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# Elephant distribution around a volcanic shield dominated by a mosaic of forest and savanna (Marsabit, Kenya)

Shadrack M. Ngene<sup>1,2\*</sup>, Andrew K. Skidmore<sup>2</sup>, Hein Van Gils<sup>2</sup>,  
Iain Douglas-Hamilton<sup>3</sup> and Patrick Omondi<sup>4</sup>

<sup>1</sup>Kenya Wildlife Service, Meru National Park, PO Box 11, Maua, Kenya, <sup>2</sup>International Institute for Geo-Information Science and Earth Observation (ITC), Hengelosestraat 99, PO Box 6, 7500 AA, Enschede, The Netherlands, <sup>3</sup>Save the Elephant Trust, PO Box 54667, Nairobi 00200, Kenya and <sup>4</sup>Kenya Wildlife Service, PO Box 40241, Nairobi, Kenya

## Abstract

We investigated the factors that influenced the distribution of the African elephant around a volcanic shield dominated by a mosaic of forest and savanna in northern Kenya. Data on elephant distribution were acquired from four female and five bull elephants, collared with satellite-linked geographical positioning system collars. Based on the eigenvalues (variances) of the correlation matrix, the six factors that contributed significantly to high total variances were distance from drinking water (24%), elevation (15%), shrubland (10%), forest (9%), distance from settlements (8%) and distance from minor roads (7%), contributing to 73% in the observed variation of the elephant distribution. The elephants were found at high forested elevations during the dry season but they moved to the lowlands characterized by shrubland during the wet season. Elevation acts as a proxy for the vegetation structure. The presence of elephants near permanent water points (13%) and seasonal rivers (11%) during the dry and wet seasons, respectively, demonstrates that water is the most important determinant of their distribution throughout the year. We conclude that the distribution of elephants in Marsabit Protected Area and its adjacent areas is influenced mainly by drinking water and vegetation structure.

*Key words:* elephant, forest, Marsabit Protected Area, principal component analysis, satellite-linked GPS collars, shrubland, soils

## Résumé

Nous avons étudié les facteurs qui influencent la distribution de l'éléphant africain autour d'un bouclier volcanique

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\*Correspondence: E-mail: [ngene@itc.nl](mailto:ngene@itc.nl)

dominé par une mosaïque de forêt et de savane dans le nord du Kenya. Les données sur la distribution des éléphants furent acquises grâce à quatre femelles et cinq mâles équipés de colliers radio avec GPS par satellite. En se basant sur les valeurs propres (variances) de la matrice de corrélation, les six facteurs qui ont contribué significativement à de fortes variances totales étaient la distance par rapport à l'eau (24%), l'élévation (15%), la savane arbustive (10%), la forêt (9%), la distance par rapport à des installations (8%) et celle par rapport à des routes peu importantes (7%), qui contribuent donc ensemble à 73% de la variation observée dans la distribution de l'éléphant. Des éléphants se trouvaient sur de hautes élévations forestières pendant la saison sèche, mais ils se déplaçaient vers les terrains de basse altitude caractérisés par des broussailles pendant la saison des pluies. L'élévation sert de proxy à la structure de la végétation. La présence d'éléphants près des points d'eau permanents (13%) et des rivières saisonnières (11%) pendant la saison sèche et la saison des pluies respectivement montre que l'eau est le déterminant le plus important de leur distribution tout au long de l'année. Nous concluons que la distribution des éléphants dans la *Marsabit Protected Area* et dans les zones adjacentes est influencée principalement par la disponibilité de l'eau et la structure de la végétation.

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## Introduction

The distribution of animals including elephants varies across landscapes. Interacting factors, which influence this distribution, include drinking water sources, forage, shelter, salt licks, soil fertility (nutrients for plants), slope angle and elevation (Tchamba, Bauer & De Iongh, 1995; Thouless, 1996a,b; Blom *et al.*, 2005; Wall,

Douglas-Hamilton & Vollrath, 2006). Infrastructure (settlements, crop fields, roads, fences and so on) often restricts or compresses the elephants' range and may block migratory routes (Newmark, 1996).

Studies on the African elephant have analysed home range, movement patterns, foraging behaviour and population dynamics (e.g. Douglas-Hamilton, 1973; Leuthold & Sale, 1973; Lindeque & Lindeque, 1991; Tchamba, 1993; Whyte, 1993; Grunblatt *et al.*, 1995; Tchamba *et al.*, 1995; Thouless, 1995, 1996a,b; Galanti *et al.*, 2000; Blake & Douglas-Hamilton, 2001; Douglas-Hamilton, Krink & Vollrath, 2005; Leggett, 2006 among others). Technological limitations and associated high costs of radio-telemetry had made data collection over 24-h periods difficult (Leuthold & Sale, 1973; Thouless, 1995, 1996a,b). However, recent advancements in wildlife telemetry have tackled most of these limitations and allowed a refocusing of research on elephant distribution (Douglas-Hamilton *et al.*, 2005).

The development of satellite-linked geographical positioning system (GPS) collars has resulted in a better understanding of the interaction between elephants and their biotic and abiotic environment (Galanti *et al.*, 2000). With this new technology, data on elephant locations may be collected over 24-h periods. This makes it possible to overlay elephant location data on environmental data layers and analyse their interactions, allowing researchers to establish the main factors influencing elephant distribution. GPS collars provide high spatial-temporal resolution and plot individual locations (Douglas-Hamilton *et al.*, 2005). Our study is the first to track elephants in Marsabit, and then explain the elephants' usage of a landscape dominated by a mosaic of forest and savanna.

A mosaic of forest and savanna occurs around Mount Marsabit, a volcanic shield surrounded by a desert and semi-desert environment (McLaughlin, Dougherty & McLaughlin, 1973). Because of its high altitude of about 1680 m above sea level, the mountain receives an annual rainfall of between 800 and 1000 mm annual rainfall, which is adequate to support forest cover (Oroda *et al.*, 2005). However, the areas below the peak of the mountain are characterized by a gently sloping plateau of volcanic origin (McLaughlin *et al.*, 1973). The mountain peak with its gently sloping plateau makes the mountain look like a shield. The plateau receives <250 mm annual rainfall, which is adequate to support shrubby vegetation. The rich volcanic soils support nutritious plants, which are consumed by elephants (Ngene & Omondi, 2005). The

mountain has permanent water sources, whereas water on the gently sloping plateau is available only during the rainy season (Loltome, 2005). Woody plants around the mountain are evergreen, whereas shrubs and trees on the gently sloping plateau shed their leaves and are consequently of less nutritional value to the elephants (Ngene & Omondi, 2005). Humans have settled around the mountain because of the availability of drinking water and good soils (Oroda *et al.*, 2005).

Space for elephants has decreased with the increase in human population, thereby causing changes in land use and even land tenure systems (Douglas-Hamilton *et al.*, 2005). It is therefore important to understand and explain how different factors interact and influence the elephant distribution (Douglas-Hamilton *et al.*, 2005). This knowledge may be used by park managers to effectively provide security for elephants throughout the year. In this study, we quantify the impact of a set of environmental factors on the spatial distribution of elephants in Marsabit Protected Area. The potential implications of the extension of settlement schemes and drinking water points on the future of elephant conservation in Marsabit are also forecast.

## Materials and methods

### Study site

Marsabit National Park (360 km<sup>2</sup>) and Reserve (1132 km<sup>2</sup>) are together labelled as a protected area (Fig. 1) and are centred on longitude 37°20'E and latitude 2°20'N. Its precipitation regime is characterized by two rainy seasons, with peaks in April and November. The annual rainfall varies from 50 to 250 mm on the plains and 800 to 1000 mm on the mountain. The evaporation rate is high, at about 2400 to 2600 mm per year (Synott, 1979). The eco-climatic zone of the forest is categorized as sub-humid and the surrounding plains fall within the very arid category (Eiden, Keith & Jonnes, 1991).

A characteristic feature of the protected area is Mount Marsabit (1680 m a.s.l) and its conspicuous evergreen forest covering about 12.5 km<sup>2</sup> (Oroda *et al.*, 2005). The mountain, a dormant remnant of a shield volcano, arose in the Tertiary (McLaughlin *et al.*, 1973). The surrounding areas are characterized by a gently sloping plateau of volcanic origin (McLaughlin *et al.*, 1973). Spectacular craters indent the surface of the protected area. Most prominent are Sokorte Dike, which contains a small lake and Gof Sokorte Guda, which envelops Lake Paradise, both

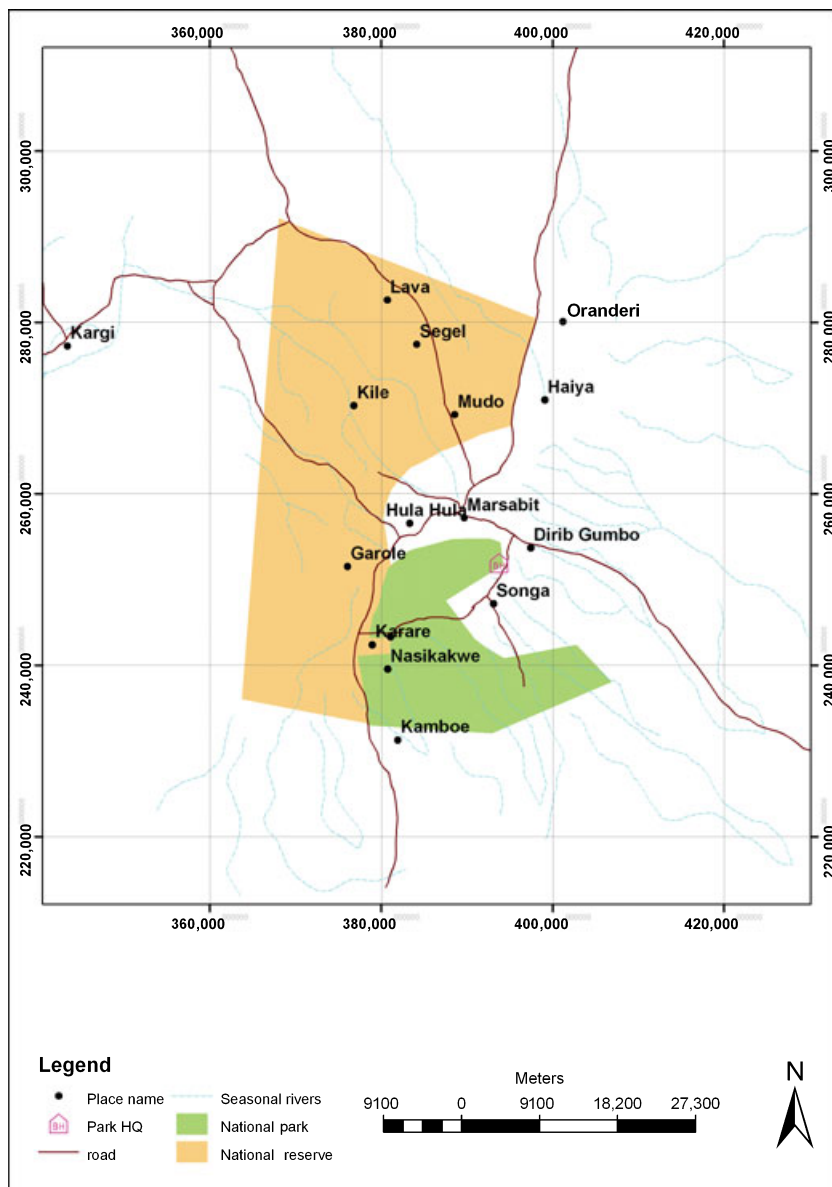


Fig 1 Location of Marsabit Protected Area (National Park and Reserve) and its adjacent area

within the forest. Two other notable craters are Gof Bongole and Gof Redo, both with waterholes at the bottom, which are frequented by elephants (McLaughlin *et al.*, 1973).

Generally, Marsabit is a water deficit area (Loltome, 2005). Mount Marsabit supplies groundwater to the surrounding areas. No permanent rivers originate from Mount Marsabit (Oroda *et al.*, 2005). Permanent springs occur inside the forest and along the forest edges (Loltome, 2005).

The vegetation within the protected areas ranges from evergreen forest, shrubland, perennial grassland, and evergreen to semi-deciduous bushland (Harlocker, 1979). The evergreen forest occurs on high elevations (elevation of over 1000 m; Oroda *et al.*, 2005). Some common forest tree species are *Croton megalocarpus* Hutch., *Strombosia schleffler* Blume, *Diospyros abyssinica* (Hiem) F. White, *Olea Africana* L., and *Olea capensis* L. (Schwartz, 1991). The savanna, which is characterized by a mixture of shrubs, a few trees and grasses, occurs in the lowlands (elevation of

<1000 m; Oroda *et al.*, 2005). Respectively, common savanna trees, shrubs and grasses include: *Acacia brevispica* Harms and *Boscia minimifolia* Chiov.; *Bauhinia tomentosa* Vell, *Phyllanthus sepialis* Mull. Arg, *Grewia fallax* K. Schum and *Aspilia mossambicensis* (Olive) Wild; *Eragrostis tenuifolia* (A. Rich.) Steud., *Themeda triandra* Forssk, *Chenopodium quinoa* Willd and *Cynodon dactylon* (L.) Pers. (Schwartz, 1991). Common plants consumed by Marsabit elephants include *Bauhinia tomentosa*, *Phyllanthus sepialis*, *Grewia fallax*, *Acacia brevispica* and *Aspilia mossambicensis* (Ngene & Omondi, 2005; Githae *et al.*, 2007).

Common mammals in the Marsabit Protected Area include: the African elephant (*Loxodonta africana*), the greater kudu (*Tragelaphus strepsiceros*), the African buffalo (*Syncerus caffer*), the bushbuck (*Tragelaphus scriptus*), the common duiker (*Sylvicapra grimmia*), the warthog (*Phacochoerus aethiopicus*), the olive baboon (*Papio hamadryas anubis*), the vervet and Sykes' monkey (*Chlorocebus pygerythrus* and *Cercopithecus albogularis*), the lion (*Panthera leo*) and the leopard (*Panthera pardus*; McLaughlin *et al.*, 1973).

The rural residents neighbouring Marsabit Protected Area are either semi-nomadic pastoralists (of the Rendile, Gabbra, and Boran tribes) or crop farmers (the Burji tribe). The Burji came as refugees from Ethiopia in the early 1980s and are now recognized as settlers in Kenya (Oroda *et al.*, 2005). Rainfed crop farming and its associated sedentary lifestyle are increasingly adopted by the previously nomadic pastoralists in areas with suitable soils and sufficient rainfall for maize, bananas, fruits and vegetables. The crop farmers keep some livestock in the dry lowlands.

#### Elephant location data

Four female and five male elephants were collared with Iridium satellite-linked GPS collars manufactured by Televilt Positioning AB of Sweden. We followed the procedures as described by Thouless (1996a,b) and Whyte (1996) during the collaring operations. The first group of seven elephants was collared between 4 and 16 December 2005. The elephants were collared in the north western, western, south western and southern parts of the Marsabit forest. The second group of two female elephants was collared between 7 and 11 July 2006 in the northeastern and southeastern parts of Marsabit National Park. Darting for collaring was carried out on foot in 2005 and from a helicopter in 2006.

In addition to the GPS position transmission via satellite, the collars emitted a very high frequency (VHF) signal, which we used on the ground or for aerial tracking as

required. The battery life of the collar is almost 7 years, given an hourly schedule of data recording.

All collars were set to collect and record a position once every hour and to emit a VHF signal every day between 06.00 and 19.00 hours. The collected positions were transmitted to the Iridium satellite every 48 h. The original time record was in GMT; a span of 3 h is added to obtain the local time. The position data were sent from the satellite to an e-mail account and downloaded automatically using STE downloader software (Save the Elephant, Nairobi, Kenya).

A point map was prepared from the elephant location data for the period December 2005–November 2006. The Spatial Analyst and Spatial Statistics tools in ArcMap 9.2 were applied for analysis (ESRI, 2006).

#### GIS and remote sensing data layers

Data layers for analysis included drinking water points, settlements, elevation, slope, main roads, minor roads, seasonal rivers, soil types and vegetation cover. Drinking water points and settlements were mapped during a ground survey by recording their UTM co-ordinates with a hand-held GPS at a spatial accuracy of about 4 m. Co-ordinates for settlements were taken at the centre, middle and periphery. Spatial data for elevation, slope, main roads, minor roads, vegetation cover, seasonal rivers and soil types were acquired from the United Nations Environment Programme (UNEP), Marsabit Forest Database. The classification accuracy of the vegetation cover map (87%) is above the threshold of 85% for operational mapping accuracy (Anderson *et al.*, 1976). The elevation and slope angle were extracted from a 90-m resolution digital elevation model (DEM) of Mount Marsabit and its environs (NASA, 2000).

#### Data analysis

We used ArcMap's Spatial Analyst in order to create distance surfaces from roads, drinking water points, settlements, main roads, minor roads and seasonal rivers (ESRI, 2006). Elevation and slope of the study area were obtained from the Marsabit DEM acquired from the UNEP. The vegetation cover and soil maps were rasterized. STE tracking database interface software was applied to download elephant locations onto ArcMap 9.2. Lastly, we extracted values for each factor at each elephant location.

All extracted elephant location values were correlated with corresponding distance values extracted for each factor under examination. Before the correlation analysis was undertaken, the datasets were visually inspected and tested for normality using the Kolmogorov–Smirnov method (Fowler, Cohen & Jarvis, 1998). Normality was assumed if  $P > 0.05$ . However, Spearman's rank correlates were used as almost all the datasets were not normally distributed (Fowler *et al.*, 1998). The strength of the correlations was interpreted following guidelines described by Fowler *et al.* (1998). In addition, a chi-squared test was undertaken in order to test the significance of elephant locations in relation to elevation during the dry and wet seasons, following procedures described by Fowler *et al.* (1998). The datasets were tested for multicollinearity and autocorrelation problems in the data.

Multicollinearity of the factors was tested using tolerance in multiple regressions (Statsoft, 2002). The tolerance of a factor was defined as 1 minus the squared multiple regression of this factor with all other independent factors (Dirk & Bart, 2004). A tolerance of  $<0.1$  indicated a multicollinearity problem (Dirk & Bart, 2004).

Autocorrelation between the factors was tested using the 'Durbin–Watson statistic ( $d$ )' in multiple regressions (Statsoft, 2002). Its value lies between 0 and 4. A value from 0.8 to 2 indicated that there was no autocorrelation between the factors being tested. If the Durbin–Watson statistic was  $<0.8$ , the factors being tested were then autocorrelated (Verbeek, 2004). Small and large values of  $d$  indicated that successive error terms were positively and negatively correlated, respectively (Verbeek, 2004). Finally, a principal component analysis (PCA) was carried out (Statsoft, 2002).

We used PCA (Statsoft, 2002) to compose the original autocorrelated variables into linearly independent orthogonal principal components (PCs). The variables used as inputs to the PCA were elevation, soil types, land cover types, slope and distance to: drinking water points, settlements, seasonal rivers, minor roads and major roads. PCA transforms a number of potentially correlated variables into a smaller number of uncorrelated components, the first of which accounts for as much variability in the data as possible, followed by the second and subsequent components (Blom *et al.*, 2005). Using the first two components, this technique provides an ordination of the environmental variables in a two-dimensional plane, onto which their multi-correlation can be explored (Kent & Coker, 1994). For example, a PCA involving  $k$  variables

decomposes into the following linear combinations of original variables (Khaemba & Stein, 2000):

$$PC_i = \xi_{i1}X_{1i} + \xi_{i2}X_{2i} + \dots + \xi_{ij}X_{ij} + \dots + \xi_{ik}X_{ki},$$

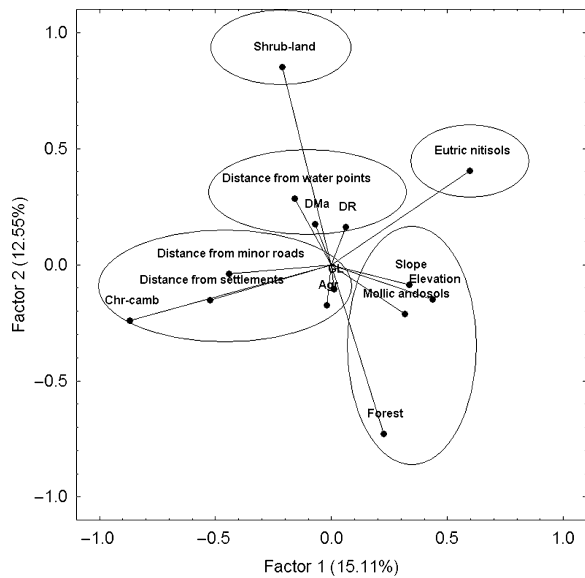
where  $PC_i$  is the  $i$ th PC and  $\xi_{ij}$  is the coefficient corresponding to variable  $X_{ij}$ . The coefficient  $\xi_{ij}$  forms a matrix  $\xi$  composed of eigen vectors from the correlation matrix of explanatory variables (Jambu, 1991). Eigen values derived from the correlation matrix represent the PCs' ability to reflect the original variables (Affi, Clark & May, 2004). We report factors with eigen-values  $>1$  as recommended by Affi *et al.* (2004). For each of the PCs, the factors with a correlation greater than coefficient ' $0.7/(\text{eigen value})^{0.7}$ ' were significant (Affi *et al.*, 2004). Using the elephant tracking data, new factors were derived from the PCs and used to discern which PCs best explained the distribution of elephants in Marsabit Protected Area.

## Results

The distribution of elephants in Marsabit Protected Area could be explained by seven out of an initial fourteen factors. The seven factors were distance from drinking water points (13%), distance from seasonal rivers (11%), elevation (15%), shrubland (10%), forest (9%), distance from settlements (8%) and distance from minor roads (7%). These factors contributed to 73% of the observed variation in elephant distribution. The remaining factors were correlated with the above seven factors (Fig. 2), and therefore their influence on the distribution of elephants in Marsabit Protected Area was masked. The elevation and distance from drinking water points are illustrated in a bi-plot (shown in Fig. 2) as they had the highest influence on the distribution of elephants in Marsabit Protected Area.

Our results indicate that the distribution of elephants in Marsabit Protected Area is positively influenced by vegetation and soils, which are both correlated with elevation. Chromic cambisols and open shrubland, and eutric nitisols and forest are negatively and positively associated with the location of elephants in the Marsabit Protected Area, respectively (Fig. 2). In fact, the elephants did not often visit areas characterized by closed grassland or agriculture.

The elephants were all found at high elevations during the dry season but six moved to the lowlands during the wet season (dry season:  $\chi^2 = 59.6$ ,  $P < 0.05$ ; wet season:  $\chi^2 = 23.4$ ,  $P < 0.05$ ; Fig. 3). During the dry season, at night, most of the elephants were found in the shrublands rather than in the forest (night:  $\chi^2 = 4.2$ ;  $P < 0.05$ ).



**Fig 2** X-Y vector plot of factor loadings for the location of elephant and each explanatory factor. All the factors were used to define the principal component space (active factors). The X-axes display factor loadings (correlations) of the first PCA factor; the Y-axes display the factor loadings for the explanatory factors along the second PCA factor. (dr) = Distance from seasonal rivers; (Mar) = Distance from major roads; Agr (a) = Agriculture; The length of the vector in the bi-plot is a measure of the strength of the relationship between that factor and the axis

During the wet season, the elephants were more common in the lowland shrublands than the highland forest both during both the day and the night (day:  $\chi^2 = 29.0$ ;  $P < 0.01$ ; night:  $\chi^2 = 84.6$ ;  $P < 0.01$ ).

In the Marsabit Protected Area, soils were correlated with elevation. The mollic andosols and eutric nitisols were positively correlated with elevation, whereas the chromic cambisols were negatively correlated with elevation (Fig. 3a,b). Elephants were present at high elevations with mollic andosols ( $r_{f3.ma} = 0.74$ ). However, as intermediate elevations decreased, they were found in areas with eutric nitisols ( $r_{f3.en} = -0.60$ ). At low elevations, away from settlements ( $r_{f1.ds} = -0.52$ ) and minor roads ( $r_{f1.mr} = -0.44$ ), elephants were associated with areas dominated by chromic cambisols ( $r_{f1.cc} = -0.87$ ) rather than eutric nitisols ( $r_{f3.en} = -0.60$ ; Table 1). Mollic andosols are found at the peak of the mountain and nitric nitisols at lower elevations.

We recorded elephants in shrubland ( $r_{f2.os} = 0.87$ ), closed grassland ( $r_{f6.cg} = 0.85$ ) and agricultural fields ( $r_{f5.agr} = 0.78$ ). However, within the forest, the presence of

elephants decreased with an increase in elevation ( $r_{f2.cf} = -0.73$ ; Table 1;  $R^2 = 0.88$ ; tolerance = 0.12; Fig. 3a,b).

Distances to drinking water points and seasonal rivers were negatively correlated with shrubland. More elephants were observed near drinking water points ( $r_{f4.dw} = -0.72$ ;  $R^2 = 0.55$ ; tolerance = 0.45) and seasonal rivers ( $r_{f4.dr} = -0.79$ ). In addition, many elephants occurred near seasonal rivers, with 72% of the elephant locations being within <1 km from the seasonal rivers. The presence of elephants decreased with increase in distance from settlements ( $r_{f1.ds} = -0.52$ ) and minor roads ( $r_{f1.mr} = -0.44$ ; Table 1).

## Discussion

Elephants utilize the evergreen Marsabit mountain forest and adjacent deciduous lowland shrub savanna in a unique way. They stay in the highlands during the dry season and move to the lowlands during the rainy season. The lowlands lack both drinking water and green forage during the dry season. The mountain forest provides the only drinking water during the dry season, as well as salt licks. However, the mountain lacks sufficient forage for year-round provision for a sizeable elephant population. Annual migration between the mountain forest and lowland savanna is therefore essential. Similar observations have been reported in the Meru, Mount Kenya and the Samburu areas by Douglas-Hamilton *et al.* (2005), the northern Namib Desert, Namibia by Viljoen (1989), and the Kunene region, northwest Namibia by Leggett (2006).

### *Vegetation, soils and slope*

The vegetation on Marsabit Mountain and its environs is associated with elevation. At the high and intermediate elevations, evergreen forests dominate. Part of the intermediate elevations and the lowlands consist of shrubland and closed grasslands, with the former being dominant. Mollic andosols, eutric nitisols and chromic cambisols dominate the highlands, intermediate elevations and lowlands, respectively. Most of the drinking water points are located within the intermediate elevations with eutric nitisols. The presence of elephants follows the same trend, with few elephants being recorded at high elevations dominated by mollic andosols. Different observations were reported in Samburu, where elephants avoided a hill rising only 300 m from the lowlands (Wall *et al.*, 2006). In

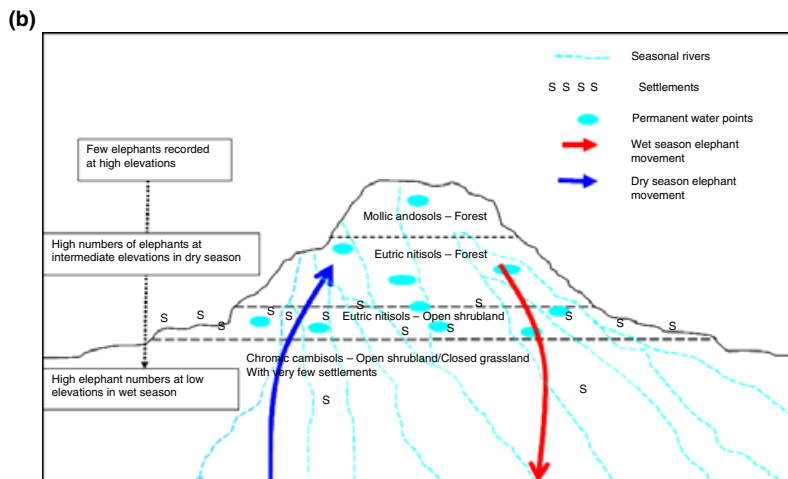
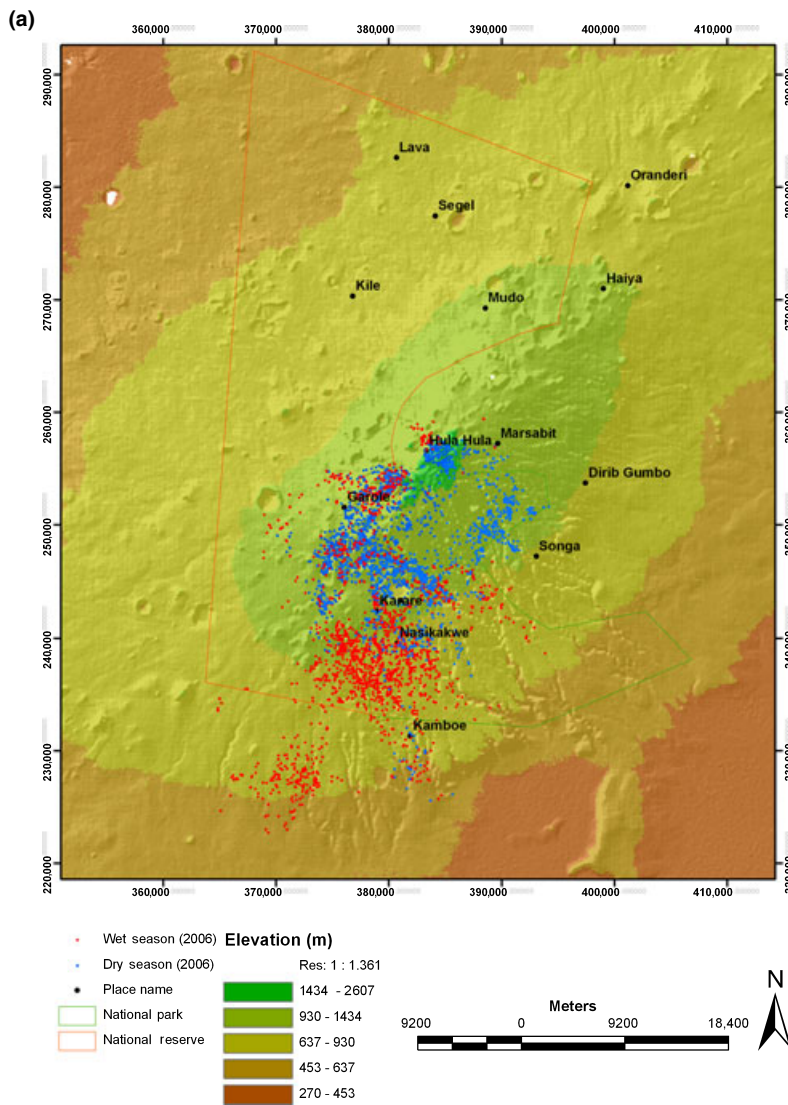


Fig 3 (a) A map showing the distribution of elephants during the dry and wet seasons (2006) in relation to elevation in the Marsabit Protected Area. Elephants were common in high and low elevations during the dry and wet seasons, respectively. (b) A diagram showing an increase in elephant presence with a decrease in elevation in Marsabit Protected Area. Elephants moved from higher elevations to lower elevations during the wet season. The reverse happens during the dry season

**Table 1** Seven principal factors derived from the initial fourteen explanatory factors and their corresponding scores

Factors/factor loadings	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7
Elevation	<b>0.44</b>	-0.15	0.39	-0.17	0.12	0.22	0.36
Distance from permanent water points	-0.16	0.29	-0.06	<b>-0.72</b>	0.00	-0.10	-0.21
Distance from seasonal rivers	0.06	0.16	0.01	<b>-0.79</b>	-0.02	0.05	-0.16
Shrubland	-0.21	<b>0.85</b>	0.32	0.17	-0.24	0.15	0.09
Distance from minor roads	<b>-0.44</b>	-0.04	-0.17	0.02	-0.03	0.06	0.04
Distance from settlements	<b>-0.52</b>	-0.15	0.12	-0.01	0.22	0.10	0.16
Distance from major roads	-0.07	0.17	-0.35	0.25	-0.19	-0.37	-0.55
Slope	0.34	-0.08	0.19	0.20	0.06	0.01	-0.28
Forest	0.22	-0.73	-0.40	-0.16	-0.44	0.13	0.02
Agriculture	-0.02	-0.17	0.05	0.05	<b>0.78</b>	0.30	-0.46
Closed grassland	0.01	-0.11	0.05	-0.08	0.38	<b>0.85</b>	0.31
Mollic andosols	0.32	-0.21	<b>0.74</b>	-0.01	-0.24	-0.18	-0.28
Eutric nitisols	<b>0.60</b>	0.40	<b>-0.60</b>	0.03	0.22	0.10	0.18
Chromic cambisols	<b>-0.87</b>	-0.24	0.00	-0.03	-0.03	0.05	0.04
Eigenvalue	2.12	1.76	1.54	1.35	1.22	1.22	1.04
% total variance	15.11	12.55	10.97	9.61	8.71	7.96	7.41
Cumulative (%)	15.11	27.67	38.64	48.25	56.96	64.92	72.32
0.7/(eigenvalue) <sup>0.7</sup>	0.41	0.47	0.51	0.57	0.61	0.65	0.68

PCs with correlation values  $> [0.7/(\text{eigenvalue}^{0.7})]$ , i.e. significant correlations, are in bold. Factors with an eigenvalue of  $<1$ , as recommended by Afifi *et al.* (2004), do not have significant influence on elephant distribution and are therefore excluded from this table.

Marsabit, elephants were recorded at elevations from  $<500$  to  $>1600$  m. We suggest that elephants use the vegetation communities in high elevation where the soils support their food resources (forage, salt licks and water), as the latter are correlated with soils (Pomeroy & Service, 1992). Common plants consumed by elephants at high elevations include *Bauhinia tomentosa*, *Phyllanthus sepialis*, *Grewia fallax*, *Acacia brevispica* and *Aspilia mossambicensis* (Ngene & Omondi, 2005; Githae *et al.*, 2007). Our results agree with those of Anderson & Herlocker (1973), Bell (1982), McNaughton (1988) and Mwangi, Milewski & Wahungu (2004), who showed that vegetation and mineral content of soil influence wildlife distribution. Also, our results are supported by Ayien (2005), who reported that the Marsabit soils are rich in clays and essential minerals for wildlife as they are of volcanic origin. However, the clay soils do become slippery during the wet season.

During the dry season, drinking water points in the lowlands dry up and forage plants shed their leaves, therefore becoming unavailable to elephants (Ngene & Omondi, 2005; Githae *et al.*, 2007). This makes the lowlands unattractive to elephants during the dry season. Conversely, during the same period, the high groundwater

table at the high elevations results in drinking water availability and green forage, making the area attractive to elephants (Ngene & Omondi, 2005; Githae *et al.*, 2007). However, during the wet season, drinking water is found over the entire research area and the withered plants regenerate their leaves. Therefore, elephants move from the high elevations to the lowlands as water and food in the lowlands are not limiting during the wet season.

Elephants avoid the mountain forest or high elevations during the wet season. First, the forest trees are tall (over 20 m), have little undergrowth and few shrubby patches, and are therefore unavailable or have inadequate forage. Second, it is possible that elephants avoid high elevation areas (forest) during the wet season because of their steepness. This is because the risk of injury in steep areas is high during the wet season as the Marsabit volcanic soils are slippery. In addition, it becomes impossible for elephants to access shrubby patches inside the forest. However, the risks become minimal during the dry season, when water and forage become scarce (Ngene & Omondi, 2005). Consequently the elephants move up to the high elevations and steeper slopes to enable them to access resources (water, salt licks and forage). They use 'ziz-zag routes' in order to enable them to overcome the steep slopes

in the highest elevation areas. However, cliffs are totally avoided during the wet and dry seasons as the elephants cannot make any manoeuvres to overcome their steepness.

#### *Water points, seasonal rivers, settlements and roads*

Elephants require drinking water every 1 or 2 days (Douglas-Hamilton, 1973). Generally, Marsabit is a water deficit area (Loltome, 2005). Water sources are located in the forest and along its edges, whereas seasonal rivers traverse the entire Marsabit lowlands during the rains. Our results indicate that elephants prefer to be near drinking water points and seasonal rivers. The mean distance of elephant locations to water points was 4.3 km. The distance of elephant locations to drinking water points ranged from 0 km to over 45 km, with 25–75% of elephant locations being 1.7–6.1 km from drinking water points. In addition, the mean distance of elephant locations to seasonal rivers was 0.77 km. The distance of elephant locations to seasonal rivers ranged from 0 to 25.6 km, with 25–75% of elephant locations being 0.23–1.1 km from seasonal rivers. Similar observations were made for elephants in Samburu (Thouless, 1995), Maasai Mara Game Reserve (Khaemba & Stein, 2000), Tsavo East National Park (Leuthold & Sale, 1973; Ayeni, 1975; Western, 1975; Albricht, 1995), Maputo Elephants Reserve in Mozambique (Boer *et al.*, 2000), Serengeti National Park in Tanzania (McNaughton, 1990), the Kunene region in northwest Namibia (Leggett, 2006), the northern Namib Desert (Viljoen, 1989) and northern Kenya (Leeuw *et al.*, 2001). We conclude that during the dry season, the Marsabit elephants depend on drinking water points within the Marsabit mountain forest. During the rainy season, the main drinking water points are the seasonal rivers in the lowlands. Both scenarios indicate that water availability influences the distribution of the Marsabit elephants throughout the year. However, the same water points are also used by humans.

Our results show that the Marsabit elephants congregate close to human settlements. The mean distance of elephant location to settlements was 3.1 km. The distance between elephant locations and settlements ranged from 0 km to over 45 km, with 25–75% of elephant locations being 1.2–3.1 km from settlements. The Marsabit case is unique as only a small area around the forest has water resources, used by both elephants and humans. The mean distance of water points to settlements was 4.4 km. The distance between water points

and settlements ranged from 1.3 to 6.4 km, with 25–75% of water points being 3.7–5.1 km away from settlements. As a result, elephants have no choice but to remain close to settlements. Blom *et al.* (2005) reported that elephants in Dzanga-Ndoki National Park and the Dzanga-Sangha Dense Forest Reserve (southwest Central African Republic) were significantly less common near settlements. Such avoidance behaviour has also been reported in Gabon (Barnes *et al.*, 1991), northern Cameroon (Tchamba *et al.*, 1995), northern Congo (Fay & Agnagna, 1991) and Samburu (Thouless, 1995). Most settlements are linked to water points via the road networks.

Elephants were found close to minor and major roads. As Marsabit is a water deficit area, with only a small area around the forest being the sole source of water for both elephants and humans, elephants have no choice but to cross roads as they move from feeding grounds to water points and back. In addition, where poaching is rampant, closeness to roads may increase the possibility of poaching. However, in Marsabit, the roads are used for security patrols and as a consequence poaching from roads is rare. Instead, poachers appear to conceal themselves in the thickets and forest. Therefore, elephants feel more secure when they are close to roads. In contradiction to our findings, Barnes *et al.* (1991) and Blom *et al.* (2005) reported that, in southwest Central African Republic and Gabon, elephants avoided areas near roads as poachers use them to penetrate into the national parks. It appears that in the dry savanna-forest ecosystem of Marsabit, with inadequate water supplies during the dry season, humans and elephants co-exist.

#### *Implication of extending settlement schemes and associated water points on the future conservation of elephants in Marsabit*

Settlements occur all around the Marsabit forest: Marsabit town, Hula Hula, Kijiji, Karare, Lpus, Kituruni, Songa, Leyai, Badassa, Gabbra Scheme, Sagante and Dirib Gombo. However, uninhabited corridors between settlements connect the mountain forest and lowlands. These corridors are currently used as migratory or dispersal routes by the elephants. Within heavily settled areas, such as Sagante, Dirib Gombo, Gabbra Scheme and Badassa, patches of shrublands occurring along the seasonal rivers are used by the elephants as corridors between the mountain forest and the lowlands. As the human population increases and

its demand for land increases (Oroda *et al.*, 2005), these corridors are likely to be cleared and lost as vital migratory and dispersal routes. If so, the elephants will have two options; first, they could continue migrating or dispersing using traditional routes; second, they could explore alternative routes.

Therefore, as their fragmented forest and shrub covers give way to settlements and farms in the future, we expect the population of Marsabit elephants to decline. To remedy the situation, we propose that the expansion of settlements and farms from Karare to Hula Hula, Karare to Kituruni, and Kituruni to Badassa be regulated by land use zoning, or alternatively by gazettement these areas as part of the Marsabit National Park. In addition, we propose that elephants be guided through the few existing corridors by landscaping the terrain and vegetation or by fencing these corridors.

## Conclusions

In this study, we have evaluated fourteen environmental and human factors that potentially influence the seasonal distribution of Marsabit elephants. Our results demonstrate the interaction of factors. We conclude that the distribution of elephants in Marsabit Protected Area is mainly influenced by the seasonal availability of drinking water and green forage. However, elevation influences the type of soils, vegetation and water availability and appears to act as a proxy for both drinking water points and vegetation. Croplands and closed grassland were less frequently visited. The two contrasting seasonal Marsabit elephant habitats are separated by settlements interspersed with narrow migration corridors. Ongoing expansion of farming settlements threatens the vital corridors and therefore the Marsabit elephants.

Mosaics of forest and savannah are important for elephant populations (as shown by many studies in Africa) as they provide them with vital resources (food, shelter, saltlicks, and water) throughout the year (McNaughton, 1990; Thouless, 1996a,b; Boer *et al.*, 2000; Douglas-Hamilton *et al.*, 2005; Leggett, 2006). The remnant forest-savannah mosaic sustains the Marsabit elephant population, which is the only large elephant population remaining in northern Kenya beyond the Laikipia–Samburu area.

The use of satellite-linked GPS collars provided us with an opportunity to further our understanding of the interaction of elephants with important environmental factors.

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## References

- AFIFI, A., CLARK, V.A. & MAY, S. (2004) *Computer-Aided Multivariate Analysis*. Chapman and Hall/CRC, FL, U.S.A.
- ALBRICHT, R.C. (1995) Where are the Tsavo elephant? GIS modeling of elephant distribution in the Tsavo National Park, Kenya. MSc Thesis. ITC, Enschede, The Netherlands.
- ANDERSON, G.D. & HERLOCKER, D.J. (1973) Soil factors affecting distribution of the vegetation types and their utilization by wild animals in Ngorongoro crater, Tanzania. *J. Ecol.* **61**, 627–651.
- ANDERSON, J.R., HARDY, E.E., ROACH, J.T. & WITMER, R.E. (1976) *A Land Use and Land Cover Classification System for Use with Remote Sensing Data*. Geological Survey Professional Paper 964. USA Government Printing Office, Washington, DC, U.S.A.
- AYENI, J.S.O. (1975) Utilization of water holes in Tsavo National Park (East). *E. Afr. Wildl. J.* **13**, 305–323.
- AYIEN, O.E. (2005) An assessment of soil erosion susceptibility and conservation in Mount Marsabit Forest, Kenya. MSc Thesis. University of Nairobi, Nairobi, Kenya.
- BARNES, R.F.W., BARNES, K.L., ALERS, M.P.T. & BLOM, A. (1991) Man determines the distribution of elephants in the rainforests of northeastern Gabon. *Afr. J. Ecol.* **29**, 54–63.
- BELL, R.H.V. (1982) The effect of soil nutrient availability on community structure in African ecosystems. In: *Ecology of Tropical Savannas* (Eds B. J. HUNTLEY and B. H. WALKER). Springer-Verlag, Berlin.
- BLAKE, S. & DOUGLAS-HAMILTON, I. (2001) GPS telemetry of forest elephants in central Africa: results of a preliminary study. *Afr. J. Ecol.* **39**, 178–186.
- BLOM, A., ZALINGE, R., HEITKONIG, M.A. & PRINS, H.H.T. (2005) Factors influencing the distribution of large mammals within protected central African forest. *Oryx* **39**, 381–388.

- BOER, W.F., NTUMI, C., CORREIA, A.U. & MAFUCA, M.J. (2000) Diet and distribution of elephant in the Maputo elephant reserve, Mozambique. *Afr. J. Ecol.* **38**, 188–201.
- DIRK, V.P. & BART, L. (2004) Attrition analysis for financial services using proportional hazard models. *Eur. J. Oper. Res.* **157**, 196–217.
- DOUGLAS-HAMILTON, I. (1973) On the ecology and behaviour of the lake Manyara elephants. *E. Afr. Wildl. J.* **11**, 401–403.
- DOUGLAS-HAMILTON, I., KRINK, T. & VOLLRATH, F. (2005) Movement and corridors of African elephant in relation to protected areas. *Naturwissenschaften* **92**, 158–163.
- EIDEN, A., KEITH, G. & JONNES, M. (1991) Large scale monitoring of rangelands vegetation using NOAA/11 AVHRR LAC data. In: *Range Management Handbook of Kenya Vol. III, Part IV* (Eds. D. WALTHER and S. SHAABANI). Ministry of Livestock Development, Nairobi, Kenya.
- ESRI (ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE) (2006) *ArcGIS: Arc Map Version 9.2*. ESRI, CA, U.S.A.
- FAY, J. & AGNAGNA, M. (1991) A population survey of forest elephant in Northern Congo. *Afr. J. Ecol.* **29**, 177–187.
- FOWLER, J., COHEN, L. & JARVIS, P. (1998) *Practical Statistics for Field Biology*. John Wiley and Sons, West Sussex, U.K.
- GALANTI, V., TOSI, G., ROSSI, R. & FOLEY, C. (2000) The use of GPS radio-collars to track elephants in the Tarangire National Park, Tanzania. *Hystrix* **11**, 27–37.
- GITHAE, E.W., PETIOT, M.C., MWORIA, J.K. & ODEE, D.W. (2007) A botanical inventory and diversity assessment of Mt. Marsabit forest, a sub-humid montane forest in the arid lands of northern Kenya. *Afr. J. Ecol.* **46**, 39–45.
- GRUNBLATT, J., SAID, M., WARGUTE, P. & KIFUGO, S.C. (1995) *DRSRS Aerial Surveys Database*. Ministry of Planning and National Development, Nairobi, Kenya.
- HARLOCKER, D.J. (1979) Vegetation of southern Marsabit, Kenya. IPAL Technical Report D-1. UNEP-MAB Integrated Project for Arid Lands. UNESCO, Nairobi, Kenya.
- JAMBU, M. (1991) *Exploratory and Multivariate Data Analysis: Statistical Modeling and Decision Science*. Academic Press, Ltd, San Diego, CA, U.S.A.
- KENT, M. & COKER, P. (1994) *Vegetation Description and Analysis: A Practical Approach*. John Wiley and Sons, Chichester, U.K.
- KHAEMBA, W.M. & STEIN, A. (2000) Use of GIS for a spatial and temporal analysis of Kenyan wildlife with generalized linear modeling. *Int. J. Geogr. Inf. Sci.* **14**, 833–853.
- LEEUEW, J., WAWERU, M.N., OKELLO, O.O., MALOBA, M., NGURU, P., SAID, M.Y., ALIGULA, H.M., HETKÖNIG, I.M.A. & REID, R.S. (2001) Distribution and diversity of wildlife in northern Kenya in relation to livestock and permanent water Points. *Biol. Conserv.* **100**, 297–308.
- LEGGETT, K.E.A. (2006) Home range and seasonal movement of elephant in the Kunene region, northwestern Namibia. *Afr. Zool.* **41**, 17–36.
- LEUTHOLD, W. & SALE, J.B. (1973) Movements and patterns of habitat utilization in Tsavo National Park, Kenya. *E. Afr. Wildl. J.* **11**, 369–384.
- LINDEQUE, M. & LINDEQUE, P.M. (1991) Satellite tracking of elephants in north-western Namibia. *Afr. J. Ecol.* **29**, 196–206.
- LOLTOME, M.L. (2005) Water resources assessment for the Marsabit mountain catchment areas and its associated watersheds. MSc Thesis. University of Nairobi, Nairobi, Kenya.
- MCLAUGHLIN, J.S., DOUGHERTY, D.G. & MCLAUGHLIN, E.C. (1973) *A conceptual master plan for Marsabit National Reserve*. A National Parks of Kenya Report, Nairobi, Kenya.
- MCNAUGHTON, S.J. (1988) Mineral nutrition and spatial concentrations of African ungulates. *Naure* **334**, 343–345.
- MCNAUGHTON, S.J. (1990) Mineral nutrition and seasonal movements of African migratory ungulates. *Nature* **345**, 613–615.
- MWANGI, P.N., MILEWSKI, A. & WAHUNGU, G.M. (2004) Chemical composition of mineral licks by elephant in Aberdares National Park, Kenya. *Pachyderm* **37**, 59–67.
- NASA (NATIONAL AERONAUTICS SPACE ADMINISTRATION) (2000) *Shuttle Radar Topographic Mission*. NASA, Washington, DC, U.S.A.
- NEWMARK, W.D. (1996) Insularization of Tanzanian parks and local extinction of large mammals. *Conserv. Biol.* **10**, 1549–1556.
- NGENE, S.M. & OMONDI, P. (2005) *Elephants and Man Destroy Vegetation in Marsabit Protected Area, Northern Kenya*. A Technical Report to United States Fish and Wildlife Service, Nairobi, Kenya.
- ORODA, A.S.K., OLUKOYE, G.A., KOSKE, J. & LAMBRECHTS, C. (2005) *The Impact of Land Sub-division and Sedentarization on the Land Cover Dynamics in Mt. Marsabit Area, Kenya*. Marsabit Forest Project: UNEP/AGREF Technical Report. UNEP, Gigiri, Nairobi.
- POMEROY, D. & SERVICE, M.W. (1992) *Tropical Ecology*. Longman Group Limited, Essex, U.K.
- SCHWARTZ, H.J. (1991) Marsabit District. In: *Range Management Handbook of Kenya*. Vol. II, Part I (Eds H.J. SCHWARTZ, S. SHAABANI and D. WALTHER). Ministry of Livestock Development, Nairobi, Kenya.
- STATSOFT, INC (2002) *Statistica Release 6.0*. Statsoft, Inc, NY, U.S.A.
- SYNOTT, T.J. (1979) *Impact of Human Activities and Land Practices on Grazing Lands*. IPAL Technical Report D-2. UNEP-MAB Integrated Project for Arid Lands. UNESCO, Nairobi, Kenya.
- TCHAMBA, M.N. (1993) Numbers and migratory patterns of savanna elephants in Northern Cameroon. *Pachyderm* **16**, 66–71.
- TCHAMBA, M.N., BAUER, H. & DE IONGH, H.H. (1995) Application of VHF-radio and satellite telemetry techniques on elephants in northern Cameroon. *Afr. J. Ecol.* **33**, 335–346.
- THOULESS, C.R. (1995) Long distance movements of elephants in northern Kenya. *Afr. J. Ecol.* **33**, 321–334.
- THOULESS, C.R. (1996a) Home ranges and social organization of female elephants in northern Kenya. *Afr. J. Ecol.* **33**, 284–297.
- THOULESS, C.R. (1996b) Satellite tracking of elephants. In: *Studying Elephants* (Ed. K. KANGWANA). African Wildlife Foundation Technical Series Handbook No. 7. Nairobi, Kenya.

- VERBEEK, M. (2004) *A Guide to Modern Econometrics*. John Wiley and Sons, Chichester, U.K.
- VILJOEN, P.J. (1989) Spatial distribution and movements of elephants in the northern Namib desert region of Kaokoveld, Namibia. *S. Afr. J. Zool.* **219**, 1–19.
- WALL, J., DOUGLAS-HAMILTON, I. & VOLLRATH, F. (2006) Elephants avoid costly mountaineering. *Curr. Biol.* **16**, 527–529.
- WESTERN, D. (1975) Water availability and its influence on the structure and dynamics of a savannah large mammal community. *E. Afr. Wildl. J.* **13**, 265–286.
- WHYTE, I.J. (1993) The movement patterns of elephants in the Kruger National Park in response to culling and environmental stimuli. *Pachyderm* **16**, 72–80.
- WHYTE, I.J. (1996) Studying elephant movements. In: *Studying Elephants* (Ed. K. KANGWANA). African Wildlife Foundation Technical Series Handbook No. 7, Nairobi, Kenya.

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