, develop and implement the management plans, then monitor and adjust accordingly through time (Muñoz-Erickson, Aguilar-González et al. 2007).

5.7: Implications for wildlife conservation and livestock management

This chapter offers some new information on the environmental factors influencing the distribution of wild herbivores of different body sizes between the CAs and the adjacent pastoral areas in Kalahari savanna rangelands. The increase in human population and land-use pressure threaten the wildlife and livestock co-existence (Lamprey and Reid 2004). Therefore, resulting in wildlife population declines because the survival of wildlife depends on the seasonal movement between CAs and pastoral areas (Bolger et al. 2008, NeCArk 2008). Studies in Kenya (Woodroffe et al. 2005), Zimbabwe (Valeix et al. 2009) and Kalahari, Botswana (Chapter 5 & 6), have shown that in many areas as pastoralists activities adjacent to CAs increase conflicts between human and wildlife appear to be increasing in intensity and frequency, leading to killing or harming of both herbivores and carnivores. Therefore, research that advances knowledge on the interactions between, pastoralists, wildlife and free-ranging livestock in CAs and adjacent pastoral areas are imperative to reduce human-wildlife conflicts.

However, most of the ecological research on wild herbivores has been conducted in CAs in areas without livestock (Graham et al. 2005, McNaughton 1990, Ogutu, Bhola et al. 2005, Anderson, Hopcraft et al. 2010, Hopcraft, Anderson et al. 2012), between CAs and human-dominated pastoral ranches (Maddox 2003, Bhola, Ogutu et al. 2012). Paradoxically, the distribution and interactions of wild herbivores and free-ranging livestock in pastoral-dominated, semi-arid, communally managed rangelands near the CAs in the Kalahari ecosystem, southern Africa are less understood. Therefore, this study contributes towards improving our knowledge on the environmental factors influencing the distribution of multiple wild herbivores of different body sizes in CAs and adjacent communally managed pastoral areas and well as providing insights on the consequences of the land-use change on the distribution of wild herbivores.

Chapter 6

The effects of pastoral activities, free-ranging livestock and environmental factors on the distribution of carnivores

Abstract

Human-carnivore conflicts threaten the future feasibility of carnivore species in pastoral areas of Africa. Habitat modification and pastoral activities cause a decline in the carnivore population. Nonetheless, there is less documentation on the interactions between carnivores, pastoralists' activities and free-ranging livestock in the Kalahari rangelands. However, information on their interactions can be used to reduce conflicts and promote coexistence of carnivores and pastoral activities. Therefore, this chapter examines the spatial distribution of twelve carnivorous mammals (>1kg) in relation to pastoral activities and the grazing distribution of four free-ranging livestock in CGAs and CAs of southern Africa. Data from a two-year sampling survey using carnivores and livestock spoor/track information, road-side field observations and cattle fitted with GPS telemetry is analysed. Large-sized carnivores (Lion, Spotted Hyena, and Cheetah) were associated with CAs and at greater distances from the settlements, cattle posts, and boreholes in both seasons. However, other large carnivores, Leopard and Aardvark (formivore) were related to moderately grazed areas and on the boundary of CGAs & CAs in both seasons. The brown hyena was associated with CGAs than CAs in both seasons. Medium-sized carnivores; African Wild Dog and Caracal were attracted to CGAs than CAs in both seasons combined. However, during the dry and wet seasons, they tend to be associated with CAs and CGAs, respectively. Nonetheless, the distribution of Caracal is decreasing and African Wild Dog is increasing with less livestock grazing intensity (LGI). The distribution of small-sized carnivores (Black-backed Jackal and Bat-Eared Fox) were associated with both land use, however in CGAs Bat-Eared Fox was related to less LGI, while Black-backed Jackal was also associated with increased pastoral activities closer to settlements. On the other hand, Honey Badger and Blandford's Fox tended to be related to CAs and CGAs, respectively. The most significant gradients influencing carnivorous mammals' distribution are Livestock grazing intensity, pastoral activities and food availability. The results show how the distribution of carnivores of different body sizes is predictably influenced differentially by free-ranging livestock grazing, and pastoral activities in CGAs and the adjacent CAs depending on the season.

6.1: Introduction

Changes in land tenure, land use types, increase in human population, pastoral activities, such as cultivation, settlements, cattle posts and boreholes result in habitat loss, land degradation, and fragmentation (Dublin 1995, Homewood, Lambin et al. 2001). Consequently, competition for forage resource between livestock and wild herbivores is conceivable, which leads to the decrease of natural prey for carnivores (Chapter 5). Hence, leading to an increase in the persecution of carnivores because of livestock depredation (Ottichilo, De Leeuw et al. 2000). Consequently, the possibility of local extinction of carnivores (Woodroffe and Ginsberg 1998, Woodroffe and Ginsberg 2000). For example, Maasai Mara National Reserve has the high record of Lion density in the African savanna. However, the surrounding livestock farms have the low density of Lions (Ogutu and Dublin 2002), possibly linked to the adverse impacts of pastoral activities on Lion distribution (Ogutu and Dublin 2004).

Nonetheless, a study by Maddox (2003) found no significant difference in large-sized carnivores (Cheetah, Lion and Spotted Hyena) on pastoral rangelands of Maasai (Loliondo and Ngorongoro) and the reserves of Serengeti National Park, Tanzania. Declines in carnivore numbers are caused by the reduction of their habitats and human activities (Woodroffe 2000). Consequently, human-carnivore conflict is triggered by the interactions between human and carnivores, leading to livestock predation (Karani 1994). Human-carnivore conflicts are highest in the wet season, especially closer to the protected areas boundary (Mwangi 1997) when the availability of wild herbivores is low (Karani 1994, Patterson, Kasiki et al. 2004).

On the other hand, certain carnivores can adapt to land use changes and associate themselves with pastoral activities (Woodroffe 2000, Sunquist and Sunquist 2001, Wallgren, Skarpe et al. 2009). For example, Wallgren, Skarpe et al. (2009) found out that the Bat Eared Fox and Black-backed Jackal were associated with moderate livestock grazing intensity (LGI). Large-sized carnivores have an essential role in regulating and limiting the populations of prey species (Sinclair, Mduma et al. 2003), while the small-sized carnivores restrict the populations of insects and rodents in semi-arid rangelands (Stenseth, Leirs et al. 2003), which could otherwise become pests. Despite the essential roles of carnivores and the possible impacts from pastoral activities on the ecosystem dynamics, knowledge on the interactions between free-ranging livestock and pastoralists in the southern African rangelands is seldom available. However, few studies in the Kalahari rangelands, for example, (Blaum, Rossmanith et al. 2007acd), found out that the decline of small to medium-sized carnivores in private ranches was due to LGI. Ironically, the impact of free-ranging, land use and other pastoral activities on carnivores of different body sizes in extensive communally managed rangelands of southern Africa adjacent to CAs remains unclear and less documented (Blaum, Tietjen et al. 2009, Wallgren, Skarpe et al. 2009). Nevertheless, reasonable administration and protection of carnivores in a way that lessens human-carnivore conflicts require knowledge on the spatial dispersion of various carnivores in connection to livestock grazing and pastoral activities disturbance gradients and land use types.

Human population growth, the associated expansion of settlements (Lamprey and Reid 2004), arable farming, sedentary cattle posts (Western, Russell et al. 2009) alters vegetation composition and structure in African rangelands, hence influencing the spatial grazing distribution of carnivores. Despite the previous research on wildlife and livestock interactions, there is still controversy surrounding co-existence or resource partitioning of carnivores and livestock. Wildlife habitats in CGAs surrounding conservation areas (CAs) are fragmented and degraded (Bhola, Ogutu et al. 2012), due to pastoral activities, hence restricting seasonal movements of wildlife between CAs and CGAs. Large predators in East African rangelands have been found avoiding pastoral activities in CGAs and concentrate in conservation areas (Ogutu, Bhola et al. 2005). Therefore, predation is more in the CAs than in CGAs due to taller grasses in the wet (Ogutu, Bhola et al. 2005) and the dry season (Reid, Rainy et al. 2003).

In African tropical savannas, most studies on the distribution of carnivores occurred in East African CAs (Ogutu, Bhola et al. 2005, Anderson, Hopcraft et al. 2010, Bhola, Ogutu et al. 2012) and between protected areas and pastoral farms (Mworia, Kinyamario et al. 2008, Bhola, Ogutu et al. 2012), where livestock are herded during the day. However, in the sub-tropical savanna rangelands, for example, southern Africa, there have been very few studies on carnivores and livestock interactions between extensive communal grazing rangelands surrounding protected areas and also in different seasons (Verlinden 1997, Verlinden, Perkins et al. 1998, Anthony 2006, Wallgren, Skarpe et al. 2009). Nevertheless, the distribution of carnivores between CGAs, dominated by free-ranging livestock (not herded) and other pastoral activities, such as arable fields, and sedentary cattle posts and CAs is less known. Such an evaluation is needed for strategic management of carnivores and livestock coexistence or resource partitioning in communal grazing rangelands and their surrounding protected areas. For example, in Kalahari communal rangelands in Botswana, where most of the livestock are free-ranging during the day and controlled by the boreholes rather than the herders.

Human population growth, intensification of land use, sedentary cattle posts, poor livestock husbandry in East Africa aggravate pastoralists-carnivore conflicts (Ogutu and Dublin 2004). Nonetheless, in the Kalahari rangelands, southern Africa, the influence of pastoral activities on the distribution of carnivores of different body sizes across the landscape is less understood. The Kalahari rangelands are massive, semi-arid and consist of mainly infertile red sandy soil and several calcrete pans (Knight, knighteloff et al. 1988). There is no permanent natural water in these rangelands (Engineers 1980), except in the ephemeral pans during the wet seasons. In the past, the Kalahari ecosystem was dominated by a diversity of wildlife species. However, the increase in the human and livestock population which is associated with the intensification of other pastoral activities resulted in resource pressure (Williamson, Williamson et al. 1988). Livestock in the Kalahari rangeland is raised in an "open system" in CGAs and only the water rights are granted for pastoralists, but not the grazing resources (Sebego, Atlhopheng et al. 2017); hence pastoralists can graze their livestock anywhere in the CGAs.

The Kalahari CGAs are surrounded by the CAs (i.e. CAs) and are within the critical wet season core area, known as the Schwelle, for all Kalahari wildlife from the Central Kalahari Game Reserve (CKGR) and Kalahari Trans-frontier Park (KTP) (Engineers 1980). The resident wildlife moves seasonally between the CAs and the CGAs responding to variation in forage quality, quantity and predation risk (Ogutu, Piepho et al. 2008, Fynn and Bonyongo 2011). Therefore, the increase of sedentary cattle posts and other pastoral activities have interfered with the wild herbivores' grazing distribution across the Kalahari pastoral areas (Verlinden 1997, Mbaiwa and Mbaiwa 2006, Chapter 5), consequently, the possibility of uniquely influencing the distribution of carnivores of different body sizes. Thus, this chapter aims to investigate how CAs and pastoral activities and free-ranging grazing intensity influence the distribution of small, medium and large carnivorous mammals (>1kg) during the wet and dry seasons, in extensive communally managed rangelands adjacent to CAs in Kalahari ecosystem, Botswana. Several hypotheses hypotheses were tested to determine factors regulating the spatial and temporal distribution of carnivores of different body sizes in relation to LGI and pastoral activities in CGAs and adjacent CAs. The study tested the following three hypotheses;

i) (H3a) The spatial distribution of small (e.g. black back Jackal) and medium-sized (e.g. Cheetah) carnivores are expected to decrease in pastoralists-dominated areas in CGAs due to the human disturbance such as pastoralists-induced risk, predator control measures (Blaum, Rossmanith et al. 2007c,d) and increased livestock grazing intensity with improved visibility against the predators.

ii) (H3b) However, the spatial distribution of small to medium-sized carnivores would increase in areas with moderate livestock grazing intensity because of vegetation heterogeneity (i.e. grasses and woody plants) (Jeltsch, Milton et al. 1996), prey availability (Blaum, Rossmanith et al. 2007c,d), less the pastoralists-induced and less predation risks from dominant carnivores (Creel and Creel 1996, Mills and Gorman 1997) in CGAs compared to CAs in both seasons.

iii) (H3c) On the contrary, the spatial distribution of the large-sized carnivores, like Lions and Spotted Hyena, would to be associated with areas with high vegetation cover, prey availability and less the pastoralists-induced risk in CAs (Ogutu and Dublin 2002, Wallgren, Skarpe et al. 2009, Hopcraft, Anderson et al. 2012) compared to CGAs where there is reduced vegetation cover and high visibility against large-sized carnivores and human disturbance.

6.2: Materials and methods

6.2.1: Study area and data collection

This study was conducted at Kalahari north, Botswana, a radius of 60km from Hukuntsi, Lehututu, Tshane, and Lokgwabe. The study involved twelve carnivores (>1kg) and four domestic herbivore species using sample surveys of spoor (tracks, pellets) and road-side observation. Surveys were performed along five 60km transects radiating from the major settlements in two dry seasons (August to October 2014 & 2015) and two wet seasons (March to May 2015 & 2016). The carnivorous mammals' spoor data (pellets and tracks) at each sample point were counted, however, their pellets were rarely found compared to the herbivores. Also, the spatial distribution of pastoral activities, such as cattle posts, agricultural fields, and remote access roads was mapped using ArcGIS and Google Earth images (2014) (Chapter 5). The grazing distribution of free-ranging livestock from the watering points and cattle posts were determined through monitoring several cattle using the GPS telemetry during the wet and dry seasons (Chapter 5). The spatial distribution of carnivores was also associated with the distribution of wild herbivores (Prey) as established in (Chapter 5). The details of the methods are described in Chapter 3.

6.2.2: Data analysis

The spatial distribution of the pastoral activities, such as boreholes, wells, cattle posts, within the study area was mapped using Google Earth images (2014) and ArcGIS 10.1 software (see Chapter 5). Also, the free-ranging livestock grazing distribution in relation to land uses was established in Chapter 5. Spoor data on the distribution of carnivores was analysed using PCA and GLM (Poisson regression) to explore the distribution of different carnivorous mammals in relation to free-ranging livestock grazing gradient, wild herbivores and pastoral activities in CGAs and CAs. To assess the variation of carnivore distribution along livestock grazing and pastoral activities disturbance gradients and across land use types and the influence of the environmental variables, Canonical Correspondence Analysis – CCA technique using a CANOCO program package of (Ter Braak 1986, Ter Braak 1988, Ter Braak 1990) was applied to analyse the spoor of the distribution of carnivores. Analysis (HCA), was used to quantify the similarities and dissimilarities of the animal variables. Spatial distribution patterns for free-ranging livestock and carnivorous mammals were mapped using Inverse Distance Weighted (IDW) interpolation and buffering. The details of the data analysis are given in section 3.4.3.

6.3: Results

The distribution of carnivores between land uses, seasons and along pastoral activities disturbance gradient was multifaceted and varied with carnivores of different body sizes, however, some regular overall patterns were persistent. Carnivores of varying body sizes and livestock were tenacious in spatially in different areas along the pastoral activities disturbance gradient, between land use and seasons. The distribution of carnivores was associated with the spatial distribution of pastoral activities such as sedentary cattle posts, wells and boreholes for watering cattle, settlements, arable fields and the livestock grazing intensity as established in Chapter 5.

Three (3) general patterns of the distribution of carnivores were evident. (1) Large-sized carnivores (Lion, Spotted Hyena, and Cheetah), except Leopard and Aardvark (formivore) concentrated in CAs and within greater distances from the settlements, cattle posts, and boreholes in both seasons. The distribution of Leopard and Aardvark (formivore) was associated with moderately grazed areas and on the boundary of CGAs & CAs in both seasons, while the Brown hyena was associated with CGAs than CAs in both seasons. (2) The distribution of Medium-sized carnivores, African Wild Dog and Caracal, except Striped hyena, was associated with CGAs than CAs in both seasons combined. However, during the dry and wet seasons, they tend to be associated with CAs and CGAs, respectively. The distribution of Caracal was increasing with increasing LGI and within pastoralists-dominated areas, while African Wild Dog is decreasing with increasing LGI and in pastoralists-dominated areas. (3) On the contrary, the distribution of small-sized carnivores (Black-backed Jackal and Bat-Eared Fox), except Honey Badger and Blandford's Fox, is associated with both land use, however in CGAs Bat-Eared Fox is related to less LGI, while Black-backed Jackal is also associated with increased pastoral activities closer to settlements. Honey Badger and Blandford's Fox tend to be related to CAs and CGAs, respectively. The results show that LGI, pastoral activities (i.e. pastoralists-induced risk) and food availability influenced the distribution of carnivores of different body sizes differently.

6.3.1: Spatial distribution of carnivores

Species composition

Eleven (11) carnivores, one omnivore, one insectivore and one formivore (> 1kg) were recorded in two dry and two wet seasons using spoor/tracks. The species that were classified as large-sized carnivores include five carnivores (Lion *Panthera leo* Linnaeus, Hyena *Crocuta crocuta* Erxleben, Cheetah *Acinonyx jubatus* Schreber, Brown Hyena *Parahyaena brunnea* Thunberg, & Leopard *Panthera pardus* Linnaeus) and one Formivore (Aardvark *Orycteropus afer* Pallas). Striped Hyena *Hyaena hyaena* Linnaeus, African Wild Dog *Lycaon pictus* Temminck, & Caracal - *Caracal caracal* Schreber were classified as medium-sized carnivores. However, Black-backed Jackal *Canis mesomelas* Linnaeus, Honey Badger *Melivora capensis* Schreber, Blanford's Fox *Vulpes cana* and African Wild Cat *Felis silvestris* Forster, Bat eared Fox *Otocyon megalotis* Desmarest were classified as small-sized carnivores. Three species are classified as vulnerable (Cheetah, Leopard and Lion), one near threatened (Striped Hyena), two endangered

(African Wild Dog & Brown Hyena) and the rest were least concerned according to the IUCN 3.1 conservation status (Appendix 6A).

Most of the carnivore species were recorded in both the CGA and CA, except Lion, brown hyena, and Striped hyena, which were only recorded in CAs (Appendix 6B). Therefore, indicating that Lion, Brown Hyena and Striped Hyena were uncommon in CGA but CAs. Caracal, Lion, Striped Hyena, Brown Hyaena, Honey Badger, and African Wild dog were not observed during both seasons and along all transects, hence further indicating that these species were uncommon in the study area. Eight carnivores (Honey Badger, Striped Hyena, African Wild Dog, Brown Hyena, Blanford's Fox, Leopard, Caracal, and Lion) were rare in the study area (frequency between 0 to 20%) during both seasons (Appendix 6C). However, Black-backed Jackal, Spotted Hyena and Bat eared Fox which were common with the frequency of appearance of at least 40% in both seasons. Nevertheless, Cheetah was rare only in the dry season but moderate (frequency of 20 to 40%) in the wet season, while Aardvark remained moderate in both the wet and dry seasons. African Wild Cat was only rare in the wet season but moderate in the dry season.

The distribution of carnivores in relation livestock grazing and pastoral activities disturbance gradients and vegetation structure

PCA showed that spoor data of all carnivore species satisfied the 0.3 cross-factor loading minimum limits in the varimax rotated matrix, with Kaiser-Meyer-Olkin (KMO) test of 0.736. The Bartlett's test of sphericity was also significant ($X2 = 9843.613$, $p < 0.001$, $df = 105$) (Table 6.1). Consequently, PCA extracted three distinct components with eigenvalues greater than 1 and explained 39.335% of the total variance of the dataset in both seasons combined, hence each component representing a variable in the model (Table 6.1). The first component explained 17.810% of the variance and highly loaded on the following animals; Wild dog, Caracal, Lion, Spotted Hyena, Bat-eared Fox, Black-backed Jackal and Aardvark, respectively, therefore, reflecting the distribution of mainly large-sized carnivores.

The second component accounts for 11.224% of the variance characterized by the following Leopard, Brown Hyena, Cheetah and Striped Hyena hence reflecting the distribution of medium-sized carnivores. Lastly, the third component highly loaded on livestock (donkey, cattle, small stock and horse, respectively) and accounted for 10.34%, therefore, representing the distribution of livestock (Table 6.1). Therefore, PCA revealed three patterns of carnivores' spoor data distribution long the livestock grazing gradient. Consequently, suggesting that the three patterns consisted of (i) large-sized carnivores, (ii) small and medium sized carnivores, lastly the (iii) livestock distribution. PCA showed a clear separation between spoor data of carnivores and livestock distribution (Table 6.1). Also, the PCA extracted vegetation and wildlife scores were used in Hierarchical Cluster Analysis (HCA) (Figure 6.1).

HCA results were similar to PCA, hence classified all the variables into three statistically significant clusters in both seasons combined (phenon line distance of 15) (Figure 6.1). Cluster I is composed of palatable perennials grasses (high species richness, density, and diversity of palatable perennial grass), and spoor data of three large-sized carnivores (Lions, Spotted Hyena, and Aardvark) and other carnivores (Bat-eared Fox, African Wild dog, Caracal). Therefore, showing that large sized carnivores mostly concentrated in areas with less livestock grazing intensity (CGAs) and areas without livestock grazing in CAs (i.e. areas with palatable perennial grasses).

Cluster II includes palatable and unpalatable annual grasses and high density of forbs. This cluster comprises of two large-sized carnivores (Leopard, Cheetah) and two medium carnivores (Brown Hyena and Striped Hyena). Hence, indicating that these carnivores were associated with moderate livestock grazing. However, Cluster 3 was characterized by high tree density and unpalatable perennials grasses, and was associated with livestock (cattle, donkey, horse and small stock) grazing. Cluster I is interrelated to cluster II than cluster III, henceforth, indicating that the distribution of most of carnivores showed a clear separation with livestock distribution. The Generalized Linear Model (GLM) was also performed on the spoor data of each carnivore to explore the unique and combined variance explained by the estimated and measured environmental variables. The PCA extracted vegetation principal components scores (palatable perennial & annual grasses, unpalatable perennial & annual grasses, density of trees and forbs) (see Chapter 4) were used as covariates and the categorical environmental variables (sub-transects, transects, land use types, LGI, distance from cattle posts) were used as fixed factors.

Table 6. 1: Rotated Component Matrix on carnivorous mammals and livestock
The matrix with factor loadings (>0.3). Componrnt 1, 2 & 3 reflect large-sized, medium-sized carnivorous mammals and livestock distribution, respectively during the wet and dry season combined. However, classification was not perfect in the sence that small to medium carnivores were also classified with large carnivores or large carnivores also grouped with small to medium carnivores. (L), (M), (S) represent large, medium and small carnivores, respectively

English name	**Scientific Name**	**Large carnivores**	**Small & Medium carnivores**	**Livestock**
Wild dogs (M)	*Lycaon pictus*	**0.741**		
Caracal (M)	*Caracal caracal*	**0.738**		
Lion (L)	*Panthera leo*	**0.712**		
Spotted hyaena (L)	*Crocuta crocuta*	**0.567**		
Bat eared fox (S)	*Otocyon megalotis*	**0.523**		
Black-backed Jackal (S)	*Canis mesomelas*	**0.371**		
Aardvark (L)	*Orycteropus afer*	**0.309**	**0.308**	
Leopard (L)	*Panthera pardus*		**0.713**	
Brown hyena (L)	*Parahyaena brunnea*		**0.596**	
Cheetah (L)	*Acinonyx jubatus*	**0.437**	**0.542**	
Striped hyaena (M)	*Hyaena Hyena*		**0.413**	
Cattle	*Bos taurus*			**0.768**
Donkey	*Equus asinus*			**0.756**
Small stock	*Ovis aries & Capra aegagrus hircus*			**0.385**
Horse	*Equus caballus*			**0.378**
	Eigenvalue	**2.672**	**1.684**	**1.545**
	Initial variance	**17.810**	**11.224**	**10.300**
	Cumulative variance	**17.810**	**29.034**	**39.335**

*Extraction Method: Principal Component Analysis, Rotation Method: Varimax with Kaiser Normalization, a Rotation converged in 4 iterations and three components were produced. KMO = 0.736, $X^2 = 9843.613$, df = 105, $p < 0.001$

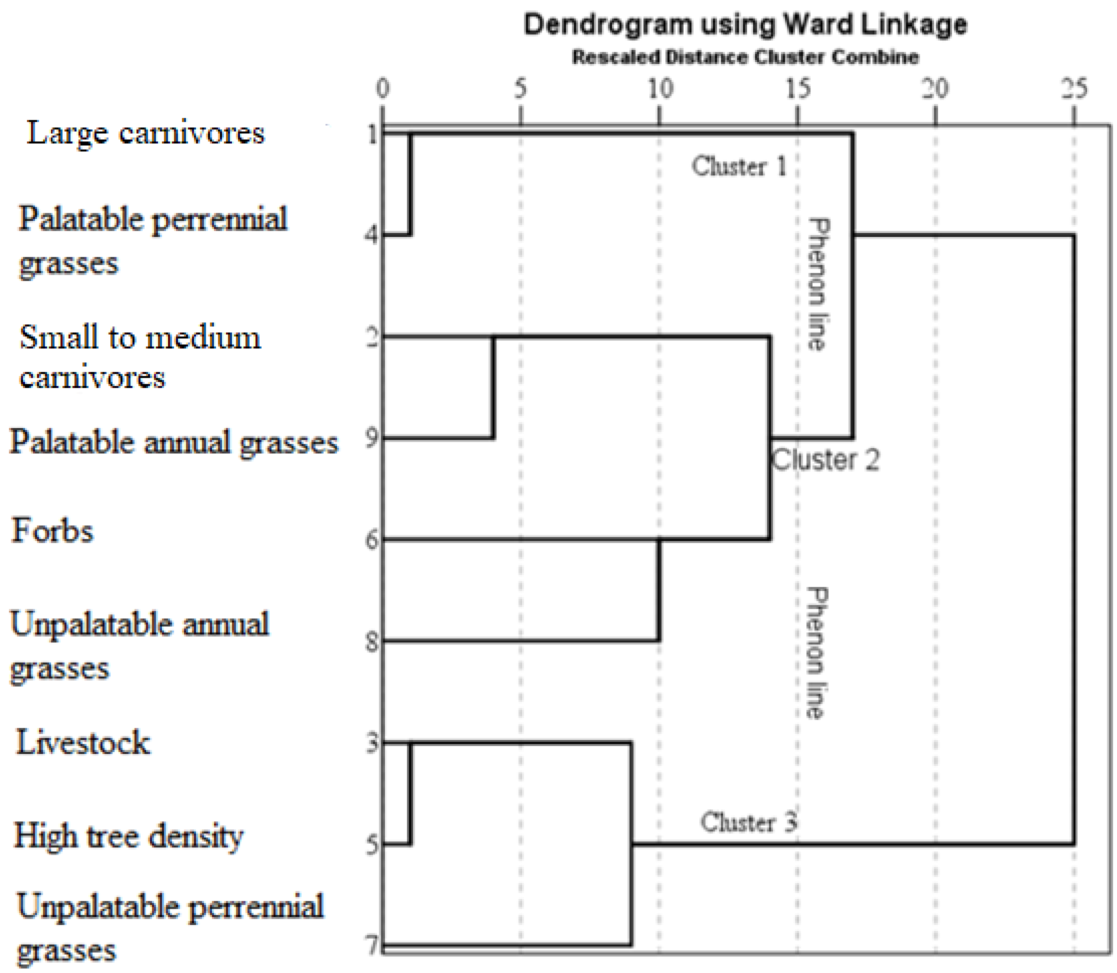


Figure 6.1: Dendrogram for classification of vegetation and carnivorous mammals Statistical grouping, amid the wet and dry season combined. Hierarchical Cluster Analysis performed by application of Ward's method. The values for the variables are the PCA scores standadised to z scores. Large carnivores group included three large-sized carnivores (Lions, Spotted Hyena, and Aardvark) and other carnivores (Bat-eared Fox, African Wild dog, Caracal). While small to medium carnivores included two medium carnivores (Brown Hyena and Striped Hyena) and two large carnivores (Leopard, Cheetah). This shows that other small to medium carnivores were also classified with the group of large carnivores. The same way as other large large carnivores were classified with small to medlium carnivores. Livestock included donkey, horse and small stock.

Distribution large-sized carnivores

The Poisson regression models on spoor data for all the large-sized carnivore species were statistically significant. For example, Poisson regression model for the following carnivores; Lion, χ^2 (23) = 1250.9, P < 0.001), Spotted Hyena, χ^2 (23) = 921.71, P < 0.001), and Leopard, χ^2 (23) = 647.97, P < 0.001) (Table 6.2). Of the eleven predictors, some variables were statistically significant, while others were not depending on the carnivore species (as shown in Table 6.2). For example, Leopard, six predictors (sub-transect, transects, LGI, tree density (p < 0.001), land use (P = 0.028), distance from cattle posts (P = 0.028) were statistically significant, while the other five predictors were not (P > 0.05). Spotted hyena: seven predictors (sub-transect, LGI, distance from cattle posts and unpalatable annual grasses (P < 0.001), palatable perennial grasses (P = 0.006), palatable annual (P = 0.024) were statistically significant, while the rest were not (P > 0.05) (Table 6.2).

The distribution of most large-sized carnivores was mainly recorded along the direction towards Kalahari Trans Frontier Park (KTFP) (Lokgwabe/Mabuasehube transect) (P < 0.005), except Brown Hyena and Leopard (P < 0.001) (Table 6.2). However, Aardvark was also highly distributed along Hukuntsi/Zutshwa and Lokgwabe/Mabuasehube. The GLM (Poisson regression) shows that Lion, χ^2 (1) = 26.81), leopard, χ^2 (1) = 4.83, P = 0.028) were attracted to CAs, however, Aardvark was related to CGAs (χ^2 (1) = 26.21, P < 0.001) amid the wet and dry season combined (Table 6.2). However, Spotted Hyena, Cheetah and Brown Hyena distribution were not statistical significantly associated with any land use types (P > 0.05) when combining the wet and dry seasons data. Spotted Hyena and Aardvark were recorded from the minimum distances of 13km respectively in the CGAs. However, Lion spoor data was recorded from the lowest distance of 38 km & 25km in the wet and dry seasons, respectively (Figure 6.2**)**.

The distribution of all large-sized carnivores, except Brown Hyena, was increasing with distance from cattle posts and settlements (less livestock grazing intensity) (P < 0.001) (as shown in Table 6.2). Therefore, implying large-sized carnivores (Lions, Spotted Hyena, Leopard, Cheetah, and Aardvark) avoided pastoral impacted areas (e.g. cattle posts, boreholes, settlements) in both seasons (Figure 6.2 & 6.3). Nonetheless, Brown Hyena was associated with less to none LGI (P = 0.038). Consequently, Lion, χ^2 (1) =

11.33, $P < 0.001$) and Spotted Hyena, χ^2 (1) = 7.46, $P = 0.006$) were associated with tall palatable perennial grasses in the CAs and on the boundary of CGAs/CAs, respectively (Table 6.2).

On the contrary, when separating the dataset by seasons, Lion was still associated with CAs ($P > 0.001$), while the Spotted Hyena was associated with CAs in dry season, χ^2 (1) = 9.620, $P = 0.002$) but not significantly related to any land use in the wet season, χ^2 (1) = 0.728, $P = 0.394$). Therefore, indicating that Lion avoided CGAs in all seasons, but Spotted Hyena was associated with both land use depending on the season. Cheetah was associated with CGAs in the wet season, χ^2 (1) = 6.53, $P = 0.012$); however, its distribution was not statistically significant with any land use types ($P > 0.05$) amid the dry season. Leopard was not statistically significant with any land use when separating the wet and dry season data ($P > 0.05$) (Figure 6.3). Therefore, suggesting that Cheetah and leopard were present in both CAs and CGAs, but sensitive to livestock grazing intensity and pastoral activities. Consequently, Cheetah and Leopard distribution were increasing with increasing distance from cattle posts and settlements (less livestock grazing intensity) ($P < 0.001$) in both seasons (Table 6.2). Their spoor observations were recorded in all transects in both seasons and more abundant along Lokgwabe/Mabuasehube, and Hukuntsi/Zutshwa transects ($P < 0.001$) (Figure 6.3); hence highly distributed than Lions. There was less spoor observation of Brown Hyena, indicating that it was uncommon in the study area. Still in separating data set by season Aardvark was associated with CGAs in both the wet, χ^2 (1) = 18.11, $P <0.001$) and dry, χ^2 (1) = 16.16, $P < 0.001$), but avoiding pastoral dominated areas.

Table 6. 2: Poisson regression (Generalized Linear Model) coefficients on the distribution of large carnivorous mammals
Shows change in log count, Wald Chi-Square and p-values per species. The relationship of the estimated and measured environmental variables was in both seasons combined. P-value computed using alpha = .05, hence P < 0.05 shows significant at the 0.05 level (2-tailed) (bold P-values). LGI = livestock grazing intensity. Omnibus test (showing df, Likelihood Chi-Square, P-value) compares the fitted model against the intercept only model for each herbivore.

		Lion			**Spotted hyena**			**Leopard**		
Parameter	**df**	**B (Δ log count)**	**Wald Chi-Square**	**P-value**	**B (Δlog count)**	**Wald Chi-Square**	**P-value**	**B (Δ log count)**	**Wald Chi-Square**	**P-value**
Omnibus test	**23**		**1250.9**	**<0.001**		**921.71**	**<0.001**		**647.97**	**<0.001**
Sub-transects			24.92	**<0.001**		10.9.27	**<0.001**		65.18	**<0.001**
[sub-transect=6]	1	-2.81	0.00	>0.05	0.50	3.57	0.059	28.40	4126.38	**<0.001**
[sub-transect=5]	1	-3.40	0.00	>0.05	0.05	0.03	0.862	27.19	3301.97	**<0.001**
[sub-transect=4]	1	-3.59	0.00	>0.05	0.53	4.52	0.034	27.95	4359.57	**<0.001**
[sub-transect=3]	1	-2.83	0.00	>0.05	-0.04	0.03	0.87	29.81	10186.16	**<0.001**
[sub-transect=2]	1	-0.42	0.00	>0.05	1.31	44.96	**<0.001**	28.77c	-	-
[sub-transect=1]		0 *[b]	-	-	0 *[b]	-	-	0 *[b]	-	-
Transects	4					100.82	**<0.001**		74.45	**<0.001**
[Transect=5.0]	1	-27.09	0.00	>0.05	0.11	0.35	0.552	-1.8	19.54	**<0.001**
[Transect=4.0]	1	-52.14	0.00	>0.05	-0.62	7.46	**0.006**	-1.08	11.41	**0.001**
[Transect=3.0]	1	-0.14	0.00	>0.05	0.66	11.48	**0.001**	0.24	0.50	0.48
[Transect=2.0]	1	0.19	0.00	>0.05	0.84	22.12	**<0.001**	-0.29	0.84	0.359
[Transect=1.0]	1	0 *[b]	-	-	0 *[b]	-	-	0 *[b]	-	-
[Land use=2]	1	26.81 *[c]	-	-	0.31	2.34	0.126	0.87	4.83	**0.028**
[Land use=1]		0 *[b]	-	-	0 *[b]	-	-	0 *[b]	-	-

Table 6. 2 continues:

		Lion			Spotted hyena			Leopard		
Parameter	**df**	**B (Δ log count)**	**Wald Chi-Square**	**P-value**	**B (Δlog count)**	**Wald Chi-Square**	**P-value**	**B (Δ log count)**	**Wald Chi-Square**	**P-value**
LGI	3		7.91	**0.005**		82.66	**<0.001**		70.14	**<0.001**
[LGI =3]	1	-24.33	0.00	>0.05	-1.03	31.06	**<0.001**	-1.72	27.92	**<0.001**
[LGI =2]	1	-25.86	0.00	>0.05	-1.27	65.48	**<0.001**	-1.75	49.53	**<0.001**
[LGI=1]	1	0.5	7.92	**0.005**	-0.66	51.31	**<0.001**	-1.09	48.31	**<0.001**
[LGI=0]		0 *[b]	-	-	0 *[b]	-	-	0 *[b]	-	-
Distance cattle posts	4		4.89	**0.027**		43.26	**<0.001**		10.85	**0.028**
[Distance cattle post=5]	1	0.15	0.00	>0.05	0.89	16.22	**<0.001**	-0.43	1.15	0.283
[Distance cattle post=4]		0.1	0.00	>0.05	0.31	1.18	0.277	-0.02	0.01	0.937
[Distance cattle post=3]	1	26.11	0.00	>0.05	1.17	26.22	**<0.001**	-0.62	4.38	**0.036**
[Distance cattle post=2]	1	0.84	4.89	**0.027**	0.68	21.35	**<0.001**	-0.49	4.87	**0.027**
[Distance cattle post=1]		0 *[b]	-	-	0 *[b]	-	-	0 *[b]	-	-
Palatable perennials	1	0.22	11.33	**0.001**	0.10	7.46	**0.006**	-0.12	3.47	**0.063**
Tree density	1	0.09	0.95	0.329	-0.06	1.63	0.201	-0.40	24.76	**<0.001**
Forbs	1	-0.1	0.99	0.32	0.00	0.00	0.989	0.08	1.28	0.258
Unpalatable perennia	1	-0.01	0.01	0.935	0.06	1.88	0.17	0.08	1.09	0.298
Unpalatable annuals	1	-0.47	13.70	**<0.001**	-0.20	13.97	**<0.001**	-0.03	0.31	0.578
Palatable annuals	1	-0.02	0.12	0.731	-0.07	5.12	**0.024**	-0.01	0.06	0.803

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Table: 6.2: continues:

		Cheetah			Aardvark			Brown Hyena		
Parameter	**df**	**B (Δ log count)**	**Wald Chi-Square**	**P-value**	**B (Δ log count)**	**Wald Chi-Square**	**P-value**	**B (Δ log count)**	**Wald Chi-Square**	**P-value**
Omnibus test	**23**		**871.46**	**<0.001**		**554.64**	**<0.001**		**176.40**	**<0.001**
Sub-transect	4		81.39	**<0.001**		56.65	**<0.001**		-	-
[sub-transect=6]	1	2.421	20.006	**<0.001**	2.431	40.923	**<0.001**	26.392	0	-
[sub-transect=5]	1	0.915	2.917	0.088	2.615	48.88	**<0.001**	26.482	0	-
[sub-transect=4]	1	1.029	4.047	**0.044**	1.942	30.035	**<0.001**	-0.454	0	-
[sub-transect=3]	1	-0.517	1.14	0.286	1.996	32.982	**<0.001**	16.395c	-	-
[sub-transect=2]	1	0.319	0.556	0.456	1.301	15.788	**<0.001**	-0.462	0	-
[sub-transect=1]		0 *[b]	-	-	0 *[b]	-	-	0 *[b]	-	.
Transects	4		71.35	**<0.001**		137.15	**<0.001**		-	-
[Transect=5.0]	1	-0.287	0.35	0.554	-0.456	3.567	0.059	12.389	0	>0.05
[Transect=4.0]	1	-0.031	0.006	0.94	-0.181	0.465	0.495	25.422	0	>0.05
[Transect=3.0]	1	1.784	15.293	**<0.001**	0.79	10.284	**0.001**	10.551	0	>0.05
[Transect=2.0]	1	0.281	0.436	0.509	1.259	38.814	**<0.001**	10.805	0	>0.05
[Transect=1.0]	1	0 *[b]	-	-	0 *[b]	-	-	0 *[b]	-	-
[Land use=2]	1	-0.516	2.047	0.152	-1.217	26.218	**<0.001**	-54.91	0	>0.05
[Land use=1]		0 *[b]	-	-	0 *[b]	-	-	0 *[b]	-	-

Table: 6.2: continues:

		Cheetah			Aardvark			Brown Hyena		
Parameter	**df**	**B (Δ log count)**	**Wald Chi-Square**	**P-value**	**B (Δ log count)**	**Wald Chi-Square**	**P-value**	**B (Δ log count)**	**Wald Chi-Square**	**P-value**
LGI	3		76.36	**<0.001**		16.77	**0.001**		-	-
[LGI=3]	1	-2.407	49.426	**<0.001**	-0.096	0.181	0.67	-14.012	0	>0.05
[LGI=2]	1	-33.728b	.	.	-0.265	2.159	0.142	-26.47	0	>0.05
[LGI=1]	1	-1.235	76.359	**<0.001**	-0.483	14.191	**<0.001**	-1.749	4.327	**0.038**
[LGI=0]		0 *b	-	-	0 *b	-	-	0 *b	-	-
Distance cattle posts	4		48.27	**<0.001**		78.61	**<0.001**		-	-
[Distance cattle post=5]	1	-0.535	1.189	0.275	1.786	41.765	**<0.001**	27.346	0	>0.05
[Distance Cattle post=4]	1	-0.435	1.08	0.299	0.749	7.199	**0.007**	15.739c	-	-
[Distance Cattle post=3]	1	1.326	13.309	**<0.001**	-0.189	0.306	0.58	-13.405	0	>0.05
[Distance cattle post=2]	1	0.426	2.552	0.11	0.783	32.921	**<0.001**	-14.192	0	>0.05
[Distance cattle post=1]		0 *b	-	-	0 *b	-	-	0 *b	-	-
Palatable perennials	1	-0.099	2.202	0.138	0.057	1.395	0.238	-0.626	4.649	**0.031**
Tree density	1	-0.003	0.002	0.967	-0.071	1.359	0.244	-0.618	2.522	0.112
Forbs	1	0.271	17.503	**<0.001**	0.141	10.123	**0.001**	-0.074	0.049	0.824
Unpalatable perennial	1	0.082	0.883	0.347	-0.136	4.668	**0.031**	1.133	6.934	**0.008**
Unpalatable annual	1	-0.076	1.153	0.283	-0.042	0.842	0.359	0.322	2.89	0.089
Palatable annuals	1	0.157	11.425	**0.001**	0.04	0.867	0.352	-0.247	0.454	0.5

Note: *b Set to zero because this parameter is redundant and is used as a reference point for comparison, B = regression coefficient, LGI = livestock Grazing intensity (LGI = 0 to 3– zero to high livestock grazing intensity respectively, Land use 1 & 2 = CGA and CAs, respectively, Sub-transect 1– 6 = near and furthest distance from settlements, distance from cattle posts 1- 5 = near to furthest. The bold P-values are significant
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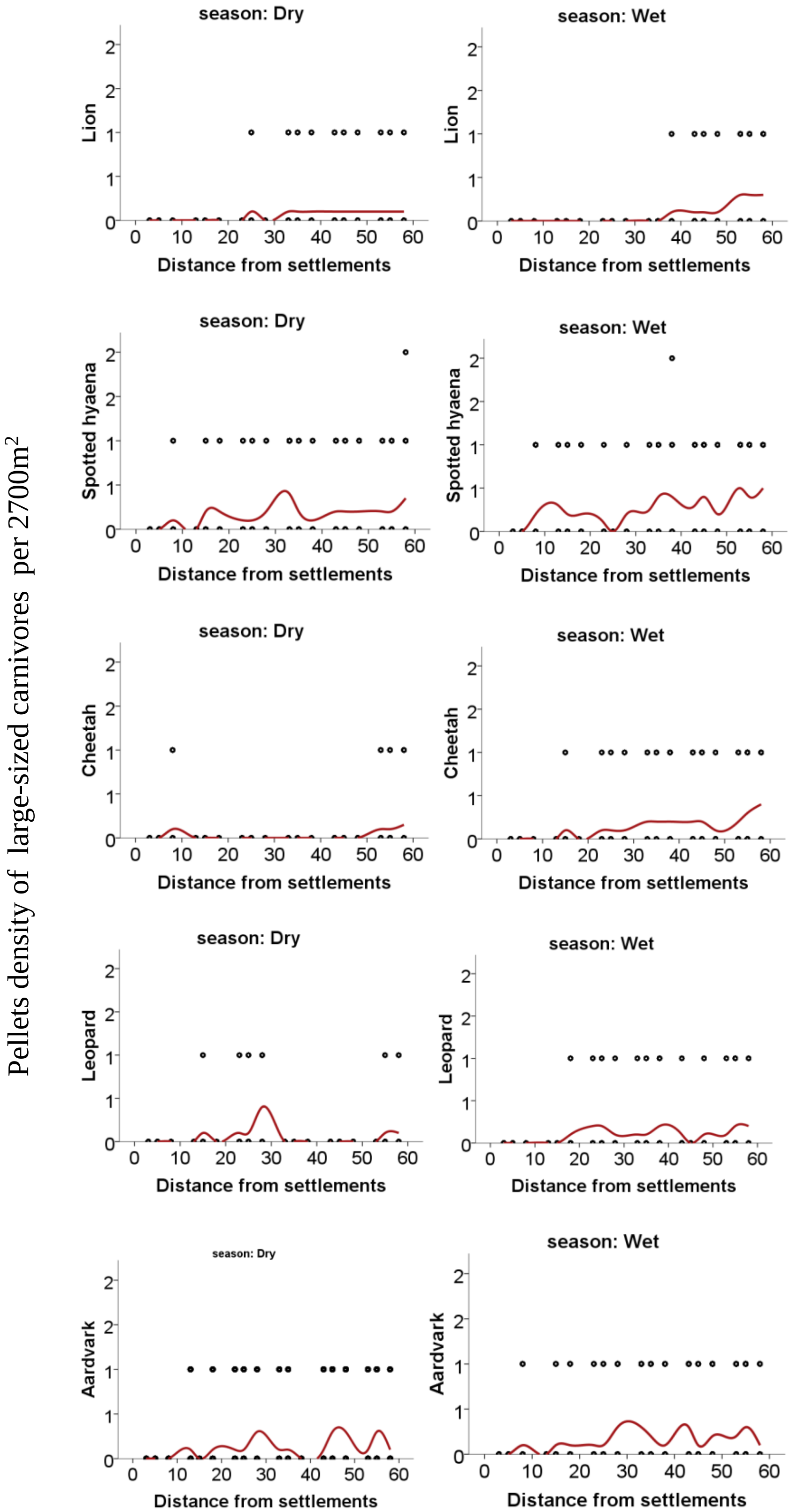

Figure 6. 2: Scatter plots showing the distribution of large-sized carnivorous mammals Scatter plots (present/absent) fitted with natural cubic spline interpolation to show the variation in distribution (red line) of Lion, Spotted Hyena, Cheetah, Leopard, and Aardvark along free-ranging livestock grazing and pastoral activities disturbance gradient (km) in northern Kalahari, Botswana, during the dry and wet seasons, respectively. The y-axis represent the density of wildlife pellets per 2700m^2 plot within each sample poin and the x-axis if the distance from cattle settlements in km.

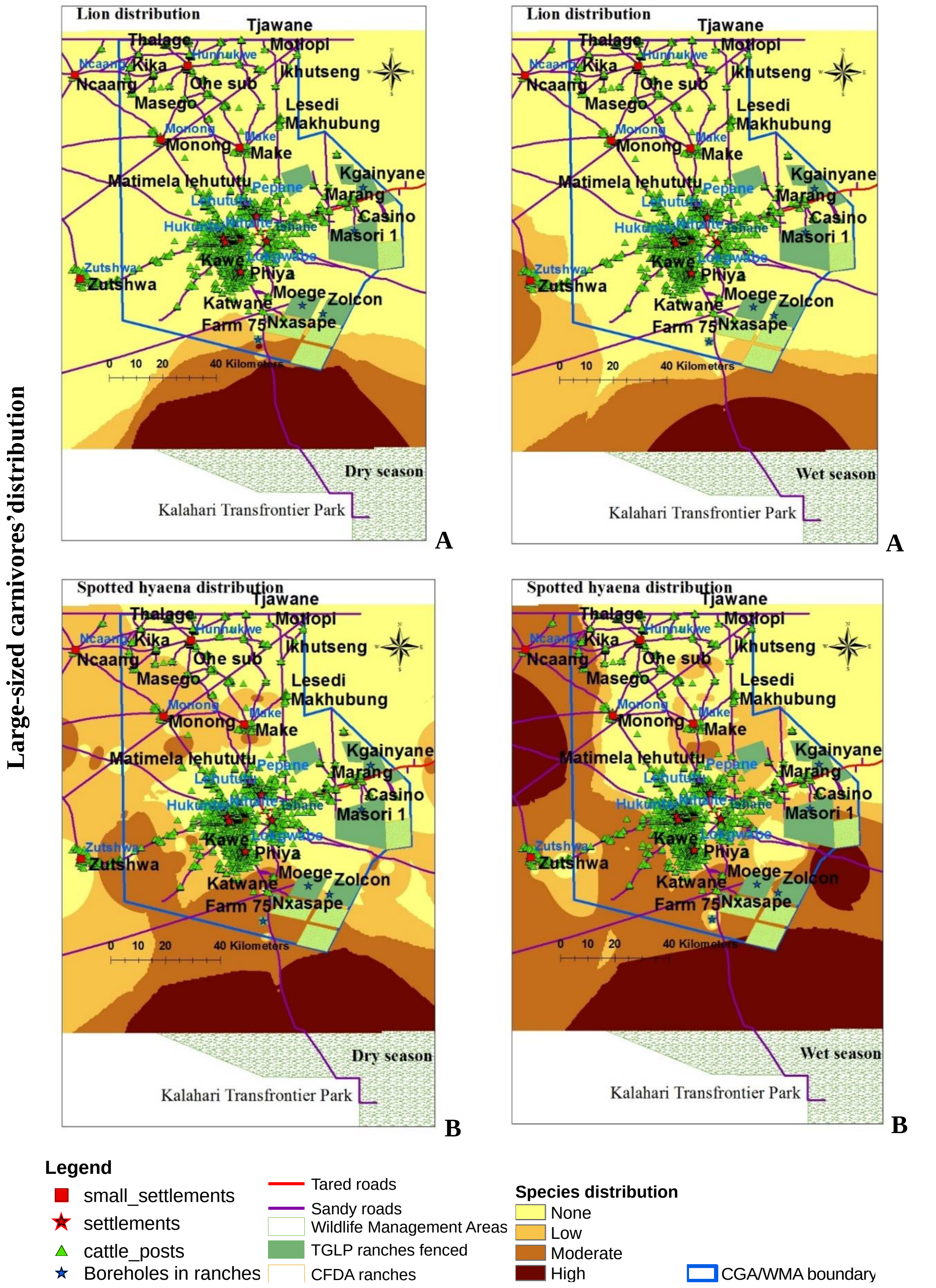

Figure 6. 3: Spatial distribution of large-sized carnivorous mammals in relation to land use types
(Inverse Distance Weighted interpolation based on sample points) (A) Lion, (B) Spotted Hyena, along a pastoral activities disturbance gradient (distance from main settlements) in northern Kalahari, Botswana, during the dry and wet seasons, respectively. The green triangles represent individual cattle posts.

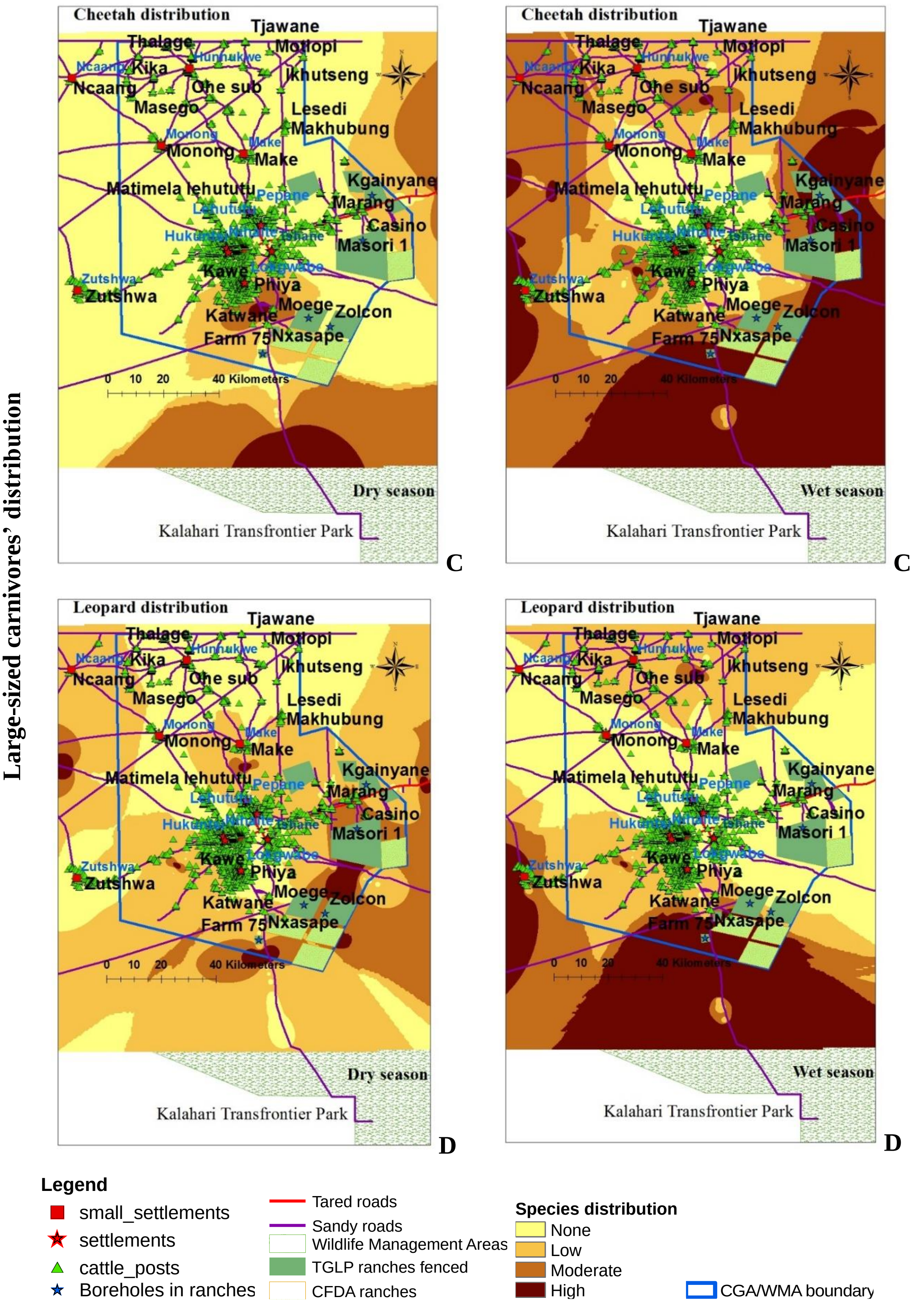

Figure 6.3 Continued: Spatial distribution patterns of large-sized carnivorous mammals (Inverse Distance Weighted interpolation based on sample points) (C) Cheetah, (D) Leopard in relation to land use and pastoral activities disturbance gradient (distance from main settlements) in northern Kalahari, Botswana, during the dry and wet seasons, respectively. The green triangles represent individual cattle posts.

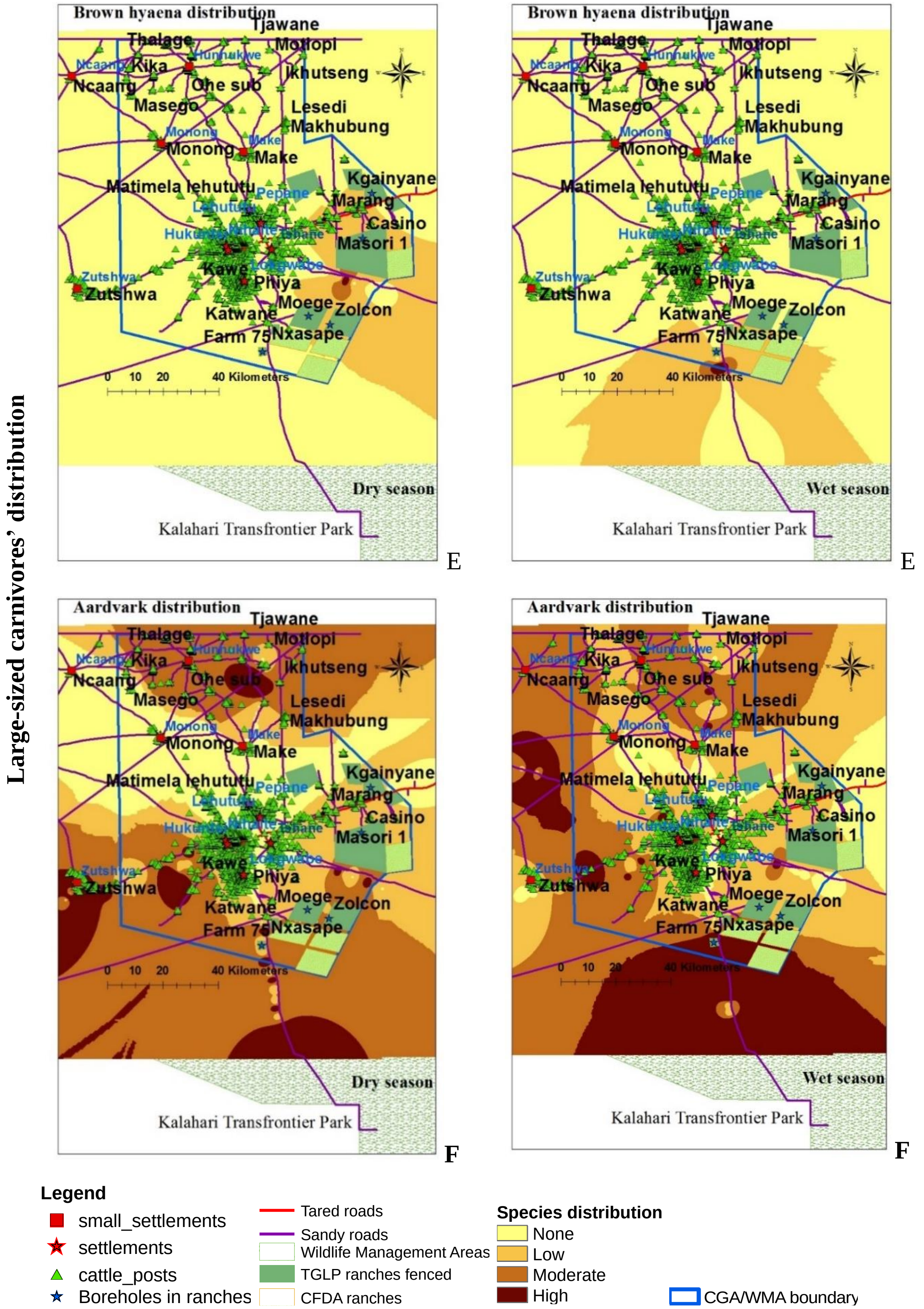

Figure 6.3: Continued: Spatial distribution patterns of large-sized carnivorous mammals (Inverse Distance Weighted interpolation based on sample points) (E) Brown Hyaena, (F) Aardvark in relation to land use and pastoral activities disturbance gradient (distance from main settlements) in northern Kalahari, Botswana, during the dry and wet seasons, respectively. The green triangles represent cattle posts.

Distribution of Small to Medium- sized carnivores

Medium-sized carnivores included African Wild dog, Caracal, and Striped hyena, while small carnivorous mammals were Black-backed Jackal, Honey Badger, Blandford's Fox, and Bat eared Fox. Spoor data for Black Back Jackal and porcupine did not follow Poisson distribution. Also, there were few observations on Honey Badger, Blandford Fox and African Wild Cat. Hence the spoor data for these carnivores were not analysed using Poisson regression model. The Poisson regression models on spoor data for most of the small to medium carnivore species, were statistically significant. For example, Poisson regression model on the spoor of the following carnivores; African Wild Dog, χ^2 (23) = 1863.37, P < 0.001, Caracal, χ^2 (23) = 680, P < 0.001, and Bat Eared Fox, χ^2 (23) = 497.26, P < 0.001 (Table 6.3). Of the eleven predictor variables, some were statistically significant, while others were not depending on the species (as shown in Table 6.3). For example, African Wild Dog, four predictors (sub-transect, χ^2 (3) = 14.88, P = 0.002, Palatable perennial grasses, χ^2 (1) = 13.17, P < 0.001, Forbs, χ^2 (1) = 7.09, P = 0.008 and palatable annual grasses, χ^2 (1) = 10.22, P = 0.001) were statistically significant, while the other seven were not (P > 0.05) amid the wet and dry seasons combined. Caracal: four predictors (LGI, χ^2 (3) = 45.03, P < 0.001), increased tree density, χ^2 (1) = 5.83, P = 0.016, unpalatable perennial grasses, χ^2 (1) = 5.39, P =0.020, and unpalatable annual grasses, χ^2 (1) = 5.15, P = 0.023, were statistically significant, while the rest were not (P > 0.05) (Table 6.3).

The Poisson regression (GLM) shows that all medium-sized carnivores (African Wild Dog, Caracal) were not statistically significantly different with land use types (P > 0.05) when combining the wet the dry season data. Hence, their spatial distribution was the same between CGAs and CAs (Table 6.3 & Figure 6.5). However, African Wild Dog, χ^2 (3) = 14.87, P = 0.02, was increasing and decreasing with distance from the settlements, but there was no significant difference in the distribution of Caracal, χ^2 (4) = 6.81, P = 0.146 with distance from the settlements. Therefore, suggesting that they were associated with moderate livestock grazing intensity. Consequently, the distribution of African Wild Dog, χ^2 (4) = 4.08, P =0.130 and Caracal, χ^2 (4) = 0.0, P = 0.999 showed not statistically significant difference with distance from the cattle posts. The distribution of African Wild Dog also showed no significant difference with LGI, χ^2 (1) = 0.501, P = 0.479, however, Caracal distribution was decreasing with increasing LGI, χ^2 (4) = 45.03, P < 0.001 (Table 6.3). African Wild Dog & Caracal were observed from the minimum distances of 9 km respectively during the wet season (Figure 6.4). Hence, demonstrating their attraction to CGA in the wet season. Therefore, implying that these medium-sized carnivores were attracted to CGAs, nonetheless, avoiding pastoral impacted areas, such as high densities of cattle posts, settlements and arable agricultures fields (Figure 6.5). On the other hand, Striped Hyena concentrated in CAs and no observations were recorded in the CGAs, indicating that it was not common in the study area and most probably negatively affected by pastoral activities. All the predictor variables were not statistically significant predictors of Striped Hyena distribution ($P > 0.05$).

The PCA and HCA indicate that small Carnivore (Black-backed Jackal) was associated with CAs ($P < 0.001$) and decreased with increasing livestock grazing intensity, and distance from cattle posts ($P < 0.001$). However, Poisson regression shows that Bat-Eared Fox, which is an insectivore, was the same in both land uses, χ^2 (1) = 0.382, P = 0.536 (Table 6.3). The distribution of Black-backed Jackal and Bat-Eared Fox were observed from minimum distances of 3km and 9km, respectively (Figure 6.4). However, Bat-eared Fox, χ^2 (5) = 79.89, P = 0.536, $P < 0.001$ and Black-backed Jackal (P = 0.008) distribution were increasing and decreasing with distance from settlements, respectively in both seasons combined (Table 6.3). Bat Eared Fox decreased with increasing livestock grazing intensity, χ^2 (3) = 190.09, $P < 0.001$, and distance from cattle posts, χ^2 (4) = 36.31, $P < 0.001$. Therefore, indicating that Black-backed Jackal was not impacted by livestock grazing intensity and pastoral activities (Figure 6.5), hence grazing facilitation. There were few observations on Honey Badger, Blandford Fox and African Wild Cat, hence were not be analysed by the GLM, and not mapped, but suggest that there were uncommon.

Table 6. 3: Poisson regression (Generalized Linear Model) coefficients on the distribution of small to medium carnivorous mammals
Shows change in log count, Wald Chi-Square and P-values. The relationship of the estimated and measured environmental variables was in both seasons combined. P-value computed using alpha = .05, hence P < 0.05 shows significant at the 0.05 level (2-tailed). LGI = livestock grazing intensity. Omnibus test (showing df, Likelihood Chi-Square, P-value) compares the fitted model against the intercept only model for each herbivore.

		Wild Dog			**Caracal**			**Bat Eared Fox**		
Parameter	**df**	**B (Δ log count)**	**Wald Chi-Square**	**P-value**	**B (Δ log count)**	**Wald Chi-Square**	**P-value**	**B (Δ log count)**	**Wald Chi-Square**	**P-value**
Omnibus test	**23**		**1863.37**	**<0.001**		**680.30**	**<0.001**		**497.26**	**<0.001**
Sub-transects	4		14.88	**0.002**		6.81	0.146		79.89	**<0.001**
[sub-transect=6]	1	-25.16	<0.001	>0.05	-0.172	0.125	0.723	1.15	32.81	**<0.001**
[sub-transect=5]	1	-25.162	<0.001	>0.05	0.234	0.234	0.629	0.961	22.972	**<0.001**
[sub-transect=4]	1	-24.541	<0.001	>0.05	-0.013	0.001	0.979	0.763	17.49	**<0.001**
[sub-transect=3]	1	25.276	<0.001	>0.05	-1.675	8.823	**0.003**	0.574	10.135	**0.001**
[sub-transect=2]	1	0.834	3.938	**0.047**	0.296	0.55	0.458	1.138	54.348	**<0.001**
[sub-transect=1]	.	0b	.	.	0b	.	.	0b	.	.
Transects	4		-	-		0.238	0.626		36.03	**<0.001**
[Transect=5.0]	1	-2.5	<0.001	>0.05	-33.073 *c	.	.	-0.055	0.204	0.652
[Transect=4.0]	1	49.48	<0.001	>0.05	-0.362	0.7	0.403	-0.313	4.669	**0.031**
[Transect=3.0]	1	24.998	<0.001	>0.05	-0.154	0.238	0.626	0.346	6.421	**0.011**
[Transect=2.0]	1	-1.003	<0.001	>0.05	-32.238 *c	.	.	-0.107	0.642	0.423
[Transect=1.0]	.	0b	.	.	0b	.	.	0b	.	.
[Land use=2]	.	-2.437c	.	.	-1.449	3.06	0.08	0.095	0.382	0.536
[Land use=1]	.	0b	.	.	0b	.	.	0b	.	.

Table 6. 3: continues

		Wild Dog			Caracal			Bat Eared Fox		
Parameter	**df**	**B (Δ log count)**	**Wald Chi-Square**	**P-value**	**B (Δ log count)**	**Wald Chi-Square**	**P-value**	**B (Δ log count)**	**Wald Chi-Square**	**P-value**
LGI	3		0.501	0.48		45.03	**<0.001**		190.01	**<0.001**
[LGI=3]	1	25.895	<0.001	>0.05	-2.242	30.778	**<0.001**	-1.685	157.695	**<0.001**
[LGI=2]	1	-0.052	0.021	0.885	-0.395	1.453	0.228	-1.11	100.877	**<0.001**
[LGI=1]	1	0.139	0.501	0.479	-0.403	6.174	**0.013**	-0.847	106.97	**<0.001**
[LGI=0]	.	0b	.	.	0b	.	.	0b	.	.
Distance cattle posts	4		4.08	0.130		0	.999		36.32	**<0.001**
[Distance cattle posts=5]	1	78.355	0	0.999	1.241	1.893	0.169	-0.675	15.153	**<0.001**
[Distance cattle posts=4]	1	25.418	0	>0.05	0.308	0.286	0.593	-0.465	6.696	**0.01**
[Distance cattle posts=3]	1	26.115	0	0.999	0.934	2.941	0.086	-0.068	0.187	0.665
[Distance cattle posts=2]	1	25.694	0	>0.05	-32.893 *c	.	.	-0.412	16.353	**<0.001**
[Distance cattle posts=1]	.	0b	.	.	0b	.	.	0b	.	.
Palatable perennials	1	0.283	13.166	**<0.001**	0.113	3.187	0.074	0.008	0.055	0.815
Tree density	1	-0.109	1.29	0.256	-0.206	5.83	**0.016**	0.024	0.324	0.569
Forbs	1	0.209	7.093	**0.008**	0.011	0.023	0.878	0.054	3.494	0.062
Unpalatable perennials	1	-0.191	2.535	0.111	-0.277	5.391	**0.02**	0.008	0.057	0.812
Unpalatable annuals	1	0.026	0.236	0.627	-0.215	5.147	**0.023**	-0.089	6.091	0.014
Palatable annuals	1	0.257	10.217	**0.001**	-0.044	0.623	0.43	-0.14	43.829	**<0.001**

Note: *b Set to zero because this parameter is redundant and is used as a reference point for comparison, B = regression coefficient, LGI = livestock Grazing intensity (LGI = 0 to 3– zero to high livestock grazing intensity, respectively, Land use 1 & 2 = CGA and CAs, respectively, Sub-transect 1– 6 = near and furthest distance from settlements, distance from cattle posts 1- 5 = near to furthest. The bold P-values are significant.

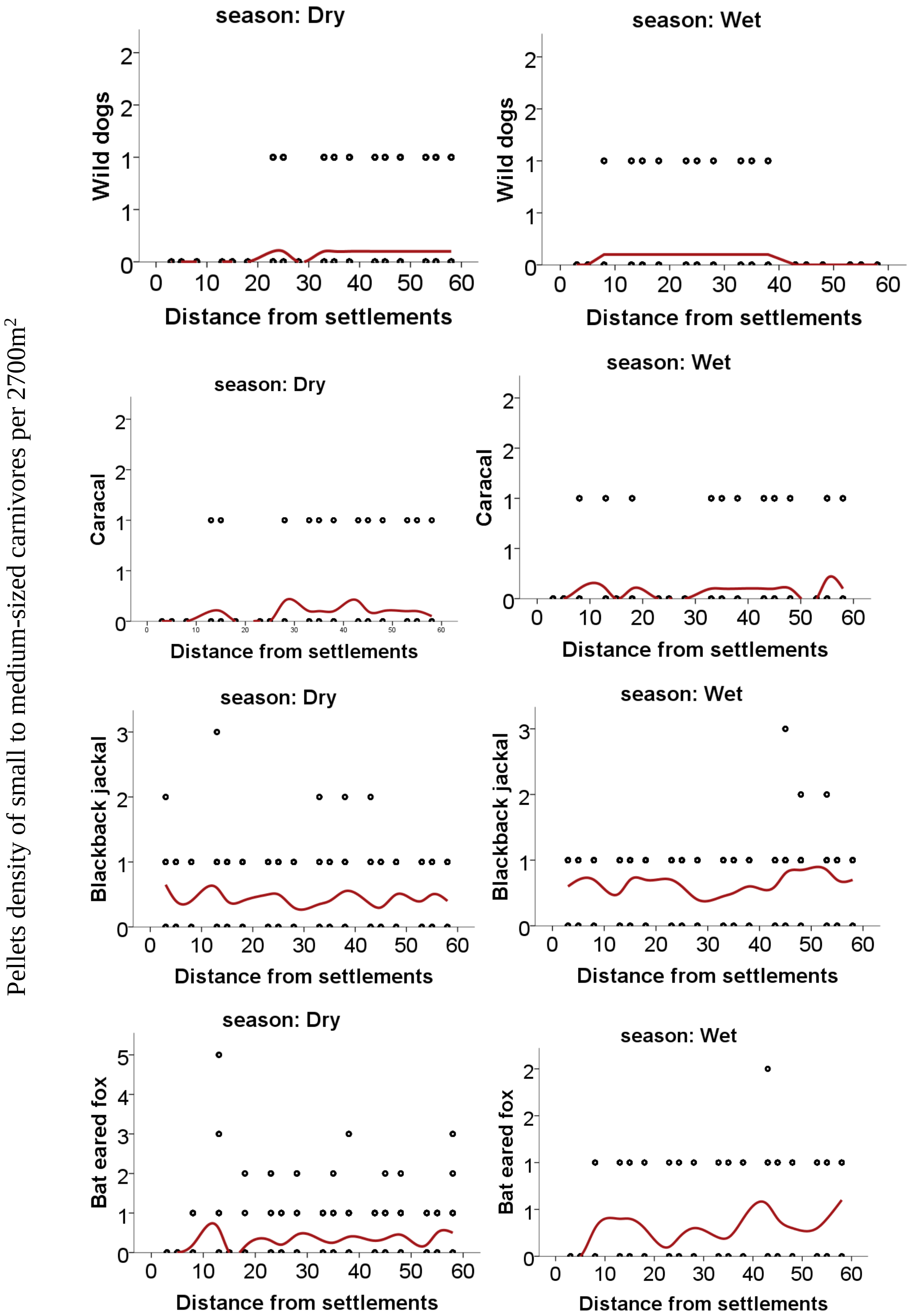

Figure 6. 4: Scatter plots showing the distribution of small to medium-sized carnivores Scatter plots fitted with natural cubic spline interpolation to show the variation in distribution of small to medium-sized carnivores (red line): African Wild Dog, Caracal, Black-backed Jackal, and Bat eared Fox along livestock grazing and pastoral activities disturbance gradient (km) in northern Kalahari, Botswana, during the dry and wet seasons, respectively. The y-axis represent the density of wildlife pellets per 2700m^2 plot within each sample poin and the x-axis if the distance from cattle settlements in km.

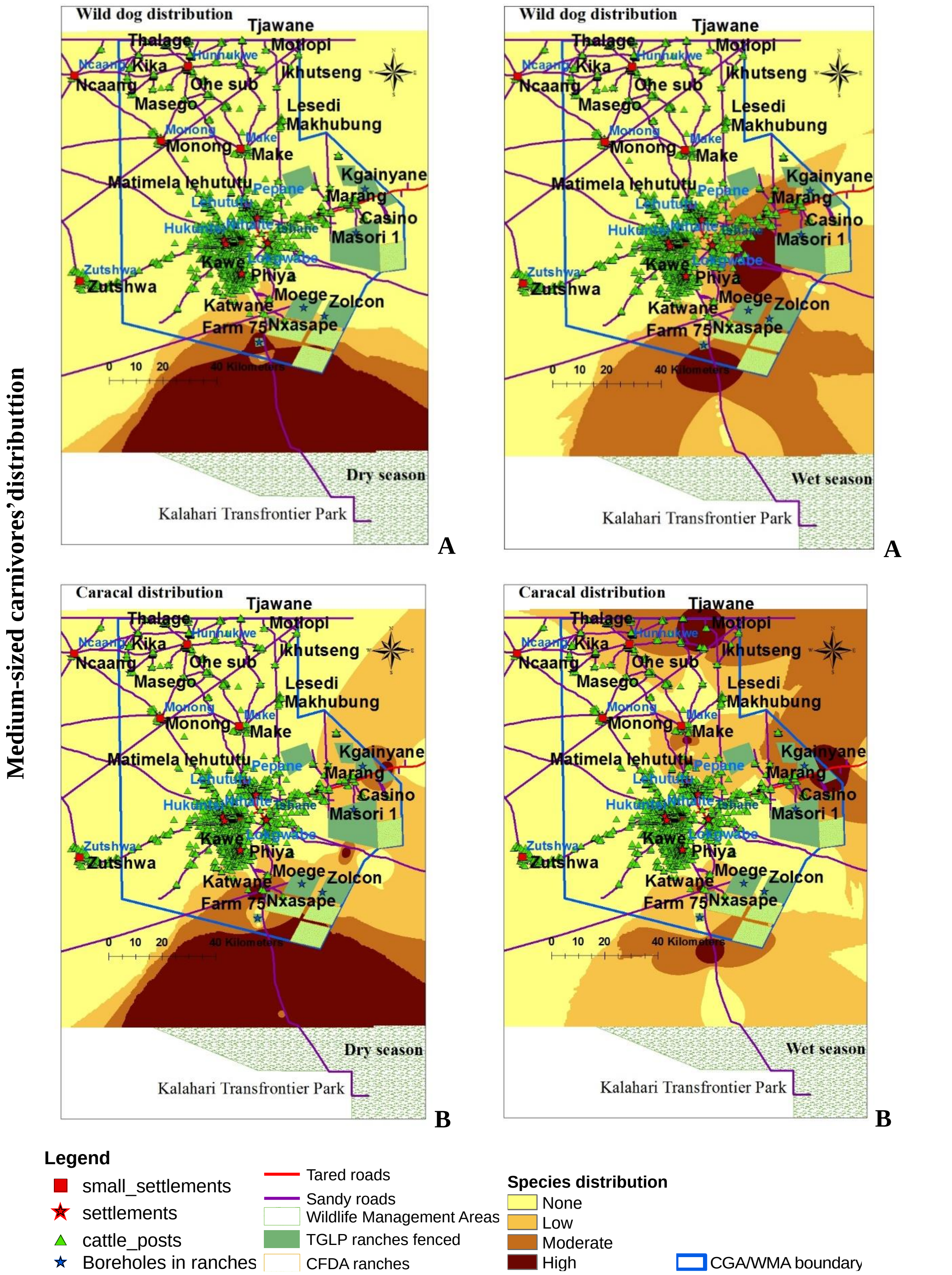

Figure 6. 5: Spatial distribution of medium-sized carnivores in relation to land use types (Inverse Distance Weighted interpolation based on sample points) of (A) African Wild Dog, (B) Caracal in relation pastoral activities disturbance gradient (distance from main settlements) in northern Kalahari, Botswana, during the dry and wet seasons, respectively. The green triangles represent individual cattle posts

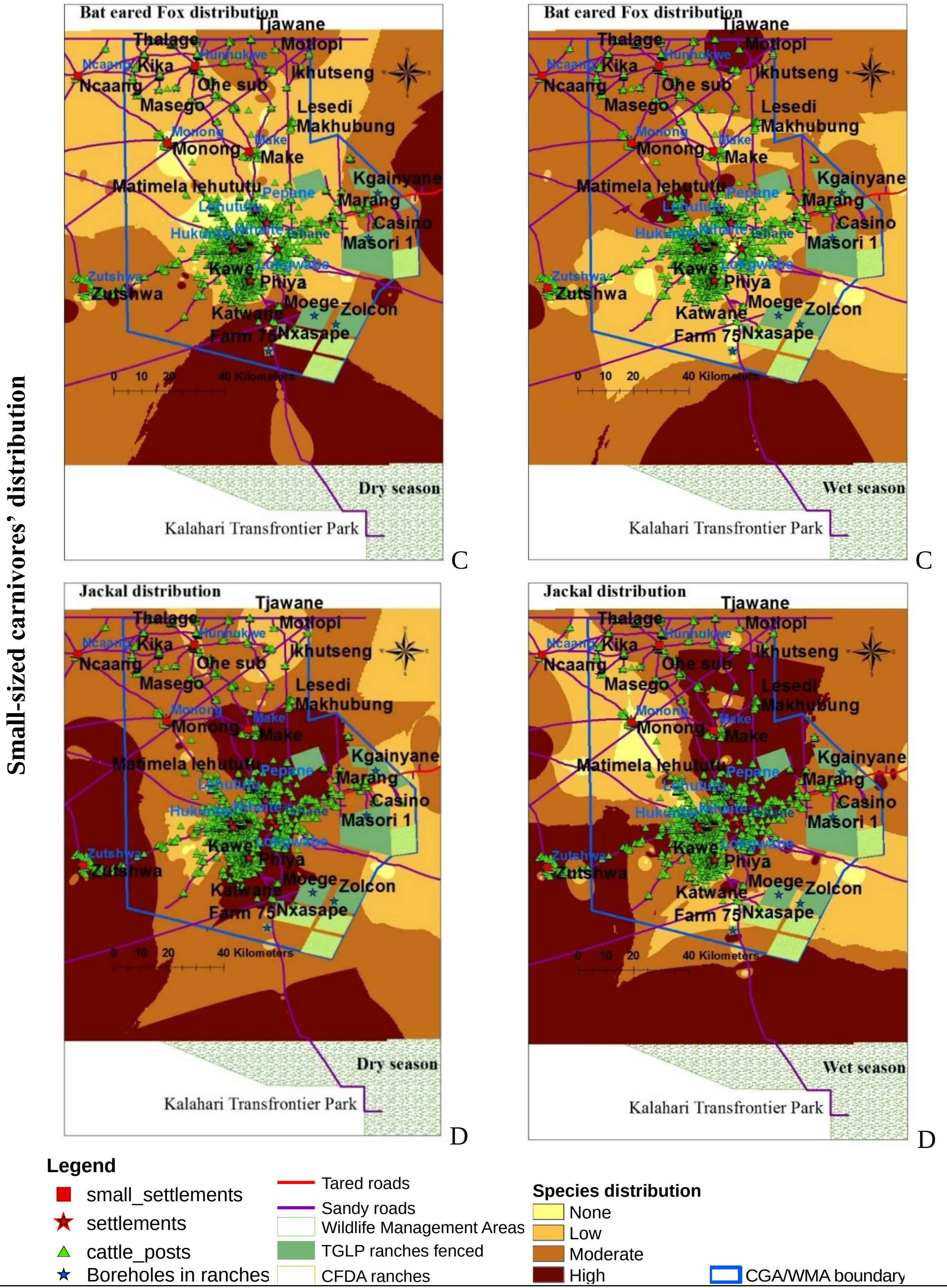

Figure 6.5 continued: Spatial distribution of small-sized carnivores (Inverse Distance Weighted interpolation based on sample points) of (C) Bat eared Fox *Otocyon megalotis* Desmarest (D) Black-backed Jackal *Canis mesomelas* Linnaeus in relation to land use and pastoral activities disturbance gradient (distance from main settlements). The green triangles represent cattle posts

6.3.2: Environmental factors influencing the distribution of carnivores

The distribution of carnivores amid the dry and wet season

Six and five environmental variables statistically significantly explained the variance in the distribution of carnivorous mammals and livestock data in dry (0.882/2.377 = 37%) and wet (0.88/2.228 = 39.5%) season, respectively ($p < 0.05$) (Table 6.4 & 6.5). Despite the omission of other environmental variables, the eigenvalues of the first two axes remained reasonable high in dry (AX1 = 0.523, AX2 = 0.173) and wet season (AX1 = 0.495, AX2 = 0.181). Therefore, indicating that the first axes for the dry and wet seasons, represented the effective gradients, explaining 22 & 22.2% of the variance respectively. These first two axes for each season, explained 29.3 & 30.4% of the total variance in the species data in the dry and wet season, respectively (Table 6.4). Most of the retained environmental variables were not highly correlated in both seasons; hence no multicollinearity between the variables as evident through the correlation coefficients and all their variance inflation factors (VIF) values are less than 10 (using a Tolerance level of 0.10) (Tabachnick, Fidell et al. 2001).

During the dry season, along with the first axis, distance from cattle posts had the highest positive correlation (0.8034) followed by areas without livestock grazing (0.7745), and habitat type (Arable fields/Woody cover) (-/+0.5474) (Table 6.4). Hence, this first axis is a gradient of increasing distance from cattle posts, towards CA, together with the woody cover, hence reflecting less livestock grazing intensity (Figure 6.6A). Therefore, indicating that less livestock grazing intensity and less pastoral activities were the most important environmental variables influencing the distribution of carnivorous mammals and livestock during the dry season. Other relevant environmental variables during the dry seasons were habitat type (arable fields/woody cover) (-/+0.4678) and forb cover (0.3368), which showed the highest correlation with the second axis respectively (Table 6.4). Consequently, in the dry season, the first CCA biplot axis is a gradient of increasing distance from cattle posts (less livestock grazing intensity), towards the areas without livestock grazing, with fewer pastoral activities, such as arable fields, from left to right. While the second axis is a gradient of woody cover and forb cover, hence also reflecting less livestock grazing intensity from bottom up (Figure 6.6A).

On the contrary, during the wet season, grass cover (-0.7332) has the highest negative correlation with the first axis. Distance from settlements (-0.7328), areas without grazing

(-0.6659) also have the high negative correlation, while arable agriculture fields (0.7063) has a positive association with the first axis (Table 6.4). Consequently, in the wet season, the first CCA biplot axis is a gradient of reduced grass cover together with decreasing distance from settlements (increasing livestock grazing intensity), increased arable agriculture fields near the settlements from left to right (Figure 6.6A). Therefore, demonstrating that grass cover, increasing livestock grazing intensity, and arable agriculture fields were the most significant environmental variables influencing the distribution of carnivores and livestock during the wet season. Other relevant environmental variables which influence their distribution are the distance from cattle posts (0.3817), areas without livestock grazing (0.3964) which had the highest positive correlation with the second axis respectively (Table 6.4). Therefore, the second axis is a gradient of increasing distance from the cattle posts, towards areas without livestock grazing from bottom up (Figure 6.6B).

Table 6.4: Summary of the forward selection on the retained environmental variables on carnivorous mammals in dry and wet season
The two axes for the dry and wet seasons, represented the effective gradients, explaining 29 3 & 30.4% of the variance respectively.

	Dry season				Wet season			
Axes	**1**	**2**	**3**	**Total inertia**	**1**	**2**	**3**	**Total inertia**
Eigenvalues	**0.523**	**0.173**	0.096	2.377	**0.495**	**0.181**	0.085	2.228
Species-environment correlations	0.921	0.708	0.59		0.905	0.738	0.793	
Cumulative percentage variance								
of species data	22	**29.3**	33.3		22.2	**30.4**	34.2	
of species-environment relation:	59.3	78.9	89.8		56.2	76.9	86.6	
Sum of all eigenvalues				**2.377**				**2.228**
Sum of all canonical eigenvalues				**0.882**				**0.88**

Table 6. 3: The inter-set correlation coefficients of the environmental variables on the distribution of carnivorous mammals
The first three ordination species axes showing their influence on the distribution of carnivores, in northern Kalahari, Botswana in dry and wet seasons. The **bold** correlation coefficients are the highest in each axis.

	Dry season			Wet season		
Environmental variables	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 1**	**Axis 2**	**Axis 3**
Areas without livestock grazing	**0.7745**	-0.237	0.0831	**-0.6659**	**0.3964**	0.1864
Less livestock grazing intensity	0.2919	0.2469	0.1992			
Habitat type (Arable fields)	**-0.5474**	**-0.4678**	-0.2034	**0.7063**	**0.4565**	-0.0026
Habitat type (Woody Cover)	**0.5474**	**0.4678**	0.2034	**-0.7063**	**-0.4565**	0.0026
Distance from cattle posts	**0.8034**	-0.2736	-0.0882	-0.6828	**0.3817**	-0.1445
Unpalatable perennial grasses	-0.1005	0.2419	-0.1818			
Forb cover	0.1576	**0.3363**	0.2033			
Distance from settlements				**-0.7328**	0.0518	-0.0856
Grass cover				**-0.7332**	0.1551	0.0089
Palatable annual grasses				-0.189	0.0956	-0.0679

The CCA biplot ordination diagrams, in which the quantitative environmental variables are presented by arrows radiating from the origin of the graphs (Figure 6.6). Carnivores were positively associated with less livestock grazing intensity. However, livestock was positively correlated with increasing livestock grazing intensity and other pastoral activities, such as arable fields in CGAs in both seasons (Figure 6.6). During the dry seasons, large-sized carnivores (Spotted Hyena, Lion, and Cheetah) were related to increasing distances from cattle posts in areas without livestock grazing. However, Leopard and Aardvark were weakly associated with increasing distances from the cattle posts but positively correlated with unpalatable perennial grasses and forb cover. Therefore, showing that they were related to moderately grazed areas in the dry season. Nonetheless, during the wet season, all large-sized carnivores were positively associated with increasing distance from settlements, grass cover, and distance from the cattle posts in areas without livestock grazing intensity. Therefore, suggesting that the distribution of large-sized carnivores was influenced by land use, pastoral activities, grass cover and less livestock grazing intensity in both seasons. Hence, they concentrated in CAs and avoided pastoral impacted areas in CGAs. However, Aardvark and Leopard also was associated with the moderately grazed area, hence suggesting grazing facilitation by less livestock grazing intensity.

On the other hand, during the dry season, the medium-sized carnivores (Caracal, Wild Dog) were positively associated with increasing distance from the cattle posts in the area with less livestock grazing intensity and without livestock grazing (Figure 6.6). However, in wet season they were weakly associated with distances from settlements, cattle posts and grass cover. Therefore, indicating that Caracal and Wild dog avoided areas with increasing livestock grazing intensity during the dry season but concentrated in areas with moderate livestock grazing in the wet season. On the other hand, Brown Hyena was weakly correlated to distance from the cattle posts in both season, and weakly correlated with grass cover and distance from settlements. Therefore, suggesting that Brown Hyena avoided areas with high grass cover, increased livestock grazing intensity, hence remained in areas with moderate grazing.

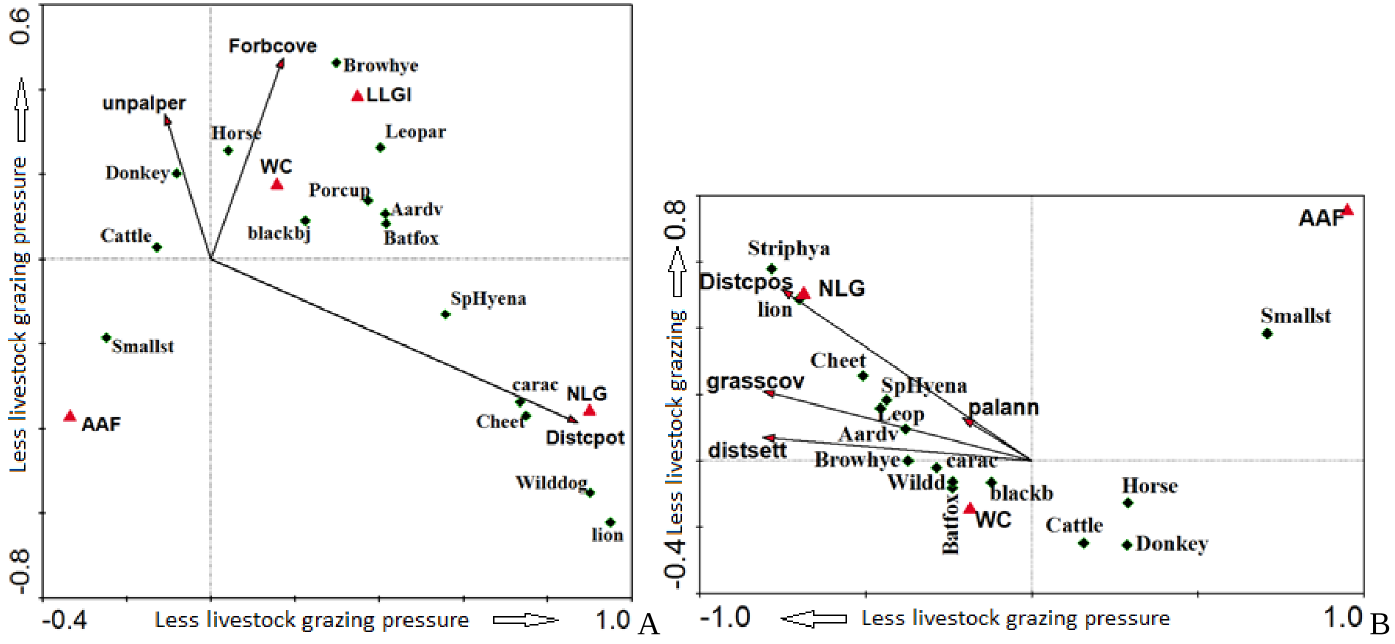

Figure 6. 6: Biplot ordination diagram based on canonical correspondence analysis – CCA for the carnivores and livestock distribution as influenced by livestock grazing intensity and quantitative (grasscov, forbcove, Distsett, Distcpot, unpalper, palann) and nominal (habitat type, livestock grazing intensity) environmental variables in northern Kalahari, Botswana, during the dry season (A) and wet season (B). Quantitative and qualitative environmental variables are indicated by arrows and triangles, respectively. Wild herbivores and livestock species are shown as green dots. For dry season, the species – environmental correlation for the first two axes are 0.921 and 0.708, respectively (eigenvalue 1 = 0.523, eigenvalue 2 = 0.173; scaling = 2, sum of all canonical eigenvalues is 0.882), while for wet season are 0.905 and 0.738, respectively (eigenvalue 1 = 0.495, eigenvalue 2 = 0.181; scaling = 2, sum of all canonical eigenvalues is 0.88). Distsett, Distcpot, = distance from settlements, cattle posts, respectively, grasscov = grass cover, forbcove = Forb cover, unpalper = unpalatable perennial grasses, palann = palatable annual grasses. Habitat type (AAF = arable agriculture fields, WC = woody cover), Livestock grazing intensity (NLG = livestock grazing absent, LLGI = less livestock grazing intensity). Wildd = Wild dog, Carac = caracal, Cheet = Cheetah, Sphyena = Spotted Hyena, Batfox = bat eared fox, Aardv = Aardvark, Blackb = Black-backed Jackal, Leop = Leopard, Browhye = brown Hyena, Striphya

Striped Hyena was not recorded in the dry season, however, in the wet season, it was associated with increasing distance from settlements, cattle posts and high grass cover in CAs. Small-sized carnivores (Black-backed Jackal and Bat-eared Fox) concentrated in moderately grazed areas because they were weakly associated with distance from the cattle posts in both seasons. They also avoided areas with high grass cover and weakly related with distance from the settlements in the wet season. Therefore, suggesting that even though Black-back and Bat-eared Fox avoided pastoral impacted areas closer to settlements, and were associated with moderately grazed areas in both seasons. Hence facilitation by Livestock grazing.

6.4: Discussion

Despite the essential roles of carnivores of different body sizes and the possible effects from pastoral activities on the ecosystem dynamics, knowledge on the interactions between carnivores, free-ranging livestock and pastoralists in communally managed rangeland adjacent to the CAs in the southern African, is rarely available. Hence, the likely effects of land-use change, LGI, and pastoralists-induced risk (i.e. human disturbance) on the distribution of carnivores of different body sizes in these communally managed rangelands are less understood. Therefore, the impacts of pastoralists activities such as pastoralists-induced risk, free-ranging LGI on the distribution of carnivores in semi-arid communally managed rangeland near CAs are less documented. Nevertheless, in southern African rangelands, some carnivores such as Cheetah, African wild dogs exist outside protected areas because of avoiding other large-sized carnivores (Blaum, Rossmanith et al. 2007c). Therefore, this study explored factors regulating the spatial and temporal distribution of carnivores of different body sizes in CGAs supporting free-ranging livestock adjacent CAs.

The study revealed four distinct general distribution patterns of the carnivores in CGAs and adjacent CAs; (i) The distribution of most of the carnivores (e.g. Lion, and Striped, cheetah, Spotted Hyena and honey badger) were not in CGAs but CAs, except Black-backed Jackal, Brown Hyena, African Wild Dog, Leopard, Aardvark and Bat-eared Fox. (ii) The distribution of small-sized carnivores (Black-backed Jackal and Bat-Eared Fox) was associated with both land uses, however, in CGAs Bat-Eared Fox was related to less LGI, which agrees with (H3a, H3b). Nonetheless, Black-backed Jackal was also associated with increased pastoral activities closer to settlements, which is not consistent with the hypotheses (H3a & H3b). Therefore, suggesting that small-sized, carnivores are tolerant of moderate LGI and less pastoral activities, hence facilitation. However, Black-backed Jackal is also tolerant of increased LGI and pastoralists activities, which is not in agreement with the Hypotheses (H3 a & b).

(iii) Medium-sized carnivores; African Wild Dog and Caracal were more associated to CGAs than CAs in both seasons combined. However, during the dry and wet seasons, they tend to be associated with CAs and CGAs, respectively. Nonetheless, the distribution of medium-sized carnivores was associated with less LGI in the dry season than in the wet season, which is in support with the hypotheses (H3a & H3b). (iv) On the contrary, Large-sized carnivores (Lion, Spotted Hyena, and Cheetah) were associated with CAs and at greater distances from the settlements, cattle posts, and boreholes in both seasons, which agrees with (H3c). However, Leopard and Aardvark (formivore) were related to moderately grazed areas and on the boundary of CGAs & CAs in both seasons, which agrees with hypothesis (H3c). Unexpectedly, the brown hyena was associated with CGAs than CAs in both seasons, which is not consistent with (H3c), possibly avoiding areas exploited by Spotted Hyena and other large-sized carnivores. Therefore, these patterns suggest that the most significant gradients influencing the distribution of carnivores are livestock grazing intensity, pastoral activities, predation and food availability.

6.4.1: Spatial distribution of carnivores

Factors influencing the distribution of large-sized carnivore distribution

The distribution of large-sized carnivores (Lion, Spotted Hyena, and Cheetah) was associated with CAs and at greater distances from the settlements, cattle posts, and boreholes in both seasons, which agrees with (H3c). The distribution of all large-sized carnivores was increasing with distances from the settlements, cattle posts (less to zero livestock grazing intensity) and was abundant towards Kalahari Trans-Frontier Park (KTFP). Therefore, suggesting that the distribution of these large-sized carnivores avoided pastoral impacted areas near the main settlements and concentrated in CAs, where there is increased vegetation cover. The distribution pattern of Lion, Spotted Hyena, and Cheetah agrees with hypothesis (H3c) and also similar to studies by (Karani 1994, Reid, Rainy et al. 2003). These latter authors reported a lower number of Lions in the pastoral areas, implying a long-term threat to the population of Lion in the pastoral dominated areas (Woodroffe and Ginsberg 1998, Woodroffe and Ginsberg 2000).

The findings agrees with studies by several authors, for example (Ogutu and Dublin 2002, Ogutu and Dublin 2004, Gusset, Swarner et al. 2009, Wallgren, Skarpe et al. 2009, Hopcraft, Anderson et al. 2012), These authors documented that large carnivores movements as being influenced by spatial resource heterogeneity between CAs and pastoral dominated areas and mostly being associated with CAs. A possible explanation for large-sized carnivores avoiding pastoral impacted areas in CGAs in the Kalahari rangelands is conflicts with pastoralists (Ogutu, Bhola et al. 2005) and also because of the abundance of resident medium to large-sized herbivores in the CAs (Ogutu and Dublin 2002, Ogutu and Dublin 2004) than in CGAs (see Chapter 5). Besides, in the present study, pastoralists and Wildlife Officers were physically driving the Lions away from closer to settlements and cattle posts, using horses and pick-up trucks. Sometimes the Lions were captured and moved to the conservation areas (Personal communication with farmers and Wildlife Officers), hence forcing these large carnivores to avoid the CGAs.

The primary predators of livestock in the present study are Lion and Spotted Hyena; therefore, the negative interactions with the pastoralists. Human-carnivore conflicts in CGAs are due to the carnivore contact with pastoralists and livestock depredation by predators (Karani 1994). Therefore, the possibility of selective killing of the predators, hence forcing the distribution of these predators to increase with distances from settlements and cattle posts and concentrate in the CAs (Ogutu and Dublin 2002). These findings suggest that pastoralists-induced risk play a significant role in the distribution of large-sized carnivores. The others explanation why large-sized carnivores correlated with CAs is possible because of kleptoparasitism (i.e. the stealing of other carnivores' killings) among large African carnivores (Creel and Creel 1996, Mills and Gorman 1997). Consequently, carnivores like Spotted Hyena prefers following other large carnivores like Cheetah, Leopard, and Lions for an opportunity to steal their killings.

Paradoxically, the distribution of the Leopard and Aardvark (formivore), which are also large-sized carnivores, concentrated on the boundary of CGAs & CAs in both seasons, which is not consistent with (H3c). Therefore, suggesting that Leopard and Aardvark were avoiding improved visibility and pastoralists-induced risk in pastoral impacted areas (cattle posts and arable agriculture fields). Besides, they also avoided other large-sized carnivores, such as the Lion and Spotted Hyena in the CAs in both seasons. Leopard is secretive, solitary predators, which seek concealment on top of the trees (Leopard)

(Broomhall, Mills et al. 2003) to avoid their enemies such as Lions and Spotted Hyena from killing their cubs (Laurenson 1994) and stealing their killings (Caro 1994). Hence, the areas that provide vegetation cover and away from the enemies is an ideal place for the Leopard. Aardvark concentrated on the boundary of CAs and CGAs, further away from settlements, possibly because it feeds on ants, termites and beetle larvae and locusts (Kenmuir and Williams 1975). Therefore, in areas with high livestock grazing intensity, the herbaceous cover was reduced, hence less food for termites and ants, resulting in its prey population declining. Also, Aardvark is hunted for meat by the pastoralists (personal communication); hence, the possibility for illegal killings.

Though the distribution of Spotted Hyena, was associated with CAs, it was also recorded within a 10km distance from settlements, possibly because of it also scavenge on livestock carcasses and also influenced by the abundance of their potential preys, such as small to medium-sized herbivores in CGAs (see Chapter 5). The pattern of Spotted Hyena to be recorded in areas with high livestock grazing intensity is similar to the findings of a study by (Ogutu, Bhola et al. 2005). Therefore, suggesting that it is less targeted by pastoralists than Lion. A possible explanation could be that Spotted Hyena does not usually kill adult cows but small stock and calves (personal communication) and hide in burrows during the day. However, most of the time, small stock and calves do not travel long distances from the cattle posts, and they are kraaled at night, resulting in less conflict.

On the other hand, the distribution of Brown hyena was not in agreement with hypothesis (H3c), Its distribution was similar in both land uses in both seasons, yet being attracted to areas with moderate livestock grazing intensity in CGAs and avoiding pastoral impacted areas. The most likely explanation could be that Brown Hyena avoids areas exploited by Spotted Hyena because they compete for food (Mills 1990). Spotted Hyena steals and scavenges on large-sized carnivores' kills, which could otherwise benefit the Brown Hyena. Therefore, most probably Brown Hyena preferred areas with few Spotted Hyena so that it can scavenge on livestock carcasses and less resource competition from Spotted Hyena and other large-sized carnivores, implying facilitation by livestock production.

However, the distribution of large carnivores was not consistent with Maddox (2003), who reported no significant difference in large-sized carnivores (Cheetah, Lion and

Spotted Hyena) on pastoral rangelands of Maasai (Loliondo and Ngorongoro) and the reserves of Serengeti National Park, Tanzania. The most likely explanation for the difference could be that the density of carnivores (e.g. lions 0.37 km -2) and herbivores in Serengeti are higher than in Kalahari, hence their distribution in both pastoralists and conservation areas. Furthermore, there are more wild herbivores on the Massai rangelands outside the conservation areas due to seasonal migration (Maddox 2003), and possibly attracting predators. However, in the present study area, there is less wildlife migration, hence large and medium wild herbivores concentrated in CAs due to pastoral activities and competition for resources with free-ranging livestock grazing in CGAs. As a result, they are attracting the large-sized carnivores in the CAs. Human population growth, intensification of land use, sedentary cattle posts, poor livestock husbandry (Ogutu and Dublin 2004), increasing arable fields and settlements in CGAs and CAs in Kalahari, Botswana, aggravate pastoralists-carnivore conflicts.

Even though the density of potential prey (livestock) for large-sized carnivores was high in CGAs, the carnivores avoided these areas due to high the pastoralists-induced risk and less herbaceous cover. Therefore, implying that the distribution of large-sized carnivores was mainly controlled by the pastoralists-induced risk and vegetation cover than feeding resources. Pastoral activities could influence the distribution of carnivores; for example, the Maasai in Kenya responded to livestock depredation by indiscriminate killing of the suspected predators (Karani 1994, Omondi 1994). In northern Botswana, some pastoralists practised illegal killing of predators regardless of compensation schemes for livestock losses by Government (Gusset, Swarner et al. 2009).

Factors influencing the distribution of small to medium- sized carnivores

The distribution of medium-sized carnivores (African Wild Dog and Caracal) avoided pastoral impacted areas, such as high densities of cattle posts, settlements, and arable agricultures fields, but was attracted to moderate livestock grazing intensity in CGAs and CAs in the dry season, hence feeding facilitation by moderate livestock grazing. This pattern agrees with hypothesis (H3b). African Wild Dog and Caracal are potential predators for livestock (Blaum, Tietjen et al. 2009), especially small stock and calves, hence the potential conflicts with pastoralists closer to settlements and cattle posts. Consequently, Caracal and African Wild Dog avoided areas closer to settlements and cattle posts, possibly because of pastoralists control measures. For example, Blaum, Tietjen et al. 2009 reported that Black-backed Jackal and Caracal were negatively affected by farmers' predator control measures because they were perceived as potential predators. The distribution pattern for these medium carnivores is similar to a study in southern Africa (Blaum, Rossmanith et al. 2007a,c,d), who also reported that medium-sized carnivores are declining due to habitat modification and livestock grazing-induced changes.

Direct impacts of predator controls by pastoralists and indirect effects of bush encroachment (Blaum, Rossmanith et al. 2007) enhanced by livestock grazing could be responsible for the declining of medium-sized carnivores closer to settlements. African Wild dog live in pack averaging nine dogs and have a vast territory size (350 – 950 km 2). Hence food dispersion does not determine their densities and distribution (Mills and Gorman 1997). Consequently, their distribution between CGAs and CAs in the present study, because they can travel long distances for their prey.

The other possible explanation of why the African Wild Dogs avoided CAs is because there are avoiding territories with Lion and Spotted Hyena. The former is the primary causes of Wild Dog mortality, while the latter mainly compete for food with the Wild Dogs (Mills and Gorman 1997) and also kills their young ones (Creel and Creel 1996). Lions are the essential cause of Wild Dog mortality in South Africa (e.g. in Kruger National Park), accounting for natural mortality of 39% and 43% of puppies and adult individuals respectively (Van Heerden, Mills et al. 1995). Consequently, in the present study, the Wild Dogs tend to concentrate on the CGAs. Therefore, suggesting that African Wild Dogs & Caracal were avoiding larger predators in CAs and pastoralists control measures near cattle posts and settlements, hence tend to be associated with moderate livestock grazing areas. Also, in the moderately grazed areas, there was high visibility and high density of small to medium-sized herbivores (see Chapter 5), hence attracting medium-sized carnivores. However, in the CAs, there is high vegetation cover, which is not favoured by the Wild Dogs possibly because of the thick bushes and tall grasses which hinder their hunting strategy (Mills and Gorman 1997).

On the contrary, Striped Hyena was uncommon in the study area; its distribution was associated with CAs, which is not in agreement with hypothesis (H3b). Therefore, suggesting that it was rare and avoided CGAs. Striped Hyena is a scavenger (Hofer and

Mill 1998), and it inhabits a range of natural surroundings relying upon the accessibility of nourishment, and water (<10km) (Kruuk 1976). The distribution pattern of Striped Hyena is similar to the findings from a study by Alam (2011), who reported a high density of Striped Hyena being positively correlated with grass availability than tree density. Therefore, its distribution might be influenced by grass cover and large-sized predators (Lions, Leopard, Cheetah) in the CAs, as a result following more kills and incidence of carcasses (Alam 2011, Meena and Kumar 2012).

Small-sized carnivores include Black-backed Jackal, Bat-eared Fox, Honey Badger, Blandford's Fox, and African Wild Cat. However, few observations recorded for Honey Badger, Blandford's Fox and African Wildcat. The possible explanation for the few observations of the above small-sized carnivores could be that their tracks were not easily visible on the dry sandy soil. Other methods, such as night drives observations (Wallgren, Skarpe et al. 2009) could have been feasible to observe the distribution of small-sized carnivores, hence recommended for future research. Small-sized carnivores Black-backed Jackal and Bat-Eared Fox were associated with both land-uses in both seasons. However, the distribution of Black-backed Jackal and Bat-Eared Fox was also observed near the settlements during the wet season, indicating that they were not negatively impacted by moderate livestock grazing intensity and pastoral activities, hence feeding facilitation by livestock grazing. This pattern is not consistent with hypothesis (H3a), which state that the spatial distribution of small and medium-sized carnivores is expected to decrease in pastoralists-dominated areas in CGAs due to the human disturbance such pastoralists-induced risk. However, their distribution decreased with increasing livestock grazing intensity, and closer to cattle posts.

The distribution of Black-backed Jackal was not consistent with Blaum et al. 2009, who reported adverse affection of Black-backed Jackal with predator control measures, but was not significantly influenced by woody plant density (Blaum, Rossmanith et al. 2007c). However, Black-backed Jackal concentrated in CGAs even closer to the settlements and in areas with high livestock grazing intensity. Implying that most probably the pastoralists in the study areas were not using predators control measures on Jackals, hence facilitation by livestock production. The small-sized carnivores' abundance and reproduction success are linked to the availability of their prey, such as termites, insects (Maas and Macdonald 2004) and also mesopredator release (Blaum, Tietjen et al. 2009).

Bat Eared Fox was negatively associated with increasing woody plant density; a pattern also observed by (Blaum, Rossmanith et al. 2007c). Bat-eared Fox and Black-backed Jackal were associated with moderate livestock grazing intensity; a pattern like previous study (Wallgren, Skarpe et al. 2009). Therefore, implying that Bat-eared Fox and Black-backed Jackal were not negatively impacted by moderate livestock grazing during both seasons but avoided pastoral impacted areas and increasing livestock grazing intensity. As a result, Bat-eared Fox and Black-backed Jackal were weakly related to distance from cattle posts in both seasons and weakly related to grass cover and distance from settlements in the wet season. Therefore, suggesting the possibility of coexistence with moderate livestock grazing, a pattern similar to a study by (Ogutu, Bhola et al. 2005). Black-backed Jackal is a scavenger and preys on the small stock in CGAs, implying some feeding facilitation; hence these could explain its distribution closer to settlements in the wet season. However, closer to settlement, there was less to no herbaceous cover due to overgrazing by livestock. Hence no food for termites and insects, as a result negatively affecting the distribution for Bat-eared Fox, therefore suggesting resource competition closer to settlements.

According to Blaum (2009), small-sized carnivores such as Africa Wild Cat and Bat-eared Fox are positively affected by mesopredator release and increasing woody plant density (Blaum, Rossmanith et al. 2007c). Reducing the number of medium-sized carnivores, increase in the population of these small-sized carnivores (i.e. mesopredator release) (Crooks and Soulé 1999, Schmidt 2003) because of the reduction of their predators. For example, in a fragmented landscape in California, small carnivore population increased after the decrease of Coyotes, resulting in a decline in avian prey (Crooks and Soulé 1999).

Therefore, in the present study there was a decline in large and medium-sized carnivores closer the main settlements and cattle posts (see Chapter 5) due to pastoral activities, hence, facilitation of the distribution of Blandford's fox, African Wild Cat, and other small-sized carnivores. Consequently, the possibility for their population to increase in pastoralism dominated areas, as evidenced by some observations of Blandford's fox and

African Wild Cat spoor information closer to settlements and cattle posts. On the contrary, Honey Badger tends to concentrated in areas with the high herbaceous cover in CAs because that is where some of their few tracks were found than closer to settlements, therefore, indicating avoidance of livestock grazing areas and suggesting resource competition. A possible reason could be due to the reduction of Honey Badger prey availability linked to the decrease in herbaceous cover by livestock grazing.

6.4.2: Limitations

Although the observer estimated the environmental variables, hence observer –biased, the data is entirely consistent for the whole study area, and therefore, it is useful data to conclude from it. Most of the information on the distribution of the carnivores and livestock were obtained from surveys of spoor (tracks, pellets) and road-side observation; however, it was not easy to locate some small-sized carnivores' tracks on dry sandy soils. However, in the wet season, it was easy to find and identify them, therefore augmenting information from the dry season. Furthermore, the study was conducted in two dry and wet seasons, respectively, hence perfecting on the identification of small-sized carnivore's tracks. Spoor data and observations methods have been used in the past to establish the distribution of wildlife (Parris and Child 1973, Verlinden 1997, Verlinden, Perkins et al. 1998). Therefore, these methods are practical to use in determining carnivores and livestock distribution. Night drives (Wallgren, Skarpe et al. 2009, Wallgren, Skarpe et al. 2009) could have augmented the surveys of spoor, especially for small nocturnal carnivores. Nonetheless, night drives observations were not performed because of limited time and greater spatial distance of the study area.

6.5: Conclusion

The purpose of this Chapter was to determine how different carnivores interact with free-ranging livestock and pastoralists' activities such as cattle posts, arable fields, settlements, among others in CGAs and CAs. Carnivore species associated differently with pastoral activities and the distribution of free-ranging livestock, depending on their body size and the seasons. Large-sized carnivores (Lion, Spotted Hyena, and Cheetah) were associated with CAs and at greater distances from the settlements, cattle posts, and boreholes, in areas with little and without livestock grazing in both seasons. However, the distribution of Brown Hyena, Leopard and Aardvark was related to moderately grazed areas and on the boundary of CGAS/CAs in the dry and wet seasons. Furthermore, these large-sized carnivores were related to areas with high grass cover, suggesting adverse impact with livestock grazing. Brown hyena was associated with moderately grazed areas in CGA than CA in both seasons, possibly avoiding areas exploited by Spotted Hyena, other large-sized carnivores to reduce resource competition and avoiding pastoral impacted areas. The current resource partitioning ability between large-sized carnivores and livestock could suggest that there are fewer conflicts due to less human and large carnivore contact, therefore, the possibility for coexistence at a regional scale (i.e. carnivores are associated with CAs and while livestock concentrate in CGAs).

Medium-sized carnivores; African Wild Dog and Caracal were attracted to both land uses types in both seasons combined. Nonetheless, there was no significant difference in the distribution of Caracal with distance from settlements, while Wild Dog was increasing with less livestock grazing intensity. Therefore, indicating that Caracal was less sensitive to pastoral activities than Wild Dog. Overall, medium-sized carnivores avoided human-impacted areas, such as high densities of cattle posts, settlements, and arable agricultures fields, but were attracted to moderate livestock grazing intensity, hence feeding facilitation. Striped hyena was rare in the study area and concentrated in CAs, and no observations were recorded in the CGAs. Small-sized carnivores Black-backed Jackal was related to CAs, while Bat-Eared Fox was associated with both land uses. However, the distribution of Black-backed Jackal and Bat-Eared Fox were also observed near the settlements during the wet season, indicating their tolerance to moderate livestock grazing intensity and pastoral activities, hence feeding facilitation by livestock grazing. There were few observations recorded for Honey Badger, Blandford's Fox and African Wildcat suggesting that they were uncommon in the study area. However, Honey Badger and Blandford's Fox tend to be related CAs and CGAs, respectively. The most significant gradients influencing the distribution carnivores were livestock grazing intensity, pastoral activities, and food availability.

6.6: Recommendations

Woodroffe (2000) found out that there was a positive association with the decline of carnivores and human density in North America. However, Linnel et al. (2001) also showed that large-sized carnivores could coexist with high human density if management policies for both wildlife and livestock are enforced properly. For example, the Brown Bear *(Ursus arctos*) in Scandinavia (Taberlet, Swenson et al. 1995), which shows that its population is increasing because of the enforcement of policies, regardless of the high human population. Also, in Europe, Lynx (*Lynx lynx*) and Wolves (*Canis lupus lupus*) are surviving regardless of the high density of humans (Linnell, Swenson et al. 2001). Also, Tiger (*Panthera tigris*) was shown to coexist with humans inside and outside Nepal's Chitwan National Park (Carter, Shrestha et al. 2012).

Furthermore, in Kasane, Botswana, different wildlife species are coexisting with humans within the limited area (personal observations), possibly linked to the enforcement of the wildlife policy, and maybe because the local people have accepted the presence of wildlife because Kasane is a tourist area. Therefore, it is recommended that to reduce predator conflicts, the current resource partitioning ability between large predators and livestock in the present study, should be maintained by forcing the larger predators out of the cattle posts zones to reduce conflicts. Other small to medium predators, which are not causing too many conflicts can be allowed to coexist with livestock. Also, pastoralists should practice livestock management strategies, such as kraaling the domestic animals at night to reduce livestock depredation.

Despite the current Botswana government compensation schemes for livestock losses due to predation, pastoralists are still not prepared to coexist with predators (Gusset, Swarner et al. 2009), resulting into illegal killings of the predators due to livestock depredation. Consequently, there is a need for revision of the Botswana Government Compensation Policy for livestock losses. For example, some of the carnivores, such as Black-backed Jackal, Caracal, and Spotted Hyena, are not compensated for when they have killed the livestock. If the current Government of Botswana hunting ban is enforced properly, and people are educated on its benefits, the persistence of carnivores within the pastoralism rangelands might improve. Human-wildlife conflicts should be addressed to reduce costs and improve benefits (Gusset, Swarner et al. 2009) to the local community to promote the coexistence of carnivores and livestock. For example, pastoralists should be compensated for all the carnivores' killings for their livestock.

Economic incentives for tourism projects (Mworia, Kinyamario et al. 2008), can favour local communities to support the conservation of carnivores within pastoralism rangelands. Furthermore, the reduction of competition for forage resource between livestock and wild herbivores by avoiding overgrazing by livestock can maintain carnivore prey in CGAs; hence, it might minimise livestock depredation by carnivores. Consequently, there is the need for collaboration among the stakeholders (Pastoralists, Government) to identify conflicts and opportunities (Austin, Smart et al. 2011) through Adaptive Management (AM) approach (Heritage 2015). Both the stakeholders should determine carnivores and livestock management goals, develop and implement the management plans, then monitor and adjust accordingly through time (Muñoz-Erickson, Aguilar-González et al. 2007)

6.7: Implications for carnivore conservation and and livestock management

This Chapter offers some new information on the environmental factors influencing the distribution of carnivores of different body sizes between the CAs and the adjacent pastoral areas in Kalahari savanna rangelands. The increase in human population and land-use change threaten coexistence of carnivores, pastoralists and livestock (Lamprey and Reid 2004). Conservation of carnivores in pastoral areas has been a severe challenge (Treves and Karanth 2003) due to livestock depredation (Woodroffe and Ginsberg 1998). Human-carnivore conflicts in pastoral areas are due to the carnivore contact with pastoralists and livestock depredation by predators (Karani 1994). In pastoral areas, there is competition for forage resource between livestock and wild herbivores, which leads to the decrease of natural prey for carnivores (Chapter 5). Hence, leading to an increase in the persecution of carnivores because of livestock depredation (Ottichilo, De Leeuw et al. 2000). Consequently, the possibility of local extinction of carnivores (Woodroffe and Ginsberg 1998, Woodroffe and Ginsberg 2000). Given the above, it raises the fundamental questions on the possibility of coexistence between pastoral activities and a variety of carnivore species.

Therefore, research that advances knowledge on the interactions between, pastoralists, carnivores and free-ranging livestock in pastoral areas and adjacent CAs is imperative to reduce human-carnivore conflicts. However, most of the ecological research on carnivores has been conducted in CAs in areas without livestock (Graham et al. 2005, McNaughton 1990, Ogutu, Bhola et al. 2005, Anderson, Hopcraft et al. 2010, Hopcraft, Anderson et al. 2012), between CAs and human-dominated pastoral ranches (Maddox 2003, Bhola, Ogutu et al. 2012). Ironically, the distribution and interactions of carnivores and free-ranging livestock in pastoral-dominated, semi-arid, communally managed rangelands near the CAs in the Kalahari ecosystem, southern Africa are less understood. Therefore, the new findings from this study contribute towards improving our knowledge on the environmental factors influencing the distribution of many carnivores of different body sizes in communally managed pastoral areas with free-ranging livestock and adjacent CAs and well as providing insights on the possibility of coexistence between carnivores, pastoralists and free-ranging livestock. The findings from this chapter can be used to inform policymakers and livestock managers in the conservation of carnivores and livestock management in the communally managed pastoral areas to promote their coexistence.

Chapter 7

Synthesis: Pastoralists, free-ranging livestock, wildlife interactions and the possibility of co-existence

7.1: Introduction

African savannah rangelands support a diversity of wildlife, such as herbivores, carnivores, omnivores, insectivores and domestic herbivores (Homewood 2008, Craigie, Baillie et al. 2010). These wildlife and domestic herbivores have lived together and interacted positively for more than 2000 years (Homewood 2008, Fynn, Augustine et al. 2016), possibly because of traditional moderate pastoral activities (Young, Palmer et al. 2005). However, the increase in the human population, domestic herbivores, and land-use pressure threaten this co-existence (Lamprey and Reid 2004). Though pastoralism can be detrimental to wildlife (Terborgh 2002), a study by (Augustine, Veblen et al. 2011) suggests that moderate pastoral activities could benefit wildlife. Most of CAs do not contain a full range of functional resource gradients, migration corridors and seasonal habitats essential for the maintenance of the wildlife populations (Fynn and Bonyongo 2011), because forage quality and quantity is variable both spatially and temporally (Fryxell, Wilmshurst et al. 2005, Illius and O'Connor 2000, Owen-Smith and Mills 2006). For example, Nairobi National Park, Kenya, with its high rainfall form the dry season range, while the low rainfall Athi-Kaputiei plains (not protected) form the wet season ranges for large-sized herbivores (Norton – Griffiths 1977). Hence the wildlife movement between the protected areas and the pastoral areas.

Also, in the Kalahari ecosystem, the seasonal movement of the wildlife between the protected areas and the low rainfall gradients areas have been documented (Fynn and Bonyongo 2011). However, pastoral activities in the critical seasonal ranges for wildlife promotes homogeneity and fragmentation of rangelands (Fynn and Bonyongo 2011), consequently affecting the distribution of wildlife. Increase in the human population, sedentarization of pastoral activities, privatization of land, overgrazing by livestock and increase in settlements result in adverse impacts on the movement of wildlife between CAs and CGAs (Ogutu, Piepho et al. 2009, Fynn and Bonyongo 2011). Wildlife species risk local eradication due to human effects (Carter, Shrestha et al. 2012), consequently the idea that large-sized carnivores and herbivores cannot exist together with pastoralists at a local level. Subsequently, conservation models have been designed to facilitate coexistence of wildlife and pastoral activities on a different spatial scale (Western, Wright et al. 1995, Berkes 2007). For example, wildlife conservation models are premeditated to promote coexistence with pastoralism at the regional level (separating protected areas and pastoral areas) (Dudley 2008, Western, Russell et al. 2009).

However, animals that need dry and wet season habitats often move between CAs and pastoral areas (Illius and O'Connor 2000, DeFries, Hansen et al. 2007). Consequently, these animals are more vulnerable to anthropogenic activities. Nonetheless, there is also the possibility for some wildlife species coexisting with free-ranging livestock and other pastoral activities at an intermediate (community-managed areas) (Western, Wright et al. 1995, Berkes 2007) or fine level (local level) (Carter, Shrestha et al. 2012). Such information is relevant for Adaptive Management (AM) approach (Heritage 2015) to wildlife and livestock, because of the current increasing human population and pastoral activities near CA. Due to resources limitation, it is essential to establish factors that influence the distribution of multiple wildlife species between the pastoral areas and the CAS. For example, the rapid wildlife population declines due to pastoralism activities, rapid human population growth, sedentarisation of cattle posts adjacent the CAs, makes identification of factors that control the distribution of wildlife urgent (Ottichilo et al. 2000, Owen-Smith and Mills 2006, Ogutu et al. 2009, Western et al. 2009). Henceforth, to design wildlife and livestock management strategies, it is imperative to evaluate the effects of pastoral activities inside and outside the CAs to reduce the adverse impacts of pastoralism on the distribution of wildlife (Ogutu, Piepho et al. 2009).

Even though livestock and wildlife share most of the pastoral areas worldwide, there is little research on the interactions of multi wildlife species of different body sizes with livestock, pastoralists and the possibility for coexistence during different seasons in communally managed rangelands of southern African. Furthermore, few studies in southern Africa rangelands (Verlinden 1997, Wallgren, Skarpe et al. 2009) have focused on resource partitioning abilities and interactions between free-ranging livestock, pastoralists and a range of multi wildlife species(i.e. herbivore and carnivores of different body sizes) in extensive rangelands. Consequently, quantitative information on the ability for multiple wildlife species to coexist with pastoralists, free-ranging livestock at different spatial scales in southern Africa CGAs near CAs is lacking.

Therefore, this study suggests three essential characteristics that need to be evaluated to determine the possibility of co-existence between pastoralists, free-ranging livestock and wildlife in CGAs and adjacent CAs. First, how do free-ranging livestock affect the forage resource productivity and availability in the pastoral areas adjacent to the CAs? Second, what is the influence of human disturbance (i.e. pastoralists-induced risk) on the distribution of wildlife in the pastoral areas adjacent to CAs? Third, the impact of the pastoral areas adjacent to the CAs on the distribution and conservation of wild herbivores and carnivores, which are necessary for the conservation and management of wildlife in CAs. It is essential to understand how these factors influence the distribution of wildlife of different body sizes between CGAs and adjacent CAs to determine the possibility of co-existence between pastoralists, free-ranging livestock and wildlife in these areas.

Most of CAs are not sufficiently large enough to satisfy all the wildlife of different body sizes, because they do not contain a full range of functional resource gradients, migration corridors and seasonal habitats essential for the maintenance of the wildlife populations (Fynn and Bonyongo 2011). Forage quality and quantity are variable both spatially and temporally (Owen-Smith and Mills 2006). Consequently, the areas with less predation risk, and more forage quality and quantity will have high distribution and abundance of wildlife (McNaughton 1990, Anderson, Hopcraft et al. 2010). Nevertheless, intensification of anthropogenic activities in the pastoral areas adjacent to the CAs creates spatial heterogeneity in predation risk, forage quality and quantity between the CAs and the pastoral areas (Bhola, Ogutu et al. 2012). Therefore, influencing the movements of herbivores and carnivores between the CAs and CGAs in different seasons to maximise access to forage resources and reduce predation risk. However, the theory suggests that the choice of habitat depends on the body size of the wildlife because the net effects of food supply and predation risk between large and small-sized wildlife defers (Hopcraft, Anderson et al. 2012).

Wildlife in CAs areas surrounded by pastoral areas with intensive pastoral activities such as free-ranging livestock grazing, cultivation, expanding settlements is more vulnerable than the ones in CAs with little human disturbance (Bhola, Ogutu et al. 2012). Communally managed pastoral areas are fragmented and degraded, hence the possibility for restriction in seasonal movements of wildlife between CAs and CGAs. Beside CAs near pastoral areas where communities rely on bushmeat or poaching are also likely to be more vulnerable (de Leeuw, Waweru et al. 2001). Forage availability (i.e. quality and quantity) is variable both spatially and temporally (Fynn and Bonyongo 2011) between CAs and CGAs, hence the seasonal movement of the wildlife amongst the CAs and the pastoral areas during the wet and dry seasons (Bhola, Ogutu et al. 2012). Hence the potential for co-existence between pastoralists, free-ranging livestock and wildlife in CGAs and adjacent CAs. Therefore, it is essential to determine the potential for restriction of wildlife in CGAs or the potential for co-existence to design wildlife and livestock management strategies inside and outside the CAs to reduce the adverse impacts of pastoralism on the distribution of wildlife (Ogutu, Piepho et al. 2009). Therefore, based on the above views, this chapter aims to determine the possibility of co-existence between pastoralists, free-ranging livestock and wildlife in CGAs and adjacent CAs. Hence, the relationship between the availability of forage resources, the grazing patterns of wild herbivores, and how these influence the distribution of carnivores in pastoralists-dominated communally managed areas and adjacent CAs in southern Africa is evaluated. In turn, how these patterns are modified by the interactions between pastoralists and their grazing livestock.

7.1.1: Re-cap of this thesis

This study explores the relationship between the availability of food resources, the grazing patterns of wild herbivores, and how these influence the distribution of carnivores. In turn, how these patterns are modified by the interaction between pastoralists and their free-ranging livestock. In Chapter 4, I evaluated the spatial variation of forage availability (i.e. quality and quantity) and vegetation heterogeneity relative to pastoral activities disturbance gradient and land use in Kalahari rangelands. This Chapter attempts to determine how free-ranging livestock affect the forage resource productivity and availability in the pastoral areas adjacent to the CAs. Subsequently, Chapter 5 relates the distribution of forage availability and vegetation heterogeneity to the distribution of pastoral activities and wild herbivores. Chapter 5 attempts to establish the influence of human disturbance and other pastoral activities, such as livestock grazing intensity among others in the distribution of wild herbivores in pastoral areas adjacent to CAs. In turn, the influence of vegetation heterogeneity, pastoral activities and the distribution of wild herbivores (i.e. prey availability) on the distribution of carnivores is deliberated (Chapter 6). In this Chapter (7), I first discuss 1) how free-ranging livestock affect the forage resource productivity and availability along the grazing gradient in the pastoral areas adjacent to the CAs. This is followed by discussion of 2) the influence of human disturbance on the distribution of wildlife in the pastoral areas nearby CAs. This sets the basis to discuss 3) the influence of pastoral areas adjacent to the CAs on the distribution of wild herbivores and carnivores and the possibility for coexistence.

7.2: How free ranging livestock affect the forage resource productivity and availability along the grazing gradient in the pastoral areas adjacent to the CAs

In this section, I discuss the effect of livestock grazing on the forage availability with livestock grazing intensity in CGAs and CAs. Then in the later sections, I relate forage availability to the distributions of wild herbivores and carnivores. It is clear from the evidence provided in Chapter 4 that there was a difference in the spatial distribution of vegetation heterogeneity and forage availability along livestock grazing gradients and between land-use types. In Chapter 5, I show that closer to settlement and cattle posts, there was a high density of livestock compared to far from the settlements. Consequently, there was overgrazing by livestock closer (< 15km) to settlements and cattle post due to continuous livestock grazing. Therefore, the reduction of palatable and nutritious herbaceous plants over time (Mphinyane, Tacheba et al. 2008, Tefera, Dlamini et al. 2010) and were replaced by unpalatable herbaceous plants (Adler, Milchunas et al. 2005) in areas near the settlement and cattle posts (<15km). Hence, unpalatable perennial grasses and increased woody plant density/cover and the bare ground was associated with high LGI near the settlements and cattle posts in the dry season. While during the wet season, unpalatable annual grasses, forb species richness and density were related to areas with increased LGI. The variation of palatable perennial grass across land-use was because of LGI, which is in concordant with previous studies in southern Africa (Weber, Jeltsch et al. 1998, Mbatha and Ward 2010, Kgosikoma 2012) and China (Lin, Hong et al. 2010).

Therefore, suggesting that there were low forage quality and quantity in areas within a radius of 15km from the settlements. These findings are consistent with studies elsewhere (Diaz, Lavorel et al. 2007), who reported that overgrazing leads to an increase in the bare ground, promotes annual grasses and forbs (Hayes and Holl 2003). Further overgrazing also increases woody plants (Moleele and Perkins 1998) and loss of vegetation diversity and cover (Oba, Vetaas et al. 2001) and reduces species composition (Skarpe 1992). Overgrazing by livestock removes fuel load from rangelands, resulting in fewer fire frequencies (Heinl, Sliva et al. 2008, Lehmann, Prior et al. 2008); hence promoting woody plants regenerations. Besides, continuous livestock grazing removes most of the palatable perennial grasses over time and are replaced by unpalatable plants, together with annual grasses and forbs (Skarpe 1992) as compared to moderate LGI. Historically high livestock stocking rates have been distinguished as the primary source of rangeland degradation

(Heitschmidt and Taylor Jr 1991). Subsequently, the findings from Chapter 4 show that within the 15km from the settlements, there was competition for grazing resources between livestock and medium to large-sized wild herbivores.

On the contrary, in Chapter 4, I show that palatable perennial and annual grasses, grass cover, grass diversity were associated with moderate LGI far from the settlements in CGAs and within CAs in both seasons. Therefore, suggesting that forage quality was associated with moderately grazed areas far from the settlements and high forage quantity was in CAs in both seasons. This pattern agrees with several studies elsewhere, for example (Fryxell et al. 2005) who argued that repeated moderate livestock grazing increases the crude protein production of the grasses. As expected, Chapter 4, also revealed that plant species diversity (grasses, forbs) was high in moderately grazed areas in both seasons, is consistent with the previous studies. For example, Gilfedder and Kirkpatrick (1994) argued that moderate levels of disturbance are needed to conserve native plant species. Therefore, short grass, which is maintained by moderate livestock grazing in CGAs, provides forage quality. While taller grasses in CAs provide forage reserve in the dry season and during drought (Owen-Smith 2004, Hobbs, Galvin et al. 2008, Hopcraft, Olff et al. 2010). On the contrary, CAs were associated with increased herbaceous cover, tall perennial grasses, and less woody plants in both seasons. In general Chapter 4, shows that Vegetation heterogeneity (i.e. a mixture of grasses, forbs and woody plants) was associated with moderate livestock grazing and decreasing in areas with increased LGI in CGAs and CAs in both seasons.

It is clear from the evidence provided in Chapter 4, that, the spatial distribution of forage availability and vegetation heterogeneity in a landscape is not only determined by the interaction between the abiotic factors (soil quality, rainfall, fire), but also by the biotic processes. Besides livestock and wildlife grazing intensity also determine forage availability, which agrees with other studies elsewhere (Anderson, Ritchie et al. 2007a, Anderson, Ritchie et al. 2007b, Bond and Keeley 2005). Hence, forage quality and quantity varies both spatially and temporally (Ellis and Swift 1988, Illius and O'Connor 2000, Fryxell et al. 2005) along the livestock grazing gradient and land use types. Subsequently, the stability of wildlife populations depends upon being able to track this spatial and temporal variability in forage quantity and quality (Hopcraft et al. 2010, Fryxell et al. 2005, Hopcraft, Anderson et al. 2012). Therefore, restricting the seasonal movement of wildlife into the pastoral areas, that provide the nutritious grasses, can harm the productivity and sustainability of the wildlife (Fynn and Bonyongo 2011). Pastoral areas also offer improved visibility for herbivores to be able to see their predators. Nevertheless, intensification of anthropogenic activities in pastoral areas creates strong gradients of pastoralists-induced risks between the CAs and pastoral areas (Bhola, Ogutu et al. 2012). Hence, influencing the distribution of wildlife.

7.3: The influence of human disturbance, such as pastoralists-induced risk, on the distribution of wildlife in the pastoral areas adjacent to CAs

African CAs are surrounded by a rapidly growing human population and expanding settlements. Besides, changes in rainfall patterns and increasing temperatures make forage resources production for wildlife less predictable, especially during the dry periods (Bhola, Ogutu et al. 2012). Therefore, the CAs and their surrounding pastoral areas are becoming degraded and fragmented. These changes restrict the seasonal movements of wildlife because of pastoral activities and human disturbance in the pastoral areas adjacent CAs to access their traditional wet season resources (Fynn and Bonyongo 2011). Therefore, understanding the effects of human disturbance on the distribution of wildlife is essential for the conservation of wildlife. In Chapter 5 & 6, I show that the distribution of medium and large herbivores and carnivores was not associated with human-dominated areas (i.e. near cattle posts and settlements). Thus, implying displacement of medium to large herbivores, possibly partly because of pastoralists-induced risk (i.e. pastoral activities) (Chapter 5) and partly due to the competition of forage resources with livestock (Chapter 4). The conclusion agrees with studies elsewhere (Verlinden (1998), de Leeuw, Waweru et al. 2001), who reported that human disturbance restricts the spatial distribution of large-sized herbivores more than the competition for grazing resources by livestock.

On the contrary, Chapter 5 & 6 also show that small-sized wild herbivores and carnivores were associated with human-dominated areas. Hence, implying tolerance to pastoralists-induced risk, therefore, implying facilitation. This conclusion is not in agreement with studies from East African rangelands in Mara (Lamprey and Reid 2004, Bhola, Ogutu et al. 2012), Kenya's Amboseli (Western et al. 2009) and Tanzania's Tarangire-Simanjiro (Msoffe et al. 2010), who reported the decline of wildlife, irrespective of body size and feeding style, in areas with increased human population. Nevertheless, these studies are in agreement that pastoralist-induced risk restricts the seasonal movement of the medium to large-sized wildlife between CAs and the pastoral areas. Given the above, it can be concluded that human disturbance, in pastoral areas is restricting the traditional dispersal ranges of medium to large herbivores and carnivores. This conclusion is also agrees with a study by (Newmark 2008, Ogutu et al. 2009, Bhola, Ogutu et al. 2012). Other factors in pastoral areas could also be restricting the seasonal movement of wildlife. For example, livestock grazing intensity, among others, henceforth, in the next section, I discuss the influence of pastoral areas that are adjacent to CAs on the distribution and conservation of wildlife.

7.4: The influence of pastoral areas adjacent to the CAs on the distribution and conservation of wild herbivores

In this section, I use evidence provided in this study and other studies elsewhere to discuss the effect of pastoral areas that are adjacent to conservation areas on the distribution and conservation of wildlife. The CAs are a foundation of worldwide preservation efforts to protect wildlife from anthropogenic effects, such as land-use changes and habitat loss (Ceballos et al .2005, Chape, Harrison et al. 2005). Henceforth, the dominant traditional conservation paradigm assumes that pastoral areas harm wildlife. Consequently, the number of CAs in Africa has increased exponentially in recent years. However, CAs viability in wildlife conservation is in question because many are small and isolated (NeCArk 2008, Caro and Scholte 2007), and are surrounded by pastoral areas. In most cases, CAs area boundaries were not established with animal movement/dispersal in mind. Besides, CAs are often located in less productive rangelands (Scott et al. 2001), while cultivation, settlements and livestock grazing are located in fertile rangelands (Serneels et al. 2001, Thompson and Homewood 2002). Therefore, most of the time, CAs do not contain a full range of functional resource gradients, migration corridors and seasonal habitats essential for the maintenance of the wildlife populations (Fynn and Bonyongo 2011). Consequently, forage availability (i.e. quality and quantity) is variable both spatially and temporally (Chapter 4, Fynn and Bonyongo 2011) between CAs and adjacent pastoral areas, hence the seasonal movement of the wildlife between the CAs and the pastoral areas during the wet and dry seasons (Bhola, Ogutu et al. 2012).

The seasonal movements of wildlife have been documented in Kalahari rangelands across the Schwelle and Central Kalahari Game Reserve (CKGR), in Botswana (Verlinden 1997, Verlinden, Perkins et al. 1998), Etosha National Park and several other African conservation areas (Fynn and Bonyongo 2011). Similarly, Nairobi National Park in Kenya form the dry season range and the pastoral areas of Athi-Kaputiei Plains form the wet season range for wildlife migrations (Norton-Griffiths 1977). Therefore, implying that, the CAs, are often excluded from the areas that are essential for wildlife maintenance in other seasons. Low-rainfall regions often support short nutritious grasslands (Anderson, Hopcraft et al. 2010); hence, it creates the wet season range of many wild herbivores. By contrast, the high-rainfall regions and floodplains, which provide some green grazing in the dry season, forms the dry season ranges (Fynn and Bonyongo 2011). Similarly, moderate livestock grazing in the pastoral areas adjacent the CAs keeps the grass short and actively growing; hence, providing high quality and digestible forage (Owen-Smith and Mills 2008, Fynn and Bonyongo 2011) to wild herbivores during the wet season. On the contrary, CAs provide mostly the dry season forage resources (Fynn and Bonyongo 2010).

Therefore, wildlife needs to move between these low-rainfall and high rainfall regions, or between pastoral areas and CAs to maximise forage quality and quantity, depending on the season. The seasonal movement of the wildlife from CAs into the pastoral areas in the wet season and back into the CAs during the dry season have been documented, for example (Bhola, Ogutu et al. 2012), hence facilitation by moderate livestock grazing. Nevertheless, moderate livestock grazing is not always a guarantee in the pastoral areas, especially in pastoral areas supporting free-ranging livestock as shown by the findings from this study (Chapter 4). Overgrazing by livestock restrict the distribution of wild herbivores and the carnivores in CGAs.

In Chapter 4, I show that there was over-grazing by livestock within a radius of 15 km, implying competition for forage resources with wild herbivores. Hence, the displacement of medium to large herbivores within the 15km radius from the settlements. However, areas with moderately LGI attracted small to medium herbivores in both seasons; hence, indicating facilitation. This pattern is partly consistent with a study in East Africa by (Bhola, Ogutu et al. 2012), who reported that small and medium herbivores, for example, Thomson’s gazelle, impala, were associated with moderately grazed areas in the ranches than the protected areas. Therefore, suggesting that small to medium herbivores preferred short grass areas maintained by livestock grazing in the ranches (Fryxell 1991, Illius and Gordon 1992). Besides, small to medium herbivores preferred moderately grazed areas because in the wet season in the CAs, grasses are tall, hence the risk for predation risk because predators hide in the tall grasses (Hopcraft, Sinclair et al. 2005). Besides, medium to large carnivores are displaced from the CGAs because of the improved visibility due to livestock grazing (Chapter 4, Hopcraft, Anderson et al. 2012) and also due to pastoralists-induced risks, as shown in Chapter 5.

The difference between livestock grazing in the ranches and CGAs is that in the ranches livestock grazing is controlled, hence moderate grazing (Bhola, Ogutu et al. 2012). However, in the later, it is not controlled, resulting in overgrazing in areas closer to the settlements and cattle posts (Chapter 4). Hence negative interactions with wild herbivores between wildlife and livestock in CGAs, especially closer to the settlements and cattle posts. Therefore, it can be concluded that the seasonal variation in forage quality, quantity, pastoralists-induced risk and predation between CGAs and CAs directly regulate the distribution of wildlife differently depending on their body sizes and feeding guild (Chapter 4, 5 & 6). These findings are consistent with studies elsewhere (Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012).

Therefore, exclusion of pastoral areas from the CAs or the home ranges of the wild herbivores have a negative impact on the productivity and sustainability of the wildlife (Bolger et al. 2008, Hopcraft, Olff et al. 2010, Fynn and Bonyongo 2011), because they provide the nutritious grasses and improved visibility during the wet season. Nevertheless, human population densities, settlements and livestock grazing pressure in the pastoral areas adjacent to CAs have increased (Ogutu et al. 2009), therefore, restricting the seasonal wildlife movements outside the CAs. Hence, raising fundamental questions about the possibility for co-existence between pastoralists, free-ranging livestock, and herbivores during different seasons. Based on the above view, the following can be concluded on the possibility of co-existence between pastoralists, free-ranging livestock and wildlife in Kalahari rangelands.

Evidence from Chapter 5 reveals that there is the possibility for large-sized wild herbivores, pastoralists, and free-ranging livestock to coexist at a regional scale or resource partitioning (i.e. pastoralists and free-ranging livestock remaining in CGAs while large-sized herbivores concentrating in CAs in both seasons) due to pastoralists-induced risk and competition for grazing resources with livestock in CGAs as reflected in Chapter 4. Hence, there is no coexistence of large-sized herbivores, free-ranging livestock and pastoralists' activities in CGAs at the intermediate and local levels in both seasons. These findings are explained by the fact that large-sized herbivores require bulk forage and there are less susceptible to predation (Sinclair, Mduma et al. 2003, Hopcraft, Olff et al. 2010, Hopcraft et al. 2012); hence, they are associated with CAs. The findings from Chapter 4 show that the forage quantity was high in CAs and low in CGAs in both seasons. Nevertheless, large herbivores are negatively affected by the pastoralists-induced risk in pastoral areas; hence, they are also not associated with human-dominated areas in CGAs.

In Chapter 5, I show that medium-sized herbivores co-existed with pastoralists and free-ranging livestock on the CGAs/CAs boundary. Therefore, indicating an attraction to moderate LGI and avoiding highly human-impacted areas near the settlements in both seasons, which is partly in agreement studies by (Bhola, Ogutu et al. 2012, Hopcraft, Anderson et al. 2012). Medium-sized herbivores avoided pastoralists dominated areas in CGAs, most likely because of the pastoralists-induced risk and competition for forage resources by livestock (Chapter 4). Within 15km distance from the settlements, Chapter 4 shows that there was reduced herbaceous cover and increased woody plants, therefore reflecting low forage quality and quantity. Medium herbivores prefer high forage quality (Fryxell 1991, Illius and Gordon 1992), which is found in moderately grazed areas by livestock (Bhola et al. 2012). These findings are in agreement with several studies elsewhere, for example (Fryxell et al. 2005), who argued that repeated grazing increases the crude protein production of grasses. Hence, medium herbivore can extract high energy from selecting high-quality forage from moderately grazed areas.

Contrary to the distribution of medium to large herbivores, Chapter 5 revealed that the small-sized wild herbivores and Ostrich co-existed with pastoralists activities and free-ranging livestock in intermediate and fine-scale (pastoral dominated areas) in both seasons, even closer to settlements and cattle posts, hence feeding facilitation. The small-sized herbivores concentrated in pastoralists dominated areas because of the reduced predation and improved visibility in CGAs. The CAs have tall grasses that conceal predators and helps them in catching their prey (Hopcraft et al. 2005). Besides, small herbivores are benefiting from selecting high-quality short grasses due to repeated livestock grazing (Fryxell et al. 2005). Nonetheless, small herbivores were not significantly affected by the pastoralists-induce risk, suggesting co-existence.

7.5: The influence of pastoral areas adjacent to the CAs on the distribution and conservation of carnivores

In Chapter 6, I show that large-sized carnivores concentrated in the CAs in both seasons, while the medium-sized carnivores were associated with both the CAs and CGAs/CAs boundary. On the contrary, small-sized carnivores were not negatively affected by LGI and pastoralists activities. Hence they have associated with CGAs in both the moderately grazed and pastoralists dominated areas. Therefore, suggesting that pastoral areas adjacent to the CAs have both the negative and positive influences on the distribution and conservation of carnivores. The distribution pattern of large carnivores; Lion, Spotted Hyena, and Cheetah is similar to studies in Masai Mara National Reserve by (Karani 1994, Reid, Rainy et al. 2003). Large carnivores' movements are being influenced by spatial resource heterogeneity between CAs and pastoral areas. Hence, large carnivores favour CAs because of high vegetation cover, which they hide in and helps them in catching their prey (Hopcraft et al. 2005). Large carnivores avoided pastoral areas, most probably because of conflicts with pastoralists (Ogutu, Bhola et al. 2005) and also because there are following the abundant resident medium to large-sized herbivores in the CAs (Ogutu and Dublin 2002, Ogutu and Dublin 2004) than in CGAs, as I have shown in Chapter 5.

Large-sized carnivores are the primary predators of livestock, hence the conflict with pastoralists (Chapter 6). Human-carnivore conflicts in CGAs are mainly due to the carnivore contact with pastoralists and livestock depredation by predators (Karani 1994). Consequently, the possibility of selective killing of the large predators, hence, their displacement from the CGAs and concentrating in the CAs (Ogutu and Dublin 2002). Thus, it can be concluded that pastoralists-induced risk plays a significant role in the distribution of large-sized carnivores. Besides, other carnivores like Spotted Hyena prefers following other large carnivores like Cheetah, Leopard, and Lions for an opportunity to steal their killings (Creel and Creel 1996, Mills and Gorman 1997). Nevertheless, Chapter 6 also show that the distribution of the large carnivores; Leopard and Aardvark concentrated on the boundary of CGAs & CAs in both seasons, which was not expected. The possible explanation could be that there are avoiding improved visibility and pastoralists-induced risk in pastoral impacted areas but at the same time avoiding other large-sized carnivores, such as the Lion and Spotted Hyena in the CAs (Laurenson 1994, Caro 1994). However, the distribution of large carnivores was not consistent with Maddox (2003), who reported no significant difference in large-sized carnivores (Cheetah, Lion and Spotted Hyena) on pastoral rangelands of Maasai (Loliondo and Ngorongoro) and the reserves of Serengeti National Park, Tanzania.

The distribution of medium-sized carnivores; African Wild Dog and Caracal were associated with moderately grazed areas, while small carnivores were not negatively affected by LGI and pastoralists activities. Direct impacts of predator controls by pastoralists and indirect effects of bush encroachment (Blaum, Rossmanith et al. 2007) enhanced by livestock grazing could be responsible for the displacement of medium-sized carnivores closer to settlements. Besides, medium carnivores are also avoiding large carnivores in CAs because of competition for food and killing their young ones (Mills and Gorman 1997, Creel and Creel 1996). On the other hand, the distribution of small carnivores in areas of increased LGI and near the settlements and cattle posts was surprising. The distribution of small-sized carnivores was not consistent with Blaum et al. 2009, who reported adverse affection of small carnivores (e.g. Black-backed Jackal) with predator control measures. Therefore, it can be concluded that pastoral areas facilitate the distribution of small-sized carnivores, possible because of the effects of mesopredator release (i.e. the displacement of medium to large carnivores from pastoral regions) and increasing woody plant density, which they prefer (Blaum, Rossmanith et al. 2007c). After factoring the effects of free-ranging livestock on forage resources availability, the influence of human disturbance and the impact of pastoral areas on the distribution of wild herbivores and carnivores the following can be concluded on the possibility of co-existence between pastoralists, free-ranging livestock and carnivores in Kalahari rangelands.

Based on the above views from the literature and findings Chapter 6, it can be concluded that there is the possibility for carnivores to co-exist differently with pastoralists, free-ranging livestock at different scales. It is not possible for large-sized carnivores to co-existence with free-ranging livestock and pastoralists activities in CGAs in both seasons because of the reduced vegetation cover by livestock grazing (Hopcraft et al. 2005), reduced prey availability and pastoralists-induced risk (de Leeuw, Waweru et al. 2001). Nonetheless, there a possibility for the medium-sized carnivores to co-exist at both the regional (CAs) and intermediate (CGAs/CAs boundary) level with pastoralists and free-ranging livestock, as shown by Chapter 6. Hence, suggesting resource competition in pastoral dominated areas and facilitation in moderately grazed areas. On the contrary, the small-sized carnivores displayed co-existence with pastoralists and free-ranging livestock at both intermediate (moderately grazed) and fine-scale (pastoralists dominated areas). The next section, I discuss the implication of this study for wildlife conservation and management.

7.6: Results implications and recommendations on free-ranging livestock and wildlife management

This study offers some insights and new understandings on how pastoralists, free-ranging livestock and different wildlife species interact in CGAs surrounding CAs and the possibility for co-existence both the wet and dry seasons. There is the belief that pastoral activities in areas surrounding conservation areas, threaten the survival of wild animals which depend on seasonal movements (Bolger, NeCArk et al. 2008, NeCArk 2008). As a result, pastoral activities can compel wildlife from exploring their seasonal rangelands outside the conservation areas (Bhola, Ogutu et al. 2012). However, the present study and other studies from Kenya, for example by (Augustine, Veblen et al. 2011) have demonstrated that in the exception of the pastoralists-induced risk resulting from pastoral activities, moderate livestock grazing could benefit small to medium wildlife species. However, continuous livestock grazing could result in overgrazing, and leading to competition for resources with medium to large-sized wildlife, especially in the dry season when resources are limiting. On the other hand, there is grazing facilitation between livestock and small wildlife species. Most conservation areas do not fulfil the needs of mobile wildlife that search for spatial and temporal variability in forage resource (Harris, Thirgood et al. 2009, Craigie, Baillie et al. 2010, Fynn and Bonyongo 2011). Consequently, the seasonal wildlife movement outside the CAs into the pastoral areas for wet season grazing resources.

Therefore, research that enhances our understandings on how wildlife and pastoralists' interact is vital to reduce human-wildlife conflicts and improves conservation of wildlife and management of livestock. Thus, this study has further revealed information on the interaction between different wildlife species, pastoralists, free-ranging livestock and the possibility of coexistence at various scales. Henceforth, the results from this study could be used to provide baseline information to the design of wildlife and livestock management strategies in the Kalahari rangelands of Botswana and other similar savannah rangelands in African. Consequently, both stakeholders (Pastoralists, Governments) could use these findings to design, develop, implement wildlife and free-ranging livestock management plans, monitor and adjust accordingly through time

(Muñoz-Erickson, Aguilar-González et al. 2007). Similar studies could be repeated at different intervals to measure the after-effects of the management plans.

Given this new information on the pastoralists, free-ranging livestock and wildlife interactions from this study area, the following recommendations are suggested to improve the interactions in Kalahari savannah rangelands. The findings from this thesis indicate that the pastoralists-induced risk (such as illegal hunting), pastoral activities and competition for grazing resources by livestock, are significantly contributing to the spatial distribution of wildlife. Henceforth, there is a need for a coordinated effort between government, pastoralists and other stakeholders to tackle illegal activities such as hunting of wildlife and improve incentives for pastoralists to participate in wildlife conservation in CGA. To attain effective collaborative management it is imperative for the government to communicate, give feedback and negotiate with stakeholders (mainly the pastoralists) rather than to supply them with information (Prager, Reed et al. 2012). Consequently, the collaboration between the stakeholders can help to identify conflicts and opportunities to improve the interactions between pastoralists, livestock and wildlife. Stakeholder participation is essential to determine, quantify perceptions and preferences (Austin, Smart et al. 2014) for everyone who is involved in livestock and wildlife management.

The current wildlife hunting ban in Botswana revealed an open door for diversifying profits from Community Based Natural Resource Management (CBNRM) projects because they depended on legal hunting of wildlife. Consequently, the current hunting wildlife hunting ban has reduced the economic incentives to the local community. Therefore, it is vital to find other ways of improving incentives to the local community without depending on legal hunting of wildlife, for them to participate in wildlife conservation. Human-wildlife conflicts should be addressed to reduce costs and improve benefits (Gusset, Swarner et al. 2009) to the local community to promote the coexistence of carnivores and livestock. Examples of benefits from the presence of carnivores could be economic incentives for tourism projects (Mworia, Kinyamario et al. 2008), to favour local communities to support the conservation of carnivores within CGAs. Furthermore, the Botswana Government Compensation Scheme for livestock losses due to depredation should be revised, for example, to incorporate most of the predators, such as Black-backed Jackal, Caracal, and Spotted Hyena, which are not currently compensated for when they have killed the livestock.

Pastoral activities should be prevented from encroaching the CAs because the uncontrolled movement of free-ranging livestock and other pastoral activities into the CAs can threaten medium to large-sized wildlife. Therefore, the location of settlements, cattle posts and boreholes in CAs and closer to the CGA/CA boundaries should be discouraged. The number of livestock in the small settlements in the CAs should be controlled to avoid overgrazing near these settlements. Livestock in CGAs should be managed strategically to improve livestock husbandry (Ogada, Woodroffe et al. 2003, Fynn, Augustine et al. 2016) to reduce overgrazing, and promote moderate livestock grazing. The numbers of livestock at each watering points closer to the main settlements should be regulated to minimize overgrazing within 15km from the settlements, through the reticulation of water to the less utilized areas where there is no access to drinking water for livestock in CGAs. Consequently, facilitating the spread of livestock grazing intensity over a larger area, to promote moderate grazing.

Furthermore, in collaboration with pastoralists, the government should regulate the number of livestock in CGAs to a manageable carrying capacity through incentives, to reduce overgrazing. Thus, promoting herbaceous heterogeneity and maintaining short-high quality grasses in the wet season. Hence promoting less competition, and facilitation for forage resource between small to medium-sized herbivores and livestock. If possible, livestock grazing concessions within non-sensitive parts of the CAs could be used as an incentive to the pastoralists (Fynn, Augustine et al. 2016). Through allowing livestock grazing in CAs at a particular time of the year to reduce high grass biomass in CAs and rangeland recovery in The CGAs. However, grazing concessions in CAs are complicated because they would need collaboration from many stakeholders (for example, ecologists, wildlife Officers, pastoralists, and government). Excessive uncontrolled livestock grazing in CAs would adversely affect the distribution of medium to large-sized wildlife (Coppolillo, Kashaija et al. 2004), hence monitoring and evaluation by all stakeholders is essential.

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Appendices

Appendix 3A: Examples of data collection in pictures

A: Researcher in a meeting, introducing the project to the communities in the study area

B: GL300 GPS telemetry in a plastic container being fitted on the cow

B: Example of artificial boreholes and hand dug wells in a calcrete pans for watering livestock

C: Data collection in CAs, on the boundary and in CGAS amid the dry season

D: Examples of wildlife spoor data (pellets & tracks)

Appendix 4A: Desirability, life forms, habitat and ecological status of grass species (Oudtshoom 2002). P = Perennial, A = annual, WP = weak perennial. Desirability is based on livestock preference as determined by (Trollope et al., 1989; du Plessis et al., 1998), Decreaser are grass species that tend to decrease when overgrazed, while increaser are species that increase when under or over utised.

Scientific name	**Common name**	**Desirability**	**Life form**	**Habitat**	**Ecological status**
Stipagrostis uniplumis(Lincht)	Silky Bushman grass	Medium	P	Important sand veld grass	Decreaser
Melinis repens (Willd)	Natal red top	Medium	WP	Disturbed, undisturbed places	Decreaser
Schmidtia pappophoroides (Steud)	Sand quick	High	P	Drought & grazing resistant	Decreaser
Aristida meridionalis (Stapf)	Gaint three-awn	Medium	P	Good veld condition	Decreaser
Panicum coloratum L.	Small buffalo grass	High	P	Good veld condition	Decreaser
Dactyloctenium giganteum B.S.	Giant crowfoot	High	A	Good veld condition	Decreaser
Panicum maximum(Jacq)	Guinea grass	High	P	Good veld condition	Decreaser
Centropodia glauca (Nees)	Gha grass	High	P	Good veld condition	Decreaser
Cenchrus ciliaris L.	Foxtail Buffalo grass	High	P	Good veld condition	Decreaser
Brachiaria nigropedata (Munro)	Black-footed grass	High	P	Good veld condition	Decreaser
Digitaria eriantha (Steud)	Common finger grass	High	P	Good veld condition	Decreaser
Anthephora pubescens (Nees)	Wool grass	High	P	Good veld condition	Decreaser
Tricholaena monachne (Trin)	Blue-seed grass	Medium	P	indicator to disturbance	Increaser
Aristida congesta (Roem & Schult)	Tassel three-awn	Low	WP	indicator to overgrazing	Increaser
Aristida stipitata (Hack)	Long-awned grass	Low	WP	indicator to overgrazing	Increaser
Brachiaria marlothii (Hack)	creeping grass	High	WP	indicator to overgrazing	Increaser
Enneapogon cenchroides (Lincht)	Nine-awned grass	Low	A	indicator to overgrazing	Increaser
Digitaria sanguinalis L.	Crab finger grass	Low	A	indicator to overgrazing	Increaser
Eragrostis biflora (Hack*)*	Shade Eragrostis	Medium	A	indicator to overgrazing	Increaser
Schmidtia kalihariensis (Stent)	Kalahari sour grass	Medium	A	indicator to overgrazing	Increaser
Seteria verticillata (L.)	Bur Bristle grass	High	A	indicator to overgrazing	Increaser
Tragus barteronianus (Schult)	Carrot-seed grass	Low	A	indicator to overgrazing	Increaser
Urochloa trichopus (Hochst)	Bushveld Signal grass	Medium	A	indicator to overgrazing	Increaser
Perotis petens (Gand)	Cat's tail	Low	A	indicator to overgrazing	Increaser

Eragrostis lehmannian (Nees)	Lehmann's love grass	High	P	indicator to overgrazing	Increaser
Pogonathria squarrosa (Roem & Schult)	Herringbone grass	Low	P	indicator to overgrazing	Increaser
Eragrostis pallens (Hack)	Broom love grass	Low	P	Good veld condition	Decreaser
Triraphis purpurea (Hack)	Red honey grass	Low	A	Disturbed area	Increaser
Dactyloctenium aegyptium L.	Common crowfoot	High	A	Disturbed area	Increaser

Appendix 4B: Explained variance, variable inflation factors, cumulative and individual variances (%)of grass species distribution data during the dry (A) and wet (B) seasons in northern Kalahari, Botswana.

A) dry season

Variables	Variance inflation factor	F-value	P-Value	Cumulative variance (%)	Individual variance (%)
Grass height	3.0863	8.651	0.002	18.59	18.59
Unpalatable perennial	1.3666	6.16	0.002	31.05	12.46
Palatable annual	1.2667	6.275	0.002	43.05	12.00
Grass diversity	4.4956	4.672	0.002	51.66	8.61
Habitat type	2.3175	4.439	0.002	59.49	7.83
Distance from settlements	2.6036	4.983	0.002	67.84	8.35
Unpalatable annual	1.1109	4.115	0.002	74.56	6.72
Land use	2.7164	3.479	0.002	80.04	5.48
Annual rainfall	1.6913	2.715	0.002	84.21	4.17
Palatable perennial	3.2245	2.56	0.004	88.06	3.85

B) Wet season

Variables	Variance inflation factor	F-value	P-Value	Cumulative variance (%)	Individual variance (%)
Palatable annual	7.7701	19.428	0.002	34.00	34.00
Unpalatable perennial	1.1436	7.633	0.002	46.41	12.41
Unpalatable annual	1.1445	5.025	0.002	65.23	18.82
Palatable perennial	3.767	7.669	0.002	67.18	1.95
Livestock grazing intensity	7.2631	4.816	0.002	71.90	4.72
Distance from settlements	3.1918	2.924	0.002	75.85	3.95
Distance from cattle posts	7.6228	2.985	0.014	79.49	3.64
Grass cover	2.6703	2.015	0.028	82.77	3.28
Land use	6.3935	2.216	0.042	85.23	2.46

Appendix 4C: Names for Forb species recorded in the study area in both seasons. Life cycle: P = Perennial, A = annual

No	Scientific name	Acronym	Life cycle	English name
1	*Acanthosicyos naudinianus* (Sond)	Acna	P	
2	*Acrotome inflata* (Benth)	Acin	A	tumbleweed
3	*Aptosimum decumbens* (Schinz)	Apde	P	
4	*Athrixia elata* (Sond)	Atel	P	Wild tea
5	*Tephrosia purpurea* (L.)	Tepu	P	Silver tephrosia
6	*Bulbostylis hispidula (*Vahl.)	Buhi	P	
7	*Chamaecrista mimosoides (*L.)	Chmi	P	Gold flower
8	*Chamaesyce protrata (*Ait)	Chpr	A	
9	*Commelina benghalensis* L.	Cobe	P	African Commelina
10	*Crotalaria sphaerocarpa* (Perr.)	Crsp	A	Crotolaria
11	*Cucumis africanus* (L.F.)	Cuaf	A	wild cucumber
12	*Cyamopsis serrata* (DC.)	Cyse	A	
13	*Dicoma capensis* (Less)	Dica	P	Fever bush
14	*Evolvulus alsinoides* (L.)	Eval	P	Blue haze
15	*Geigeria burkei (*Harv.)	Gebu	A	
16	*Gisekia pharnacoides* (L.)	*Giph*	*P*	Old maid
17	*Gisekia africana (*Lour)	*Giaf*	*P*	Gisekia
18	*Harpagophytum procumbens (*Burch)	Hapr	P	Devil's claw
19	*Helichrysum argyrosphaerum* (DC.)	Hear	A	Everlasting weed
20	*Hellotropium ciliatum (*Kaplan)	Heci	P	white head
21	*Hermbstaedtia fleckii (*Schinz)	Hefl	P	
22	*Indigofera alternans* (DC.)	Inal	P	
23	*Indigofera flavicans* (Baker)	Infl	P	
24	*Ipomoea hackeliana* (Schinz)	Ipha	P	

25	*Ipomoea magusiana* (Schinz)	Ipma	P	
26	*Ocimum americanum* (L.)	Ocam	P	African basil
27	*Limeum fenestratum* (Fenzl)	Life	A	Window weed
28	*Macrotyloma axillare (*E. Mey*)*	Maax	P	Archer axillaris
29	*Malhania prostrata* (DC.)	Mapr	P	
30	*Asparagus nelsii* (Schinz)	Asne	P	Monteiro vine
31	*Talinum crispatulum* (Dinter)	Tacr	P	Wild vygie
32	*Oxygonum alatum* (Burch)	Oxal	A	Bushman's salt
33	*Sida cordifolia* L.	Sico	P	Heartleaf sida
34	*Pergularia daemia* (Forssk)	Peda	P	Heart-leaf twiner
35	*Phylanthus angolensis* (Mull. Arg)	Phan	A	
36	*Pollichia campestris* (Aiton)	Poca	P	Barley sugar bush
37	*Pupalia lappacea* (L.)	Pula	P	
38	*Requienia sphaerosperma* DC.	Resp	P	
39	*Senna italica* (Mill.)	Seit	P	Wild senna
40	*Sesamum triphyllum* (Welw)	Setr	P	wild sesame
41	*Sida chrysantha* Ulbr.	Sich	P	
42	*Solanum elaeagnifolium* Cav.	Soel	P	Silver bitter apple
43	*Solanum supinum* (Dunal)	Sosu	P	Poison apple
44	*Senecio consanquineus* (DC.)	Seco	P	
45	*Striga gesneriodes* (Wild.)	Stge	A	Purple witch weed
46	*Tribulus terrestris* L.	Trte	A	Devil's thorn
47	*Xenostegia tridentata* (L.)	Xetr	P	Merremia
48	*Pavonia burchellii* (DC.)	Pabu	P	Dainty pavonia
49	*Citrullus lanatus* (Thunb)	Cila	A	Desert melon
50	*Gnidia capitata* (L.F.)	Gnca	P	Curry flower
51	*Indigofera daleioides* (Harv)	Inda	P	

Appendix 4E: Woody plant species composition, ecological status recorded in the study area and their association with livestock grazing intensity (LGI).

	Scientific name	English name	Setswana name	**Associated with high LGI**	Bush encroacher
1	*Rhigozum brevispinosum* (Kuntze)	Western rhigozum	Mofurokwane	**X**	Yes
2	*Vachellia haematoxylon (*Willd*)*	Grey camel thorn	Mokholo		No
3	*Vachellia luederitzii* (Engl.)	Kalahari sand thorn	Mokgwelekgwele		No
4	*Boscia albitrunca* (Burch)	Shepherds' tree	Motlopi		No
5	*Cadaba termitaria* (N.E. Br)	Pink Cadaba	Makgolela	**X**	No
6	*Diospyros lysioides* (Desf.)	Red star-apple	Letlhajwa	**X**	No
7	*Ehretia rigida* (Thunb)	Puzzle bush	Morobe	**X**	No
8	*Grewia retinervis* (Burret)	False sand papper raisin	Motsutsujane		No
9	*Lycium bosciifolium* (Schinz)	Limpopo honey-thorn			No
10	*Rhus tenuinervis* (Engl)	Kalahari karee	Modupaphiri		No
11	*Terminalia sericea* (Burch)	Silver cluster-leaf	Mogonono	**X**	No
12	*Senegalia fleckii* (Schinz)	Blade thorn	Mohahu	**X**	No
13	*Asparagus nelsii* (Schinz)	Asparagus Fern	Mohalatsa maru	**X**	No
14	*Kleinia longiflora* (DC.)	Paintbrush flower	Mosimama		No
15	*Lonchocarpus nelsii* (Schinz)	Kalahari apple-leaf	Mhatana		No
16	*Bauhinia petersiana* (Bolle)	White bauhinia	Mochancha		No
17	*Vachellia hebeclada (*DC.)	Candle thorn	Sekhi	**X**	Yes
18	*Vachellia erioloba (*E. Mey*)*	Camel thorn	Mogotlho		Yes
19	*Vachellia karroo* (Hayne*)*	White thorn	Mokha	**X**	Yes
20	*Senegalia mellifera* (Vahl)	Wait a bit thorn	Mongana	**X**	Yes
21	*Dichrostachys cinerea* (L.)	Sickle bush	Moselesele		Yes
22	*Grewia flava* (DC.)	Wild plum	Moretwa	**X**	Yes
23	*Ziziphus mucronata* (Willd)	Buffalo thorn	Mokgalo	**X**	Yes

Appendix 5A: Species, type of feeder and life body weight (kg) (>1kg) and IUCN (3.1) conservation status of wild herbivores & livestock in northern Kalahari, Botswana. G= prefer grazing, B=prefer browsing, M=mixed feeder, OM = omnivore, LC = least concern, DOM = domesticated.

English name	**Local name**	**General key track**	**Scientific name**	**Feeder type**	**Life weight**	**Status IUCN 3.1**
Common eland	Phofu	Cloven hooves large	*Tragelaphus oryx* (Pallas)	B (M)	680 - 720	LC
Oryx (Gemsbok)	Kukama	Cloven hooves large	*Oryx gazella* (Linnaeus)	G	180 – 240	LC
Red Hartebeest	Khama	Cloven hooves large	*Alcelaphus bucelaphus* (Hilaire)	G	120 - 150	LC
Blue Wildebeest	Kgokong	Cloven hooves large	*Connochaetes taurinus* (Burchell)	G	190 - 260	LC
Greater Kudu	Tholo	Cloven hooves medium	*Tragelaphus strepsiceros* (Pallas)	B	120 – 270	LC
Springbok	Tshephe	Cloven hooves medium	*Antidorcas marsupialis* (Zimmermann)	M	27 - 42	LC
Common Warthog	Mathenthenyane	Cloven hooves medium	*Phacochoerus africanus* (Gmelin)	OM/G	45 – 150	LC
Common Duiker	Phuti	Cloven hooves small	*Sylvicapra grimmea* (Linnaeus)	B	12 - 25	LC
Steenbok	Phuduhudu	Cloven hooves small	*Raphicerus campestris* (Thunberg)	B (M)	11 – 13	LC
Savanna hare	Mmutla	cluster of paws	*Lepus microtis* (Heuglin)	M	1.5 - 3	LC
Cape Porcupine	Noko	Paws with claws	*Hystrix africaeaustralis*	B	5 - 27	LC
Springhare	Ntlole	Three-toed	*Pedetes capensis* (Llliger)	B	2.7 – 3.65	LC

Common Ostrich	Ntshe	Two toes forward	*Struthio camelus* (Linnaeus)	M	70 – 90	LC
Livestock						
Cattle	Kgomo	Cloven hooves large	*Bos taurus* (Linnaeus)	G/B	272 - 454	DOM
Sheep/goats	Podi/Nku	Cloven hooves medium	*Ovis aries/Capra aegagrus hircus* (Linnaeus)	G/B	20 - 100	DOM
Donkey	Tonki	Non-cloven hooves	*Equus asinus* (Linnaeus)	G	80 – 480	DOM
Horse	Pitsi	Non-cloven hooves	*Equus caballus* (Linnaeus)	G	380 - 550	DOM

Appendix 5B: Wild herbivores and livestock species composition observations (tracks and pellets) along five transects and land use in dry (August - October 2014 & 2015) and wet (March - May 2015 & 2016) seasons, in northern Kalahari, Botswana. Lehututu/Hukuntsi (T1), Hukuntsi/Zutshwa (T2), Lokgwabe/Mabuasehube (T3), Tshane/Kang (T4) and Hukuntsi/Ngwatle (T5) transects, Communal Grazing Area (CGA) and Wildlife Management Area (CA). Animals' tracks and pellets present (P) or absent (A) during the dry (D), wet (W), and dry and wet DW) seasons

English name	**T1***	**T2***	**T3***	**T4***	**T5***	**CGA***	**CA***
Wildlife							
Common eland	NO	DW	DW	D	D	P	P
Oryx (Gemsbok)	NO	NO	DW	DW	DW	P	P
Red Hartebeest	DW	DW	DW	DW	DW	P	P
Blue Wildebeest	DW	DW	DW	DW	DW	P	P
Greater Kudu	DW	DW	DW	DW	DW	P	P
Springbok	DW	DW	DW	DW	DW	P	P
Common Warthog	D	W	DW	D	W	P	P
Common Duiker	DW	DW	DW	DW	DW	P	P
Steenbok	DW	DW	DW	DW	DW	P	P
Savanna hare	DW	DW	DW	DW	DW	P	P
Springhare	DW	DW	DW	DW	DW	P	P
Common Ostrich	DW	DW	DW	DW	DW	P	P
Livestock							
Cattle	DW	DW	DW	DW	DW	P	P
Sheep & goats	DW	DW	DW	DW	DW	P	P
Donkey	DW	DW	DW	DW	DW	P	P
Horse	DW	DW	DW	DW	DW	P	P

Appendix 5C: Wild herbivores and livestock frequencies (%) of appearance from a total of 90 sample plots during the dry and wet seasons within different Land uses (CGAs and CAs), use in northern Kalahari, Botswana. The following classifications were used; Rare (0 to 20%), Medium (20 to 40%), Frequent (40 to 60%) and Very frequent (>60%). Frequency of appearance per land use was calculated as the total observations of the species in that land use out of the total number of sample plots in that respective land use.

	Overall/Season		**Land use**			
			Dry season		**Wet season**	
Name	**Dry**	**Wet**	**CGAs**	**CAs**	**CGAs**	**CAs**
Common eland	**16.7**	**14.4**	1.6	48.3	3.3	37.9
Oryx (Gemsbok)	22.2	18.9	6.6	55.2	9.8	37.9
Red Hartebeest	72.2	73.3	59	100	60.7	100
Blue Wildebeest	14.4	26.7	6.6	31	9.8	62.1
Greater Kudu	44.4	32.2	39.3	55.2	27.9	41.4
Springbok	25.6	24.4	24.6	27.6	16.4	41.4
Common Warthog	**16.7**	**11.1**	6.6	37.9	3.3	27.6
Common Duiker	100	100	100	100	100	100
Steenbok	100	100	100	100	100	100
Common Ostrich	68.9	52.2	70.5	65.5	52.5	51.7
Livestock						
Cattle	71.1	70	91.8	27.6	90.2	27.6
Sheep & goats	32.2	23.3	44.3	6.9	32.8	3.4
Donkey	42.2	32.2	52.5	20.7	45.9	3.4
Horse	33.3	23.3	42.6	13.8	31.1	6.9

Appendix 5D: Explained variance, inflation factor, and p-values for wild herbivores and livestock species distribution data during the dry and wet seasons in northern Kalahari, Botswana. Variable inflation factors. CGA = communal grazing areas, CA = wildlife management areas, AAF = arable agriculture fields, WC = woody cover, NLG = livestock grazing absent.

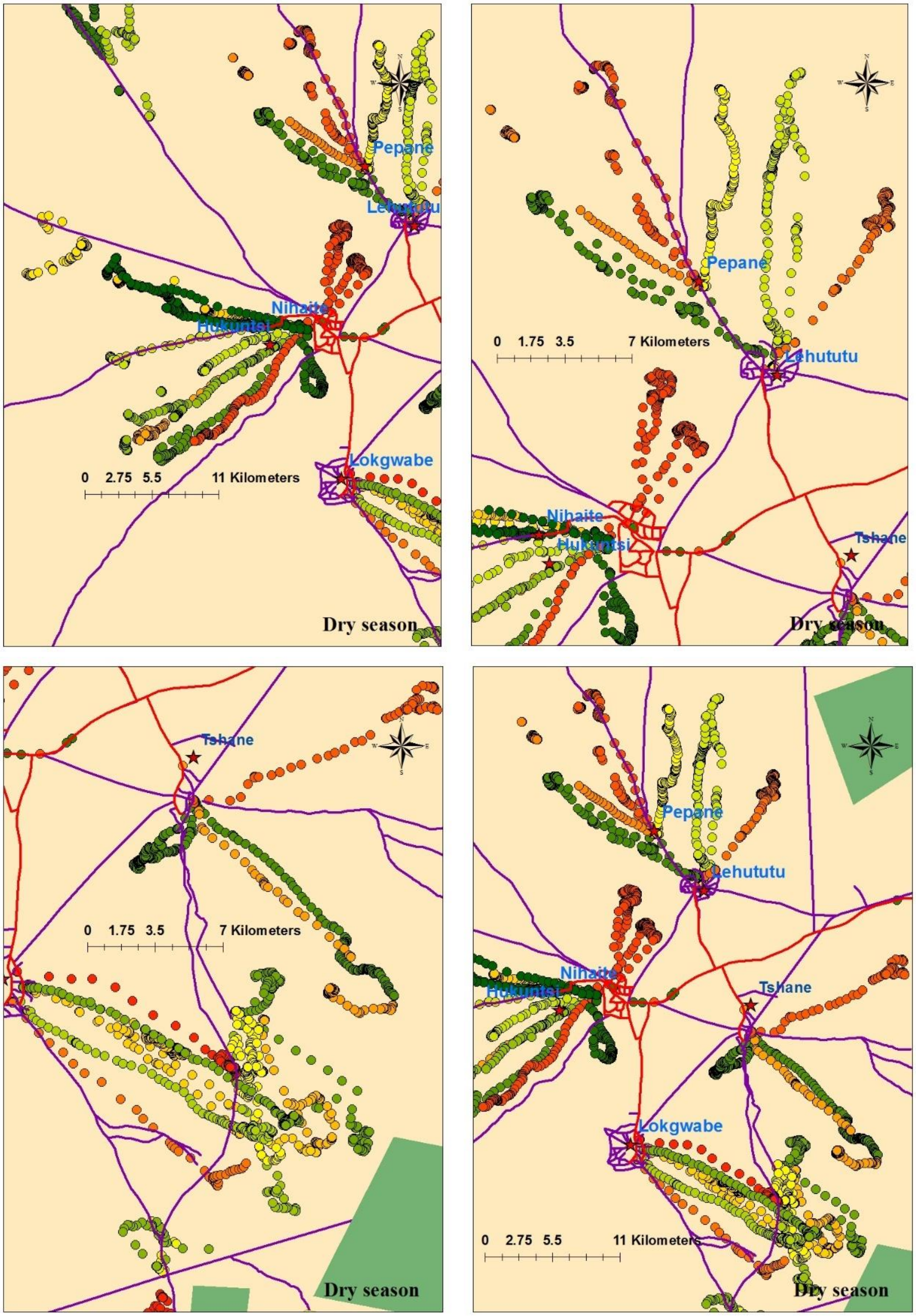
Dry season

Variables	**inflation factor**	**variance explained**	**F**	**P-value**
Distance from settlements	3.8899	0.448	20.087	0.002
Grass diversity	3.6578	0.748	15.641	0.002
Distance from cattle posts	5.8232	0.956	12.26	0.002
Habitat type (AAF/WC)	2.0885	1.095	9.026	0.002
Land use (CGA/CA)	5.0394	1.217	8.546	0.002
Grass height	3.3099	1.27	3.85	0.002
Unpalatable perennial grasses	1.2403	1.31	2.957	0.008
Forb cover	1.8133	1.348	2.864	0.012
Livestock grazing absent (NLG)	6.2982	1.378	2.354	0.042

Wet season

Variables	**inflation factor**	**variance explained**	**F**	**P**
Livestock grazing absent (NLG)	8.0847	1.115	3.091	0.002
Less Livestock grazing intensity	1.4031	1.149	3.069	0.002
Land use (CGA/CA)	5.3398	0.686	21.64	0.002
Habitat type (AAF/WC)	1.4116	0.947	20.862	0.002
Distance from cattle posts	6.7691	0.353	18.548	0.002
Distance from settlements	2.8853	1.045	3.873	0.002
Palatable annual grasses	1.8946	1	4.344	0.004
Grass diversity	1.6846	1.081	3.189	0.002

Appendix 5 E: Example of movements of selected cattle fitted with GPS telemetry
Cattle were selected from cattle posts/water points and their grazing patterns were monitired amid the dry (2014 & 2015 and wet seasons (2015 & 2016). Different colors show movement of individual cow fitted with GPS telemetry



Appendix 6A: Species, type of feeder and life body weight and IUCN (3.1) conservation status of wildlife & livestock
OM = omnivore, CAR = carnivore, INS = insectivore, SCA = scavenge, FOR = formivore, LC = least concern, VU = vulnerable, NT = near threatened, EN = endangered

English name	**Local name**	**Scientific name**	**Feeds type**	**Life weight(kg)**	**Status (IUCN 3.1)**
Black-backed jackal	Phokoje	*Canis mesomelas* (Linnaeus)	CAR	6 - 13	LC
Spotted Hyena	Phiri o moramaga	*Crocuta crocuta* (Erxleben)	CAR	65 - 70	LC
Honey badger	Matshwane	*Melivora capensis* (Schreber)	CAR	5 – 16	LC
Cheetah	Nkwe	*Acinonyx jubatus* (Schreber)	CAR	21 – 72	VU
Striped Hyena	Phiri	*Hyaena hyaena* (Linnaeus)	SCA	22 – 25	NT
African Wild dog	Lekanyane	*Lycaon pictus* (Temminck)	CAR	20 - 25	EN
Brown Hyena	Phiri	*Parahyaena brunnea* (Thunberg)	SCA	35 – 44	EN
Blanford's fox	Ntsije	*Vulpes cana* (Blanford)	OM	1 – 1.5	LC
Leopard	Letlotse	*Panthera pardus* (Linnaeus)	CAR	28 – 90	VU
African wild cat	Katsi ya naga	*Felis silvestris* (Forster)	CAR	3 – 4.5	LC
Caracal	Phage	*Caracal caracal* (Schreber)	CAR	8 - 18	LC
Lion	Tau	*Panthera leo* (Linnaeus)	CAR	150 – 250	VU
Bat-eared fox	Motlhose	*Otocyon megalotis* (Desmarest)	INS	3 – 5.5	LC
Aardvark	Thakadu	*Orycteropus afer* (Pallas)	FOR	60 – 80	LC

Appendix 6B: Wildlife and livestock species recordings (tracks and pellets) along five transects and land use types
Data collected during the dry (August - October 2014 & 2015) and wet (March - May 2015 & 2016) seasons, in northern Kalahari, Botswana. Lehututu/Hukuntsi (T1), Hukuntsi/Zutshwa (T2), Lokgwabe/Mabuasehube (T3), Tshane/Kang (T4) and Hukuntsi/Ngwatle (T5) transects, Communal Grazing Area (CGA) and Wildlife Management Area (CA). Animals' tracks and pellets present (P) or absent (A) during the dry (D), wet (W), dry and wet DW) seasons and not observed in both seasons (NO).

English name	**T1***	**T2***	**T3***	**T4***	**T5***	**CGA***	**CA***
Black-backed jackal	DW	DW	DW	DW	DW	P	P
Cape Porcupine	DW	DW	DW	DW	DW	P	P
Spotted Hyena	DW	DW	DW	DW	DW	P	P
Honey badger	DW	DW	NO	NO	W	P	P
Bat-eared fox	DW	DW	DW	DW	DW	P	P
Cheetah	DW	DW	DW	DW	DW	P	P
Striped Hyena	**NO**	**D**	**NO**	**NO**	**NO**	**A**	**P**
African Wild dog	NO	NO	DW	W	W	P	P
Brown Hyena	**NO**	**NO**	**W**	**D**	**NO**	**A**	**P**
Blandford's fox	DW	DW	DW	DW	DW	P	P
Leopard	DW	DW	DW	DW	DW	P	P
African wild cat	DW	DW	DW	DW	DW	P	P
Caracal	DW	NO	DW	DW	NO	P	P
Lion	**NO**	**NO**	**DW**	**NO**	**NO**	**A**	**P**
Aardvark	DW	DW	DW	DW	DW	P	P

Appendix 6C: Wildlife and livestock frequencies (%) of appearance relative to land use types and seasons

Data from a total of 90 sample plots during the dry and wet seasons within different Land uses (CGAs and CAs), in northern Kalahari, Botswana. Rare (0 to 20%), Medium (20 to 40%), Frequent (40 to 60%) and Very frequent (>60%). Frequency of appearance per land use was calculated as the total observations of the species in that land use out of the total number of sample plots in that respective land use.

	Overall/Season (%)		**Land use (%)**			
			Dry season		**Wet season**	
Name	**Dry**	**Wet**	**CGAs**	**CAs**	**CGAs**	**CAs**
Black-backed jackal	75.6	84.4	72.1	82.8	82	89.7
Spotted Hyena	30	41.1	19.7	51.7	27.9	69
Honey badger	**6.7**	**6.7**	4.9	10.3	6.6	6.9
Bat-eared fox	45.6	52.2	32.8	72.4	42.6	72.4
Cheetah	4.4	24.4	1.6	10.3	9.8	55.2
Striped Hyena	**0**	**4.4**	0	0	0	13.8
African Wild dog	**12.2**	**13.3**	3.3	31	14.8	10.3
Brown Hyena	**1.1**	**1.1**	1.6	0	1.6	0
Blandford’s fox	**0**	**16.7**	0	0	1.6	48.3
Leopard	0	15.6	0	0	8.2	31
African wild cat	32.2	12.2	24.6	48.3	16.4	3.4
Caracal	**16.7**	**13.3**	6.6	37.9	9.8	20.7
Lion	**11.1**	**11.1**	1.6	31	0	34.5
Aardvark	21.1	25.6	18	27.6	19.7	37.9

Appendix 7: Examples of key field data sheets used during the field work.
A = grass species, B = forb species, C = woody species and D = wildlife and livestock field data sheets. Square plot or quadrats were used and the sizes for the quadrats were 1m x 1m for grasses and forbs parameters, 30m x 30m for woody plants parameters, wildlife and livestock pellets, 30m x 90m for wildlife and livestock tracks.

A: grass species

	sample point 1												sample point 2											
Transect:	**Quadrat 1**						**Quadrat 2**						**Quadrat 1**						**Quadrat 2**					
Species/parameters	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
Total grass cover (%)																								
Total bareground cover (%)																								
Average grass height (cm)																								
Grass biomass (kg/ha))																								
Dactyloctenium aegyptium																								
Aristida congesta subsp congesta																								
Aristida meridionalis																								
Aristida stipitata subsp stipitata																								

B: Forb species

	sample point 1												sample point 2											
Transect:	**Quadrat 1**						**Quadrat 2**						**Quadrat 1**						**Quadrat 2**					
Species/parameters	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
Total forb cover (%)																								
w/water melon plants (900m2)																								
Average forb height (cm)																								
Forb Biomass (g/m2)																								
Beans																								
Zonks																								
pinkflower																								
wild sesame																								

C: Woody cover

Transect:												
Land use types (Wildlife management Areas, communal Grazing Area)												
Habitat type (woody cover, Arable fields, cattle posts)												
Fire occurance ((0 = no signs of fire, 1 = old signs of fire on trees, 2 = few months on trees and grasses; 3 freshly burnt evident on herbaceous layer)												
Livestock grazing intensity (LGI) (none = 0, low = 1, mederate = 2, high = 3)												
	SP1		**SP2**		**SP3**		**SP1**		**SP2**		**SP3**	
Species	**QD1**	**QD2**	**QD1**	**QD2**	**QD1**	**QD2**	**QD1**	**QD2**	**QD1**	**QD2**	**QD1**	**QD2**
Acacia herbaclada (sekhi)												
Acacia eriloba (mogotlho)												
Acacia haematoxylon												
Acacia karroo (mokha)												
Acacia luederitzii												

D: Wildlife and livestock species

	Sub-transect:								
Transect:	**Sample point 1**			**Sample point 2**			**Sample point 3**		
Animals	**Dung/pellets**		**# tracks (2700m2)**	**Dung/pellets**		**# tracks (2700m2)**	**Dung/pellets**		**# tracks (2700m2)**
Wildlife	**Quad 1**	**Quad 2**	**Prest (1) absnt (0)**	**Quad 1**	**Quad 2**	**Prest (1) absnt (0)**	**Quad 1**	**Quad 2**	**Prest (1) absnt (0)**
Duiker									
Eland									
Gemsbok									
Livestock									
Goats									