Ecological variables governing habitat suitability and the distribution of the endangered Juliana's golden mole

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Juliana's golden mole (*Neamblysomus julianae*) occurs in three isolated populations in the northeastern parts of South Africa. This cryptic species is not evenly distributed throughout its restricted range and appears to have very specific habitat requirements. Its endangered status reflects the necessity for a conservation management programme, which to date has not been comprehensive. A primary hindrance to such initiatives has been the lack of information pertaining to its habitat requirements. We assessed various soil and vegetation parameters, at each population site, in areas where the animals were found to be present or absent. A multiple logistic regression model highlighted the importance of soil hardness (governed by soil particle size distribution), in combination with the cover provided by trees, as the two ecological factors that best explained habitat suitability for Juliana's golden mole at the three localities. An IndVal analysis failed to identify any plant species that could reliably act as an indicator of habitat suitability for this fossorial mammal. These results have important implications for the conservation of the species.

Key words: *Neamblysomus julianae*, golden moles, small mammals, habitat suitability, habitat requirements, distribution.

INTRODUCTION

Landscapes are naturally heterogeneous, comprising a mosaic of various habitat types that result in an uneven distribution of species over space (Mauritzen *et al.* 1999; Sanderson *et al.* 2002). Through evolutionary processes, organisms may respond to this variation by becoming either niche specialists or generalists (Elena & Sanjuán 2003; Harmon *et al.* 2005). Highly specialized species are often limited to a particular type of landscape, being dependent on the ecological processes associated with it (Harmon *et al.* 2005). Effective conservation planning thus needs to consider the heterogeneous and dynamic nature of ecosystems (Huston 1994; Koehler 2000) as well as the underlying processes that shape a species' distribution (Caughley & Gunn 1996).

Most golden mole species (Chrysochloridae) are fossorial and difficult to detect in their subterranean niche. Furthermore, many species in this 50-million-year-old family (Stanhope *et al.* 1998) are habitat-specific and are range restricted on account of their acute adaptations to specific soil conditions (Bronner 1997; Bronner & Bennett

2005). These attributes, in combination with anthropogenic modification of habitats, are the primary reasons why 10 of the 21 species appear on the IUCN red list, with an additional three species listed as data-deficient (Bronner 2006). The 2004 IUCN assessment of southern African mammals listed five golden mole species within the 10 most endangered mammal species. After De Winton's golden mole (*Cryptochloris wintoni*), known from only a few specimens collected more than 50 years ago (Bronner 1997), Juliana's golden mole (*Neamblysomus julianae*) is South Africa's second most endangered golden mole (Pretoria population; Bronner 2006).

The species was only described in 1972 from a specimen on the Bronberg Ridge (BR) in eastern Pretoria, and was subsequently found at Nylsvley Nature Reserve (NNR) 120 km to the north, and the southwestern Kruger National Park (KNP) 350 km to the east (Meester 1972; Bronner & Bennett 2005). The dearth of information available for this species is typical for the majority of golden mole species (Bronner & Bennett 2005). Juliana's golden mole is restricted to sandy soils (Skinner & Smithers 1990), but individuals are not evenly

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distributed throughout this species' geographic range and appear to be restricted to particular bushveld habitat types (C.R.J., pers. obs.).

Habitat requirements underlying the patchy distribution of golden moles are not understood and this data deficiency compromises conservation efforts. Adequate habitats need to be identified and conserved to protect and sustain the ecological requirements of this species. This is especially important for the Bronberg population of Juliana's golden mole, which probably had a historical distribution in an area approximately 15 km long by 1 km wide that is now estimated to have declined by 80% (Bronner 2006) because the natural habitat has been transformed by roads and housing. The other two populations of this species have also seen large reductions in their available habitat resulting from various land use practices (including cultivation) resulting in extensive habitat loss and fragmentation (Bronner 2006). Some mammal species may be well adapted to these highly fragmented habitats (Terborgh 1974; Barko *et al.* 2003) but golden moles are certainly not because of their specialized adaptations for their subterranean life, coupled with poor dispersal capabilities.

Dealing with the special habitat requirements, poor dispersal capabilities, sensitivity to human disturbance, and low detection probabilities typically associated with many rare, habitat specific or cryptic species, pose serious challenges for conservation planning (Piggott & Taylor 2003). Conservation efforts are desperately required to address the issue of habitat connectivity and protection for Juliana's golden mole. This necessitates a thorough understanding of the ecological requirements and distribution of the species, both at local and regional scales. This paper documents the first investigation into the habitat characteristics associated with the distribution of Juliana's golden mole.

METHODS

Habitat requirements were inferred by the assessment of soil and vegetation properties at study plots where signs of Juliana's golden mole were present and in plots where they were absent. Fresh signs of golden mole burrowing activity in the form of newly pushed ridges are only observed after periods of rain, which softens the soil and makes it more cohesive. During the summer rainfall months of February and March 2005, soil and vegetation properties were recorded in 48 study plots (NNR: 12, BR: 13, KNP: 23) and incorporated

both presence and absence of the Juliana's golden mole. Study plots consisted of randomly selected 5 × 5 m plots, with a minimum distance of 100 m between plots. We ensured that the vegetation in the plots was representative of the surrounding vegetation by visually assessing the dominant species and vegetation structure in and around the plot.

Determination of presence/absence status

Species presence/absence surveys are commonly used in ecology and conservation management, yet they can never be used to confirm that a species is absent from a given location (MacKenzie *et al.* 2002; Guisan & Zimmerman 2000; MacKenzie 2005). Failure to detect the presence of a species in an occupied habitat patch is a common sampling problem when a) the population size is small, b) individuals are difficult to sample, or c) sampling effort is limited (Gu & Swihart 2004). Detecting the presence of Juliana's golden mole is difficult because of the animal's cryptic ways. Another difficulty is that not all suitable habitat is always occupied, which may result in false negative observations (Fielding & Bell 1997).

Juliana's golden mole does not usually move aboveground or produce conspicuous soil mounds on the soil surface and it is very difficult to catch. This means that one has to observe foraging tunnels to be certain that the species is present and that the habitat is suitable. Ecological data collected for presence plots in this study will therefore accurately describe the habitat of the species. Certain plots where the species is considered to be absent may have been patches of unoccupied but suitable habitat or a patch in which the presence of the animal went undetected. However, all plots were carefully searched to ensure that if the animal was present that it was detected. Despite certain limitations, this method suffices to highlight habitat preferences of the species thus aiding conservation planning. The likely consequence of false negative errors is to reduce the magnitude of difference observed between habitat that is considered to be suitable and habitat that is considered to be unsuitable.

Vegetation survey

In each plot, the cover of each plant species was assessed using the Braun-Blanquet scale (Kent & Coker 1995). Total vegetation cover for a plot was assessed by calculating the total surface area of the 25 m² quadrat, expressed as a percentage, that had

some form of vegetation cover emanating from it. Furthermore, the relative cover provided by the tree, shrub and herbaceous layers was evaluated. Tree density (individuals greater than 2 m in height), average height (to the nearest half-metre) and canopy cover (percentage of total quadrat) was assessed within a greater 10×10 m area that incorporated the original 25 m^2 plot. The larger area provided a more realistic representation of these properties within the general landscape.

Soil properties

At all four corners of a quadrat, soil samples were augured (auger bucket 80 mm in diameter), soil depth evaluated to a maximum depth of one metre (measuring maximum auger depth), and a static cone-penetrometer (Herrick & Jones 2002) assessment was undertaken. Soil samples were transferred directly into plastic bags. Soil texture was ascertained after drying samples in an oven at 40°C to constant mass.

Soil texture provides an indication of the relative proportions of the various separates in the soil (Van der Watt & Van Rooyen 1995). The particle size distribution or range of particle sizes in a sample influence several soil properties, including compaction and soil permeability to water (Brady & Weil 1999). A well-graded soil refers to the constituent particles being distributed over a wide range of sizes and, conversely, a uniformly or poorly graded soil refers to the size of particles being distributed over a narrow size range. A representative sub-sample (approximately 500 g) was put through a series of nine sieves that ranged in size from 8 mm to 0.063 mm and were vibrated on an electronic shaker for 10 minutes (Briggs 1977). Individual sieve contents were weighed and the relative proportion of the sample calculated, thereby giving the particle-size distribution of each sample. Shannon's Diversity index (*H*) was used to assess the degree of heterogeneity in soil particle-size distributions for presence and absence plots (Smith & Smith 2003).

A penetrometer (Eikelkamp Agricultural Instruments, Netherlands), consisting of a rigid cone-tipped rod attached to a pressure-measuring device (proving ring), was used to determine the hardness of the soil. During testing the penetrometer was pushed into the ground at a slow, steady speed and the soil resistance was measured at 50-mm intervals, beginning at the soil surface. The measure of soil strength (or resistance) was taken directly from the dial on the proving ring and the units of measurement are presented in kN/50 mm. These measurements facilitate the quantitative characterization of soil hardness, which is thought to be one of the major factors governing soil suitability for golden moles.

Statistical analysis

IndVal Indicator Analysis. The association of specific plant species with golden mole presence or absence was investigated using IndVal-indicator analysis (Dûfrene & Legendre 1997) programmed in MATLAB® R2006a (The MathWorks, Inc., U.S.A.). The indicator value method facilitates the identification of indicator species for *a priori* established groups of samples (in this case presence and absence). The indicator value of a species *i* in group *j* is calculated by multiplying its group specificity (A_{ij}) with its group fidelity (B_{ij}). A_{ij} is the mean abundance of the species *i* in the sites of group *j* relative to its abundance in all groups considered. B_{ij} is the relative frequency of occurrence of species *i* in the sites of group *j*:

$$A_{ij} = (n \text{ individuals}_{ij})/(n \text{ individuals}_i)$$

$$B_{ij} = (n \text{ sites}_{ij})/(n \text{ sites}_j)$$

$$\text{IndVaL} = (A_{ij}) \times (B_{ij}) \times 100$$

The resulting indicator value is expressed as percentage of perfect indication (i.e. when all individuals of a species are found only in one of the *a priori* established groups and when the species occurs in all sites of that group). A species with high specificity and high fidelity will have a high indicator value (McGeoch *et al.* 2002).

Multiple logistic regression analysis

The presence of the golden mole in a plot can be considered as a binominal process; it is either present with a probability of *P* or absent with a probability of $1 - p$, where var $(p) = p (1\ p)$. Such data are therefore suitable for logistic regression analysis by means of generalized linear mixed effects models. Population was included as a random effect to incorporate spatial variability. A global model was produced to investigate the relative importance of each explanatory factor (ecological variables). This model applied a multiple regression analysis to the explanatory factors. Eleven alternative and biologically relevant candidate models, all derived from the global model, were analysed. The models incorporated the fact that data were collected from three different popula-

tions. Akaike's Information Criterion (AIC; Burnham & Anderson 2002), based on the principle of parsimony, was employed to select the most appropriate model. In particular, the equation

$$\text{AIC}_c = -2\log_e(L\hat{\theta}) + 2K + \frac{2K(K+1)}{(n-K-1)}$$

was used and can account for low sample sizes. K denotes the number of parameters estimated in the model, and n is the sample size. In addition, Akaike weights were calculated as:

$$\omega_i = \frac{\exp(-\Delta_i/2)}{\sum_{r=1}^{R}\exp(-\Delta_r/2)} \ .$$

In the AIC sense, this can be interpreted as the probability that a specific model is the best, in that it minimizes the expected Kullback-Leibler (KL) discrepancy, given the data and the set of candidate models (Burnham & Anderson 2002).

The model with the highest Akaike weights (ω) consequently explains the most variation using the fewest parameters. At the same time the biological relevance of the models must always be carefully considered (Burnham & Anderson 2002). Because all the models had a similar structure and sample size, the respective AIC$_C$ values from the different models were comparable. In order to calculate the confidence intervals for the coefficients of the best model, the Markov Chain Monte Carlo method was used, which generates a sample from the posterior distribution of the parameters of the fitted model (R Development Core Team 2006). Coefficients were considered significant when confidence intervals did not overlap with zero (Burnham & Anderson 2002).

Owing to the problem of multi-collinearity in multiple regression analyses, the pairwise correlation between all the variables was evaluated. In particular, there was strong inter-correlation among the various tree variables and soil variables. Thus, to avoid multi-collinearity among the explanatory variables in the multiple regression analysis as well as to reduce the number of explanatory factors, the first component from two principal component analyses (PC1-factor; SPSS 2005) was used. For the vegetation variables, the PC1-factor was based on the measurements of tree layer, average tree height, canopy cover and tree density, while the Shannon index (particle size distribution) and soil hardness were included for the soil variables. For the tree measurements, the PC1

accounted for 63% of the total variance of the variables included in the analysis (Eigenvalue = 2.53), and was positively correlated with canopy cover ($r = 0.875$, $P < 0.001$), tree layer ($r = 0.841$, $P < 0.001$), average tree height ($r = 0.802$, $P < 0.001$) and tree density ($r = 0.640$, $P < 0.001$). The PC1-factor can thus be interpreted as the physiognomic properties of trees based on the variables included in the principal component analysis, and will hereafter be referred to as the 'tree factor'. For the soil measurements, the PC1 accounted for 80% of the total variance of the variables included in the analysis (eigenvalue = 1.59), and was positively correlated with Shannon's index ($r = 0.892$, $P < 0.001$) and soil hardness ($r = 0.892$, $P < 0.001$). The PC1-factor in this principal component analysis can therefore be interpreted as the soil variables governing and describing soil hardness and compaction, and will hereafter be referred to as the 'soil factor'.

RESULTS

Plant species

A total of 245 plant species were recorded from all of the study plots (Appendix A). The indicator analysis did not yield any species that had both a high specificity and fidelity to presence sites. A subjective benchmark value of 70% IndVal was used to denote an indicator species (McGeoch *et al.* 2002). Only three species emerged at each population that had significant probabilities, but these all had low IndVal values, ranging from 20.00% to 55.56% (Table 1). The highest ranked species across all plots had an IndVal value of 55.56% and was a grass species, *Eragrostis trichophora,* found in BR.

Multiple logistic regression

The logistic regression model investigated the relative importance of all the environmental explanatory factors on the probability of finding Juliana's golden mole present in the study plots. Initially, a global multiple regression model was constructed that included all explanatory variables, namely: soil factor, tree factor, soil depth, vegetation cover and shrub layer. Then a number of alternative models were run (Table 2). The AIC$_C$ criteria favoured a model that included a significant effect of tree factor and soil factor. The tree factor was positively associated with the presence of the mole, indicating that the probability of golden mole occurrence increased as tree factor increased. In light of the variables comprising the 'tree

Table 1. Plant species associated with presence plots at each population that had significant probability values. The corresponding IndVal values are presented.

Population	Species	IndVal	Probability
KNP	*Ascolepis capensis*	20.00	0.010
	Helichrysum acutatum	20.00	0.008
	Tristachya leucothrix	20.00	0.006
NNR	*Acacia toritillis*	28.57	0.044
	Dichrostachys cinerea	28.57	0.049
	Justicia flava	28.57	0.043
BR	*Eragrostis trichophora*	55.56	<0.001
	B8-64 (unidentified)	44.44	<0.001
	Combretum molle	33.33	0.015

Table 2. The candidate models explaining the probability of finding Juliana's golden mole present in study plots. The models are based on multiple logistic regression analyses and ranked according to descending values of the Akaike weights (ω_i). According to the principle of parsimony, the model with the highest ω_i explains most of the variation using the fewest parameters. K indicates the number of model terms plus one for intercept and error term, AIC_C represents Akaike information criterion corrected for small sample size, and ΔAIC_C denotes the deviance in AIC_C from the model with the lowest AIC_C. The table lists the five best candidate models out of 11 potential models.

Model	K	AIC_C	ΔAIC_C	ω_i
Soil factor + Tree factor	3	50.33	0.00	0.335
Soil factor + Tree factor + Shrub layer	4	51.34	1.01	0.202
Soil factor	2	52.46	2.13	0.116
Soil factor + Tree factor + Soil depth	4	52.66	2.33	0.105
Soil factor + Tree factor + Veg. cover	4	52.76	2.43	0.099

factor', this indicates that an increase in tree height, layer, density, and canopy cover increases the habitat suitability for Juliana's golden mole. The soil factor was negatively associated with the presence of the golden mole, indicating that occurrence of the mole decreased as soil factor increased. Thus, as soil particle size heterogeneity (Shannon's index) increases, which in turn results in a corresponding increase in soil hardness, the probability of finding Juliana's golden mole decreases.

Statistical support for the chosen model was not as pronounced when compared to the second best model, as it was compared to the third, fourth and fifth best models, as the two highest ranked models had both a ΔAIC_C less than 2 (Table 2). The Akaike weight criteria suggested that the highest ranked model was 1.66 times more likely to be the KL best model compared to the second ranked model (Table 2), which also included the effect of shrub layer. Accordingly, this indicates that shrub layer, which was positively correlated with the occurrence of the mole, should be considered as a contributing component of the characteristics that determine the habitat suitability for Juliana's golden mole. Table 3 shows the statistical attributes for components incorporated in the best model.

DISCUSSION

IndVal

Climate and substrate are the two determining factors for vegetation growth and each ecological region has its own set of unique variables that

Table 3. Factors affecting the probability of finding Juliana's golden mole present in study plots. β, S.E., t and CI_{min}, CI_{max} denote the regression coefficient, standard error, t-value and 97.5% confidence interval for the coefficients, respectively. Coefficients are considered significant when confidence intervals do not overlap with zero.

Coefficients:	β	S.E.	T	CI_{min}, CI_{max}
(Intercept)	1.527	0.088	17.421	1.362, 1.694
Soil factor	–0.334	0.065	–5.174	–0.449, –0.200
Tree factor	0.112	0.057	1.946	0.009, 0.230

influence the plant community structure (Bredenkamp & Brown 2001). The IndVal analysis investigated the potential use of sympatric plant taxa as indicator species, but did not yield any associations of great affinity. An important consideration is the size and number of sample plots. A relatively low sample size incorporating 5 × 5 m quadrats may not have been sufficiently large to capture all plant species occurring within the suitable habitat. Species that occur at lower densities within this region may thus have only been recorded in a small percentage of sample plots. Their significance could potentially be overlooked or the projected probability underestimated when using the IndVal analysis. It is thus difficult to interpret the present results of the IndVal analysis. Although IndVal values were significant for some species all species showed low indicator values (ranging between 20.00 and 55.56%), whereas values greater than 70% would typically be required before a species is considered to have a meaningful indicator value (McGeogh *et al.* 2002). This means that none of the species sampled were present in most of the plots where Juliana's golden mole was recorded as present (presence plots) and absent from most of the absence plots.

The results from this study suggest that none of the species recorded can be considered to be reliable indicator species for Juliana's golden mole habitat.

Dense stands of large (>3 m) *Terminalia sericea* are very common in both the NNR and KNP, but are absent from the BR. These species are good indicators of sandy soils and often highlight areas that are inhabited by Juliana's golden mole (C.R.J., pers. obs.). This species did not feature strongly in the IndVal analysis, most likely because it does not occur at the BR population. When combining the plant species from all three populations, this would directly affect the IndVal analysis. Additionally, the subjective placement of the relatively small survey quadrats may not have adequately captured the occurrence of these trees. Since this paper aims to describe the habitat utilized by Juliana's golden mole, it is important to state the nature of this association. In areas of mixed bushveld, *Terminalia sericea* often occurs in a shrub-like form and does not form dense stands of tall conspecifics. It should be noted that in these instances the presence of the species is not usually associated with loose sandy deposits, and would consequently not indicate potentially suitable habitat (C.R.J., pers. obs.).

Multiple logistic regression

The multiple logistic regression revealed that the model including the soil factor (derived from particle size distribution (PSD) and soil hardness) in combination with the tree factor (derived from tree density, layer, height, and canopy cover) best explained the probability of habitat being suitable for Juliana's golden mole. The model indicated a positive relationship between the presence of Juliana's golden mole and the tree factor, but an inverse association between the soil factor and the presence of the golden mole. The soil factor accounts for more variation than tree factor, and this variable (on its own) is ranked as the third best model overall. Based on the above, we can conclude that a poorly graded soil largely determines habitat suitability for Juliana's golden mole, but with an increasing amount of shade provided by trees, the habitat suitability greatly increases.

Poorly graded soil, with a more uniform PSD, is more resistant to compaction while the availability of various particles sizes in well-graded soils makes such substrates prone to compaction (Brady & Weil 1999). The significant positive correlation between soil PSD and soil hardness confirms that as the heterogeneity in the PSD increases, soil hardness also increases (Jackson *et al.* 2008). The PSD regulates the ease of tunnelling and consequent energy expenditure, with the small, 35 g golden moles being confined to softer soils. The high energetic costs of underground locomotion by subterranean mammals have been well documented (Nevo 1979; Bennett & Faulkes 2000; Luna *et al.* 2002; Luna & Antinuchi 2006) and burrowing efficiency is affected primarily by the relationship between soil hardness and the cost of tunnelling (Luna & Antinuchi 2006). The Namib Desert golden mole (*Eremitalpa granti namibensis*) occurs in exceptionally loose dune sands. In this species, the gross energy cost of sand swimming was found to be 26 times more expensive than running on the surface (Seymour *et al.* 1998). Sand swimming through soft sands, however, only incurred energetic costs amounting to less than one tenth of the energy required by mammals tunnelling through compact soils (Seymour *et al.* 1998). The physical and energetic implications of harder soils would consequently make occupying such soils unfeasible.

The role of the physiognomic vegetation properties in the two best models emphasize the contribution of vegetation structure to habitat suitability. Increased vegetation cover would be expected to

have a major influence on microclimatic conditions such as soil temperature and soil moisture. A combination of these two factors, specifically in the relatively hot and dry conditions characteristic of all three populations, would directly affect soil hardness and consequently the optimal microhabitat conditions for the species (Jackson 2007). In addition, soil moisture and temperature affect the biology of soil micro-arthropods (Choi *et al.* 2002) with moister rather than drier conditions expected to be more favourable for these organisms (Ivask *et al.* 2006). Such conditions would most likely support a greater abundance and diversity of soil invertebrates thus making food acquisition easier for golden moles. Subterranean mammals occupy an energy-restricted environment, and when locomotion and food acquisition is energetically demanding, a reliable food source is of vital importance.

The effect of PSD on vegetation structure chiefly concerns soil permeability and associated nutrient status. Characteristic tree species that are frequently associated with well-drained, nutrient poor sandy soils in the north eastern parts of South Africa include *Terminalia sericea* and *Burkea africana* (Low & Rebelo 1996). These broadleaved species have large spreading canopies that provide shade and are frequently encountered in Juliana's golden mole habitat (C.R.J., pers. obs.). Leaves that are lost by the trees also accumulate on the soil surface, further buffering the substrate from direct sunlight. Limiting the amount of sunlight on the soil surface would keep the soil temperature lower and the soil moist for longer periods. These variables have been shown to be important for both daily and seasonal activity patterns in Juliana's golden mole (Jackson 2007). Poorly graded sandy soils with a very sparse vegetation cover may thus not provide microclimatic conditions essential to Juliana's golden mole, as soils would be hotter and harden more rapidly after rainfall events, limiting the window period during which foraging would be possible (Jackson 2007).

Although the IndVal analysis failed to highlight the importance of any one species as an indicator of the presence of *N. julianae,* the multiple logistic regression highlighted the importance of a well-established layer of vegetation for this species. It appears that the role of the vegetation in shaping microclimatic conditions is more important than the presence of any particular plant species.

This study suggests that conserving this species would entail more than just protecting sandy soils.

The structural properties of the sandy soils are important, as well as the amount of vegetation cover. Considering vegetation structure in conservation programmes would be of great importance since many areas in southern African have seen indigenous trees removed for firewood and natural vegetation replaced by monocultures. This would leave the soil surface more exposed and alter components of the natural ecosystem such as soil temperature and moisture. These changes may be very detrimental to this highly habitat-specific golden mole species. Consequently, the effect of land use is also of importance for conserving the species as it may not survive successfully on private land should the land use be of an incompatible nature.

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Appendix A. Plant species lists for the Bronberg Ridge, Nylsvley Nature Reserve and Kruger National Park study areas. The occurrence of a plant species in a presence or absence study quadrat is designated by †. Specimen codes are provided for species that were not successfully identified in the herbarium, and are listed at the bottom of each list.

Table A1. Plant species recorded in presence and/or absence study quadrats on the Bronberg Ridge, Gauteng Province, South Africa.

Species name	Presence	Absence
Acacia sp.	†	
Acalypha angustata	†	
Acalypha villicaulus	†	
Adenia glauca	†	
Aloe sp.	†	†
Argyrolobium pauciflorum		†
Aristida adscensionis	†	
Aristida congesta	†	
Aristida transvallensis		†
Asparagus africanus	†	
Athrixia elata	†	
Barleria sp.	†	†
Berkheya seminivera	†	
Bidens pilosa	†	
Brachiaria serrata		†
Burkea africana	†	
Canthium gilfillanii	†	
Canthium mundianum	†	
Cheilanthus hirta	†	
Cleome maculata	†	†
Combretum molle	†	
Commelina africana	†	
Cryptolepis oblongifolia	†	
Cymbopogon plurinodis	†	
Dichoma zeyheri		†
Diheteropogon amplectens	†	†
Elephantorrhiza burkei	†	
Elephantorrhiza elephantina		†
Eragrostis curvula	†	
Eragrostis gummiflua		†
Eragrostis trichophora	†	†
Eustachys paspaloides	†	
Foeniculum vulgare		†
Hebenstretia angolensis	†	
Helichrysum rugulosum	†	†
Hibiscus trionum	†	
Hypharrenia filipendula	†	
Indigofera hilarus	†	†
Justicia anagalloides	†	†
Leonotis sp. 1	†	
Loudetia simplex	†	†
Melinis nerviglumis	†	
Melinis repens	†	†
Ochna pulchra	†	†
Oldenlandia corymbosa	†	†
Opuntia ficus-indica	†	
Parinari capensis	†	
Pearsonia sessilifolia	†	

Species name	Presence	Absence
Pellaea calomelanos	†	†
Rhynchosia caribaea	†	
Rhynchosia minima		
Rhynchosia nitens	†	†
Rhynchosia totta	†	
Senecio inornatus	†	†
Senecio macrocephalus		†
Senecio sp. 1		†
Setaria sphacelata	†	†
Strychnos pungens	†	
Tagetes minuta	†	
Tephrosia sp.	†	
Themeda triandra	†	†
Tristachya biserata	†	
Urelytrum agropyroides	†	†
Vernonia staehelinoides	†	
Xerophyta retinervis	†	†
B11-77		†
B11-79		†
B11-81		†
B12-86	†	
B1-3	†	†
B13-88	†	
B1-4	†	
B16-94	†	
B2-28	†	†
B4-38	†	
B5-44		†
B5-46		†
B5-48		†
B8-64	†	

Table A2. Plant species recorded in presence and/or absence study quadrats in Nylsvley Nature Reserve, Limpopo Province, South Africa.

Species name	Presence	Absence
Abutilon angulatum		†
Acacia karroo		†
Acacia toritillis		†
Achyranthes aspera		†
Aerva leucura		†
Aristida congesta	†	†
Aristida diffusa	†	†
Asparagus africanus	†	†
Blepharis integrifolia		†
Burkea africana	†	
Carrisa bispinosa		†

Species name	Presence	Absence
Chaelanthus costatus	†	
Cleome maculata	†	
Combretum molle	†	
Commelina africana	†	†
Crabbea acaulis	†	
Dactyloctenium aegyptium		†
Dichrostachys cinerea	†	†
Digitaria eriantha	†	
Diheteropogon amplectens	†	
Diospyros lycioides		†
Eragrostis curvula	†	†
Eragrostis gummiflua		†
Eragrostis sp. 2	†	†
Eragrostis trichophora		†
Euclea crispa		†
Euclea natalensis	†	
Eustachys paspaloides		†
Grewia flava		†
Grewia monticola	†	
Gymnosporia sp.		†
Hermannia sp.	†	
Hermannia sp. A		†
Hermannia sp. B		†
Hermannia sp. C	†	
Ipomoea sinensis	†	
Isoglossa grantii		†
Justicia flava		†
Kohautia virgata	†	
Lannea discolor	†	
Lobelia sp.	†	
Melinis repens	†	
Oldenlandia corymbosa	†	
Panicum maximum	†	†
Perotis patens	†	
Rhus dentata	†	
Rhynchosia totta	†	
Sida cordifolia		†
Solanum delagoensis	†	†
Strychnos madagascariensis	†	
Strychnos pungens	†	
Tephrosia polystacha	†	†
Terminalia sericea	†	†
Themeda triandra	†	
Urelytrum agropyroides	†	
Waltheria indica	†	
Ziziphus mucronata		†
N10-74	†	
N10-78	†	
N10-80	†	†
N1-1	†	
N1-10	†	
N1-16	†	
N11-84		†
N12-88		†
N14-100		†

Species name	Presence	Absence
N14-99		†
N1-9	†	
N2-19	†	
N2-20	†	
N2-22	†	
N2-25	†	
N2-26	†	
N3-34	†	†
N3-36	†	
N3-38	†	
N7-55	†	
N7-59	†	
N7-61	†	
N8-63	†	
N8-64	†	
N8-67	†	
N9-73		†

Table A3. Plant species recorded in presence and/or absence study quadrats in the Kruger National Park, Mpumalanga Province, South Africa.

Species name	Presence	Absence
Acacia swazica		†
Achyropsis avicularis	†	
Aeschynomene micrantha	†	
Agathesanthemum bojeri	†	†
Alysicarpus rugosus subsp. perennirufus	†	†
Andropogon schirensis	†	†
Argyrolobium sp.	†	
Argyrolobium speciosum	†	
Argyrolobium transvaalense	†	
Aristida congesta		†
Ascolepis capensis		†
Balanites maughamii		†
Barleria gueinzii	†	†
Barleria sp.	†	†
Bidens bipinata		†
Bothriochloa insculpta		†
Brachycorythis pleistophylla	†	
Cassia abbreviata	†	†
Chamaechrista plumosa	†	†
Combretum apiculatum	†	†
Combretum collinum	†	†
Combretum molle	†	†
Combretum zeyheri		†
Commelina africana	†	†
Commelina benghalensis	†	
Commelina eckloniana	†	
Cucumis zeyheri	†	†
Dalbergia melanoxylon		†

Species name	Presence	Absence
Dicerocorym seneliodes	†	
Dichrostachys cinerea	†	†
Digitaria eriantha	†	†
Dioscorea sylvatica	†	
Eragrostis superba	†	†
Euclea natalensis	†	
Evolvulus alsinoides	†	
Gladiolus dalenii		†
Gloriosa superba var. *superba*	†	
Grewia monticola		†
Gymnosporia buxifolia	†	
Helichrysum acutatum	†	
Hermannia sp. A		†
Hermannia sp. B	†	†
Heteropogon contortus	†	†
Hibiscus engleri	†	†
Hibiscus micranthes	†	
Hyperthelia dissoluta	†	†
Indigofera delagoensis	†	†
Jasminium fluminense	†	†
Justicia flava	†	
Lipocarpha chinensis	†	
Lotononis laxa		†
Melhania prostrata		†
Melinis repens	†	†
Panicum maximum	†	†
Pellaea calomelanos		†
Peltophorum africanum		†
Pentanisia angustifolia		†
Perotis patens	†	†
Philenoptera violacea		†
Phyllanthus cedrelifolius	†	†
Phyllanthus incurvus	†	
Phyllanthus reticulatus	†	
Pogonarthria squarrosa	†	†
Pterocarpus angolensis	†	
Pterocarpus rotundifolia		†
Rhoicissus tridentata	†	†
Rhus dentata	†	
Rhus gueinzii		†
Rhus pyroides	†	†
Rhus sp.		†
Rhynchosia minima		†
Rhynchosia totta	†	†
Schmidta pappophoroides		†
Schotia brachypetala	†	
Setaria sphacelata	†	†
*Setaria*16	†	†

Species name	Presence	Absence
Sida acuta		†
Solanum delagoensis	†	†
Solanum panduriforme		†
Sphedamnocarpus pariens	†	
Sporobolus afrincanus		†
Stachys natalensis	†	
Strychnos gerrardii	†	
Strychnos henningsii	†	†
Stylochiton natalense	†	†
Tephrosia polystacha	†	†
Tephrosia sp.	†	†
Terminalia sericea	†	†
Themeda triandra	†	†
Tristachya leucothrix		†
Urochloa mosambicensis	†	†
Vernonia natalensis	†	
Vigna unguiculata	†	
Vitex harveyana		†
Zanthoxylum capense	†	
K1-10		†
K11-103		†
K13-110	†	
K13-112	†	
K14-119	†	
K17-143	†	
K18-145		†
K18-147		†
K19-150	†	
K20-160	†	†
K20-163	†	
K22-180		†
K22-181		†
K22-185		†
K23-188		†
K23-189		†
K23-190		†
K23-194		†
K23-195		†
K25-206	†	
K25-210	†	
K25-212	†	
K25-213	†	†
K25-214	†	
K26-218		†
K26-219		†
K26-221		†
K6-51		†