A presence-only habitat suitability model for large grazing African ungulates and its utility for wildlife management

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Abstract

A Geographic Information System (GIS)-based model, using presence-only data, was used to predict suitability of habitat for large grazing ungulates on a Zimbabwean wildlife reserve. The management-driven study focused on rare and economically valuable herbivores during the resource-limited hot-dry season. The modelling software Biomapper was used to quantify species–habitat association and derive habitat suitability (HS) maps. Herbivore distribution was primarily determined by distance to surface water, time since last burn and herbaceous layer composition. Findings are discussed within the context of tools available to management and are used to address concerns about the potential for interspecific competition at the habitat level, stocking rate estimation and proposed infrastructure development. Biomapper allowed for the derivation of HS maps here despite the authors' little modelling experience, and appears well suited to management-driven research of African fauna where access to GIS software is available.

Key words: ecological niche factor analysis, GIS, grazing ungulates, habitat suitability, wildlife management, Zimbabwe

Résumé

Un modèle base sur un Système d'Information Géographique, utilisant des données portant uniquement sur la présence, a servi pour prédire si un habitat convenait à de grands ongulés herbivores dans une réserve de faune au Zimbabwe. L'étude orientée sur la gestion se concentrait sur des herbivores rares qui sont économiquement intéressants pendant la chaude saison sèche, quand les ressources sont limitées. On a utilisé le logiciel Biomapper pour quantifier l'association espèce/habitat et en déduire des cartes des habitats qui pourraient convenir. La distribution des herbivores a d'abord été déterminée en fonction de la distance par rapport à l'eau accessible, du laps de temps écoulé depuis le dernier feu et de la composition de la strate herbacée. On discute les résultats dans le contexte des outils disponibles pour la gestion et on s'en sert pour répondre aux inquiétudes concernant la possibilité de compétition interspécifique au niveau de l'habitat, l'estimation de la capacité de charge et le développement des infrastructures. Biomapper a permis ici l'obtention de cartes sur l'adéquation de l'habitat alors que les auteurs n'avaient encore que peu d'expérience de modélisation, et ce logiciel semble bien convenir à la recherche liée à la gestion de la faune africaine lorsque l'accès au matériel SIG est possible.

Introduction

Conservation practitioners have increasingly come to rely on models of natural systems and populations as predictive tools to aid decision-making (Shaffer, 1981; Hilborn & Mangel, 1997). There has been an attendant rise in the use of spatially explicit habitat models over the past two decades (Guisan & Zimmermann, 2000) and recent efforts have linked Geographic Information Systems (GIS) with multivariate models in an attempt to understand both species–habitat associations and derive habitat suitability (HS) maps (Lenton, Fa & Perez Del Val, 2000; Hirzel, Hausser & Perrin, 2001; Marzluff *et al.*, 2004). The application of these models to real-world situations and assessment of their utility are in the early stages, and very little has been done within African ecosystems.

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Research here was undertaken on Malilangwe Estate (hereafter Malilangwe), a wildlife sanctuary situated in the Zimbabwean south-east lowveld. In 1994, Malilangwe initiated a re-stocking programme of large ungulate species, in accordance with their conservation objectives. Re-introduced species included the conservation-dependent (IUCN, 2004) Cape buffalo *Syncerus caffer* (Sparrman), sable antelope *Hippotragus niger* (Harris), waterbuck *Kobus ellipsiprymnus* (Ogilby) and wildebeest *Connochaetes taurinus* (Burchell) and the near-threatened white rhinoceros *Ceratotherium simum* (Burchell). Given the conservation status of these animals and the financial investment made, management expressed concern about the long-term viability of the populations. Monitoring of species survival rates began in 1994 and research into species habitat associations was identified and initiated here.

Concomitant to this research, we used discriminant function analysis (DFA) to identify the determinants of ungulate habitat use, and these are described in a separate study (Traill, 2004). Here, we made a retrospective decision to use the available species presence and habitat data to derive HS maps, and gain further insight into the determinants of habitat utilization. We used the GIS-based software Biomapper (Hirzel *et al.*, 2001) to analyse data collected during the late dry season only, when resources were most limiting. Output was additionally validated using independently derived presence data from the Malilangwe annual game census.

Methods

Study area

Malilangwe Estate lies in the south-east lowveld region of Zimbabwe, between 20°58′ and 21°15′S, and 31°47′ and 32°01′E. The property covers *c.* 40,000 ha and slopes gently from rocky outcrops at 500 m a.s.l., to perennial river systems at 290 m a.s.l. Soils vary, being principally derived from alluvium, sandstone, paragneiss and basalt. Vegetation types can be crudely classified as riverine, hill miombo, mopane *Colophospermum mopane* (Kirk ex Benth) veld, thorn thicket and open woodland (Clegg, 1999). Naturally occurring springs and pans exist on the property. Several dams have been maintained, as have a few artificially supplied waterpoints. Rainfall patterns are erratic and the area is prone to drought. Mean annual rainfall is approximately 550 mm, with the wet season occurring November to March (Chawanji, 2000). Malilangwe is privately owned and fenced along all but the western boundary, where it abuts a neighbouring wildlife estate. The estate is thus a closed ecosystem from the perspective of most large mammals.

Study species

The study focused on large grazing ungulates, as this group included most of the introduced species. Data collection was restricted to the hot-dry season (September–October) as this was the most resource-limited season for the study species (Jarman & Sinclair, 1979). Mixed feeders were excluded as their potential for competitive overlap with the species of concern was limited: mixed feeders switching to browse during the hot-dry period (Jarman & Sinclair, 1979). Study species were thus Cape buffalo, sable antelope, waterbuck, white rhino, wildebeest and zebra *Equus burchelli* (Burchell). Zebra were included here as a potentially competitive species.

Software

The package Biomapper was used. We selected this software for a number of reasons: (a) species' presence data were collected initially in accordance with the research objectives outlined in Traill (2004). During the study period (2001), we considered the need for HS maps but had no reliable absence data. Biomapper was at that time novel and required only presence data. Moreover, (b) the model is based on principal component analysis (PCA), allowing comparison to the findings of the DFA of species habitat utilization (Traill, 2004). Finally (c) the output coverages were compatible with the Malilangwe GIS database using Idrisi (Clark Labs, 1999a).

Biomapper uses ecological niche factor analysis (ENFA) to compute HS maps, and define the niche of a respective species according to a few important habitat variables (Hirzel *et al.*, 2002). The program has been used in studies on several terrestrial vertebrates (Dettki, Lofstrand & Edenius, 2003; Reutter *et al.*, 2003; Brotons *et al.*, 2004), none of these being in Africa however. ENFA models HS by collating the ecographical data (the term used in Biomapper to describe both ecological and geographical variables) and then comparing these where species are present to those of all locations of the study area. Similar to PCA, ENFA transforms the original predictor variables into new, uncorrelated axes. Unlike PCA, where the successive axes are selected to match the direction of maximum variance in the multi-dimensional space, the principal components of ENFA have ecological significance (Hirzel *et al.*, 2002). The first component, the marginality factor (MF), passes through the centroid of all species observations and the centroid of all background cells in the study area. A high MF value therefore indicates that the species requirements are significantly different from average habitat conditions. Several specialization factors (SF) are then successively extracted from the $n - 1$ residual dimensions. A high SF value indicates restricted ecological tolerance compared with the overall range of prevailing conditions. The combination of these scores is derived for each focal cell and an overall suitably index (0–1) obtained and assigned to each pixel in the subsequent raster output. Further information can be obtained from Hirzel *et al.* (2002).

We do not attempt here to compare Biomapper with other available software, nor measure relative performance of the ENFA. Since this work was done, some authors have compared Biomapper to more standard techniques, such as generalized linear models (GLM) [see Hirzel *et al.* (2002); Dettki *et al.* (2003); Engler, Guisan & Rechsteiner (2004)]. Brotons *et al.* (2004) found GLM to be more accurate than ENFA only where reliable absence data were available. Readers are recommended to source these references and choose the technique best suited to their own objectives.

Species' presence data

The entire reserve was sampled using road transects. Adequate coverage and representation was ensured as the network traversed most of the property. A stratified random technique was devised based on vegetation types mapped by Clegg (1999), and vegetation communities were sampled in proportion to their abundance. Vegetation type was generally correlated with other habitat variables such as soil type and rockiness, for example miombo type veld occurred on rocky outcrops, while mopane veld dominated the basalt plains. Sampling was carried out with the assistance of Idrisi and the companion editing software Cartalinx (Clark Labs, 1999b). Daily distance covered (by vehicle) within each vegetation community was calculated using Cartalinx (length of arc represented length in metres on ground). From this, a record was kept of proportional distance covered (distance covered in vegetation community/total distance covered) in each vegetation community against proportional area of each respective vegetation community. A total distance of 944 km was sampled here.

Sampling took place 6 days a week during the months of September and October 2001, and was restricted to the daylight hours 05.30–10.00 and 16.00–18.00 local time. Ungulates are known to feed mostly during these times, taking to the shade at midday (Jarman & Sinclair, 1979).

An open vehicle was driven at an average speed of 25 km h^{-1}. One observer stood in the centre of the vehicle, and when an animal or herd was sighted, the precise location was taken using a handheld Global Positioning System (GPS) receiver. These data were later downloaded to Cartalinx and exported to Idrisi as separate (species) vector coverages. Pegs were placed at each site and the drive continued. The pegs were later returned to and habitat variables recorded.

Over the 2-month period, species were sampled with the following frequency (number of sightings where sites were sampled): 23 buffalo; 26 sable antelope; 28 waterbuck; 31 wildebeest; 21 white rhino and 37 zebra.

Environmental variables

Environmental variables thought to determine utilization of habitat by grazing herbivores were estimated. When an animal or herd had been sighted (as above), a 20 m × 20 m plot was demarcated. Measurements characterizing the herbaceous layer were made by subsampling with 20 × 1 m^2 quadrats in diagonal lines, viz. ten quadrats placed from one corner of the plot to the other. Within each quadrat, mean maximum grass sward height (cm) was estimated with the aid of a calibrated rod. Percent cover of green (photosynthetically active) grass, sedges and forbs was visually estimated using an adapted rank-score method from Walker (1976). Grass species in the herbaceous layer were ranked according to the dry-weight-rank technique of 'T Mannetje & Haydock (1963), using the formula given by Walker (1976). Most grass species were discarded because of their low percent contribution to herbaceous biomass, leaving *Digitaria eriantha* (Steud.), *Panicum maximum* (Jacq.) and *Urochloa mossambicensis* (Hack.). Canopy volume (m^3 ha^{-1}) was estimated by Clegg (2001) and included all woody vegetation >1 m in height. Canopy height and width were estimated visually and canopy was assumed to be cylindrical.

Three soil variables were included in the analysis (phosphorous, nitrogen and potassium), with all other soil variables being discarded because of collinearity. Data for soil variables were taken from Chawanji (2000) and assigned to an Idrisi raster coverage. Rock cover was visually estimated as proportion of site comprising rocks >5 cm in diameter.

Distance to the nearest water was computed using the GIS. All surface water points were recorded using a GPS receiver at the end of September 2001. The locations were then downloaded to Idrisi and a coverage representing the Euclidean distance from each waterpoint created. Time since last burn was calculated from historical records (in months) and converted to raster coverage. Elevation was available as a coverage from the Malilangwe Research Department.

All variables were attributed to respective GIS raster coverages in Idrisi. Coverages were then exported to Biomapper and tested for correlation (with each other). Where two-or-more variables were strongly correlated ($r > 0.7$, and including negative values), the variables thought less informative to management were discarded (see Table 1). So for example, distance to water was kept in preference to elevation.

Validation

Separate HS maps were composed for each of the study species using the presence data collected during the October 2001 aerial census (Goodman, 2001). The census took place over 3 days and covered the entire property. HS maps were validated here using the VALIDATE function in Biomapper. The aerial census data were analysed in Biomapper using the same habitat variables and the resultant HS maps were used as truth maps. The VALIDATE function used Pearson's correlation coefficient to assess the accuracy of each result map (maps derived using our presence data) against each truth map (Hirzel *et al.*, 2002). The results are presented in Table 2.

Results

Output of the ENFA included a factor table and HS map for each study animal. An example of a suitability coverage for waterbuck is given in Fig. 1.

Factor table scores allowed for useful interpretation of ungulate habitat preferences. MF scores for each species are shown in Table 3.

All species showed a strong association with green grass cover (Table 3). Scores for distance to water indicated that buffalo and waterbuck did not venture far from the mean (mean distance for all species = 1022 m, range =

Table 1 Variables used in the ecological niche factor analysis. Discarded variables are listed with justification

Ecographical variable	Discard criteria and action taken
Available phosphorus (%)	Correlated with forb cover ($r = 0.77$), discarded
Canopy volume (m^3 ha^{-1})	Used in analysis
Clay (%)	Corr. with sward height ($r = 0.89$), discarded
Digitaria eriantha (%)	Used in analysis
Distance to water (m)	Used in analysis
Elevation (m)	Corr. with greenness of grass ($r = 0.87$), water distance ($r = 0.74$), discarded
Forb cover (%)	Used in analysis
Greenness of grass (%)	Used in analysis
Magnesium (%)	Corr. with greenness of grass ($r = 0.85$), discarded
Nitrogen content (%)	Corr. with greenness of grass ($r = 0.87$), sward height ($r = 0.86$), discarded
Panicum maximum (%)	Used in analysis
Potassium (%)	Corr. with greenness of grass ($r = 0.71$), sward height ($r = 0.79$), discarded
Rock cover (%)	Used in analysis
Sand (%)	Corr. with rock cover ($r = 0.70$), discarded
Sedge (%)	Corr. with *D. eriantha* ($r = 0.90$), discarded
Silt (%)	Corr. with greenness of grass ($r = 0.71$), sward height ($r = 0.73$), discarded
Sward height (cm)	Corr. with greenness of grass ($r = 0.94$), discarded
Time since burn (months)	Used in analysis
Urochloa mossambicensis (%)	Used in analysis

Table 2 Results of the validation analysis of habitat suitability maps composed of grazing ungulates by comparing composed result maps against truth maps. The greater the *r*-value, the higher the predictive power of the map

Study animal	Correlation coefficient (*r*)	Standard deviation
Buffalo	0.92	0.02
Sable antelope	0.74	0.15
Waterbuck	0.78	0.08
White rhino	0.86	0.07
Wildebeest	0.94	0.04
Zebra	0.98	0.01

20–3086 m). Sable antelope and white rhino utilized habitat farther from the mean (distance to water) value. MF scores for time since last burn were mostly low, indicating ungulate preference for recently burnt veld at this time of the year, with the exception of buffalo. Low scores were prevalent for canopy volume, rock cover and percent contribution to herbaceous biomass by *P. maximum*. Buffalo and waterbuck showed a strong association with *D. eriantha*, while wildebeest and zebra associated with veld dominated by *U. mossambicensis*. Finally sable antelope and zebra associated with habitat where forb cover was above average.

Scores for the first speciality factor are given in Table 4. Buffalo were restricted by canopy volume, waterbuck by surface water and forb cover, white rhino and wildebeest by rock cover and zebra by *D. eriantha*.

In summary, buffalo associated with less recently burnt veld, close to water where grass cover was dominated by *D. eriantha*. Sable antelope utilized closed woodland, relatively far from water where forb cover was high. Waterbuck stayed close to surface water points, in areas where burns were less frequent and veld dominated by *D. eriantha*. White rhino utilized veld further from water where rock cover was low. Wildebeest and zebra associated with recently burnt veld dominated by *U. mossambicensis*. All ungulates actively associated with a relatively green grass sward.

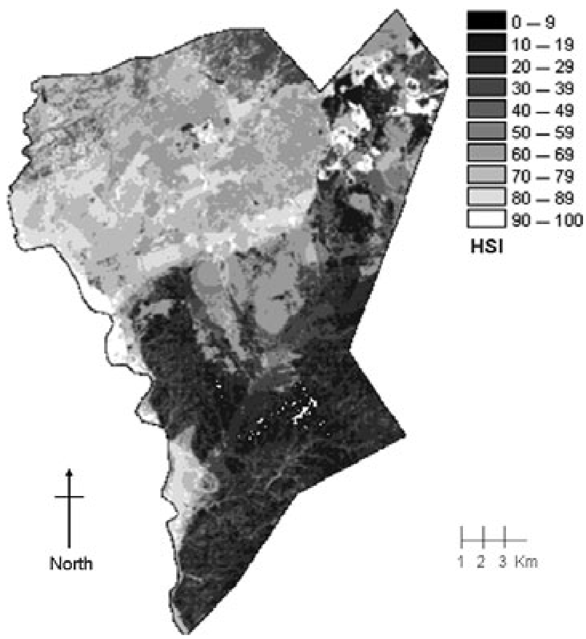

Fig 1 Habitat suitability map for waterbuck during the hot dry season at Malilangwe Estate. The habitat suitability index (HSI) is categorized for easy visual interpretation

Findings here were similar to those of the DFA carried out by Traill (2004), and other studies on the habitat

Table 3 Marginality factor (MF) scores for grazing ungulates during the hot dry season. Values in bold face are considered strongly influential. A high MF value indicates that the species requirements are significantly different from average habitat conditions

	Species					
Variables	Buffalo	Sable	Waterbuck	White rhino	Wildebeest	Zebra
Canopy volume	0.09	0.21	0.15	0.13	0.20	0.35
D. eriantha	**0.63**	0.33	**0.80**	0.11	0.01	0.04
Distance water	0.04	0.37	−0.04	**0.56**	0.17	0.29
Greenness of grass	**0.43**	**0.60**	**0.42**	**0.66**	**0.47**	**0.53**
Time since burn	**0.47**	0.16	0.27	0.16	0.02	0.21
Forb cover	0.16	**0.55**	0.12	0.30	0.27	**0.41**
P. maximum	0.35	0.06	0.25	0.22	0.09	0.25
Rock cover	0.22	−0.03	0.04	−0.15	−0.05	0.03
U. mossambicensis	0.09	0.14	0.09	0.19	**0.79**	**0.48**
Percent variance	48	29	53	38	51	51

Species/variables	Buffalo	Sable	Waterbuck	White rhino	Wildebeest	Zebra
Canopy volume	**0.89**	−0.13	0.22	−0.08	0.08	0.01
D. eriantha	0.05	0.06	−0.01	0.01	−0.13	**−0.85**
Distance water	0.38	−0.10	**−0.80**	−0.04	0.16	0.32
Greenness of grass	−0.19	0.37	0.19	−0.04	−0.09	−0.02
Time since burn	−0.06	−0.09	−0.20	−0.08	−0.17	0.11
Forb cover	−0.13	−0.18	**−0.46**	−0.13	−0.10	−0.02
P. maximum	0.01	−0.18	−0.13	−0.03	0.03	−0.05
Rock cover	0.01	−0.03	0.01	**−0.97**	**−0.95**	**−0.40**
U. mossambicensis	0.03	−0.04	0.03	−0.15	−0.03	−0.09
Percent variance	23	40	23	44	25	13
Total variance (MF and SF)	71	69	76	82	76	64

Table 4 Specialization factor (SF) scores (first only) for grazing ungulates during the hot dry season. Values in bold face are considered strongly influential. A high SF value indicates restricted ecological tolerance compared with overall range of prevailing conditions. Total variance extracted for the marginality factor (MF) and first SF given

preferences of African ungulates (Jarman & Sinclair, 1979; Ben-Shahar, 1995; Dekker *et al.*, 1996; Mwangi & Western, 1998).

Discussion

Key findings and implications for management at Malilangwe

Results are considered within the context of tools available to management, after Trollope (1990). Thus the influence that surface water, fire and veld structure had on ungulate habitat preference is discussed.

Greenness of grass was the main determinant of habitat utilization by large grazing ungulates at Malilangwe, with all species associating with a relatively greener grass sward. A senescent, highly lignified sward is a poor food source to ungulates (Sinclair, 1975), and they are therefore likely to avoid it. Grass sward height and grass greenness were found to be correlated here, and of the two, greenness was used in the model. A key finding of Traill (2004) was that ungulates separated themselves ecologically by grass height.

Distance to surface water separated species ecologically. Sable antelope and white rhino used habitat farther from water, relative to all other ungulates, while waterbuck and buffalo used habitat close to water. Management were cautioned on proposed future placement of artificial water supply in habitat highly suitable for sable antelope, as this could possibly be to the detriment of the population (Collinson & Goodman, 1982; De Boer & Prins, 1990).

Time since last burn also accounted for ecological separation, buffalo and waterbuck utilizing less recently burnt veld, and wildebeest associating with freshly burnt veld. The burning programme at Malilangwe ensured that burnt blocks were of adequate size to sustain grazing pressure and no further recommendations were made.

Wildebeest and zebra associated with closed canopies, usually open woodland, while buffalo associated with more open, rocky terrain. A shift towards more woody habitat would possibly be to the detriment of buffalo, and those ungulates that preferred open woodland. Ungulate associations with *U. mossambicensis* and *D. eriantha* did not imply that these grasses were being eaten, and further research into feeding selection and potential for competition at this level was advised.

Recommendations came with a caveat. Research was conducted during one dry season only, where rainfall in the preceding years had been above average, thus allowing a very narrow window-of-time in an atypical year. Ongoing monitoring of the ungulate populations and habitat was recommended.

Further applications

The raster format of the HS maps, and their compatibility with an advanced GIS package such as Idrisi allowed for further management-oriented analyses.

Percent area coverage of suitable habitat for each respective species allowed for more accurate stocking rate estimation, based on carrying capacities (not carried out by these authors). Waterbuck populations, for example, potentially only utilize about half of the estate. Further to this, HS maps were used to predict areas of potential use for species below estimated carrying capacity.

Species' coverages were overlayed and areas of potential competitive overlap for habitat identified. This was useful for ecologically sensitive species, such as sable antelope, which are likely to be out-competed by bulk grazing species, such as buffalo (Collinson & Goodman, 1982).

Finally, HS maps were used by management for impact assessment (again, not carried out by these authors). Proposed development of roads, for example, accounted for the habitat preference of IUCN listed species, in addition to other factors such as gradient and soil type.

In conclusion, sub-Saharan Africa faces many socio-political challenges, mostly to the detriment of biodiversity (Newmark & Hough, 2000; Hearn, 2001). Conservation practitioners have to account for these and other local challenges, while also attempting to make sound ecological decisions based on empirical research. The development of research tools that are freely available, compatible with popular software and require little modelling experience such as Biomapper, are especially welcome. Here we show Biomapper to be an adequate package for modelling HS where absence data are either lacking or unreliable, and where there is access to GIS software.

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