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How are people affecting the distribution of less migratory wildlife in the southern Kalahari of Botswana? A spatial analysis

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Previous studies suggested an influence of human settlements on the distribution patterns of some less migratory wildlife species in the Kalahari ecosystem. This study addresses two alternative hypotheses to explain the observed patterns: habitat change caused by livestock grazing, and wildlife utilization. Relationships between selected common and less migratory wildlife species and livestock distribution were examined using aerial counts, ground counts, spoor (tracks and dung) information and vegetation surveys in a portion of the Kalahari of Botswana in a Geographical Information System (GIS).

The vegetation surveys indicated effects on the vegetation up to 10 km from the livestock waterpoints. Livestock-induced habitat change appeared to have little effect on most wildlife species. All wildlife survey methods and analyses indicated the occurrence of a gap between the impact radius of livestock and high densities of gemsbok *Oryx gazella*, suggesting that the distribution of the latter was to be attributed to high hunting pressure resulting in displacement.

It is suggested that selective wildlife utilization is a more important factor in the current distribution of common game species than avoidance of areas changed by livestock in the southern Kalahari.

Keywords: livestock; wildlife; vegetation; Kalahari; utilization; spatial statistics

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Introduction

Agricultural utilization of arid and semi-arid environments in Africa used to be restricted (Cooke, 1985; Perkins & Thomas, 1993) and these environments were generally neglected except by hunter–gatherer and pastoral–nomad groups in low densities. From the 1950s onwards the Kalahari was increasingly viewed as a large, virtually untapped grazing resource (Debenham, 1952). Exploitation of this resource has been made possible by the sinking of boreholes to tap ground-water permitting year-round grazing (Perkins & Thomas, 1993). The growth of the Kalahari cattle industry, especially since the 1970s, has generated both social and environmental issues (Perkins, 1996), including conflicts between wildlife and livestock utilization (e.g. Thomas, 1988) and the idea that livestock grazing is causing widespread range degradation and desertification (e.g. Cooke, 1985). Important declines in wildlife populations in the recent past (Spinage & Matlhare, 1992; Department of Wildlife and National Parks, 1995) have often been attributed to livestock encroachment and associated developments in dry season wildlife refuges (Williamson *et al*., 1988). Most important declines were found in highly migratory species while less migratory species seemed much less affected.

Using coarse resolution aerial survey and environmental data on vegetation cover and fire distribution, Verlinden (1997) demonstrated differences in distribution between wildlife and livestock, with some species clearly avoiding livestock areas and other species less affected. The grid resolution was 10×10 km in wildlife areas and 10×20 km in livestock areas. While appropriate in a regional context, this grid size is less suited to detect more subtle differences in wildlife distribution. Research in the eastern Kalahari has demonstrated that the impact of livestock on the environment is generally restricted to a radius of less than 5 km from the waterpoint (Perkins, 1991, 1996). In addition, these data do not allow differentiation between two alternative effects of human interference: (1) wildlife utilization (hunting and poaching) and (2) competition for the grazing resource by livestock. Parris & Child (1973) have suggested that effects of livestock keeping on the vegetation in the southern Kalahari could still be noticed after several decades of protection with likely negative effects on wildlife. However, little information is available to allow one to determine causal relationships between livestock impact and wildlife distribution.

The present study aims first to determine the extent of environmental changes associated with unfenced borehole-based livestock keeping in a representative portion of the southern Kalahari. The environmental changes are then compared with livestock and wildlife spoor (dung and tracks), ground counts and aerial survey distribution, and analysed in a spatial context to explore the alternative effects of human interference on wildlife. In the study area various inhabitants and hunters reported a gradual decline in most wildlife populations over the last 20 years in the communal areas (DHV Consulting Engineers, 1980; De Kock, pers. comm.; White, pers. comm.), while Bonifica (1992*a*) and Department of Wildlife and National Parks (1995) found no declines for less migratory species in adjacent protected areas. Smithers (1971) noted large numbers and important nomadic movements of wildlife in an area where now only livestock can be seen, demonstrating that current livestock areas were suitable for most wildlife species in the past.

Study area

Figure 1 shows the area studied in the south-western part of the Kalahari of Botswana. Geologically, the Kalahari is regarded as an extensive basin infilled with sediments dominated by nutrient-deficient Kalahari sand (Thomas & Shaw, 1990, 1991). Average rainfall is around 300 mm in Tsabong (Fig. 1) with an inter-annual variability as high as 45% (Bhalotra, 1985). The Kalahari has no permanent surface water and access to permanent water on its boundaries is increasingly being hampered by fencing and associated human developments. These factors make the Kalahari a location where natural water availability is very limited. Traditionally, wildlife coped with the lack of water by physiological mechanisms and/or by migration. This study concentrates on less migratory species, not moving towards greener patches over large distances (Verlinden & Masogo, 1997), and which are known to have occurred in large numbers throughout the southern Kalahari (Bonifica, 1992*b*).

Methods

Spoor

At 43 points along tracks indicated in Fig. 1, counts of wildlife and livestock tracks and dung were undertaken, and vegetation surveys were carried out in September 1991 at the peak of the dry season. Communal grazing areas, wildlife management areas (WMAs) and a portion of Gemsbok National Park were sampled. Data were collected during the hunting season. All locations were obtained with a Global Positioning System (GPS).

Dung and tracks were identified using a reference collection gathered by following herds and identifying fresh tracks and dung specimens. Liebenberg (1990) was used as an additional reference. Spoor data have been used before in the Kalahari (Parris & Child, 1973). At each sampling point a transect of 100 m perpendicular to the track was followed, starting 50 m from the track. Although most tracks were little used by vehicles, the first 50 m were not included to minimize a possible edge-effect. Although the original wildlife data were counts, they were converted to the following categories:

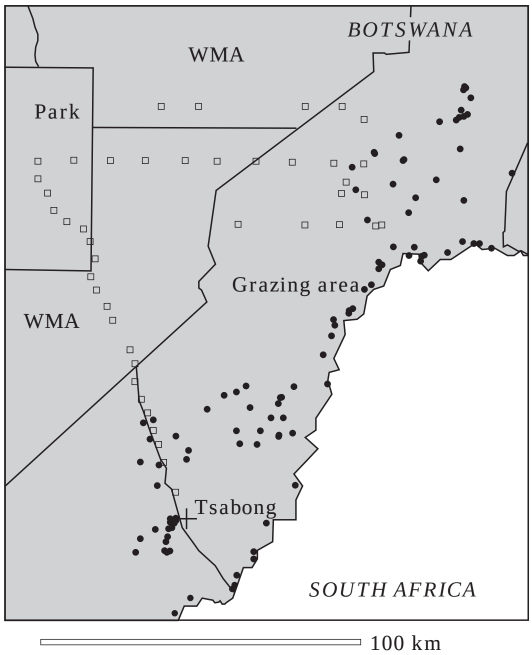

Figure 1. Map of the surveyed area in Botswana ▢, with location of waterpoints for livestock (●) and location of the vegetation/spoor samples (☐). Grazing area is the communal grazing area, WMA are wildlife management areas and Park is a portion of Gemsbok National Park.

(0) not present; (1) very low density, 1–2 counts of tracks or dung; (2) low density, 3–5 counts; (3) medium density, 5–10 counts; (4) high density, 10–20 counts; and (5) very high density, > 20 counts. Due to the sometimes very high spoor densities of livestock, they were not counted but scored on the scale of 0 to 5.

Vegetation

Vegetation was sampled in 20×50 m quadrats, an area found to be suitable for vegetation surveys in the Kalahari (Skarpe, 1986). Cover of each species was estimated using the method of Mueller-Dombois & Ellenberg (1974), including an estimate of bare ground. Only woody species, dwarf shrubs and grasses were included, as Skarpe (1986) found that the inclusion of herbs did not influence vegetation classification.

Ground counts

Another wildlife and livestock density index was derived from 16 ground counts undertaken between April 1991 and April 1992 from a vehicle driving at a speed of 40 km h^{-1} along the track between Tsabong and Gemsbok National Park (Fig. 1). All species sighted were counted. Distances were obtained by odometer readings and GPS readings at 5-km intervals. The mean number seen on 5-km stretches was used as an index of density.

Aerial counts

The methodology of Norton-Griffiths (1978) was used to monitor wildlife and livestock populations. The surveys covered the district degree square by degree square, using 6 min of longitude as the basic spacing. In livestock areas, transects were flown at 12 min spacing. Sampling strips were demarcated by rods and streamers attached to the lift struts of a Cessna 206 aircraft and calibrated trigonometrically. The mean strip width was calibrated at 200 m at a flying height of 90 m. The average density distribution of six surveys between 1989 and 1993 was used to obtain the estimates of the main livestock and wildlife populations of the study area (Table 1).

Data analysis

Waterpoint locations were derived from a waterpoint survey of the area (Natural Resources Services & Knight-Piésold Botswana, 1991) (Fig. 1). Waterpoints for wildlife were excluded, to ensure that only waterpoints used for livestock, usually in the

Table 1. *Estimated total numbers and 95% confidence limits (CL) of main livestock and wildlife species in six aerial counts between 1989 and 1993 for the study area (total area 20,294 km^2)*

Species	Average total	±95% CL
Cattle	27,132	798
Gemsbok	10,201	268
Springbok	8254	574

form of a cattle-post, were included in the analysis. All GPS readings were converted to a UTM-34 projection using IDRISI, a Geographical Information System (GIS) (Eastman, 1996).

The GIS was used to calculate a distance image from the waterpoint locations. Using overlays with the GPS readings of the sampling points, the distance from each sampling point to the nearest waterpoint was determined.

The change in vegetation cover and animal density as a function of distance from the waterpoint was examined. Because some animal density estimates were expressed on a categorical scale, Spearman rank correlation coefficients (r_s) were used to estimate the magnitude of change with distance. As scatterplots indicated that the change was often not gradual, but rather followed a step function, the form of the relationship was estimated using first order asymptotic models of the form:

$$y = \mathrm{a1} + \mathrm{a2}/(1 + e^{\mathrm{b1}-\mathrm{b2}x})$$

where x = distance from the waterpoint and y = the variable under consideration, fitted using least squares.

More gradual changes were tested for significance with Kruskal-Wallis one-way analysis of variance by ranks (Siegel & Castellan, 1988).

Animal density distributions were calculated with computer programs developed by Bonifica (1992*a*) for aerial census data. The resulting grid maps were converted to the UTM-34 S projection. As data of only one survey show many empty cells, the average distribution of six aerial counts between 1989 and 1993 was used for comparing the results obtained by the index of tracks and dung and the ground counts.

Non-random systematic sampling methods often result in high degrees of spatial autocorrelation (Legendre & Fortin, 1989) and therefore lack independence, prohibiting the use of conventional statistics for testing spatial relationships. Spatial autocorrelation was tested with Moran's I (Moran, 1948). Trend surface analysis (Gittins, 1968) was used to analyse spatial trends. Following Legendre & Fortin (1989) and Borcard *et al.* (1992) a second order polynomial trend-surface regression equation of the form:

$$z = \mathrm{b0} + \mathrm{b1}\ x + \mathrm{b2}\ y + \mathrm{b3}\ x^2 + \mathrm{b4}\ xy + \mathrm{b5}\ y^2$$

with geographical coordinates latitude (x) and longitude (y) was fitted to the data. High determination coefficients of fitted polynomials in the trend-surface analysis have ecological meaning (Gittins, 1968). Spatial autocorrelation of the residuals was also tested with Moran's I. No significant autocorrelation of the distribution of the residuals indicate that most spatially dependent information is explained by the trend surface analysis.

Geostatistical techniques including variogram analysis and kriging, a statistical and exact interpolation method (Journel & Huijbrechts, 1978), were carried out with GEO-EAS software on the aerial survey estimates. To predict animal densities a semi-variogram of the aerial counts was analysed. A spherical model with a nugget C_0 and a sill C_1 was chosen to fit the semi-variogram. These variogram parameters were used in ordinary kriging to describe the spatial structure of gemsbok distribution in more detail.

Results

Effects of distance from the waterpoint on vegetation cover

Figure 2 shows the results obtained by fitting the asymptotic models to the vegetation cover data. It demonstrates bush encroachment around the waterpoints, with higher cover of woody plants decreasing from the waterpoint significantly (r_s = –0·56,

$p < 0{\cdot}001$). The asymptotic model suggests a decrease at 6 km onwards but extending up to 8 km from the waterpoint.

Grass cover increased from an average of 15% close to the waterpoint to an average of 45% ($r_s = 0{\cdot}77$, $p < 0{\cdot}001$). The fitted model suggests an effect up to 20 km from the water point, although already at 10 km the influence is low.

Effects of distance from the waterpoint on livestock densities

Cattle spoor densities decreased sharply from the waterpoint ($r_s = –0{\cdot}87$, $p < 0{\cdot}001$). The asymptotic model suggests a decrease from 7 km onwards and a low level from 9 km onwards. However, some cattle tracks were found up to 20 km from the waterpoint, indicating that livestock have an effect on vegetation up to 20 km. Cattle ground counts indicated a similar negative correlation with distance ($r_s = –0{\cdot}89$, $p < 0{\cdot}001$). The fitted model indicated a decrease at 12 km with no cattle sighted at distances further than 13 km.

The correlations for donkey and goats + sheep with distance were similar to those obtained for cattle (donkey $r_s = –0{\cdot}78$, $p < 0{\cdot}001$; goats + sheep $r_s = –0{\cdot}79$, $p < 0{\cdot}001$). The fitted models suggest that especially goats + sheep tend to stay closer to the waterpoints.

Combining the results of the livestock data with the vegetation data, the effects of livestock can be summarized in the following zones: (1) 0–1 km: a very high impact zone of livestock trampling and grazing on grass cover, commonly resulting in bare ground and bush encroachment; (2) 1–5 km: a high impact zone of livestock resulting in low grass cover and bush encroachment; (3) 5–10 km: a low impact zone of livestock

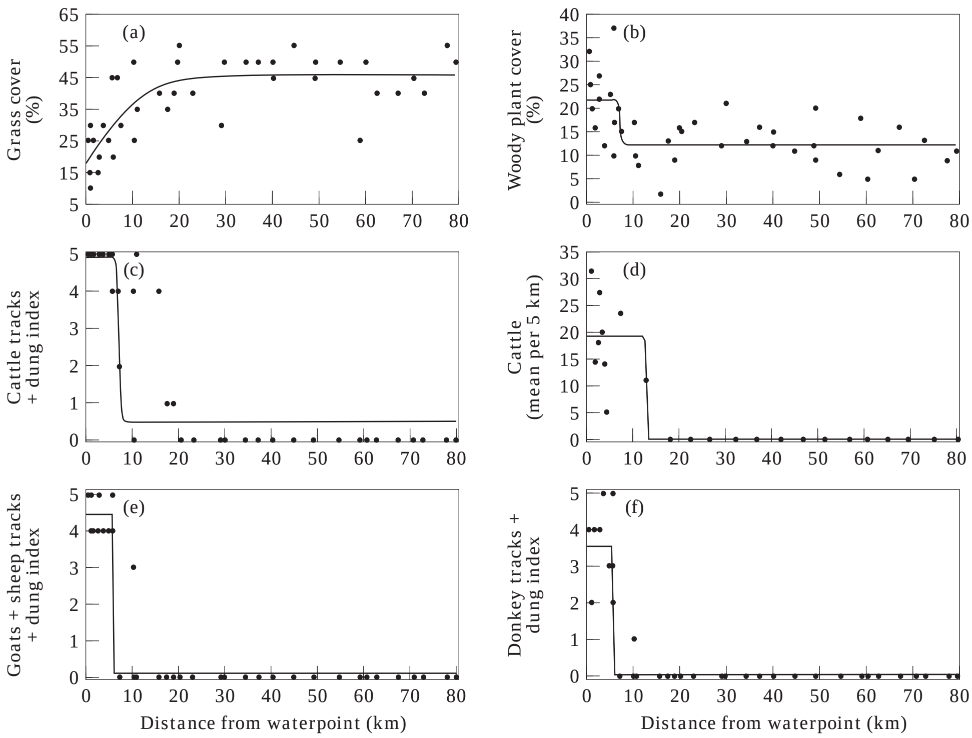

Figure 2. Relationships between distance from waterpoint and (a) grass cover, (b) tree cover, (c) cattle spoor, (d) cattle ground counts, (e) sheep + goats spoor, and (f) donkey spoor.

with bush encroachment non-existent further than 8 km and characterized by below average grass cover; and (4) 10–20 km: only occasional traces of cattle, probably visited only in the cold dry season. Effects on the vegetation are not important in this last zone.

Figure 3 illustrates the geographical extent of effects of livestock in the study area, based upon the locations of waterpoints used for livestock and the impact zones. The National Park and the WMAs do not show effects of livestock grazing and most livestock effects appear to be concentrated along the border with South Africa.

Effects of distance from the waterpoint on wildlife densities

The fitted models of the wildlife spoor and count data in Fig. 4 demonstrate important differences between gemsbok (*Oryx gazella*), steenbok (*Raphicerus campestris*), duiker (*Sylvicapra grimmia* spp.) and springbok (*Antidorcas marsupialis*). Although kudu (*Tragelaphus strepsiceros*) were occasionally sighted and their spoor found, the numbers were too low to provide useful information. Gemsbok spoor densities and the numbers counted from road transects increased with distance (r_s = 0·89, p < 0·001, r_s = 0·92, p < 0·001, respectively). The fitted models in the graphs suggest a gradual impact of distance to waterpoints on gemsbok distribution to a radius of about 45–50 km. Between 0 and 20 km gemsbok are likely to be very rare. Kruskal-Wallis ANOVA was applied to the data on gemsbok spoor and counts of the zones 0–20 km, 20–40 km and > 40 km from waterpoints. Gemsbok spoor density was much lower in the zone 0–20 km than in the zone 20–40 km (Kruskal-Wallis H = 16·7, p < 0·001, N = 27), while spoor in the zone 20–40 km was also less abundant than at > 40 km (Kruskal-Wallis H = 8·2, p < 0·01, N = 22). Gemsbok counts were much lower in the zone

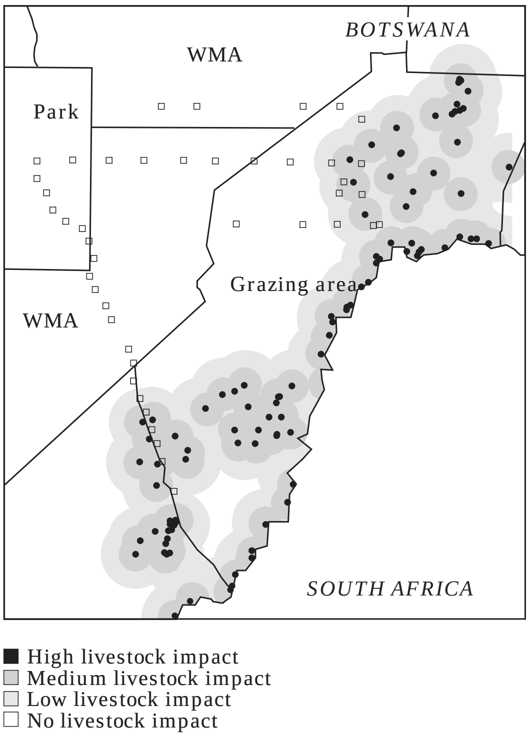

Figure 3. Livestock impact zones in the study area derived from the results of the vegetation change studies.

< 20 km than in the zone 20–40 km (Kruskal-Wallis $H = 12{\cdot}6$, $p < 0{\cdot}001$, $N = 17$) while also lower in the zone 20–40 km than in the zone > 40 km (Kruskal-Wallis $H = 4{\cdot}7$, $p = 0{\cdot}03$, $N = 13$).

Steenbok and duiker (combined) spoor data resulted in a minor impact up to 8 km from the waterpoint with distance ($r_s = 0{\cdot}39$, $p = 0{\cdot}01$), while steenbok counts were only marginally significant ($r_s = 0{\cdot}58$, $p < 0{\cdot}05$). The distance relationships with springhare *Pedetes capensis* and scrubhare *Lepus saxatilis* were not significant ($r_s = 0{\cdot}2$, $p > 0{\cdot}1$), suggesting no impact of livestock or utilization on presence and abundance. High scores of springbok are frequent at short distances from waterpoints, but they select also pan habitats that are unrelated to waterpoint locations.

Aerial survey estimates and livestock influences

In Fig. 5 overlays of density distribution maps from aerial survey estimates with the livestock impact map of Fig. 3 are presented. While the distributions of steenbok,

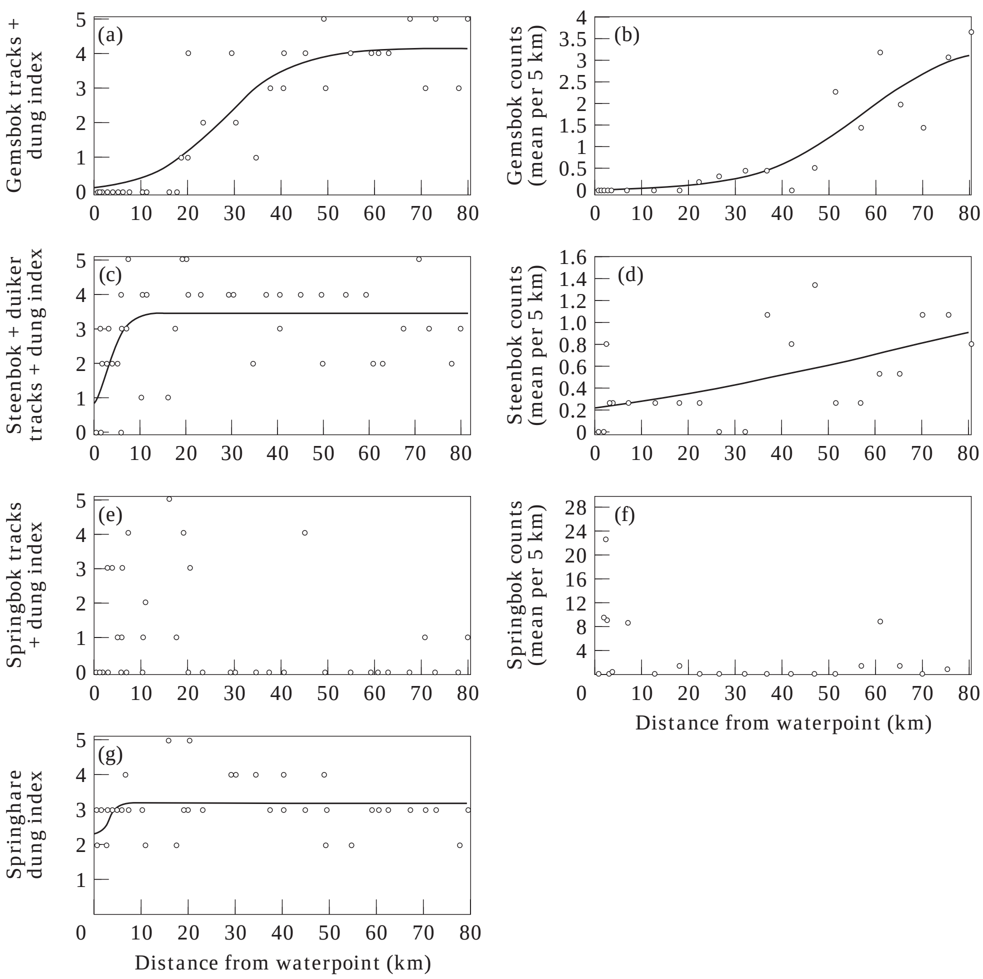

Figure 4. Relationships between distance from waterpoint and (a) gemsbok spoor, (b) gemsbok ground counts, (c) steenbok + duiker spoor, (d) steenbok ground counts, (e) springbok spoor, (f) springbok ground counts, and (g) springhare spoor.

duiker and springbok are in agreement with the analysis of the spoor and ground count data, a visual comparison of the gemsbok distribution with the cattle distribution shows that gemsbok are very rare in livestock areas, but a zone of lower densities beyond the livestock impact is hard to distinguish by eye. Therefore, the relationship between gemsbok densities and waterpoint distance had to be statistically tested.

The gemsbok distribution image showed high spatial autocorrelation (Moran's $I = 0{\cdot}31$, $Z = 5{\cdot}7$, $p < 0{\cdot}001$) and therefore conventional statistics could not be applied to test the significance of density–distance relationships. A second order

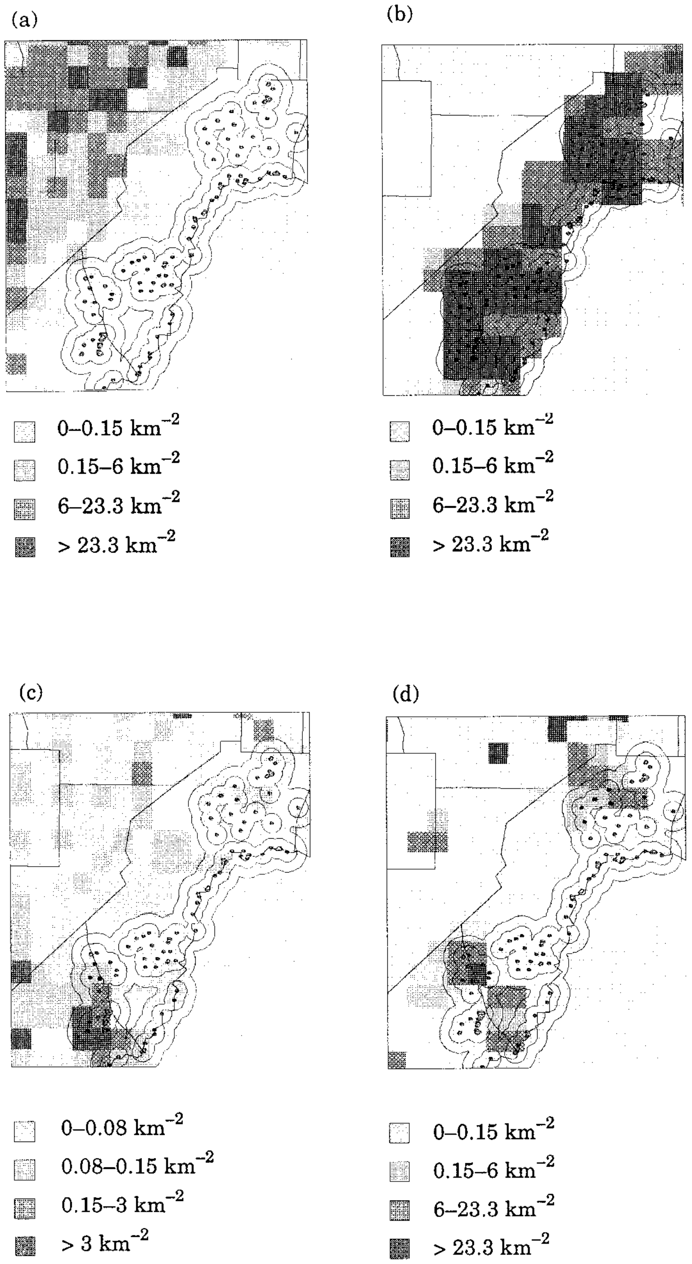

Figure 5. Overlays of livestock impact zones with animal density distribution maps from aerial surveys 1989–1993: (a) gemsbok; (b) cattle; (c) steenbok + duiker; and (d) springbok.

polynomial trend-surface regression equation was fitted to the gemsbok aerial survey estimates in order to isolate the spatial structure. This resulted in a smooth model with a determination coefficient $R^2 = 0{\cdot}36$. The trend corresponded with the gradual increase in gemsbok density with distance from waterpoints as was suggested by the gemsbok spoor and ground counts analysis. Higher order polynomials did not improve the fit. The image of the residuals after fitting the trend-surface equation suggested that there was no other spatially related variation in the data (Moran's $I = 0{\cdot}06$, $Z = 1{\cdot}19$, $p = 0{\cdot}23$). There appeared indeed to be no further relationship between the residuals and distance to waterpoints. Given the high coefficient of determination of the trend-surface analysis, it is suggested that the density distribution of gemsbok in the study area is largely determined by distance from waterpoints.

A semi-variogram of the gemsbok estimates suggested a best fit of a spherical model with a nugget $C_0 = 1000$ and a sill $C_1 = 7{\cdot}50$ at a lag distance of 100 km. These variogram parameters were used in ordinary kriging. The predicted gemsbok densities obtained by kriging are presented in Fig. 6, together with the livestock impact zones. The kriged density contours demonstrate a gradual increase in gemsbok density beyond the areas affected by livestock, a gradient that was not obvious in the density distribution map of gemsbok in Fig. 5.

Discussion

The vegetation data confirmed the occurrence of bush encroachment and a reduction in grass cover as a result of livestock keeping in the immediate surroundings of the waterpoint. The effect on grass cover in the dry season apparently extends further than found in other areas during the wet season (Perkins, 1991; Perkins & Thomas, 1993) but this might be influenced by the wide variation around the average cover further away from the waterpoint.

The highest densities of cattle coincide with waterpoint locations and there is a high overlap between the livestock impact zones and cattle distribution. The aerial survey distribution data indicate that low densities of cattle were indeed found outside the 10 km zone as was suggested by the spoor data and ground counts.

Although spoor information and ground count data on many game species were collected, useful information for this study was only obtained for the four common antelope species in the area. Springbok appeared not adversely affected by livestock presence or human wildlife utilization. Although quite common close to waterpoints, their preference for pans elsewhere precluded a demonstrable relationship with waterpoint distance using an asymptotic model. The data suggest strongly that springbok are attracted to the areas of lower grass cover associated with livestock keeping. Springbok are known to select high quality forage (Skinner *et al.*, 1987). In terms of wildlife utilization, it means that this resource could easily be depleted as they seem to occur concentrated in patches in the same area throughout the year. Data on steenbok and duiker suggest that numbers are somewhat lower than average between 0–8 km from the waterpoint. Aerial surveys are less useful here as these animals are easily overlooked. As with springbok, it is unlikely that livestock grazing and browsing causes competition for resources as very high densities are found well within the radius of high livestock impact.

Of the four common larger game species, only gemsbok were very rare inside the livestock impact radius (two sightings during aerial surveys). Ground counts and spoor data indicated a gradual increase of gemsbok between the livestock impact zones and protected areas where they occur at high densities. This gradient was confirmed with trend surface analysis and ordinary kriging on the aerial counts. Competition for resources between livestock and gemsbok is unlikely to cause these differences in distribution. Preference for gemsbok meat, hunting methods used (horses with dogs and spears) and poaching affect the level of hunting pressure on gemsbok. Many subsistence hunters claim that hunter effort per kg of meat is still greater for steenbok and duiker than for gemsbok though this is likely changing in some areas. Special game licence quotas, issued by the Department of Wildlife and National Parks, are now supposed to be included in total gemsbok hunting quota for each hunting area.

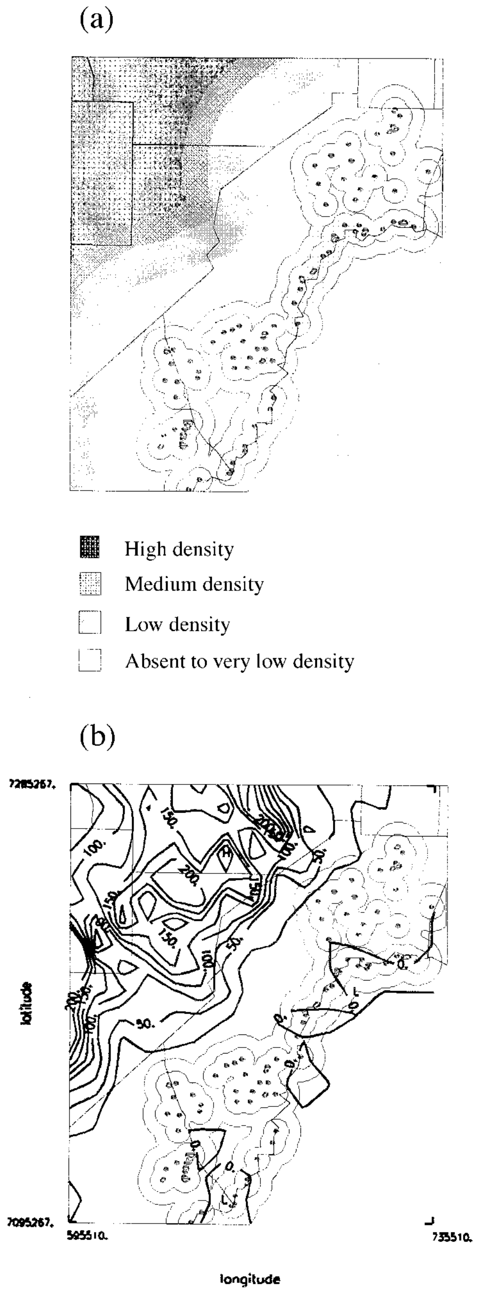

Figure 6. (a) Overlay of livestock impact zones and abundance zones of gemsbok derived from the relationships between ground counts and spoor with distance, and (b) overlay of livestock impact zones with predicted gemsbok densities (number per 100 km^2) using ordinary kriging on aerial survey counts.

The results presented here suggest that aerial survey data, used in conjunction with wildlife spoor data, waterpoint and vegetation surveys and to a lesser extent ground counts, are useful for the spatial analysis of species distributions in the Kalahari. The direct impact of vegetation change caused by livestock on less migratory wildlife in the Kalahari appears to be small in comparison with wildlife utilization by humans.

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