THE ECONOMICS OF LAND DEGRADATION

Report to the Economics of Land Degradation Initiative

Land Use, Rangeland Degradation and Ecosystem Service Provision: New Analyses from southern Kalahari, Botswana

April 2014

Executive summary

This report presents new ecological analyses assessing the links between land use, rangeland degradation and ecosystem service provision in southern Kgalagadi District, Botswana. A dual-scale approach was followed in this study assessing both farm-scale patterns of ecological change and landscape-scale patterns of change in green vegetation biomass (from satellite data) and animal distribution (from national aerial census of animals). This dual-scale approach is essential for providing new insights on the spatial and temporal dynamics of dryland ecosystem services and their links to both poverty alleviation and wildlife conservation goals.

The main findings were affected by the below average rainfall in the study year which led to a high proportion of bare ground (typically 70-90%) and forb cover (5–20%) across all land uses, displaying the major impact of rainfall variability in determining the ecological cover in field surveys. Widespread bush encroachment was found across the study area resulting in an increase in the shrub cover and density at the expense of the grass layer on which cattle production is based. Bush encroachment is particularly prevalent in semi-arid sites where *Acacia mellifera* and *Dichrostachys cinerea* are widespread in both communal grazing areas and private ranches, showing that land tenure changes (to private ownership) have not prevented rangeland degradation across the Kalahari. Grass cover is dominated in intensively grazed areas by the annual *Schmidtia kalahariensis* and in moderately grazed areas by the perennial *Eragrostis lehmannia*. Both these species are less nutritious than perennial grass species *Schmidtia pappophoroides*, *Anthephora pubescens* and *Eragrostis pallens* that remain prevalent in lightly grazed wildlife management areas.

New ecological change pressures were observed in sites close to the Molopo river where the exotic species *Prosopis glandulosa* was observed at intensively grazed sites in both communal grazing and private ranch areas. Although initially valued for its fodder potential and drought resistance, this invasive multi-stemmed shrub is today blamed for declining soil moisture and groundwater levels and is expensive to remove using chemical or physical treatments.

For arid sites, *Rhigozum trichotomum* is forming impenetrable thickets on calcareous soils, close to boreholes. Bush encroachment is otherwise absent in the SW Kalahari system, with dune instability occurring up to a distance of 1.2km from boreholes following the removal of *Stipagrostis amabilis* grass cover.

Regional patterns of key wildlife species show that the expansion of cattleposts and fenced ranches has led to large areas of ‘empty savanna’ in the southern Kalahari with low biodiversity value even in areas where cattle production is not practiced due to the absence of suitable groundwater resources.

1. Introduction

This study assesses the links between land use and degradation in the semi-arid rangeland system of the Kalahari in Kgalagadi District, Botswana. It provides new ecological analyses along 'piosphere' grazing gradients away from borehole waterpoints. Three main land uses were considered:

1. communal grazing lands;
2. private cattle ranches; and
3. private game ranches.

This report analyses the above data together with key ecological indicators available from remotely-sensed data on both vegetation cover (satellite-derived NDVI as a measure of green biomass cover over the period 2000-2013) and animal numbers (from the 2012 national aerial census).

Such dual-scale ecological assessments are essential for advancing understanding of the dynamics faced in the Kalahari rangelands (as synthesised below) and semi-arid rangelands more widely (UNEP, 1997; Millennium Ecosystem Assessment, 2005).

2. Background Context: Kalahari Rangeland Degradation Assessments

Kalahari rangeland systems support pastoral livelihoods through cattle, smallstock and game and also include extensive areas assigned for wildlife conservation (Figure 1). Concerns are growing over dual threats of rangeland degradation, notably through bush encroachment and loss of nutritious perennial grass species (Moleele *et al*., 2002; Thomas and Twyman, 2004; Dougill *et al*., 2010), and increasing rural poverty levels (Perkins, 1996; Atlhopheng *et al*., 1998; Chanda *et al*., 2003), as with other semi-arid rangeland systems across sub-Saharan Africa (Reynolds *et al*., 2007; Sankaran *et al*., 2008; UNDP, 2011).

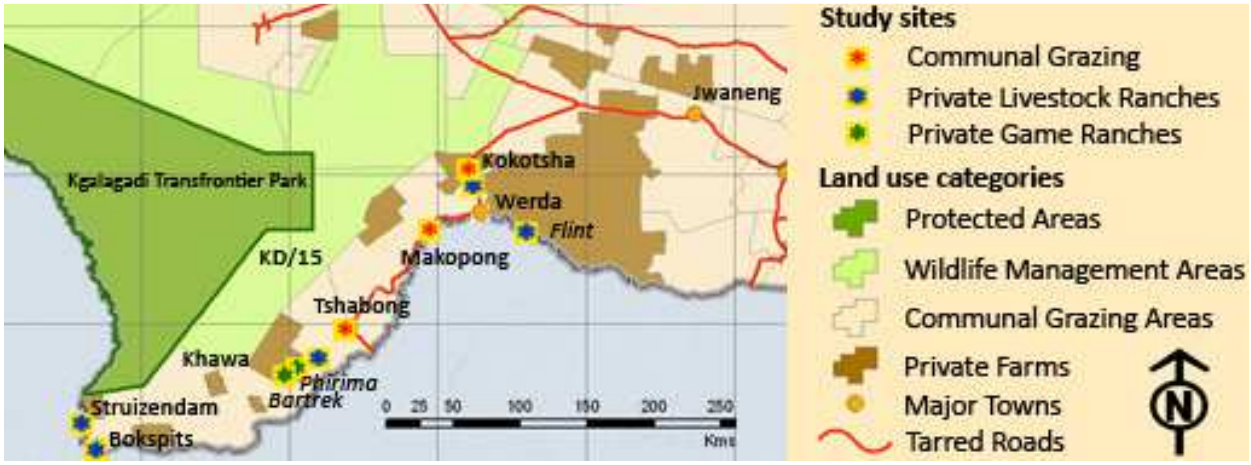


Figure 1. Land use of southern Kalahari with project ecological study sites marked

Previous studies in southern Kgalagadi District, as the driest and most degradation-prone region of Botswana's Kalahari, have documented bush encroachment of *Acacia mellifera* in semi-arid regions as the most extensive form of rangeland degradation (e.g. Reed *et al*., 2007; Moleele and Mainah, 2003). Bush encroached zones found around major communal villages (Figure 2a) now typically extend around 10 km from villages in the semi-arid areas such as around Tshabong (Reed *et al*., 2007) and the Matsheng villages of Tshane, Hukuntsi and Lehututu (Chanda *et al*., 2003). In the more arid areas of southwest Botswana around Bokspits and Struizendam, encroachment of *Rhigozum trichotomum* on calcareous soils (Figure 2b) is seen as the major ecological change causing economic losses, and thus rangeland degradation, in the mixed cattle and smallstock systems of this part of the Kalahari (Reed *et al*., 2007). Reduced grass cover, notably of the dune stabilising *Stipagrostis amabilis* grass (Figure 2c), leads to re-activation of dunes around boreholes (Thomas *et al.*, 2005), which form a spectacular shifting dune-scape within 0-200m of the waterpoint, with dune crests observed to be re-activated up to a distance of 1.2kms in the 1023-2014 rainfall season.

Figure 2. Main forms of Rangeland Degradation in Kalahari rangelands. (a.) Dense stands of *Acacia mellifera*; (b.) Thickets of *Rhigozum trichotomum*; (c.) Mobilised sand dunes in arid southwest

Source: Nicola Favretto, field visit, 2013

For both arid and semi-arid regions of southern Kgalagadi District, rangeland assessment guides based on a combination of 'local' and 'scientific' knowledge have been developed (Reed and Dougill, 2010) and linked to land management options (e.g. grazing levels, prescribed burning, bush control and removal options). Further analysis of the ecological impacts of different land use and management practices, as per the aim of this report, remains essential to develop further practical decision support tools and to explore the socio-environmental impacts of changing land use and management pressures. Such ecological assessments are also required to ensure that economic and policy instruments align to support sustainable land management practices that are capable of avoiding further rangeland degradation, in line with moves towards a Land Degradation Neutral World (UNCCD, 2011).

3. Research Design and Methods

A dual-scale approach was followed in this study. We assessed both ***farm-scale*** patterns of ecological change with distance from the waterpoint (borehole) and the ***landscape-scale*** patterns of change in green vegetation biomass from satellite data and animal distribution from national aerial census of animals (Republic of Botswana, 2012). This dual-scale approach is deemed essential for providing new insights on the spatial and temporal dynamics of ecosystem services and their links to both poverty alleviation and wildlife conservation goals.

Ecological surveys were undertaken in March 2014 on 5km transects at 10 study sites (Figure 1). These sites included:

- 3 communal grazing areas (Kokotsha, Makopong and Tshabong);
- 5 private cattle ranches (Van Zyl ranch (Tshabong), Mpungwa ranch (Kokotsha), Flint farm (Molopo Farms) where 3 paddocks surveyed to assess impacts of *Acacia mellifera* clearance, and Esterhuizen ranches near Struizendam and Bokspits where paddocks with a and without karakul sheep were studied); and
- 2 private game farms (Bar Trek and Phirima).

Each ecological survey transect included 7 sampling points (50m, 200m, 400m, 800m, 1500m, 3km, 5km from waterpoint) providing a gradient of declining grazing intensity (Perkins and Thomas, 1993). In the case of ranches the 'best' and 'worst' condition paddock were sampled, depending on the management strategies (e.g. cleared and not cleared). Where the sampling point was located in a dune field, the dune and inter dune valley was sampled in order to capture the variation in plant diversity caused by habitat variation. Bush cover, species and canopy dimensions were assessed in a 30x30m quadrat at each sampling point and grass cover, biomass and species composition were assessed in 9 1x1m quadrats at each sampling point. This allowed both summary plots of ecological cover change with distance to be provided and for a Detrended Correspondance Analysis (DCA) to be undertaken to identify gradients within the full species dataset collected across all sampling points (Jongman *et al*., 1987).

Satellite data analyses involved spatial assessments of the satellite derived Normalised Difference Vegetation Index (NDVI) measurements, as a surrogate indicator of green vegetation cover (Dougill and Trodd, 1999) from across southern Botswana for the period from 2000-2013. Data from the 250m resolution MODIS/NDVI time series database with early May (end of wet season) were chosen as the sample timeframe to compare between years and to examine spatial and temporal anomalies over the dataset (see Figure 3 showing annual variability). Early May NDVI values give an indication of the available fodder resource for dry season grazing when pressure on forage resources is most marked and likely to cause ecological change thresholds to be crossed (Dougill *et al*., 1999).

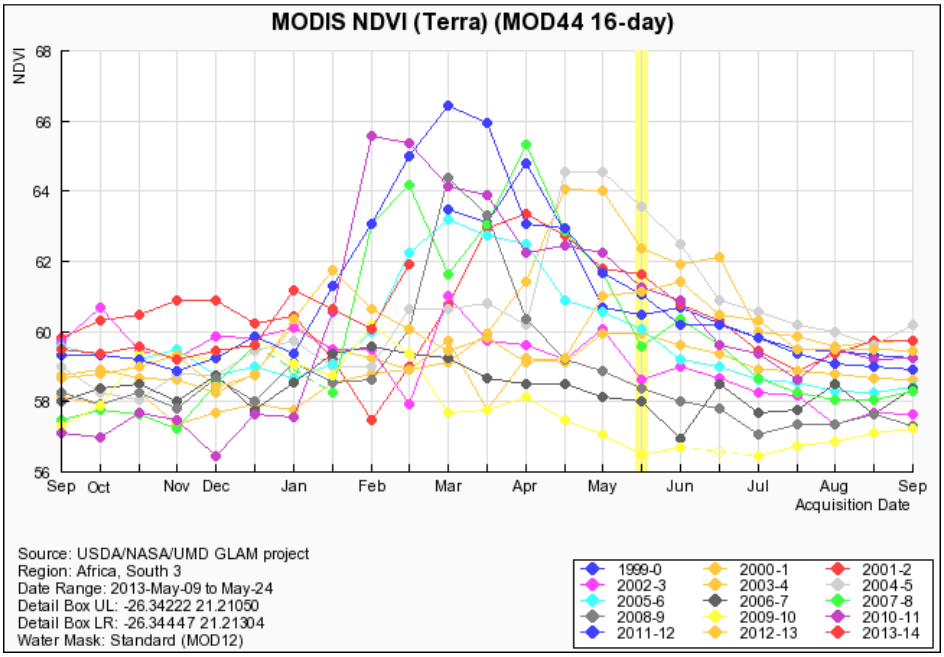


Figure 3. Annual variations on MODIS NDVI values for southwest Kalahari site (S 26°34' E 21°21')

Regional-scale data on animal distributions (both domestic stock and wildlife) for the 2012 dry season were analysed from the national aerial census of animals, which includes spatial comparisons with the 1992 animal census data (Republic of Botswana, 2012). We compared the spatial distributions of cattle, smallstock and key wildlife species (Wildebeest and Eland) to assess trade-offs between economic (meat-based sales) and biodiversity (wildlife numbers) values of the rangeland systems.

4. Results and Discussion

This section presents the main ecological results from both the 'piosphere' farm-scale and also from regional landscape-scale with integrated discussion included throughout given the additional strength of evidence provided using such a dual-scale approach.

Given the non-equilibrium dynamic nature of dryland ecosystems (Behnke *et al*., 1993; Reynolds *et al*., 2007), it is important to highlight the field-based ecological survey findings in the context of the rainfall pattern experienced in the 2013/14 wet season. Typically, this

was characterised by an early period of drought followed by relatively good rains in December / January, but then a period of low rainfall in February / March prior to the field survey. This pattern can partly explain the high proportion of bare ground (typically 70-90%) and forb cover (5–20%) found at all sampling points across all land uses (see Figure 4 as example), displaying the major impact of rainfall variability in determining the ecological cover in field surveys. This is also shown clearly in the temporal variability in NDVI anomalies by year across 2000-2013 which are greater than any impact associated with land use or rangeland management (Figure 5).

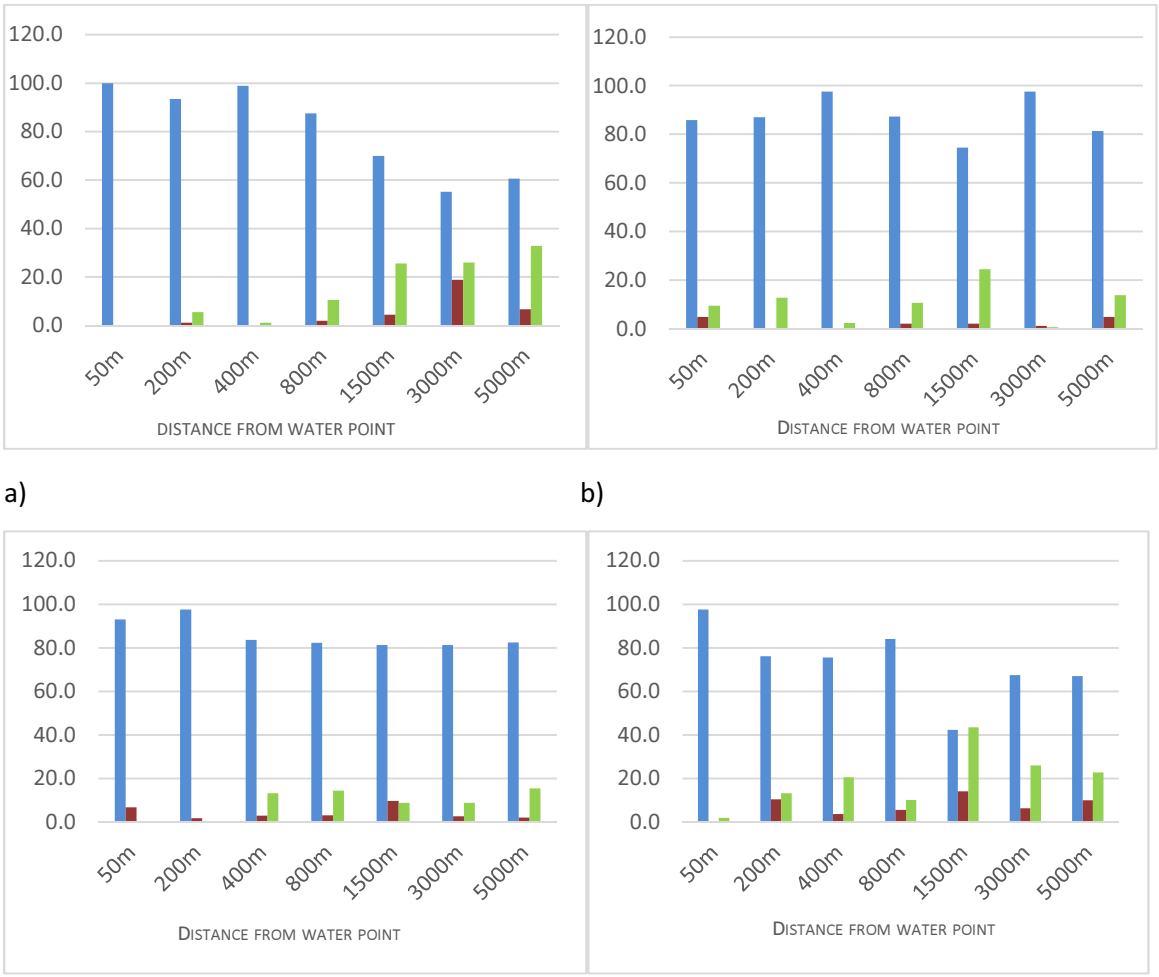
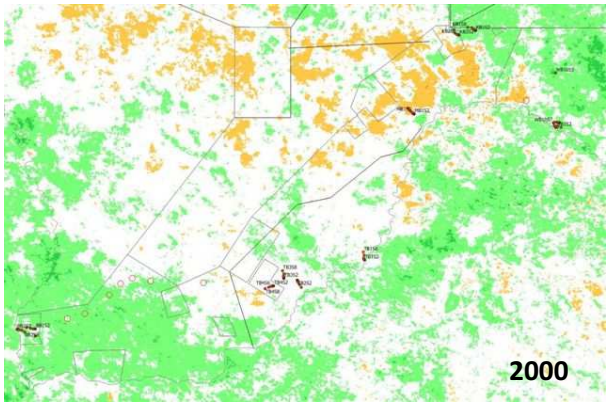


Figure 4. Ecological survey findings for % bare ground cover (blue shading), forb cover (red shading) and grass cover (green shading) at (a.) Ditira communal grazing area, Tsabong; (b.) Bartrek game ranch, Tsabong; (c.) Van Zyl cattle ranch, Tsabong; (d.) Esterhuizen cattle & small stock ranch, Struizendam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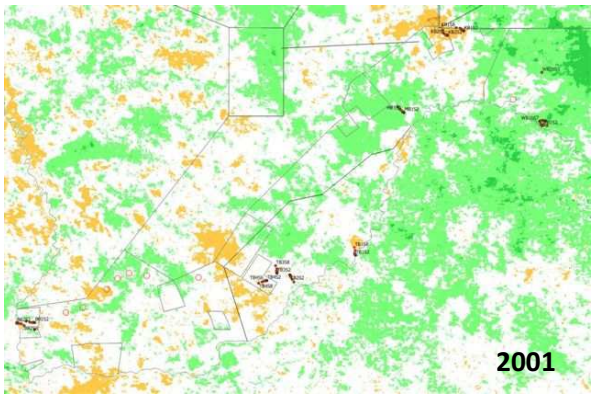
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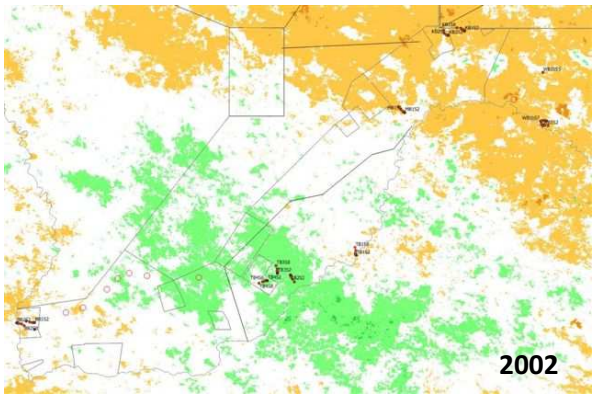
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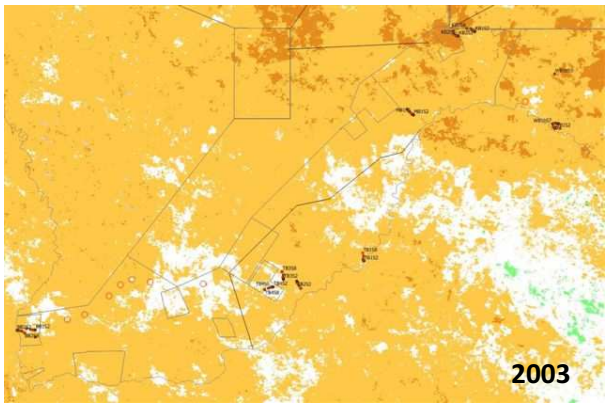
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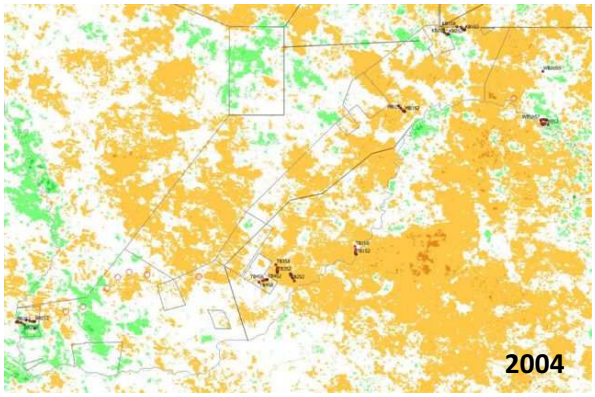
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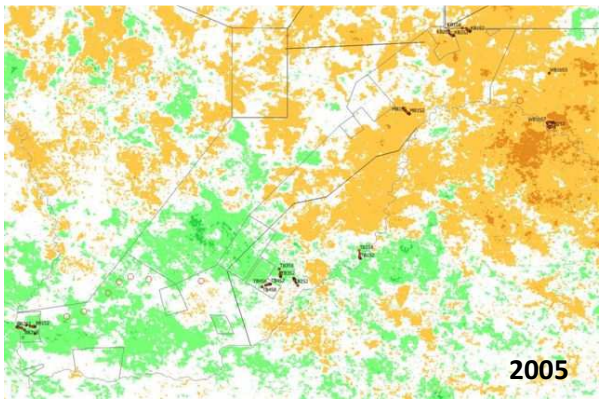
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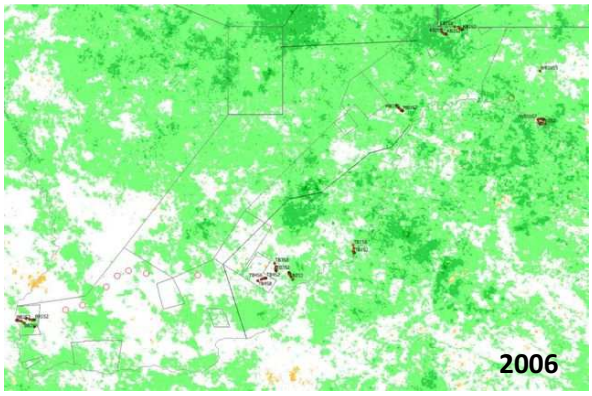
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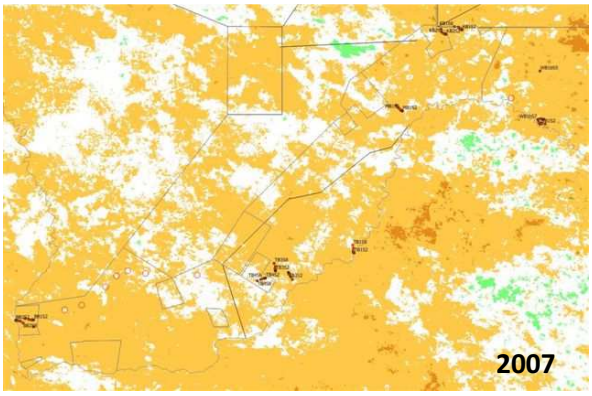
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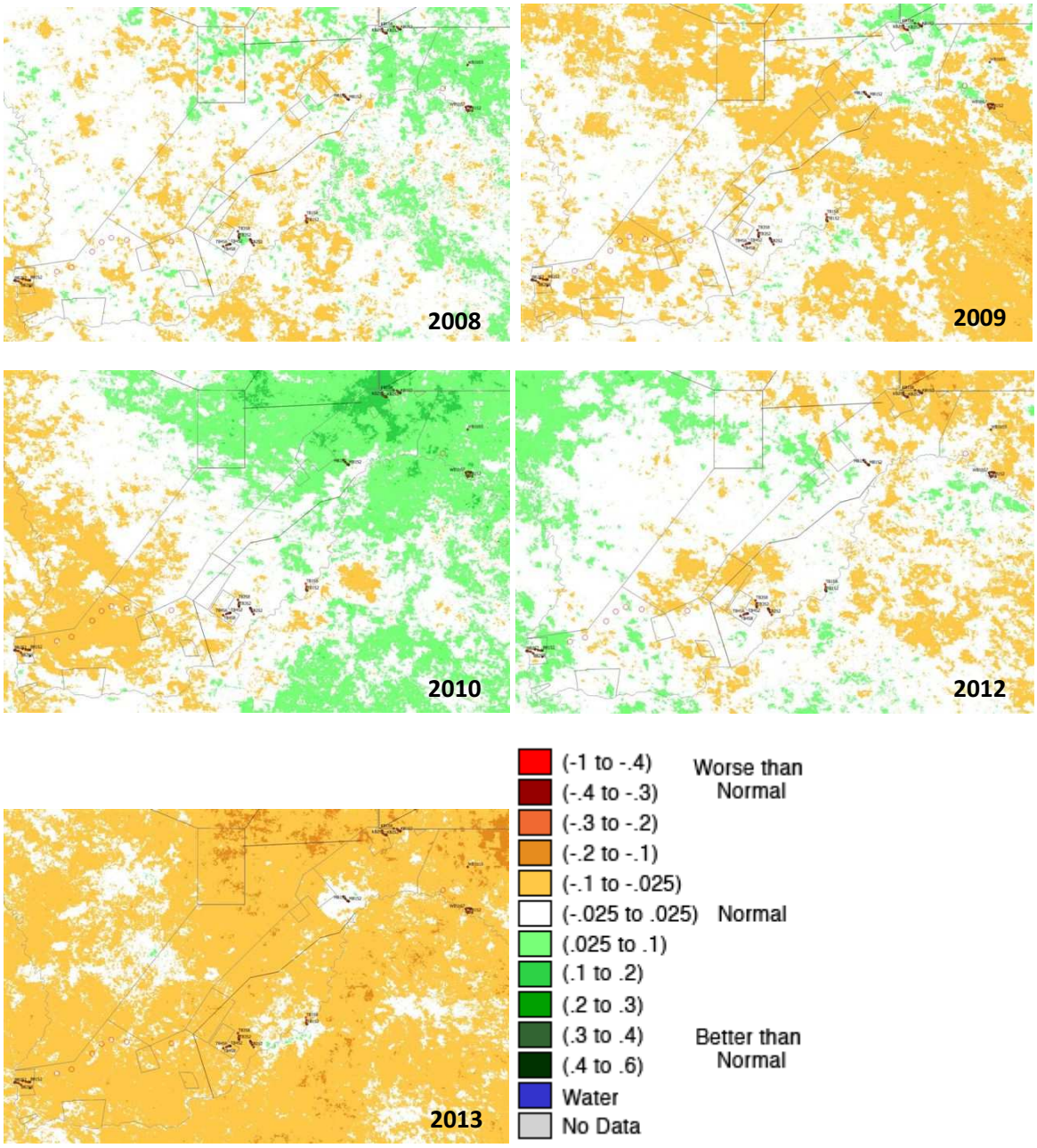

Figure 5. MODIS NDVI anomalies across southern Kalahari for 2000-2013 based on an early May sample timeframe to provide average value used (2000-2013) to generate spatial anomaly maps for each year (excluding 2011 due to poor image availability)

Given the spatial and temporal variability of rainfall, satellite data landscape-scale studies alone cannot identify ecological changes affecting pastoral productivity of rangelands, a factor exacerbated by the difficulties in using NDVI to record changes in vegetation structure, such as the bush:grass ratio (Dougill and Trodd, 1999). As such, the farm-scale piosphere ecological surveys are vital. The studies in this project add further evidence (Figure 6) to the growing body of literature (e.g. Jeltsch *et al.*, 1996; Reed and Dougill, 2002, 2010; Chanda *et al*., 2003; Thomas and Twyman, 2004; Reed *et al*., 2007, 2008) outlining the widespread nature of bush encroachment in the semi-arid portions of the southern Kalahari. Bush encroachment is found across in both communal grazing areas and private ranches

and results in an increase in the shrub cover and density at the expense of the grass layer on which cattle production is based. Bush encroachment is particularly prevalent in semi-arid sites where *Acacia mellifera*, *Acacia karroo*, *Grewia flava* and *Dichrostachys cinerea* are widespread. Species level associations were assessed using the DCA technique (Figure 7) and show that the main encroaching species are clustered (and thus often closely co-located). However, camel thorns *Acacia erioloba* and *Acacia haematoxylon* (a near endemic to the SW Kalahari) have different distribution given their prevalence in more arid parts of the southern Kalahari.

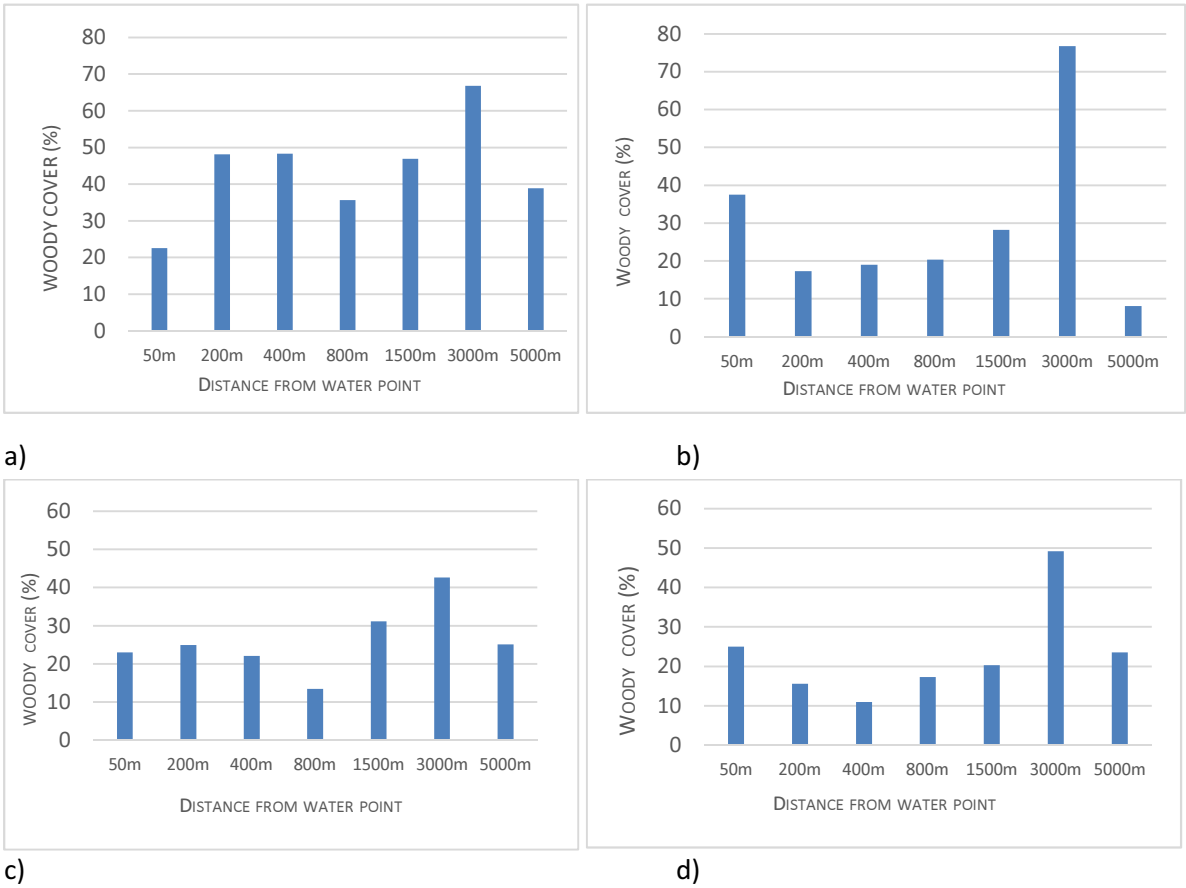

Figure 6. Woody cover as recorded at two paired sample transects at neighbouring sites differentiated by land use. (a.) Kokotsha communal grazing area; (b.) Mpungwa cattle ranch (Kokotsha); (c.) Van Zyl Cattle Ranch; (d.) Phirima Game Farm

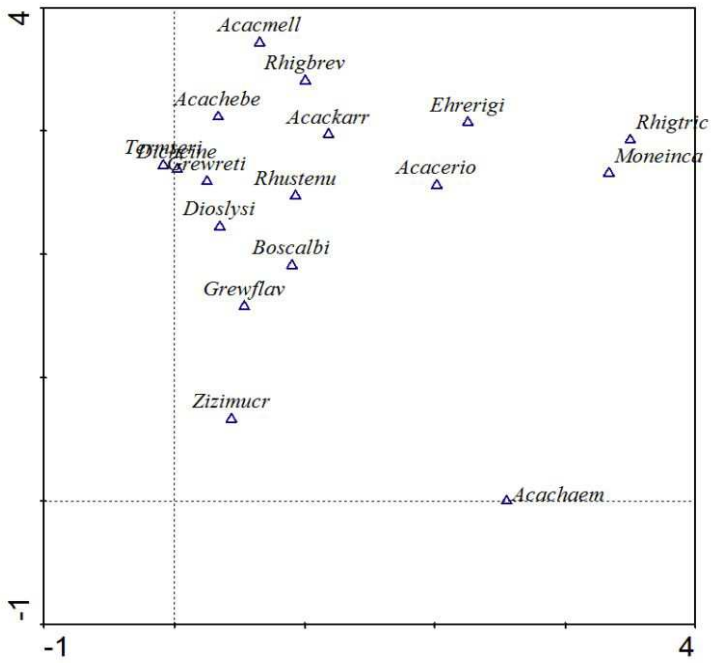

Figure 7. Woody cover DCA eigenanalysis plot for data from all sampling points / study sites (abbreviations of main bush / tree species recorded)

Grass species cover at the semi-arid sites does show significant changes with grazing, with intensively grazed areas being dominated by the annual *Schmidtia kalahariensis* and in moderately grazed areas by the perennial *Eargrostis lehmannia*. Both these species are less nutritious than perennial grass species such as *Schmidtia pappophoroides*, *Anthephora pubescens* and *Eragrostis pallens* that remain prevalent in lightly grazed wildlife management areas. Given the sparse grass cover at the time of sampling (Figure 4), the DCA analysis on both grass density and cover does not identify any significant correlation with distance from borehole (and thus grazing intensity) with rare species and outliers tending to dominate the dataset.

New ecological change pressures were observed in sites close to the Molopo river where the exotic species *Prosopis glandulosa* (Bromilow, 2001) was observed (Figure 8) at intensively grazed sites in both communal grazing and private ranch areas. Initially heralded for its drought tolerance, ability to withstand high temperatures and heavy grazing pressure, as well as its dune stabilising potential, *Prosopis* has spread rapidly in the southern Kalahari and is now widely bemoaned and held to be responsible for declining water levels experienced by village and livestock boreholes. As a dense, multi-stemmed shrub it reduces fodder availability and is expensive to remove using chemical or physical treatments, implying that the spread of *Prosopis* via seed dispersal in dung (Milton and Dean, 2001) seems likely to increase as a new form of rangeland degradation affecting the Kalahari.

Figure 8. The exotic bush *Prosopis glandulosa,* in the Molopo valley

Source: Jeremy Perkins, field visit, 2013

Another exotic species causing new degradation pressures was identified in arid sites near Struizendam, where the Mexican poppy (*Argemone ochroleuca*) a noxious weed, was found on disturbed ground close to the borehole and kraals.

The final element of ecological changes that must be considered in assessments of ecosystem services and the changing nature of the rangeland systems are the wildlife numbers supported by these rangelands. In particular, the southern Kalahari is home to key ungulate species such as the springbok *(Antidorcas marsupialis*), eland *(Taurotragus oryx*), gemsbok (*Oryx gazella*), red hartebeest (*Alcelaphus buselaphus*) and blue wildebeest (*Connochaetes taurinus*). These ungulates are highly mobile in response to the green grass that follows isolated rainfall and fire events and can they are well adapted by being able to obtain sufficient moisture from their food, such as the tsamma melons and Gemsbok cucumber, with early morning dew on vegetation is especially important for these species. In drought periods, wildebeest must migrate to surface water to drink, which in the 1982-86 drought led to an over 90% die off of the Kalahari population and also that of hartebeest. The 1980s die-off was exacerbated by the lack of secure access to water and grazing due to the veterinary cordon fences for disease control in the livestock sector which had blocked migratory routes, leading to calls (e.g. Williamson and Williamson, 1985; Owens and Owens, 1986; Verlinden *et al*., 1998) for wildlife corridors between the southern Kalahari and the Central Kalahari Game Reserve and continued recognition of the importance of Wildlife

Management Areas (DHV, 1980; Twyman, 2000) and the need to protect them from illegal livestock encroachment.

Regional patterns of key wildlife species (eland, wildebeest) compared to cattle and smallstock distributions as published in the *Aerial Census of Animals in Botswana: 2012 Dry Season* (Figure 9) show that the expansion of cattleposts and fenced ranches is associated with large areas of 'empty savanna' in the southern Kalahari that have low numbers of these key ungulate species. Groundwater in the southern Kalahari is generally too salty and too deep for borehole-based livestock production, with periodic droughts and spatially and temporally highly variable rainfall requiring mobility on the part of the key ungulate species in order for them to survive. It is a situation that has been accentuated by the erection of a 100km long 'lion proof fence' from Two Rivers along the south-eastern boundary of the Kgalagadi Transfrontier Park. It was built in the late 1990s in order to prevent livestock encroaching into the Kgalagadi Transfrontier Park and lions and predators from taking domestic stock from nearby cattleposts (van Vuuren *et al*., 2005). With respect to lion predation losses, it has failed as many holes dug under the fence by jackals and hyenas allow lions through, but it has acted as a barrier to wild ungulate movement.

Local Community-Based Natural Resources Management (CBNRM) initiatives, particularly those relating to ecotourism and multi-species projects have failed, not least due to sectoral policy conflicts related to encouraging livestock development adjacent to the Kgalagadi Transfrontier Park on the one hand, and having to compensate for depredation, and poverty, on the other. The borehole based expansion of cattleposts and associated fences has therefore been associated with large tracts of the southern Kalahari having relatively low biodiversity value and becoming prone to wildfire due to the low levels of wild and domestic stock. It is situation that can be rectified by the effective co-existence of livestock and wildlife-based economies, through the sustainable promotion of both sectors.

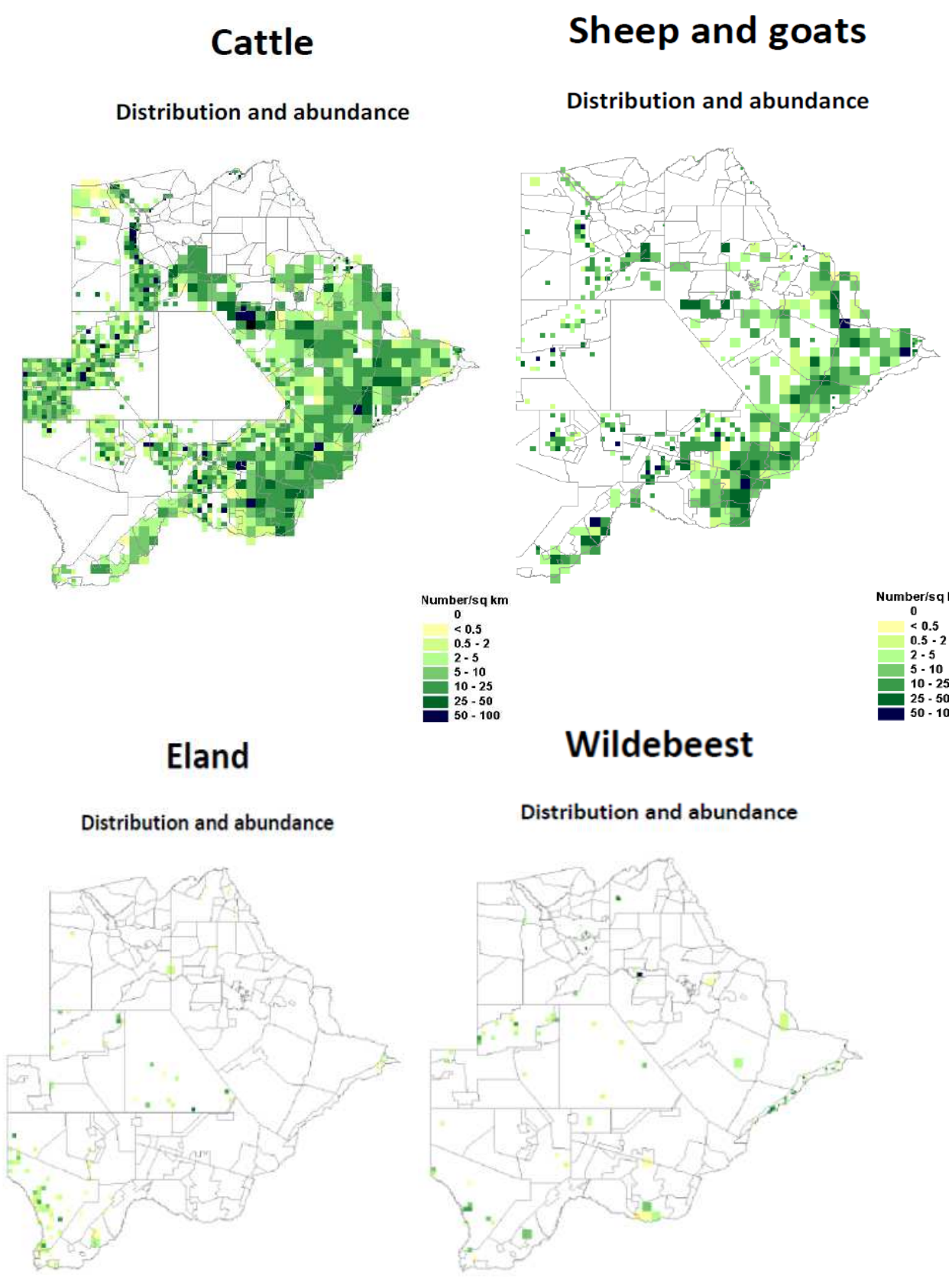

Figure 9. Spatial Distribution and Abundance of (a.) Cattle; (b.) Smallstock (sheep and goat); (c.) Eland; and (d.) Wildebeest

Source: Aerial Animal Census (Republic of Botswana, 2012)

5. Conclusions

Dual-scale ecological analyses from the southern Kalahari add new insights and evidence outlining rangeland degradation and biodiversity conservation problems associated with intensive grazing of arid and semi-arid rangelands and the specific pressures affecting the southern Kalahari in Botswana. Dune mobilisation at arid sites and extensive bush encroachment by *Acacia mellifera* and associated woody species at semi-arid sites are the most notable forms of rangeland degradation and are linked to intensive grazing pressures on both communal and privately-owned land. Landscape-scale studies also show the wider impacts on biodiversity, in terms of wildlife numbers of ungulate species, caused by shifts in land use towards more widespread, and intensive, cattle grazing.

In summary, the main findings of this integrated study are:

- Below average rainfall in the study year led to a high proportion of bare ground (typically 70-90%) and forb cover (5–20%) across all land uses (Figure 4), displaying the major impact of rainfall variability in determining the ecological cover in field surveys. This is also shown clearly in the temporal variability in NDVI anomalies by year (Figure 5).
- Widespread bush encroachment is found across the study area (Figure 6) resulting in an increase in the shrub cover and density at the expense of the grass layer on which cattle production is based. Bush encroachment is particularly prevalent in semi-arid sites where *Acacia mellifera* and *Dichrostachys cinerea* are widespread in both communal grazing areas and private ranches, showing that land tenure changes (to private ownership) have not prevented rangeland degradation across the Kalahari.
- For arid sites in the southwest, the main encroaching bush species were *Rhigozum trichotomum* on calcareous soils close to boreholes. Degradation was observed through dune instability following removal of *Stipagrostis amabilis* grass cover which is vital for binding the soil and stabilising dunes.
- Grass cover is dominated in intensively grazed areas by the annual *Schmidtia kalahariensis* and in moderately grazed areas by the perennial *Eragrostis lehmannia*. Both these species are less nutritious than perennial grass species such as *Schmidtia pappophoroides*, *Anthephora pubescens* and *Eragrostis pallens* that remain prevalent in lightly grazed wildlife management areas.
- New ecological change pressures were observed in sites close to the Molopo river and nearby villages where the exotic species *Prosopis glandulosa* was observed (Figure 8) at intensively grazed sites in both communal grazing and private ranch areas. This invasive multi-stemmed species was once heralded for its fodder value and drought resistance, but is today widely blamed for declining soil moisture and groundwater levels and is expensive to remove using chemical or physical treatments.
- Regional patterns of key wildlife species (Figure 9) show that the expansion of cattleposts and fenced ranches has led to large areas of ‘empty savanna’ in the southern Kalahari with low biodiversity value even in areas where cattle production is not practiced due to the absence of suitable groundwater resources.

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