Dolomitic vegetation of the Sterkfontein Caves World Heritage Site and its importance in the conservation of Rocky Highveld Grassland

F. SIEBERT and S.J. SIEBERT

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An analysis of the vegetation of the Sterkfontein Caves (i.e. the natural area surrounding the caves) is presented. Relevés were compiled in 24 stratified random sample plots. A TWINSPAN classification, refined by Braun-Blanquet procedures, revealed six plant communities, also referred to as vegetation units. For each of these vegetation units the species richness was determined. Plant communities of conservation importance were identified and new associations were formally described.

Key words: biodiversity, conservation, dolomite, Gauteng, grassland, phytosociology, species richness.

F Siebert and S.J Siebert, Department of Botany, University of Zululand, Private Bag X1001, KwaDlangezwa, 3886 Republic of South Africa

Introduction

Sterkfontein Caves are world renowned for fossil deposits, especially the discovery of the skull and associated skeleton of *Australopithecus* (Clarke 1998). From a botanical perspective, fossil woods at Sterkfontein Caves have provided evidence regarding the vegetation of South Africa during the Pliocene (Bamford 1999). The caves were declared a World Heritage Site in 1999, and are presently in the first stages of development for ecotourism initiatives. As the conservation of fauna and flora (biodiversity) and all natural features within 'The Cradle of Humankind' is part of the Mission Statement of the World Heritage Site (http//www.thecradle.co.za), a field assessment was undertaken to investigate the conservation value and status of the vegetation of Sterkfontein Caves (i.e. the natural area surrounding the caves and excavations). An ecological survey and phytosociological classification is valuable for the development planning of the site and its management as a conservation area (Groves 2003). The aim of this study was to classify, describe, interpret and map the vegetation units of Sterkfontein Caves.

Study area

Sterkfontein Caves are situated at 26°10'S latitude and 27°45'E longitude, north of Krugersdorp, Gauteng, 3 km northeast of Oaktree. The study area includes the fenced area surrounding the caves, which is 20 ha in size and situated on the farm Zwartkrans 172-IQ (portion 1: proclamation area) (2627BB).

The most representative underlying geology of the study site is dolomite of the Monte Christo Formation, although quartzite and shale of the Water Tower Formation are also present (Visser *et al.* 1989). The soil is generally shallow and varies between loam and sandy loam in most parts of the study area. Loam to clay soil occurs where shale outcrops. Soils are generally rocky and non-arable. The topography of the study site varies between crest, midslope and footslope. Due to the undulating landscape, aspect varies considerably. The climate of the study area corresponds with the description for the Krugersdorp area (Behr & Bredenkamp 1988), and can be regarded as typical Highveld.

On a regional scale, the vegetation of Sterkfontein Caves is classified as Rocky High-

veld Grassland within the Grassland Biome (Bredenkamp & Van Rooyen 1996). Acocks (1988) classified the area as Bankenveld. Bredenkamp & Brown (2003) delimit the major structural and floristic vegetation types within the Bankenveld. A local-scale, floristic study by Mogg (1975) at Sterkfontein Caves provides a useful contribution and shows that the vegetation of Sterkfontein Caves is not related to the Protea-veld of the quartzite ridges in Krugersdorp area (Behr & Bredenkamp 1988).

According to Bredenkamp & Van Rooyen (1996) more than 65 % of the Rocky Highveld Grassland is transformed. Ridges in Gauteng are characterised by a unique plant species composition that is found nowhere else (Pfab 2002a). Furthermore, crests and slopes of ridges and hills in Gauteng form habitat for at least 40 % of the Gauteng threatened plant taxa (Pfab & Victor 2002). These species-rich ridges in Gauteng should be regarded as some of the most important natural assets of urban open spaces (Grobler *et al.* 2002). A ridge policy has been approved by the Department of Agriculture, Conservation, Environment and Land Affairs (DACEL) to enforce strict measures that will ensure low impact development on the ridges of Gauteng (Pfab 2001).

Methods

Relevés were compiled in 24 stratified random sample plots (Table 1). Stratification was based on topographical position, using terrain types, which include crest, midslope and footslope (Fig. 1). The number of plots per unit varied between three and six. Cultivated and built-up areas were excluded from the survey. In accordance with Bezuidenhout & Bredenkamp (1990), plot sizes were fixed at 16 m² for grassland vegetation and 100 m² for woodland vegetation. The Braun-Blanquet cover abundance scale was used (r, +, 1, 2a, 2b, 3, 4, 5). General height (m) and canopy cover (%) of the tree, shrub and herbaceous layers were noted, and an average value was calculated for each layer in each community. Environmental data recorded were aspect, slope, rock type, terrain type, soil type, soil depth and rockiness of the soil surface.

All species were recorded for each plot and where species were not identifiable in the field, specimens were collected for identification at the Pretoria National Herbarium (PRE). Names of taxa and growth forms conform to Germishuizen & Meyer (2003). Poor or sterile specimens of some important

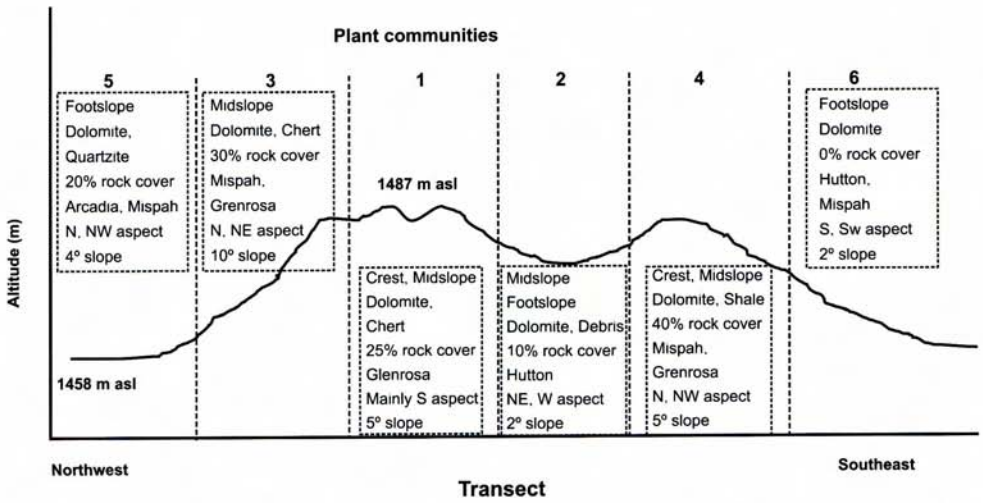

Fig. 1. Location of the vegetation units along a topographical profile of the study area based on a northwest to southeast transect (community numbers correspond with the text).

Table 1

Synoptic table of the plant communities of the area surrounding the Sterkfontein Caves

Community	Life form		1	2	3	4	5	6
Species Group A: *Rhoo pyroidis–Celtidetum africanae*								
Panicum maximum	gr	p	V					
Olea europaea	tr	p	V		II			
*Bidens pilosa**	he	a	IV					I
Euclea crispa	sh	p	IV					
Kiggelaria africana	tr	p	IV					
Ziziphus mucronata	tr	p	IV					
Tritonia nelsonii	ge	p	III					
Sida rhombifolia	he	a	III					
Ceropegia rendallii	he (s)	p	III	.				.
Euphorbia rhombifolia	he (s)	p	III					
Bauhinia galpinii	sh	p	III					
Grewia flava	sh	p	III					
Heteromorpha arborescens	sh	p	III					
Rhoicissus tridentata	sh	p	III			II		
Combretum erythrophyllum	tr	p	III					
Diospyros whyteana	tr	p	III					
Erythrina lysistemon	tr	p	III					
Rhamnus prinoides	tr	p	III					
Bowiea volubilis	ge	p	II					
Cheilanthes hirta	ge	p	II					
Eriospermum cooperi	ge	p	II					
Ornithoglossum vulgare	ge	p	II	.				
Scadoxus puniceus	ge	p	II					
Chloris pycnothrix	gr	a	II					
*Cortaderia jubata**	gr	p	II					
Setaria pumila	gr	a	II					
Sporobolus africanus	gr	p	II					
*Alternanthera pungens**	he	p	II					
*Araujia sericifera**	he	p	II					
Bulbostylis humilis	he	a	II					
*Chenopodium album**	he	a	II					
Ipomoea bathycolpos	he	p	II					
Lepidium bonariense	he	a	II					
*Physalis peruviana**	he	p	II					
Rubia horrida	he	p	II					
*Schkuhria pinnata**	he	a	II					
Sisymbrium thellungii	he	a	II					
Solanum retroflexum	he	a	II					
Cyphostemma lanigerum	he (s)	p	II					
Euphorbia pseudotuberosa	he (s)	p	II					
Kalanchoe rotundifolia	he (s)	p	II					
Senecio rhomboideus	he (s)	p	II					
Acalypha glabrata	sh	p	II					
Asparagus africanus	sh	p	II	.				
*Agave americana**	sh (s)	p	II					
Aloe marlothii	sh (s)	p	II					
Lopholaena coriifolia	sh (s)	p	II					
Senecio pleistocephalus	sh (s)	p	II					
Lannea edulis	su	p	II	.				.
Cussonia paniculata	tr	p	II					
Dombeya rotundifolia	tr	p	II					
Dovyalis zeyheri	tr	p	II					
Ficus ingens	tr	p	II					
Halleria lucida	tr	p	II					
Maerua cafra	tr	p	II					
*Morus alba**	tr	p	II					
Mystroxylon aethiopicum	tr	p	II					
*Prunus serotina**	tr	p	II					
Rhus lancea	tr	p	II					

Table 1(continued)

Community	Life form		1	2	3	4	5	6
Species Group B: *Rhoo pyroidis–Digitarietum erianthae*								
Eragrostis chloromelas	gr	p		V				
Eragrostis gummiflua	gr	p		V				
Aristida canescens	gr	p		IV				.
Artemisia afra	sh	p		IV				
Gymnosporia polyacantha	tr	p		IV				
Heteropogon contortus	gr	p		III				
Helichrysum caespititium	he	p		III			I	
Indigofera daleoides	he	p		III				
Salvia runcinata	he	p		III				
Senecio erubescens	he	p		III				
Tephrosia polystachya	he	p		III				
Clematis villosa	sh	p		III				
Aristida congesta	gr	p		II				
Digitaria eriantha	gr	p		II				
Hyparrhenia tamba	gr	p		II				
*Paspalum dilatatum**	gr	p		II				
Helichrysum lepidissimum	he	p		II				
Sonchus nanus	he	p		II				
*Sonchus oleraceus**	he	a		II				
*Taraxacum officinale**	he	p		II				
Tephrosia lupinifolia	he	a		II				
Thesium costatum	he	p		II				
Tribulus terrestris	he	a		II				
*Verbena bonariensis**	he	a		II			I	
Leucosidea sericea	sh	p		II				
Species Group C								
Celtis africana	tr	p	V	III	I			
*Tagetes minuta**	he	a	IV	III				
*Zinnia peruviana**	he	a	IV	III				
Cynodon dactylon	gr	p	III	IV				
Gymnosporia buxifolia	tr	p	III	III				
*Bidens bipinnata**	he	a	II	III				
*Pyracantha angustifolia**	sh	p	II	III				
Acacia karroo	tr	p	II	III		I		
*Melia azedarach**	tr	p	II	III				
Enneapogon cenchroides	gr	a	II	II				
Clematis brachiata	he	p	II	II		I		
Cyperus rotundus	he	p	II	II				
*Euphorbia hirta**	he	a	II	II	.			
Diospyros austro-africana	sh	p	II	II				
Rhus dentata	sh	p	II	II				.
Tarchonanthus camphoratus	sh	p	II	II				
*Opuntia ficus-indica**	sh(s)	p	II	II				
Species Group D: *Loudetio simplicis–Diheteropogonetum amplectentis*								
Vangueria parvifolia	tr	p		IV				
Indigofera cryptantha	sh	p		III				
Rhus discolor	su	p		III				
Anthephora pubescens	gr	p		II				
Helichrysum cerastioides	he	p		II				
Kyllinga alba	he	p		II				
Pentarrhinum insipidum	he	p		II				
Brachystelma barberae	ge	p		II				
Drimia calcarata	ge	p		II				
Crassula setulosa	he (s)	p		II				.
Senecio oxyrifolius	he (s)	p		II				
Cryptolepis oblongifolia	sh	p		II				

Table 1(continued)

Community	Life form		1	2	3	4	5	6
Species Group D *(continued)*								
Tephrosia capensis	sh	p				II		
Ozoroa paniculosa	tr	p				II		
Species Group E:								
Monocymbio ceresiiformis–Schizachyrietum sanguinei								
Macledium zeyheri	he	p				IV		II
Xerophyta viscosa	he	p				IV		
Zaluzianskya katharinae	he	p				IV		
Protea welwitschii	sh	p				IV		
Raphionacme velutina	ge	p				III		
Eragrostis capensis	gr	p				III		
Raphionacme velutina	ge	p				III		
Eragrostis capensis	gr	p				III		
Loudetia simplex	gr	p				III		
Athrixia elata	he	p				III		
Gazania krebsiana	he	a				III		
Vernonia galpinii	he	p				III		
Vernonia natalensis	he	p				III		
Vernonia sutherlandii	he	p				III		
Diospyros lycioides	sh	p				III		
Rhus rigida	sh	p				III		I
Rhus magalismontana	su	p				III		
Aspidoglossum glabrescens	ge	p				II		
Brachystelma circinatum	ge	p				II		
Drimia elata	ge	p				II		
Drimia multisetosa	ge	p				II		
Pachycarpus schinzianus	ge	p				II		
Aster harveyanus	he	p				II		
Callilepis leptophylla	he	p				II		
Felicia muricata	he	a				II		
Lotononis foliosa	he	p				II		
Oldenlandia herbacea	he	p				II		
Striga elegans	he	p				II		
Huernia loeseneriana	he (s)	p				II		
Buddleja saligna	sh	p				II		
Solanum lichtensteinii	sh	p				II		I
Species Group F								
Xerophyta retinervis	he	p				IV	II	
Raphionacme hirsuta	ge	p				III	III	
Pellaea calomelanos	ge	p	I			III	II	
Kalanchoe paniculata	he (s)	p				III	II	
Elephantorrhiza elephantina	su	p				III	II	
Senecio coronatus	he	p				II	III	
Triraphis andropogonoides	gr	p				II	II	
Bulbostylis hispidula	he	a				II	II	
Crabbea angustifolia	he	p		.		II	II	
Cyanotis lapidosa	he	p				II	II	
Species Group G								
Bonatea speciosa	ge	p	II				II	
Moraea stricta	ge	p				II	II	
Eustachys paspaloides	gr	p			II	II	II	
Melinis repens	gr	p			II		II	
Trichoneura grandiglumis	gr	p			II	II	II	
Commelina africana	he	p	II			II		
*Conyza albida**	he	a			II	II	II	
Gnidia caffra	he	p			II	II	II	
Indigofera melanadenia	he	p	II			II		
Ipomoea crassipes	he	p			II	II	II	

Table 1(continued)

Community	Life form		1	2	3	4	5	6
Species Group G *(continued)*								
Ipomoea obscura	he	p		II	II		I	
Lantana rugosa	he	p	II			II		
Limeum viscosum	he	a		II	II			
Pentanisia prunelloides	he	p		II	II	II		
Phyllanthus parvulus	he	p	II		II			
Tephrosia multijuga	he	p	II		II			
*Verbena aristigera**	he	p		II	II			
Buddleja salviifolia	sh	p	II			II		
Withania somnifera	sh	p		II		II		
Scolopia zeyheri	tr	p	II			II		
Species Group H:								
Hyparrhenio hirtae–Eragrostidetum curvulae								
Hypoxis iridifolia	ge	p					III	
Chaetacanthus costatus	he	p					III	
Cucumis zeyheri	he	p					III	
Eriosema salignum	he	p					III	
Kohautia amatymbica	he	a					III	
Wahlenbergia undulata	he	p					III	
Pygmaeothamnus zeyheri	su	p					III	
Haemanthus humilis	ge	p					II	
Dimorphoteca spectabilis	he	p					II	
Helichrysum aureonitens	he	p					II	
Tephrosia elongata	he	p					II	
Vahlia capensis	he	a					II	
Asparagus laricinus	sh	p					II	.
Seriphium plumosum	sh	p					II	
Species Group I								
Monocymbium ceresiiforme	gr	p					IV	III
Urelytrum agropyroides	gr	p					III	III
Sporobolus ioclados	gr	p					III	II
Bulbostylis burchellii	he	p					III	II
Gnidia capitata	he	p					III	II
Seddera capensis	su	p					III	II
Albuca glauca	ge	p					II	II
Pearsonia sessilifolia	he	p					II	II
Species Group J:								
Cymbopogono plurinodis–Eragrostidetum gummifluae								
Eragrostis superba	gr	p						IV
Gladiolus crassifolius	ge	p			I			III
Hypoxis argentea	ge	p						III
Pelargonium luridum	ge	p						III
Aristida meridionalis	gr	p						III
Gnidia kraussiana	he	p			I			III
Neorautanenia ficifolius	he	p						III
Pearsonia aristata	he	p			I			III
Dolichos angustifolius	he	p		I				III
Eriosema cordatum	he	p		I				III
Hermannia transvaalensis	he	p		I				III
Eucomis autumnalis	ge	p						II
Oxalis depressa	ge	p						II
Digitaria monodactyla	gr	p						II
Convolvulus sagittatus	he	p						II
Pearsonia cajanifolia	he	p						II
Vigna vexillata	he	p						II
Species Group K								
Helichrysum rugulosum	he	p					III	III

Table 1(continued)

Community	Life form		1	2	3	4	5	6
Species Group K *(continued)*								
Hypoxis hemerocallidea	ge	p		I			III	III
Monsonia angustifolia	he	a		II			III	II
Justicia anagalloides	he	p		II			III	II
Conyza podocephala	he	p		I			II	III
Hermannia depressa	he	p		I			II	III
Selago densiflora	he	p		II			II	III
Scabiosa columbaria	he	p		I			II	III
Corchorus asplenifolius	he	p		I			II	II
Chlorophytum cooperi	ge	p					II	II
Hypoxis interjecta	ge	p					II	II
Rhynchosia monophylla	he	p					II	II
Species Group L								
Schizachyrium sanguineum	gr	p			IV	V	III	
Pollichia campestris	he	p			IV	II	IV	
Boophone disticha	ge	p			IV	II	III	II
Aristida diffusa	gr	p			IV	II		IV
Parinari capensis	su	p			III	V	III	
Trachypogon spicatus	gr	p			III	III	IV	V
Gladiolus permeabilis	ge	p			III	III	II	
Eragrostis racemosa	gr	p			III	II	III	
Setaria sphacelata	gr	p			III	II	III	II
Melinis nerviglumis	gr	p			III	II	II	
Dianthus mooiensis	he	p			III	II	II	
Panicum natalense	gr	p			II	IV		III
Tristachya rehmannii	gr	p			II	III	IV	
Aristida transvaalensis	gr	p			II	III	II	II
Acalypha angustata	he	p			II	III		II
Chamaecrista mimosoides	he	a			II		II	III
Senecio isatideus	he	p			II		III	II
Ledebouria ovatifolia	ge	p				III	IV	II
Indigofera hilaris	he	p				III	II	IV
Lotononis calycina	he	p				III	II	III
Sphenostylis angustifolia	he	p				III	II	II
Ledebouria marginata	ge	p				II	III	II
Helichrysum harveyanum	he	p				II	III	II
Striga asiatica	he	a				II	II	III
Ziziphus zeyheriana	su	p				II	II	III
Species Group M								
Hypoxis rigidula	ge	p	II		II	II		II
Ledebouria cooperi	ge	p	II	II	IV	II	II	
Bewsia biflora	gr	p		II	II		II	II
Brachiaria serrata	gr	p	II	V	II		II	II
Cymbopogon excavatus	gr	p		II		II	III	IV
Diheteropogon amplectens	gr	p		III	V	V	V	V
Elionurus muticus	gr	p	III	II	III	III	II	
Eragrostis curvula	gr	p		III	II		III	II
Hyparrhenia hirta	gr	p	III	III	II		III	IV
Themeda triandra	gr	p	II	II	IV	III	V	V
Anthospermum rigidum	he	p		II	II	II	II	
Blepharis innocua	he	p		II	II	II	II	IV
Dicoma anomala	he	p		II	II		II	II
Geigeria burkei	he	p		II		II	II	II
Helichrysum nudifolium	he	p		II	II		II	III
Ipomoea ommaneyi	he	p	II		II	II	II	.
Pentanisia angustifolia	he	p		II		II	II	II
Polygala hottentotta	he	p		II		II	II	II
Pseudognaphalium luteo-album	he	a		II	II	II	II	II
Ruellia patula	he	p		II	II		II	II

Table 1(continued)

Community	Life form		1	2	3	4	5	6
Species Group M *(continued)*								
Senecio venosus	he	p		II	II	III	IV	II
Vernonia oligocephala	he	p	II	II	IV	III	II	II
Aloe greatheadii	he (s)	p	II	III	V	II	II	II
Asparagus suaveolens	sh	p	II		II	II	II	II
Jamesbritten burkeana	su	p	II	II	II	II		
Rhus pyroides	tr	p	III	V	II	II	II	II
Releves			6	5	3	4	3	3
Total number of species			96	87	82	105	82	70
Aliens			17	13	2	1	1	1
Perennials			81	74	77	99	75	65
Annuals			15	13	5	6	7	5

Key
ge = geophyte, gr = grass, he = herb,
su = suffrutex, sh = shrub, tr = tree

(s) = succulent p = perennial, a = annual
* = alien species

(protected) species, such as geophytes, especially the Orchidaceae, and species of the Asclepiadoideae (Apocynaceae) could not be identified below family level. A list of Red Data plant species in the Sterkfontein Caves area (2627BB) was obtained from the Department of Agriculture, Conservation, Environment and Land Affairs in Gauteng.

An objective statistical classification technique, TWINSPAN (Hill 1979), was used in conjunction with the subjective Braun-Blanquet technique for processing raw data and refining results. This approach has, in the past, produced ecologically reliable results for phytosociological studies conducted in the Bankenveld of the Grassland Biome (Bezuidenhout *et al* 1994a; Smit *et al* 1997). A synoptic table was constructed and further refined to delimit major groups (Table 1), as it summarises gamma diversity (species pools and meta-communities). Species of each major group are presented at a constancy value based on a 20 % interval scale (I to V). Only species with a minimum constancy value of 20 % (II) in any given group were included in the table.

Syntaxa without formal descriptions were hierarchically classified and described according to the Code of Phytosociological Nomenclature (Weber *et al* 2000). The small data set used in this paper does not allow for the selection of suitable nomenclatural types. Therefore, nomenclatural type relevés were

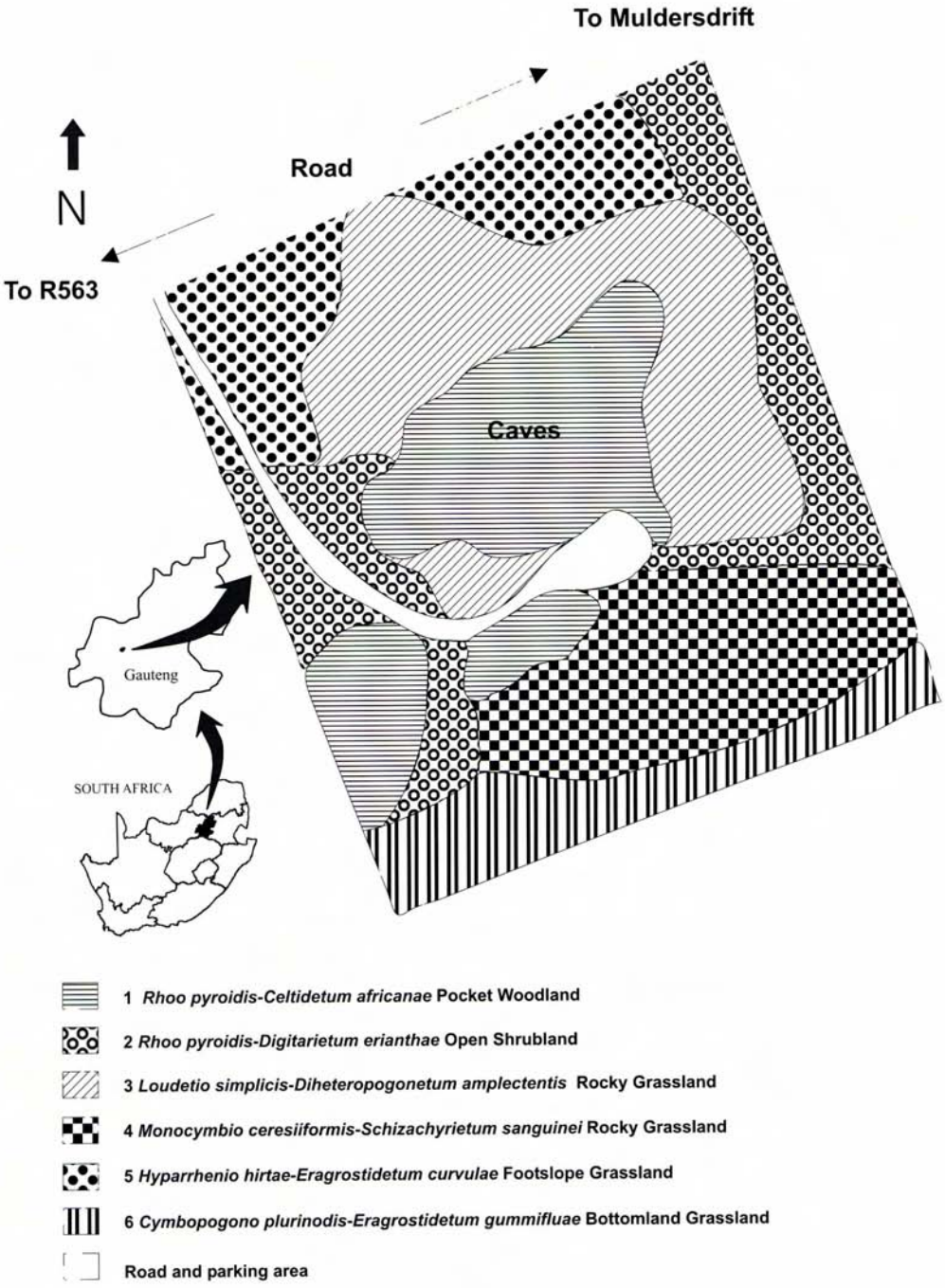

Fig. 2. Vegetation map of the area surrounding the Sterkfontein Caves.

Table 2

Ten most dominant plant families recorded for the six plant communities of the Sterkfontein Caves (number of species per family per community is given)

Family	Plant community						Total
	1	2	3	4	5	6	
Poaceae	10	21	20	22	17	14	45
Asteraceae	10	19	10	16	14	12	40
Fabaceae	5	6	7	7	8	11	26
Apocynaceae	2	0	4	6	0	1	11
Hyacinthaceae	2	1	2	5	4	4	9
Rubiaceae	1	3	3	4	4	1	9
Anacardiaceae	4	3	3	3	1	1	8
Euphorbiaceae	5	1	2	1	0	1	6
Acanthaceae	0	3	3	2	4	3	5
Hypoxidaceae	1	1	1	1	3	4	5
Number of species	40	58	55	67	55	52	164
Percentage of total	42	67	67	64	67	74	64

selected from papers where the plant communities were first described, but informally.

Alpha diversity (species richness) is defined as the number of species per unit area within a homogeneous plant community (Whittaker 1977). In this study the mean number of species per unit area was calculated from the total richness obtained for each plot of a plant community to make it comparable with other studies. Shannon-Wiener diversity indices were used to combine species richness and relative abundance among species (Barbour *et al.* 1987). In this study the Braun-Blanquet scale was converted to percentage cover, and the mean cover per species in each plant community was taken as its abundance value. We realise that the rather large class intervals calculated arithmetically by using the midpoint value conversion (Mueller-Dombois & Ellenberg 1974) might have obscured some results.

A profile of a transect (Fig. 1) and a vegetation map (Fig. 2) of the plant communities of the study area is presented. The conservation status of each plant community was assessed according to the following criteria:

(1) very high (Red Data/endemic species found or sensitive habitat of important conservation value); (2) high (protected species found, community provides habitat for Red Data/endemic species or habitat may be sensitive); (3) moderate (no protected or Red Data/endemic species found although the area is fairly undisturbed); (4) low (no protected or Red Data/endemic species found and area is disturbed)

Results and Discussion

Classification

The analysis resulted in the recognition of six different plant communities. Three associations are described formally for the first time. A total of 255 plant species were recorded for these vegetation units (20 ha) (Table 1), although non-flowering species could have been overlooked. The Poaceae, Asteraceae and Fabaceae are the most dominant plant families and ten families account for 64 % of the plant diversity (Table 2). Based on the TWINSPAN divisions of the floristic data set, the hierarchical classification and formal community names are as follows:

1. *Rhoo pyroidis-Celtidetum africanae*
2. *Rhoo pyroidis-Digitarietum erianthae*
3. *Loudetio simplicis - Diheteropogonetum amplectentis*

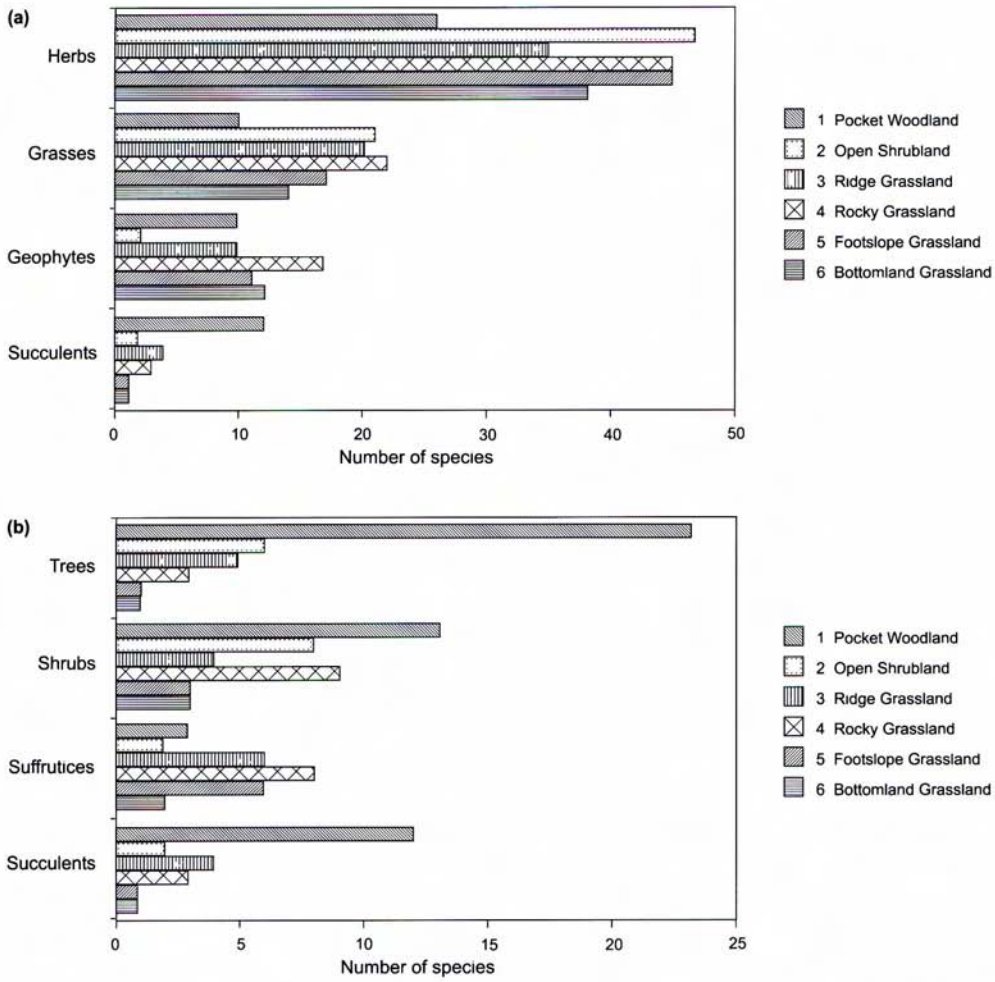

Fig. 3. Occurrence of different growth forms in the six vegetation units measured as the number of species per growth form: (a) 0–2.5 m layer, and (b) 2.51–7.5 m layer.

Table 3

Mean height (H) and cover (C) of the woody, herbaceous and grass strata of the six plant communities distinguished for the Sterkfontein Caves

Community	Strata							
	Woody (trees,shrubs)		Herbaceous (herbs, geophytes)		Grass layer		Mean height	Total cover
	H (m)	C (%)	H (m)	C (%)	H (m)	C (%)		
1	2 93	73	0.83	3	0.87	8	1.96	84
2	2.53	61	0.53	4	0.99	10	1 11	75
3	1.96	12	0.51	22	0.80	31	0.89	65
4	1.35	9	0.59	19	0.68	37	0.81	65
5	0.94	6	0.45	20	0.70	37	0.61	63
6	1.01	6	0.45	18	0.80	43	0.62	67

4. *Monocymbio ceresiiformis-Schizachyrietum sanguinei*
5. *Hyparrhenio hirtae-Eragrostidetum curvulae*
6. *Cymbopogono plurinodis - Eragrostidetum gummifluae*

Grassland plant communities are regularly described informally, with different authors providing their own set of common names for the communities within a broad vegetation type. This leads to confusion in the literature regarding the relationship and similarity between communities. Syntaxonomic nomenclature provides a means to give structure to the description and classification of plant communities and to relate current descriptions to previously published work. This paper is an example of how previously formally described communities have enabled the authors to place the vegetation of Sterkfontein in context with the grassland of the region. In addition, it highlighted the existence and subsequent formal description of informally described communities previously thought to be pseudo-communities.

Description

1. *Rhoo pyroidis-Celtidetum africanae* ass. nova hoc loco

Nomenclatural type: relevé 3, Table 1 (Bredenkamp *et al.* 1994) (holotypus).

Species group A in this paper (Table 1).

The pocket woodland of excavation sites described here was informally described in the past and is synonymous to the *Rhus pyroides-Celtis africana* Bush Community (Bredenkamp *et al.* 1994) of dolomite sink holes and ridges. It is related to the *Rhus pyroides-Acacia karoo* Woodland (Bezuidenhout & Bredenkamp 1990). It is classified under the *Grewio flavae-Rhoion pyroidis* (Bezuidenhout *et al.* 1994b).

This community is usually found on rocky crests and on moderately sloped (± 5°) southern aspects of hills (Fig. 1). The geology is mainly dolomite, but quartzite and chert ridges outcrop. Rock cover on the soil surface is ± 25 % and rock size in cross section varies from boulders (>2 m) to moderate rocks (± 0.3 m). White pebbles are scattered on the soil surface. Soils are shallow, sandy loam of the Glenrosa form.

The community comprises a mosaic of bush clumps and grassland patches, which makes it the most heterogeneous in the study area. It is predominantly a moderately open to closed woodland pocket in man-made excavations or sinkholes, with few herbs and grasses (Fig. 3a). The woody layer has a mean tree height of ± 2.93 m (up to 5 m) which result in a total vegetation cover of ± 84 % (Table 3). The dominant tree species include *Celtis africana* (species group C), *Olea europaea* subsp. *africana* (A) and *Rhus pyroides* (M) (Table 1). Other prominent woody species include, amongst others, *Bauhinia galpinii*, *Combretum erythrophyllum*, *Euclea crispa*, *Heteromorpha arborescens*, *Kiggelaria africana*, *Rhamnus prinoides* and *Ziziphus mucronata* (species group A). The dominant forbs are mainly alien weed species such as *Bidens pilosa* (species group A), *Schkuhria pinnata* (A), *Tagetes minuta* (C) and *Zinnia peruviana* (C), although many indigenous forb species were recorded. The grass layer is dominated by *Panicum maximum* (species group A).

Like sinkholes, the excavation areas provide suitable habitat for colonisation by many indigenous woody species. Although these habitats are anthropogenic, the total number of species is 96 (includes 17 alien species). A total of 56 plant species are diagnostic for this community in the study area (species group A) (Table 1). Two protected species were positively identified, namely *Cussonia paniculata* and *Scadoxus puniceus* (Van Wyk & Malan 1997). Large colonies of an orchid species occur in this habitat, but the infertile material could not be positively identified. This habitat is suitable for succulent species (Fig. 3b) and could contain three Red Data species, namely *Bowiea volubilis*, *Delosperma vogtsii* and *Eulophia leachii* (Pfab & Victor 2002). Apart from the rare and protected species found in this plant community, the habitat is a typical example of a sensi-

tive ridge (Pfab 2001). Based on the findings above it is classified as Status 1.

2. *Rhoo pyroidis-Digitarietum eriantha*e ass. nova hoc loco

Nomenclatural type: relevé 120, Table 1 (Bezuidenhout *et al.* 1994b) (holotypus).

Species group B in this paper (Table 1).

The open shrubland community of ancient drainage lines described here was informally described in the past and is synonymous to the *Digitaria eriantha-Rhus pyroides* Shrubveld (Bezuidenhout *et al.* 1994b). It is related to the *Eustachys paspaloides-Rhus pyroides* Secondary Savanna (Bezuidenhout & Bredenkamp 1990). It is classified under the *Grewio flavae-Rhoion pyroidis* (Bezuidenhout *et al.* 1994b).

This community occurs along the lower-lying midslope and footslope areas between the two hills (Fig. 1). The drainage line slopes gently (± 2°) across north-eastern and western aspects of the hills. Soils of the drainage line are moderately deep loam, especially of the Hutton form. Dolomite, debris and white pebbles are frequently exposed on the soil surface. Rock cover on the soil surface is ±10 % and rock size ± 0.2 m.

The community occurs along drainage lines on the eastern and the western sides of the main hill of Sterkfontein Caves. This wooded grassland community has continuous shrubland. Total vegetation cover is ± 75 %, of which the grass and forb layers are well developed and species rich (Fig. 3a). Shrubs are prominent in this community with a mean height of ± 2.53 m (Table 3). Dominant taxa include *Brachiaria serrata* (species group M), *Eragrostis gummiflua* (B) and *E. chloromelas* (B) in the grass layer, *Artemisia afra* (B) in the shrub layer, and *Gymnosporia polyacantha* subsp. *vaccinifolia* (B) and *Rhus pyroides* (M) in the tree layer. Various forb species were recorded for this community, all of which are equally abundant (Table 1).

This community is not disturbed and serves as a drainage line on the eastern and western sides of the study area. It has value as natural woodland of urban open space (Grobler *et al.* 2002). Although 87 species (including 13 alien species) were recorded for this community, no rare or protected species were found. A total of 23 species are diagnostic for this community in the study area (species group B) (Table 1). Based on the findings above it is classified as Status 3.

3. *Loudetio simplicis-Diheteropogonetum amplectentis* (Bezuidenhout *et al* 1994b)

Species group D (Table 1).

This ridge grassland is classified under the *Trachypogono spicati-Diheteropogonion amplectentis* (Bezuidenhout *et al.* 1994b).

This plant community occurs on the north and northeast aspects of steep (± 10°) rocky hillslopes (Fig. 1). Dolomite and chert ridges characterise the habitat, with rock cover on soil surface reaching ± 30 %. Quartzite pebbles are scattered on the soil surface. Soils are shallow, sandy loam and predominantly of the Mispah and Glenrosa forms.

This rocky grassland community occurs on the warm, dry slope of the Sterkfontein Caves hill. The total vegetation cover is ± 65 % of which the grass and forb layers predominate. Open, ridge grassland is recognisable by the occurrence of a few stunted trees and many suffrutices (Fig. 3b). Mean height of the vegetation is ± 0.89 m (Table 3). Grasses such as *Aristida diffusa* (species group L), *Diheteropogon amplectens* (M), *Schizachyrium sanguineum* (L) and *Themeda triandra* (M) dominate (Table 1). Forbs include *Aloe greatheadii* (species group M), *Pollichia campestris* (L), *Vernonia oligocephala* (M), *Xerophyta retinervis* (F), and geophytes include *Boophone disticha* (L) and *Ledebouria cooperi* (M).

Fourteen of the 82 recorded plant taxa are diagnostic for this community in the study area (species group D) (Table 1). Although less rich in species, this rocky terrain hosts some interesting plant species that might be sensitive to disturbance. These species are from the Apocynaceae, Fabaceae and Orchidaceae and are protected by law. Two pro-

tected species were recorded, namely *Gladiolus permeabilis* and an orchid, probably *Eulophia ovalis* subsp. *ovalis* (Van Wyk & Malan 1997). This habitat is also suitable for three Red Data species, namely *Brachiaria subulifolia*, *Habenaria mossii* and *Lotononis adpressa* subsp. *leptantha* (Pfab & Victor 2002). Apart from the protected species found in this area, the habitat of this plant community is representative of the sensitive Gauteng ridges (Pfab 2001). Based on the findings above it is classified as Status 1.

4. *Monocymbio ceresiiformis-Schizachyrietum sanguinei* (Bezuidenhout *et al* 1994a)

Species group E (Table 1).

This rocky grassland is classified under the *Diheteropogono amplectentis-Schizachyrion sanguinei* (Bezuidenhout *et al.* 1994a).

This grassland community is found on hill crests and higher lying areas of north to northwest facing slopes (± 5°) (Fig. 1). Dolomite, quartzite and an outcrop of shale makes up the geology. Rock cover on the soil surface is ± 40 % (boulders and moderate rocks). Larger boulders contain iron spots. Soils are shallow, with a coarse sandy loam texture. Dominant soils are of the Mispah and Glenrosa forms.

This community of moderately closed to open rocky grassland with scattered trees has a total vegetation cover of ± 65 %. Grass and forb layers predominate (Fig. 3a), resulting in a mean height of ± 0.81 m (Table 3). *Diheteropogon amplectens* (species group M), *Monocymbium ceresiiforme* (I) and *Schizachyrium sanguineum* (L) are the dominant grass species, whereas *Indigofera hilaris* (L), *Macledium zeyheri* (E), *Xerophyta viscosa* (E) and *Zaluzianskya katharinae* (E) are the most conspicuous forbs and *Parinari capensis* (L) a prominent suffrutex. This community is characterised by a high species richness of geophytes and suffrutices (Figs. 3a & 3b). The species composition on the shale outcrop is slightly different, and it is along this outcrop that *Protea welwitschii* (species group E) and other shrubs occur scattered in the grassland (Table 1).

Rocky grassland has the highest species richness in the study area (105 taxa). It shares ten species with the *Loudetio simplicis-Diheteropogonetum amplectentis*, but 26 species are diagnostic for this community in the study area (species group E) (Table 1). The presence of many diagnostic species is ascribed to the location of this community at a higher altitude. Four protected species were recorded, namely *Protea welwitschii*, *Gladiolus permeabilis* and orchids, probably *Eulophia ovalis* subsp. *ovalis* and *Bonatea speciosa* (Van Wyk & Malan 1997). This habitat is also suitable for four Red Data species, namely *Habenaria mossii*, *Lithops lesliei* var. *rubrobrunnea*, *Lotononis adpressa* subsp. *leptantha* and *Melolobium subspicatum* (Pfab & Victor 2002). Apart from the protected species found in this area, the habitat of this plant community is typical of the sensitive Gauteng ridges (Pfab 2001). Based on the findings above it is classified as Status 1.

5. *Hyparrhenio hirtae-Eragrostidetum curvulae* ass. nova hoc loco

Nomenclatural type: relevé 230, Table 1 (Bezuidenhout & Bredenkamp 1990) (holotypus).

Species group H in this paper (Table 1).

The footslope grassland described here is typical of drier ground further away from drainage channels. In the past it was informally described, and is synonymous to the *Eragrostis curvula-Hyparrhenia hirta* (Bezuidenhout & Bredenkamp 1990). It is related to the *Hyparrhenio hirtae-Eragrostidetum planae* (Bezuidenhout *et al.* 1994a) of lower lying, moister areas.

This grassland community covers the north-facing footslope on the elevated area above the floodplain (Fig. 1). The geology is typically underlying dolomite, with quartzite and iron pebbles on the soil surface. The soil is a slightly sloped (± 4°), moderately shallow loam, mainly of the Arcadia and Mispah forms. Rock cover on the soil surface is ± 20 %.

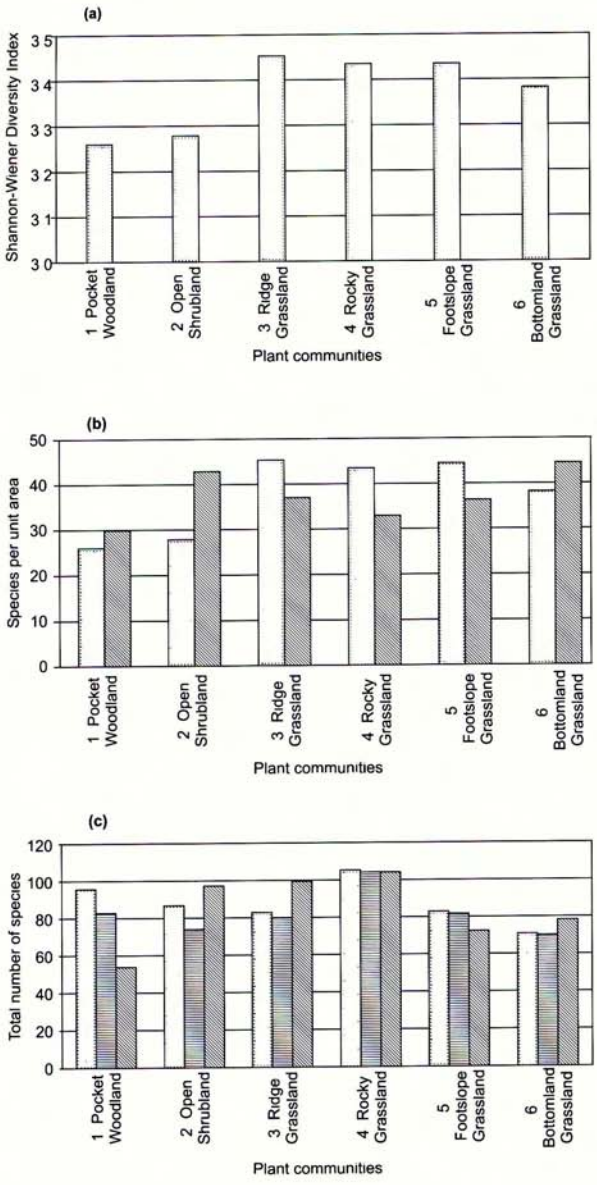

Fig. 4. Analysis and comparison of species diversity and richness of the plant communities of Sterkfontain Caves: (a) Shannon-Wiener Diversity Index, (b) mean species richness per unit area, and (c) total species richness [horizontal bars = total - alien taxa; diagonal bars = Bredenkamp *et al.* (1994); Bezuidenhout & Bredenkamp (1990); and Bezuidenhout *et al* (1994a, 1994b)].

This moderately open grassland, with dense cover in the herbaceous layer and a near absent woody layer (few isolated shrubs), has a total cover of ± 63 %. The mean height of the vegetation is ± 0.61 m (Table 3). The community is characterised by a dense cover of grass species, dominated by *Diheteropogon amplectens* (species group M), *Monocymbium ceresiiforme* (I), *Themeda triandra* (M), *Trachypogon spicatus* (L) and *Tristachya rehmannii* (L) (Table 1). A rich diversity of forb species occur (Fig. 3a), of which *Pollichia campestris* (E) and *Senecio venosus* (M) are the most conspicuous. Populations of geophytes are locally abundant in this community of which *Ledebouria ovatifolia* (species group L) is the most dominant.

Fourteen of the 82 species recorded are diagnostic for this community in the study area (species group H) (Table 1). Sensitive species that occur within this community include geophytes, which are generally protected, such as *Eucomis autumnalis* and *Gladiolus permeabilis* (Van Wyk & Malan 1997). This community is not disturbed and provides suitable habitat for two Red Data species, namely *Lotononis adpressa* subsp. *leptantha* and *Melolobium subspicatum* (Pfab & Victor 2002). Based on the findings above it is classified as Status 2.

6. *Cymbopogono plurinodis-Eragrostidetum gummifluae* (Bezuidenhout *et al* 1994b)

Species group J (Table 1).

This bottomland grassland is classified under the *Trachypogono*

spicati-Diheteropogonion amplectentis (Bezuidenhout *et al.* 1994b).

This community is typical of high lying bottomlands (Fig. 1), with moderately deep, sandy loam Hutton and shallow, rocky Mispah soil forms. Dolomite is the underlying geology, but does not outcrop on the soil surface (few scattered pebbles). The topography is relatively flat (± 2°) and has a southern aspect.

This slightly degraded open grassland has a total vegetation cover of ± 67 %, of which the grass and forb layers dominate (Fig. 3a). The mean height of the vegetation is ± 0.62 m (Table 3). It is dominated by *Aristida diffusa* (species group L), *Cymbopogon excavatus* (M), *Diheteropogon amplectens* (M), *Themeda triandra* (M) and *Trachypogon spicatus* (L) in the grass layer (Table 1). Dominant forbs include *Blepharis innocua* (M) and *Indigofera hilaris* (L). Trees or shrubs recorded for this community numbered less than five species (Fig. 3b).

Of the 70 species recorded for this community, it shares twelve species with the *Hyparrhenio hirtae-Eragrostidetum curvulae* and 11 species are diagnostic for this community in the study area (species group J) (Table 1). Apart from the protected species *Eucomis autumnalis* and *Gladiolus dalenii* (Van Wyk & Malan 1997), this community does not harbour large populations of rare taxa. However, *Neorautanenia ficifolius* is no longer common in its natural habitat due to overexploitation (medicinal value), and is regarded as rare for this study area. This community provides suitable habitat for two Red Data species, viz., *Lotononis adpressa* subsp. *leptantha* and *Melolobium subspicatum* (Pfab & Victor 2002). Based on the findings above it is classified as Status 2.

Diversity

A high Shannon-Wiener Diversity Index (> 3) shows lack of dominance of a single or few species and indicate that all species are evenly distributed in the community (Barbour *et al.* 1987). This evenness is more often than not associated with more pristine systems, as the lowest index value was recorded for the slightly degraded *Cymbopogono plurinodis-Eragrostidetum gummifluae* Bottomland Grassland (Fig. 4a). Shannon-Wiener Diversity Index values for this part of the Bankenveld compare favourably with the values recorded for the diverse eastern part of the Bankenveld (Smit *et al.* 1997). For instance, the 3.3 (Fig. 4a) calculated for *Rhoo pyroidis-Digitarietum erianthae* Open Shrubland is slightly lower than the 3.7 for *Themeda triandra-Mundulea sericea* Open Shrubland (Smit *et al.* 1997). The 3.4 (Fig. 4a) calculated for *Monocymbio ceresiiformis-Schizachyrietum sanguinei* Rocky Grassland is slightly higher than the 3.1 for *Berkheya insignis-Diheteropogon amplectens* Rocky Grassland (Smit *et al.* 1997).

Smit *et al.* (1997) recorded a mean species richness of 48 for *Themeda triandra-Elephantorrhiza elephantina* Rocky Grassland per 100 m² in the eastern part of the Bankenveld. The grassland associations of Sterkfontein compare well (between 38 and 45 species per 100 m²), and improves on previously published figures for dolomite grassland (Fig. 4b). However, the woody associations of the study area have a much lower mean species richness (between 26 and 28 species per 100 m²) than the 30 to 43 recorded elsewhere on dolomites in the Bankenveld (Fig. 4b). From the data it is evident that woodlands on dolomite generally harbour a much lower richness per unit area, especially if the 53 species per 100 m² for *Themeda triandra-Mundulea sericea* Open Shrubland is considered (Smit *et al.* 1997).

Plant species richness of communities is generally lower at Sterkfontein Caves than recorded for other areas on dolomite (Fig. 4c), probably due to localised sampling. For instance, a depleted flora was recorded for the *Loudetio simplicis-Diheteropogonetum amplectentis* Ridge Grassland (3), nearly 20 species less than recorded by Bezuidenhout *et al.* (1994b). However, in two instances, namely *Rhoo pyroidis-Celtidetum africanae* Pocket Wood-

land (1) and *Hyparrhenio hirtae-Eragrostidetum curvulae* Footslope Grassland (5), the opposite is true. Probably because these two communities are well represented in the Sterkfontein area. This study also confirmed the finding of Bezuidenhout *et al.* (1994b), namely that *Monocymbio ceresiiformis-Schizachyrietum sanguinei* Rocky Grassland (4) is a species-rich plant community (Fig. 4c).

Conclusion

The aim of this study was to identify, characterise and interpret ecologically, by using habitat characteristics, the vegetation units that occur on a dolomitic hill. An investigation of the natural vegetation at the Sterkfontein Caves site revealed diverse habitat and associated plant communities. The ecological interpretations of the distinguished plant communities and description of new associations contribute significantly to the present knowledge of dolomitic grasslands by relating vegetation units to threatened plants and their associated habitats. As ecologically sound plant communities were distinguished during this reconnaissance survey, the general description of the vegetation should serve as a basis for further detailed and broad-based botanical studies at this World Heritage Site.

We conclude that the natural vegetation surrounding the Sterkfontein Caves is of important conservation value. Care should be taken when planning new developments (Pfab 2002b), not only for the sake of the rare (nine taxa) and threatened (eight taxa) species that occur or potentially occur on the site (Pfab 2002c), but the grassland biome is also under severe pressure from urban development, and where possible it is necessary to conserve the remaining natural, pristine habitats. Since it has World Heritage Site status, the protection of this area holds a promising contribution for long-term conservation of the biodiversity of the fast declining Rocky Highveld Grassland.

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