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Land use, rangeland degradation and ecological changes in the southern Kalahari, Botswana

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Abstract

Dual-scale analyses assessing farm-scale patterns of ecological change and landscape-scale patterns of change in vegetation cover and animal distribution are presented from ecological transect studies away from waterpoints, regional remotely sensed analysis of vegetation cover and animal numbers across the southern Kalahari, Botswana. Bush encroachment is prevalent in semi-arid sites where *Acacia mellifera* Benth. is widespread in communal areas and private ranches, showing that land tenure changes over the last 40 years have not avoided rangeland degradation. Herbaceous cover is dominated in intensively grazed areas by the annual grass *Schmidtia kalahariensis* Stent and in moderately grazed areas by the perennial grass *Eragrostis lehmanniana* Nees. Nutritious perennial grass species including *Eragrostis pallens* Hack. Ex Schinz remain prevalent in Wildlife Management Areas. Other ecological changes include the invasion of the exotic *Prosopis glandulosa* Torr. and dense stands of *Rhigozum trichotomum* Kuntze. in the arid southwest. Regional patterns of wildlife species show that the expansion of cattleposts and fenced ranches has led to large areas of low wildlife conservation value even in areas where cattle production is not practiced. Findings show the need for integrated landscape-scale planning of land use if the ecological value and biodiversity of the southern Kalahari is to be retained.

Key words: Acacia mellifera Benth., bush encroachment, Kgalagadi, *Prosopis glanulosa* Torr., wildlife conservation

Résumé

Nous présentons des analyses à double échelle évaluant, à l'échelle des exploitations, les schémas des changements écologiques et, à l'échelle du paysage, les schémas des changements de la couverture végétale et de la distribution animale, schémas obtenus à partir d'études écologiques de transects situés loin de points d'eau et d'une analyse régionale par télédétection de la couverture végétale et du nombre d'animaux dans tout le sud du Kalahari, au Botswana. L'envahissement des arbustes est fréquent dans les sites semi-arides où *Acacia mellifera* Benth. est répandu dans les zones communales comme dans les ranches privés, ce qui montre que les changements de gestion foncière des 40 dernières années n'ont pas permis d'éviter la dégradation du territoire. Le couvert herbacé est dominé, dans les zones intensément pâturées, par la graminée annuelle *Schmidtia kalahariensis* Stent et, dans les zones modérément broutées, par la graminée pérenne *Eragrostis lehmanniana* Nees. Des espèces de graminées pérennes nourrissantes telles qu' *Eragrostis pallens* Hack ex-Schinz restent abondantes dans les Aires de gestion de la faune. Parmi les autres changements écologiques, citons l'invasion de la plante exotique *Prosopis glandulosa* Torr. et de denses peuplements de *Rhigozum trichotomum* Kuntze dans le sud-ouest aride. Les schémas régionaux des espèces animales montrent que l'expansion des élevages et des ranches clôturés a entraîné la formation de grandes étendues à faible valeur de conservation pour la faune, même là où l'on ne pratique pas la production de bétail. Ces résultats montrent la nécessité d'une planification de l'utilisation du territoire intégrée à l'échelle du paysage si l'on veut préserver la valeur écologique et la biodiversité du sud du Kalahari.

Introduction

Kalahari rangeland systems support pastoral livelihoods through cattle, smallstock and game and also include

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extensive areas assigned for wildlife conservation (Fig. 1). Concerns are growing over dual threats of rangeland degradation, notably through bush encroachment with extensive dense stands of *Acacia mellifera* Benth. and an associated loss of nutritious perennial grass species (Moleele *et al.*, 2002; Thomas & Twyman, 2004; Reed, Dougill & Taylor, 2007), and increasing rural poverty levels (Atlhopheng *et al.*, 1998; Chanda *et al.*, 2003). This matches concerns raised globally for semi-arid rangeland systems (Reynolds *et al.*, 2007; UNDP, 2011). The Botswana Kalahari case offers important global insights given the ability to directly assess land tenure issues (Adams *et al.*, 2002; Dougill, Fraser & Reed, 2010), due to the Botswana Government's support for the privatization of land ownership ever since the Tribal Grazing Land Policy of 1975.

Despite its regional and global significance, ecological information on the extent and nature of changes affecting the southern Kalahari remain sparse and dated (DHV, 1980). The most detailed recent studies assessing ecological changes are in South African (O'Connor, Puttick & Hoffman, 2014) or Namibian (Lohmann *et al.*, 2014) portions of the Kalahari. Our study explicitly assesses the links between land use and degradation in the Kalahari across the southern portion of Kgalagadi District, Botswana (Fig. 1). It provides new ecological analyses along 'piosphere' grazing gradients away from borehole waterpoints for three main land uses: communal grazing lands, private cattle ranches and private game ranches.

This study analyses ecological survey data from across these three land use types, together with key ecological indicators available from remotely sensed data on both vegetation cover and animal numbers. Such dual-scale ecological assessments are essential for advancing understanding of the ecological changes faced in semi-arid savannahs (UNEP, 1997; MA, 2005). By assessing both farm-scale and landscape-scales (the latter including assessment of change through time), provides scope to explore the drivers of ecological change and to outline implications for local-scale rangeland management, district-scale land-use planning and national land policy development. Such integrated assessments are essential to assess the success of land privatization initiatives and shifts in rangeland management practices, such as through rotational grazing, changes in livestock/smallstock numbers and bush removal activities (see Reed & Dougill, 2010 for review of rangeland management options in the southern Kalahari).

Material and methods

Ecological surveys were undertaken in March 2014 on 5-km-long transects at each of ten study sites (Fig. 1). These sites included:

1 Three communal grazing areas (Kokotsha, Makopong and Tshabong);

2 Five private cattle ranches (near Tshabong, Kokotsha, in Molopo Farms (where three paddocks were surveyed to assess impacts of *Acacia mellifera* clearance), and near Struizendam and Bokspits where paddocks with and without karakul sheep were studied); and

3 Two private game farms (Bar Trek and Phirima).

Each ecological survey transect included seven sampling points (50 m, 200 m, 400 m, 800 m, 1500 m, 3 km, 5 km from waterpoints) providing a gradient of declining grazing intensity (higher grass biomass and fewer animal

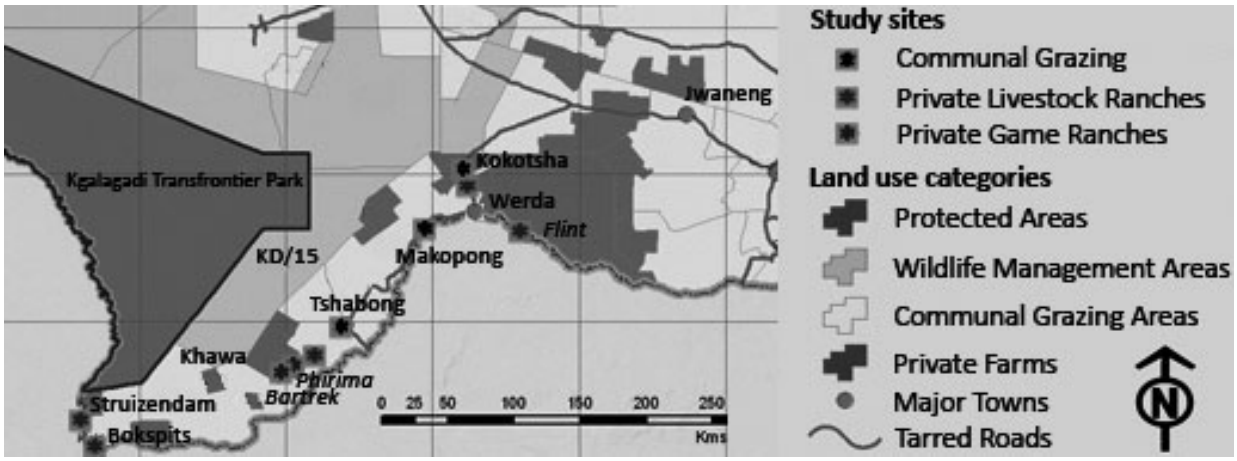

Fig. 1 Land use of southern Kalahari with study sites marked

tracks away from a borehole) (Perkins & Thomas, 1993). In the case of ranches the grazing pressure within the paddocks was subjectively determined through observing the magnitude to which the herbaceous layer was damaged and from the frequency of cattle tracks (Moleele & Mainah, 2003). From these observations the 'best' and 'worst' condition paddocks were selected and sampled, while also noting the recent management strategies (e.g. bush removal practiced or not). Where the sampling point was located in a dune field, sites on the dune crest and inter dune areas were sampled to capture the variation in plant diversity caused by this geomorphologically controlled habitat variation (Thomas, Knight & Wiggs, 2005). Vegetation characteristics were assessed at two levels, focusing on woody and herbaceous layers. For woody vegetation (trees and shrubs), canopy cover, species composition, density and frequency were determined from a 30 × 30 m plot at each sampling point, an area shown to be suitable for vegetation surveys in the Kalahari ecosystem (Skarpe, 1986; Moleele & Mainah, 2003). For the herbaceous canopy cover (grasses and forbs), density, frequency, species composition and bare ground were recorded in nine systematically placed (10 m apart) 1 × 1 m quadrats within the 30 × 30 m plots at each sampling point.

The analysis of field ecological data provided summary plots of ecological cover change with distance and for a Detrended Correspondence Analysis (DCA) to be undertaken using the DECORANA statistical analysis package to identify gradients within the full species data set collected across all sampling points (Jongman, ter Braak & van Tongeren, 1987).

Satellite data analyses involved spatial assessments of Normalized Difference Vegetation Index (NDVI) measurements, as a surrogate indicator of green vegetation cover from across southern Botswana for the period from 2000 to 2013. Data from the 250 m resolution MODIS/NDVI time series database were used with an early May (end of wet season) sample timeframe to give an indication of the peak availability of herbaceous biomass (Perkins, 2002). Data were obtained from the 250-meter MODIS/NDVI Time Series Database from the Global Agriculture Monitoring (GLAM) Project. Visualization of regional NDVI data and associated anomalies was generated from MODIS, with site hosts geocoded by 16-day interval time slices. Rainfall records from five meteorological stations across this region (Werda, Tshabong, Khawa, Middlepits and Bokspits) were obtained for 2000–2013 to enable comparison of annual NDVI patterns with recorded annual rainfall.

Regional-scale data on animal distributions (both domestic stock and wildlife) for the 2012 dry season were analysed from data obtained in the national aerial census of animals (Republic of Botswana, 2012). We compared the spatial distributions of cattle, smallstock and key wildlife species, notably Wildebeest (*Connochaetes taurinus*) and Eland (*Taurotragus oryx*), as these species are good indicators of the wildlife numbers of the Kalahari ecosystem (Verlinden, Perkins & Murray, 1998).

Results

Ecological cover

Given the nonequilibrium dynamic nature of dryland ecosystems, it is important to highlight the field-based ecological survey findings presented here in the context of the rainfall pattern experienced in the 2013/14 wet season. This was characterized 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 (70–90%) and forb cover (5–20%) across all land uses (Fig. 2), resulting from the major impact of rainfall variability in determining the ecological cover in field surveys.

The dynamic nature of vegetation cover is also shown in the annual variability in NDVI anomalies over the period 2000–2013 which are greater than any impact associated with land use or rangeland management (Fig. 3 for snapshot of this variability from 2008 to 2013). Patterns between years broadly match the inter-annual variability in rainfall recorded in the regional meteorological records from the five rainfall stations. The spatial and temporal variability in rainfall means that satellite data studies alone cannot identify ecological changes affecting the pastoral productivity of rangelands (Behnke, Scoones & Kerven, 1993), a factor exacerbated by the difficulties in using NDVI to record changes in vegetation structure, such as the bush : grass ratio (Dougill & Trodd, 1999).

Bush cover

Farm-scale ecological surveys (Fig. 4) show the widespread bush encroachment affecting study sites. Importantly, bush encroachment is found to a similar extent (in terms of % bush cover) across both communal grazing areas and neighbouring private ranches (Fig. 4 for paired

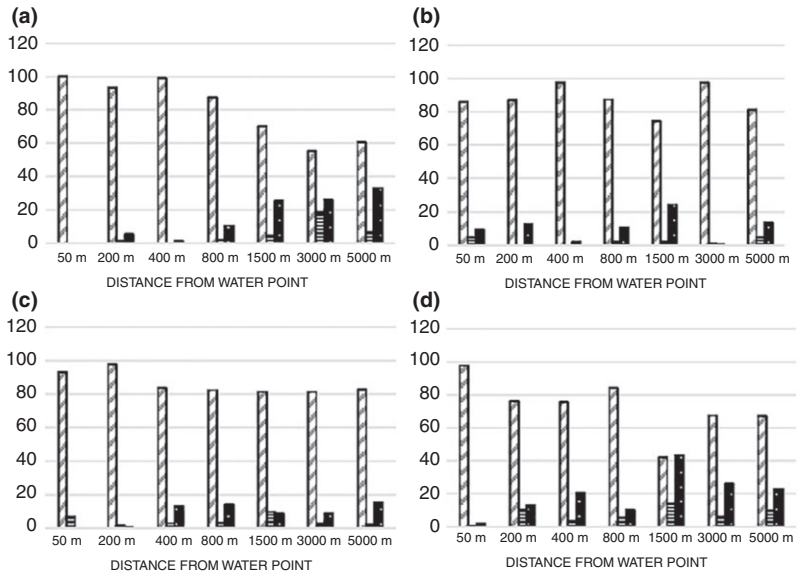

Fig. 2 Ecological survey findings for % bare ground cover (▨), forb cover (▤) and grass cover (▩) at (a) Ditira communal grazing area, Tsabong; (b) Bartrek game ranch, Tsabong; (c) Van Zyl cattle ranch, Tsabong and (d) Esterhuizen cattle and small stock ranch, Struizendam

sampled sites). Results show an increase in bush cover and density at the expense of the grass layer, with bush encroachment particularly prevalent in semi-arid sites where *Acacia mellifera*, *Acacia karroo* Hayne, *Grewia flava* DC. and *Dichrostachys cinerea* (L.) Wight & Arn. are widespread.

Species level associations were assessed using the DCA technique and Fig. 5 shows some clustering of the encroaching species from semi-arid sites, as shown by the co-location of *Acacia mellifera*, *Rhigozum brevispinosum* Kuntze., *Terminalia sericea* Burch. ex DC. and *Acacia hebeclada* DC. *subsp. hebeclada* on Axis 1 of the DCA plot (Fig. 5).

Further ecological change pressures were observed in sites close to the Molopo river where the exotic species *Prosopis glandulosa* Torr. was observed at intensively grazed sites in both communal grazing and private ranch areas. *Prosopis* has spread rapidly in the southern Kalahari (Bromilow, 2001) and is held responsible for declining water levels experienced by village and livestock boreholes.

Herbaceous cover and diversity

Herbaceous species cover and diversity findings were greatly affected by the dry conditions prior to survey, but in general supported findings of past ecological studies (DHV, 1980). Semi-arid sites show significant changes with grazing, with intensively grazed areas dominated by the annual *Schmidtia kalahariensis* Stent and moderately grazed areas dominated by the perennial *Eragrostis lehmanniana* Nees. Both these species are less nutritious than perennial grass species such as *Schmidtia pappophoroides* Steud ex J.A. Schmidt, *Anthephora pubescens* Nees and *Eragrostis pallens* Hack. Ex Schinz, all of which remain prevalent in lightly grazed Wildlife Management Areas. At arid sites, the most significant changes relates to intensive grazing (on sites with both cattle and smallstock, and that with solely karakul sheep) leading to declines in the perennial grass *Stigarostis amabilis* Schweick. up to 1.2 km from boreholes (Dougill *et al.*, 2014) leading to reduced herbaceous cover on dune crests.

Animal distributions

Regional patterns of key wildlife species (eland, wildebeest) compared to cattle and smallstock distributions (Fig. 6) show that the expansion of cattleposts and fenced ranches (since the demarcation of ranch blocks in the 1970s and subsequent provision of potable borehole water at sites close to Kgalagadi Transfrontier Park) has led to large areas of the southern Kalahari that have low numbers of these once prevalent ungulates.

Discussion

The findings of the ecological surveys in this study add further evidence to a growing body of literature describing the extensive nature of bush encroachment problems

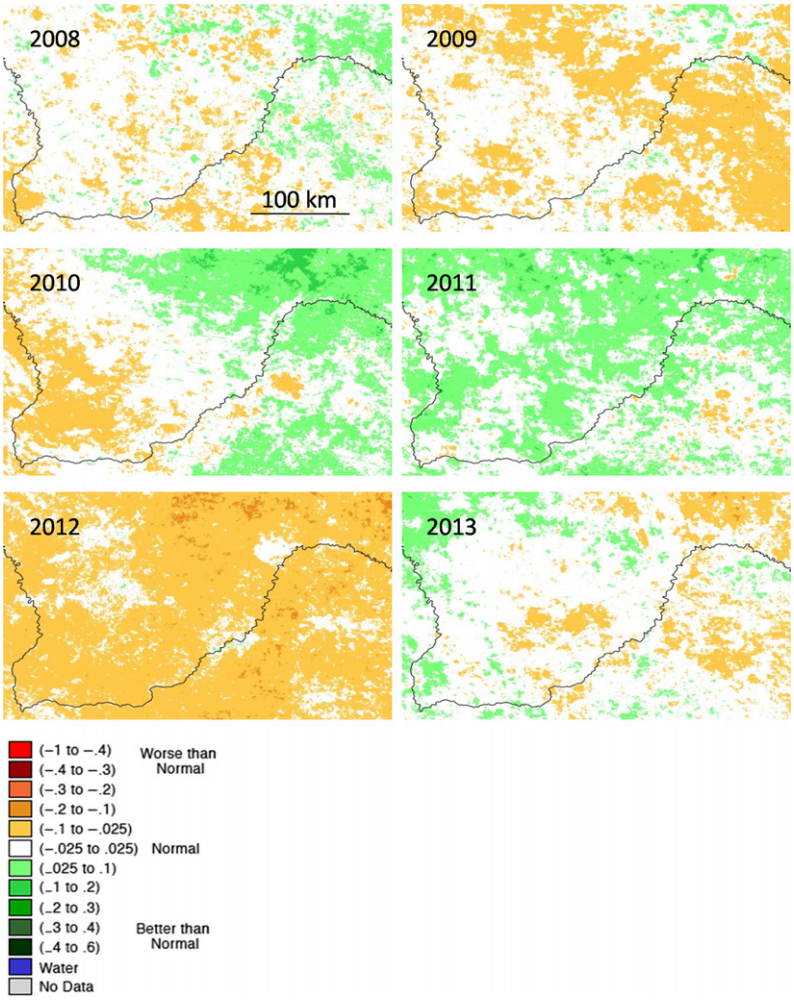

Fig. 3 MODIS NDVI anomalies for southern Kalahari, from 2008 to 2013, depicting early May, end of wet season timeframe. Period of 2000–2013 was used to provide average value. 508 × 635 mm (96 × 96 DPI)

across the semi-arid portions of the southern Kalahari (Jeltsch *et al.*, 1996; Mainah, 2001; Chanda *et al.*, 2003; Thomas & Twyman, 2004; Reed, Dougill & Taylor, 2007; Reed, Dougill & Baker, 2008; Reed *et al.*, 2015). Previous studies in southern Kgalagadi District, have similarly documented bush encroachment of *Acacia mellifera* in semi-arid regions as the most extensive form of rangeland degradation (Moleele & Mainah, 2003; Reed, Dougill & Taylor, 2007) with problems extending nationally (Perkins *et al.*, 2013) and into South Africa (O'Connor, Puttick & Hoffman, 2014) and Namibia (Joubert, Smit & Hoffman, 2013). Previous studies had indicated that more sustainable land management practices and bush encroachment prevention could be achieved in privatized commercial ranch systems (Perrings & Stern, 2000; Thomas & Twyman, 2004; Reed & Dougill, 2010). However, our findings show that reduced bush cover has not been realized on privately owned ranches in our semi-arid study sites. Similarly, in the more arid areas of southwest Botswana, encroachment of *Rhigozum trichotomum* on calcareous soils is the major ecological change, with no significant differences between paddocks with and without karakul sheep. Reduced grass cover in the arid southwest, notably of the dune stabilizing *Stipagrostis amabilis* grass, has led to re-activation of dunes around boreholes (Thomas, Knight & Wiggs, 2005), even though shrub cover remains high on degraded dunes (Rutherford & Powrie, 2009).

The low wildlife numbers reported result from the extensive declines since the 1970s caused by the blocking of migratory routes by veterinary cordon fences (Williamson & Williamson, 1984; Owens & Owens, 1984; Verlinden, Perkins & Murray, 1998). The declines shown in the southern Kalahari (Fig. 6, as compared to previous

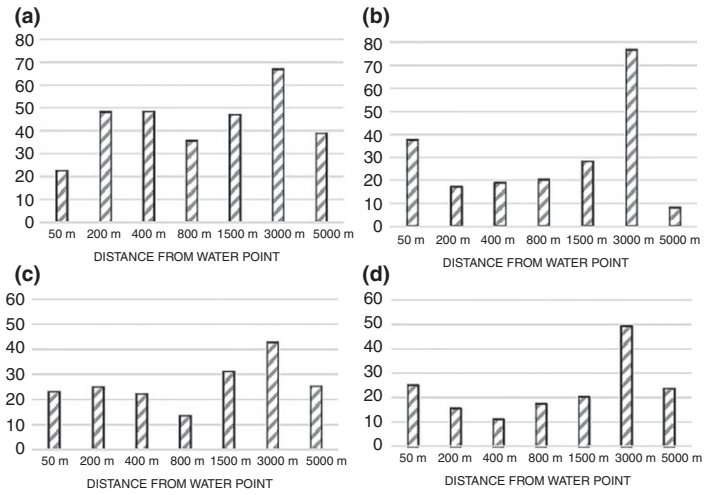

Fig. 4 Woody cover as recorded at two paired sample transects at neighbouring sites differentiated by land use. (a) Kokotsha communal grazing area; (b) Mpungwa cattle ranch (Kokotsha); (c) Van Zyl Cattle Ranch; and (d) Phirima Game Farm

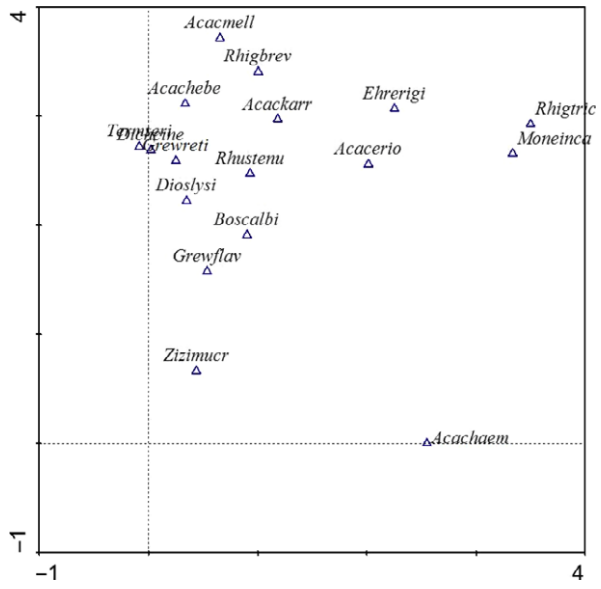

Fig. 5 Woody cover DCA eigenanalysis plot for data from all sampling points/study sites (abbreviations of main bush/tree species recorded)

assessments in DHV, 1980) have been accentuated by the erection of a 100 km 'lion proof fence' along the south-eastern boundary of the Kgalagadi Transfrontier Park and extending into the Wildlife Management Area. This fence was built in the late 1990s. It was erected to prevent livestock encroaching into the Kgalagadi Transfrontier Park and lions and predators from taking domestic stock from six nearby cattleposts where potable water has been secured from deep groundwater reserves (van Vuuren, Herrmann & Funston, 2005). With respect to lion predation losses, the fence has failed. Holes are dug under it by jackals and hyaenas which allow lions through (Kesch, Bauer & Loveridge, 2013). However, the fence acts as a barrier to wild ungulate movement into the large area (*c.* 2000 km^2) between the fence and the Molopo River basin, where potable borehole water is not available due to the high salinity of groundwater. The borehole based expansion of cattleposts and associated fences close to the Kgalagadi Trans-Boundary National Park, and around the settlement of Khawa, has therefore been associated with large tracts of the southern Kalahari having relatively low wildlife numbers making it increasingly difficult to prevent the encroachment of cattle into the Wildlife Management Areas of the region (Twyman, 2000; Sallu, Twyman & Stringer, 2010).

The decline of wildlife is primarily attributed to loss of ungulate mobility due to the erection of fences. This has prevented seasonal migrations to wetter areas such as around the Boteti River or to the mineral rich belt of pans known as the Schwelle that is an important wet season calving area (DHV, 1980). These Kalahari findings match those from studies assessing the negative impacts of livestock expansion on wildlife numbers in northern Kenya (Leeuw *et al.*, 2001). Declines in wildlife numbers impact on the ability of Wildlife Management Areas to generate income from community-based tourism initiatives (Mulale & Mbaiwa, 2012), with the scope for income from hunting licenses being removed entirely by the national hunting ban that came into effect in early 2014. Government support measures continue to incentivize the livestock

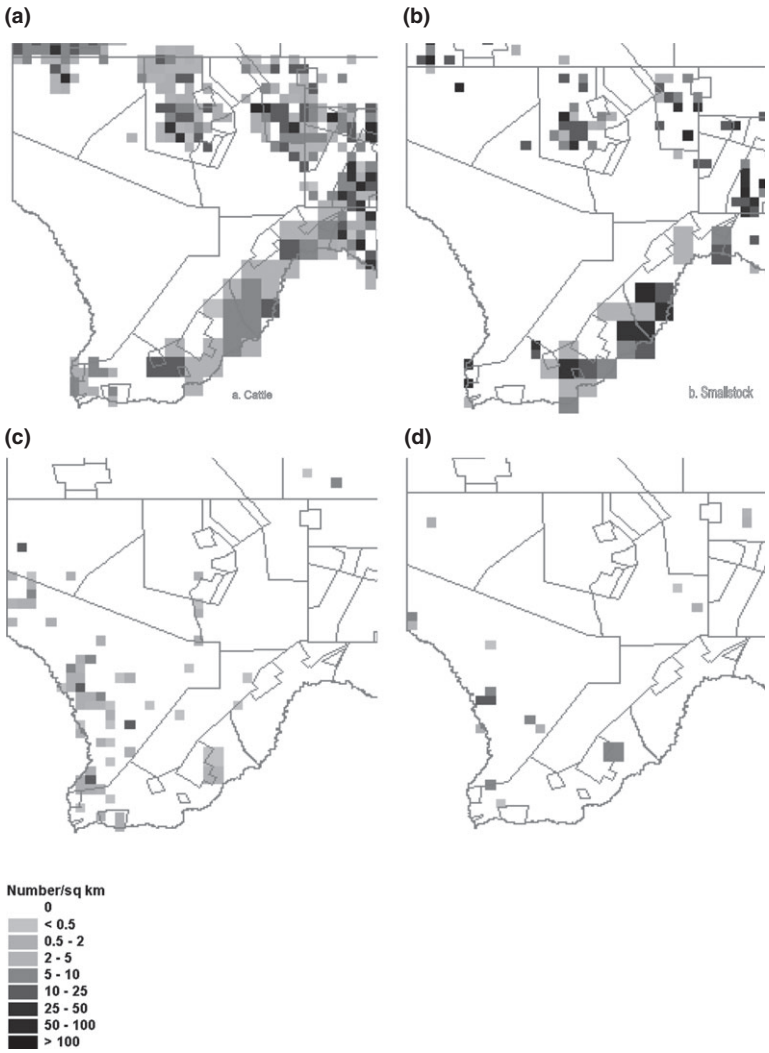

Fig. 6 Spatial Distribution and Abundance of (a) Cattle; (b) Smallstock (sheep and goat); (c) Eland; and (d) Wildebeest for southern Kalahari region. *Source: Amended from Aerial Animal Census* (*Republic of Botswana, 2012*)

sector in the southern Kalahari leading to land degradation concerns of bush encroachment and dune activation, as well as wildlife declines.

The dual-scale ecological analyses from the southern Kalahari presented here add new insights and multi-scale evidence outlining rangeland degradation and wildlife conservation problems associated with intensive grazing of arid and semi-arid rangelands and the specific pressures affecting the southern Kalahari, Botswana. Dune mobilization 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. These are linked to intensive grazing pressures affecting both communal and privately owned land. Landscape-scale studies show the wider impacts on aspects of biodiversity, in terms of wildlife numbers of ungulate species, caused by shifts in land use towards more widespread cattle grazing, even where this is not intensive due to water or ecological constraints. This integrated, farm- and regional-scale ecological evidence will be used in holistic assessment and economic valuation studies (Favretto *et al.*, 2014) to consider land use policy and rangeland management options for the future Kalahari.

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