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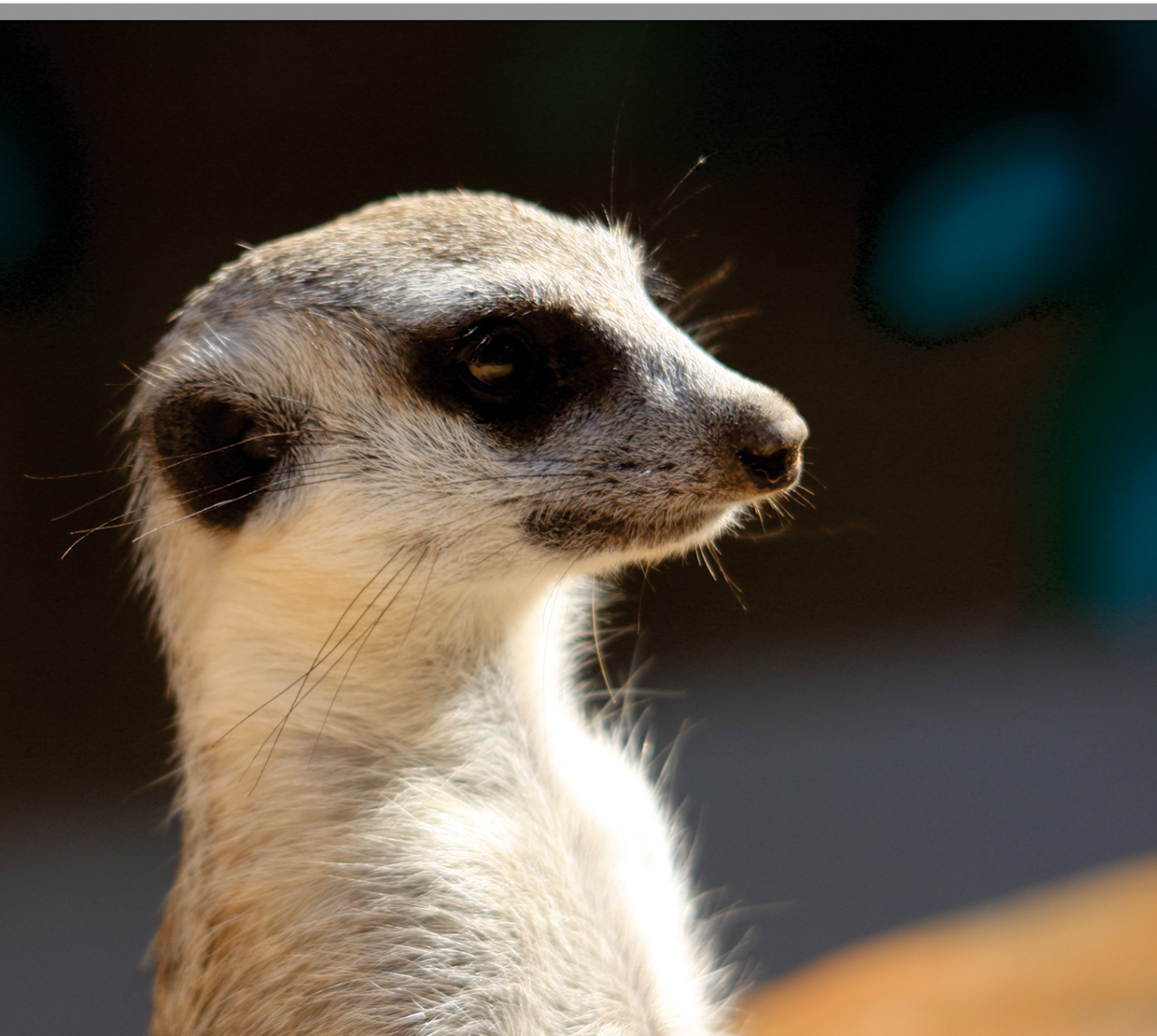

ISSN: 0006-8241

Volume 51, Issue 2. 2021

SANBI
Biodiversity for Life
South African National Biodiversity Institute

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A peer-reviewed publication of the
South African National Biodiversity Institute

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Biodiversity for Life
South African National Biodiversity Institute

Bothalia – African Biodiversity and Conservation is published by the South African National Biodiversity Institute (SANBI), a government funded entity under the Department of Environment, Forestry & Fisheries.

Cover photograph:
Marinda Koekemoer (SANBI)

Website: http://abcjournal.org

General enquiries: +27 (0) 843 5017

ISSN: 2311-9284 (Online)

ISSN: 0006-8241 (Print)

Obtainable from: SANBI Bookshop, Private Bag X101, Pretoria, 0001 South Africa.
Tel.: +27 12 843 5000
E-mail: sanbibookshop@sanbi.org.za
Website: www.sanbi.org
Printed by: xxxxxxxxxxxxxxxxxxxxxx

BOTHALIA – African Biodiversity & Conservation
ISSN: (Online) 2311-9284, (Print) 0006-8241

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Information for Authors and Readers

Focus and scope

The journal aims to disseminate, to a wide audience, knowledge, information and innovative approaches that promote and enhance the wise use and management of biodiversity in order to sustain the systems and species that support and benefit the people of Africa.

The journal publishes original research findings, as well as reviews, commentaries or perspectives, strategies and short communications. Special focus issues emanating from symposia or conferences that fall within the scope of the journal may also be published.

Authors should contextualise submissions within the framework of the value chain of biodiversity knowledge from its generation, to its application and use. We are especially interested in articles that are written using language and terminology that is accessible to a wide audience.

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2. Assessment of biodiversity, including the status of populations, species and ecosystems, the impacts of threats, harvesting and disturbance or of interventions on populations, species and ecosystems, and the value of the goods and services provided by biodiversity.
3. Innovation in science- or evidence-based decision-making for biodiversity in Africa. This includes the publication of case studies, best practices, tools and plans for the conservation, use and management of biodiversity.
4. Cross-cutting fields specifically developments and innovation in human capital development in the biodiversity sector and innovation in biodiversity information management and dissemination systems and tools for use of biodiversity information.
5. Strategic frameworks that provide guidance and direction for biodiversity research, assessment and management at community, local, national, regional or continental levels, especially those that integrate biodiversity management with local and regional socio-economic systems.

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All manuscripts submitted to Bothalia – African Biodiversity & Conservation will be reviewed by experts in the field and will undergo a double-blind review process.

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ISSN: (Online) 2311-9284, (Print) 0006-8241

Habitat description of the rare orchid *Didymoplexis verrucosa* for more effective conservation

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Dates

Submitted: 9 June 2020
Accepted: 17 February 2021
Published: 8 July 2021

How to cite this article:

Mostert, T.H.C. & Mostert, R.E., 2021, 'Habitat description of the rare orchid Didymoplexis verrucose for more effective conservation', *Bothalia* 51(2), a2. http://dx.doi.org/10.38201/btha.abc.v51.i2.2

Background: *Didymoplexis verrucosa* is a cryptic, leafless, saprophytic ground orchid (~70 mm tall) growing on the coastal forest floors of southern Zululand and classified as Vulnerable (D2). As part of a population monitoring programme, 960 man-hours of species-specific searching over five consecutive flowering seasons were conducted, yielding only one individual plant.

Objective: The aim of this study was to increase detection rate by developing a profile of environmental indicators for the accurate identification of suitable habitat.

Methods: A detailed description of suitable habitat was compiled based on the Braun-Blanquet approach.

Results: The results showed that key attributes shared by localities include similar topographic position in the landscape, hydrology, soils, vegetation composition and structure, forest age, leaf-litter composition of the forest floor, the co-occurrence of *Isoglossa woodii*, and a similar degree of protection from sunlight, wind and desiccation.

Conclusion: This profile of essential habitat characteristics can be used as a surrogate in the absence of actual locality data when identifying target conservation areas and compiling management strategies for this very cryptic species. A by-product of this habitat analysis was the discovery of a long list of impacts on the long term survival of *D. verrucosa*. The combination of these stochastic and deterministic events will drive habitat change at rates beyond the species' ability to adapt. Managing these variables forms the crux of its successful conservation. A revision of the conservation status, based on the formal IUCN criteria, indicates that *D. verrucosa* should be reclassified as Critically Endangered Category B2a and D.

Keywords: habitat description, habitat fragmentation and degradation, Red Data List, saprophyte.

Introduction

Didymoplexis verrucosa J.Stewart & Hennessy (Orchidaceae: Epidendroideae) is a small and cryptic, leafless, saprophytic ground orchid discovery by the Dutch botanist C.G.G.J. Van Steenis in 1975 (Stewart & Hennessey 1980). It grows along the forest floors of the coastal dune cordon of southern Zululand (northern KwaZulu-Natal, South Africa). The known distribution range is restricted to the forests south and east of the town Mtunzini. These saprophytes obtain all the energy they need from parasitising the network of fungal hyphae within the leaf-litter carpet of the deeply shaded forest floors. They are therefore classified as mycoheterotrophs (Miura et al. 2018) and do not photosynthesise their own carbohydrates like most plants. This parasitic dependency on fungi evolved from the normally mutualistic relationship between plants and mycorrhiza fungi, which may have evolved many times over, independently in many different plant families (Miura et al. 2018).

Didymoplexus verrucosa forms small tubers (up to 90 × 20 mm) within the decomposed organic matter of the forest floor, accumulating resources from fungal hyphae around their root system (Stewart & Hennessey 1980). With no need to synthesise their own food, they do not invest in leaves and chlorophyll for photosynthesis. The accumulated resources are used in early spring to produce a single erect, very delicate, leafless, cream-coloured flowering stem (± 70 mm tall) bearing eight to twelve very small (10–13 mm in diameter) white flowers tinged pinkish brown (Stewart & Hennessey 1980). The flowers open sequentially, but each flower remains open for only a few hours for pollination before it closes again, and no floral odour has been detected (Stewart & Hennessey 1980). Cross pollination has not yet been recorded and the specific pollinating vector is still unknown. In the absence of insect pollination, Stewart and Hennessey (1980) observed potential cleistogamous self-pollination behaviour of the flowers.

Historical perspective of discovery and rarity

The search for *D. verrucosa* began long before its discovery. During the 1920s and 1930s Van Steenis compiled keys to the many saprophytic species of a wide range of flowering plants occurring in the tropical forests of the Malesia Floristic Region (Kalkman 1990). Based on the knowledge that he gained regarding suitable habitat for such species, he predicted that the coastal dune forests of Zululand would contain saprophytic orchid species (Stewart & Hennessey 1980). After numerous botanical expeditions to these Zululand forests, his wife found such a species, which he concluded belonged to the genus *Didymoplexis*. Based on the warty protrusions on the fruit capsule, it was named *D. verrucosa* (Stewart & Hennessey 1980). Initially, only a single plant was found on the Farm Twinstreams, then owned by conservationist Ian Garland. Subsequent searches in the following years revealed a small population numbering approximately 15 plants. Local ecologist C.J. Ward photographed the flowers for the first time in August 1978 and Garland continued to monitor the population for a few years. Subsequent recordings of these very cryptic plants became more sporadic, often with decades passing between sightings (Victor et al. 2005).

In the early 2000s, orchid enthusiast Herbert Stärker from Vienna (Austria), contributed to compile photographic field guides for the orchids of Africa and in particular South Africa (Johnson, Bytebier & Stärker 2015). Over a period of two decades he made regular trips to Africa to photograph orchids, including *D. verrucosa*. After many unsuccessful attempts to find this species, his wife joined a search expedition and rediscovered the long-lost orchid near Mtunzini in August 2011. Additional searches were conducted, leading to the discovery of another two plants in close proximity to the first. Over time he revisited these plants in the hope of photographing their fully opened flowers. No additional plants or populations were found after that. Due the sensitive nature of the rediscovery of these rare plants, Stärker and his colleagues kept their rediscovery quiet until more plants and populations could be found.

Unaware of the rediscovery of this orchid, the Custodians of Rare and Endangered Wildflowers (CREW) in association with the South African Botanical Society and the South African National Biodiversity Institute (SANBI) contacted the University of Zululand (UniZul) to request help to find and monitor some of Zululand's Red List plant species, of which *D. verrucosa* is one. Due to the ethical considerations surrounding research on such rare species, we decided that no vegetative or reproductive material needed to be collected during the initial stages. Therefore, no collection permits were requested from Ezemvelo KZN Wildlife. With the help of many students, a variety of methods were employed during the initial searches for *D. verrucosa* plants and populations. We initially followed the standard procedure used by CREW, which is to visit known historical localities and to conduct species-specific searches. All searches were conducted during the flowering–fruiting season of *D. verrucosa*, which was estimated to range from early August to late September. In some years we extended our searches into the month of October in the hope of finding dried fruit capsules. We spent approximately 195 man-hours in searches at known historical sites, covering approximately 6.5 ha over a period of five flowering seasons. Failing to record any plants, we adopted a grid-search strategy, during which ten fieldworkers searched a one-hectare sized area along predetermined gridlines ten metres apart, scanning the forest floor vegetation within mature Northern Coastal Forest (national vegetation type FOz7) (Mucina & Rutherford 2006). We spent approximately 672 man-hours in grid-searching mature forest, covering approximately 22.4 ha over a period of four flowering seasons. Failing to find *D. verrucosa*, we stratified the forest into dune crests, dune slopes and dune valleys before repeating our grid-search technique within each stratified unit again. This approach helped us to conduct more consistent searches within the relatively homogenous vegetation structure of each stratified unit. This follow-up search (90 man-hours covering 3 ha) was also done later (October) in the flowering–fruiting season, in the hope that a shift in search timing may lead to successful finds. Despite a total of approximately 960 man-hours spent searching an estimated 31.9 ha of forest floors south and east of Mtunzini over five consecutive flowering seasons, we did not locate any plants of *D. verrucosa*. Some of the above methods were employed concurrently, between September 2009 and October 2013. A chance discovery of a single plant was made in September 2013 by R.E. Mostert,

News of our discovery prompted Stärker to reveal the locality of their discovery to pool knowledge and manpower for more effective research and conservation efforts. At that time, these two localities (northeastern locality and southwestern locality) presented us with the opportunity to potentially monitor the four plants recorded. Three plants were recorded again the following year (2014), one in the northeastern locality and two in the southwestern locality. Whether these were the same plants as those recorded the previous years are unknown. No plants were recorded in the subsequent two years (2015 and 2016) at these two localities, despite very careful marking and thorough follow-up searches.

Objective

It was at this stage that we decided to change our strategy and follow Van Steenis' initial approach that contributed to chance discovery of *D. verrucosa* by focussing on ecosystem characteristics rather than the actual plants themselves. The aim of this study was therefore to produce a profile of indicators for the accurate identification of suitable habitat by analysing site characteristics of the two most recent discoveries. Such a profile could then be used to direct future search efforts better, or as a surrogate in the absence of actual field records when compiling conservation strategies and identifying target areas for the conservation of *D. verrucosa*. Whether these two localities truly represent optimal habitat or merely marginally suitable habitat is unknown at this stage.

Methods

The habitat descriptions were compiled from both floristic and environmental data gathered at the two most recent known localities of *D. verrucosa*. The two localities are approximately 2.3 km apart from one another. Field surveys were conducted while the plants were flowering/fruiting (2011–2012), before their subsequent disappearance. Due to the very sensitive nature of locality information of rare and endangered species, the exact localities are not provided here, with only an approximate locality of the study area presented in Figure 1 (straddling quarter degree squares 2831DC and 2831DD) (Larsen et al 2009). Exact localities were provided to the provincial conservation authority, Ezemvelo KZN Wildlife. For the purposes of this paper, we differentiate between the two localities by simply referring to them as the northeastern locality and southwestern locality. It was decided to exclude historically known localities (1975 to 1993) from this habitat description due to the dynamic changes often associated with the forest floor conditions of Northern Coastal Forest (Lubke, Avis & Moll 1996; Zungu, Mostert & Mostert 2018). Vegetation structure was described in terms of the height and density of the various strata within the forest. Stratum classes were assigned according to the dominant height class structure system devised by Edwards (1983) for South African forest vegetation structure classification: upper canopy layer 15–25 m, short tree layer 8–15 m, tall shrub layer 3–8 m, short shrub layer 1–3 m, herbaceous layer 0.1–1.2 m.

The floristic composition of each stratum was described using the Braun-Blanquet approach. The Braun-Blanquet sampling method (Werger & Coetzee 1978) was specifically chosen for its international recognition as the most appropriate technique for the description of vegetation when based on total floristic composition (Brown et al. 2013). By using an internationally accepted standard, the data and vegetation description will be compatible and comparable with data from other regions and landscapes. Such comparability and compatibility are crucial for the regional and international coordination of vegetation and ecosystem conservation. Based on the recommendations by Brown et al. (2013), plot sizes were set at 400 m^2 and were marked out in the field to ensure consistency. In all sample plots, each plant species was recorded and the cover–abundance value of each species determined using the modified Braun-Blanquet cover–abundance scale: r (very rare, with a negligible cover), + (present but not abundant, with a cover value of < 1% of the quadrat), 1 (numerous but covering less than 1% of the sample area), 2a (covering 5%–12% of the sample area), 2b (covering 13%–25% of the sample area), 3 (covering 25%–50% of the sample area), 4 (covering 50%–75% of the sample area), 5 (covering 75%–100% of the sample area) (Brown et al. 2013).

A wide range of environmental parameters were recorded and compared at the two localities. Distance from the average high-tide level along the nearby beach, as a measure of exposure to salt-clipping and wind-shearing from onshore wind and airborne sand particles, was calculated from georeferenced aerial imagery. Position and orientation descriptions within the vegetated dune cordon took into account whether a locality was situated on a dune crest, slope or valley and the number of dunes between it and the prograding beach. Soil texture and type was described using the standardised South African soil classification system (Fey 2010). Soil profile colour was described using the Munsell soil colour chart (Brady & Weil 2004). Thickness of the leaf-litter layer was measured in 10 mm increments. Texture of the leaf-litter was determined

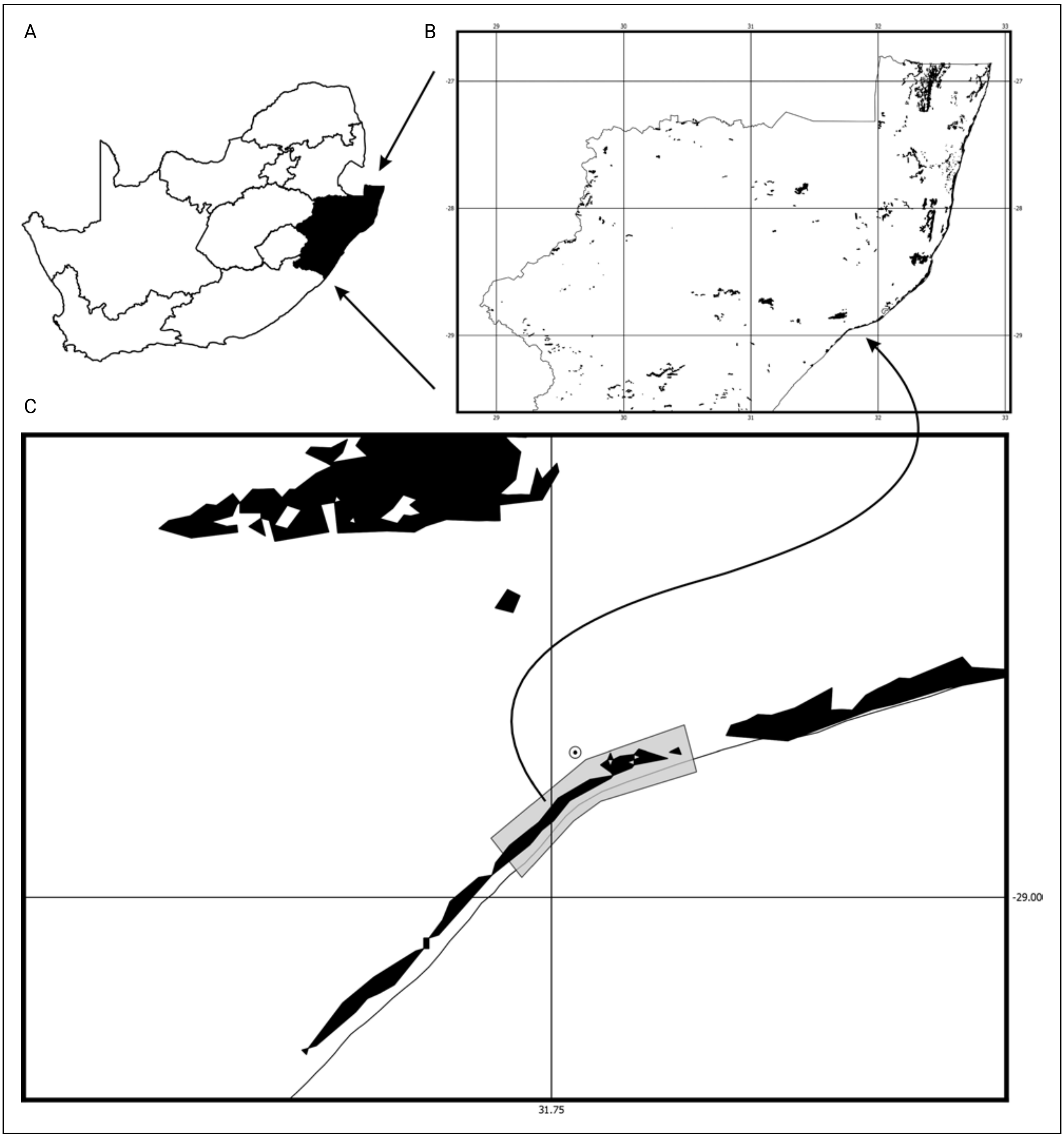

Figure 1. A, Location of the province of KwaZulu-Natal within South Africa; B, northern KwaZulu-Natal showing the very limited extent of remaining forest ecosystems shaded in black with degree grid lines for spatial reference; C, study area shaded in grey south of the coastal town of Mtunzini with quarter degree grid lines for spatial reference.

by measuring particle size (n = 100) at 10 mm above the soil surface. Composition of the leaf-litter on the forest floor was determined by a morphological analysis of decaying leaf fragments based on venation and trichome patterns. For this, 500 cm^3 of organic material was collected from the upper layer leaf-litter layer between one and two metres away from the recorded *D. verrucosa* plants, taking care not to disturb the plants. Light penetration at forest floor level was determined by measuring the percentage of area covered in shadow and direct sunlight at 12:00 within the 400 m^2 Braun-Blanquet vegetation quadrat. Hydrology was described based on the soil profile characteristics and the water holding capacity of the A horizon using the soil-sausage technique (Fey 2010). Slope was determined using a clinometer, while aspect was determined using a compass. Levels of ecosystem disturbance and fragmentation were described based on the degree of invasion by invasive alien plant species, the presence and extent of human activity, extent of animal impact on above-ground vegetation and leaf-litter movement, extent of damage to the herbaceous vegetation along the forest floor by falling trees or branches and the extent of damage to vegetation and leaf-litter by wind and water. The potential of localities to withstand storm damage were described based on a visual assessment of wind damage to plants and the redistribution of dead organic matter along the forest floor.

In addition to recording the above-mentioned environmental drivers of suitable habitat, some of the potential threats to the survival of *D. verrucosa* within one kilometre of the two localities were investigated and described. This included formal protection status, illegal logging, slash-and-burn agricultural practices, changes to natural burning regimes, human settlement, livestock grazing and browsing, impact of tourism, mining activities, invasive alien plant species, natural resource utilisation and management and illegal collection by traditional healers, nurseries and amateur collectors. Due to the low number of localities investigated (n = 2), no statistical correlation analyses were conducted on the data.

Results

Macro habitat description

The study area is located within the southernmost extremity of the Maputaland Centre of Plant Endemism (Van Wyk & Smith 2001) and within the Maputaland–Pondoland–Albany Hotspot, which is listed as one of the world's 36 most important biological hotspots (Myers et al. 2000). These hotspots are areas containing more than 1 500 endemic vascular plant species with less than 30% of their original vegetation still intact. The Maputaland–Pondoland–Albany Hotspot in particular contains approximately 1 900 endemic plant species, with less than 25% of its original vegetation still intact by 2004 due to anthropogenic activities (Steenkamp et al. 2004). The rate of ecosystem transformation has since increased (CEPF 2010).

Both sample localities fall within the Northern Coastal Forest vegetation type (FOz7) of the Indian Ocean Coastal Belt Biome (Mucina & Rutherford 2006). These forests are associated with wind-blown sand dunes that form some of the youngest geological formations in South Africa (<10 000 years old) (Gaugris et al. 2004). Within the study area, this specific dune cordon is currently expanding in the direction of the ocean at a rate of approximately one new dune per decade (Van Daalen et al. 1986; Weisser, Garland & Drews 1982; Weisser & Muller 1983) and is stabilised by one of the few examples of primary succession of vegetation in South Africa (Todd 1994; Zungu et al. 2018).

The overall climate in the study area is subtropical with hot, humid summers and cool moist winters (Boyes et al. 2011; Nevill & Nevill 1995; Rawlins 1991). The mean minimum and maximum temperatures are 11°C (July) and 30°C (December) respectively. Rainfall peaks twice a year with most received in summer (60% in November–March) and the rest in winter (40% in June–July) with a mean annual total of 1 100 mm. (Rawlins 1991; Tyson & Preston-White 2000). Relative humidity in summer usually exceeds 80% and during winter it often ranges from 50% to 60%. Potential evaporation exceeds average precipitation for all months except January, February and December and varies from 190 mm in January to 84 mm in June (Schulze 1982).

Microenvironment description

Abiotic parameters

The northeastern and southwestern localities both lie between the third and fourth dune series, respectively 370 m and 460 m from the average high-tide mark on the beach. Both are associated with relatively flat to slightly concave inter-dune valley topography of the dune cordon system. These protected valleys accumulate very large quantities of leaf-litter, leading to a very thick and stable carpet (40–80 mm) of decaying organic material on the forest floor (Moll 1972; Van Aarde, Smit & Claassens 1998). The leaf-litter is highly decomposed with a high density of fungal hyphae binding organic material into a mat. Although organic particle sizes range from microscopic dust to decaying tree trunks, the general texture of this organic carpet (at 10 mm above the soil surface) is relatively fine (1–7 mm in diameter). The morphological analysis of decaying leaf fragments (based on venation and trichome patterns) indicated that most leaf-litter comes from *Isoglossa woodii*, which often forms monotypic stands within the forest understorey where *D. verrucosa* grows.

Due to the relatively high elevation (15–25 m above sea level) of these specific dune valleys and the deep sandy soils associated with *D. verrucosa*, water drainage is very fast with no accumulation of free surface water, even during very heavy rainfall events (Watkeys, Mason & Goodman 1993). This results in relatively dry, aerobic conditions within the leaf-litter layer above the soil (Van Aarde et al. 1998). The soil associated with both sites is classified as cover sands (Fey 2010), with a mean grain size of 330 μm (Ware 2001) and highly leached (Watkeys et al. 1993). The upper 15 mm of sand directly below the leaf litter is greatly enriched with finely decomposed organic particles, resulting in colouration described by the Munsell Soil Colour Chart as 10YR3/3 dark yellow brown (Munsell 1980). Sand colour at a depth of 15–450 mm can be described as 10YR6/2 light brownish grey, while sand from 450–1 200 mm matched 10YR8/6 yellow of the Munsell chart.

The structural complexity of these forests and their topographic position result in a high level of protection from wind exposure, with no evidence of wind damage recorded within the forest understorey of the sampling quadrats. The only disturbance recorded within the forest floor of the sample quadrats were tracks, communal defecation middens and browsing damage to plants from red duiker (*Cephalopus natalensis*) and bushbuck (*Tragelaphus sylvaticus*). However, severe disturbances caused by indigenous bush pigs (*Potamochoerus larvatus*) and a small group of feral pigs (*Sus scrofa*) within the forest floor were recorded in nearby forest patches.

Vegetation structure

Both localities fall within mature Northern Coastal Forest vegetation with multiple strata of interlocking canopies resulting in a total canopy cover of 100%. The fourth dune generally contains some of the oldest and structurally most complex forest vegetation within this dune cordon (Von Maltitz, Van Wyk & Everard 1996; Zungu et al. 2018). Beyond the fourth dune, most forest vegetation has been transformed by anthropogenic activities, with only very small sections of the fifth and sixth dunes still covered by the original coastal forest. The upper canopy on the fourth dune is approximately 20 m high and contributes to 40% of the total vegetation cover. This upper canopy interlocks with a shorter tree layer of approximately 8–15 m tall with a 60% cover. The tall shrub layer (3–8 m tall) is relatively sparse with a sub-canopy cover of approximately 20%. A very large number of lianas enter the canopy and an estimation of their contribution to the total canopy cover was not attempted. The herbaceous layer (0.1–1.2 m tall) is relatively dense (40–80% sub-canopy cover) and very dynamic. The dominant species within this layer is the long-lived, synchronously monocarpic herbaceous *Isoglossa woodii*, which grows for approximately 4–7 years before mass-flowering, setting seed and dying (Griffiths et al. 2010). This results in extreme structural changes within this vegetation layer at the end of each synchronised flowering cycle.

Floristic composition of the associated plant community

The uppermost stratum contains many old and reproductively mature trees (15–20 m high, 40% canopy cover) and is dominated by species such as *Mimusops caffra, Sideroxylon inerme, Albizia adianthifolia, Ficus natalensis* and *Ekebergia capensis*. Other prominent species within this layer include *Cussonia spicata*, *Vepris lanceolata*, *Harpephyllum caffrum* and *Trichilia emetica*. Zungu et al. (2018) described similar vegetation within the Umlalazi Nature Reserve as the *Carissa bispinosa–Mimusops caffra* climax coastal dune forest community.

The next stratum of shorter trees (8–15 m, 60% canopy cover) is dominated by species such as *Brachylaena discolor*, *Psydrax obovata*, *Dovyalis longispina*, *Gymnosporia arenicola*, *Protorhus longifolia*, *Tricalysia sonderiana*, *Apodytes dimidiata*, *Deinbollia oblongifolia* and *Clerodendrum glabrum*. Other prominent species within this layer include *Maytenus acuminata*, *Teclea gerrardii*, *Catunaregam obovata*, *Garcinia gerrardii*, *Maytenus procumbens*, *Tabernaemontana ventricosa*, *Chaetachme aristata*, *Olea woodiana*, *Bridelia micrantha, Putterlickia verrucosa, Grewia caffra* and *Canthium inerme*.

Below the above stratum, a sparse layer of tall shrubs and low trees (3–8 m, 20% canopy cover) are dominated by *Carissa bispinosa*, *Monanthotaxis caffra*, *Ochna serrulata*, *Peddiea africana*, *Eugenia capensis*, *Euclea natalensis*, *Cussonia zuluensis*, *Pavetta revoluta*, *Scutia myrtina*, *Allophylus natalensis*, *Kraussia floribunda* and *Dracaena aletriformis*.

The lowest stratum is dominated by the herbaceous species *Isoglossa woodii*. This long-lived, synchronously monocarpic species ranges from 0.1 m tall during its first year of life, to 1.2 m tall by the time it flowers in mass approximately 4–7 years later. At the peak of its growth cycle, it covers between 40 and 80% of the forest floor, while the synchronised mass die-off event at the end of the growth cycle renders the forest floor almost devoid of live plant cover. Other species were recorded only at very low densities and included the ground orchid *Cheirostylis gymnochiloides*, the fern *Microsorum scolopendria*, the grass *Oplismenus hirtellus*, and other herbaceous forbs such as *Behnia reticulata* and *Aneilema aequinoctiale*.

Numerous woody lianas and herbaceous climbers penetrate various strata within the forest and include species such as *Rhoicissus rhomboidea, Rhoicissus tomentosa, Rhoicissus sessilifolia, Dalbergia armata, Smilax anceps, Landolphia capensis, Dioscorea cotinifolia, Asparagus falcatus, Adenia gummifera, Cissampelos torulosa, Senecio tamoides, Senesio deltoideus* and *Secamone filiformis*. A wide variety of epiphytes were recorded and include the fern *Microsorum punctatum*, the orchids *Polystachya sandersonii*, *Cyrtorchis praetermissa*, *Cyrtorchis arcuata* and *Ansellia africana*, as well as the parasitic mistletoe *Erianthemum dregei*.

Some of the invasive alien species recorded within the sample plots included *Lantana camara*, *Chromolaena odorata* and *Rivina humilis*. Although these species were only recorded at very low densities, large sections of adjacent forest patches have been completely invaded by *Chromolaena odorata* and *Rivina humilis*, transforming the forest floor conditions.

Discussion

As is the case with most taxonomic and phytosociological research, this habitat study should be regarded as a descriptive study. Due to the paucity of *D. verrucosa* localities (n = 2), no meaningful statistical correlation analyses could be conducted on the data. Whether the two sample localities represent distinct populations or only one is not known. Unfortunately, this scenario is all too common for many of South Africa's rare and endangered species (SANBI 2010). Suppressing the publication of such descriptive studies due to their lack of statistical verification will result in valuable information never being incorporated into conservation strategies and management plans (Pierce et al. 2005).

Critical environmental factors shaping suitable habitat for *D. verrucosa* are those that affect conditions along the forest floor. Based on the limited ecological information provided by Stewart and Hennessy (1980) and the habitat description presented in this study, we suggest that the following be considered to be critical parameters for suitable *D. verrucosa* habitat:

- Old-growth Northern Coastal Forest in pristine condition. Along this pro-grading shoreline, such forest is restricted to between the third to fourth dune from the beach, but along a degrading beach these old-growth forest patches may occur closer to the beach.
- High relative humidity under a dense multi-stratum canopy (100%) that buffers daily fluctuations in extreme temperature, light exposure, wind speed and desiccation.
- The co-occurrence of *Isoglossa woodii* (or similar perennial herbaceous species) as the dominant species in order to create medium-term (4–7 years) stable conditions within the lowest stratum of the forest vegetation.
- A thick carpet of fine textured organic matter mostly comprising of soft-leafed herbaceous material, such as that provided by *Isoglossa woodii*.
- Topography that results in the net accumulation of organic material with *in situ* decomposition.
- Low levels of disturbance within the leaf-litter mat and protection from damage by wind, water, large animals and invasive alien plant species.
- Fast draining sandy soil to ensure aerobic conditions, with no free-standing water along the forest floor. Soil texture, structure and nutrition seem to be less important to *D. verrucosa* since the roots and tubers are situated within the leaf-litter and were not recorded to enter the soil itself.
- High density of fungal hyphae in the soil which are parasitised by *D. verrucosa*.

As a by-product of the habitat analysis, a wide range of threats to the long-term survival of *D verrucosa* at these two localities, as well as at other similarly suitable habitats in the immediate surroundings, were recorded. These include:

- Lack of effective protection of remaining suitable habitat, with only one of the sites formally protected (Umlalazi Nature Reserve).
- Habitat degradation and fragmentation of the remaining Northern Coastal Forests due to unlawful logging, slash-and-burn agricultural practices, burning of adjacent rangelands to improve grazing for cattle, formal and informal settlements, recreational hiking trails and open-cast mining for heavy metals.
- Invasive alien plant species such as *Chromolaena odorata* (Ambika 2002; Hu & Zhang 2013) and *Rivina humilis* (Ravi et al. 2020), which are changing the forest floor characteristics dramatically due to competition and allelopathic effects of the secondary metabolites they contain.
- Increased chances of forest fires due to the forest margin changing from being fire-proof to fire-prone under the influence on *Chromolaena odorata* and *Lantana camara*.
- Current efforts to mechanically eradicate *Chromolaena odorata* and *Rivina humilis* in the immediate vicinity leads to the severe disruption of the leaf-litter on the forest floor.
- The impact of a small group of feral pigs.
- Close proximity to footpaths, making them vulnerable to accidental trampling and illegal collection.
- The negative effects of environmental stochasticity on small populations.

It is unknown whether the dramatic changes caused by the cyclical synchronised mass die-off of *Isoglossa woodii* after flowering present *D. verrucosa* with critical opportunities (e.g. easier cross pollination) or critical obstacles (e.g. exposure to unfavourable environmental conditions). Nonetheless, it is likely to have a profound effect on the flowering, pollination and seeding opportunities for *D. verrucosa*.

It is unknown whether *D. verrucosa* is a long-lived intermittent flowering species or whether they are simply short-lived reseeders. Autecological studies are needed to answer such questions. The precise environmental cues that trigger the tuber to produce a flowering stalk is still unknown. We have been trying for the last ten years to predict flowering times without any success. The answer may lie in the tubers it produces, enabling them to use previous years' resources for reproduction at a more flexible time frame to synchronise their phenology with environmental variables, such as the emergence of a suitable pollinator. The most detailed and comprehensive visual account of *D. verrucosa* is still the sketch made by E.F. Hennessy (Stewart & Hennessy 1981), based on observations made from a few plants she grew and maintained in a shoe box.

Although a small number of Hymenoptera and Diptera species have been recorded landing on the flowers during our surveys, no pollination behaviour was recorded. With flowers staying open for only a few hours before closing again, and the recorded spatial distribution of plants, successful crosspollination by an insect seems to be a truly herculean accomplishment. The heavy use of insecticides, herbicides and fertilisers within Zululand may have already had dire consequences for many potential pollinator species (Rother et al. 2008). Although the cleistogamous self-fertilisation recorded in *D. verrucosa* may provide a back-up chance to ensure a next generation, regular inbreeding as a result of continued failure to cross pollinate, will make the species less adaptable and more vulnerable to future environmental changes.

The combination of the many stochastic and deterministic events recorded in this study drive habitat change at rates beyond the ability of *D. verrucosa* to adapt its life history strategies for long term survival (Pressey et al. 2007). Managing anthropogenic degradation and fragmentation of suitable habitat should be our first priority when compiling conservation strategies of this very unique and rare species (Margules & Pressey 2000).

Conservation status revision

Raimondo et al. (2009) conducted a formal conservation status revision for *D. verrucosa* in 2009 and assigned the status of 'Vulnerable due to a population with a very restricted area of occupancy (less than 20 km^2) and with locations (typically five or fewer) such that it is prone to the effects of human activities or stochastic events within a very short time period in an uncertain future, and is thus capable of becoming Critically Endangered or even Extinct in a very short time period (VU D2)'. After our own evaluation of the current situation using the formal IUCN criteria for assigning conservation status to species (IUCN 2020), we propose that this species be assigned the conservation status of Critically Endangered Category B2a and D. We base our recommendation on the following: IUCN Criterion B2a – Geographic area of occupancy estimated for *D. verrucosa* is less than 10 km^2, and estimates indicate (a) severely fragmented population, as well as IUCN Criterion D – Population size estimated to number fewer than 50 mature individuals. Based on the difficulty to find and monitor these seemingly fleeting populations, we regard the population trend as unstable.

Suitable habitat for *D. verrucosa* is very limited within the region and under severe threat of degradation and fragmentation due to the long list of threats provided above. This is exacerbated by the limited effective protection of mature Northern Coastal Forests along this section of KwaZulu-Natal. At present, only the north-eastern locality falls within a formally protected area (Umlalazi Nature Reserve).

Conclusion

Traditional search techniques are inadequate for population monitoring programmes of rare and cryptic species such as *D. verrucosa*. This results in a lack of much needed quantitative data to better analyse and understand their ecology (Rouget et al. 2003). In the absence of such data, this study provides conservation agencies with a detailed description of its current known habitat, presenting a profile of indicators for the accurate identification of suitable habitat. Such information can now be used to direct future search efforts, or it can act as a surrogate in the absence of actual field records when compiling conservation strategies and management plans for *D. verrucosa* (Hannah et al. 2002; Pierce et al. 2005). This newly developed suitable-habitat-profile search strategy is currently being implemented by re-mapping all suitable habitat before searching for new *D. verrucosa* localities and colonies.

Acknowledgements

Herbert Stärker for sharing his knowledge and experiences regarding the rediscovery of *D. verrucosa*.

Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

THCM: Project coordinator, research design, interpretation of results, discussion and conclusion.

REM: Data collection, vegetation analysis and description, conservation status revision.

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SANBI Biodiversity for Life
South African National Biodiversity Institute

BOTHALIA – African Biodiversity & Conservation
ISSN: (Online) 2311-9284, (Print) 0006-8241

Motivations and contributions of volunteer groups in the management of invasive alien plants in South Africa's Western Cape province

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Dates

Submitted: 11 August 2020
Accepted: 13 January 2021
Published: 8 July 2021

How to cite this article:

Jubase, N., Shackleton, R.T. & Measey, J., 2021, 'Motivations and contributions of volunteer groups in the management of invasive alien plants in South Africa's Western Cape province', *Bothalia* 51(2), a3. http://dx.doi.org/10.38201/btha.abc.v51.i2.3

Background: Research and management of biological invasions traditionally focuses on state-operated, large-scale control initiatives, with little emphasis on volunteers. Volunteering can, however, contribute to detection, extirpation and containment of invasive alien plant species (IAPS). Understanding the extent of involvement and motivations of volunteers in IAPS management is important to improve the success of invasive alien species control.

Objectives: In this study we aimed to: 1) identify volunteer groups controlling IAPS in the Western Cape province of South Africa; 2) understand their practices and contributions towards detecting and controlling IAPS; 3) examine volunteer's motivations for controlling IAPS; and 4) identify the challenges individual volunteers and groups face.

Methods: The data were collected using online questionnaires.

Results: In total, we identified 52 volunteer groups. We broadly estimate that half of these groups that participated in the survey clear nearly 5 300 ha of land per year with estimated labour contributions of ZAR 5.1 million (equivalent to USD 0.32 million) when aligned with formal state management cost estimates. Most volunteer groups raise their own funds to facilitate their work, however, many suggest support from government entities, landowners and Non-Government Organisations would help. Most volunteers (82%) detect and report invasive species to their team leaders, citizen science platforms and relevant authorities. Volunteers themselves gain physical and psychological fulfilment and build their social capital by meeting new people.

Conclusion: Our findings point to the valuable contribution of these groups, but also the need for better co-ordination and engagement between volunteer groups and mandated authorities on science, policy and management.

Key words: biological invasions; citizen science; hack groups; invasive alien species; management; stakeholder engagement.

Introduction

Globally, invasive alien species (IAS) pose a significant and accelerating cost to economies, societies and ecosystems around the world (Pimentel et al. 2005; Jeschke et al. 2014). Humans are responsible for the initial introduction of IAS and their management at later stages (Hulme et al. 2008; Faulkner et al. 2015; Novoa et al. 2018; Shackleton et al. 2019). The rate at which IAS spread and the difficulty of managing them, has resulted in the recognition of the need for collaborations in research and management that enhance the link between science, policy, management and citizens around the world (Novoa et al. 2017; Abrahams et al. 2019). These integrative management approaches should include citizens and volunteers to help improve the effectiveness of IAS management over the long-term (Novoa et al. 2018; Dechoum et al. 2019), and support conservation work in times of budgetary constraint (Pagès et al. 2019).

According to Shackleton et al. (2019), there are many ways of involving society in the management of IAS, such as through citizen science and volunteer initiatives to monitor and/or control IAS. Volunteers can make a significant contribution in the local management of IAS at a reasonable cost and their efforts can be sustained over time (Dechoum et al. 2019). Volunteer programmes can also be helpful in increasing public awareness of environmental issues and encourage local people to join groups (Dechoum et al. 2019). More experienced volunteers, or champions, can be very helpful in the early detection of new and satellite infestations. There are various examples of the benefits volunteers can have for IAS management. For example, Dechoum et al. (2019) show that management programmes for invasive pines (*Pinus* spp.) involving volunteers were effective, and resulted in overall reduction in their abundance and distribution in southern Brazil. Similarly, Delaney et al. (2008) showed a significant contribution by volunteers in detecting the range expansion of Japanese shore crabs (*Hemigrapsus sanguineus*) in the United States of America. Thomas et al. (2017) demonstrated the value of using citizens to detect invasive animal species using active and passive surveillance in Australia.

Considering the success of volunteers in facilitating IAS management elsewhere in the world, research needs to be undertaken to better understand and document the role of volunteers in the management of IAS in South Africa – which remains a current knowledge gap.

South Africa has major problems with both plant and animal IAS (van Wilgen et al. 2020). Invasive alien plant species (IAPS), in particular, pose a major threat across most of the country and the efforts to control them cost approximately ZAR 2 billion each year (USD 120 million) (van Wilgen et al. 2020). If left unmanaged, the impacts of IAPS on South African ecosystems are likely to increase (Wilson et al. 2020). South Africa has a long history of managing IAPS dating back to 1913 (van Wilgen et al. 2020). The Working for Water (WfW) programme launched by the South African government in 1995 (van Wilgen & Wannenburgh 2016) is a globally recognised and well-documented control initiative (Richardson & van Wilgen 2004; van Wilgen et al. 2012). The purpose of this public works programme is to control IAPS as well as create employment opportunities for disadvantaged people (van Wilgen & Wannenburgh 2016). WfW operates on public and private land, and uses a mixture of biological, chemical and manual control methods (van Wilgen et al. 2020). Furthermore, South Africa has strong legislation, the National Environmental Management: Biodiversity Act ([NEM: BA] Act 10 of 2004), that underpins the management of IAS.

There is, however, limited research and emphasis on volunteering or private control initiatives in the country (van Rensburg et al. 2017). Understanding the motivations and contributions of volunteers to manage IAS and developing strategies to maintain their enthusiasm and willingness to participate is important to improving successful IAS control. Emphasis should also be placed on understanding the barriers that can negatively affect volunteer participation to guide relevant adaptive responses and policy (Shackleton et al. 2016).

Therefore, this study aims to: 1) identify volunteer groups controlling IAPS in the Western Cape province of South Africa; 2) understand the practices and contributions of volunteer groups towards detecting and controlling IAPS; 3) examine volunteer motivations for managing IAPS; and 4) identify the challenges or barriers that are faced by volunteers when managing IAPS.

Methods

Study site

The study was conducted in the Western Cape province, which is located on the southwestern coast of South Africa's Cape Floristic Region (CFR) with a population of approximately 6.8 million people (StatsSA 2019). Almost all of the province's urban population is concentrated in the city of Cape Town, which is also the country's legislative and provincial capital. The Western Cape experiences a Mediterranean climate with hot dry summers and cold rainy winters (Rebelo et al. 2006). The primary vegetation type of the Western Cape is 'fynbos': a highly diverse, evergreen, hard leafed shrubland growing in nutrient poor soils (Rebelo et al. 2006).

The CFR is recognised as a global biodiversity hotspot due to its high levels of plant endemism and diversity (Rebelo 2006). The region is also the most invaded terrestrial area in South Africa, especially by IAPS in the genera *Acacia*, *Hakea* and *Pinus* (Richardson et al. 2020; van Wilgen et al. 2020), which pose a serious threat to the biodiversity, as they alter ecosystem processes and reduce local species richness (van Wilgen et al. 2008). The economic impacts caused by these IAPS in the region are also high (van Wilgen 2016), where historical costs for control over the past 20 years have amounted to ZAR 564 million (2015 values) (van Wilgen et al. 2016). These costs do not include control efforts of IAPS by private landowners and volunteers.

Identifying volunteer groups in the Western Cape

To identify and map existing volunteer groups in the Western Cape managing IAPS, an online search (Google) was conducted using the following terms in English, isiXhosa and Afrikaans 'hack groups, volunteer groups, invasive alien species control, and friends' groups' in April 2019. Researchers, managers and other stakeholders in the conservation sector (e.g. the Botanical Society of South Africa (Botsoc), Custodians or Rare and Endangered Wildlife (CREW) and Environment Society of South Africa (WESSA) were also consulted and asked to report known volunteer groups in the Western Cape. A short document asking people to report known volunteer groups in the Western Cape was produced and shared on social media (Facebook) and independently shared by users with personal accounts and groups. This yielded more results than other search efforts. Snowballing (word-of-mouth referrals) methodology was also used to source additional volunteer groups whereby in interviews we asked volunteer group leaders to identify other groups known to them.

Questionnaires

The survey was conducted through two different online questionnaires using Google Forms. One was directed at volunteer groups and was completed by the group co-ordinators or group leaders and contained 30 questions (Supplementary material, Document 1), and the other was directed at individual volunteers and had 26 questions (Supplementary material, Document 2).

The volunteer group–related questionnaire aimed to better understand how the whole group functions and contained different questions relating to: 1) how and when the group was formed; 2) the motivation behind forming the group; 3) how the group operates; 4) how they measure success in managing IAPS; 5) whether there is a group budget, the source of funding and what the budget is used for; 6) whether the groups require additional support from government entities, landowners and non-governmental organisations (NGO's); and 7) challenges faced by the groups.

The questionnaire directed at individuals who volunteered for groups controlling IAPS in the Western Cape aimed to understand the motivations, values and practices of volunteers. This questionnaire covered themes such as: 1) how they joined the volunteer groups; 2) their initial reasons for participating in IAS management; 3) their current motivations to volunteer, 4) the primary positive experiences or benefits they get from volunteering, 5) how often they volunteer; 6) whether volunteering cost them anything financially; 7) whether they detect and report IAS; and 8) any challenges they faced as volunteers. The second section of this questionnaire captured the demographic profile of respondents such as age, location, education level and current or previous field of work.

Both questionnaires contained open and closed ended questions, each with an estimated completion time of around 15 minutes. The final questionnaires were piloted, and the responses from the pilot experiment were not used in the results. The questionnaire was shared by intermittent posting from August 2019 to May 2020 and participants could use a link to access the survey and participate voluntarily online or there was the option to organise a telephonic interview. Government entities and NGOs such as City of Cape Town Invasive Species Unit and WESSA assisted with the distribution of the survey link throughout their volunteer networks using a mixture of direct emails and social media posts. The online survey ran for ten months and was the format through which most responses were collected, with very few done by telephonic interview during the same period.

Data analysis

Most questions related to motivations and challenges were open-ended to avoid forced responses. There are several different ways of classifying motivations, but for the purpose of this study, motivations were grouped into a mixture of categories identified by Bruyere and Rappe (2007), Measham and Barnett (2008), and West et al. (2015). Our categories relate broadly to different environmental values, socio-cultural values, personal well-being and educational values (see Supplementary material, Document 3). Responses were categorised post hoc and were assigned into different categories. Responses that were difficult to classify or that did not fall into any of the pre-determined categories were then assigned to the 'other' category (i.e. '*the managing authority [name withheld] and other state environmental entities, including provincial and local structures, are not doing their job to conserve and protect the Lourens River riverine area'*).

Ethics

The necessary ethical clearance to conduct the research was obtained from the REC: Humanities at Stellenbosch University – Project number: 9578. All ethical standards were adhered to. An informed consent was obtained from all participants and anonymity was assured.

Results

Volunteer groups

We identified 52 volunteer groups (Supplementary material, Document 4); of these, we received 26 completed responses from volunteer group co-ordinators and 56 responses from individual volunteer members. Most of the volunteer groups are concentrated within the city of Cape Town, with some groups in smaller towns scattered throughout in the rest of the province (Figure 1). The geographical spread of the groups has a full coverage of the Western Cape (with the furthest distance between Knysna and near Clanwilliam being over 500 km, but some groups were less than 10 km apart). The fynbos biome was more represented than other biomes and most groups were situated in and around larger towns and cities in the region.

The oldest volunteer groups were initiated in the early 1980s. Many groups (43%) were triggered by the expansion of IAPS and members realising the need to stop their spread (Figure 2). For example, one group co-ordinator highlighted their motivation for starting the group as '*The overwhelming growth of alien invasive in the Pledge Nature Reserve after the June 2017 fires*'. The second-most important motivation for the groups was the need to preserve nature and biodiversity (20%). For example, '*Elsies Peak was at that time a forest of invasive species. We wanted the fynbos back*'. Moral obligation (14%) also played an important role in forming some volunteer groups, for example, one group's motivation was to '*To put back something to Nature*', while another group leader said, '*We love and care for this place*'. This was followed by the need to preserve ecosystem services (11%). Other groups (6%) felt the need to get involved and protect important cultural and biodiversity sites. For example, *'Getting involved with the arboretum to formulate a draft management plan within the fynbos environment envisaged for the future. Focus on heritage, recreation and management*'. While some groups (6%) were initiated due to their desire to preserve environmental aesthetics.

The volunteer groups vary considerably in their size (maximum of 50 members and minimum of two members) with a mean of 12 members per group (Figure 1). Most groups met once a week, mainly during spring, summer and autumn. The average distance that members of the groups travelled to the sites where they worked was 8.6 km with the maximum being 75 km and the minimum being 1 km. Half of the groups spent about three hours in the field controlling IAPS and the other half spent five or more hours when they met.

Most of the groups (60%) also conduct other social and environmental activities such as environmental education, drawing up land use plans, restoring indigenous species and participating in river clean-ups, with an average of 20% of their time spent on IAS control. Groups prioritised work sites based on infestation densities, ease of plant identification and the terrain within their respective areas.

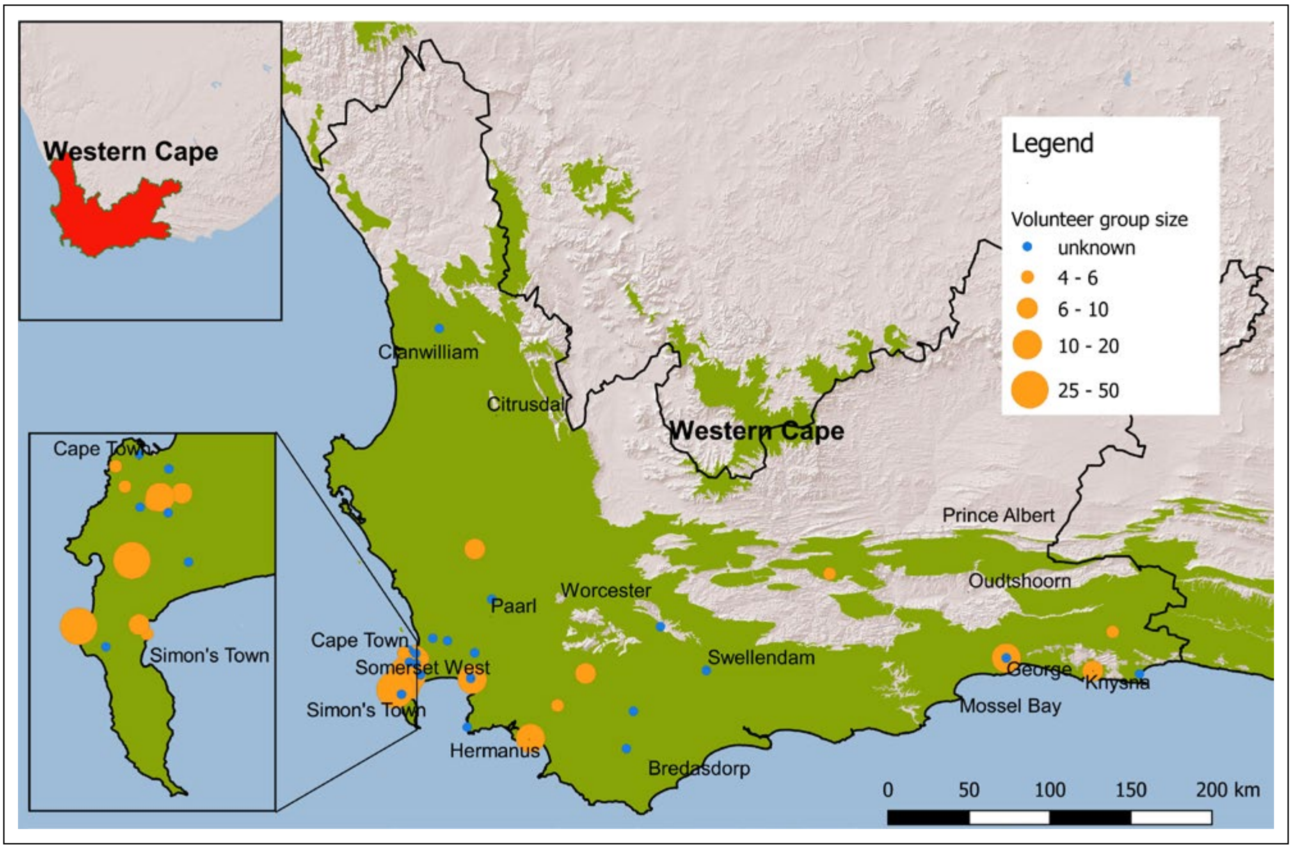

Figure 1. Identified volunteer groups (52) in Western Cape of South Africa. Groups that participated in the survey (26) are indicated by circles that also show group sizes (individual members per group). Groups that did not participate in the survey are indicated by blue circles. The green area on the map represents the fynbos biome.

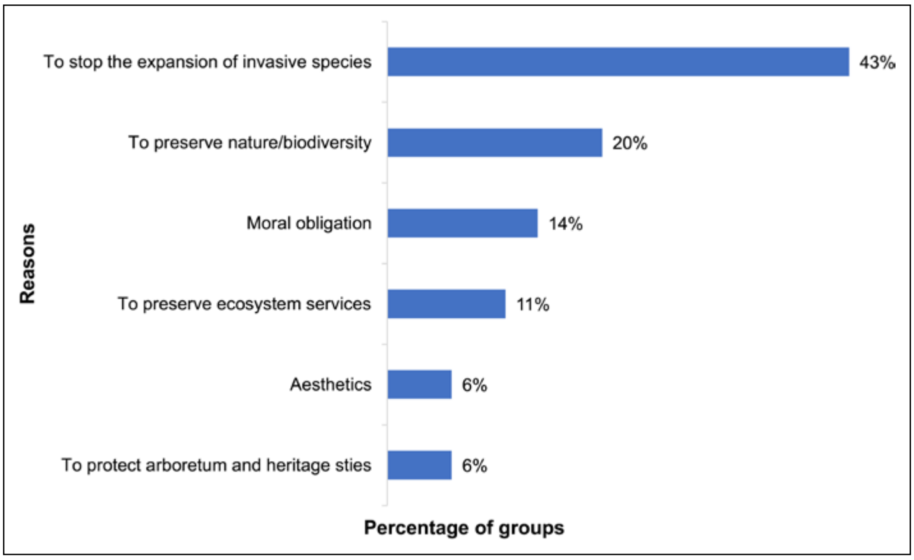

Figure 2. Motivations (n = 35) for forming volunteer groups that remove alien invasive plants in Western Cape, South Africa.

Almost all the groups concentrated their effort to control and reduce the spread and impact of widespread invasive woody trees such as: *Acacia saligna* (Port Jackson), *Acacia mearnsii* (black wattle), *Acacia longifolia* (golden wattle) and *Acacia cyclops* (*rooikrans*). Some groups also controlled emerging species with low population densities listed as Category 1a on South Africa's NEM:BA Act such as *Spartina alterniflora* (smooth cordgrass), *Lythrum salicaria* (purple loosestrife) and *Melaleuca* species (Supplementary material, Document 5). Almost all the groups used integrated control, combining manual removal and chemical control with herbicides at the site. However, only 16% of the groups indicated that they have qualified Pest Control Operators (PCO) in their groups. A PCO is someone who is trained and qualified to use herbicides to control IAPS.

Most groups (90%) indicated that they do not collect any data on their management implementation. The groups mostly relied on visual assessment to measure progress on their management interventions.

Estimated value of contributions by volunteer groups

The majority (68%) of the groups operated with no group budget, while the rest raised their own funds with a mean budget of ZAR 2 923 per month, equivalent to ZAR 26 307 per year (minimum ZAR 1 000 and maximum ZAR15 000 per month). Generally, there was no assistance from government entities, municipalities or NGOs, except for herbicide supply for some groups (46%). The money raised by groups was mainly for wages (for additional labour) and tools.

We used the data submitted by 26 volunteer groups that participated in the survey to estimate the equivalent total labour value contributed by these groups (26) to control IAPS in Western Cape drawing on WfW standards. The estimate of the equivalent cost if it were done by WfW teams was calculated as: Number of hours worked by each group × number of volunteers × number weeks worked by the groups each year = the labour hours per group per year × by the general worker wage rate used by the WfW program. The totals for all 26 groups were added together and resulted in = ZAR 5 106 241 (equivalent to USD 0.32 million). In considering all groups this number is probably closer to 10 million ZAR per annum.

The area of land cleared was calculated as: Total number of hours worked by the groups annually / number of hours to clear 1 ha at an assumed 5% density as per WfW standards: 42 165/8 = 5 271 ha cleared by 26 groups annually, again this is probably closer to 10 000 ha if all groups are considered.

Challenges mentioned by volunteer groups

The top ranked challenge for most groups was to attract new members (23%) (Figure 3). The challenge of extirpating the targeted IAPS (19%) was ranked highly by the groups. Some groups had volunteers that are old (60 or more years) (16%) who struggled with some aspects of controlling IAPS, which also links to difficult terrain (12%). To a lesser the extent sustainability of long-term funding (6%) was also viewed as a challenge. Historically bad control of IAPS, lack of support from government entities and landowners and fluctuating volunteer support were equally ranked as an issue (4%) by only two groups. The 'other' category (12%) included responses that relate to time constraints (volunteering time) as well as health and safety issues.

Most groups (72%) indicated that they need extra support from government entities with the removal of biomass, for manpower to remove big trees, training for

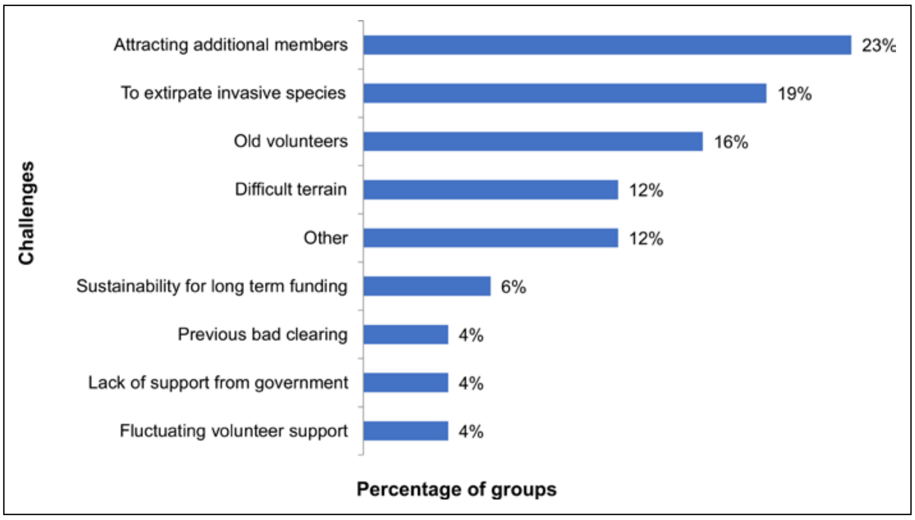

Figure 3. Challenges (n = 26) faced by volunteering by groups in the management of invasive alien plants in Western Cape, South Africa.

new group members, as well as for extra funding, tools, labour and herbicide.

Volunteer profiles

Respondents' ages ranged between 24 and 83, with a mean age of 56. Most respondents (32%) had been volunteering for five years or more, while (30%) had been volunteering for three to four years and 38% for one year and less. Most respondents were highly educated with the minimum education level being matric (completed high school) and some had a PhD. Eighty-two per cent of respondents had a degree (bachelors to PhD). Six percent of respondents were employed in the environmental sector.

Most volunteers (31%) initially got involved to stop the expansion of IAPS and to preserve nature (18%). The desire to protect nature (moral obligation, environmental values) played an important role for some volunteers to join the groups (25%). For example, one volunteer said, '*I wanted to contribute something to environmental protection*', whereas another said, '*I take much from nature and want to give back*'. Enjoyment and socialising (8%) also triggered some volunteers to take part in IAPS management. Aesthetics (3%), preserving ecosystem services (8%), exercise (4%) and education awareness (2%) were ranked as the last four initial motivations to get involved in IAPS management. The 'other' category included one response associated with looking for something useful to do because they were retired.

The initial motivations for volunteers to get involved in IAPS management were often different to the current motivations (Figure 4). Forty-six per cent of the volunteers felt their motivations had changed over time, in particular, their motivations changed from social reasons to contributing towards protecting nature and sharing their knowledge.

In answer to the question on current motivations to remain involved in the management of IAPS, many

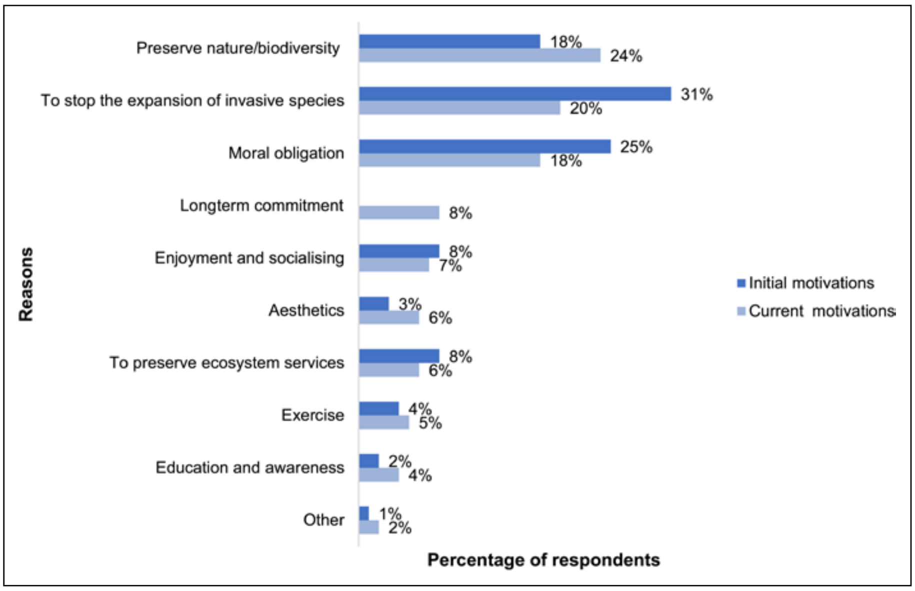

Figure 4. Reasons for initial engagement (n = 71) in volunteering and the current motivations (n = 86) for volunteers to be involved in the management of invasive alien plant species in Western Cape, South Africa.

respondents said they were volunteering to preserve nature and biodiversity (24%) and to stop the expansion of IAS (20%) (Figure 4). Some responses (18%) were linked to moral obligation. These include responses such as '*It would be a shame to lose our indigenous species*' and '*I care very much about nature*'. A few volunteers (8%), said they have been doing this for many years and it is very difficult to give up as they can see some progress (longterm commitment): '*Difficult to give it up after 16 years*'. Some volunteers (7%) were more interested in socialising, while others (6%) were doing it for aesthetic reasons and to preserve ecosystem services. There were also reasons relating to exercise (5%) and education and awareness (4%) (teaching and learning from others about IAS). Two responses that were difficult to classify into any of the mentioned categories (included in the 'other"' category) were mostly related to poor implementation by state institutions, for example, '*the managing authority [name withheld] and other state environmental entities, including provincial and local structures, are not doing their job to conserve and protect the Lourens River riverine area*'.

Over a third of volunteers (38%) identified a great sense of achievement and progress (i.e. reduction in IAPS numbers and recovery of indigenous vegetation) as the primary positive experience they get from volunteering. The second-most listed positive experience by volunteers was the sense of camaraderie and spending time with like-minded people (20%). For example, one volunteer said, '*We have a lovely friendly group of volunteers; we laugh as we work, it is healthy to be outdoors in the fresh air; we get exercise and all of this leaves us with a really good feeling*'. Getting some exercise and being outdoors (27%) was also identified as an important primary benefit by volunteers. Other volunteers (15%) were happy with knowing that they are making a difference by giving something back to nature, teaching others about IAS and at the same time learning from others. For example, one volunteer said '*The satisfaction of knowing I'm doing something to contribute to benefiting society, as well as nature. Not only for now, but for future generations*', while another said, '*I get a great sense of achievement, teaching the volunteers about invasive and indigenous species and also learning from others.*'

On average, respondents volunteered once a week to clear IAPS, depending on their availability and most volunteers (54%) said they would do more if they had the time. Most respondents (54%) indicated that volunteering does not cost them anything financially while others (46%) said they spend money on transport (between their home and the site) and membership fees.

Most volunteers (82%) said that they do detect and report IAS. Most sightings were reported to group leaders (54%) and on iNaturalist (11%). For example, in 2019, the Friends of Tokai discovered *Callitris rhomboidea* (Oyster Bay pine), which is currently not listed on NEM:BA and this represents the first record of this species in the region. Other volunteers (29%) reported their sightings to different relevant local environmental authorities.

Challenges faced by volunteers

Most respondents (39%) said that they do not face any challenges, while some (23%) mentioned challenges related to time constraints (they feel they do not volunteer enough due to other commitments) (Figure 5). Lack of coordination and support from government management institutions and landowners was another important barrier identified by volunteers (13%). For example, one volunteer said, '*Better co-operation between official bodies involved with alien vegetation management and volunteer groups is needed. Though we engage with SANParks and let them know what we are planning, we've had an instance where we spent a day clearing with volunteers, only to find that the site was already earmarked by SANParks and cleared by them the week after. We could have spent our time a lot*

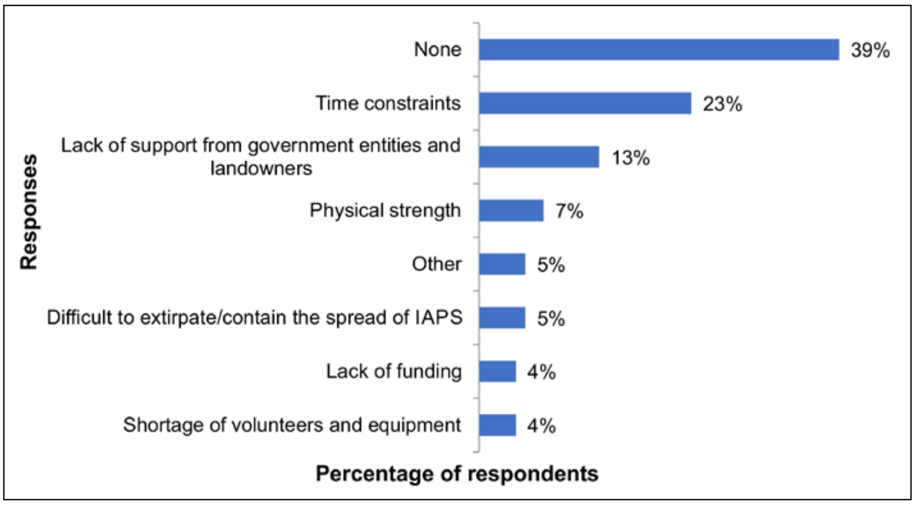

Figure 5. Challenges (n = 56) faced by individual volunteers in the management of invasive alien plant management in Western Cape, South Africa.

better!' Another volunteer said, *'There are just too many invasives and no help from government. From emails it is apparent to me that* [name withheld] *is battling to get CapeNature to send us a team of helpers'*. Physical strength (7%) was ranked as a challenge by a few volunteers. Some volunteers are old and unable to get to some areas, especially those with difficult terrain. Some 'other' (5%) responses were also mentioned, for example '*I prefer to operate as an individual – more flexibility for targeted work*'. The challenge of extirpating or even containing the spread of IAPS was ranked the bottom three motivations by volunteers (5%). For example, one volunteer said, *'Sometimes it feels that our small group is never going to be able to succeed, there are just too many invasives and no help from government'*. Lack of funding and shortage or fluctuating support of volunteers was identified as the last two challenges identified by volunteers (4%).

Discussion

Identifying and promoting volunteer groups

In this study, we established a list of 52 volunteer groups controlling IAPS in South Africa's Western Cape province (see Supplementary material, Document 4). Half of these groups did not participate in the survey and it is therefore unknown if they currently exist or not, or if our survey simply did not reach these groups. The geographical spread of the groups has a full coverage of the Western Cape, with volunteering groups in fynbos biome being more represented than other biomes (Figure 1). Interestingly, this biome corresponds closely with invasion hotspots in South Africa, and is an area with a long history of research and management of IAS (Bennett & van Sittert 2019; van Wilgen et al. 2020). Interest in the management of biological invasions and preserving unique and famous indigenous fynbos species is also stronger in this region than elsewhere in the country (Bennett & van Sittert 2019).

Volunteer groups also seems to be more closely associated with larger towns and cities in the region. Half of the groups that participate in the survey are estimated to clear approximately 5 300 ha of land annually although if all groups are considered this is more likely to be 10 000 ha. This shows a huge commitment from these volunteer groups in stopping the expansion of IAPS. However, to do this effectively, there needs to be better voluntary engagement between groups, conservation managers and other relevant actors (see Crall et al. 2010).

Volunteer initiatives could be co-ordinated and focus on areas that are lightly invaded while the state-run management programmes could focus in highly invaded areas. Formal state-run management programmes can also work on projects or species that require chemical control and extensive labour force to remove IAPS, removing this burden from volunteer groups. Assessing the distribution and contributions of volunteer groups and to IAPS management should also be conducted elsewhere in South Africa, and in other countries. Volunteer groups could also engage more with scientists to produce useful research moving forward.

The benefits of volunteer groups and volunteering

Volunteers contribute directly to the control of IAPS thus providing valuable services for the state, landowners and broader society (Pagès et al. 2019). This is evident from our results where we estimated the groups to clear approximately 5 300 ha of land with estimated labour value of ZAR 5.1 million annually when aligned with formal WfW rates and control programmes. Most volunteers were also engaged in detecting and reporting IAPS, which is another valuable contribution for management of biological invasions.

Over and above the actual detection and clearing of IAPS, volunteers can possibly play an important role in promoting awareness and social learning about IAPS among themselves and to the public (Shackleton et al. 2019). This could result in a change in the knowledge and perceptions of the public and volunteers themselves with respect to IAPS (Shackleton et al. 2019), which is important for future management.

At the same time volunteers themselves gain fulfilment and build their social capital by meeting new people and making friends, giving something back to nature by helping to stop the expansion of IAPS (Figure 4) (Measham & Barnett 2008; Geoghegan et al. 2016). Many aspects of volunteering, as indicated in this and other studies globally, can contribute to psychological and physical well-being as well (Koss & Kingsley 2010; Molsher & Townstead 2016).

Volunteers' motivations for controlling IAS

Volunteers have a variety of different motivations and it is important for managers implementing IAPS control initiatives to have a sound understanding of volunteers' knowledge, needs and motivations (Measham & Barnett 2008; Geoghegan et al. 2016; Ganzevoort et al. 2017). Knowing and addressing volunteers' needs can help with keeping volunteers motivated as well as aid with promoting initiatives and attracting new members.

Most volunteers ranked environment-related motivations higher than social-related motivations as both their initial and current motivations. This is in accordance with previous studies where the preservation of the natural environment is noted to be the central motivation for volunteers (e.g. Hobbs & White 2012; Ganzevoort et al. 2017; Pagès et al. 2019). It also shows the importance of volunteers and their connection with nature (Ganzevoort et al. 2017).

With time, respondents' motivations changed from social reasons to making a contribution towards protecting the natural environment and learning and sharing their knowledge (Figure 4). This suggests that volunteering makes people more environmentally aware and proactive (Ganzevoort et al. 2017).

Respondents were encouraged by seeing reduction of IAPS and recovery of indigenous vegetation, as a result this was identified as a primary positive experience they get from volunteering. Our study therefore supports the notion that the recovery of indigenous vegetation is very encouraging, and a key reason for the long-term commitment of volunteers (Pagès et al. 2019), especially for those that have been involved in volunteering work for long periods.

Challenges to volunteering and the way forward

The biggest challenge faced by groups was attracting new volunteers to join the groups (Figure 3). This may be linked to the lack of advertising by groups as well as difficulty making contact, which was an issue was reinforced during data collection. The moderate number of responses received (26 out of 52 groups) in this study was because many groups were untraceable due to invalid contact details and/or non-existent group websites and pages on the internet or the fact that some of these groups might no longer exist. This could also mean that the number of extant volunteer groups is lower than 52.

According to Ganzevoort et al. (2017), social media and websites of environmental groups are the best platforms for the promotion of nature-based citizen science projects. More volunteer groups should take advantage of the available online and social media platforms to publicise their groups and regularly share the work that they are doing. Volunteers and groups can further use social media to attract more volunteers, aid with co-ordination and increase awareness about IAS (Blood 2016). However, this may potentially require on-going technical and administrative support (Pagès et al. 2019).

Another important challenge to volunteering identified by group leaders and individual volunteer respondents related broadly to co-ordination between and long-term support from government entities, NGOs and landowners. It is recommended that there is improved communication and coordination between all stakeholders involved in IAPS management and volunteers to improve and support the work done by volunteer groups (Ellwoodd et al. 2017).

According to Dechoum et al. (2019), volunteers can be helpful across multiple scales, but their effort must be combined with other stakeholders' efforts to ensure long-term success and improved outcomes, which would also address another challenge of making little progress (Figure 3 and 5). The groups indicated that they require support from government entities, landowners and Non-Government Organisations (NGOs) mainly for removal of biomass, manpower to remove bigger plants, tools, training for new members and provision of herbicide. For this to happen, we recommend a better engagement between groups and other actors and relevant platforms for this need development.

The coordination of multiple volunteer groups using umbrella partnerships and other actors seems particularly successful, similarly appointing a co-ordinator to support groups could also help (Pagès et al. 2019). A co-ordinator should create a database of all groups across the country, respond to their needs and aid with promotion that helps with recruitment of volunteers. Linking volunteer groups and schools could lead to beneficial education and learning opportunities for children and potentially increase interest in volunteering in future generations. The co-ordinator could also assist with planning control activities and the prioritisation of species and areas. For example, the Custodians of Rare and Endangered Species (CREW), where citizens assist with the monitoring of threatened plant species (Araya et al. 2009; Young 2009), and SANParks honorary rangers, are both useful models for developing co-ordinated volunteer networks in South Africa.

Importantly, the co-ordinator should reduce the bureaucracy while supporting groups, integrating volunteers' work to national and local programmes dealing with biological invasions. Their role could link the groups together and bridge the work done by volunteers with science, policy and management (Novoa et al. 2018; Abrahams et al. 2019). It could also help to promote these groups and the work they do in the wider community, increasing awareness of IAS. This could also help to monitor and collect data to account for the valuable contributions of volunteers to controlling IAS at regional and national levels (Delaney et al. 2008; Dechoum et al. 2019).

Most volunteer groups work on containing established invasive Australian species (the most widespread invasive taxa in South Africa) with very few groups working on emerging IAS or populations with low densities (for example, *Lythrum salicaria, Melaleuca* sp. and *Spartina alterniflora*). In the long term, early detection and extirpation of IAS is the most cost-effective management option (Rejmánek & Pitcairn 2002; Fitzpatrick et al. 2009). Volunteers offer an avenue for detecting and containing the spread of IAPS while the populations are still small and localised (e.g. Delaney et al. 2008; Dechoum et al. 2019). It would be beneficial if volunteers can be trained on relevant species identification and effective ways of controlling IAPS to improve their early detection and extirpation efforts (Gallo & Waitt 2011). Volunteers should also be trained about the correct use of herbicides, including health and safety measures, to avoid possible health effects (Macfarlane et al. 2013). The use of mobile apps such as iNaturalist should also be utilised for species identification and to connect citizens and experts in the field (Silvertown et al. 2015).

Conclusion

In conclusion, it is evident that volunteers play an important role in IAPS management and are likely to continue doing so into the future. Better co-ordination and engagement between volunteers and mandated authorities on science, policy and management are required to improve the groups and keep volunteers motivated about managing IAPS.

Acknowledgements

The South African Department of Forestry, Fisheries and the Environment (DFFE) are thanked for funding, noting that this publication does not necessarily represent the views or opinions of the DEFFE or its employees. We also thank and acknowledge the South African National Biodiversity Institute's Biological Invasions Directorate, the volunteers who participated in our survey and our reviewers. In particular, we thank John Wilson, Mlungele Nsikani and Thulisile Jaca for helpful comments on the manuscript. We would like to thank the DSI-NRF Centre of Excellence for Invasion Biology.

Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

NJ, RTS and JM conceived the study. NJ collected and analysed the data and drafted the article. All authors gave final approval of the version published in Bothalia.

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Supplementary Material

Only available online: doi: http://dx.doi.org/10.38201/btha.abc.v51.i2.s3

SANBI
Biodiversity for Life
South African National Biodiversity Institute

BOTHALIA – African Biodiversity & Conservation
ISSN: (Online) 2311-9284, (Print) 0006-8241

The structure and composition of the woody plant communities of Majete Wildlife Reserve, Malawi

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Dates

Submitted: 6 October 2020
Accepted: 21 May 2021
Published: 10 September 2021

How to cite this article:

Nieman, W.A., van Wilgen, B.W. & Leslie, A.J., 2021, 'The structure and composition of the woody plant communities of Majete Wildlife Reserve, Malawi', *Bothalia* 51(2), a7. http://dx.doi.org/10.38201/btha.abc.v51.i2.7

Background: The role of protected areas as sanctuaries for indigenous vegetation in Malawi, particularly miombo woodlands, will become increasingly important in the face of global change and rising human populations. Accurate knowledge of the extent and composition of woody components of plant communities will therefore play a vital part in informing conservation and management initiatives.

Objectives: The aims of this study were to (1) classify, describe and map the woody plant communities of the Majete Wildlife Reserve (MWR) using a combination of remote sensing and on-the-ground surveys, and (2) to compile an inventory of the tree and shrub species present in MWR.

Methods: A combination of remote sensing and on-the-ground surveys was used to classify, describe and map the woody plant communities of MWR. Additionally, an inventory of the tree and shrub species in each delineated woody plant community was made.

Results: Five distinct woody plant communities, two of which were subdivided into three sub-communities each, were recognised in MWR, and a total of 118 woody plant species within 31 families were identified. A description of the location, structure and species composition of each community is provided. Miombo was the most widespread community (covering 35.9% of the area), while the lower-altitude shrublands and woodlands were the richest floristically.

Conclusion: This information is intended to provide a basis for improved management planning and policy development, including fire management, the placement of infrastructure, and the re-introduction of extirpated mammal species, as well as providing a baseline against which to monitor change. Additionally, this study provided an example of how the combination of remote sensing and ground surveys can provide a rapid and relatively inexpensive method for classifying the woody components of communities at a relatively fine scale over large areas, which may become particularly relevant for developing countries and regions that undergo rapid and constant change.

Keywords: fire management; miombo; remote sensing; savanna; woodland.

Introduction

Savanna ecosystems cover approximately 40% of Africa (Scholes & Walker 1993), and the most common variant in southern and eastern Africa, namely miombo woodland, covers approximately 2.7 million km^2 in seven countries (Frost 1996; Kutsch et al. 2011). Malawi falls entirely within the Miombo Ecoregion (~3.6 million km^2; Byers 2001), and the ecoregion was identified as one of five global wilderness areas that require conservation prioritisation (Mittermeier et al. 2003). The Miombo Ecoregion is an amalgamation of several smaller ecoregions, with the southern section of Malawi containing the Eastern Miombo Woodlands Ecoregion (EMWE), extending from southeastern Tanzania and northern Mozambique into parts of southeastern Malawi, and the Zambezian and Mopane Woodland Ecoregion (ZMWE) in southwestern Malawi (Malaisse & Parent 1985; Byers 2001). The EMWE is dominated by miombo *sensu stricto*, characterised by trees in the genus *Brachystegia*, occurring either alone or together with *Julbernardia* and *Isoberlinia* species (Geldenhuys & Golding 2008). The EMWE is further subdivided into drier miombo and wetter miombo by the 1 000 mm rainfall isohyet (White 1983; Byers 2001). The ZMWE consists mainly of broadleaf, deciduous savannas and woodlands interspersed with edaphic grasslands (White 1983; Chirwa, Syampungani & Geldenhuys 2014). Collectively, these two ecoregions were formerly classified by Huntley (1982) as *Caesalpinoid* (now *Detarioideae*) woodland, or broadleaved dystrophic savanna woodland, while White (1983) classified the area as the Zambezian Phytoregion, with Zambezian woodland being the most widespread woody plant community in the region.

True miombo woodland constitutes 92.4% of the natural vegetation of Malawi (Government of Malawi 2010). The vast majority of extant natural vegetation is, however, confined to small, isolated areas that are subjected to rapid deforestation rates of up to 0.9% annually (FAO 2015). Additionally, while projections of future drier climates in sub-Saharan Africa suggests the range of dry miombo may expand (Jinga & Palagi 2020), a sharp increase in the human population (Eastwood & Lipton 2011) will place undue pressure on remaining miombo woodlands, which already support the livelihoods of more than 100 million people either directly or indirectly (Syampungani et al. 2009). The role of protected areas (PAs) as sanctuaries for miombo vegetation, as well as other woodland vegetation types, will thus become even more significant in the future, and knowledge of their composition and structure is needed as a basis for their sustainable management. Majete Wildlife Reserve (MWR) in Malawi was proclaimed in 1955 and was taken over in 2003 by African Parks with the aim of restoring, developing and preserving the integrity of all facets of the area's biodiversity. The reserve is situated in southwestern Malawi, at the intersection of the EMWE and the ZMWE (Byers 2001; Munishi, Temu & Soka 2011), making this a unique study site to compare contrasting vegetative communities. Different plant communities may also require specific management approaches, adding to the need for an accurate vegetation description at a scale appropriate to management. Though useful, the coarse-scale classification of ecoregions fails to describe plant communities and their distributions at the scale of PAs. Classifying vegetative communities at scales finer that those of ecoregions can be extremely resource intensive and is therefore likely not realistic in most African countries. More cost-effective solutions are thus needed, and remote sensing may offer such a solution to delineate woody plant communities in Africa (Peel, Kruger & MacFadyen 2007; van Rooyen et al. 2008). The delineation of non-woody vegetative components, which may be crucial to certain aspects of environmental management, is however likely not achievable with remote sensing approaches.

Some information on the vegetation of MWR or nearby regions can be found in unpublished theses (e.g. Olivier 2018; Sherry 1989), technical reports (e.g. Dowsett-Lemaire & Dowsett 2002; Kabwazi et al. 2000; Nieman 2020), or peer-reviewed articles (e.g. Hall-Martin & Drummond 1980; Nieman, van Wilgen & Leslie 2021), but an updated and detailed description of the woody vegetation in MWR is lacking. The miombo woodlands found in MWR fall within the distribution of dry miombo (White 1983; Frost 1996), which is floristically poor compared to the much more diverse wet miombo, and is characterised by the presence of *Brachystegia boehmii*, *B. spiciformis*, and *Julbernadia globiflora* (Frost 1996; Kapinga et al. 2018; Moura et al. 2018). Typically, miombo woodlands are bordered by *Baikiaea* woodlands, *Acacia* (now *Vachellia* or *Senegalia*)–*Combretum* woodlands, mopane woodlands, or *Burkea–Terminalia* woodlands (Byers 2001; Chirwa, Syampungani & Geldenhuys 2014; Maquia et al. 2019).

The aims of this study were to (1) classify, describe and map the woody plant communities of MWR using a combination of remote sensing and on-the-ground surveys, and (2) to compile an inventory of the tree and shrub species present in MWR. This information is intended to provide a basis for improved management planning and policy development, including fire management, the placement of infrastructure, and the re-introduction of extirpated mammal species, as well as providing a baseline against which to monitor change (Kremen 1992; Peel et al. 2007).

Materials and methods

Study site

Majete Wildlife Reserve (MWR) is situated in the Lower Shire Valley, part of the Great Rift Valley in the south of Malawi. The reserve covers roughly 700 km^2 and is situated in a tropical climate zone. The underlying climate can be categorised into three distinct seasons (Hall-Martin 1972), namely the wet season (December to March), the cool dry season (April to August), and the hot dry season (September to November). Mean monthly temperatures range from 20.5°C (June and July) to 27.8°C (November), with maximum temperatures often reaching ~45°C. A distinct N–S line divides MWR into the western upland area (altitude > 350 mamsl) and the eastern lowland area (altitude < 350 mamsl). The topography of the eastern lowlands is relatively flat with few rocky outcrops, with mean annual precipitation (MAP) ranging between 680–800 mm, while the western uplands consists of many rocky outcrops, and receiving slightly higher MAP (700–1 000 mm) (Hall-Martin 1972). A detailed description of the geology and soils of MWR is lacking, but most soils are shallow, stony lithosols of poor nutrient status, with fertile alluvial soil only occurring along a few river beds (Bell 1984; Sherry 1989). Two perennial rivers occur in the northeastern section of MWR, which, along with ten artificial water points and seven natural springs, provide the only source of water for animals in the dry season. The vegetation was previously described by Sherry (1989) as tropical dry deciduous woodland, miombo savanna woodland, riverine associations, and riparian thicket. Several browsing herbivore species that affect the structure of woody vegetation are present in MWR, notably elephant (*Loxodonta africana*), black rhinoceros (*Diceros bicornis*), giraffe (*Giraffa camelopardalis*), kudu (*Tragelaphus strepsiceros*) and impala (*Aepyceros melampus*).

Data collection and analyses

Delineation of land cover types with remote sensing

The Sentinel-2 cloudless land cover product was obtained from the Copernicus global land service (Buchhorn et al. 2019), and used to map land cover at 100 m spatial resolution for MWR in QGIS v3.10. The product uses supervised classification of reflectance data and provides 23 distinct land cover classes globally. Five of these (open woodlands, closed woodlands, shrublands, herbaceous vegetation, and permanent inland water bodies) were present in MWR. The classification product was in sinusoidal UTM projected at Datum WGS84 and is updated at annual time steps. The latest available iteration (2018) was used. Additionally, the ASTER digital elevation model (DEM) version 3 (ASTGTM v003) was obtained from the U.S. Geological Survey and used to create an elevation profile for MWR at a spatial resolution of 1 arc second (~ 30 m). The inclusion of a DEM would likely allow for better separation of plant communities (Sedano, Gong & Ferrão 2005). The DEM was simplified in QGIS v3.10 to display three equal interval elevation categories in MWR, and used to divide land cover classes into separate elevation categories where relevant. The lowest point in MWR is where the Mwembezi River exits the reserve (90 mamsl) in the northeast, and the highest point is at Kapirimbewe in the northwest (880 mamsl). The final land cover classes were reprojected to 5 ha grid cells for subsequent analyses.

Delineation of plant communities

Following the delineation of land cover classes with remote sensing, 195 field sites (circular plots of 50 m radius, covering an area that was considered adequate to encapsulate the composition of the woody plant community) were selected across all classes for the final classification of woody plant communities based on the dominant tree species. Each site was chosen to be homogenous and representative of the respective land cover classes, and the sites were surveyed during May–June 2020. The number of sites surveyed in each land cover class was proportional to its extent (area) and ranged from two to 66 per land cover class. At each of the 195 field sites, a count of the number of individual trees or shrubs belonging to eight woody genera was made. Based on their prevalence in MWR, and woody plant community classifications in other savannas (White 1983; Byers 2001; Peel et al. 2007; Gandiwa & Kativu 2009; Munishi et al. 2011; Clegg & Connor 2012; Maquia et al. 2019), the chosen genera incorporated the most important characteristic species for classifying woody plant communities, and were ultimately used as a basis for describing the final plant communities present in MWR. The chosen genera were: *Senegalia* (including *S. galpinii, S. nigrescens* and *S. burkei*), *Vachellia* (including *V. karroo, V. nilotica* and *V. torrei*), *Brachystegia* (including *B. boehmii, B. allenii, B. longifolia, B. spiciformis* and *B.utilis*), *Julbernardia* (including *J. globiflora*), *Sclerocarya* (including *S. birrea*), *Terminalia* (including *T. mollis, T. sericea* and *T. stenostachya*), *Combretum* (including *C. adenogonium, C. apiculatum, C. hereroense, C. imberbe, C. molle, C. mossambicense* and *C. zeyheri*), and *Colophospermum* (including *C. mopane*).

Accuracy assessment

Woody vegetation structural data were collected at each of the 195 field sites to assess whether the remotely sensed land cover classes were matched by vegetation physiognomy on the ground. At each field site, the physiognomy and structure of the vegetation was classed according to the broad classification of Edwards (1983) by recording the dominant primary growth form (trees or shrubs), projected crown cover classes (closed, open, sparse or scattered), and the mean number of crown diameters by which plant crowns were separated. The accuracy assessment was done by comparing the classified pixel to the same site in the field through a confusion matrix that compared the Edwards classifications to the Sentinel land cover classes. Overall map accuracy was determined by summing the number of pixels classified correctly and dividing by the number of pixels (Mohd Hasmadi, Pakhriazad & Shahrin 2009).

Plant community richness and diversity

At 94 of the 195 field sites, a list of all tree and shrub species present was compiled by noting the species that were visible to an observer walking along a line transect of 50 m. The location of the transects was chosen to be relatively evenly distributed across MWR, while still encapsulating obvious landscape variations (such as topography and riverbeds) and to ensure that all woody vegetative variations were sampled. Prior to conducting the inventories, the species–area method (Smith, Meredith & Johns 1999) was used to determine the optimal length of transects by noting the increase in the number of species observed as the transect length increased. Transect length was deemed optimal when additional sampling did not identify a significant number of novel species. Species were identified on site where possible, but a sample was taken for later identification where uncertainty existed.

Sampling performance of species inventories made along the 94 transects was evaluated through the construction of species accumulation curves for each woody plant community and for MWR as a whole (Colwell & Coddington 1994). Species accumulation curves also provided a reliable estimate of species richness due to the variation in sample sizes, and provided an estimate of the predicted number of species that could be found if sampling continued indefinitely based on the rate of species discovery in this study (Colwell 2005). For this purpose, the performance of six non-parametric species richness estimators appropriate for incidence-based data were used, namely the Chao 2 estimator, the bias-corrected form of the Chao 2 estimator (Chao 2-bc), a newer version of the Chao 2 estimator (iChao2), the incidence-based coverage estimator (ICE), and two Jackknife species richness estimators (Jack 1 and Jack 2) (Burnham & Overton 1978; Chao 2005; Chiu et al. 2014). The sample order was randomised 100 times for each of the calculations to provide mean statistics at each sample order, thereby generating smooth accumulation curves (Colwell & Coddington 1994; Nieman, Leslie & Wilkinson 2019). Due to its relatively small extent in MWR, grasslands (Gr) were grouped with shrublands and woodlands (SW – see plant community descriptions) based on the clear similarity in geographical location and woody species similarity between these plant communities. In addition, the woody species diversity and evenness or equitability was quantified with the use of standard ecological diversity indices for MWR as a whole, as well as for each of the plant communities. Specifically, woody species diversity was expressed using the Shannon-Wiener diversity index (H′), the Simpson diversity index (1-D), and inverse Simpson diversity index (1/D). In all instances, higher values equate to a higher level of diversity in the sample, and thus higher entropy and less dominance by one or a few species. Evenness was expressed with the Shannon evenness index (J′), wherein values approaching zero represent low evenness in the sample, and thus dominance by one or a few species. The coefficient of variation (CV) was used to describe the degree of heterogeneity among species incidence, where zero represents a completely homogenous sample. Finally, the Jaccard coefficient was used to determine similarity between the species' assemblages compiled for each plant community, and a dendrogram was constructed using the k-means clustering algorithm with Euclidian distances. All species richness estimator and index values were calculated in R v4.0.1.

Results

Woody plant communities recognised

The final classification of the land cover of MWR was done at 90.77% accuracy (i.e. 90.77% of pixels from the Sentinel map matched the corresponding woody plant community structure on the ground), and included five woody plant communities, two of which were further subdivided into three sub-communities each (Table 1). The extent and distribution of these plant communities and sub-communities were subsequently mapped at the scale of the individual 5 ha pixels (Figure 3). At the level of the individual plant communities and sub-communities, a clear distinction in terms of woody species assemblages was confirmed by the Jaccard similarity index (Figure 1). The floristic composition of riparian woodland was the least similar to all other woody plant communities, while grassland was closely related to the shrubland and woodland sub-types. The floristic composition of all miombo sub-types were also closely related.

Plant community descriptions

Riparian woodland

Riparian woodland (Rw) (Figure 2A) occurred on alluvium fringing the only two perennial rivers in MWR, namely the Mkulumadzi and Shire rivers. The rivers respectively form 9 km and 7 km of the outer reserve boundary in the northeastern section of the reserve. As expected (Smith, Meredith & Johns 1999), this plant community was characterised by a distinct species composition and density compared to the rest of MWR, but unlike the other plant communities, was not characterised by one or a few dominant genera or species. The species recorded most frequently (≥ 40%) were *Philenoptera violacea, Allophylus africanus, Senegalia nigrescens, Terminalia sericea, Sclerocarya birrea, Cleistochlamys kirkii, Kigelia africana, Combretum imberbe, Pterocarpus rotundifolius, Cremaspora triflora, Gymnosporia senegalensis, Diospyros squarrosa, Croton megalobotrys* and *Grewia flavescens* (Table 2). This woody plant community was made up by 52 pixels, thus covering 245.1 ha, or 0.34% of MWR. Tree cover

Table 1. The extent of woody plant communities and sub-communities in Majete Wildlife Reserve, and an assessment of the extent of agreement between remotely sensed land cover types and assessments of vegetation structure in ground surveys

Plant community	Number of 5 ha pixels	Area occupied (ha)	Number of sampling sites	Extent of agreement between satellite and ground classification (%)
Riparian woodland (Rw)	52	245.1	15	100.00
Grassland (Gr)	47	221.6	2	100.00
Shrublands and woodlands (SW)	3912	19 855.4	59	86.44
Shrubland (SW1)	250	2 592.7	8	87.50
Open woodland (SW2)	3 226	15 207.4	42	90.48
Closed woodland (SW3)	436	2 055.3	9	66.67
Transitional woodland (Tw)	5 392	25 417.9	53	100.00
Miombo (M)	5 446	25 672.4	66	84.85
Open miombo (M1)	1 073	5 058.1	11	100.00
Low-altitude, closed miombo (M2)	2 385	11 242.9	24	83.33
High-altitude, closed miombo (M3)	1 988	9 371.4	31	80.65
Total	**14 849**	**71 412.4**	**195**	**90.77**

was typically between 10 and 75%, and tree height often exceeded 15 m. The woody plant community occurred at low elevation (< 250 mamsl), and contained very little grass cover, while bare ground patches and forbs were prominent.

Grassland

Grassland (Gr) (Figure 2B) was found in a few scattered locations in the low-altitude (< 250 mamsl) belt of the MWR, and its presence was thus not significant, as it only covered 221.6 ha, or 0.31% of MWR. The factors determining the occurrence and distribution of grasslands are not known, but likely pertain to edaphic factors. Additionally, the location of most grassland sites on the boundary of MWR suggests that these areas may have been illegally logged and cultivated by local communities prior to the erection of the reserve fence in 2004. Grasslands in MWR may thus represent a state of secondary vegetation succession, and it is possible that they may eventually revert back to shrubland and woodland states if left undisturbed. The dominant tree and shrub species were similar to those reported in shrublands and woodlands (SW), but woody species were mostly absent or their growth was stunted. Both tree and shrub cover were less than 0.1%, while grass height mainly exceeded 1 m, and grass cover was between 10 and 100%. Additionally, grassland sites were

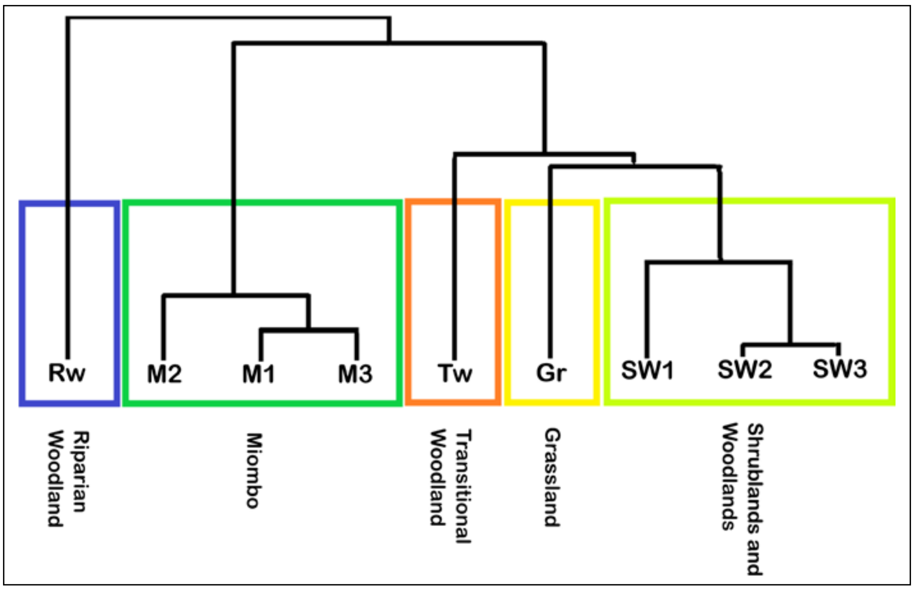

Figure 1. Dendrogram of species composition for different woody plant communities based on the Jaccard similarity index.

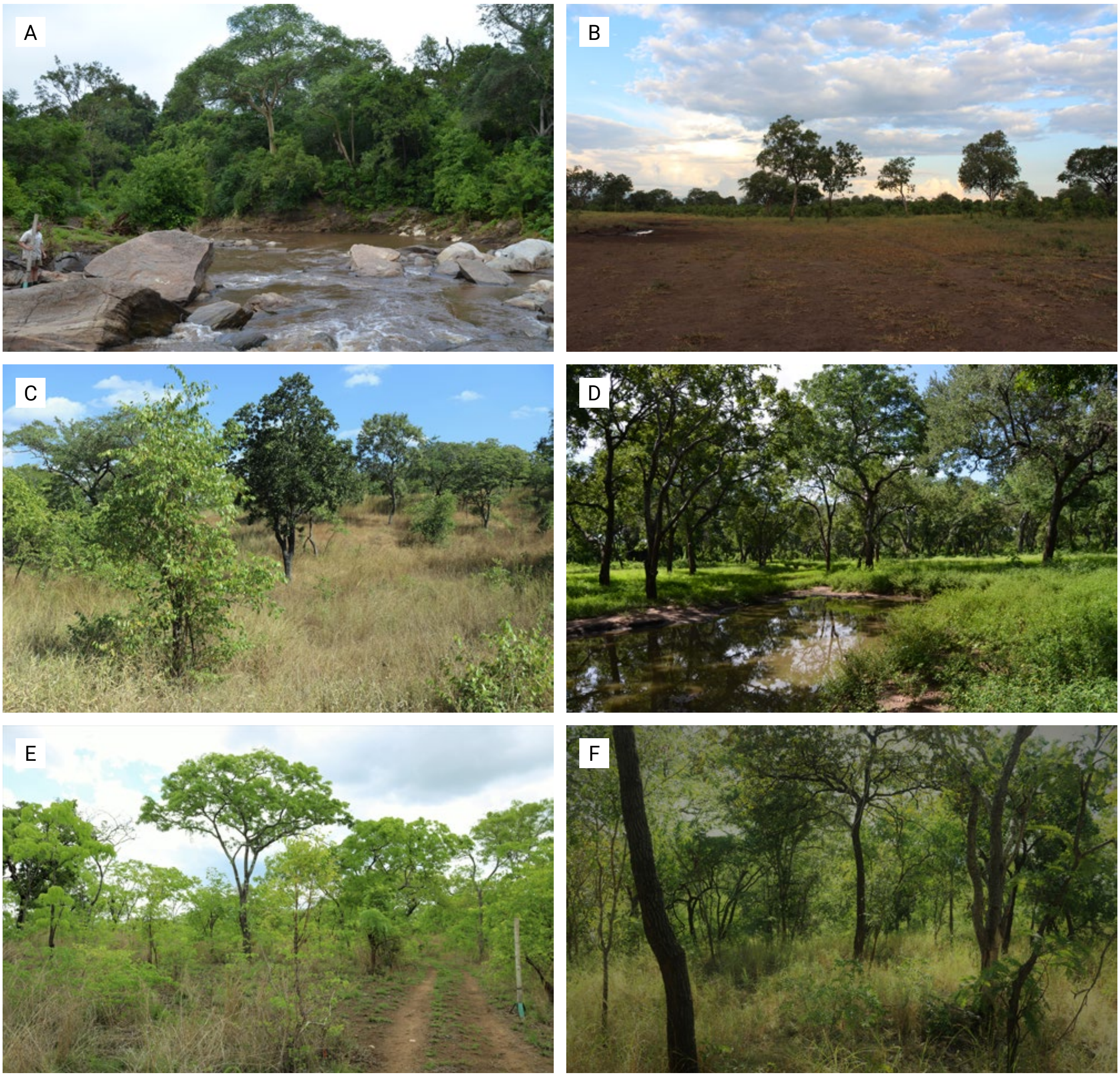

Figure 2. Typical examples of the plant communities in Majete Wildlife Reserve; A, riparian woodland (Rw); B, grassland (Gr); C–D, shrublands and woodlands (SW); E, transitional woodland (Tw); and F, miombo (M). Photo credits: W.A. Nieman.

often accompanied by large expanses of bare ground, and are thus presumably exposed to higher erosion risk due to decreased soil stabilisation.

Shrublands and woodlands

Shrublands and woodlands (SW) (Figure 2C–D) covered the largest portion of the low-altitudinal (< 250 mamsl) band in the east of MWR, and extended into some of the medium-altitude (250–450 mamsl) areas. This woody plant community was floristically rich and characterised by species in the genera *Combretum, Terminalia, Vachellia, Senegalia* and *Sclerocarya*. The most frequently recorded species (≥ 40%) were *Combretum adenogonium, Senegalia nigrescens, Combretum imberbe, Diospyros mespiliformis, Terminalia sericea* and *Sclerocarya birrea* (Table 2). Miombo dominants such as *Brachystegia* and *Julbernardia* are extremely gregarious, and rarely occur in other woody plant communities (Geldenhuys & Golding 2008). The shrublands and woodlands in MWR were thus distinguished by the absence of typical miombo species rather than by the presence of other species (White 1983). The woody plant community was further subdivided into three sub-communities on the basis of tree and shrub cover and height that were intermixed with each other, namely shrubland (SW1), open woodland (SW2) and closed woodland (SW3).

Open woodland (SW2) was the most widespread and prevalent of the three sub-communities, covering 15 207.4 ha, or 21.30%, of MWR. The sub-community

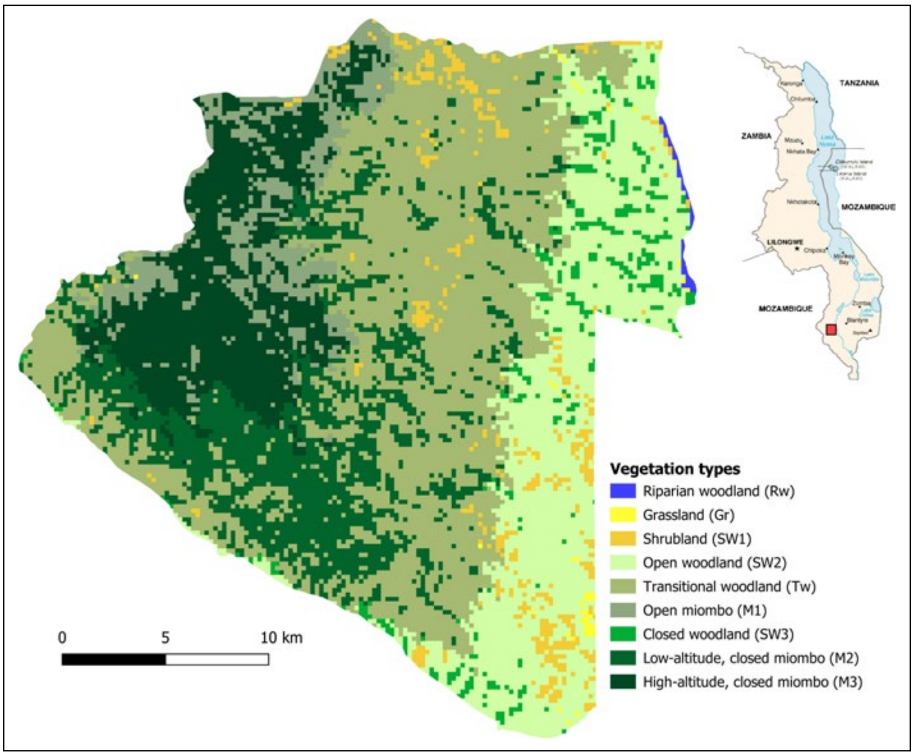

Figure 3. Distribution of woody plant communities in Majete Wildlife Reserve (MWR). The inset shows the location of the MWR in Malawi.

was differentiated by its open canopy, with tree cover ranging between 1 and 10%. Closed woodland (SW3) was much less widespread, and confined to small, isolated patches covering 2 055.3 ha, or 2.88% of MWR. The sub-community was differentiated by its closed canopy, with tree cover ranging between 10 and 75%. In both SW2 and SW3, tree height was generally greater than 10 m, and shrubs higher than 1 m in height covered less than 10% of the total area. Shrubland (SW1) was widely dispersed, but covered only 2 592.7 ha, or 3.63% of MWR. It was dominated by shrubs of 2–5 m in height, and stunted trees. Total tree cover was below 1%, while total shrub cover ranged between 10 and 100%. It is unclear why the woody component in these areas is stunted, although either short fire return intervals, high fire intensity or high herbivory pressure (particularly high elephant densities), or a combination of these, may have played a role (Trollope, 1998; Shannon et al. 2011).

Transitional woodland

Transitional woodland (Tw) (Figure 2E) was the second most widespread plant community in MWR, and existed as a transitional state between shrublands and woodlands (SW), and miombo (M) at lower and higher elevations respectively. The dominant genera thus comprised of a mixture of the genera found in the neighbouring plant communities, as well as interspersed patches of *Colophospermum mopane*, and included predominantly *Combretum, Terminalia, Senegalia, Colophospermum* and *Brachystegia*. The most frequently recorded species (≥ 40%) were *Combretum adenogonium, Diospyros mespiliformis, Diplorhynchus condylocarpon, Combretum hereroense, Colophospermum mopane* and *Terminalia sericea,* while miombo species (e.g. *Brachystegia longifolia and B. utilis)* were also commonly recorded (Table 2). The area occupied 5 392 pixels, thus covering 25 417.9 ha, or 35.59% of MWR. The plant community occurred at medium-altitude (250–450 mamsl). Tree cover ranged from 1 to 10%, and trees were generally higher than 10 m. Shrubs higher than 1 m covered less than 10% of the total area. The isolated pockets of mopane woodlands were dominated by small (< 5 m) *Colophospermum mopane* shrubs, either alone or together with *Senegalia nigrescens, Vachellia nilotica, Cassia abbreviata, Dalbergia melanoxylon, Pterocarpus lucens, Pterocarpus rotundifolius* and *Xeroderris stuhlmannii*. The extent of these patches was however too small to be included as a significant and separate woody plant community in the MWR.

Miombo

Miombo woodlands (M) (Figure 2F) covered the largest area of MWR (35.9%), and were located at high altitudes (> 250 mamsl, but mostly > 450 mamsl) in the western upland escarpment, where steep slopes and high rock cover predominated. This thus substantiated the notion that slope and elevation are important determinants of miombo plant community patterns (Munishi, Temu & Soka 2011). As expected of typical miombo ecosystems, the miombo plant community was dominated by trees in the legume sub-family *Detarioideae* (formerly *Caesalpinoideae*), and the genera

Brachystegia and *Julbernardia*. The widespread presence of *Brachystegia boehmii, Brachystegia spiciformis*, and to a lesser extent, *Julbernardia globiflora* (Table 2), coupled with typical MAP < 1 000 mm, placed the MWR's miombo woody plant communities in the dry miombo category (White 1983; Frost 1996; Kapinga et al. 2018; Moura et al. 2018). Additionally, characteristic species of wet miombo (e.g. *Brachystegia floribunda, B. glaberrima, B. taxifolia* and B. *wangermeeana*) (White 1983) were absent from MWR. Other commonly occurring species found in miombo in this study were *Pseudolachnostylis maprouneifolia* and *Diplorhynchus condylocarpon*, as previously found by Ribeiro et al. (2008) in northern Mozambique. A well-developed grass layer was also present throughout. The miombo woodland community was further subdivided into three sub-communities based on altitude and canopy cover, namely open miombo (M1), low-altitude, closed miombo (M2), and high-altitude, closed miombo (M3). In all three sub-communities, trees were generally taller than 10 m, and shrubs above 1 m in height covered less than 10% of the total area.

Table 2. Dominant species associated with four woody plant communities in Majete Wildlife Reserve. Species were included if they occupied > 40% of all sites surveyed (indicated by 'X') or if they were found in one plant community only [indicated by '*', note that species only encountered once in the survey (singletons) are not included]

Species	Woody plant community			
	Riparian woodland	Shrublands and woodlands	Transitional woodlands	Miombo
Dalbergia arbutifolia	*			
Ficus sycamorus	*			
Friesodielsia obovata	*			
Philenoptera violacea	X			
Allophylus africanus	X			
Cleistochlamys kirkii	X			
Pterocarpus rotundifolius	X			
Kigelia africana	X			
Cremaspora trifolia	X			
Gymnosporia senegalensis	X			
Diospyros squarrosa	X			
Croton megalobotrys	X			
Grewia flavescens	X			
Senegalia nigresens	X	X		
Allophylus africanus	X	X		
Combretum imberbe	X	X		
Sclerocarya birrea	X	X		
Terminalia sericea	X	X	X	
Hyphaene petersiana		*		
Kirkia acuminata		*		
Combretum adenogonium		X	X	
Diospyros mespiliformis		X	X	
Combretum heteroense			X	
Colophospermum mopane			X	
Diplorhynchus condylocarpon			X	X
Brachystegia longifolia				X
Brachystegia utilis				X
Julbernadia globiflora				*

Open miombo (M1) was characterised by low tree cover (1–10%), and occupied 5 058.1 ha, or 7.08% of MWR. It occurred only at elevations greater than 450 mamsl in the western uplands of MWR, and mainly on the fringes of the denser, closed-canopy miombo woodlands. The most frequently recorded species were *Brachystegia longifolia, Julbernardia globiflora, B. utilis* and *Diplorhynchus condylocarpon*. Low-altitude, closed miombo (M2) occurred at elevations between 250 and 450 mamsl in the southwestern regions of the MWR, but smaller patches were also interspersed with transitional woodland. This sub-community covered 11 242.9 ha, or 15.74% of MWR. Tree cover ranged between 10 and 75%. The most frequently recorded species were *Brachystegia longifolia, Diplorhynchus condylocarpon, B. utilis, Diospyros mespiliformis, Colophospermum mopane, Combretum adenogonium* and *Pseudolachnostylis maprouneifolia*. High-altitude, closed miombo (M3) occurred at elevations above 450 mamsl in the western uplands of MWR, where it covered 9 371.4 ha, or 13.12% of MWR. Tree cover ranged between 10 and 75%, and trees between 20 and 30 m in height were present in a few areas. The most frequently recorded species were *Brachystegia longifolia, Julbernadia globiflora, B. utilis and B. boehmii*, while the associate species *Diplorhynchus condylocarpon, Erythrophleum africanum, Diospyros mespiliformis, Combretum adenogonium, Pseudolachnostylis maprouneifolia* and *Diospyros kirkii* were also abundant.

Woody species diversity

A total of 868 individuals of 118 woody plant species were identified along 94 transects in MWR, representing 16 orders and 31 families (Supplementary Material). The most species belonged to the families *Fabaceae* (37 species), *Combretaceae* (10 species), *Phyllanthaceae* (8 species) and *Malvaceae* (7 species). Together, these four families contributed more than half (52.5%) of all species recorded. Most species were recorded infrequently, with 29 species recorded only once, and a further 17 species only recorded twice.

The species accumulation curves for MWR (Figure 4) clearly indicated that the expected number of species had reached an asymptote, suggesting that sampling size was sufficient, and that an adequate proportion of the total woody species present in MWR were identified in our survey (Begossi 1996). In contrast, none of the individual woody plant communities ever reached an asymptote. However, given the rapid initial rates of discovery, the relatively large study area, and the high species richness present in all woody plant communities, it is unlikely that a true asymptote will ever be reached without excessive sampling (Williams, Witkowski & Balkwill 2007).

Shrublands and woodlands consistently had the highest level of diversity in terms of woody plants, while

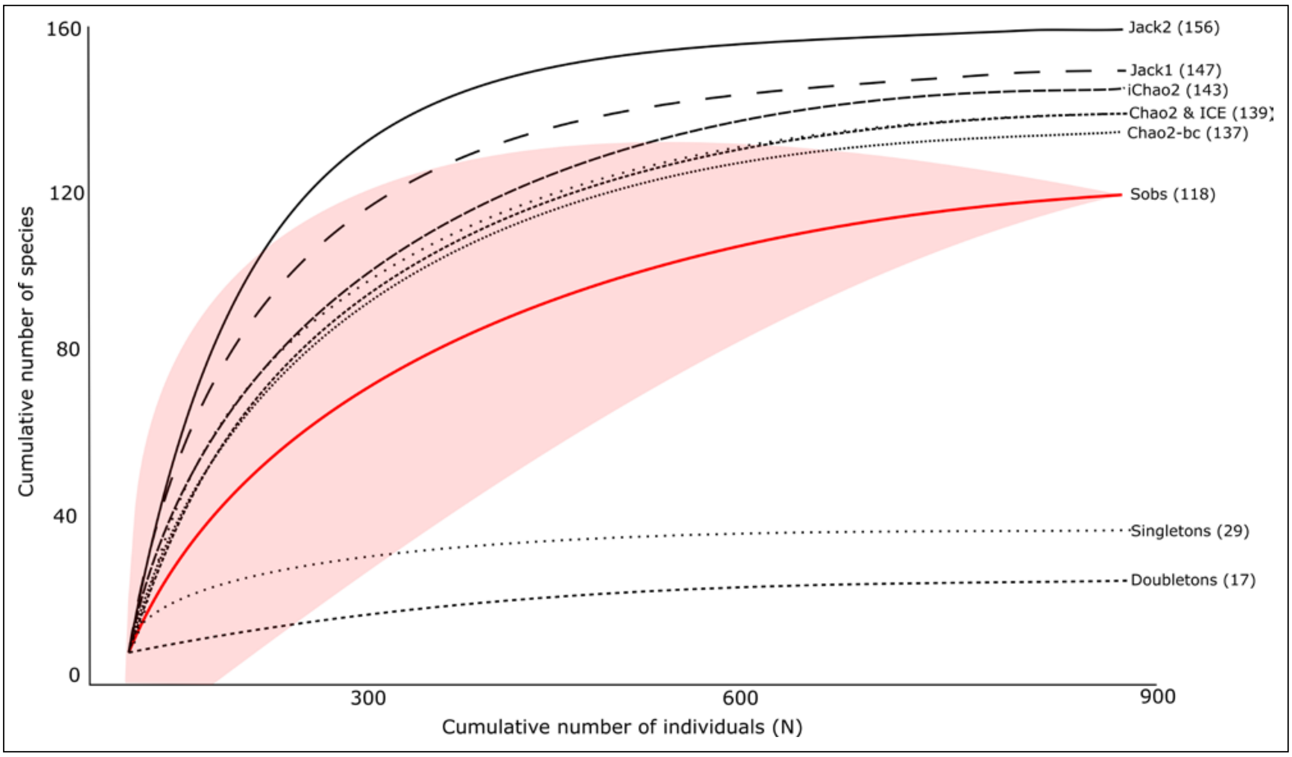

Figure 4. The comparative performance of six incidence-based species richness estimators (Chao 2, Chao 2-bc, iChao 2, Jack 1, Jack 2 and ICE) for all woody plant species recorded in Majete Wildlife Reserve (n = 118). The observed species accumulation curve (Sobs) with 95% confidence intervals, as well as the cumulative number of singletons (the number of species recorded only once during the survey) and doubletons (the number of species recorded only twice during the survey), were also plotted. Estimated woody species richness values are indicated in brackets.

riparian-, miombo- and transitional woodlands had comparatively lower diversity. Shannon-Wiener diversity (H′) values ranged between 3.80 ± 0.50 (riparian woodland) and 4.02 ± 0.05 (shrublands and woodlands), while Simpson diversity values (1-λ) all ranged between 0.96 and 0.98, with the exception of riparian woodland (0.83). Evenness values were highest for miombo and riparian woodland (J′ = 2.40 and 2.34, respectively), and comparatively lower for transitional woodlands, and shrubland and woodlands (J′ = 2.15 and 2.12, respectively). Overall evenness in all samples was low (J′ = 2.04). The species richness estimates and selected ecological diversity index values can be found in Table 3.

Discussion

The plant communities of Majete Wildlife Reserve

Five distinct woody plant communities, along with six sub-communities, were identified and classified in this study (Table 1; Figure 3) based on their altitudinal and geographical location, vegetation physiognomy and structure, and woody plant species composition. Geographically, all of the woody plant communities can be broadly placed in the Miombo Ecoregion (Byers 2001), while floristically, all would fall within the Zambezian Phytoregion (White 1983; Byers 2001; Goyder et al. 2018). At the level of the entire MWR, it is clear from the species richness estimators that further sampling would not yield a significant number of novel, unrecorded tree or shrub species. However, at the level of individual plant communities, it was evident that further sampling could result in a far more complete species list. Similarly, the species richness estimators predicted that between 76 and 86% of all woody species in the MWR were recorded in our survey, which is regarded as adequate (Heck Jr, van Belle & Simberloff 1975). However, at the individual plant community level, it was predicted that up to 75 more woody species in addition to the 44 recorded, could be found in miombo alone. This is likely due to the comparatively low sampling intensity in miombo, as a result of difficulty in accessing the area.

Mwase et al. (2007) and Missanjo et al. (2014) found 48 and 22 tree and shrub species in Malawian miombo

Table 3. Species richness estimates and selected measures of diversity calculated for woody tree and shrubs species recorded in four vegetation groupings, as well for Majete Wildlife Reserve as a whole

Index/measure		Riparian woodland	Shrublands and woodlands	Transitional woodland	Miombo	Majete Wildlife Reserve
Samples (n)		8	42	27	17	94
Individuals (N)		114	408	248	98	868
Coefficient of variation (CV)		1.12	1.22	1.06	1.14	1.34
Species richness (S_{Obs})		42	95	65	44	118
Shannon-Wiener index (H′)		3.80 ± 0.50	4.20 ± 0.05	3.90 ± 0.08	3.94 ± 0.17	4.22 ± 0.03
Simpson's index (1-λ)		0.83 ± 0.00	0.97 ± 0.00	0.97 ± 0.00	0.96 ± 0.00	0.98 ± 0.00
Simpson's inverse (1/λ)		36.71 ± 1.74	38.60 ± 2.14	30.69 ± 1.73	22.65 ± 2.20	41.99 ± 1.62
$H'_{max} = \ln(S)$		1.62	2.00	1.81	1.64	2.07
Shannon $J' = (H'/H'_{max})$		2.34	2.12	2.15	2.40	2.04
Singletons[1]		7	36	25	28	29
Doubletons[2]		21	19	17	5	17
Estimated species richness	ICE	110.23 ± 25.16	137.57 ± 14.71	117.70 ± 24.70	101.33 ± 29.14	138.71 ± 8.10
	Chao 2	111.36 ± 36.23	128.29 ± 14.66	82.70 ± 9.28	104.56 ± 42.16	138.78 ± 11.00
	Chao2-bc	98.40 ± 28.69	125.75 ± 13.55	81.05 ± 8.52	90.70 ± 31.30	137.11 ± 9.37
	iChao2	115.10 ± 38.18	135.71 ± 9.28	83.74 ± 5.86	109.12 ± 36.19	142.98 ± 6.53
	Jack 1	67.26 ± 5.95	130.14 ± 8.33	89.07 ± 6.87	59.20 ± 6.92	146.67 ± 7.55
	Jack 2	87.00 ± 11.22	146.78 ± 14.22	97.09 ± 11.61	78.04 ± 11.29	155.69 ± 12.98

[1]Number of species occurring only once across all samples
[2]Number of species occurring only twice across all samples

ecosystems respectively, on plots ≤ 6.5 ha in size. Further sampling of the miombo community in MWR will thus likely be needed to provide a complete list of species present in MWR. Similarly, the riparian woodlands were slightly underrepresented in this study, and many more species are predicted to occur in this woody plant community. However, given the limited extent of riparian woodlands in MWR, it is unlikely that more sampling could occur without introducing spatial autocorrelation biases, and further sampling would thus have to occur outside the reserve perimeter. The reserve is also dominated by a vast network of seasonal streambeds that become active in the rainy season (December–March), and it is possible that sampling of these streambeds could reveal similar floristic compositions to those found along perennial rivers in this study. However, despite the apparent incompleteness of the species inventory, the genera used to differentiate plant communities (*Combretum, Senegalia, Terminalia, Sclerocarya, Brachystegia, Julbernardia, Colophospermum* and *Vachellia*) were all easily and frequently recorded. The failure to detect a potentially large number of species does therefore not affect the plant community classifications produced in this study. In fact, with the exception of the genus *Julbernardia*, and the addition of the genera *Diplorhynchus* and *Diospyros*, these were the most abundant genera recorded in MWR. All quadrats were thus dominated by a particular combination of these genera.

Remote sensing as an aid to vegetation surveys

Producing vegetation maps for large areas from ground-based measurements is extremely resource-intensive, and their accuracy would likely be compromised in the absence of intensive surveys. Remote sensing provides a relatively inexpensive and efficient way to overcome this logistical barrier through relatively fine-scale land cover classifications over a large area. In this study, remote sensing also allowed for the accurate placement of sampling plots that were used to add detail for the completion of the vegetation survey. Despite the overall congruence between remotely sensed and ground-surveyed information in this study, as determined by the accuracy assessment, remote sensing should be accompanied by ground-truthing methods in future studies, and in many instances (especially for fine-scale vegetation mapping), more than simple ground-truthing may be necessary (Smith, Meredith & Johns 1999). Remote sensing on its own also lacks the fine detail obtained from ground-based surveys, further substantiating the need for integrating both approaches to achieve optimal vegetation classifications (Kerr & Ostrovsky 2003; Clegg & Connor 2012). The combination of remote sensing and ground surveys was previously shown to be a successful method for delineating plant communities in southern Africa (Peel et al. 2007; van Rooyen et al. 2008) and elsewhere (Smith, Meredith & Johns 1999; Satyanarayana et al. 2011).

Because detailed information on the distribution and extent of ecosystems, and contractions or expansions of land-types, will become increasingly important in the face of global change (Jinga & Palagi 2020), the importance of rapid classification tools such as remote sensing will likely increase. Additionally, the relatively low cost of woody vegetation classifications through remote sensing, even when combined with field surveys, offers an attractive application for protected and near-natural areas in developing countries, as well as in regions that undergo rapid and constant change. Future management and conservation initiatives will thus likely rely on similar methods as those used in this study to identify and describe habitats or species that require prioritised attention. Some limitations of the method can however be expected in heavily degraded or non-natural areas, such as where natural areas have been converted for agricultural use. In these areas, poor resolution and misclassifications of remote sensing products may have a large impact on vegetation mapping and classification, and land cover classes alone will likely not be sufficient.

Implications for fire management

Most savanna trees are morphologically and physiologically adapted to persist in the presence of regular fires (Duvane et al. 2017), but fire effects may vary substantially depending on the frequency, intensity and season of the burn, as well as on woodland type (Smit et al. 2010) and interactions with other processes such as herbivory (Shannon et al. 2011). Woody vegetation maps thus provide a useful tool to plan fire management according to the distribution of dominant tree species. However, elements of fire regimes are also closely connected to non-woody components of vegetation, and information on non-woody vegetation structure and composition can thus improve approaches to fire management significantly (Nieman 2020).

In this study, the two dominant and contrasting woody plant communities, namely shrublands and woodlands, and miombo woodlands, differed substantially in terms of species composition and density, and the approaches to fire management in these areas may have to be adjusted accordingly (Nieman et al. 2021). The dominant genera of shrublands and woodlands are typically more tolerant of repeated fires of high-intensity than their miombo counterparts. In particular, *Vachellia* species display enhanced coppicing abilities, and fire is thus rarely able to prevent establishment and recovery, even after substantial damage to tree canopies and large-scale die-back are caused (Russell, Tedder & Demmer 2019), and even in drier systems where the effects of fire are more pronounced (van der Merwe et al. 2019). Similarly, fire has been found not to affect germination rates of *Senegalia* species (Walters, Midgley & Somers 2004), and *Sclerocarya birrea* was shown to be highly tolerant to fire (Luoga et al. 2004). For this reason, reversing undesirable woody encroachment in shrublands and woodlands would require the repeated application of high-intensity fires (Walters et al. 2004), which has been shown to be effective in reducing tree and shrub densities in *Combretum, Senegalia* and *Sclerocarya* woodlands (Sweet 1982; Enslin et al. 2000), as well as reduce tree heights and basal areas (Trapnell 1959; Shackleton & Scholes 2000; Nefabas & Gambiza 2007; Gandiwa & Kativu 2009), and hamper seedling establishment and growth (Jacobs & Biggs 2001). Ultimately, this may lead to the formation of extensively coppiced shrublands (or in extreme circumstances over a prolonged period, grasslands) (Mapaure 2001), by continually preventing trees from growing out of the fire trap and developing into tall adults (Bond & van Wilgen 1996), as seen in nearly 3 000 ha of MWR.

Increased fire frequency has also been shown to promote tree and shrub density in mopane woodlands (Gandiwa & Kativu 2009), and to increase the number of stems on individual plants (Jacobs & Biggs 2001; Kennedy & Potgieter 2001). In areas of MWR where the goal is to increase the incidence of taller, closed vegetation, fire should thus be excluded for a sufficient period, or applied as low-intensity burns in the wet or early dry season (Enslin et al. 2000; Kennedy & Potgieter 2001). Finally, *Brachystegia–Julbernadia* tree species have been extensively shown to be unable to adequately recover following annual or even biennial burns, and particularly from high-intensity fires in the late dry season (Thomson 1975; Ryan & Williams 2011), resulting in the conversion of miombo woodland to a grassland state (Furley et al. 2008). In contrast, the complete absence of fire may allow miombo woodland to develop into a closed canopy forest (Trapnell 1959). Fires in the miombo woodlands of MWR should therefore be limited to the early dry season, and on a rotation of at least two years (Nieman et al. 2021).

Additionally, riparian woodlands are arguably the most important woody plant community for ensuring the survival of large mammals due to their proximity to water, and provision of shade and highly palatable vegetation (Anderson & Walker 1974; Conybeare 2004), making appropriate conservation essential. Riparian woodlands do not burn frequently, and tend to persist in the absence of fire (van Wilgen et al. 2014), so that prescribed burning is not necessary. However, the only invasive alien plant species recorded in this study (i.e. *Lantana camara* and *Eucalyptus camaldulensis*) were found in or near the riparian woodland plant community. Presumably, the river systems act as a pathway for propagule transport originating outside MWR. These species may have the potential to facilitate fire spread (Dew et al. 2017), and fire has previously been applied by management to control *L. camara* spread in MWR (Nieman et al. 2021). Although not excessively encroached in the reserve at the time of the study, these invasive species pose a potential threat to the indigenous vegetation and should be removed.

Conclusions

The process of compiling information for the classification and identification of woody plant communities for MWR in this study was achieved at a relatively low cost and during a short time, thus providing an accurate and efficient method to elucidate fine-scale vegetation patterns in an area where little prior information existed. The short duration of the survey in a single season may translate to an underrepresented species inventory, and future studies may therefore benefit from identifying species in a variety of seasons. For example, a number of species identified by Sherry (1989) were not found in this study, including *Vachellia tortilis, Breonadia microcephala, Sterculia appendiculata, Pterocarpus angolensis* and *Strychnos madagascariensis*. Furthermore, though edaphic factors were not assessed, they are likely an important determinant of plant distributions. For example, miombo is typically found on freely drained (leached), acidic soils with a restricted rooting environment (White 1983; Jinga & Palagi 2020), typical of the western uplands of MWR. For this reason, and many other related to environmental understanding and management, a detailed description of the geology and soils of MWR is required. Nevertheless, the woody vegetation classification and mapping of MWR achieved in this study is comprehensive, and more than adequate to effectively guide management decision-making on a variety of environmental topics, as well as policy development and species- or habitat- conservation strategies. The spatial boundaries of woody plant communities produced in this study are predominantly determined by factors that only change over geological time (e.g. slope, elevation and soils), and should therefore remain unchanged in the long-term. In contrast, the sub-type vegetation classifications (as well as grasslands), based predominantly on vegetation composition, physiognomy and structure, may be temporally altered through the effects of, among others, elephants and fire, and will therefore need to be updated periodically.

Acknowledgements

This work was supported by the Earthwatch Institute under the Majete Wildlife Research Programme, Malawi, Grant to AJI, the DSI-NRF Centre for Invasion Biology, Stellenbosch University, and the National Research Foundation of South Africa [grant number 109467 to BWvW]. WAN acknowledges logistical support received from African Parks Ltd.

Competing interests

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this article.

Author's contributions

WAN sourced the data, conducted the analyses, and co-wrote the paper with BWvW. AJL provided editorial input. All authors read and approved the final manuscript

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Supplementary Material

Table S1. List of tree and shrub species found in Majete Wildlife Reserve in this study, as well as the number of transects and the woody plant communities in which species occurred. The woody plant communities are: Rw = Riparian woodland, Gr = Grassland, SW = Shrublands and woodlands, Tw = Transitional woodland, and M = Miombo.

Family	Species	Number of transects present	Vegetation types present
Arecaceae [the palm family]	*Hyphaene coriacea* (lala palm)	4 (4.26%)	Rw and SW
	Hyphaene petersiana (vegetable ivory palm)	3 (3.19%)	SW
	Phoenix reclinata (wild date palm)	2 (2.13%)	SW and Tw
Boraginaceae [the borage or forget-me-not family]	*Ehretia amoena* (sandpaper stamperwood)	6 (6.38%)	Rw, SW and Tw
Capparaceae [the Caper family]	*Boscia salicifolia* (willow-leaved Boscia)	3 (3.19%)	Rw and Tw
	Cadaba kirkii (wormbush)	1 (1.06%)	SW
Celastraceae [the staff wine or bittersweet family]	*Gymnosporia senegalensis* (confetti tree)	6 (6.38%)	Rw and Tw
	Pleurostylia capensis (coffee pear)	1 (1.06%)	M
Ebenaceae [the ebony family]	*Diospyros kirkii* (large-leaved jackalberry)	26 (27.66%)	Rw, SW, Tw and M
	Diospyros mespiliformis (jackalberry)	39 (41.49%)	SW, Tw and M
	Diospyros squarrosa (rigid star-berry)	6 (6.38%)	Rw and SW
	Diospyros usambarensis (sand star-apple)	2 (2.13%)	SW
Fabaceae [the legume, pea or bean family]	*Afzelia quanzensis* (pod mahogany)	2 (2.13%)	SW
	Albizia harveyi (bushveld Albizia)	4 (4.26%)	SW and Tw
	Bauhinia petersiana (Zambezi coffee)	3 (3.19%)	SW and Tw
	Bolusanthus speciosus (tree wisteria)	2 (2.13%)	SW and Tw
	Brachystegia allenii (escarpment Brachystegia)	1 (1.06%)	Tw
	Brachystegia boehmii (Prince of Wales feathers)	5 (5.32%)	Tw and M
	Brachystegia longifolia (mubombo)	29 (30.85%)	Rw, SW, Tw and M
	Brachystegia spiciformis (zebrawood)	7 (7.45%)	Rw, Tw and M
	Brachystegia utilis (false mafuti)	21 (22.34%)	SW, Tw and M
	Burkea africana (wild seringa)	1 (1.06%)	SW
	Cassia abbreviata (sjambok pod)	6 (6.38%)	SW and Tw
	Colophospermum mopane (mopane)	26 (27.66%)	SW, Tw and M
	Cordyla africana (wild mango)	4 (4.26%)	Rw and SW
	Craibia brevicaudata (mountain ironwood)	1 (1.06%)	Tw
	Dalbergia arbutifolia (eastern climbing Dalbergia)	2 (2.13%)	Rw
	Dalbergia boehmii (large-leaved Dalbergia)	3 (3.19%)	SW and M
	Dalbergia melanoxylon (African blackwood)	10 (10.64%)	Rw, SW, Tw and M
	Dalbergia obovata (climbing flat-bean)	4 (4.26%)	SW and Tw
	Dichrostachys cinerea (sicklebush)	5 (5.32%)	Rw, SW and Tw
	Erythrophleum africanum (ordeal tree)	6 (6.38%)	SW and M

Table S1. List of tree and shrub species found in Majete Wildlife Reserve in this study, as well as the number of transects and the woody plant communities in which species occurred. The woody plant communities are: Rw = Riparian woodland, Gr = Grassland, SW = Shrublands and woodlands, Tw = Transitional woodland, and M = Miombo (continued).

Family	Species	Number of transects present	Vegetation types present
Fabaceae [the legume, pea or bean family] (continued)	*Julbernardia globiflora* (munondo)	6 (6.38%)	SW, Tw and M
	Mundulea sericea (cork bush)	5 (5.32%)	SW and Tw
	Ormocarpum kirkii (caterpillar bush)	7 (7.45%)	SW, Tw and M
	Philenoptera bussei (small apple-leaf)	2 (2.13%)	SW and M
	Philenoptera violacea (apple-leaf)	20 (21.28%)	Rw, SW, Tw and M
	Piliostigma thonningii (camel's foot)	2 (2.13%)	SW and M
	Pterocarpus lucens (small-leaved bloodwood)	2 (2.13%)	SW and M
	Pterocarpus rotundifolius (round-leaved bloodwood)	16 (17.02%)	Rw, SW and Tw
	Senegalia burkei (black monkey thorn)	5 (5.32%)	SW, Tw and M
	Senegalia galpinii (monkey thorn)	6 (6.38%)	SW, Tw and M
	Senegalia nigrescens (knob-thorn)	41 (43.62%)	Rw, SW, Tw and M
	Tamarindus indica (tamarind)	5 (5.32%)	SW and Tw
	Tephrosia aequilata (common name unknown)	1 (1.06%)	SW
	Vachellia karroo (sweet thorn)	1 (1.06%)	SW
	Vachellia nilotica (gum arabic tree)	23 (24.47%)	Rw, SW, Tw and M
	Vachellia torrei (Mozambique sticky thorn)	14 (14.89%)	Rw, SW, Tw and M
	Xeroderris stuhlmannii (wing pod)	11 (11.70%)	Rw, SW, Tw and M
Apocynaceae [the dogbane family]	*Diplorhynchus condylocarpon* (horn-pod tree)	34 (36.17%)	SW, Tw and M
	Holarrhena pubescens (fever-pod)	11 (11.70%)	Rw, SW, Tw and M
Rubiaceae [the coffee, madder or bedstraw family]	*Catunaregam obovata* (coastal bone-apple)	4 (4.26%)	SW and Tw
	Cremaspora trifloral (cremaspora)	7 (7.45%)	Rw, SW and Tw
	Crossopteryx febrifuga (common crown-berry)	1 (1.06%)	SW
	Gardenia volkensii (bushveld gardenia)	1 (1.06%)	Tw
	Pavetta schumanniana (poison pavetta)	2 (2.13%)	SW
Bignoniaceae [the jacaranda family]	*Kigelia africana* (sausage tree)	9 (9.57%)	Rw, SW and M
	Markhamia acuminate (bean-tree)	4 (4.26%)	Rw, SW and M
	Stereospermum kunthianum (pink jacaranda)	1 (1.06%)	M
	Tecoma nyassae (Cape honeysuckle)	1 (1.06%)	SW
Lamiaceae [the mint, deadnettle or sage family]	*Karomia tettensis* (northern Chinese-hats)	1 (1.06%)	SW
Verbenaceae [the verbena family]	*Lantana camara* (West Indian lantana)	2 (2.13%)	Rw
Annonaceae [the custard apple family]	*Friesodielsia obovata* (northern dwaba-berry)	2 (2.13%)	Rw
	Monanthotaxis caffra (dwaba-berry)	1 (1.06%)	SW
Clusiaceae [the St John's wort family]	*Garcinia livingstonei* (African mangosteen)	1 (1.06%)	SW
Euphorbiaceae [the euphorbia family]	*Croton megalobotrys* (fever-berry)	5 (5.32%)	Rw and SW
	Croton sylvaticus (forest croton)	2 (2.13%)	SW

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Family	Species	Number of transects present	Vegetation types present
Ochnaceae [the ochna family]	*Ochna mossambicensis* (large-flowered ochna)	1 (1.06%)	SW
Phyllanthaceae	*Bridelia cathartica* (blue sweetberry)	5 (5.32%)	SW and Tw
	Cleistanthus schlechteri (muti-usina-zita)	1 (1.06%)	SW
	Cleistochlamys kirkii (purple cluster-pear)	11 (11.70%)	Rw, SW, Tw and M
	Flueggea virosa (snowberry tree)	2 (2.13%)	SW
	Hymenocardia acida (large red-heart)	1 (1.06%)	Tw
	Phyllanthus reticulatus (potato plant)	1 (1.06%)	SW
	Pseudolachnostylis maprouneifolia (duiker-berry)	10 (10.64%)	SW, Tw and M
	Uapaca sansibarica (lesser mahobohobo)	1 (1.06%)	M
Salicaceae [the willow family]	*Flacourtia indica* (governor's plum)	4 (4.26%)	Tw and M
Dipterocarpaceae [the meranti family]	*Monotes africanus* (Muwase)	4 (4.26%)	SW and Tw
Malvaceae [the mallow family]	*Adansonia digitata* (African baobab)	5 (5.32%)	Rw and SW
	Grewia bicolor (white-leaved raisin)	5 (5.32%)	Rw and SW
	Grewia flavescens (sandpaper raisin)	5 (5.32%)	Rw and SW
	Grewia forbesii (worty donkey-berry)	7 (7.45%)	SW and Tw
	Sterculia africana (African star-chestnut)	11 (11.70%)	Rw, SW, Tw and M
	Sterculia quinqueloba (large-leaved star-chestnut)	3 (3.19%)	Rw and SW
	Sterculia rogersii (small-leaved star-chestnut)	2 (2.13%)	SW and Tw
Meliaceae [the mahogany family]	*Trichilia emetica* (Natal mahogany)	3 (3.19%)	Rw and SW
Combretaceae [the combretum family]	*Combretum adenogonium* (four-leaved bushwillow)	51 (54.26%)	Rw, SW, Tw and M
	Combretum apiculatum (red bushwillow)	28 (29.79%)	SW, Tw and M
	Combretum hereroense (russet bushwillow)	15 (15.96%)	SW, Tw and M
	Combretum imberbe (leadwood)	34 (36.17%)	Rw, SW and Tw
	Combretum molle (velvet bushwillow)	21 (22.34%)	Rw, SW, Tw and M
	Combretum mossambicense (knobbly bushwillow)	2 (2.13%)	SW
	Combretum zeyheri (large-fruited bushwillow)	22 (23.40%)	Rw, SW, Tw and M
	Terminalia mollis (large-leaved terminalia)	4 (4.26%)	SW, Tw and M
	Terminalia sericea (silver cluster-leaf)	33 (35.11%)	Rw, SW, Tw and M
	Terminalia stenostachya (rosette-leaved terminalia)	3 (3.19%)	SW, Tw and M
Myrtaceae [the eucalyptus family]	*Eucalyptus camaldulensis* (river red gum)	1 (1.06%)	SW
Proteaceae [the protea family]	*Faurea rochetiana* (broad-leaved beechwood)	4 (4.26%)	SW and Tw

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Family	Species	Number of transects present	Vegetation types present
Moraceae [the fig or mulberry family]	*Ficus abutilifolia* (large-leaved rock fig)	1 (1.06%)	SW
	Ficus sycamorus (sycamore fig)	2 (2.13%)	Rw
	Maclura africana (thorny mulberry)	2 (2.13%)	Rw
Rhamnaceae [the buffalo-thorn family]	*Berchemia discolor* (brown ivory)	1 (1.06%)	Tw
	Ziziphus mucronata (buffalo-thorn)	3 (3.19%)	Rw and SW
Olacaceae [the sour plum family]	*Ximenia americana* (tallow wood)	2 (2.13%)	Tw and M
	Ximenia caffra (large sourplum)	4 (4.26%)	SW and Tw
	Jasminum fluminense (Brazilian jasmine)	1 (1.06%)	SW
Anacardiaceae [the cashew or sumac family]	*Lannea stuhlmannii* (false marula)	3 (3.19%)	Rw and Tw
	Ozoroa reticulata (raisin bush)	1 (1.06%)	Tw
	Sclerocarya birrea (marula)	29 (30.85%)	Rw, SW, Tw and M
Burseraceae [the torchwood or myrrh family]	*Commiphora africana* (poison-grub corkwood)	2 (2.13%)	SW and M
	Commiphora mollis (velvet-leaved corkwood)	1 (1.06%)	SW
	Commiphora mossambicensis (pepper-leaved corkwood)	1 (1.06%)	SW
Kirkiaceae [the kirkia family]	*Kirkia acuminata* (white seringa)	3 (3.19%)	SW
	Kirkia wilmsii (wild pepper tree)	1 (1.06%)	SW
Sapindaceae [the soapberry family]	*Allophylus africanus* (African false-current)	9 (9.57%)	Rw and SW
	Dodonaea viscosa (sticky hop-bush)	2 (2.13%)	SW and Tw
	Zanha africana (velvet-fruited zanha)	1 (1.06%)	M
	Zanha golungensis (smooth-fruit zanha)	1 (1.06%)	Tw

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ISSN: (Online) 2311-9284, (Print) 0006-8241

Vegetation survey of the Khomas Hochland in central-western Namibia: syntaxonomical descriptions

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Dates

Submitted: 1 July 2020
Accepted: 15 April 2021
Published: 15 July 2021

How to cite this article:

Strohbach, B., 2021, 'Vegetation survey of the Khomas Hochland in central-western Namibia: syntaxonomical descriptions', *Bothalia* 51(2), a4. http://dx.doi.org/10.38201/btha.abc.v51.i2.4

Background: The Great Escarpment of southern Africa takes the form of an extended mountainous highland in central-western Namibia, commonly referred to as the 'Khomas Hochland'. It is regarded as an area of high botanical diversity. Yet only few localised studies on the vegetation composition are available. The Khomas Hochland is formed on the southern part of the Damara Orogen and dominated by metamorphosed sediments. Climatically it forms a transition between the hot desert of the Namib and the slightly cooler hot steppe in the inland.

Objectives: To classify and provide syntaxonomical descriptions of the vegetation of the Khomas Hochland.

Methods: A dataset comprising 1151 relevés and 914 species was compiled from various surveys, mostly collected under, and to the standards of, the umbrella project 'Vegetation Survey of Namibia'. For first classifications, the data set was reduced to a synusial set consisting of trees, shrubs, dwarf shrubs and grasses only.

Results: The classification resulted in four major landscape units, being the Pre-Namib and Escarpment zone, the Khomas Hochland proper, riverine habitats as well as surrounding lowlands. The classification was further refined using Cocktail procedures to produce 30 associations, one with four sub-associations. These are described in this paper.

Conclusion: A classification of synoptic data grouped the associations into five orders and one undefined cluster of associations on specialised desert habitats. Four of these orders correspond to the habitat types identified in the first classification. The fifth order, the *Senegalio hereroensis–Tarchonanthoetalia camphorathi*, represents high mountains of the central Khomas Hochland, which link biogeographically to the grassland biome in South Africa.

Keywords: Damara Orogen; Great Escarpment; highland savanna; modified TWINSPAN; Namib; phytosociology.

Introduction

The Great Escarpment is a ± 5000 km long geomorphological feature along the rim of the southern African subcontinent. It is regarded as a zone of high biological diversity, containing numerous Centres of Endemism (Clark et al. 2011). Whereas most of the Great Escarpment forms a narrow divide between the coastal lowlands and the inland plateaux, in central Namibia the Damara Orogen created a mountainous landscape nearly 200 km wide from west to east. This mountainous landscape is commonly referred to as the Khomas Hochland (or Khomas highlands) (Schneider 2004; Swart & Marais 2009; Goudie & Viles

2014). Giess (1998) broadly describes the vegetation as 'highland savanna', without providing any details on composition or diversity.

Although the Khomas Hochland has been identified as an area of high botanical diversity (Hofmeyr 2004; Craven & Vorster 2006), only a few localised descriptions of the vegetation of this landscape exists. Of note here are a study by Volk and Leippert (1971) on a few farms southeast of Windhoek, using data from the 1950s and 1960s; an unpublished study by Kellner (1986) focusing on the Daan Viljoen Game Reserve west of Windhoek as well as portions of two farms southwest and east of Windhoek; a preliminary description of the vegetation of the Auas Mountain Range south of Windhoek (Burke & Wittneben 2007); as well as an account of the vegetation of the Auas-Oanob Conservancy southwest of Windhoek (Strohbach 2017). None of these studies provide a comprehensive overview of the entire landscape. In contrast, a fairly comprehensive description of the adjacent central Namib desert is available (Jürgens et al. 2013).

The Vegetation Survey of Namibia project has been initiated to fill this, and similar data gaps, at a national level (Burke & Strohbach 2000; Strohbach 2001). The project is aimed at providing data about the resource 'natural vegetation' to allow for sustainable planning and management of this renewable resource (Strohbach 2018). Due to the sheer size of the country, however, a strong emphasis is placed on utilising existing reliable data sources in addition to collecting, over a number of seasons, additional, gap-filling data. At the same time, due to the lack of necessary data density for a detailed study, the result will be at a regional overview level (often referred to as 'reconnaissance level') (Küchler & Zonneveld 1988; Strohbach 2001). This paper aims to contribute a first formal classification and description at this level of the vegetation found in the Khomas Hochland in central-western Namibia.

Methods

Study area

The study area is a block of roughly 31 000 km² in central western Namibia, between the coastal Namib desert lowlands and the inland plateaux (Figure 1). It stretches from the border of the Namib-Naukluft Park in the west to about 17° 30'E, and from the B6 trunk road between Okahandja and Karibib in the north to about the Gaub Valley in the south. Administratively, it covers the western half of the Khomas Region, but also reaches into the Erongo and Otjozondjupa regions of Namibia.

The Khomas Hochland had its origin some 900 Ma ago as a sea between two tectonic plates, the Kalahari- and Congo cratons. Sediments deposited in this sea solidified and were metamorphised during the formation of the Gondwana supercontinent ± 650 to 450 Ma ago. At that stage, uplift also happened, resulting in the Damara Orogen (Schneider 2004; Swart & Marais

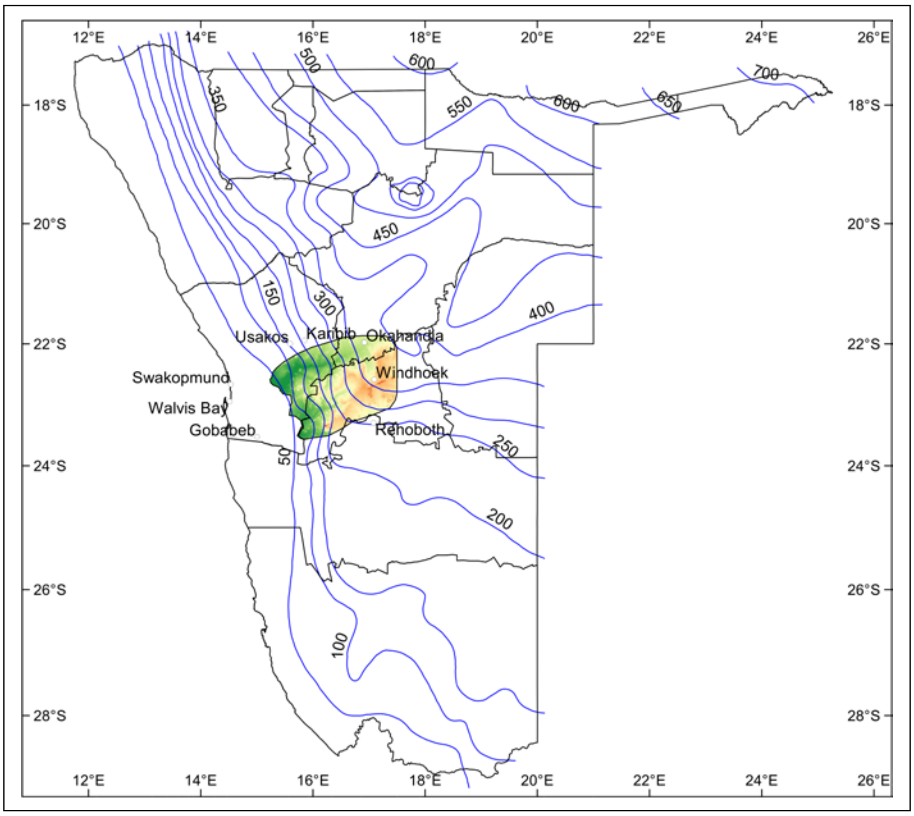

Figure 1. The study area in western central Namibia. Mean Annual Rainfall is indicated as blue isohyets. Data source: NARIS (2001).

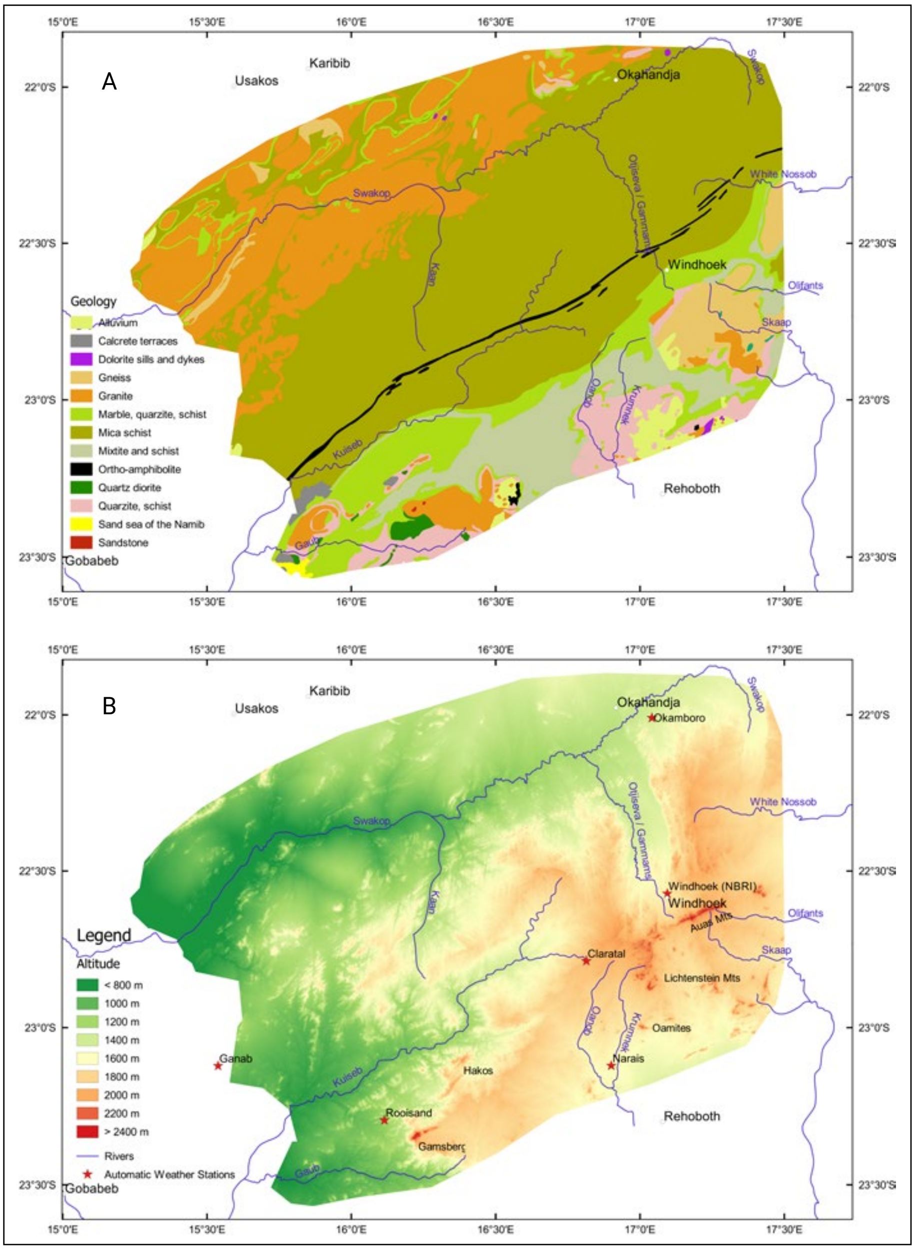

Figure 2. A, Simplified geological map of the study area, indicating the major lithological substrates; B, Topography of the study area, indicating several landmarks and major rivers draining the Khomas Hochland. Data sources: Geological map adapted from Namibia Geological Map (Geological Survey 1980); topography derived from SRTM image (Jarvis et al. 2008).

2009). The main body of the Khomas Hochland consists of mica schists of the Kuiseb and schists and mixtites of the Chuos Formation (Figure 2A). The mica schists of the Kuiseb Formation are dissected by a narrow band of ortho-amphibolites of the Matchless Member. The southern rim is formed by hardened quartzites of the Auas Formation, before merging with older rocks (granites and metamorphites of the Rehoboth Sequence) of the Kalahari Craton. To the north of the Kuiseb formation, intrusive granites resulted also in the formation of several marble ridges (Figure 2A) (Geological Survey 1980; South African Committee for Stratigraphy 1980; Schneider 2004).

The escarpment of the Khomas Hochland raises from the Namib desert plains at about 900 m above sea level (asl) to well over 1 400 m asl. The central Khomas Hochland forms a deeply dissected, steep mountainous highland, raising to over 2 000 m asl in places (Figure 2B) (Swart & Marais 2009). This is only topped by the mountain ranges Auas, Lichtenstein, Hakos and Gamsberg, which reach altitudes of over 2 400 m asl (Schalk 1983; Swart & Marais 2009). The study area is drained through a dense system of ephemeral rivers, forming tributaries to the Swakop and Kuiseb rivers to the west, Oanaob and Skaap rivers to the southeast, and White Nossob as well as Olifants rivers to the east (Figure 2b) (Strohbach 2008).

The climate can be described as a hot desert in the western half to a hot steppe in the eastern half, following Köppen (1936). The mean annual precipitation (MAP) ranges from ± 50 mm in the west to about 350 mm in the east (Figures 1 and 3), with a high degree of variation between seasons. Along the western edge of the study area, the coefficient of variation (CV)

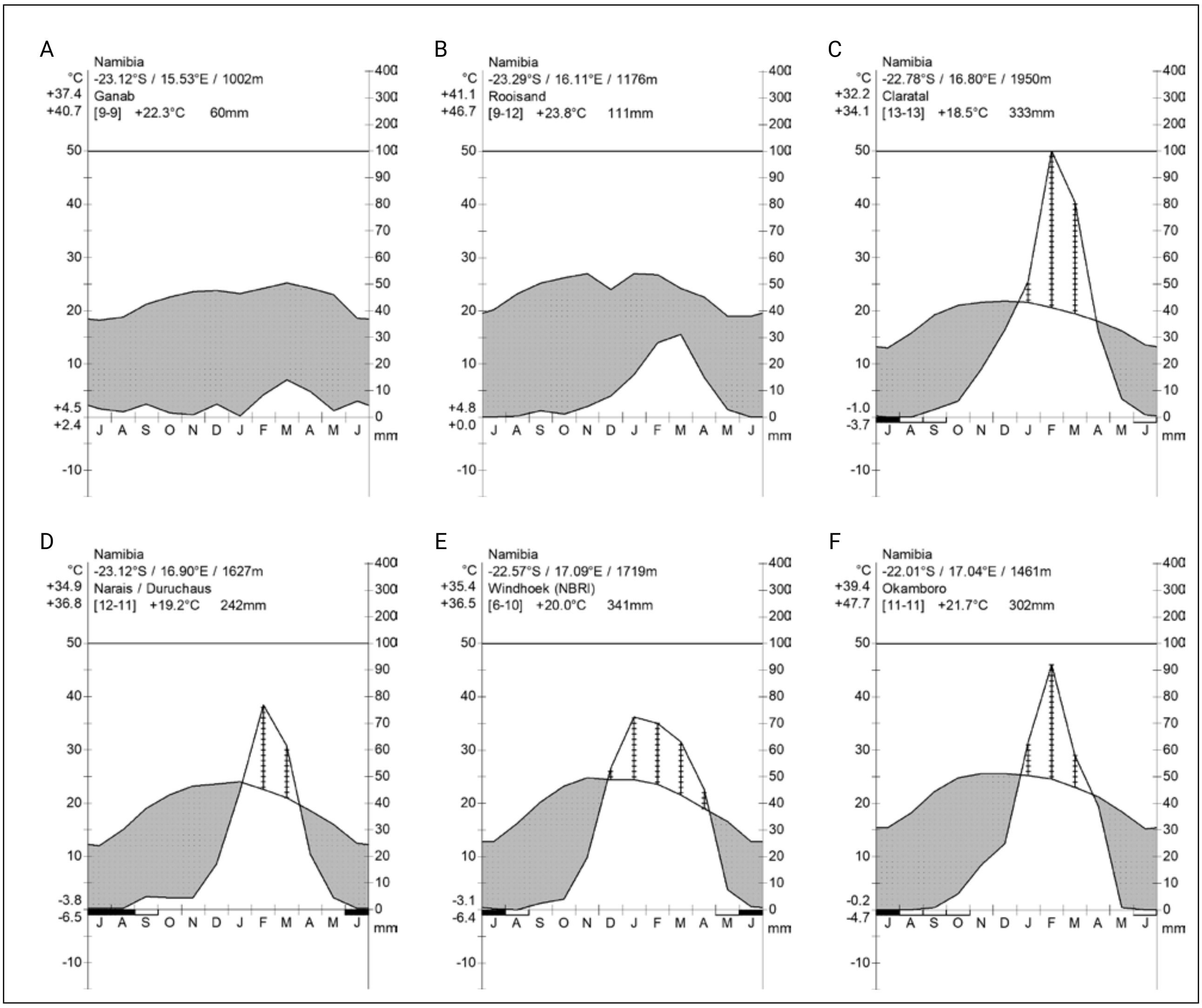

Figure 3. Climate diagrams after Walter et al. (1975) of available automatic weather stations within the study area: Ganab, Rooisand, Claratal, Narais, Windhoek (NBRI) and Okamboro. Data sources: SASSCAL (2020) and BIOTA AFRICA (2009).

of MAP is as high as 90%, in the east around Windhoek the CV of MAP is about 40% (Mendelsohn et al. 2002). The orographic effect of the escarpment and high mountains in the study area are not known. The desert margins below the escarpment become relatively hot, with maximum temperatures measured well over 40°C. Frost is also rare or absent here. In contrast, the central highlands are cooler, with maximum temperatures around 36°C. Frost regularly occurs in the highlands in the winter months between May and August, at places as late as October (Figure 3).

Data sources

A data set of 1 151 relevés with 914 species was selected from the phytosociological database of Namibia (GVID ID AF-NA-001) (Strohbach & Kangombe 2012). Details of the selected data subsets are listed in Table 1.

The quality of the rainy season, which has an influence on the growth of the vegetation, was derived according to the criteria of Botha (1998). Normal years had an annual precipitation of between the 40th and 70th percentile of long-term precipitation records, whilst extreme years had below the 10th (extreme dry) or above the 90th percentile (extreme wet) annual precipitation.

Data collected by Kellner (1986) was captured from tables in his thesis as the original relevé data (field sheets) were no longer available. These relevés were also collected from 25 × 25 m (i.e. 625 m^2) plots. No accurate position data, nor habitat data, are available for these relevés. Data collected by Burke, Wittneben and Mannheimer (Auas Mountains and Windhoek Townlands) were in the form of species lists on specific sites rather than regular survey plots. Position data are available in most cases, but the habitat data are incomplete. These data were however included, as the sites were limited to specific habitats and limited in sizes (no longer than 100 m, no wider than 10 m), i.e. comparable to regular survey sites used for the Vegetation Survey of Namibia project. Especially the data by Burke and Wittneben

Table 1. Overview of data used for this study. All data form part of GVID ID AF-NA-001 (Strohbach & Kangombe 2012)

Relevés	Dataset name	Number	Year	Season quality	Surveyor	Area of interest	Reference (if any)
937–1165	BS_Auas-Oanob	229	2000 & 2002	Extreme wet Normal	B. Strohbach	Auas-Oanob Conservancy	(Strohbach 2017)
1833–2180	Khomas_2004	204	2004	Normal	B. Strohbach	Khomas Hochland (Kuiseb valley)	
2212–2258	Khomas_2005	124	2005	Dry	B. Strohbach	Khomas Hochland (Kuiseb valley)	
2797–2977	Kellner_1985	181	1985	Normal	K. Kellner	Daan Viljoen, Claratal, Bergvlug	(Kellner 1986)
5798–5854 and 5900–5914 and 5980–5987	Zuna_2005	80 of 204	2005	Dry	Z. September	Biota transect Aris to Witvlei (limited to 17°30′ East)	
7114–7140	BS-SK_Khomas_2007	27	2007	Normal	B. Strohbach & S. Kruger	Windhoek area	
9438–9564	BS_Khomas_2009	127	2009	Wet	B. Strohbach	Northern and western Khomas	
9565–9598	Auas_W+B_2004	34	2004	Normal	A. Burke & M. Wittneben	Auas Mountain Range	(Burke & Wittneben 2007; Strohbach 2017)
10192–10221	CM_Windhoek-townlands	30	2009	Wet	C. Mannheimer	Windhoek Townlands	
10612–10632	BS_Narais_2011	21	2011	Wet	B. Strohbach	Narais observatory	BIOTA observatory (Jürgens et al. 2010)
11475–11540	BS_Midgard-2014	66	2014	Extreme wet	B. Strohbach	Midgard Country Estate (south)	
70001–70028	Ovitoto_2001	28	2001	Normal	T. Sheuyange	Ovitoto Observatory	BIOTA observatory (Jürgens et al. 2010)

(2007) covered extreme, inaccessible habitats, making the data invaluable for the completeness of this study.

All other surveys followed the guidelines of the Vegetation Survey of Namibia project, i.e. were surveyed on a 20 × 50 m (1 000 m^2) plot, whilst plot layout was restricted to a specific habitat. In cases where the nature of the habitat did not allow a 20 m × 50 m sized plot (e.g. riverine habitats, rock outcrops), the plot shape was adapted to fit the habitat, without reducing the size, nor moving into a different habitat. The size of 20 × 50 m was chosen as suitable for an arid savanna and conforms to size criteria proposed by Brown et al. (2013). For these relevés, the position as determined by GPS, as well as habitat descriptors related to landscape, topography, lithology and stone cover have been noted.

Unknown species were collected for identification in the National Herbarium of Namibia (WIND). Species' nomenclature follows Klaassen and Kwembeya (2013), with the exception of the genus *Acacia s.l.*, for which Kyalangalilwa et al. (2013) was followed.

Classification procedures

An initial classification was done using modified TWINSPAN (Roleček et al. 2009), with average Sørensen as distance measure, and utilising pseudospecies cut levels at 0 and 5% cover to differentiate between low-cover desert margin vegetation and inland vegetation at higher cover values. This classification was based on synusial data (i.e. trees, shrubs, dwarf shrubs and grasses only) (Gillet & Julve 2018), and resulted in three clusters. These clusters were interpreted as representing the Pre-Namib and Escarpment zone, the central Khomas Hochland as well as a third group comprising riverine habitats and lowlands surrounding the Khomas Hochland. This classification result was used to split the data set into three subsets for further analysis.

The three clusters were further classified using the modified TWINSPAN classification algorithm, always using average Sørensen as distance measure, and utilising pseudospecies. For the Pre-Namib/Escarpment zone cluster, these were kept at 0 and 5%; for the other clusters cut levels were set at 0 and 10%. This difference in pseudospecies cut levels was necessary because the Pre-Namib has an inherent lower vegetation cover than the inland vegetation. In the case of Cluster 3 (riverine and lowland habitats), the data set was again split into two subsets after an initial classification using synusial data. The level of splitting was determined using peaks in crispness values (Botta-Dukát et al. 2005).

The classification of the clusters using synusial data was transferred to the full data set. Analysis of the resulting clusters revealed partial mixing of relevés between associations, or in several cases, known units to be included in other associations. This prompted a refinement of the classification results using Cocktail procedures (Bruelheide & Flintrop 1994; Bruelheide 1997), based on existing descriptions (e.g. Kellner 1986; Strohbach 2017), or on field observations. A detailed account of these Cocktail refinements is presented in the Results section of this paper.

Once an ecologically interpretable result was achieved, phytosociological tables were compiled and the synopsis for various associations extracted. Diagnostic species were determined using the phi coefficient of association (Chytrý et al. 2002). For this calculation the numbers of relevés were standardised following Tichý and Chytrý (2006). Species with phi ≥ 40 were considered as diagnostic and with phi ≥ 60 as highly diagnostic; however, species with a non-significant fidelity at $\alpha = 0.05$ using Fisher's exact test were omitted. Species occurring with at least a 60% frequency were regarded as constant and with at least an 80% frequency as highly constant.

Further descriptors of the associations

The average structure for each grouping (i.e. average tree, shrub, dwarf shrub, perennial grass, annual grass and herb cover) was calculated using the available growth form data. Descriptions follow Edwards (1983). For the species density (number of species per 1 000 m^2), the relevé data from Kellner (1986) were excluded, as these were sampled on 625 m^2 plots (25 $\times$ 25 m), not 1 000 m^2 plots as for all other relevés. In addition, an estimate of potential species richness for the association has been calculated with a first order Jackknife as proposed by Heltshe and Forrester (1983) as well as Palmer (1990).

Higher syntaxonomy

Due to the extensive refining of clusters with Cocktail, partially resulting in splitting of clusters or the definition of new clusters, the initial classification dendrograms could not be used as an indication of higher-order syntaxonomy as is customary (e.g. Luther-Mosebach et al. 2012). Instead, synoptic tables of the associations were prepared using percentage frequency for all four classifications. The synopsis of each association was taken as a pseudo-relevé, and these were combined into a single data set for classification with modified TWINSPAN (Roleček et al. 2009). No pseudospecies were used for this classification. This approach follows broadly the approached used by Winterbach et al. (2000).

Results

First classification results and Cocktail refinements

The first classification resulted in three major vegetation zones, namely the Pre-Namib and Escarpment zone, the Khomas Hochland proper and the riverine habitats and lowlands vegetation surrounding the Khomas Hochland. The latter was further subdivided into two subsets for further classification. Cocktail refinements were necessary on all four clusters. Details of these refinements are provided in Table 2.

Pre-Namib and Escarpment zone

The vegetation of the Pre-Namib (*Vornamib sensu* Giess (1962, 1998) and Escarpment zone is dominated by the plant families Poaceae, Fabaceae, Bignoniaceae and Burseraceae, in descending order of importance. The classification resulted in seven associations, which are formally described according to the International Code of Phytosociological Nomenclature (Weber et al. 2000). The synoptic table for these is presented in Appendix 1, and the phytosociological table in Appendix 2, available online only (DOI: http://dx.doi.org/10.38201/btha.abc.v51.i2.s4a, DOI: http://dx.doi.org/10.38201/btha.abc.v51.i2.s4b).

Within the synopsis, basic statistics on the association (or other syntaxa) are given, as derived from the analysis of clusters in Juice. Highly diagnostic species (with phi coefficient >60) and highly constant species (occurring in more than 80% of relevés) are indicated in **bold**. All structural descriptions follow Edwards (1983). Landscape descriptors follow conventions of the Digital

Table 2. Refinements necessary to the classification results for improved ecological interpretability

Unit changed	Selection based on following criteria	Relevés involved	Based on
Cluster 1: Pre-Namib and Escarpment zone: This data cluster consisted of 279 relevés and 329 species. The synusial data had only 121 species. Classification of this subset resulted in five clusters, which were refined as follows:			
Karpfenkliffs (Association 1.1)	*Adenolobus pechuelii, Enneapogon desvauxii, Fagonia isotricha*	8 relevés from Cluster 1	Field observations
Rostock sand drift plains (Association 1.3)	*Crotalaria podocarpa, Sesuvium sesuvioides, Crinum macowani, Kohautia caespitosa, Stipagrostis obtusa, Grielum sinuatum*	7 relevés from Cluster 1	Field observations
Gravel plains of Pre-Namib (Association 1.2)		Remainder of Cluster 1	
Cluster 2: Khomas Hochland proper: This data cluster consisted of 350 relevés with 588 species. The synusial data set had only 198 species. Classification of this subset resulted in five clusters. Refinements were done as follows:			
Steep cliff faces (Association 2.2)	*Ficus ilicina*, *Pennisetum foermeranum*, *Steganotaenia araliacea*. A minimum of two of these species had to be present	5 relevés from Cluster 4 (rock outcrops)	Kellner 1986
Cluster 3 *senso lato*	*Osyris lanceolata, Hypoestes forskaolii, Danthoniopsis ramosa*	13 relevés from Cluster 5	Strohbach 2017
High altitude mountain veld of the south-facing slopes (Association 2.3)	*Jamesbrittenia pallida, Selago alopecuroides, Frankenia pomonensis, Eriocephalus dinteri*	Split from Cluster 3 (8 relevés)	Strohbach 2017
High altitude mountain veld of the north-facing slopes (Association 2.4)	*Selago angustibractea, Lopholaena cneorifolia, Cheilanthes multifida, Babiana hypogea, Eriocephalus scariosus* and *Adromischus* species	Split from Cluster 3 (8 relevés)	Strohbach 2017
Mid-altitude mountain veld (Association 2.5)		Remainder of Cluster 3	
Oamites mountain veld (Association 2.7)	*Ornithoglossum calcicola* and *Melhania damarana*	Split from Cluster 5 (9 relevés)	Strohbach 2017
Khomas Hochland mountain veld (Association 2.8)		Remainder of Cluster 5	
Cluster 3: Riverine habitats: This data cluster consisted of 59 relevés and 304 species. The synusial data contained only 114 species. Classification of this subset resulted in eight clusters. Due to high intrinsic variation however, not all associations were ecological interpretable, and extensive refinement, including partial recombination of relevés into associations was necessary.			
Dry riverbeds (Association 3.2)		Recombined clusters 2, 3 and 4 as one	
Cluster 5 *senso lato*	High abundance of *Stipagrostis namaquensis*	Split into two	
Riverine sand banks (Association 3.3)	High abundance of *Stipagrostis namaquensis*	Cluster 5A (3 relevés), as well as 1 relevé from Cluster 7 and 1 relevé from Cluster 8	Strohbach 2017
Inland riparian woodlands (Association 3.5)	High abundance of *Vachellia karroo*	Clusters 5B and 6, as well as several relevés from the surrounding lowlands (Cluster 4, mostly relevés sampled by Kellner (1986)) found to fit into this group. These were manually moved here.	Strohbach 2017; Kellner 1986

Table 2. Refinements necessary to the classification results for improved ecological interpretability (continued)

Unit changed	Selection based on following criteria	Relevés involved	Based on
Cluster 3: Riverine habitats (continued)			
Omirimbi vegetation (Association 3.4)	Manual selection according to habitat description, verified with Cocktail based on *Tragus berteronianus, Schmidtia pappophoroides, Themeda triandra, Talinum caffrum, Platycarphella carlinoides, Monsonia angustifolia, Microchloa caffra, Chloris virgata*	Remainder of clusters 5 and 6, but weakly defined	Volk & Leippert 1971; Strohbach 2017
Riparian woodlands of the westerly rivers (Association 3.6)	*Tamarix usneoides, Salvadora persica, Euclea pseudebenus, Stipagrostis hochstetteriana* and *Faidherbia albida*	Cluster 7 (remainder) and 1 relevé from Cluster 6	Field observations
Big inland rivers (Association 3.8) and Omeya plains vegetation (Association 4.7)	Geographical location and habitat	Several relevés grouped into Cluster 8 (big inland rivers) were found to belong to the Omeya plains according to their location. These were manually moved to the data subset of Cluster 4, Association 4.7	
Cluster 4: Lowlands surrounding the Khomas Hochland: This data cluster consisted of 462 relevés and 688 species. The synusial data set contained only 227 species. Classification of this data set resulted in ten clusters. On closer inspection, these were found to be fairly mixed due to the synusial data reduction, requiring extensive refinement through Cocktail procedures as follows:			
Oanob Plateau (Association 4.2)	*Panicum lanipes, Plinthus sericeus, Pteronia eenii, Pentzia incana* and *Blepharis integrifolia*	Clusters 2 and 3	Strohbach 2017
Cluster 3 *senso lato* (weakly defined)		Remainder of clusters 2 and 3	
Gölschau plains (Association 4.3)	*Aptosimum spinescens, Eriocephalus ericoides, Geigeria pectidea* and *Galenia africana*	From Cluster 3 *senso lato*	Field observations
Southern Khomas (Association 4.4)	*Aizoon schellenbergii, Panicum arbusculum, Hibiscus discophorus, Kohautia cynanchica* and *Aptosimum albomarginatum*	From Cluster 3 *senso lato*	Strohbach 2017
Degraded/bush encroached vegetation of the Khomas Hochland (Sub-association 4.8.1)		Remainder of Cluster 3 *senso lato*, combined with Cluster 9	Strohbach 2017
Khomas Hochland lowlands (Association 4.6)	*Senegalia erubescens, Combretum apiculatum, Grewia flavescens* and *Dichrostachys cinerea* (minimum of two species, with high abundance of *Senegalia erubescens*)	Cluster 5, with extra relevés from Cluster 10	Field observations
Khomas Hochland lowlands (Sub-association 4.8.1)	*Vachellia reficiens* at high abundance	Remainder of Cluster 10, excluding clusters 8 and 9	Field observations
Khomas Hochland lowlands (Association 4.8)		The recombined Clusters 7 and 10, as well as the original Clusters 8 and 9 were recognised as sub-associations of association 4.8.	

Soil and Terrain Database (SOTER) of FAO (FAO 1993). Specifically, the following slope classes apply:

- Flat: 0–1° / 0–2%
- Gently undulating: 1–3° / 2–5%
- Undulating: 3–6° / 5–10%
- Rolling: 6–9° / 10–15%
- Moderately steep: 9–17° / 15–30%
- Steep: 17–30° / 30–60%
- Very steep: >30° / >60%

This format is also followed for all further descriptions in this paper.

1.1 *Enneapogono desvauxii–Adenoloboetum pechuelii* ass. nov.

Synopsis:
Number of relevés: 8
Type relevé: 2065 (holotype), sampled on 15 March 2005 at 23°28′01″S, 16°05′22″E
Number of species observed: 27
Estimated number of species: 46
Average species density per 1 000 m^2: 14

Diagnostic species: ***Adenolobus pechuelii, Fagonia isotricha* var. *isotricha,*** *Enneapogon desvauxii, Indigofera auricoma*

Constant species: ***Euphorbia glanduligera, Eragrostis nindensis, Stipagrostis hirtigluma,*** *Tribulus zeyheri*

These low desert herblands (Figures 4A and 5B) are dominated by *Eragrostis nindensis* and *Enneapogon desvauxii*. This association occurs on old eroded fluvial deposits commonly referred to as 'Karpfenkliff Conglomerate' (Ward 1987) along the upper reaches of the Kuiseb and Gaub canyons, with altitudinal ranges between 800 and 1 100 m asl. The substrate consists of carbonate-cemented conglomerates, which are between 40 and 60 m deep. The erosion of these conglomerates results in a steeply dissected hill landscape. Low rainfall (between 100 and 150 mm Mean Annual Precipitation – MAP), high runoff and a compact substrate allowing little infiltration result in this depauperated form (diversity- and cover-wise) of the *Enneapogono desvauxii–Eragrostietum nindensis*. Because of its unique habitat, it is recognised as an association.

1.2 *Enneapogono desvauxii–Eragrostietum nindensis* ass. nov.

Synopsis:
Number of relevés: 82
Type relevé: 9439 (holotype), sampled on 10 March 2009 at 22°54′06″S, 16°37′36″E
Number of species observed: 64
Estimated number of species: 111
Average species density per 1 000 m^2: 16

Diagnostic species: *Enneapogon desvauxii*

Constant species: ***Eragrostis nindensis, Tribulus zeyheri,*** *Euphorbia glanduligera, Stipagrostis ciliata, Stipagrostis hirtigluma*

These low desert grasslands (sometimes rather desert shrublands) are dominated by *Eragrostis nindensis* and various other grass, herb and dwarfshrub species (Figures 4B and 5B). This association occurs on the expansive calcrete gravel plains of the Pre-Namib and has been described by Jürgens et al. (2013) as 'eastern calcrete plains grasslands'. The altitude ranges between 780 and 1 300 m asl, and the landscape is generally flat. MAP ranges between 50 and 150 mm, but because of the reduced run-off and looser substrate, this association is far more species rich compared to the *Enneapogono desvauxii–Adenoloboetum pechuelii* (depending on the quality of the rainfall season).

1.3 *Crotalario podocarpae–Stipagrostioetum obtusae* ass. nov.

Synopsis:
Number of relevés: 7
Type relevé: 1997 (holotype), sampled on 19 February 2004 at 23°20′49″S, 15°56′58″E
Number of species observed: 23
Estimated number of species: 34
Average species density per 1 000 m^2: 11

Diagnostic species: ***Crotalaria podocarpa, Stipagrostis obtusa,*** *Sesuvium sesuvioides, Grielum sinuatum, Crinum macowanii, Kohautia caespitosa* subsp. *brachyloba, Limeum myosotis, Stipagrostis ciliata*

These short open grasslands are dominated by *Stipagrostis ciliata* and *Stipagrostis obtusa* (Figures 4C and 5C), occurring on sand drift plains in the Pre-Namib. Striking examples are found along the western end of the C26 main road before joining the C14. The topography is an undulating sand drift plain, ranging between 1 050 and 1 100 m asl. This area receives between 50 and 100 mm MAP.

1.4 *Tribulocarpo dimorphantho–Vachellietum eriolobae* ass. nov.

Synopsis:
Number of relevés: 4
Type relevé: 2013 (holotype), sampled on 20 February 2004 at 23°15′57″S, 16°07′28″E
Number of species observed: 22
Estimated number of species: 26
Average species density per 1 000 m^2: 15

Diagnostic species: ***Xenostegia tridentata* subsp. *angustifolia, Requienia sphaerosperma, Harpagophytum***

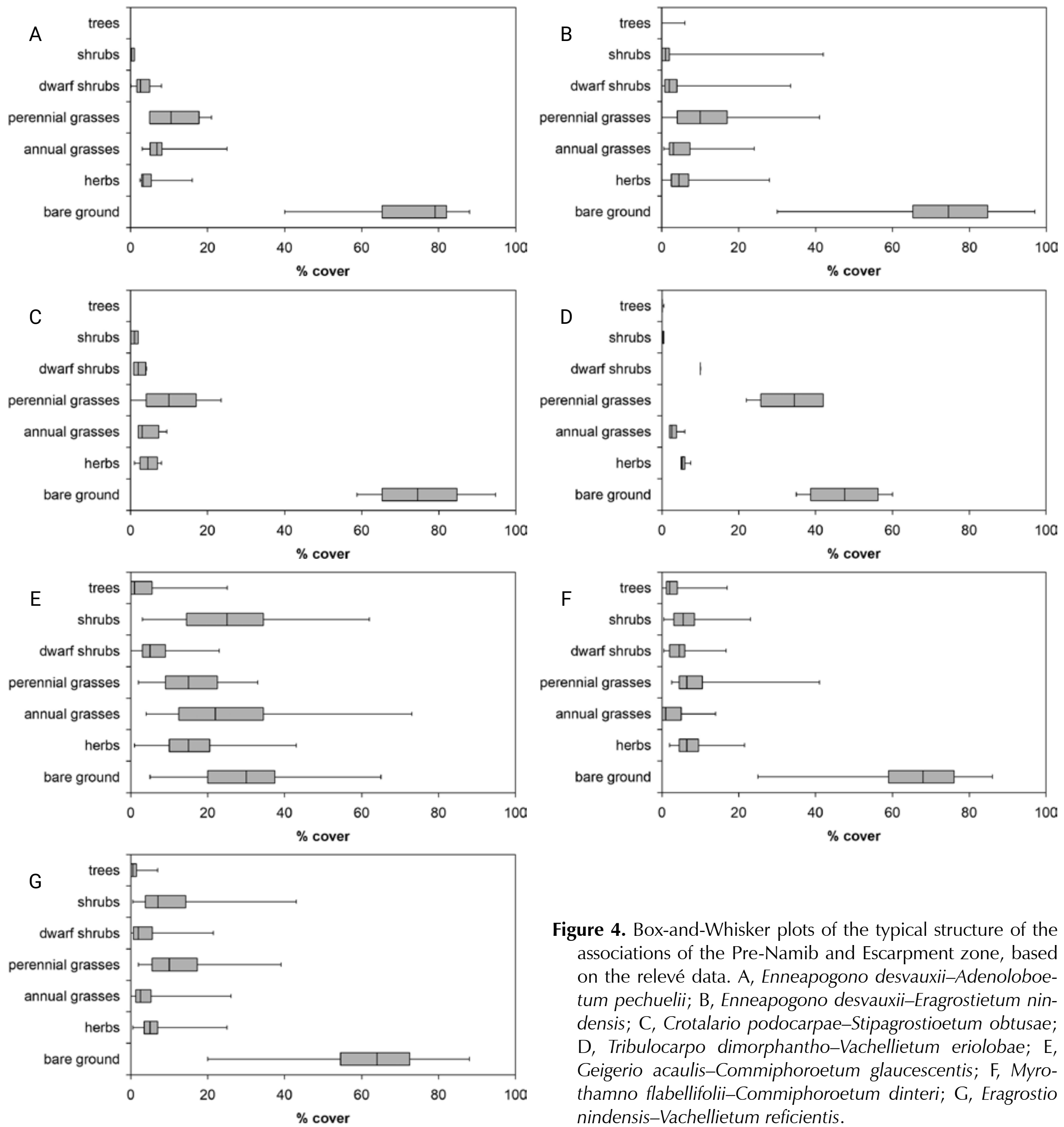

Figure 4. Box-and-Whisker plots of the typical structure of the associations of the Pre-Namib and Escarpment zone, based on the relevé data. A, *Enneapogono desvauxii–Adenoloboetum pechuelii*; B, *Enneapogono desvauxii–Eragrostietum nindensis*; C, *Crotalario podocarpae–Stipagrostioetum obtusae*; D, *Tribulocarpo dimorphantho–Vachellietum eriolobae*; E, *Geigerio acaulis–Commiphoroetum glaucescentis*; F, *Myrothamno flabellifolii–Commiphoroetum dinteri*; G, *Eragrostio nindensis–Vachellietum reficientis*.

procumbens, Hermannia guerkeana, Oxygonum alatum, Tribulocarpus dimorphanthus, Brachiaria glomerata, Ipomoea magnusiana, Vachellia erioloba, *Gisekia africana, Centropodia glauca, Stipagrostis hochstetteriana, Dicoma capensis, Stipagrostis ciliata, Heliotropium nelsonii*

Constant species: *Stipagrostis uniplumis* var. *uniplumis*

This short desert woodland is dominated by *Stipagrostis uniplumis* var. *uniplumis* and *Stipagrostis ciliata* with a scattered cover of *Vachellia erioloba* trees (Figures 4D and 5D). It is situated further inland from the *Crotalario podocarpae–Stipagrostioetum obtusae* in the valleys below the escarpment at an altitudinal range of between 1 200 and 1 250 m. The substrate is aeolian Kalahari sands, thus supporting typical Kalahari elements like *Vachellia erioloba, Brachiaria glomerata, Requienia sphaerosperma* and *Harpagophytum procumbens*. MAP ranges between 100 and 150 mm.

1.5 *Geigerio acaulis–Commiphoroetum glaucescentis* ass. nov.

Synopsis:

Number of relevés: 59
Type relevé: 9467 (holotype), sampled on 12 March 2009 at 22°21′16″S, 15°49′55″E
Number of species observed: 165

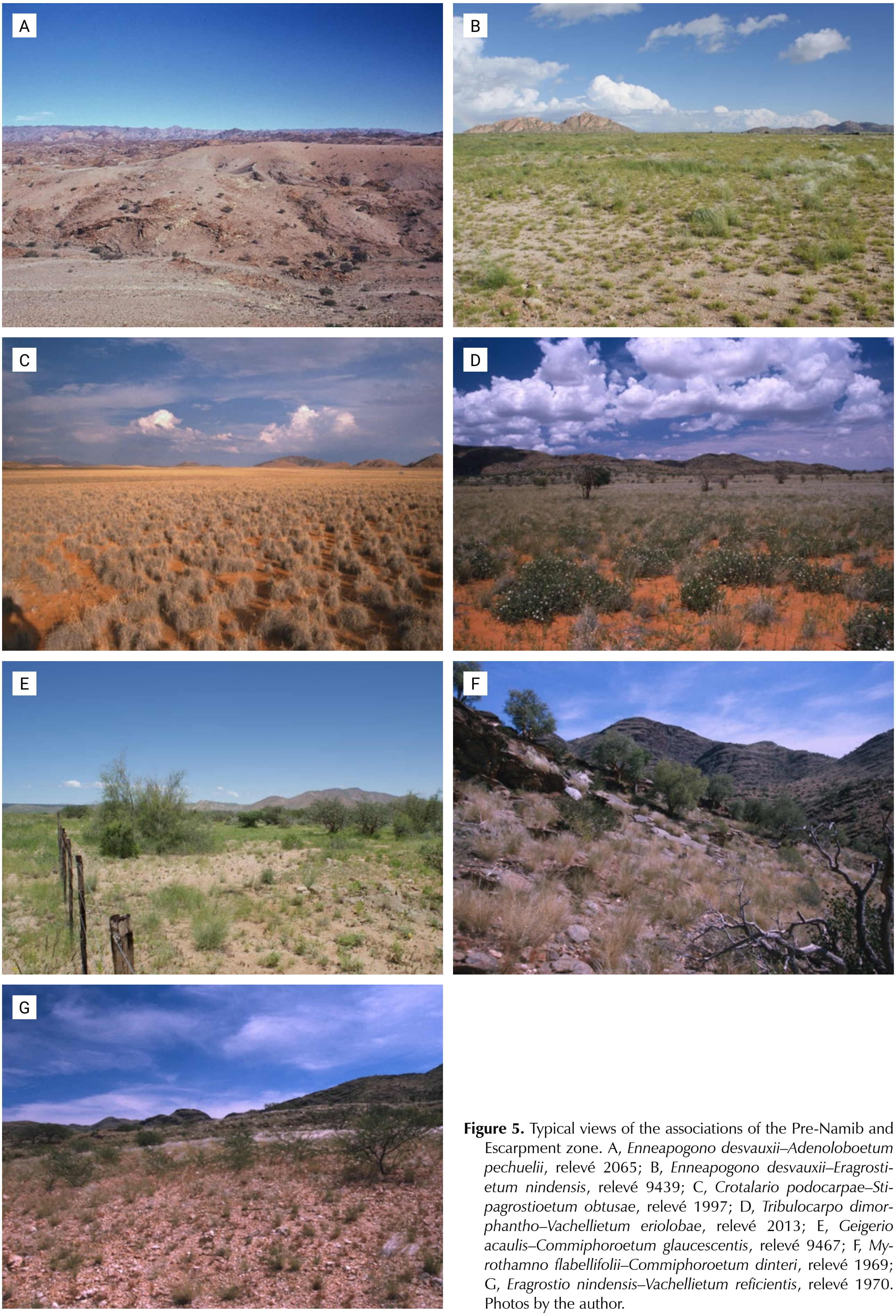

Figure 5. Typical views of the associations of the Pre-Namib and Escarpment zone. A, *Enneapogono desvauxii–Adenoloboetum pechuelii*, relevé 2065; B, *Enneapogono desvauxii–Eragrostietum nindensis*, relevé 9439; C, *Crotalario podocarpae–Stipagrostioetum obtusae*, relevé 1997; D, *Tribulocarpo dimorphantho–Vachellietum eriolobae*, relevé 2013; E, *Geigerio acaulis–Commiphoroetum glaucescentis*, relevé 9467; F, *Myrothamno flabellifolii–Commiphoroetum dinteri*, relevé 1969; G, *Eragrostio nindensis–Vachellietum reficientis*, relevé 1970. Photos by the author.

Estimated number of species: 214
Average species density per 1 000 m^2: 33

Diagnostic species: ***Schmidtia kalahariensis, Aristida adscensionis, Melinis repens* subsp. *grandiflora,*** *Lycium bosciifolium, Aristida effusa, Eragrostis porosa, Enneapogon cenchroides, Geigeria acaulis, Albizia anthelmintica, Aptosimum arenarium, Merremia bipinnatipartita, Senegalia erubescens, Grewia tenax, Kyphocarpa angustifolia*

Constant species: ***Stipagrostis uniplumis* var. *uniplumis,*** *Eragrostis nindensis, Stipagrostis hochstetteriana, Boscia foetida, Vachellia reficiens*

These semi-open high shrublands are strikingly characterised by scattered trees of *Commiphora glaucescens* (Figures 4E and 5E). They occur on the slightly undulating plains surrounding Otjimbingwe, on Donkerhuk granites, north of the central Khomas Hochland complex. Typical for these granite-derived soils in arid environments is a very high (80% or more) cover by granitic gravel. The altitude ranges between 900 and 1 300 m asl, whilst MAP ranges between 150 and 250 mm.

1.6 *Myrothamno flabellifolii–Commiphoroetum dinteri* ass.nov.

Synopsis:
Number of relevés: 42
Type relevé: 1968 (holotype), sampled on 18 February 2004 at 23°01′49″S, 16°07′24″E
Number of species observed: 123
Estimated number of species: 173
Average species density per 1 000 m^2: 29

Diagnostic species: ***Commiphora dinteri,*** *Forsskaolea viridis, Sterculia africana, Myrothamnus flabellifolius, Cheilanthes hirta, Talinum caffrum, Commiphora glaucescens, Elephantorrhiza suffruticosa, Calostephane marlothiana, Monechma spartioides, Blepharis obmitrata, Setaria appendiculata, Amphiasma divaricatum, Triraphis ramosissima, Dyerophytum africanum, Barleria lancifolia*

Constant species: ***Stipagrostis uniplumis* var. *uniplumis, Eragrostis nindensis,*** *Tribulus zeyheri, Tephrosia dregeana* var. *dregeana*

These low open bushlands are characterised by a variety of stem succulents typical of the escarpment zone (Figures 4F and 5F). They occur on the inselberg ranges along the Pre-Namib fringes as well as the lower escarpment zone, at an altitudinal range between 1 050 and 1 500 m asl. The topography consists of steep mountain slopes generally with a gradient of well above 30%, as well as with considerable stone cover (up to 80%), mostly small, medium and large stones. MAP ranges between 100 and 200 mm.

1.7 *Eragrostio nindensis–Vachellietum reficientis* ass. nov.

Synopsis:
Number of relevés: 77
Type relevé: 1970 (holotype), sampled on 18 February 2004 at 23°02′24″S, 16°08′18″E
Number of species observed: 97
Estimated number of species: 153
Average species density per 1000 m^2: 23

Diagnostic species: none

Constant species: ***Eragrostis nindensis, Stipagrostis uniplumis* var. *uniplumis, Euphorbia glanduligera,*** *Tribulus zeyheri, Entoplocamia aristulata, Catophractes alexandri, Monsonia senegalensis, Leucosphaera bainesii*

These tall open shrublands are dominated by *Stipagrostis uniplumis* var. *uniplumis, Vachellia reficiens, Catophractes alexandri, Eragrostis nindensis, Enneapogon desvauxii, Aristida adscensionis* and *Senegalia erubescens* (Figures 4G and 5G). They occur on rolling to moderately steep (10–30%) plains and footslopes of the escarpment, often occurring far inland in valleys of the escarpment. Stone cover is not as high, roughly 40%, again mostly small, medium and large stones. The altitude ranges between 950 and 1 400 m asl, whilst MAP ranges between 100 and 250 mm.

Khomas Hochland proper

The vegetation of the Khomas Hochland is dominated by the plant families Poaceae, Asteraceae, Fabaceae and Scrophulariaceae. The classification resulted in eight associations, which are formally described according to the International Code of Phytosociological Nomenclature (Weber et al. 2000) below (with one exception). The synoptic table for these is presented in online Appendix 1, and the phytosociological table in online Appendix 2.

2.1 *Digitario erianthae–Euryopietum walterorum* ass. nov.

Synopsis:
Number of relevés: 6
Type relevé: 1838 (holotype), sampled on 9 February 2004 at 23°20′19″S, 16°13′50″E
Number of species observed: 44
Estimated number of species: 70
Average species density per 1 000 m^2: 15

Diagnostic species: ***Panicum lanipes, Euryops walterorum, Eriospermum bakerianum* subsp. *bakerianum,*** *Hypertelis salsoloides, Boophone disticha*

Constant species: ***Eragrostis nindensis, Digitaria eriantha***

This moderately closed, short shrubland is dominated by the name-giving *Euryops walterorum, Eriocephalus dinteri* and *Digitaria eriantha* (Figures 6A and 7A). The occurrence of *Euryops walterorum* is restricted to the Gamsberg Plateau (i.e. a limited-range endemic) (Nordenstam 1966; Loots 2005), which is 210 ha in size. The plateau consists of a fine-grained quartzite layer ± 30 m thick, at an altitude 2 347 m asl (Wittig 1976; Schalk 1983). The topography is near flat but displays a conspicuous cover by large stones of roughly 40%. The plateau receives an estimated 150 mm MAP, based on general rainfall maps (Mendelsohn et al. 2002). This, however, does not take any possible orographic effects into account.

2.2 *Pennisetum foermerianum–Ficus ilicina* association

Synopsis:
Number of relevés: 6
Number of species observed: 97
Estimated number of species: 161
Average species density per 1 000 m^2: 23

Diagnostic species: ***Ficus ilicina, Pennisetum foermerianum, Steganotaenia araliacea* var. *araliacea,*** *Bulbostylis hispidula, Hermannia tigrensis, Datura inoxia, Cyphostemma hereroense, Calostephane divaricata, Eragrostis porosa, Sporobolus fimbriatus, Boscia albitrunca, Cheilanthes marlothii, Ozoroa crassinervia, Pupalia lappacea*

Constant species: ***Tarchonanthus camphoratus, Searsia marlothii, Combretum apiculatum* subsp. *apiculatum,*** *Triraphis ramosissima, Melinis repens* subsp. *grandiflora, Enneapogon cenchroides, Senegalia hereroensis*

This association is difficult to assign to a structural type, as the vertical dimension is dominated by the habitat, being near-vertical rock faces (Figures 6B and 7B). Most woody species have a shrub-like habit, making it essentially a short, semi-open shrubland. However, e.g. *Ozoroa crassinervia* grows to a distinct tree. This association occurs on steep rock faces throughout the central Khomas Hochland. Kellner (1986) includes this in his *Pennisetum foermerianum–Dombeya rotundifolia* association, even though it is, based on its habitat and species composition, distinctly different. Due to the low sampling density and inherent variability it is not described formally.

2.3 *Eriocephalo dinteri–Danthoniopietum ramosae* ass. nov.

Synopsis:
Number of relevés: 8
Type relevé: 9595 (holotype)
Number of species observed: 69
Estimated number of species: 93
Average species density per 1 000 m^2: 27

Diagnostic species: ***Jamesbrittenia pallida, Selago alopecuroides, Eriocephalus dinteri, Frankenia pomonensis, Senecio inaequidens, Cheilanthes hirta,*** *Leucas glabrata, Hypoestes forskaolii, Namacodon schinzianum, Danthoniopsis ramosa, Lepidium africanum, Kalanchoe* species

Constant species: ***Digitaria eriantha,*** *Oxalis purpurascens, Tarchonanthus camphoratus, Eragrostis scopelophila, Eragrostis nindensis*

These short, closed grasslands have a dense cover of perennial grasses like *Digitaria eriantha, Eragrostis scopelophila, Danthoniopsis ramosa* and *Andropogon chinensis* (Figure 6C). Scattered *Tarchonanthus camphoratus* and *Senegalia hereroensis* shrubs also occur. This association occurs on the very steep (> 60%) southern slopes of the Auas Mountain range, at altitudes from 2 150 m asl upwards (Burke & Wittneben 2007; Strohbach 2017). MAP is about 350 mm (Mendelsohn et al. 2002), again not taking any orographic effects into account.

2.4 *Danthoniopio ramosae–Oleoetum africanae* ass. nov.

Synopsis:
Number of relevés: 8
Type relevé: 9592 (holotype), sampled on 13 March 2004 at 22°37′05″S, 17°13′14″E
Number of species observed: 122
Estimated number of species: 151
Average species density per 1 000 m^2: 63

Diagnostic species: ***Selago angustibractea, Lopholaena cneorifolia, Cheilanthes multifida, Calostephane marlothiana, Adromischus* species, *Monsonia burkeana, Anthospermum rigidum, Hypoxis iridifolia, Eriocephalus scariosus, Babiana hypogea, Brachiaria serrata, Diospyros ramulosa, Thesium lacinulatum, Wahlenbergia denticulata, Ebracteola montis-moltkei, Tristachya superba, Silene burchellii* var. *burchellii, Helichrysum obtusum, Felicia muricata, Olea europaea* subsp. *africana, Polygala uncinata, Cineraria canescens, Cymbopogon caesius, Kalanchoe brachyloba, Stoebe plumosa, Osteospermum montanum,*** *Leonotis ocymifolia, Anthospermum* species, *Osyris lanceolata, Searsia tenuinervis, Pegolettia retrofracta, Sida ovata, Dicoma anomala, Danthoniopsis ramosa, Ipomoea obscura* var. *obscura, Sphedamnocarpus pruriens* subsp. *pruriens, Fockea angustifolia, Hypoestes forskaolii, Themeda triandra, Ornithoglossum*

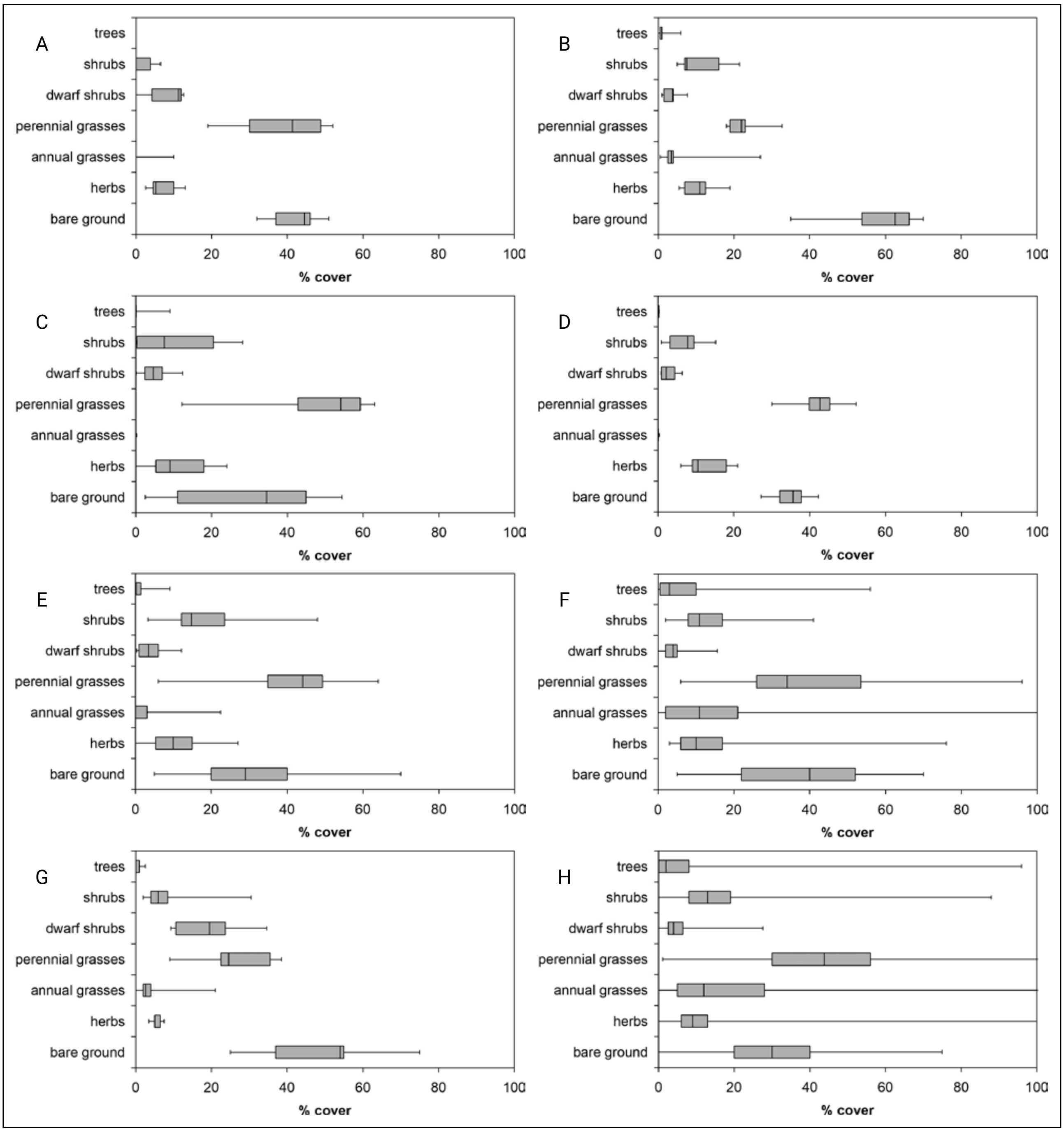

Figure 6. Box-and-Whisker plots of the typical structure of the associations of the Khomas Hochland Proper, based on the relevé data. A, *Digitario erianthae–Euryopietum walterorum*; B, *Pennisetum foermerianum–Ficus ilicina* association; C, *Eriocephalo dinteri–Danthoniopietum ramosae*; D, *Danthoniopio ramosae–Oleoetum africanae*; E, *Senegalio hereroensis–Tarchonanthoetum camphorati*; F, *Triraphio ramosissimae–Manuleopsietum dinteri*; G, *Ornithoglosso calcicolae–Fingerhuthioetum africanae*; H, *Brachiario nigropedatae–Senegalietum hereroensis*.

vulgare, Gladiolus saccatus, Rhynchosia totta, Cymbopogon pospischilii, Andropogon chinensis, Jamesbrittenia lyperioides, Crassula capitella, Cotyledon orbiculata, Gymnosporia buxifolia, Ocimum americanum var. *americanum, Moraea polystachya, Hebenstretia integrifolia, Cyperus margaritaceus, Boophone disticha, Gladiolus permeabilis* subsp. *edulis, Euphorbia spartaria, Aptosimum lineare, Hibiscus trionum, Heliophila carnosa, Solanum delagoense, Jamesbrittenia huillana*

Constant species: ***Digitaria eriantha, Senegalia hereroensis, Tarchonanthus camphoratus, Oxalis purpurascens, Eragrostis nindensis,*** *Pellaea calomelanos, Eragrostis scopelophila, Chascanum pinnatifidum, Searsia marlothii, Melinis repens* subsp. *repens, Heteromorpha arborescens, Commelina africana*

This association is best described as a short, closed grassland dominated by *Danthoniopsis ramosa* and *Heteropogon contortus*, with some sparse shrub cover.

Shrubs also occur only on the lower reaches, whilst the mountain tops are distinctly grass covered (Figures 6D and 7C). It occurs on the northern face of the Auas Mountain range at an altitudinal range of 2 200 m asl and above (Burke & Wittneben 2007; Strohbach 2017). The soil surface is rock-strewn, with quarzite boulders and solid rock of the Auas formation (Geological Survey 1980; South African Committee for Stratigraphy 1980). MAP is between 350 and 400 mm, without taking any orographic effects into account.

2.5 *Senegalio hereroensis–Tarchonanthoetum camphorati* ass. nov.

Synopsis:

Number of relevés: 22
Type relevé: 1123 (holotype), sampled on 25 April 2002 at 22°48′34″S, 17°02′00″E
Number of species observed: 171
Estimated number of species: 237
Average species density per 1 000 m^2: 43

Diagnostic species: *Sida chrysantha, Phyllanthus species, Brachiaria nigropedata, Dyschoriste pseuderecta*

Constant species: ***Senegalia hereroensis, Tarchonanthus camphoratus, Pellaea calomelanos,*** *Melinis repens* subsp. *repens, Heteropogon contortus, Eragrostis scopelophila, Eragrostis nindensis, Digitaria eriantha, Searsia marlothii, Hypoestes forskaolii*

This tall, semi-open shrubland is dominated by *Tarchonanthus camphoratus, Searsia marlothii* and *Senegalia hereroensis*, with the grasses *Brachiaria nigropedata, Eragrostis scopelophila* and *Digitaria eriantha* dominating the grass layer (Figures 6E and 7D). This association occurs on the Auas Mountain and Lichtenstein ranges at mid-altitude, between 2 000 and 2 300 m asl. No evidence could be found for a differentiation between north- and south-facing sides of the mountains, unlike reported by Burke and Wittneben (2007) or Strohbach (2017). These slopes are steep (30–60%) with considerable quartzite stone cover, especially medium to large stones, even rocks (± 80% stone and rock cover), of the Auas formation.

2.6 *Triraphio ramosissimae–Manuleopsietum dinteri* ass. nov.

Synopsis:

Number of relevés: 53
Type relevé: 1011 (holotype), sampled on 16 March 2000 at 22°46′43″S, 16°46′41″E
Number of species observed: 170
Estimated number of species: 258
Average species density per 1 000 m^2: 32

Diagnostic species: *Pennisetum foermerianum, Triraphis ramosissima*

Constant species: ***Cheilanthes marlothii, Searsia marlothii, Cenchrus ciliaris,*** *Melinis repens* subsp. *grandiflora, Eragrostis nindensis, Enneapogon cenchroides, Anthephora pubescens, Stipagrostis uniplumis* var. *uniplumis*

Typical for this short, semi-open shrubland are trees and shrubs of *Combretum apiculatum* subsp. *apiculatum, Ozoroa crassinervia, Dombeya rotundifolia* and occasionally *Euphorbia avasmontana*, together with other highland savanna species. The grass layer is also dominated by rock-specialists like *Pennisetum foermerianum, Triraphis ramosissima, Eragrostis scopelophila* and *Danthoniopsis ramosa* (Figures 6F and 7E). This association occurs on smaller mica-schist rock outcrops common within the central Khomas Hochland, as part of the Kuiseb formation. These are normally between 10 × 10 to over 50 × 50 m in surface area, but always broken, never solid rock faces. Due to the nature of the rock beds of the Khomas Hochland, many of these rock outcrops face south (but not exclusively). Altitude ranges between 1 600 and 1 800 m asl, whilst MAP ranges between 250 and 400 mm.

Kellner (1986) distinguishes two forms of this association, being a *Pennisetum foermerianum–Dombeya rotundifolia* community on broken rock outcrops, as well as a *Triraphis ramosissima–Combretum apiculatum* community on more solid, platy rock outcrops, generally also with more gentle slopes. This subdivision was neither confirmed in this study, nor by Strohbach (2017). Volk and Leippert (1971) also describe a *Combretum apiculatum–Eragrostis scopelophila* association, unfortunately without proper synopsis.

2.7 *Ornithoglosso calcicolae–Fingerhuthioetum africanae* ass. nov.

Synopsis:

Number of relevés: 9
Type relevé: 1095 (holotype), sampled on 23 April 2002 at 22°58′29″S, 17°07′00″E
Number of species observed: 98
Estimated number of species: 136
Average species density per 1 000 m^2: 37

Diagnostic species: ***Ornithoglossum calcicola, Melhania damarana, Monechma genistifolium, Zygophyllum pubescens, Cleome suffruticosa, Stipagrostis hirtigluma, Enneapogon desvauxii, Otoptera burchellii, Leucosphaera bainesii, Euphorbia lignosa, Crotalaria kurtii,*** *Blepharis mitrata, Enneapogon scoparius, Stipagrostis ciliata, Polygala pallida, Fingerhuthia africana, Sericorema sericea, Polygala leptophylla, Thesium xerophyticum, Seidelia*

Figure 7. Typical views of the associations of the Khomas Hochland Proper. A, *Digitario erianthae–Euryopietum walterorum*, relevé 1837; B, Examples of rock faces hosting the *Pennisetum foermerianum–Ficus ilicina* association, here at Midgard; C, *Danthoniopio ramosae–Oleoetum africanae* on top of the Auas Mountains; D, *Senegalio hereroensis–Tarchonanthoetum camphorati*, relevé 1123; E, *Triraphio ramosissimae–Manuleopsietum dinteri*, relevé 1011; F, *Ornithoglosso calcicolae–Fingerhuthioetum africanae*, relevé 1095; G, *Brachiario nigropedatae–Senegalietum hereroensis*, relevé 1003. Photos: C by Dr Antje Burke, remainder by the author.

firmula, Sarcostemma viminale, Senegalia mellifera subsp. *detinens, Hermannia abrotanoides, Eriocephalus luederitzianus, Croton gratissimus, Grewia flava, Aizoon virgatum, Catophractes alexandri, Monelytrum luederitzianum, Helinus spartioides, Pentzia monocephala, Justicia guerkeana, Barleria lancifolia, Aristida effusa, Pelargonium otaviense, Eragrostis echinochloidea*

Constant species: ***Searsia marlothii, Senegalia hereroensis, Eragrostis nindensis,*** *Enneapogon cenchroides, Talinum caffrum*

This short, semi-open shrubland is dominated by the dwarf shrub *Monechma genistifolium* and the grass *Fingerhuthia africana* (Figures 6G and 7F). The occasional occurrence of *Senegalia hereroensis* indicates the relationship to the central Khomas Hochland. This association occurs on the slopes of the Oamites Mountain, which is made up of grey quartzite and sericite phyllite of the Billstein formation (Geological Survey 1980; South African Committee for Stratigraphy 1980). The steep to very steep slopes are covered with rocks (up to 40%) and a mixture of small, medium and large stones (combined over 40%), at an altitudinal range of between 1 700 and 1 800 m asl, and a MAP of 350 mm.

2.8 *Brachiario nigropedatae–Senegalietum hereroensis* ass. nov.

Synopsis:
Number of relevés: 238
Type relevé: 1003 (holotype), sampled on 16 March 2000 at 22°49′33″S, 16°50′00″E
Number of species observed: 287
Estimated number of species: 403
Average species density per 1 000 m^2: 36

Diagnostic species: *Aristida meridionalis, Gnidia polycephala, Schmidtia pappophoroides, Eragrostis superba, Pogonarthria fleckii*

Constant species: ***Senegalia hereroensis, Eragrostis nindensis, Anthephora pubescens, Searsia marlothii, Melinis repens* subsp. *grandiflora,*** *Brachiaria nigropedata, Stipagrostis uniplumis* var. *uniplumis, Monelytrum luederitzianum, Enneapogon cenchroides, Ziziphus mucronata, Cenchrus ciliaris*

These short, semi-open bushlands are dominated by shrubs of *Senegalia hereroensis,* with scattered low trees and shrubs of *Tarchonanthus camphoratus, Ziziphus mucronata, Combretum apiculatum* subsp. *apiculatum, Senegalia mellifera* subsp. *detinens, Euclea undulata, Vachellia tortilis, Albizia anthelmintica* and *Vachellia reficiens*. The grass layer is rather species-rich, with *Eragrostis nindensis, Enneapogon cenchroides, Monelytrum luederitzianum, Aristida adscensionis, Cenchrus ciliaris, Brachiaria nigropedata, Aristida meridionalis, Melinis repens* subsp. *grandiflora, Anthephora pubescens, Triraphis ramosissima* and *Stipagrostis uniplumis* var. *uniplumis* being the dominating species (Figures 6H and 7G). The veld of the central Khomas Hochland occurs on moderately steep to steep hills and mountains with shallow (< 30 cm deep) soils on mica schists of the Kuiseb Formation (Geological Survey 1980, Schneider 2004). The stone cover is dominated by pebbles and medium-sized quartz stones up to 40%, with only occasional sub-outcropping mica schists. This association is the most extensive association within the central Khomas Hochland and occurs at an altitude of between 1 600 and 2 000 m asl. MAP ranges between 200 and nearly 400 mm.

Riverine vegetation

The vegetation of the riverine habitats is dominated by the plant families Poaceae, Asteraceae, Fabaceae and Amaranthaceae. The classification resulted in seven associations, which are formally described according to the International Code of Phytosociological Nomenclature (Weber et al. 2000) below. The synoptic table for these is presented in online Appendix 1, and the phytosociological table in online Appendix 2.

3.1 *Eragrostio rotiferi–Oleoetum africanae* ass. nov.

Synopsis:
Number of relevés: 3
Type relevé: 11525 (holotype), sampled on 16 April 2014 at 22°08′04″S, 17°17′45″E
Number of species observed: 51
Estimated number of species: 66
Average species density per 1 000 m^2: 34

Diagnostic species: ***Olea europaea* subsp. *africana, Brachylaena huillensis, Diospyros lycioides, Oxalis purpurascens, Searsia lancea, Alternanthera nodiflora, Digitaria eriantha, Kohautia azurea, Gladiolus permeabilis* subsp. *edulis, Crassula capitella, Commelina subulata, Cymbopogon pospischilii***

Constant species: ***Ziziphus mucronata, Tagetes minuta, Eragrostis rotifer, Commelina benghalensis, Chloris virgata, Bidens biternata,*** *Sporobolus fimbriatus, Setaria verticillata, Schoenoplectus muricinux, Pogonarthria fleckii, Panicum maximum, Oxygonum alatum, Melinis repens* subsp. *grandiflora, Eragrostis superba, Eragrostis lehmanniana, Eragrostis echinochloidea, Dactyloctenium aegyptium, Asparagus nelsii, Achyranthes aspera, Vachellia karroo*

These short, moderately closed woodlands occur in narrow, steep-sided ravines in the Khomas Hochland, forming the headwaters of the rivers. The riverbed is not well-developed, often formed by boulders and eroded rock crevices and is generally overgrown (Figures 8A and 9A). Due to the narrowness of this bed, it was sampled with the banks. Rock cover is up to 40%, with considerable small, medium and large stone cover as well. Due to the relatively small sample, no reliable indication is available on the distribution, altitudinal range or MAP. The sampled relevés range between 1 780 and 1 800 m asl, at a MAP of 350 mm.

3.2 *Cynodo dactylonis–Eragrostioetum rotiferi* ass. nov.

Synopsis:

Number of relevés: 17
Type relevé: 11520 (holotype), sampled on 16 April 2014 at 22°06′36″S, 17°17′40″E
Number of species observed: 79
Estimated number of species: 148
Average species density per 1 000 m^2: 18

Diagnostic species: *Hyparrhenia hirta, Gomphostigma virgatum, Datura inoxia, Eragrostis rotifer*

Constant species: *Chloris virgata, Eragrostis echinochloidea, Cynodon dactylon, Cenchrus ciliaris, Eragrostis superba, Bidens biternata, Tagetes minuta, Melinis repens* subsp. *grandiflora*

As the rivers widen, a distinct near-flat, coarse sandy bed is formed, on which this sparse short grassland establishes (Figures 8B and 9B). Depending on the flow regime (fast- or slow flowing, or even standing or seepage areas), a variety of species establish, often of ephemeral nature. Generally, *Chloris virgata, Sporobolus fimbriatus, Eragrostis rotifer, Eragrostis omahekensis, Eragrostis echinochloidea* and *Cynodon dactylon* dominate this association. This association occurs widespread in the study area as important part of the drainage system.

3.3 *Stipagrostioetum namaquensis* ass. nov.

Synopsis:

Number of relevés: 4
Type relevé: 973 (holotype), sampled on 20 April 2000 at 22°49′08″S, 16°49′36″E
Number of species observed: 61
Estimated number of species: 83
Average species density per 1 000 m^2: 30

Diagnostic species: ***Felicia clavipilosa, Stipagrostis namaquensis,*** *Oxygonum alatum*

Constant species: ***Pogonarthria fleckii, Acrotome fleckii,*** *Tragus racemosus, Tagetes minuta, Melinis repens* subsp. *grandiflora, Melianthus comosus, Kyllinga alata, Galenia africana, Enneapogon cenchroides, Chloris virgata, Bulbostylis hispidula, Bidens biternata, Vachellia karroo, Tetragonia calycina, Stachys spathulata, Schmidtia kalahariensis, Schkuhria pinnata, Ocimum americanum* var. *americanum, Monechma spartioides, Limeum sulcatum, Indigofera alternans, Hermbstaedtia odorata, Heliotropium nelsonii, Geigeria pectidea, Eragrostis trichophora, Eragrostis porosa, Eragrostis omahekensis, Cucumis africanus, Cenchrus ciliaris, Anthephora schinzii, Anthephora pubescens, Amaranthus thunbergii, Achyranthes aspera* var. *sicula*

Larger rivers in relatively low-gradient environments (e.g. the Oanob) form deep sandbanks adjacent to the main flow channels, on which this tall, moderately closed grassland occurs (Figures 8C and 9C). Unlike the *Cynodo dactylonis–Eragrostioetum rotiferi,* this association is of more permanent nature, with *Stipagrostis namaquensis* stabilising the sand bank, and allowing sedimentation on this sand bank. This eco-engineer also forms a suitable habitat for phanerophytic species (commonly *Vachellia karroo*, but also *Vachellia erioloba, Faidherbia albida* and *Euclea pseudebenus*) to establish. The sandbanks found in the Oanob River form the western-most occurrence of this association, with extensive sandbanks found further east in the Seeis and Nossob river systems. These sand banks occur within the study area at an altitude of between 1 850 and 1 950 m asl, and a MAP of between 300 and 350 mm.

3.4 *Themedio triandrae–Chloroetum virgatae* ass. nov.

Synopsis:

Number of relevés: 8
Type relevé: 939 (holotype), sampled on 10 April 2000 at 22°45′24″ S, 16°52′28″ E
Number of species observed: 130
Estimated number of species: 185
Average species density per 1 000 m^2: 42

Diagnostic species: ***Tragus berteronianus, Schmidtia pappophoroides, Themeda triandra, Talinum caffrum, Platycarphella carlinoides, Monsonia angustifolia, Microchloa caffra,*** *Eragrostis superba, Geigeria pectidea*

Constant species: ***Chloris virgata,*** *Eragrostis porosa, Eragrostis echinochloidea, Anthephora pubescens, Vachellia karroo, Ursinia nana, Tribulus zeyheri, Kyllinga alata, Heliotropium nelsonii, Eragrostis nindensis, Aristida congesta* subsp. *congesta, Vachellia erioloba, Urochloa brachyura, Tragus racemosus, Tetragonia calycina, Schkuhria pinnata, Pogonarthria fleckii, Lycium bosciifolium, Limeum sulcatum, Eragrostis trichophora, Eragrostis rotifer, Enneapogon cenchroides, Cymbopogon pospischilii, Cenchrus ciliaris, Acrotome fleckii*

In the low-gradient landscape of the Oanob Plateau, but also other low-gradient areas like the Regenstein Valley and at Neudamm, valleys have been filled with sediments, forming a low-gradient, overgrown ephemeral wetland locally referred to as an *omuramba* (plural – *omirimbi*) (King 1963, Strohbach 2008). This forms the habitat for the *Themedio triandrae–Chloroetum virgatae*, a short, moderately-closed grassland (Figures 8D and 9D), dominated by ephemeral species like *Geigeria pectidea, Tribulus terrestris, Chloris virgata, Aristida hordeacea* and *Aristida adscensionis*. Only *Aristida congesta* subsp. *congesta* is a prominent perennial species, whilst the name-giving *Themeda triandra* is a rare species, often only occurring as remnant of the original lush grassland described by Volk and Leippert (1971). These authors already noted the generally poor state of this vegetation, which is prone to degradation and erosion. Once erosion sets in, the sediments are soon washed away to form a low-productive riverbed similar to the *Cynodo dactylonis–Eragrostioetum rotiferi*, with shrubs and trees establishing on the sides to form the start of the *Chloro virgatae–Vachellietum karroo*. The *Themedio triandrae–Chloroetum virgatae* occurs at an altitudinal range of between 1 740 and 2 200 m asl, and at a MAP of between 300 and 400 mm.

3.5 *Chloro virgatae–Vachellietum karroo* ass. nov.

Synopsis:

Number of relevés: 37
Type relevé: 11519 (holotype), sampled on 16 April 2014 at 22°06′35″ S, 17°17′40″ E
Number of species observed: 218
Estimated number of species: 312
Average species density per 1 000 m^2: 26

Diagnostic species: ***Senegalia mellifera* subsp. *detinens,*** *Phaeoptilum spinosum, Grewia flava, Aristida adscensionis, Eragrostis rigidior, Monechma divaricatum*

Constant species: ***Vachellia karroo,*** *Eragrostis porosa, Enneapogon cenchroides, Eragrostis echinochloidea, Ziziphus mucronata, Cenchrus ciliaris, Vachellia erioloba, Chloris virgata, Stipagrostis uniplumis* var. *uniplumis, Pogonarthria fleckii, Melinis repens* subsp. *grandiflora, Aristida congesta* subsp. *congesta, Bidens biternata*

These tall, closed thickets are dominated by the tree and shrub species *Vachellia karroo, Vachellia tortilis, Senegalia mellifera* subsp. *detinens* and *Ziziphus mucronata* (Figures 8E and 9E). The herb layer consists of a mixture of various species, often shade tolerant species. The *Chloro virgatae–Vachellietum karroo* form the riparian forests lining most major inland rivers in the Khomas Hochland and have strong affinities to the *Ziziphus mucronata–Acacia tortilis* association described for the Thornbush savanna (Strohbach 2019). Both Kellner (1986) and Strohbach (2017) refer to the *Chloro virgatae–Vachellietum karroo* as *Cynodon dactylon–Acacia karroo* association, a name which was rejected as the name-giving *Cynodon dactylon* was neither a diagnostic nor constant species in this association.

The *Chloro virgatae–Vachellietum karroo* generally have a steep bank towards the riverbed but are fairly flat beyond the bank. Stone cover is low, rather occasional, mostly deposited by extreme flood events. This association occurs at altitudes of between 1 540 and 1 950 m asl, and MAP of between 250 and 400 mm.

3.6 *Salvadoro persicae–Eucleetum pseudebeno* ass. nov.

Synopsis:

Number of relevés: 5
Type relevé: 1929 (holotype), sampled on 16 February 2004 at 23°10′21″ S, 16°02′28″ E
Number of species observed: 48
Estimated number of species: 66
Average species density per 1 000 m^2: 21

Diagnostic species: ***Stipagrostis hochstetteriana, Euclea pseudebenus, Salvadora persica, Tribulus zeyheri, Portulaca oleracea***

Constant species: ***Cenchrus ciliaris,*** *Vachellia erioloba, Ziziphus mucronata, Pergularia daemia, Heliotropium nelsonii, Gisekia africana, Faidherbia albida, Amaranthus thunbergii*

The *Salvadoro persicae–Eucleetum pseudebeno* forms a tall, semi-open woodland dominated by *Faidherbia albida* and *Salvadora persica* (Figures 8F and 9F). This association form the riparian forests along the bigger rivers in the western (Pre-Namib) part of the study area, i.e. the middle reaches of the Swakop, Kuiseb and Gaub rivers. The relationship to the lower Kuiseb vegetation (Theron et al. 1980) needs to be investigated further.

The *Salvadoro persicae–Eucleetum pseudebeno* occurs in the lower rainfall areas, with a MAP of less than 200 mm, and at altitudes less than 1 100 m asl. Similar to its inland equivalents (the *Chloro virgatae–Vachellietum karroo* and the *Setario finitae–Vachellietum eriolobae*), this association displays low slope gradients (flat to gently undulating) with little stone cover.

3.7 *Setario finitae–Vachellietum eriolobae* ass. nov.

Synopsis:

Number of relevés: 18
Type relevé: 11488 (holotype), sampled on 30 March 2014 at 22°02′29″S, 17°22′08″E
Number of species observed: 69

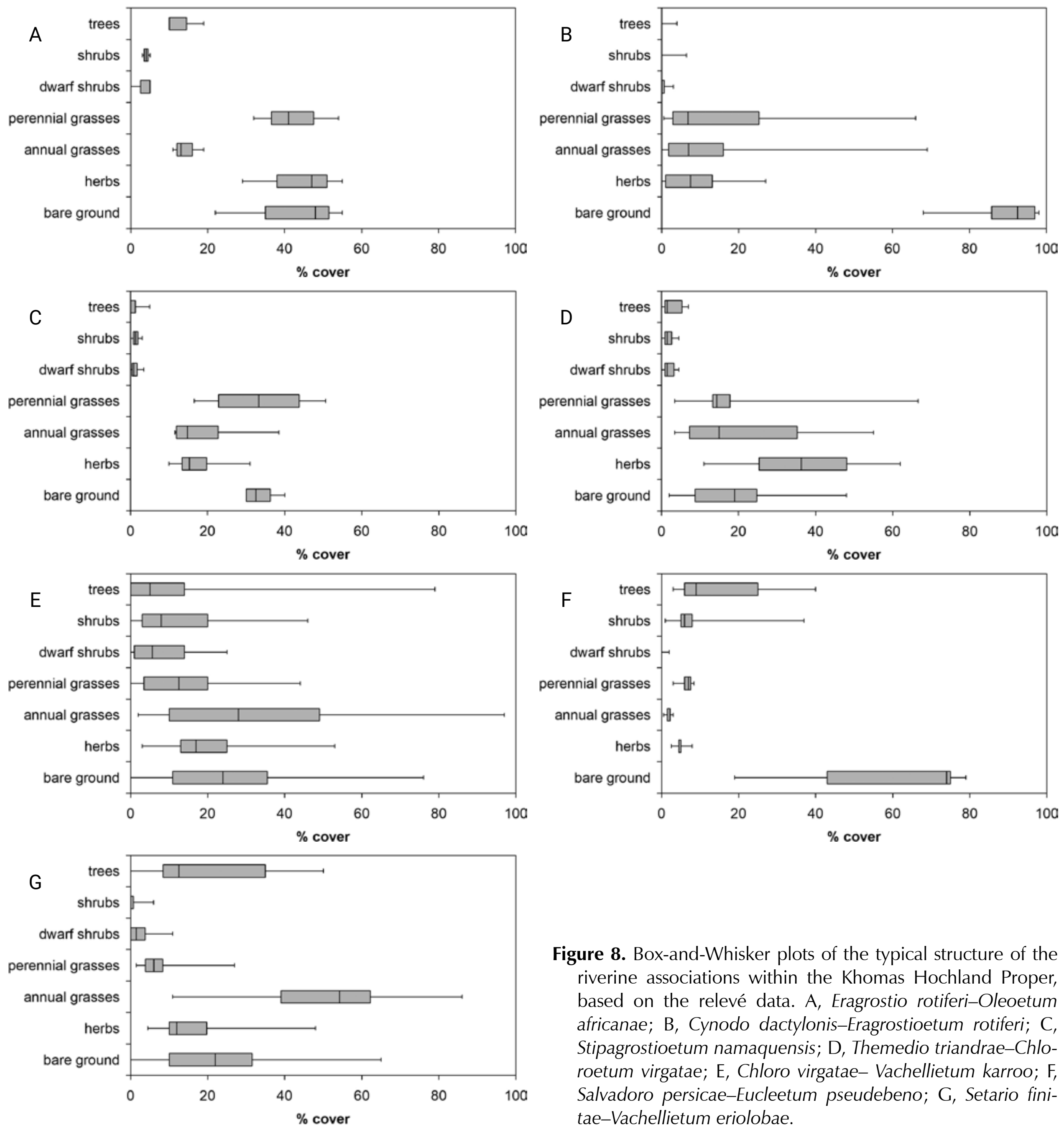

Figure 8. Box-and-Whisker plots of the typical structure of the riverine associations within the Khomas Hochland Proper, based on the relevé data. A, *Eragrostio rotiferi–Oleoetum africanae*; B, *Cynodo dactylonis–Eragrostioetum rotiferi*; C, *Stipagrostioetum namaquensis*; D, *Themedio triandrae–Chloroetum virgatae*; E, *Chloro virgatae– Vachellietum karroo*; F, *Salvadoro persicae–Eucleetum pseudebeno*; G, *Setario finitae–Vachellietum eriolobae*.

Estimated number of species: 101
Average species density per 1 000 m²: 25

Diagnostic species: ***Setaria finita, Eragrostis cilianensis, Digitaria velutina, Zehneria marlothii, Chenopodium petiolariforme, Cyperus squarrosus,*** *Sporobolus fimbriatus, Urochloa brachyura, Solanum delagoense, Cucumis meeusei, Schmidtia kalahariensis, Pechuel-Loeschea leubnitziae*

Constant species: ***Bidens biternata, Pogonarthria fleckii, Chloris virgata, Vachellia erioloba,*** *Ziziphus mucronata, Schkuhria pinnata, Cenchrus ciliaris, Bulbostylis hispidula, Vachellia karroo, Setaria verticillata, Eragrostis echinochloidea, Tagetes minuta, Eragrostis trichophora, Dactyloctenium aegyptium, Anthephora schinzii, Amaranthus thunbergii*

This tall, moderately closed woodland is found along the banks of the big inland rivers of the Khomas Hochland, notably the upper reaches of the Swakop River, but also its tributaries like the Gammams and Otjiseva rivers (Figures 8G and 9G). It is dominated by *Ziziphus mucronata, Vachellia karroo* and *Vachellia erioloba* trees, with *Faidherbia albida* also occurring occasionally.

The *Setario finitae–Vachellietum eriolobae* often forms islands within broad riverbeds, indicating a relationship,

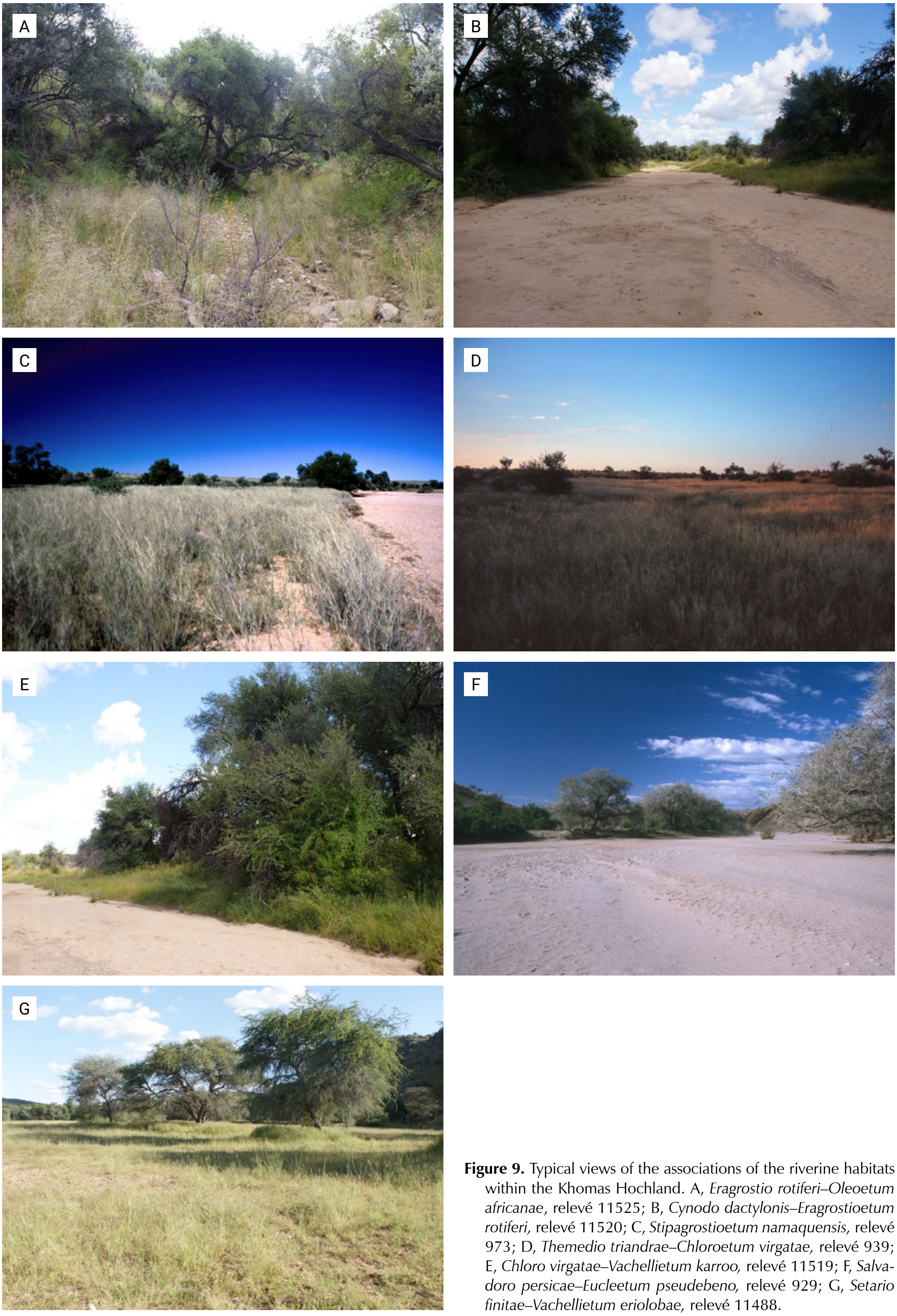

Figure 9. Typical views of the associations of the riverine habitats within the Khomas Hochland. A, *Eragrostio rotiferi–Oleoetum africanae*, relevé 11525; B, *Cynodo dactylonis–Eragrostioetum rotiferi,* relevé 11520; C, *Stipagrostioetum namaquensis,* relevé 973; D, *Themedio triandrae–Chloroetum virgatae,* relevé 939; E, *Chloro virgatae–Vachellietum karroo,* relevé 11519; F, *Salvadoro persicae–Eucleetum pseudebeno,* relevé 929; G, *Setario finitae–Vachellietum eriolobae,* relevé 11488.

possibly even a successional advanced stage, of the *Stipagrostietum namaquensis*. It has been found at altitudes of between 1 550 and 1 600 m asl, and MAP range of between 300 and 400 mm.

Lowlands surrounding the Khomas Hochland

The vegetation of the surrounding lowlands is dominated by the plant families Poaceae, Fabaceae, Asteraceae and Amaranthaceae. Eight associations, one with four sub-associations, were identified and are formally described following guidelines of the ICPN below (with one exception). Their composition is presented in Appendices 1 and 2 as synoptic and phytosociological tables.

4.1 *Pseudogaltonio clavatae–Eriocephaloetum luederitziana* ass. nov.

Synopsis:

Number of relevés: 35
Type relevé: 10624 (holotype), sampled on 18 April 2011 at 23°07′18″ S, 16°54′00″ E
Number of species observed: 131
Estimated number of species: 217
Average species density per 1 000 m^2: 37

Diagnostic species: ***Stipagrostis obtusa,*** *Senecio windhoekensis, Rosenia humilis, Sporobolus nervosus, Enneapogon desvauxii, Sida ovata, Polygala pallida, Aizoon schellenbergii, Pentzia calva, Sericorema sericea, Eragrostis echinochloidea, Melhania virescens, Pseudogaltonia clavata, Aptosimum lineare, Leobordea platycarpa, Pteronia mucronata*

Constant species: ***Leucosphaera bainesii,*** *Stipagrostis uniplumis* var. *uniplumis, Hirpicium gazanioides, Eragrostis nindensis, Eriocephalus luederitzianus, Fingerhuthia africana, Cenchrus ciliaris, Stipagrostis ciliata, Eragrostis porosa, Melinis repens* subsp. *grandiflora, Hermannia modesta, Barleria rigida, Vachellia erioloba, Tribulus zeyheri, Pogonarthria fleckii, Enneapogon cenchroides*

This low, moderately closed shrubland has a distinct karoid character, being dominated by the dwarf shrub species *Eriocephalus luederitzianus, Monechma genistifolium, Leucosphaera bainesii* and *Aizoon schellenbergii* (Figures 10A and 11A). This association is limited to the Narais plains towards Rehoboth, occurring on shallow loamy soils on calcretes, which have formed over the quarzites of the Duruchaus formation. Stone cover is about 20%, mostly calcrete gravel and small stones. Occasional deep pockets in the subsurfacing calcretes allow *Vachellia erioloba* trees to establish, adding a very sparse tree layer to this association's structure (Jürgens et al. 2010). This association receives between 250 and 300 mm MAP and is at an altitudinal range of between 1 580 and 1 640 m asl. The topography is generally flat.

4.2 *Panico lanipedis–Pentzietum incanae* ass. nov.

Synopsis:

Number of relevés: 59
Type relevé: 1020 (holotype), sampled on 17 March 2000 at 22°48′42″ S, 16°51′40″ E
Number of species observed: 180
Estimated number of species: 232
Average species density per 1 000 m^2: 52

Diagnostic species: ***Panicum lanipes, Blepharis integrifolia,*** *Eriospermum flagelliforme, Plinthus sericeus, Pteronia eenii, Pentzia incana, Ipomoea bolusiana, Talinum caffrum, Monelytrum luederitzianum, Commelina africana, Oxygonum sinuatum, Ursinia nana*

Constant species: ***Eriocephalus luederitzianus, Eragrostis nindensis, Senegalia mellifera* subsp. *detinens, Microchloa caffra, Kyphocarpa angustifolia, Aristida adscensionis,*** *Phaeoptilum spinosum, Hermannia modesta, Leucosphaera bainesii, Chascanum pinnatifidum, Schmidtia pappophoroides, Barleria rigida, Aptosimum spinescens, Melinis repens* subsp. *grandiflora, Hirpicium gazanioides, Pogonarthria fleckii, Hibiscus discophorus, Tragus berteronianus, Lycium eenii, Catophractes alexandri, Stipagrostis uniplumis* var. *uniplumis, Ocimum americanum* var. *americanum, Fingerhuthia africana, Eragrostis porosa, Aristida congesta* subsp. *congesta, Vachellia hebeclada* subsp. *hebeclada, Tarchonanthus camphoratus, Platycarphella carlinoides, Enneapogon cenchroides, Geigeria ornativa, Anthephora pubescens, Senegalia hereroensis, Searsia marlothii, Raphionacme velutina, Eragrostis trichophora, Cyperus palmatus*

The *Panico lanipedis–Pentzietum incanae* varies from a low, open to semi-open shrubland to a tall, moderately-closed shrubland, depending on its state of encroachment by savanna species. In its natural state it has a distinct karoid character, being dominated by *Leucosphaera bainesii* and *Eriocephalus luederitzianus* (Figures 10B and 11B). This association is however prone to encroachment by specifically *Senegalia mellifera* subsp. *detinens, Catophractes alexandri* and/or *Vachellia reficiens,* which causes the structure to change to a tall, denser shrubland. It occurs specifically on the rolling to moderately steep Oanob plateau, whilst similar vegetation has been also observed on the Hoffnung plateau east of Windhoek as well as at Neu Heusis west of Windhoek. As with the surrounding *Brachiario nigropedatae–Senegalietum hereroensis*, the subsurface geology are mica schists of the Kuiseb formation. However, the landscape is a gentler, undulating to rolling plateau at an altitudinal range of between 1 800 and 1 900 m asl. Stone cover is about 40%, mainly by small and medium-sized stones. MAP is between 300 and 350 mm.

4.3 *Aptosimo spinescentis–Galenietum africanae* ass. nov.

Synopsis:

Number of relevés: 8
Type relevé: 2155 (holotype), sampled on 11 February 2005 at 23°16′25″ S, 16°31′06″ E
Number of species observed: 83
Estimated number of species: 136
Average species density per 1 000 m^2: 32

Diagnostic species: ***Eriocephalus ericoides, Galenia africana, Geigeria pectidea,*** *Hermannia comosa, Aptosimum spinescens*

Constant species: *Stipagrostis uniplumis* var. *uniplumis, Eragrostis porosa, Eragrostis nindensis, Aristida adscensionis, Tribulus terrestris, Platycarphella carlinoides, Phaeoptilum spinosum, Eragrostis echinochloidea, Stipagrostis ciliata, Pentzia calva, Ocimum americanum* var. *americanum, Kohautia cynanchica, Eriocephalus luederitzianus, Eragrostis lehmanniana, Enneapogon desvauxii, Enneapogon cenchroides, Chascanum pinnatifidum, Aristida congesta* subsp. *congesta, Aptosimum albomarginatum, Vachellia erioloba*

These short, semi-open shrublands are limited to the alluvial plains around the farm Göllschau (H.E.S.S. project) in the southwestern Khomas Hochland (Figures 10C and 11C). The plains are dominated by the grasses *Stipagrostis uniplumis* var. *uniplumis, Aristida adscensionis* and *Sporobolus nervosus*, whilst the dwarf shrubs *Eriocephalus ericoides* and *Galenia africana* give it a karoid character. Occasional trees of *Vachellia erioloba* also occur here. The alluvial soils are derived from granites of the Gamsberg suite, which is sub-outcropping here (less than 5% cover). Slopes are generally flat to gently undulating, at an altitudinal range of 1 750 to 1 800 m asl. MAP is about 250 mm.

4.4 *Panico arbusculi–Senegalietum detinentis* ass. nov.

Synopsis:

Number of relevés: 28
Type relevé: 2130 (holotype), sampled on 9 February 2005 at 23°05′29″ S, 16°39′29″ E
Number of species observed: 156
Estimated number of species: 209
Average species density per 1 000 m^2: 51

Diagnostic species: ***Panicum arbusculum,*** *Hibiscus discophorus, Ipomoea obscura* var. *obscura, Aristida meridionalis, Talinum arnotii, Blepharis mitrata, Brachiaria nigropedata, Catophractes alexandri*

Constant species: ***Senegalia mellifera* subsp. *detinens, Leucosphaera bainesii, Kyphocarpa angustifolia, Eragrostis nindensis,*** *Phaeoptilum spinosum, Microchloa caffra, Chascanum pinnatifidum, Stipagrostis uniplumis* var. *uniplumis, Fingerhuthia africana, Grewia flava, Ptycholobium biflorum, Melinis repens* subsp. *grandiflora, Eriocephalus luederitzianus, Schmidtia pappophoroides, Melhania virescens, Limeum myosotis, Aristida adscensionis, Aptosimum albomarginatum, Aizoon schellenbergii, Otoptera burchellii, Ocimum americanum* var. *americanum, Monelytrum luederitzianum, Hermannia modesta, Enneapogon cenchroides, Cenchrus ciliaris, Aptosimum spinescens, Lycium eenii, Lycium bosciifolium, Hirpicium gazanioides, Barleria rigida, Asparagus exuvialis, Searsia marlothii, Raphionacme velutina, Phyllanthus maderaspatensis, Antizoma angustifolia, Kyllinga alba, Dicoma capensis, Anthephora pubescens*

These tall, moderately closed shrublands are dominated by *Senegalia mellifera* subsp. *detinens*, *Catophractes alexandri, Rhigozum trichotomum* and *Monechma genistifolium*. The grass layer contains *Panicum arbusculum, Stipagrostis uniplumis* var. *uniplumis, Melinis repens* subsp. *grandiflora, Eragrostis nindensis* and *Aristida congesta* subsp. *congesta* (Figures 10D and 11D). The presence of *Rhigozum trichotomum* and *Panicum arbusculum* within this southern Khomas Hochland is indicative of the transitional nature of these shrublands to the Dwarf Shrub Savanna *sensu* Giess (1998) or Nama Karoo. This association occurs on the rolling to moderately steep hilly landscape of the southern Khomas Hochland, and is especially well-represented along the C26. The underlying geology is formed by the mixtites of the Chuos Formation. Stone cover is about 40%, mainly small and medium-sized stones. The altitude ranges between 1 650 and 1 850 m asl, whilst the MAP ranges between 200 and 300 mm.

4.5 *Elephantorrhizo suffruticosae–Euphorbietum guerichianae* ass. nov.

Synopsis:

Number of relevés: 24
Type relevé: 2019 (holotype), sampled on 20 February 2004 at 23°15′04″ S, 16°19′02″ E
Number of species observed: 114
Estimated number of species: 172
Average species density per 1 000 m^2: 35

Diagnostic species: ***Euphorbia guerichiana, Heliotropium nelsonii, Elephantorrhiza suffruticosa, Cheilanthes marlothii,*** *Commiphora glandulosa, Setaria* *appendiculata, Helichrysum tomentosulum, Triraphis ramosissima, Blepharis obmitrata, Tephrosia dregeana* var. *dregeana, Emilia marlothiana, Anthephora pubescens, Cyphostemma currorii, Ozoroa crassinervia, Manuleopsis dinteri, Montinia caryophyllacea, Tribulus zeyheri, Boscia albitrunca*

Constant species: ***Stipagrostis uniplumis* var. *uniplumis, Otoptera burchellii, Eragrostis nindensis,*** *Talinum caffrum, Searsia marlothii, Fingerhuthia africana, Phaeoptilum spinosum, Hermannia modesta, Monechma spartioides, Cenchrus ciliaris, Vachellia reficiens, Melinis repens* subsp. *grandiflora, Combretum apiculatum* subsp. *apiculatum, Chascanum pinnatifidum, Aristida adscensionis*

These short, moderately closed bushlands occur in the upper reaches of the escarpment zone, between 1 450 and 1 780 m asl. The slopes are generally very steep (Figures 10E and 11E). This association is dominated by *Vachellia reficiens, Elephantorrhiza suffruticosa, Senegalia erubescens,* as well as the grasses *Stipagrostis uniplumis* var. *uniplumis, Eragrostis nindensis* and *Setaria appendiculata*. The latter again is an indication of a transition to mountainous habitats in the Nama Karoo biome. Geology is varied, however mostly mica schists of the Kuiseb Formation and quarzites of the Auas formation (Geological Survey 1980; South African Committee for Stratigraphy 1980). Especially rock cover is high, with up to 80% of the surface covered by large stones and/or rocks. MAP ranges between 200 and 300 mm, not taking any orographic effects into account.

4.6 *Dichrostachyo cinereae–Senegalietum erubescentis* ass. nov.

Synopsis:

Number of relevés: 91

Type relevé: 9494 (holotype), sampled on 16 March 2009 at 22°18′10″ S, 16°27′40″ E

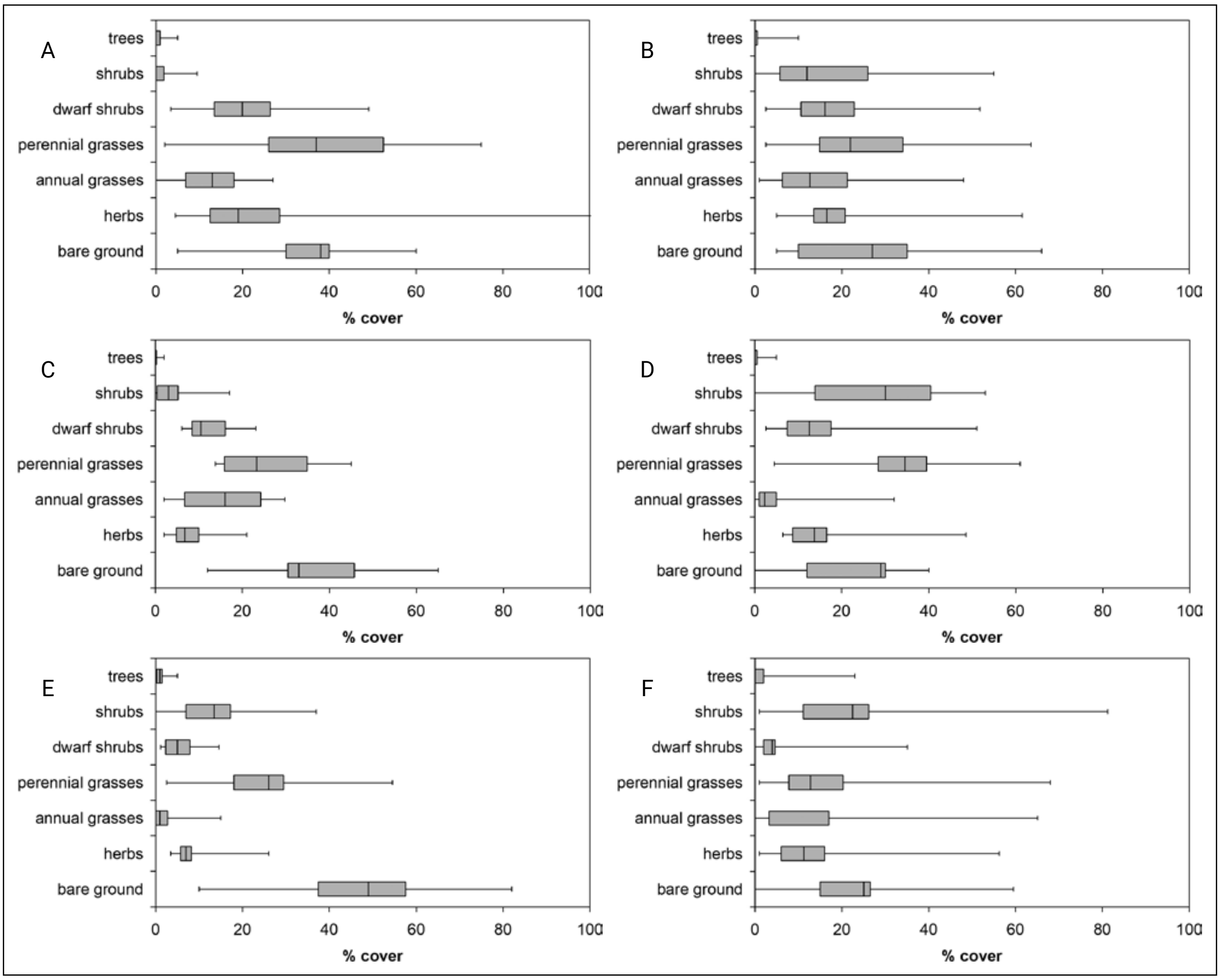

Figure 10. Box-and-Whisker plots of the typical structure of the associations of the Khomas Hochland Proper, based on the relevé data. A, *Pseudogaltonio clavatae–Eriocephaloetum luederitziana*; B, *Panico lanipedis–Pentzietum incanae*; C, *Aptosimo spinescentis–Galenietum africanae*; D, *Panico arbusculi–Senegalietum detinentis*; E, *Elephantorrhizo suffruticosae–Euphorbietum guerichianae*; F, *Dichrostachyo cinereae–Senegalietum erubescentis*.

Number of species observed: 270
Estimated number of species: 383
Average species density per 1 000 m^2: 39

Diagnostic species: ***Senegalia erubescens, Dichrostachys cinerea,*** *Grewia flavescens, Combretum apiculatum* subsp. *apiculatum, Hibiscus elliottiae*

Constant species: ***Stipagrostis uniplumis* var. *uniplumis,*** *Enneapogon cenchroides, Senegalia mellifera* subsp. *detinens, Melinis repens* subsp. *grandiflora, Eragrostis nindensis, Cenchrus ciliaris, Catophractes alexandri, Vachellia reficiens, Pogonarthria fleckii, Kyphocarpa angustifolia, Triraphis ramosissima, Aristida effusa, Anthephora pubescens, Pupalia lappacea, Grewia flava, Boscia albitrunca, Ptycholobium biflorum*

These high, moderately closed shrublands are dominated by the shrub species *Senegalia erubescens, Vachellia reficiens, Senegalia mellifera* subsp. *detinens, Melinis repens* subsp. *grandiflora* and *Dichrostachys cinerea*. The grass layer is dominated by *Enneapogon cenchroides, Eragrostis nindensis, Stipagrostis uniplumis* var. *uniplumis* and *Schmidtia kalahariensis* (Figures 10F and 11F). This association occurs in the rolling to moderately steep lowlands in the Windhoek valley, as well as Swakop valley around Okahandja. Some patches of this have also been observed in the upper Kuiseb valley. The altitude ranges between 1 300 and 1 800 m asl. Geology is varied, mainly mica schists from the Kuiseb formation, but also various intrusive granitic formations in the Swakop valley around Okahandja. Surface stone cover reaches between 40 and 80%, mainly small and medium stones. MAP ranges between 200 and 350 mm.

4.7 *Schmidtio kalahariensis–Vachellietum eriolobae* ass. nov.

Synopsis:
Number of relevés: 26

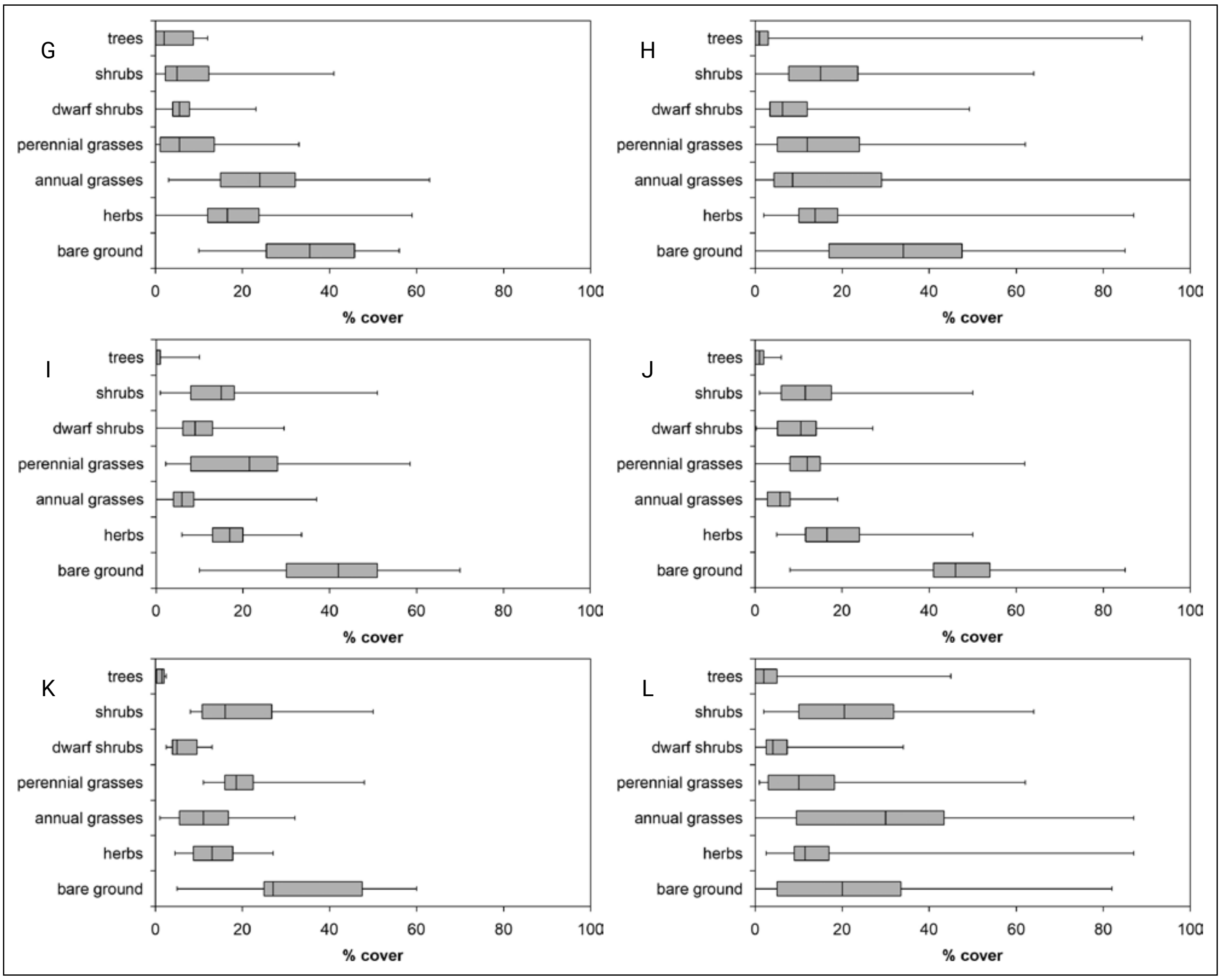

Figure 10 (continued). Box-and-Whisker plots of the typical structure of the associations of the Khomas Hochland Proper, based on the relevé data. G, *Schmidtio kalahariensis–Vachellietum eriolobae*; H, *Stipagrostis uniplumis–Senegalia detinens* association; I, *Stipagrostis uniplumis–Senegalia detinens* typical sub-association; J, *Stipagrostis uniplumis–Senegalia detinens tarchonanthus camphoratus* sub-association; K, *Stipagrostis uniplumis–Senegalia detinens vachellia tortilis* sub-association; L, *Stipagrostis uniplumis–Senegalia detinens vachellia reficiens* sub-association.

Type relevé: 1082 (holotype), sampled on 22 April 2002 at 22°52′49″ S, 17°06′13″ E
Number of species observed: 103
Estimated number of species: 161
Average species density per 1 000 m^2: 27

Diagnostic species: ***Schmidtia kalahariensis,*** *Hermbstaedtia fleckii, Eragrostis cylindriflora*

Constant species: *Phaeoptilum spinosum, Vachellia erioloba, Stipagrostis uniplumis* var. *uniplumis, Enneapogon cenchroides, Acrotome fleckii, Senegalia mellifera* subsp. *detinens, Pollichia campestris, Eragrostis porosa, Gisekia africana, Geigeria pectidea*

These tall, semi-open bushlands are dominated by *Vachellia erioloba* trees, interspersed by shrubs of *Senegalia mellifera* subsp. *detinens* and *Lycium bosciifolium*. The grass layer is dominated by *Schmidtia kalahariensis* and *Stipagrostis uniplumis* var. *uniplumis*. Conspicuous are the suffrutex *Elephantorrhiza elephantina* and the forb *Geigeria pectidea* (Figures 10G and 11G). This association occurs on the alluvial plains around Aris and at Omeya south of Windhoek but has also been observed in the Brakwater/Döbra area in the valley north of Windhoek. The slopes are flat to gently undulating, with hardly any stone cover (mostly gravel and small stones, less than 2%). The altitude ranges between 1 600 and 1 770 m asl, with MAP of between 300 and 350 mm.

4.8 *Stipagrostis uniplumis–Senegalia detinens* association

Synopsis:
Number of relevés: 162
Number of species observed: 317
Estimated number of species: 473
Average species density per 1 000 m^2: 41

Diagnostic species: none

Constant species: ***Senegalia mellifera* subsp. *detinens, Stipagrostis uniplumis* var. *uniplumis,*** *Enneapogon cenchroides, Kyphocarpa angustifolia, Cenchrus ciliaris, Ocimum americanum* var. *americanum, Melinis repens* subsp. *grandiflora, Eragrostis nindensis, Catophractes alexandri, Eragrostis porosa, Grewia flava, Boscia albitrunca, Aristida adscensionis, Ziziphus mucronata, Lycium bosciifolium, Otoptera burchellii, Phaeoptilum spinosum, Pogonarthria fleckii, Ptycholobium biflorum*

These tall, semi-open shrublands are dominated by *Senegalia mellifera* subsp. *detinens, Catophractes alexandri, Vachellia reficiens* and *Phaeoptilum spinosum* (Figure 10H). This association is often associated with degradation within various units in the Khomas Hochland, but also the regular Thornbush savanna elements to the east and north of the Khomas Hochland. Although four distinct forms have been recognised (and described as sub-associations below), there is still sufficient uncertainty regarding the classification not to allow a formal description of these communities yet.

4.8.1 *Stipagrostis uniplumis–Senegalia detinens* typical sub-association

Synopsis:
Number of relevés: 46
Number of species observed: 193
Estimated number of species: 286
Average species density per 1 000 m^2: 42

Diagnostic species: none

Constant species: ***Stipagrostis uniplumis* var. *uniplumis,*** *Phaeoptilum spinosum, Senegalia mellifera* subsp. *detinens, Ocimum americanum* var. *americanum, Eragrostis nindensis, Kyphocarpa angustifolia, Grewia flava, Enneapogon cenchroides, Schmidtia pappophoroides, Talinum caffrum, Hirpicium gazanioides, Otoptera burchellii, Catophractes alexandri, Aristida congesta* subsp. *congesta, Ziziphus mucronata, Hermannia modesta, Vachellia hebeclada* subsp. *hebeclada, Kyllinga alba, Gisekia africana, Aristida adscensionis, Indigofera vicioides, Eragrostis porosa, Dicoma capensis, Cenchrus ciliaris, Boscia albitrunca, Lycium eenii, Chascanum pinnatifidum*

These tall, semi-open shrublands are the typical form of the *Stipagrostis uniplumis–Senegalia detinens* association (Figures 10I and 11H). Strohbach (2017) referred to this as the '*Pupalia lappacea–Acacia mellifera* bush encroached lowlands', indicating that this association is often a degradation state of other associations. As *Pupalia lappacea* however was not found to be a diagnostic nor constant species, the proposed name was rejected. This sub-association is found as patches in various components and associations within the Khomas Hochland. Especially the *Brachiario nigropedatae–Senegalietum hereroensis*, the *Panico arbusculi–Senegalietum detinentis* and the *Panico lanipedis–Pentzietum incanae* seem prone to degradation to this state.

The *Stipagrostis uniplumis–Senegalia detinens* typical sub-association occurs on undulating to rolling slopes, often with up to 40% gravel and small stone cover, at altitudinal ranges between 1 650 and 1 800 m asl.

4.8.2 *Stipagrostis uniplumis–Senegalia detinens tarchonanthus camphoratus* sub-association

Synopsis:
Number of relevés: 35
Number of species observed: 194

Estimated number of species: 300
Average species density per 1 000 m²: 42

Diagnostic species: *Tarchonanthus camphoratus*

Constant species: ***Senegalia mellifera* subsp. *detinens*, *Stipagrostis uniplumis* var. *uniplumis*,** *Enneapogon cenchroides*, *Ocimum americanum* var. *americanum*, *Cenchrus ciliaris*, *Boscia albitrunca*, *Phaeoptilum spinosum*, *Lycium eenii*, *Ziziphus mucronata*, *Schmidtia pappophoroides*, *Otoptera burchellii*, *Grewia flava*, *Eragrostis porosa*, *Eragrostis nindensis*, *Achyranthes aspera* var. *sicula*, *Searsia marlothii*, *Pavonia burchellii*, *Catophractes alexandri*, *Kyphocarpa angustifolia*, *Vachellia erioloba*, *Pogonarthria fleckii*, *Monechma spartioides*, *Melinis repens* subsp. *grandiflora*, *Hermannia modesta*, *Talinum caffrum*, *Leucosphaera bainesii*, *Leucas pechuelii*, *Gisekia africana*, *Eragrostis echinochloidea*, *Ehretia rigida*

These high, semi-open shrublands are also dominated by *Senegalia mellifera* subsp. *detinens* and *Catophractes alexandri* (Figures 10J and 11I). The occurrence of *Tarchonanthus camphoratus* indicates slightly moister conditions, reflected in deeper, sandier soils, but also higher rainfall regimes (between 350 and 400 mm MAP). This sub-association is found in the eastern parts of the study area, linking into the thornbush savanna types to the east of Windhoek. The altitude ranges between 1 550 and 1 830 m asl, with rolling to moderately steep slopes. The subsurface geology are granites and gneiss from the Hohewarte complex and Gamsberg Suite. Stone cover is low (< 15%), mostly gravel and small stones.

4.8.3 *Stipagrostis uniplumis–Senegalia detinens vachellia tortilis* sub-association

Synopsis:
Number of relevés: 12
Number of species observed: 156
Estimated number of species: 267
Average species density per 1 000 m²: 39

Diagnostic species: none

Constant species: ***Melinis repens* subsp. *grandiflora*, *Enneapogon cenchroides*, *Cenchrus ciliaris*,** *Pogonarthria fleckii*, *Eragrostis porosa*, *Ziziphus mucronata*, *Stipagrostis uniplumis* var. *uniplumis*, *Eragrostis nindensis*, *Senegalia mellifera* subsp. *detinens*, *Searsia marlothii*, *Phaeoptilum spinosum*, *Aristida adscensionis*, *Anthephora pubescens*, *Triraphis ramosissima*, *Schmidtia pappophoroides*, *Eragrostis rigidior*, *Aristida congesta* subsp. *congesta*, *Ocimum americanum* var. *americanum*, *Nidorella resedifolia*, *Monechma divaricatum*, *Lycium bosciifolium*, *Eragrostis echinochloidea*

These short, semi-open bushlands are dominated by *Vachellia reficiens*, *Senegalia mellifera* subsp. *detinens* and *Vachellia tortilis* (Figure 10K). It has a limited occurrence in patches in the Khomas Hochland and has mainly been observed west of Windhoek in the Daan Viljoen Game Reserve. This sub-association occurs on moderately steep to steep slopes at altitudinal ranges between 1 500 and 1 800 m asl. Stone cover is fairly high, above 40%, mostly small and medium stones. Larger stones, and occasional rock outcrops, are also present. The subsurface geology is also mica-schists of the Kuiseb Formation.

4.8.4 *Stipagrostis uniplumis–Senegalia detinens vachellia reficiens* sub-association

Synopsis:
Number of relevés: 69
Type relevé: 9504 (holotype), sampled on 16 March 2009 at 21°55′51″ S, 16°34′36″ E
Number of species observed: 219
Estimated number of species: 341
Average species density per 1 000 m²: 39

Diagnostic species: none

Constant species: ***Senegalia mellifera* subsp. *detinens*, *Stipagrostis uniplumis* var. *uniplumis*, *Vachellia reficiens*,** *Enneapogon cenchroides*, *Lycium bosciifolium*, *Melinis repens* subsp. *grandiflora*, *Albizia anthelmintica*, *Kyphocarpa angustifolia*, *Catophractes alexandri*, *Aristida adscensionis*, *Cenchrus ciliaris*, *Ptycholobium biflorum*, *Eragrostis porosa*, *Boscia albitrunca*, *Aristida effusa*, *Pupalia lappacea*, *Schmidtia kalahariensis*, *Leucosphaera bainesii*, *Pogonarthria fleckii*, *Commelina benghalensis*, *Ocimum americanum* var. *americanum*, *Achyranthes aspera* var. *sicula*

These short, moderately closed bushlands are dominated by *Senegalia mellifera* subsp. *detinens*, *Vachellia reficiens* and *Catophractes alexandri* (Figures 10L and 11J). The grass layer is dominated by *Schmidtia kalahariensis*, *Enneapogon cenchroides*, *Stipagrostis uniplumis* var. *uniplumis* and *Aristida adscensionis*. This sub-association occurs in mosaic with the *Dichrostachyo cinereae–Senegalietum erubescentis* in the Windhoek valley and the Swakop Valley to the west of Okahandja. The relationship between these two syntaxa is not clear.

The *Stipagrostis uniplumis–Senegalia detinens vachellia reficiens* sub-association_occurs at an altitudinal range of between 1 500 and 1 800 m asl, on rolling to moderately steep slopes. Geology is varied, mostly mica schists and granites. Stone cover is mostly by gravel, small and medium sized stones, less than 40%. MAP ranges between 200 and 400 mm.

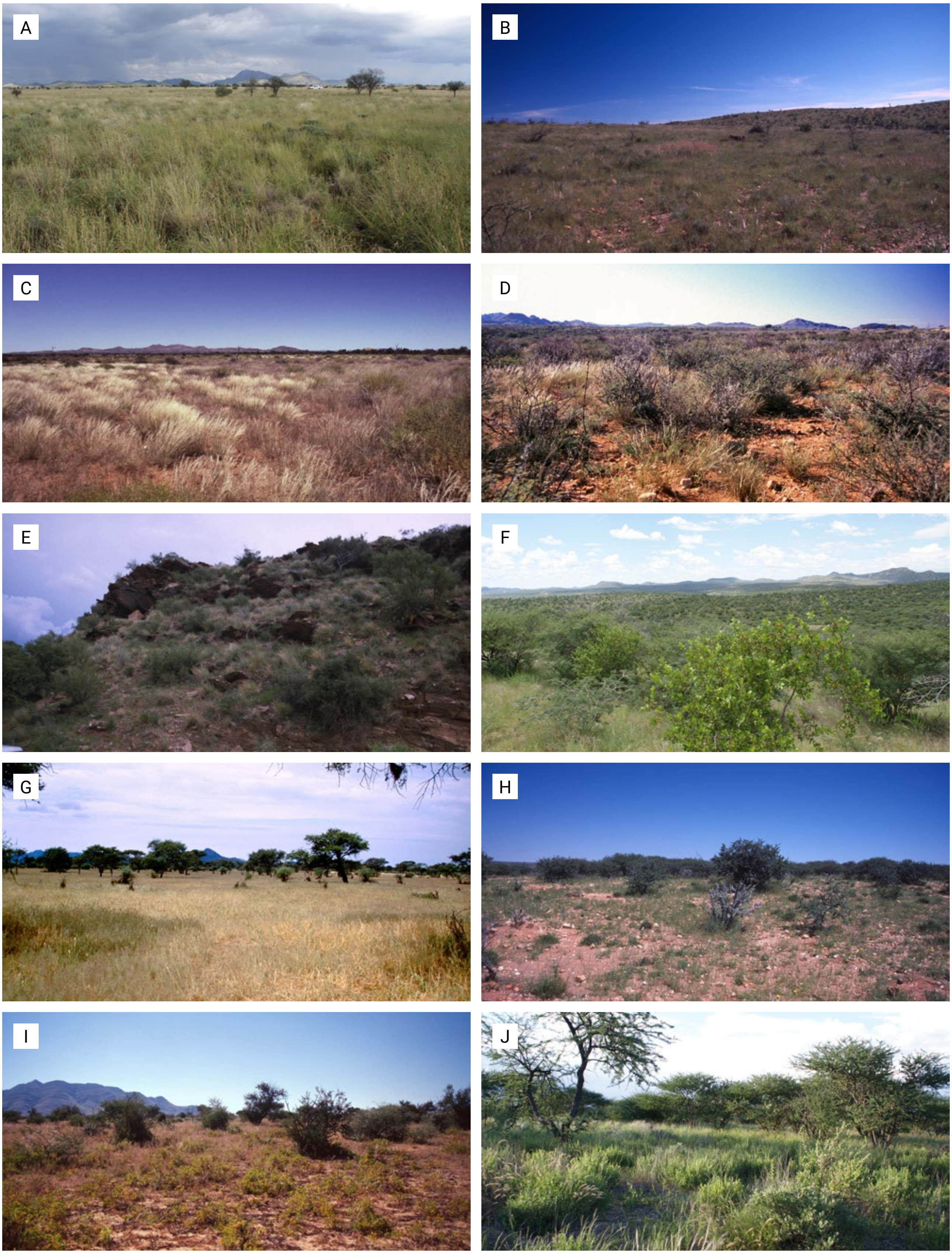

Figure 11. Typical views of the associations of the Khomas Hochland Proper. A, *Pseudogaltonio clavatae–Eriocephaloetum luederitziana*; B, *Panico lanipedis–Pentzietum incanae*, relevé 1020; C, *Aptosimo spinescentis–Galenietum africanae*, relevé 2155; D, *Panico arbusculi–Senegalietum detinentis*, relevé 2153; E, *Elephantorrhizo suffruticosae–Euphorbietum guerichianae*, relevé 2017; F, *Dichrostachyo cinereae–Senegalietum erubescentis*, relevé 9494; G, *Schmidtio kalahariensis–Vachellietum eriolobae*, relevé 1082; H, *Stipagrostis uniplumis–Senegalia detinens* typical sub-association, relevé 982; I, *Stipagrostis uniplumis–Senegalia detinens tarchonanthus camphoratus* sub-association, relevé 1146; J, *Stipagrostis uniplumis–Senegalia detinens vachellia reficiens* sub-association, relevé 9504.

Higher syntaxonomy

The classification of the synoptic relevés of 30 associations yielded a classification with crispness peaks at 4, 8, and 14/15 divisions. Accordingly, a classification with 15 clusters was accepted and interpreted. The 15 clusters were interpreted as alliances, whilst these alliances were grouped into orders between level 4 and level 8 divisions (Figure 12). An overview of associations, associated with their relevant alliances, orders and broad habitats are given in Table 3.

The *Senegalio hereroensis–Tarchonanthoetalia camphorati* is typified by the *Senegalio hereroensis–Tarchonanthion camphorati*. This order represents the high mountains of central Namibia. Based on the present data, it can be subdivided into two alliances, being the *Senegalio hereroensis–Tarchonanthion camphorati,* representing the Auas Mountains, as well as the *Digitario erianthae–Euryion walterorum*, representing the Gamsberg Mountain. The *Senegalio hereroensis–Tarchonanthion camphorati* is typified by the *Senegalio hereroensis–Tarchonanthoetum camphorati* and contains also the two other associations occurring on the Auas Mountains. The *Digitario erianthae–Euryion walterorum* is typified by the *Digitario erianthae–Euryopietum walterorum* and contains only this association.

The *Cynodo dactylonis–Eragrostioetalia rotiferi* is recognised as a provisional order representing the riverine habitats. According to the present classification, it breaks up into five alliances, each representing a single association. Due to this, and as other, similar habitats exist in central and southern Namibia, this provisional order is not yet formally described pending a thorough revision.

The *Brachiario nigropedatae–Senegalietalia hereroensis* is typified by the *Brachiario nigropedatae–Senegalion hereroensis,* which is also the only alliance to this order. This order represents the vegetation of the central Khomas Hochland. The *Brachiario nigropedatae–Senegalion hereroensis* in turn is typified by the *Brachiario nigropedatae–Senegalietum hereroensis*. In addition to the typical association, three other associations have been grouped into this alliance. Two of these represent rocky habitats typical for the central Khomas Hochland, the third represents smaller rivers within the Khomas Hochland.

The sandy and/or specialised habitats in desert environment form a cluster of associations, each being represented by an own alliance, and possibly (depending on interpretation), even own orders. One of these associations, the *Salvadoro persicae– Eucleetum pseudebeno*, could possibly also be grouped with the *Cynodo dactylonis– Eragrostioetalia rotiferi* due to its habitat. This is speculative, and subject to review in future. Because of this, no formal higher syntaxonomic groupings are described here.

The *Eragrostio nindensis–Vachellietalia reficientis* is typified by the *Eragrostio nindensis–Vachellion reficientis*. This order represents the Pre-Namib as well as the escarpment zone. The classification does not present any evidence of this order to be split into two alliances, yet, based on the habitat and vegetation of the associations in this order, a split was made between the name-giving alliance and the *Enneapogono desvauxii–Eragrostion nindensis*. The *Eragrostio nindensis–Vachellion reficientis* is typified by the *Eragrostio nindensis–Vachellietum reficientis* and includes two other association within the escarpment zone. The *Enneapogono desvauxii–Eragrostion nindensis* is typified by the *Enneapogono desvauxii–Eragrostietum nindensis* and includes the closely related *Enneapogono desvauxii–Adenoloboetum pechuelii*, as part of the Pro-Namib landscape.

The *Panico arbusculi–Senegalietalia detinentis* is typified by the *Panico arbusculi–Senegalion detinentis*. It includes

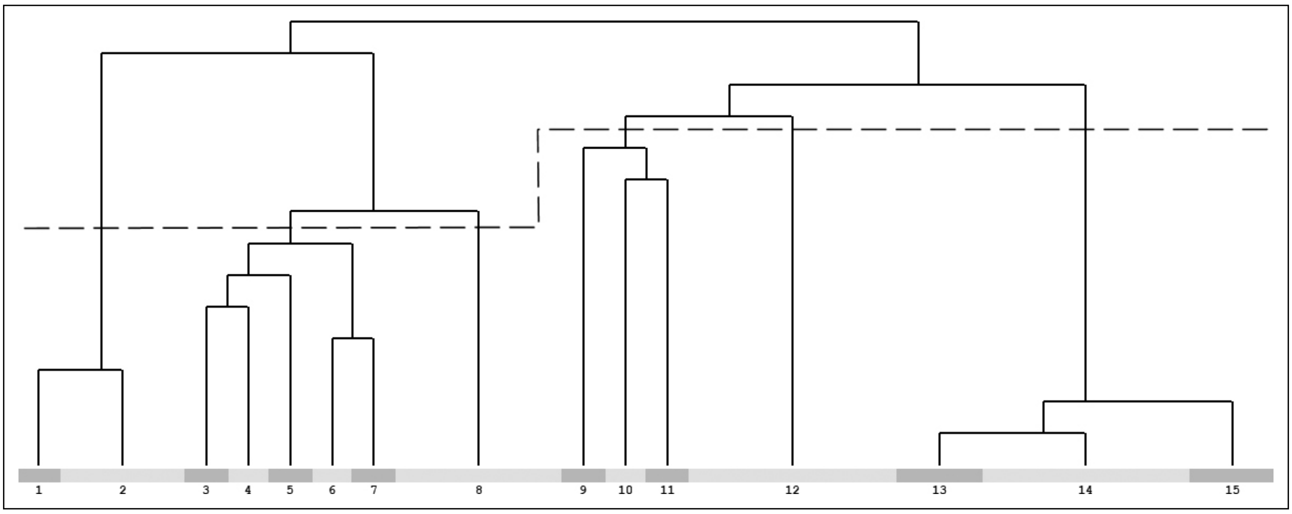

Figure 12. Dendrogram of the classification of synoptic relevés representing various associations. Groupings above the stippled line were interpreted as orders, whilst the final groupings were interpreted as alliances.

Table 3. Overview of the higher syntaxonomy of associations described in this study

	Association	Alliance	Order
2.1	*Digitario erianthae–Euryopietum walterorum*	*Digitario erianthae–Euryion walterorum*	*Senegalio hereroensis–Tarchonanthoetalia camphorati*
2.3	*Eriocephalo dinteri–Danthoniopietum ramosae*	*Senegalio hereroensis–Tarchonanthion camphorati*	High Mountains
2.5	*Senegalio hereroensis–Tarchonanthoetum camphorati*	Auas Mountains	
2.4	*Danthoniopio ramosae–Oleoetum africanae*		
3.1	*Eragrostio rotiferi–Oleoetum africanae*		*Cynodo dactylonis–Eragrostioetalia rotiferi*
3.7	*Setario finitae–Vachellietum eriolobae*		Rivers
3.3	*Stipagrostioetum namaquensis*		
3.2	*Cynodo dactylonis–Eragrostioetum rotiferi*		
3.4	*Themedio triandrae–Chloroetum virgatae*		
2.2	*Pennisetum foermerianum–Ficus ilicina* association	*Brachiario nigropedatae–Senegalion hereroensis*	*Brachiario nigropedatae–Senegalietalia hereroensis*
2.6	*Triraphio ramosissimae–Manuleopsietum dinteri*	Khomas Hochland proper	Khomas Hochland proper
3.5	*Chloro virgatae–Vachellietum karroo*		
2.8	*Brachiario nigropedatae–Senegalietum hereroensis*		
1.4	*Tribulocarpo dimorphantho–Vachellietum eriolobae*		
1.3	*Crotalario podocarpae–Stipagrostioetum obtusae*		Sandy and/or specialised habitats in desert environment
3.6	*Salvadoro persicae–Eucleetum pseudebeno*		
1.1	*Enneapogono desvauxii–Adenoloboetum pechuelii*	*Enneapogono desvauxii–Eragrostion nindensis*	*Eragrostio nindensis–Vachellietalia reficientis*
1.2	*Enneapogono desvauxii–Eragrostietum nindensis*	Pre-Namib	Desert & escarpment
1.6	*Myrothamno flabellifolii–Commiphoroetum dinteri*	*Eragrostio nindensis–Vachellion reficientis*	
1.5	*Geigerio acaulis–Commiphoroetum glaucescentis*	Escarpment	
1.7	*Eragrostio nindensis–Vachellietum reficientis*		
2.7	*Ornithoglosso calcicolae–Fingerhuthioetum africanae*	*Elephantorrhizo suffruticosa–Euphorbion guerichianae*	*Panico arbusculi–Senegalietalia detinentis*
4.5	*Elephantorrhizo suffruticosae–Euphorbietum guerichianae*	Mountainous fringes of the Khomas Hochland	Lowlands along the Khomas Hochland fringes
4.7	*Schmidtio kalahariensis–Vachellietum eriolobae*	*Panico arbusculi–Senegalion detinentis*	

Table 3. Overview of the higher syntaxonomy of associations described in this study (continued)

	Association	Alliance	Order
4.1	*Pseudogaltonio clavatae–Eriocephaloetum luederitziana*	Southern fringe communities – ecotone to Nama Karoo	
4.3	*Aptosimo spinescentis–Galenietum africanae*		
4.4	*Panico arbusculi–Senegalietum detinentis*		
4.2	*Panico lanipedis–Pentzietum incanae*		
4.6	*Dichrostachyo cinereae–Senegalietum erubescentis*	*Dichrostachyo cinereae–Senegalion erubescentis*	
4.8	*Stipagrostis uniplumis–Senegalia detinens* association	Northern and eastern fringe lowlands	

two other alliances, being the *Elephantorrhizo suffruticosae–Euphorbion guerichianae* and the *Dichrostachyo cinereae–Senegalion erubescentis*. This order represents the fringes to the Khomas Hochland to the south, east, north and, in the form of the upper escarpment, west. The *Panico arbusculi–Senegalion detinentis* in turn is typified by the *Panico arbusculi–Senegalietum detinentis*, and, together with four other associations, forms the transition to the Nama Karoo biome to the south. The *Schmidtio kalahariensis–Vachellietum eriolobae* is closely related to the vegetation of the southern Kalahari (Strohbach et al. 2019).

The *Elephantorrhizo suffruticosae–Euphorbion guerichianae* is typified *Elephantorrhizo suffruticosae–Euphorbietum guerichianae* and represents the mountainous habitats along the southern and western fringes of the Khomas Hochland. It contains one other association, the *Ornithoglosso calcicolae–Fingerhuthioetum africanae* of the Oamites mountain.

The *Dichrostachyo cinereae–Senegalion erubescentis* is typified by the *Dichrostachyo cinereae–Senegalietum erubescentis* and includes the as yet not formally described *Stipagrostis uniplumis–Senegalia detinens* association. This alliance represents the northern and eastern lowlands associated with the Khomas Hochland.

Discussion and conclusion

The higher syntaxonomy confirmed several preliminary observations. The initial classification into Pre-Namib and Escarpment, Khomas Hochland proper, Riverine habitats as well as surrounding lowlands are largely reflected in the orders *Cynodo dactylonis–Eragrostioetalia rotiferi,* the *Brachiario nigropedatae–Senegalietalia hereroensis,* the *Eragrostio nindensis–Vachellietalia reficientis* and the *Panico arbusculi–Senegalietalia detinentis*. This is also in line with the groupings proposed by Giess (1998), i.e. the Central Namib, the Desert transition and escarpment Zone as well as the Highland savanna.

A notable exception is the *Senegalio hereroensis–Tarchonanthoetalia camphorati* (high mountains), which is highlighted as a grouping on its own. This also confirms the findings of Strohbach (2017), who has highlighted the high Auas Mountain vegetation as a separate grouping. The *Senegalio hereroensis–Tarchonanthoetalia camphorati* has close affinities to the grassland biome of South Africa, with its dominant cover of grasses, in particular *Digitaria eriantha* (Mucina & Rutherford 2006). Prominent representatives of the Asteraceae in this order, amongst others *Eriocephalus* spp., *Stoebe plumosa* and *Euryops walterorum,* also have close relatives in the grasslands and adjacent Karoo vegetation in South Africa (cf. Nordenstam 1966; Müller et al. 2001; Njenga 2005), indicating a biogeographic relationship to these biomes, rather than the surrounding savanna biome.

The other notable exception is the formation of a cluster of specialised habitats within the desert biome environment. Although the *Salvadoro persicae–Eucleetum pseudebeno* has distinct affinities to the inland rivers, it still groups into the desert environment rather than the inland savanna environment. Of the other two associations in this cluster, the *Crotalario podocarpae–Stipagrostioetum obtusae* has affinities to the arid grasslands of the Nama Karoo biome (Mucina & Rutherford 2006), whilst the *Tribulocarpo dimorphantho–Vachellietum eriolobae* has affinities to the Kalahari duneveld *sensu* Mucina and Rutherford (2006) or southern Kalahari *sensu* Giess (1998).

The vegetation classification and description presented in this paper represents a broad overview, as dictated by the 'reconnaissance level' scale. Intensified sampling in several specialist habitats, e.g. the riverine habitats, the high mountains (in particular the Hakos mountains, as well as ranges like the Bismark Mountains east of the Auas and various ranges of the Kamtsas and Sinclair formations south of Windhoek) and the Matchless Member dissecting the central Khomas Hochland, will likely yield further associations. The higher syntaxonomy will likely also be clarified and strengthened once more such studies are available and included in the analysis.

Acknowledgements

I would like to acknowledge the permission granted by many farmers to work on their properties, as well as the hospitality afforded by these. Tuhafeni Sheuyange, Zuna September and Salomé Kruger assisted with the data collection, whilst the data contributed by Coleen Mannheimer, Martin Wittneben and Dr Antje Burke is gratefully acknowledged. The staff of the National Herbarium of Namibia (WIND) helped with the identification of numerous specimens. The project was financially supported by the recurrent budget of the Ministry of Agriculture, Water and Forestry (Vote 2004) as well as the BIOTA southern Africa Project, in turn funded by the German Federal Ministry of Education and Research under their promotion number 01LC0624.

Competing interests:

The author declares that he has no financial or personal relationship that may have inappropriately influenced him in writing this article.

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Appendix 1

Synoptic table for the Pre-Namib and Escarpment Zone communities, with fidelity (phi coeff.) and frequncy of occurence (%)

Available online only DOI: http://dx.doi.org/10.38201/btha.abc.v51.i2.s4a.

Appendix 2

Phytosociological Table

Available online only DOI: http://dx.doi.org/10.38201/btha.abc.v51.i2.s4b.

SANBI Biodiversity for Life
South African National Biodiversity Institute

BOTHALIA – African Biodiversity & Conservation
ISSN: (Online) 2311-9284, (Print) 0006-8241

A rapid biodiversity assessment of Lesotho's first proposed Biosphere Reserve: a case study of Bokong Nature Reserve and Tšehlanyane National Park

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Dates

Submitted: 27 March 2020
Accepted: 13 May 2021
Published: 23 August 2021

How to cite this article:

Seleteng-Kose, L., Kobisi, K., Pool-Stanvliet, R. & Mohapi, K., 2021, 'A rapid biodiversity assessment of Lesotho's first proposed Biosphere Reserve: a case study of Bokong Nature Reserve and Tšehlanyane National Park', *Bothalia* 51(2), a6. http://dx.doi.org/10.38201/btha.abc.v51.i2.6

Background: Two of Lesotho's protected areas, namely Bokong Nature Reserve and Tšehlanyane National Park, form the core area of the country's first proposed Biosphere Reserve. Biodiversity is a key aspect needed to justify nomination of a Biosphere Reserve under UNESCO's Man and the Biosphere Programme. Previously documented biodiversity of the two protected areas is limited in terms of coverage and scope as well as being outdated. The aim of the current study was to conduct a rapid assessment of the biodiversity, including endemism, of the proposed Biosphere Reserve to inform the formal nomination process.

Methods: A field survey was undertaken over 112 033 ha in the core, buffer and transition zones of the proposed Biosphere Reserve during which species of both flora and fauna were documented. Purposeful recordings were made during different seasons to incorporate various flowering seasons of the plants, as well as faunal species that may hibernate or migrate seasonally.

Results: A total of 380 plant species was recorded, 30 of which are legally protected in the country, 60 endemic to the Drakensberg Mountain Centre, and two species (*Aloe polyphylla* and *Glumicalyx lesuticus*) are endemic to Lesotho. The former is the national flower of Lesotho and is under threat due to illegal trade. Sixteen mammal species were recorded, seven of which are legally protected in the country, as well as 53 bird species (including the IUCN Red Listed vulture species, *Gyps coprotheres* and *Gypaetus barbatus*). Two fish species were also recorded including *Pseudobarbus quathlambae*, which is Lesotho's only known endemic vertebrate species, as well as seven reptile and three amphibian species (two of which are near endemic namely *Amietia delalandii* and *A. vertebralis*).

Conclusion: This survey has provided valuable baseline information on the biodiversity (particularly regarding the flora and avifauna) of the proposed Biosphere Reserve, which includes two protected areas namely Bokong Nature Reserve and Tšehlanyane National Park. The findings reflect the biodiversity value of the area and will contribute towards its nomination as Lesotho's first Biosphere Reserve.

Keywords: Drakensberg Mountain Centre, MAB Programme, endemics, Red Listed species, UNESCO

Introduction

The Man and the Biosphere (MAB) Programme, of the United Nations Educational, Scientific and Cultural Organization (UNESCO), is an intergovernmental scientific programme that seeks to establish a scientific basis for the improvement of relationships between people and their environments. The Programme is implemented through establishment of Biosphere Reserves (BRs), which are aimed at balancing human's dependence on biological resources with the ecological integrity of the natural resource base. The MAB Programme contributes to implementing elements of the Convention on Biological Diversity (CBD) through i) conservation of genetic resources, species and ecosystems; ii) scientific research and monitoring; and iii) promoting sustainable development in communities (UNESCO 1996). The guidelines indicate that each BR should contain three elements, namely: a core area/s, which is/are securely protected for conserving biological diversity as well as undertaking non-destructive research and other low-impact uses; a buffer zone, which usually surrounds or adjoins the core area/s, and is used for co-operative activities compatible with sound ecological practices; a flexible transition area, which incorporates a variety of activities including agriculture and human settlements where various stakeholders work together to manage and sustainably develop the area's resources (UNESCO 1996).

In Lesotho, two protected areas (PAs) namely Bokong Nature Reserve (BNR) and Tšehlanyane National Park (TNP) form the core areas of a proposed BR (Figure 1). The area occurs within the Grassland Biome of southern Africa, which is the second largest biome after the Savanna Biome (Mucina & Rutherford 2006). The PAs have been established under the auspices of the Lesotho Highlands Development Authority (LHDA). The BNR covers an area of about 1 970 ha, and is endowed with wetlands that provide water to the Katse Dam, which in turn supplies water to Gauteng Province in South Africa (LHDA 1998a). The wetlands also provide a habitat to the rare Sloggett's ice rat (*Otomys sloggetti* Thomas, 1902), which is endemic to southern Africa, being confined to South Africa and Lesotho (Maloti–Drakensberg).

Interestingly, BNR is the highest elevation PA in Lesotho, lying between 2 600 and 3 152 m above sea level (m.a.s.l). Tšehlanyane National Park covers an area of 5 600 ha, and serves as a conservation area for mature *Leucosidea sericea* Eckl. & Zeyh. riparian woodland, which forms the largest woodland cover of all areas in Lesotho. Woodland vegetation covers only about 1% of the whole country (May 2000). The most conspicuous plants in TNP is the oldwood (*Leucosidea sericea*), quilted sagewood (*Buddleja salviifolia* (L.) Lam. and Drakensberg bamboo (*Thamnocalamus tessellatus* (Nees)) (Soderstrom & R.P.Ellis 1982). The latter is the only endemic southern African bamboo, and occurs from the Western Cape province of South Africa, through Lesotho and KwaZulu-Natal to the Free State, at elevations of about 1 500–2 500 masl (Soderstrom & Ellis 1982). Indeed, the name of the park originates from the colour of the Drakensberg bamboo, which is yellowish (translating into Tšehlanyane in Sesotho – the local language). The plant is globally rare and provides a habitat for the Red Listed, Endangered butterfly known as the Bamboo Sylph (*Metisella syrinx* (Trimen, 1868)), which is known only from mountain summits of South Africa (Eastern Cape, KwaZulu-Natal) and Lesotho (Soderstrom & Ellis 1982).

Bokong Nature Reserve and TNP fall within the high elevation catchments of Lesotho (Lahmeyer Macdonald Consortium & Oliver Shand Consortium 1986). Being situated at a high elevation, up to 3 152 masl, the proposed BR experiences occasional snow, particularly during winter months (May to July). This has resulted in the area developing unique subalpine vegetation typical of the Maloti–Drakensberg (Mucina & Rutherford 2006). It is estimated that 30% of the plant species occurring in the area are endemic (NES 2000). However, Carbutt and Edwards (2001) considered this to be an over-estimate since the flora of the Lesotho Highlands and Eastern Cape Drakensberg was poorly explored at the time, and thus was not incorporated into the calculation of the area's endemism. Nevertheless, the area is recognised as one of southern Africa's eight hot-spots of botanical diversity as indexed by its species richness and endemism (Cowling & Hilton-Taylor 1994). Van Wyk and Smith (2001) rank the area as having the fourth richest regional flora in southern Africa.

A number of studies have discussed the biodiversity of the proposed BR, however, they were based largely on outdated literature. In addition, most of these studies were limited either in terms of scope, documenting mainly dominant and economically important species, or extent, covering only parts of the proposed BR. For example, the Conservation Development and Management Plan of BNR (LHDA 1998a) estimated floral species richness of the area at 180 flowering plants, based mainly on literature. Similarly, the Management and Development Plan for TNP (LHDA 1998b) estimated the floristic composition of the park at 220 flowering species, which is representative of the western Maloti (i.e. from Sentinel Peak to Mohale's Hoek) of the greater Drakensberg region, and documented 24 mammalian species, even though no field assessment had been made.

Insights into the biodiversity of the proposed BR were provided by Carbutt and Edwards (2004) who documented the native flora of the Drakensberg Alpine Centre (DAC), currently known as Drakensberg Mountain Centre (DMC), as comprising 2 818 taxa in 205 families and 781 genera. Of the 2 818 taxa, 89% were angiosperms, 7% bryophytes, 3% pteridophytes and 0.2% gymnosperms. In addition, they recorded 166 exotic angiosperm species. However, the work of Carbutt and Edwards (2004) is outdated and relied on literature, using regional floras such as Jacot Guillarmod (1971) and Kobisi and Kose (2003) for the Flora of Lesotho, Hilliard and Burtt (1987) and Meter et al. (2002) for the southern KwaZulu-Natal Drakensberg; and Porter et al. (1999) for the uKhahlamba–Drakensberg Park; as well as regional field guides for the trees (Pooley 1993) and mountain flowers (Pooley 2003) in the

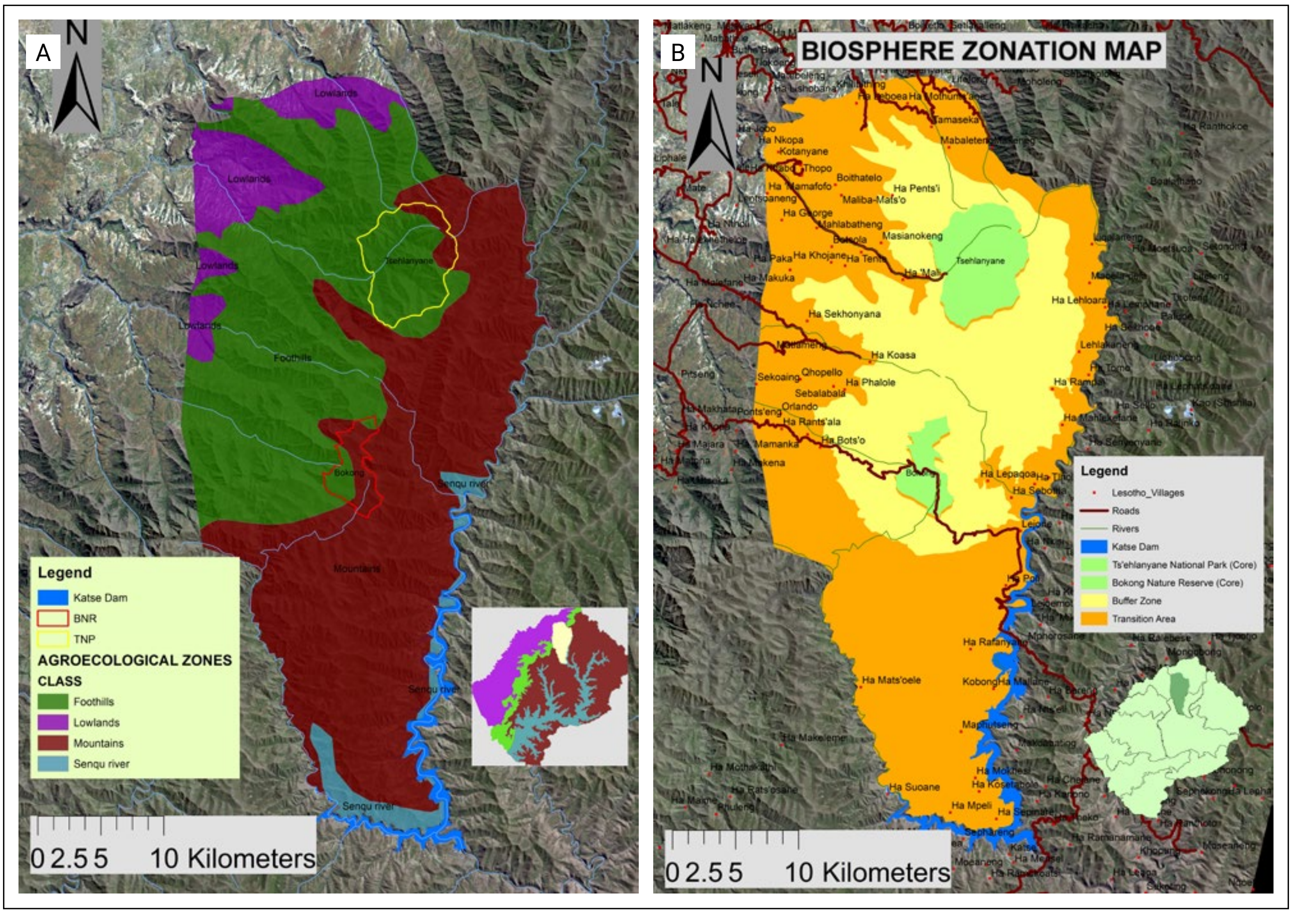

Figure 1. A & B, Lesotho's first proposed Biosphere Reserve, showing the core (Tšehlanyane National Park and Bokong Nature Reserve), buffer and transition zones (Source: T. Leballo).

Maloti–Drakensberg. As they were using regional references, Carbutt and Edwards (2004) were not able to specify which of the recorded species occur in the PAs of the proposed BR.

A publication by Carbutt and Edwards (2006) focused on the endemic and near-endemic angiosperms of the DAC, recording 334 and 595 species respectively, also based on existing literature. The study emphasised that the flora of the area must continue to receive conservation attention because many of its taxa are rare and highly restricted in distribution, and more than half of its endemics are regarded as either Red or Orange Data species. Carbutt (2019) revised the profile of angiosperm endemics provided by Carbutt and Edwards (2006), as well as the boundary of the former DAC. The study recorded 227 angiosperm species, representing 90 genera, as endemic to the DMC, based on previous literature, as well as using Google Earth Pro to delineate new boundaries of the DMC. The revision resulted in removal of about 32% of the species, which were previously regarded as endemic from the account of Carbutt and Edwards (2006), and added two more recently described species to the list.

The most focused work on the biodiversity within the proposed BR was conducted by Letšela et al. (2003), who presented findings from a survey aimed at inventorying resources on which people rely, and that were likely to be affected by the establishment of a BR that encompases both TNP and BNR. This publication is now also outdated and was confined to the proposed core area, as well as to specific taxa with socio-economic benefit. It was therefore evident that no comprehensive documentation of the biodiversity of the proposed BR had been undertaken. As a result, a detailed biodiversity survey covering the core area (BNR and TNP) as well as buffer and transition zones, was necessary to appraise the value of the area, hence supporting its nomination as a BR.

Methodology

Study area

The proposed BR covers a total area of about 112 033 ha, encompassing the core (BNR and TNP, 7 570 ha), buffer (31 050 ha) and transition zones (66 577 ha) (Figure 1), with an elevation ranging between 1 636 and 3 152 masl The area falls within the temperate grassland of southern Africa. It is located in the Leribe District in the northern part of Lesotho

(Figure 1A,B). The proposed BR forms part of the larger area covered by the Maloti–Drakensberg Transfrontier Conservation and Development Programme (MDTC-DP), which spans the border between Lesotho and South Africa, covering certain parts of the two countries (northeastern, eastern and southeastern parts of Lesotho, as well as the adjacent parts of South Africa).

Data collection

The survey stems from the need to profile the biodiversity of the proposed BR, which is needed for supporting nomination of the area to UNESCO. Therefore a rapid survey was undertaken, targeted at both flora and fauna occurring within the proposed BR (core, buffer and transition zones). Four purposeful surveys were conducted by the second and fourth authors, spanning different seasons between August 2018 and May 2019. This was done to target flowering seasons of different plant species to enable their identification, as well as to maximise opportunities to observe faunal species that may hibernate or migrate seasonally. Each of the four surveys lasted for a period of two weeks. Research and collecting permits were provided by the Department of Environment (under the Ministry of Tourism, Environment and Culture in Lesotho), which is also the custodian of the core area that forms part of the proposed BR.

The approach used for data collection was a purposeful field survey undertaken by travelling throughout the core, buffer and transition zones of the proposed BR on foot and on horseback, targeting accessible areas of the proposed BR. Data were collected by identifying and documenting species of both flora and fauna encountered in the area. Global Positioning System (GPS) coordinates were recorded (using Garmin Etrex 10) to map the area covered during the survey (Figure 2). Plants that could not be identified on site were collected and later identified using the literature or herbarium collections at the National University of Lesotho (NUL) herbarium (ROML), where the collected specimens were also deposited.

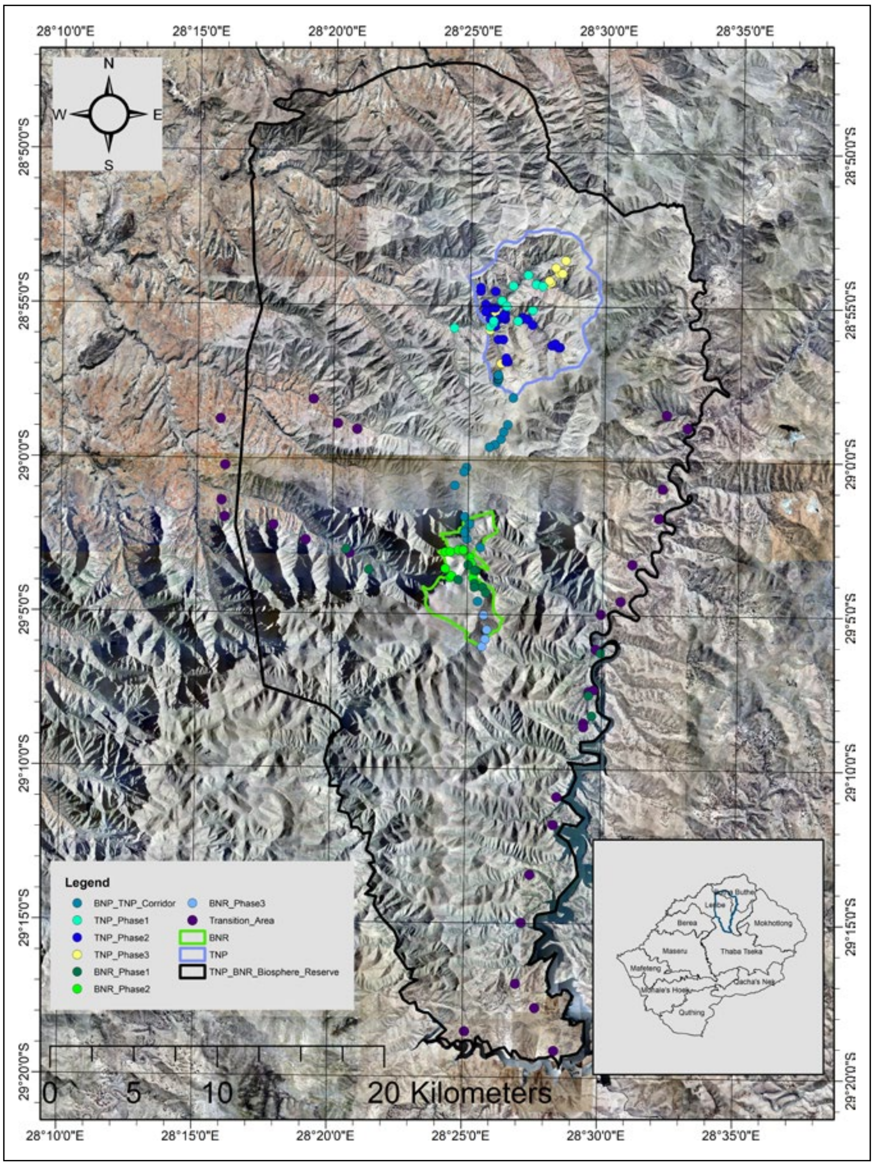

Figure 2. Transect walks covered during the different phases of the biodiversity survey (data collection) in the proposed Biosphere Reserve (Source: T. Leballo).

Fish and aquatic amphibian species were surveyed with the aid of an electro-shocker (powered by a generator) which forced organisms to float on the water surface, where they were identified. The shocking effect was temporary to avoid causing harm. The assessment was conducted in both the Bokong and Tšehlanyane rivers.

Reptiles were surveyed by turning over stones and searching in the thicket. Birds were photographed using a Canon EOS 1100D camera (with a telephoto lens of 300 mm), and identified at a later stage, whereas mammals were recorded through observation. The majority of the species were photographed to allow confirmation of their identification.

Data collection and identification of species was conducted on-site by the second author, a renowned biodiversity specialist who has contributed to various literature resources on Lesotho's flora, such as the Preliminary Checklist of the Plants of Lesotho (Kobisi 2005), a Checklist of Grasses of Lesotho (Kobisi & Kose 2003), as well as the Grassland Biome chapter in the Vegetation of South Africa, Lesotho and Swaziland (Mucina et al. 2006). Species identification was also confirmed by the first author who is a botanist and a Senior Lecturer at the National University of Lesotho. The fourth author also formed part of the expedition team, being the Conservation Officer in the Lesotho's Northern Parks (under which BNR and TNP fall), who has also been involved in several biodiversity expeditions in the country. Various literature resources were used for identification including: Moffett (1997, 2010), Van Wyk and Van Wyk (1997), Pooley (1998, 2003), Van Oudtshoorn (1999), May (2000), Van Wyk and Gericke (2000), Talukdar (2002), Coopero-Driver et al. (2008), Van Wyk et al. (2009), Bromilow (2010), Van Wyk and Smith (2014) for plants; Stuart and Stuart (2015) for mammals; Sinclair et al. (2002) for birds; Alexander and Marais (2008) for reptiles; Du Preez and Carruthers (2009) for amphibians; and NES (2000) for fish.

Limitations of the study

The surveys were undertaken when Lesotho was experiencing dry conditions due to delayed rains in 2018 to 2019. As a result, this delayed the flowering season of the majority of the plants and some specimens could only be identified to genus level. The area is not easily accessible and surveys required long, arduous walks, lasting from sunrise to sunset and are situated in areas with mountainous topography (Figure 3A, B).

Results and discussions

Species lists

The current study provides a detailed compilation of species recorded in the proposed BR (core, buffer and transition zones), covering both flora and fauna (mammals, birds, reptiles, fish and amphibians). Species lists are provided in Tables 1–6, where scientific, English (common) and vernacular (Sesotho) names have been provided, where available. The Plantzafrica website (pza.sanbi.org), as well as Pooley (1998, 2003) were used as the basis for the plant names for taxa recorded in the current study. In the case of fauna, Sinclair et al. (2002) was used for birds; Stuart and Stuart (2007, 2015) for mammals; Alexander and Marais (2008) for reptiles; NES (2000) for fish; and Du Preez and Carruthers (2009) for amphibians. The IUCN Red List status of the different species is also provided, where available. Lesotho conducted the last flora Red List assessment in 2002, focusing on a limited number of species, and based on literature (Talukdar, 2002). Therefore in most cases the Red List of South African plants has been used in the current study (http://redlist.sanbi.org). Similarly, in the case of fauna, Red Listing for Lesotho was last undertaken in 2000, also based on literature. Therefore the IUCN Red List of Threatened Species website (https://www.iucnredlist.org) has been used to provide the conservation status of the fauna species listed in Tables 2–6.

Flora

A total of 380 plant species were recorded in the proposed BR during the four biodiversity surveys undertaken (Table 1). However, six species were only identified to genus level due to absence of flowers at the time of undertaking the survey. These include *Cyrtanthus* sp. Aiton, *Delosperma* sp. N.E.Br and *Eulophia* sp. R.Br. ex Lindl. Thirty of the 380 recorded species are declared protected by law in the country (Legal Notice No. 36 of 1969, as amended by Legal Notice No. 93 of 2004 and No. 38 of 2006), and these include Drakensberg bamboo, giant alepidea (*Alepidea amatymbica* Eckl & Zeyh.), Lesotho carnation (*Dianthus basuticus* Burtt Davy), quilted sagewood (*Buddleja salviifolia* (L.) Lam.) and *Aloe* L. spp. (Table 1). The most represented genera include *Helichrysum* Mill. consisting of 25 species, followed by *Senecio* L. with eight species and *Aloe* with six species. The findings of the current study are in agreement with those of Cowling and Hilton-Taylor (1994), who ranked *Helichrysum* and *Senecio* as the top two genera with the largest number of species in the area. Similarly, Carbutt and Edwards (2006) indicated that these two genera contribute the most to the endemic and near-endemic species of the area. In addition, LHDA (1998b) also reported extensive Drakensberg bamboo communities in the area.

Of the 380 recorded plant species, 41 are exotic (marked with an asterisk in Table 1), these include black poplar (*Populus nigra* L.), four o'clock (*Mirabilis jalapa* L.), khakiweed (*Tagetes minuta* L.), inkberry (*Phytolacca octandra* L.), peach tree (*Prunus persica* (L.) Batsch) and

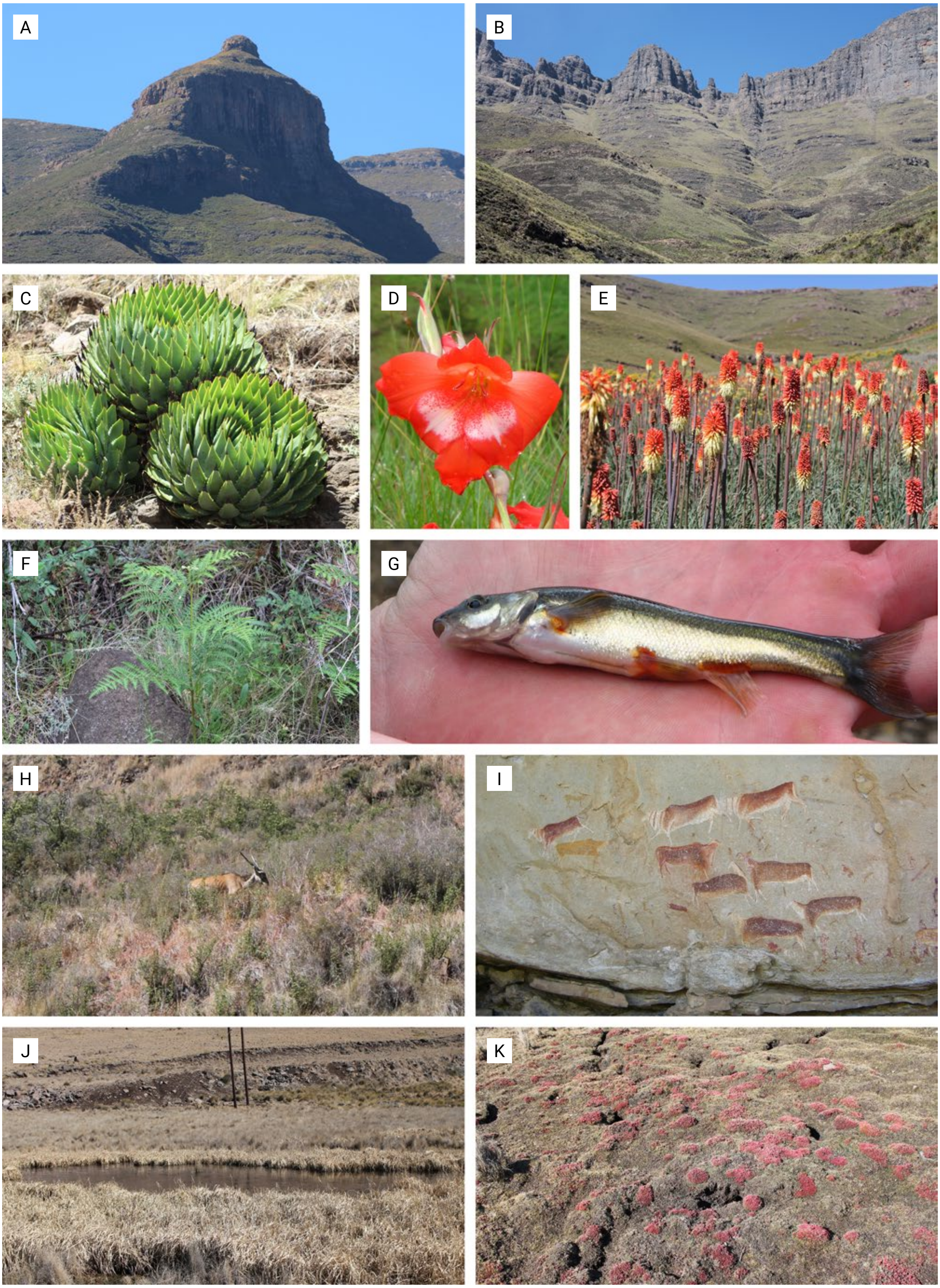

Figure 3. A & B, the spectacular scenery of mountaineous landscapes forming part of the proposed BR; C, the endemic spiral aloe; D, the near-endemic Lesotho lily; E, the Lesotho red-hot poker; F, locally uncommon fern – bracken; G, endemic Maloti minnow; H, common eland; and I, its presence on rock paintings; J, some of the wetlands in the BNR; K, some of them damaged by diggings of Sloggett's ice rat (Source: K. Kobisi).

Table 1. Plant species recorded in the first proposed Biosphere Reserve of Lesotho

Taxon	Common names	Vernacular (Sesotho) names	Habitat	Growth Form	Uses	IUCN Conservation Status	Abundance
Acacia dealbata Link	Blue wattle	*tjobasele*	Terrestrial	Tree	Firewood	Not evaluated	Very common
Afroaster erucifolius (Thell.) J.C.Manning & Goldblatt	Hoary ragwort	*mohontsoane-oa-loti*	Aquatic	Herb		Least Concern	Not common
Afroaster hispida (Thunb.) J.C.Manning & Goldblatt		*phoa*	Terrestrial	Forb	Medicinal	Least Concern	Common
[1]*Agapanthus campanulatus* F.M.Leight. subsp. *patens* (F.M.Leight.) F.M.Leight.	Bell agapanthus	*leta-la-phofu*	Terrestrial	Herb	Medicinal	Least Concern	Common
**Agave americana* L.	Blue agave	*lekhala-le-leputsoa*	Terrestrial	Tree	Ropes	Not evaluated	Common
Agrostis capillaris L.	Astoria bent, black couch, brown bentgrass	*mohloa-oa-mafika*	Aquatic	Grass	Lawns, golf course fairways	Not evaluated	Common
Agrostis lachnantha Nees	Bent grass, south african bent grass	*joang-ba-phororo*	Aquatic	Grass	Grazing	Least Concern	Common
Ajuga ophrydis Burch. ex Benth.	Bugle plant	*senyarela*	Terrestrial	Herb	Medicinal	Least Concern	Common
Alectra sessiliflora (Vahl) Kuntze	Yellow witchweed	*mokhele, sono*	Terrestrial	Forb	Parasitic	Least Concern	Common
[3]*Alepidea amatymbica* Eckl & Zeyh.	Giant alepidea	*lesoko*	Terrestrial	Herb	Medicinal	Endangered	Very common
Alepidea natalensis J.M.Wood & M.S.Evans	Natal star flower	*lesokoana*	Terrestrial	Herb		Least Concern	Common
[1]*Alepidea thodei* Dummer		*lesokoana*	Terrestrial	Herb		Least Concern	Common
[3]*Aloe boylei* Baker	Broad-leaved grass aloe		Terrestrial	Succulent	Medicinal	Least Concern	Not common
[3]*Aloe ecklonis* Salm-Dyck	Ecklon's aloe	*moroba-lihale*	Terrestrial	Succulent	Medicinal	Least Concern	Not common
[3]*Aloe maculata* All.	Common soap aloe	*lekhala-la-bafu*	Terrestrial	Succulent	Medicinal	Least Concern	Not common
[2,3]*Aloe polyphylla* Schönland ex Pillans	Spiral aloe	*lekhala-kharetsa*	Terrestrial	Succulent	Medicinal	Vulnerable	Not common
[3]*Aloiampelos striatula* (Haw.) Klopper & Gideon F.Sm.	Hardy aloe	*mohalakane*	Terrestrial	Shrub	Medicinal	Least Concern	Common
Andropogon eucomus Nees	Snowflake grass	*mohlala*	Terrestrial	Grass	Grazed	Least Concern	Common
Anisodontea julii (Burch.ex DC.) Bates subsp. *pannosa* (Bolus) Bates	African mallow	*letjeane-la-noka*	Terrestrial	Herb		Least Concern	Common
Anthemis cotula L.	Dogfennel		Terrestrial	Forb	Ornamental	Not evaluated	Common

*exotic; [1]DMC (EMR) endemic; [2]Lesotho endemic; [3]declared legally protected in the country

Table 1. Plant species recorded in the first proposed Biosphere Reserve of Lesotho (continued)

Taxon	Common names	Vernacular (Sesotho) names	Habitat	Growth Form	Uses	IUCN Conservation Status	Abundance
Anthospermum streyi Puff		*phakisane*	Terrestrial	Forb	Medicinal	Rare	Common
Argyrolobium marginatum Bolus			Terrestrial	Herb	Grazed	Least Concern	Common
Argyrolobium molle Eckl.&Zeyh.			Terrestrial	Herb		Least Concern	Common
Argyrolobium tuberosum Eckl. & Zeyh.	Little russet pea	*lebesa*	Terrestrial	Herb	Eaten	Least Concern	Not common
[1]*Aristaloe aristata* (Haw.) Boatwr. & J.C.Manning	Torch aloe	*sereleli, lekhalana*	Terrestrial	Succulent	Medicinal	Least Concern	Not common
Aristea abysinnica Pax	Blue-eyed grass		Terrestrial	Herb	Medicinal	Least Concern	Common
Aristea woodii N.E.Br.	Wood's aristea	*lethepu-le-lenyenyane*	Aquatic	Herb	Medicinal	Least Concern	Common
Aristida adscensionis L.	Annual three-awn	*mohlolohali*	Terrestrial	Grass	Grazing	Least Concern	Common
Aristida diffusa Trin. subsp. *burkei* (Stapf) Melderis	Iron grass	*bohlanya-ba-lipere*	Terrestrial	Grass	Grazing	Least Concern	Common
Aristida junciformis Trin. & Rupr.			Terrestrial	Grass		Least Concern	Common
Artemisia afra Jacq.ex Willd. var. *afra*	Wormwood	*lengana*	Terrestrial	Shrub	Medicinal	Least Concern	Very common
Asclepias humilis (E.Mey.) Schltr.	Drakensberg meadow-star		Terrestrial	Herb	Eaten	Least Concern	Common
Asclepias stellifera Schltr.	Common meadow-star	*moholantja*	Terrestrial	Herb	Medicinal	Least Concern	Common
Asparagus asparagoides (L.) Druce	Broad-leaved asparagus	*sethota-sa-mathuoela, khopa*	Terrestrial	Herb	Medicinal	Least Concern	Common
Asparagus microraphis (Kunth)Baker		*lehonyeli*	Terrestrial	Shrub	Medicinal	Least Concern	Common
Asparagus racemosus Willd.	Shatavari	*lerara-tau*	Terrestrial	Shrub	Medicinal	Least Concern	Common
Asplenium adiantum-nigrum L. var. *adiantum-nigrum*	Black spleenwort	*lehorometso*	Terrestrial	Herb		Least Concern	Common
Asplenium cordatum (Thunb.) Sw.	Resurrection fern	*lehorometso*	Terrestrial	Herb		Least Concern	Common
Asplenium monanthes L.	Single-sori fern		Terrestrial	Herb		Least Concern	Common
Athrixia angustissima DC.		*Phefshoana-e-nyenyane*			Medicinal	Least Concern	Common
Athrixia fontana MacOwan		*sepinare*	Aquatic	Herb		Least Concern	Common

[*]exotic;[1]DMC (EMR) endemic; [2]Lesotho endemic; [3]declared legally protected in the country

Table 1. Plant species recorded in the first proposed Biosphere Reserve of Lesotho (continued)

Taxon	Common names	Vernacular (Sesotho) names	Habitat	Growth Form	Uses	IUCN Conservation Status	Abundance
Athyrium schimperi Moug. Ex Fée	Grassland lady-fern		Terrestrial	Herb		Least Concern	Common
[1]*Berkheya cirsiifolia* (DC.) Roessler		*mohato-o-mosoeu*	Terrestrial	Herb	Medicinal	Least Concern	Common
[1]*Berkheya multijuga* (DC.) Roessler	*Doringrige bergdissel* (Afrikaans)	*mohatollo*	Aquatic	Herb	Medicinal	Least Concern	Common
[1]*Berkheya rosulata* Roessler	Rosette thistle	*ntsoantsoane*	Terrestrial	Shrub		Least Concern	Common
Berkheya setifera DC.	Buffalo-tongue	*leleme-la-khomo*	Terrestrial	Herb	Medicinal	Least Concern	Common
**Bidens formosa* Cav.	Cosmos		Terrestrial	Forb	Ornamental	Not evaluated	Very common
**Bidens pilosa* L.	Common black-jack		Terrestrial	Forb	Medicinal	Not evaluated	Very common
[3]*Boophane disticha* (L.f.) Herb.	Poison bulb	*leshoma*	Terrestrial	Herb	Medicinal	Endangered	Common
Brachystelma circinatum E.Mey.	Bird-cage brachystelma	*karana*	Terrestrial	Herb	Eaten	Least Concern	Not common
Bromus firmior (Nees) Stapf	Strong brome	*mukuru-oa-thaba*	Terrestrial	Grass	Grazing	Least Concern	Common
Brownleea parviflora Harv. Ex Lindl.		*mametsana*	Terrestrial	Orchid		Least Concern	Not common
Brownleea macroceras Sond.		*lefokotsane*	Aquatic	Orchid		Least Concern	Not common
[1,3]*Buddleja loricata* Leeuwenberg	Mountain sagewood	*lelora*	Terrestrial	Tree	Firewood	Least Concern	Very common
[1,3]*Buddleja salviifolia* (L.) Lam.	Quilted sagewood	*lelothoane*	Terrestrial	Tree	Firewood	Least Concern	Very common
Bulbine asphodeloides (L.) Spreng.	Spreading bulbine	*pekane*	Terrestrial	Herb	Medicinal	Least Concern	Common
Carex cognata Kunth	Nodding sedge	*lesuoane*	Aquatic	Sedge	Grazing	Least Concern	Common
Catalepis gracilis Stapf & Stent	Gause grass	*joang-ba-matlapa*	Terrestrial	Grass	Grazing	Least Concern	Common
Cerastium arabidis E.Mey.ex.Fenzl.	Snow flower	*qoqobala-ea-loti*	Aquatic	Herb		Least Concern	Common
Cheilanthes eckloniana (Kunze) Mett.	Resurrection fern	*mamarakoaneng*	Terrestrial	Forb	Medicinal	Least Concern	Common
Cheilanthes hirta Sw.		*Lehorometso*	Terrestrial	Fern		Least Concern	Common
Cheilanthes quadripinnata (Forssk.) Kuhn	Four-pinnate lip fern	*lehorometso*	Terrestrial	Fern	Medicinal	Least Concern	Common
Chrysocoma ciliata L.	Bitter bush	*sehalahala*	Terrestrial	Shrub	Firewood	Least Concern	Very common
Cineraria lyratiformis Cron		*tlali-tlali, khotolia*	Terrestrial	Shrublet		Least Concern	Common
**Cirsium vulgare* (Savi) Ten.			Terrestrial	Forb		Not evaluated	Common

*exotic; [1]DMC (EMR) endemic; [2]Lesotho endemic; [3]declared legally protected in the country

Table 1. Plant species recorded in the first proposed Biosphere Reserve of Lesotho (continued)

Taxon	Common names	Vernacular (Sesotho) names	Habitat	Growth Form	Uses	IUCN Conservation Status	Abundance
Clematis brachiata Thunb.	Traveller's joy	*morarana-oa-mafehlo*	Terrestrial	Herb	Medicinal	Least Concern	Common
Cliffortia nitidula (Engl.)	Starry rice-bush	*lenyofane*	Terrestrial	Shrub	Firewood	Not evaluated	Common
Clutia natalensis Bernh.		*mosali-mofubelu*	Terrestrial	Shrub	Fuel Wood, Medicinal	Least Concern	Very common
Conium fontanum Hilliard & Burtt			Aquatic	Herb		Least Concern	Very common
Cotula hispida (DC.) Harv.			Aquatic	Herb		Least Concern	Common
Cotyledon orbiculata L. var.*oblonga* (Haw.) DC.	Pig's ears	*serelile*	Terrestrial	Succulent	Medicinal	Least Concern	Not common
Crassula alba Forssk.		*feko*	Terrestrial	Succulent		Least Concern	Not common
Crassula dependens Bolus			Terrestrial	Succulent		Least Concern	Common
Crassula natalensis Schönl.		*bohobe-ba-setsomi*	Aquatic	Succulent	Medicinal	Least Concern	Common
Crassula peploides Harv		*serelilenyana*	Terrestrial	Succulent	Medicinal	Least Concern	Common
Crassula sarcocaulis Eckl. & Zeyh.		*serelilenyana*	Terrestrial	Succulent	Medicinal	Least Concern	Common
Crassula setulosa Harv.		*serelilenyana*	Terrestrial	Herb	Medicinal	Least Concern	Common
Ctenium concinnum Nees	Sickle grass		Terrestrial	Grass	Grazing	Least Concern	Common
**Cupressus arizonica* Greene var. *glabra* (Sudw.) Little.	Blue Arizona cypress		Terrestrial	Tree	Firewood	Not evaluated	Common
**Cuscuta campestris* Yunck.			Terrestrial	Forb	Parasitic	Not evaluated	Common
[3]*Cussonia paniculata* Eckl. & Zeyh. var. *sinuata* (Reyneke & Kok) DeWinter	Mountain cabbage	*motšetše*	Terrestrial	Tree	Medicinal	Least Concern	Not common
**Cyathula capitata* Moq.		*bohome-ba-lipoli*	Terrestrial	Herb	Medicinal	Not evaluated	Not common
Cymbopogon marginatus (Steud.)Stapf ex Burtt Davy	Turpentine grass	*lebate*	Terrestrial	Grass	Thatching	Least Concern	Common
Cymbopogon plurinodis (Steud.)Stapf ex Burtt Davy	Narrow-leaved turpentine grass	*moshanyana-maralleng*	Terrestrial	Grass	Medicinal	Not evaluated	Common
**Cynodon dactylon* (L.) Pers	Couch grass, quick grass	*mohloa*	Terrestrial	Grass	Grazing	Least Concern	Common
Cyperus congestus Vahl		*qoqothoane*	Terrestrial	Sedge		Least Concern	Common

[*]exotic;[1]DMC (EMR) endemic; [2]Lesotho endemic; [3]declared legally protected in the country

Table 1. Plant species recorded in the first proposed Biosphere Reserve of Lesotho (continued)

Taxon	Common names	Vernacular (Sesotho) names	Habitat	Growth Form	Uses	IUCN Conservation Status	Abundance
[1]*Cyrtanthus attenuatus* R.A.Dyer				Herb		Least Concern	Common
[1]*Cyrtanthus flanaganii* Baker	Flanagan's cyrtanthus	*yellow dobo lily*	Aquatic	Herb		Least Concern	Common
Cyrtanthus sp.Aiton			Aquatic	Succulent			Common
Cysticapnos pruinosa (Bernh.) Lidén	Wild fumaria	*musa-pelo-oa-noka*	Aquatic	Herb	Medicinal	Least Concern	Common
**Datura stramonium* L.	Jimsonweed	*letjoi*	Terrestrial	Herb	Medicinal	Not evaluated	Common
Delosperma cooperi (Hook.f.) L.Bolus	Table mountain		Terrestrial	Herb		Least Concern	Common
Delosperma lineare L.Bolus			Terrestrial	Herb		Least Concern	Common
Delosperma sp. N.E.Br			Terrestrial	Succulent			Common
[3]*Dianthus basuticus* Burtt Davy	Lesotho carnation	*hlokoana-la-tsela*	Terrestrial	Herb	Medicinal	Least Concern	Not common
Diascia barberae Hook. f.			Terrestrial	Herb		Least Concern	Common
Diclis rotundifolia (Hiern) Hilliard & Burtt		*leanya-poli*	Terrestrial	Herb		Least Concern	Common
Dierama argyreum L.Bolus			Terrestrial	Herb		Least Concern	Not common
[1]*Dierama robustum* N.E.Br.	Drakensberg hairbell	*lethepu*	Terrestrial	Herb	Handicrafts	Least Concern	Common
Dimorphotheca jucunda E.Phillips	Trailing pink daisy		Terrestrial	Herb	Medicinal	Least Concern	Common
[1]*Diospyros austro-africana* DeWinter var. *rubriflora* (DeWinter) DeWinter	Firesticks Star-apple	*senokonoko*	Terrestrial	Shrub	Fuel Wood	Least Concern	Common
Disa cephalotes Reichb.f. subsp. *frigida* (Schltr.) H.P.Linder			Terrestrial	Orchid		Rare	Common
Disa cornuta (L.) Swartz	Golden orchid		Terrestrial	Herb		Least Concern	Not common
Disa fragrans Schltr.	Fragrant disa		Terrestrial	Orchid		Least Concern	Common
Disperis cooperi Harv.			Aquatic	Orchid		Least Concern	Not common
Dracoscirpoides ficinioides (Kunth) Muasya		*sechaba, leloli*	Aquatic	Sedge	Handicrafts	Least Concern	Common
Empodium monophyllum (Nel) B.L.Burtt	Golden star		Terrestrial	Forb		Least Concern	Common
Eragrostis caesia Stapf		*joang-ba-mafika*	Terrestrial	Grass	Grazed	Least Concern	Common
Eragrostis chloromelas Steud.	Curly leaf	*tsaane*	Terrestrial	Grass	Grazed	Least Concern	Common

*exotic; [1]DMC (EMR) endemic; [2]Lesotho endemic; [3]declared legally protected in the country

Table 1. Plant species recorded in the first proposed Biosphere Reserve of Lesotho (continued)

Taxon	Common names	Vernacular (Sesotho) names	Habitat	Growth Form	Uses	IUCN Conservation Status	Abundance
Eragrostis plana Nees	Fan love grass, tough love grass	*molula*	Terrestrial	Grass	Grazing	Least Concern	Common
Eragrostis planiculmis Nees	Broom love grass	*joang-ba-tsaane molelengoane*	Terrestrial	Grass	Grazing	Least Concern	Common
[1]*Erica algida* H.Bolus		*lekhapu-le-lenyenyane*	Terrestrial	Shrublet		Least Concern	Common
Erica alopecurus Harv.	Foxtail erica	*molomo-oa-Lekolikotoana*	Terrestrial	Dwarf shrub	Fuel	Least Concern	Common
[1]*Erica dominans* Killick		*lekhapu*	Terrestrial	Shrub	Firewood	Least Concern	Very common
[1]*Erica frigida* H.Bolus		*khoarai*	Terrestrial	Shrublet		Least Concern	Common
Eriocaulon dregei Hochst.	Water pom-pom	*nyokoana-ea-likhoho*	Aquatic	Herb		Least Concern	Common
**Eucalyptus* sp. L'Hér	Gum tree		Terrestrial	Tree	Firewood		Common
[3]*Euclea coriacea* A.DC.		*ralikokotoana*	Terrestrial	Tree	Medicinal	Least Concern	Common
[3]*Eucomis autumnalis* (Mill.) Chitt. subsp. *clavata* (Baker) Reyneke	Common pineapple lily	*khapumpu*	Terrestrial	Herb	Medicinal	Vulnerable	Common
[1,3]*Eucomis schijffii* Reyneke	Miniature eucomis	*khapumpu*	Terrestrial	Herb	Medicinal	Least Concern	Common
[3]*Eulophia* sp. R.Br. ex Lindl.		*makholela*	Terrestrial	Herb			Common
[1]*Eumorphia prostrata* Bolus			Terrestrial	Shrub		Least Concern	Very common
[1]*Eumorphia sericea* Wood & Evans		*lirulello*	Terrestrial	Dwarf shrub	Fuel	Least Concern	Common
[3]*Euphorbia clavarioides* Boiss.	Lion's spoor	*sehloko*	Terrestrial	Succulent	Medicinal	Least Concern	Common
Euphorbia ericoides Lam.			Terrestrial	Shrublet		Least Concern	Common
[1]*Euryops decumbens* B.Nord.			Terrestrial	Shrublet		Least Concern	Common
Euryops evansii Schltr.		*sehlakoana*	Terrestrial	Tree	Medicinal	Least Concern	Very common
Euryops laxus (Harv.) Burtt Davy			Terrestrial	Herb		Least Concern	Common
[1]*Euryops tysonii* E.Phillips		*sehlakoana-se-senyenyane*	Terrestrial	Shrub	Ornamental	Least Concern	Not common
Felicia filifolia (Vent.) Burtt Davy	Fine-leaved Felicia	*sehalahala*	Terrestrial	Shrub	Firewood	Least Concern	Common

*exotic; [1]DMC (EMR) endemic; [2]Lesotho endemic; [3]declared legally protected in the country

Table 1. Plant species recorded in the first proposed Biosphere Reserve of Lesotho (continued)

Taxon	Common names	Vernacular (Sesotho) names	Habitat	Growth Form	Uses	IUCN Conservation Status	Abundance
Felicia muricata (Thunb.) Nees		*mamileng, mosala-tsela*	Terrestrial	Forb	Medicinal	Least Concern	Very common
Felicia rosulata P.F.Yeo			Terrestrial	Herb		Least Concern	Common
[1]*Festuca caprina* Nees	Goat-beard grass	*letsiri*	Terrestrial	Grass	Grazed	Least Concern	Common
Festuca costata Nees		*lekolojane*	Terrestrial	Grass	Grazed	Least Concern	Common
Fingerhuthia sesleriiformis Nees	Thimble grass	*thitapoho*	Aquatic	Grass	Brooms	Least Concern	Common
Gazania krebsiana Less.	Terracotta Gazania, common Gazania	*tsikitlane*	Terrestrial	Forb	Medicinal	Least Concern	Very common
[1]*Geranium drakensbergensis* Hilliard&B.L.Burtt			Aquatic	Herb		Rare	Not common
Geranium multisectum N.E.Br.		*hlapi-e-kholo*	Aquatic	Herb	Medicinal	Least Concern	Common
Geranium pulchrum N.E. Br.			Terrestrial	Subshrub	Ornamental	Least Concern	Common
Gerbera ambigua (Cass.)Sch.Bip.			Terrestrial	Herb	Medicinal	Least Concern	Common
Gerbera piloselloides (L.) Cass.		*tsebe-ea-pela*	Terrestrial	Herb		Least Concern	Very common
Geum capense Thunb.		*thejana, qojoana*	Aquatic	Forb		Least Concern	Very common
[3]*Gladiolus dalenii* VanGeel subsp. *dalenii*	African gladiolus	*mokhabebe*	Terrestrial	Herb	Medicinal	Least Concern	Common
[1]*Gladiolus saundersii* Hook f.	Lesotho lily	*mokhabebe*	Terrestrial	Herb	Medicinal	Least Concern	Common
[2]*Glumicalyx lesuticus* Hillard & Burtt			Terrestrial	Herb		Least Concern	Not common
[1]*Glumicalyx nutans* (Rolfe) Hilliard & Burtt		*theleli*	Terrestrial	Herb		Least Concern	Common
[1]*Gnidia aberrans* C.H.Wright			Terrestrial	Dwarf shrublet		Least Concern	Not Common
[1]*Gnidia propinqua* (Hilliard) B.Peterson			Terrestrial	Dwarf shrublet		Least Concern	Not common
Gomphocarpus fruticosus (L.) Aiton f.	Milkweed		Terrestrial	Shrub	Medicinal	Least Concern	Common
Gomphocarpus physocarpus E.Mey.	Milkweed	*moithimolo*	Terrestrial	Herb	Medicinal	Least Concern	Common
Gomphostigma virgatum (L.f.) Baill.	River stars	*koete-le-boima*	Aquatic	Shrublet	Medicinal	Least Concern	Common
[3]*Gunnera perpensa* L.	Mild rhubarb	*qobo*	Aquatic	Herb	Medicinal	Least Concern	Common

[*]exotic;[1]DMC (EMR) endemic; [2]Lesotho endemic; [3]declared legally protected in the country

Table 1. Plant species recorded in the first proposed Biosphere Reserve of Lesotho (continued)

Taxon	Common names	Vernacular (Sesotho) names	Habitat	Growth Form	Uses	IUCN Conservation Status	Abundance
Haemanthus humilis Jacq.	Rabbits ears	*tsebe-ea-phofu*	Terrestrial	Herb	Medicinal	Least Concern	Common
Haplocarpha scaposa Harv.	False gerbera	*papetloana, khutsana, lengoako*	Terrestrial	Herb	Medicinal	Least Concern	Very common
Harpochloa falx (L.f.)Kuntze	Caterpillar grass	*lefokololi*	Terrestrial	Grass	Grazed	Least Concern	Very common
[1]*Harveya huttonii* (= *H. pulchra* Hilliard & Burtt)		*moshoa-fela*	Terrestrial	Herb		Least Concern	Common
Harveya speciosa Bernh.	Tall white ink-flower		Terrestrial	Herb	Medicinal	Least Concern	Common
[1]*Hebenstretia dura* Choisy		*tsitoane*	Terrestrial	Herb	Ointment	Least Concern	Not common
Helichrysum cymosum (L.) D.Don	Yellow-tipped straw-flowers		Terrestrial	Shrublet	Medicinal	Least Concern	Common
Helichrysum trilineatum DC.		*hokobetsi*	Terrestrial	Shrub	Firewood	Least Concern	Very common
Helichrysum allioides DC.			Terrestrial			Least Concern	Common
[1]*Helichrysum aureum* (Houtt) Merrill var. *serotinum* Hilliard		*leabane*	Terrestrial	Herb		Least Concern	Common
[1]*Helichrysum basalticum* Hilliard			Terrestrial	Herb		Least Concern	Not common
[1]*Helichrysum bellum* Hilliard			Terrestrial	Herb		Least Concern	Not common
Helichrysum caespititium (DC.) Harv.	*Speelwonderblom* (Afrikaans)	*phate-ea-ngaka*	Terrestrial	Herb	Medicinal	Least Concern	Common
Helichrysum chionosphaerum DC.	Tiny snowball everlasting	*Molepelle*	Terrestrial	Herb		Least Concern	Common
Helichrysum glomeratum Klatt			Terrestrial	Forb		Least Concern	Common
[1]*Helichrysum hyphocephalum* Hilliard			Terrestrial	Herb		Least Concern	Not common
Helichrysum krookii Moeser			Terrestrial	Herb		Least Concern	Common
Helichrysum lingulatum Hilliard			Terrestrial	Herb		Least Concern	Common
[1]*Helichrysum marginatum* DC.		*tooane-balingoana-e-tsoeu*	Terrestrial	Dwarf shrub		Least Concern	Common
Helichrysum mundtii Harv.		*phefo-ea-liliba*	Terrestrial	Herb	Medicinal	Least Concern	Common

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Table 1. Plant species recorded in the first proposed Biosphere Reserve of Lesotho (continued)

Taxon	Common names	Vernacular (Sesotho) names	Habitat	Growth Form	Uses	IUCN Conservation Status	Abundance
Helichrysum nudifolium (L.) Less.	Hottentot's tea	*mohlomela-tsie, tee-ea-baroa*	Terrestrial	Herb	Tea	Least Concern	Common
Helichrysum nudifolium (L.) Less. var. pilosellum (L.f.) Beentje		*boleba, lebeko*	Terrestrial	Forb	Medicinal	Least Concern	Common
Helichrysum odoratissimum (L.) Sweet	Most fragrant helichrysum	*phefo*	Terrestrial	Herb	Medicinal	Least Concern	Very common
[1]*Helichrysum praecurrens* Hilliard			Terrestrial	Herb		Least Concern	Common
[1]*Helichrysum retortoides* N.E.Br.			Terrestrial	Herb		Least Concern	Not common
[1]*Helichrysum sessilioides* Hilliard			Terrestrial	Herb		Least Concern	Common
Helichrysum sp. Mill.			Terrestrial	Herb			Common
Helichrysum spiralepis Hilliard & B.L.Burtt		*tooane-ea-metsi*	Terrestrial	Herb		Least Concern	Common
Helichrysum splendidum (Thunb.) Less.	Cape gold	*tooane-ea-meru*	Terrestrial	Shrublet	Medicinal, ornamental	Least Concern	Common
Helichrysum sutherlandii Harv.		*molepelle*	Terrestrial	Herb	Medicinal	Least Concern	Common
Helichrysum trilineatum DC.		*hokobetsi*	Terrestrial	Shrub	Firewood	Least Concern	Very common
[1]*Helichrysum witbergense* H.Bolus			Terrestrial	Shrub	Firewood	Least Concern	Not common
Helictotrichon turgidulum (Stapf) Schweick.	Small oats grass		Terrestrial	Grass	Grazed	Least Concern	Common
[1]*Heliophila formosa* Hilliard & Burtt			Terrestrial	Herb		Least Concern	Not common
Hermannia coccocarpa (Eckl. & Zeyh.) Kuntze			Terrestrial	Forb		Least Concern	Common
Hermannia sandersonii Harv.			Terrestrial	Herb		Vulnerable	Not common
Hesperantha baurii Baker subsp. *baurii*		*khukhu-e-nyane*	Aquatic	Herb	Corms eaten	Least Concern	Common
Hesperantha coccinea (Backh. & Harv.) Goldblatt & J.C.Manning	Scarlet river lily	*khahla*	Terrestrial	Herb		Least Concern	Common
[1]*Hesperantha crocopsis* Hilliard & Burtt			Aquatic	Herb		Not evaluated	Not common

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Table 1. Plant species recorded in the first proposed Biosphere Reserve of Lesotho (continued)

Taxon	Common names	Vernacular (Sesotho) names	Habitat	Growth Form	Uses	IUCN Conservation Status	Abundance
[3]*Heteromorpha arborescens* (Spreng.) Cham. & Schltdl. var. *abyssinica* (Hochst. ex A.Rich.) H.Wolff	Parsley-tree	*monkhoane*	Terrestrial	Tree	Medicinal	Least Concern	Common
Hilliardiella hirsuta (DC.) H.Rob.	Guilted-leaved vernonia	*hlele-hlele*	Terrestrial	Forb	Medicinal	Least Concern	Common
[3]*Hirpicium armerioides* (DC.)Roessler		*shoeshoe-ea-loti*	Terrestrial	Herb		Least Concern	Common
Holothrix scopularia (Lindl.) Reichb.f.			Terrestrial	Herb		Least Concern	Common
[3]*Hyparrhenia hirta* (L.) Stapf	Common thatching grass	*mohlomo*	Terrestrial	Grass	Thatching	Least Concern	Very common
[3]*Hyparrhenia tamba* (Steud.) Stapf	Blue thatching grass	*qokoa*	Terrestrial	Grass	Thatching	Least Concern	Very common
Hypericum lalandii Choisy	Spindly hypericum	*bohlokoana*		Herb	Medicinal	Least Concern	Common
[3]*Hypoxis costata* Baker		*moli-kharetsa*	Terrestrial	Forb	Medicinal	Least Concern	Common
Hypoxis obtusa Burch. ex Ker Gawl		*moli-boea*	Terrestrial	Herb		Least Concern	Common
Hypoxis rigidula Baker	Silver-leaved star-flower	*holi*	Terrestrial	Herb		Least Concern	Common
Indigofera cuneifolia Eckl. & Zeyh.	Wedge-leaved indingo		Terrestrial	Herb		Least Concern	Common
[1]*Inulanthera thodei* (Bolus) Källersjö		*khato*	Terrestrial	Shrub	Medicinal	Least Concern	Very common
[1]*Jamesbrittenia pristisepala* (Hiern) Hilliard		*pokaetsi, phiri-ea-hlaha, sesepa-sa-linoha, letsoalo*	Terrestrial	Shrublet	Fishing	Least Concern	Common
Jamesbrittenia sp. Kuntze			Terrestrial	Shrublet			Common
Kedrostris capensis (Sond.) A.Meeuse		*sesepa-sa-linoha*	Terrestrial	Herb		Least Concern	Not common
Kiggelaria africana L.	Wild peach	*lekhatsi*		Tree	Ornamental	Least Concern	Not common
[3]*Kniphofia caulescens* Baker	Lesotho red-hot poker	*leloele-la-loti*	Aquatic	Herb	Medicinal	Least Concern	Common
[1,3]*Kniphofia evansii* Baker	Evan's poker		Terrestrial	Herb		Rare	Not common
[1,3]*Kniphofia hirsuta* Codd		*leloele*	Aquatic	Forb		Least Concern	Common
[3]*Kniphofia northiae* Bak.	Broad-leaved poker	*leloele*	Aquatic			Least Concern	Common
Koeleria capensis (Steud.) Nees	June grass	*boshoane*	Terrestrial	Grass	Grazing	Least Concern	Common
Kohautia amatymbica Eckl. & Zeyh.	Tremble tops	*lerete-la-ntja*	Terrestrial	Herb	Medicinal	Least Concern	Common

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Table 1. Plant species recorded in the first proposed Biosphere Reserve of Lesotho (continued)

Taxon	Common names	Vernacular (Sesotho) names	Habitat	Growth Form	Uses	IUCN Conservation Status	Abundance
Ledebouria cooperi (Hook. f.) Jessop	Cooper's ledebouria	*leptjetlane*	Terrestrial	Herb	Medicinal	Least Concern	Common
Ledebouria sandersonii (Baker) S.Venter & T.J.Edwards			Terrestrial	Herb	Medicinal	Least Concern	Common
Leobordea divaricata Eckl. & Zeyh.	Hairy lotononis	*namele*	Terrestrial			Least Concern	Common
Lessertia depressa Harv.		*musa-pelo*	Terrestrial	Shrublet		Least Concern	Common
Lessertia frutescens (L.) Goldblatt & J.C.Manning subsp. *frutescens*	Cancer-bush, mountain ballon pea	*musa-pelo*	Terrestrial	Herb	Medicinal	Least Concern	Common
Lessertia perennans (Jacq.) DC.	Lessertia	*musa-pelo*	Terrestrial	Shrublet		Least Concern	Common
[3]*Leucosidea sericea* Eckl. & Zeyh.	Oldwood	*cheche*	Terrestrial	Tree	Firewood	Least Concern	Very common
Limosella grandiflora Benth.		*tsika-metsi*	Aquatic	Forb	Medicinal	Least Concern	Common
[1]*Limosella vesiculosa* Hilliard & Burtt			Aquatic	Herb		Least Concern	Not common
[1]*Lobelia galpinii* Schltr.		*tenane*	Terrestrial	Herb		Least Concern	Common
[1]*Lotononis galpinii* Dummer			Terrestrial	Shrub	Grazed	Least Concern	Common
Lotononis laxa Eckl. & Zeyh.		*musa-pelo-oa-matlapa-o-monyenyana*	Terrestrial	Herb		Least Concern	Common
Lotononis lotononoides (Scott-Elliot) B.-E. vanWyk		*mosita-tlali*	Terrestrial	Herb		Least Concern	Common
[1]*Lotononis sericophylla* Benth.		*motoaitoai*	Terrestrial	Shrub		Least Concern	Common
[1]*Macowania pulvinaris* N.E.Br.		*mamotasi*	Terrestrial	Shrublet		Least Concern	Common
[1]*Macowania sororis* Compton			Terrestrial	Shrub		Least Concern	Common
Marrubium vulgare L.	Horehound	*monyeloa-ke-ntja*	Terrestrial	Herb	Medicinal	Not evaluated	Common
Melianthus comosus Vahl	Maroon honey-flower		Terrestrial	Shrub	Ornamental	Least Concern	Not common
Melolobium microphyllum (L.f.) Eckl.&Zeyh.		*mofahla-toeba*	Terrestrial	Shrublet	Grains Protector	Least Concern	Common
[3]*Mentha aquatica* L.	Water mint	*koena-ea-mekhoabo*	Aquatic	Forb	Medicinal	Least Concern	Common
#*Mentha longifolia* (L.) Huds.	Wild spearmint	*koena*	Aquatic	Forb	Medicinal	Least Concern	Common

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Table 1. Plant species recorded in the first proposed Biosphere Reserve of Lesotho (continued)

Taxon	Common names	Vernacular (Sesotho) names	Habitat	Growth Form	Uses	IUCN Conservation Status	Abundance
Merwilla plumbea (Lindl.) Speta	Large blue scilla	*kherere*	Terrestrial	Herb	Medicinal	Near Threatened	Very common
[1,3]*Merxmuellera macowanii* (Stapf) Conert		*mosika-nokana, mosea, molala-hlolo*	Aquatic	Grass	Thatching, brooms, ropes, hats, mats	Least Concern	Very common
[3]*Merxmuellera stereophylla* (J.G.Anders.) Conert		*molalahlolo*	Terrestrial	Grass	Thatching	Least Concern	Very common
Metalasia densa (Lam.) P.O.Karis	Drakensberg steekbos	*tee*	Terrestrial	Shrub	Fumigant	Least Concern	Very common
**Mirabilis jalapa* L.	Four o'clock		Terrestrial	Herb	Ornamental	Not evaluated	Common
[1]*Miscanthus ecklonii* (Nees) Mabb.	East-coast broom grass	*mothala*	Terrestrial	Grass	Thatching	Least Concern	Common
Miscanthus junceus (Stapf) Pilg.	Wireleaf daba grass		Terrestrial	Grass	Stabilising riverbanks	Least Concern	Very common
[1]*Mohria rigida* J.P.Roux			Terrestrial	Herb		Least Concern	Not common
[1]*Moraea alpina* Goldblatt			Terrestrial	Herb		Least Concern	Not Common
[1]*Moraea alticola* Goldblatt		*teele-e-kholo*	Terrestrial	Herb	Ornamental	Least Concern	Common
Moraea brevistyla (Goldblatt) Goldblatt			Terrestrial	Herb		Least Concern	Not common
Moraea modesta Killick			Terrestrial	Herb		Least Concern	Common
Moraea stricta Baker	*Bloutulp* (Afrikaans)	*qhekoe*	Terrestrial	Herb	Corms eaten	Least Concern	Common
[3]*Morella serrata* (Lam.) Killick	Lance-leaved waxberry	*maleleka*	Terrestrial	Shrub	Medicinal	Vulnerable	Not Common
[1]*Muraltia flanaganii* Bolus			Terrestrial	Shrub		Least Concern	Common
Myosotis semiamplexicaulis A.DC.	Forget-me-not		Terrestrial	Herb	Medicinal	Data Deficient Taxonomically Problematic	Common
Myrsine africana L.	Cape myrtle	*moroka-pheleu*	Terrestrial	Shrub	Medicinal	Least Concern	Common
Nasturtium officinale R.Br.	Watercress	*semetsing, selae*	Aquatic	Herb	Vegetables	Not evaluated	Common
Nemesia caerulea Hiern	Nemesia		Terrestrial	Forb		Least Concern	Common
Nemesia rupicola Hilliard			Terrestrial	Herb		Least Concern	Common

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Table 1. Plant species recorded in the first proposed Biosphere Reserve of Lesotho (continued)

Taxon	Common names	Vernacular (Sesotho) names	Habitat	Growth Form	Uses	IUCN Conservation Status	Abundance
**Nicotiana sylvestris* Speg. & Comes	Woodland tobacco	*setalane*	Terrestrial	Herb	Tobacco	Not evaluated	Common
Nidorella pinnata (L.f.) J.C.Manning & Goldblatt				Aquatic	Forb	Least Concern	
**Oenothera elata* Kunth.	Yellow evening primrose		Terrestrial	Herb		Not evaluated	Common
Ornithogalum juncifolium Jacq.	Grass-leaved	*lijo-tsa-noko, mahae*	Aquatic	Herb	Medicinal	Least Concern	Common
Ornithogalum viridiflorum (I.Verd.) J.C.Manning & Goldblatt	Green berg lily		Terrestrial	Herb		Least Concern	Common
Orthochilus aculeatus (L.f.) Bytebier subsp. *huttonii* (Rolfe) Bytebier		*mametsana*	Terrestrial	Herb		Least Concern	Not common
[1]*Osteospermum thodei* Markötter			Terrestrial	Shrub		Least Concern	Not common
Othonna burttii B. Nord.			Terrestrial	Herb	Grazing	Least Concern	Not common
Oxalis obliquifolia Steud. ex A.Rich.	Oblique-leaved sorrel	*bolila*	Terrestrial	Herb	Eaten	Least Concern	Common
Oxalis smithiana Eckl. & Zeyh.	Narrow-leaved sorrel	*boli-ba-lipoli*	Terrestrial	Herb	Medicinal	Least Concern	Common
[3]*Pachycarpus vexillaris* E.Mey.	Mountain pachycarpus	*leshokhoa*	Terrestrial	Forb	Medicinal	Least Concern	Common
Papaver aculeatum Thunb.	Orange poppy	*sehlohlo*	Terrestrial	Herb	Medicinal	Least Concern	Common
**Paspalum dilatatum* Poir.			Terrestrial	Grass	Grazing	Not evaluated	Common
[1]*Passerina drakensbergensis* Hilliard & Burtt	Drakensberg passerina	*lekhapu*	Terrestrial	Shrub	Firewood	Least Concern	Very common
[1]*Passerina montana* Thoday	Mountain passerina	*lekhapu*	Terrestrial	Shrub	Firewood	Least Concern	Very common
Pelargonium alchemilloides (L.) L'Hér.	Pink trailing pelargonium	*bolila-ba-litsoene*	Terrestrial	Herb	Medicinal	Least Concern	Very common
Pelargonium bowkeri Harv.	Carrot-leaved pelargonium	*bolila-ba-litsoene*	Terrestrial	Herb	Medicinal	Least Concern	Not Common
Pelargonium ranunculophyllum (Eckl. & Zeyh.) Baker			Terrestrial	Herb		Least Concern	Very common
Peltocalathos baurii (MacOwan) Tamura	Large-leaved ranunculus	*qojoana*	Aquatic	Herb		Least Concern	Common
**Pennisetum clandestinum* Hochst. ex Chiov.	Kikiyu	*mohloa-tsepe*	Terrestrial	Grass	Grazing	Not evaluated	Very common
Pentameris airoides Nees subsp. *airoides*			Terrestrial	Grass	Grazing	Least Concern	Very common

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Table 1. Plant species recorded in the first proposed Biosphere Reserve of Lesotho (continued)

Taxon	Common names	Vernacular (Sesotho) names	Habitat	Growth Form	Uses	IUCN Conservation Status	Abundance
Pentameris oreodoxa (Schweick.) Galley & H.P.Linder			Terrestrial	Grass	Grazing	Least Concern	Very common
Pentameris setifolia (Thunb.) Galley & H.P.Linder			Terrestrial	Grass	Grazing	Least Concern	Very common
Pentzia cooperi Harv.		*lelingoana*	Terrestrial	Shrub	Firewood	Least Concern	Very common
Persicaria decipiens (R.Br.) K.L.Wilson	Knotweed	*tolo-la-khongoana-le-lenyenyane*	Aquatic	Herb	Medicinal	Least Concern	Common
**Persicaria lapathifolia* (L.) Gray	Spotted knotweed	*khamane-ea-noka*	Aquatic	Herb	Medicinal	Not evaluated	Common
[3]*Phragmites australis* (Cav.)Steud.	Common reed	*lehlaka*	Aquatic	robust Grass	Thatching	Least Concern	Common
Phygelius aequalis Harv. Ex Hiern	River bells	*mafifi-matso*	Aquatic	Herb	Medicinal	Least Concern	Very common
Phygelius capensis E.Mey. ex Benth.	Southern phygelius	*mafifi-matso*	Terrestrial	Shrub	Medicinal	Least Concern	Common
**Phytolacca octandra* L.	Inkberry	*monatja*	Terrestrial	Herb	Medicinal	Not evaluated	Common
**Pinus radiata* D.Don	Pine tree	*phaena*	Terrestrial	Tree	Firewood	Not evaluated	Common
**Plantago lanceolata* L.	Narrow-leaved ribwort, plantain	*bolilanyana, setla-bocha*	Terrestrial	Herb	Medicinal	Least Concern	Common
**Plectranthus dolichopodus* Briq.	Blue yonder		Terrestrial	Herb	Ornamental	Least Concern	Common
Plectranthus esculentus N.E.Br.	African potato	*lephelephele*	Terrestrial	Herb	Eaten	Data Deficient Insufficient Information	Not common
Plectranthus grallatus Briq.	Tuberous spur-flower	*lephelephele*	Terrestrial	Herb	Medicinal	Least Concern	Common
Polemannia simplicior Hilliard & Burtt			Terrestrial	Shrub		Least Concern	Common
Polygala gracilenta Burtt Davy			Terrestrial	Herb		Least Concern	Common
Polygala myrtifolia L.	September bush		Terrestrial	Shrub	Ornamental	Least Concern	Very common
Polygala rhinostigma Chodat			Terrestrial	Herb	Medicinal	Least Concern	Common
Polygala virgata Thunb.	Purple broom	*ntsebele-ea-moru*	Terrestrial	Shrub	Medicinal	Least Concern	Common
[1]*Polystichum monticola* N.C. Anthony & Schelpe	Arching fronds	*lehorometso*	Terrestrial	Fern		Least Concern	Not common

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Table 1. Plant species recorded in the first proposed Biosphere Reserve of Lesotho (continued)

Taxon	Common names	Vernacular (Sesotho) names	Habitat	Growth Form	Uses	IUCN Conservation Status	Abundance
**Populus deltoides* Marshall	Eastern cottonwood		Terrestrial	Tree	Poles, Firewood	Not evaluated	Common
**Populus nigra* L.	Black poplar	*maipopo*	Terrestrial	Tree	Poles, Firewood	Not evaluated	Common
**Populus x canescens* (Aiton) Sm.	Grey poplar	*papoleri*	Terrestrial	Tree	Poles, Firewood	Not evaluated	Very common
**Portulaca oleracea* L.	Common purslane	*sereleli*	Terrestrial	Herb	Medicinal	Not evaluated	Common
Potomageton pusillus L.	Narrow-leaved pondweed	*joang-ba-metsi-bo-boholo*		Herb		Least Concern	Common
Printzia auriculata Harv.	Giant daisy bush	*sephomolo*	Terrestrial	Shrub	Ornamental	Least Concern	Common
[1]*Printzia nutans* (Bolus) Leins			Terrestrial	Herb		Least Concern	Common
Printzia pyrifolia Less.		*lekhisa*	Terrestrial	Herb	Medicinal	Least Concern	Common
**Prunus armeniaca* L.	Apricot tree		Terrestrial	Tree	Fruits	Not evaluated	Common
**Prunus persica* (L.) Batsch	Peach tree	*perekisi*	Terrestrial	Tree	Fruits	Not evaluated	Common
Pteridium aquilinum (L.) Kuhn	Bracken fern		Terrestrial	Fern	Medicinal	Least Concern	Very common
Pterygodium alticola (Parkman & Schelpe) J.C.Manning & Goldblatt			Terrestrial	Orchid		Rare	Common
Pterygodium caffrum (L.) Sw.			Aquatic	Herb		Least Concern	Common
Pterygodium cooperi Rolfe			Aquatic	Herb		Least Concern	Common
**Pyracantha angustifolia* (Franch.) C.K.Schneid.	Narrowleaf firethorn		Terrestrial	Tree	Hedge	Not evaluated	Common
Ranunculus meyeri Harv.	Bog buttercup	*bolila-ba-linku-ba-metsi*		Herb		Not evaluated	Common
Ranunculus multifidus Forsk. sens. lat.	Common buttercup	*tlhapi*	Aquatic	Herb	Medicinal	Least Concern	Very common
**Rapistrum rugosum* (L.) All.	Wild mustard		Terrestrial	Herb	Vegetables	Not evaluated	Very common
[3]*Rhamnus prinoides* L'Hèrit	Glossyleaf Dogwood	*mofifi*	Terrestrial	Tree	Medicinal	Least Concern	Very common
Rhynchosia totta (Thunb.) DC.	Yellow carpet bean	*seoelioetla, sehoete, sebalibetloa*	Terrestrial	Forb	Tuber eaten	Least Concern	Common

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Table 1. Plant species recorded in the first proposed Biosphere Reserve of Lesotho (continued)

Taxon	Common names	Vernacular (Sesotho) names	Habitat	Growth Form	Uses	IUCN Conservation Status	Abundance
**Robinia pseudoacacia* L.	Black locust	*leoka*	Terrestrial	Tree	Poles, Firewood	Not evaluated	Common
**Rorippa nudiuscula* Thell.	Yellow cress	*papasane*	Terrestrial	Herb	Vegetable	Least Concern	Common
**Rosa rubiginosa* L.	Sweet-briar, rosehip	*moroboi*	Terrestrial	Shrub	Hedge, Cosmetics	Not evaluated	Very common
**Rumex sagittatus* Thunb.	Climbing rumex	*bolila-bo-boholo*	Terrestrial	Herb	Medicinal	Least Concern	Common
**Salix babylonica* L.	Weeping willow		Aquatic	Tree	Firewood	Not evaluated	Very common
**Salix fragilis* L.	Basket willow	*moluoane*	Aquatic	Tree	Firewood	Not evaluated	Very common
Satyrium longicauda Lindl.	Blushing bride satyrium		Terrestrial	Orchid	Medicinal	Not evaluated	Common
Scabiosa columbaria L	Wild scabious	*selomi*	Terrestrial	Herb	Medicinal	Least Concern	Very common
Schistostephium crataegifolium (DC.) Fenzl. ex Harv.	Golden flat-flower	*kobo-ea-Marena*	Terrestrial	Herb	Medicinal	Least Concern	Common
Schizoglossum atropurpureum E.Mey. subsp. *atropurpureum*		*sehoete-moru*	Terrestrial	Herb	Medicinal	Least Concern	Common
[1]*Schizoglossum hilliardiae* Kupicha	Hilliard's schizoglosum		Terrestrial	Herb		Least Concern	Common
[1]*Searsia discolor* (E.Mey. ex Sond.) Sond.	Grassveld currant	*mohlohloane*	Terrestrial	Shrub	Medicinal	Least Concern	Not Common
Searsia divaricata (Eckl. & Zeyh.) Moffett	Rusty leaves currant	*kolitsana*	Terrestrial	Shrub	Medicinal	Least Concern	Very common
Searsia pyroides (Burch.) Moffett	Common currant	*kolitsane*	Terrestrial	Shrub	Firewood	Least Concern	Common
[1]*Sebaea marlothii* Gilg		*marama-a-baroetsana*	Aquatic	Herb		Least Concern	Not common
Sebaea natalensis Schinz		*marama-a-baroetsana*	Aquatic	Herb		Least Concern	Common
Sebaea sedoides Gilg		*marama-a-baroetsana*	Aquatic	Herb	Medicinal	Least Concern	Common
[1]*Sebaea thodeana* Gilg		*marama-a-baroetsana-a-masoeu*	Aquatic	Herb		Least Concern	Not Common
[1]*Selago flanaganii* Rolfe		*lenyofane*	Terrestrial	Subshrub		Least Concern	Common
Selago trauseldii Killick			Terrestrial	Herb		Least Concern	Common
Senecio asperulus DC.		*Moferefere*	Terrestrial	Forb	Medicinal	Least Concern	Very common

[*]exotic;[1]DMC (EMR) endemic; [2]Lesotho endemic; [3]declared legally protected in the country

Table 1. Plant species recorded in the first proposed Biosphere Reserve of Lesotho (continued)

Taxon	Common names	Vernacular (Sesotho) names	Habitat	Growth Form	Uses	IUCN Conservation Status	Abundance
Senecio humidanus C.Jeffrey		*lehlomane-le-leholo*	Terrestrial	Herb		Least Concern	Common
Senecio inornatus DC.		*lehlongoane-le-leholo*	Terrestrial	Herb	Medicinal	Least Concern	Common
Senecio isatideus DC.	Dan's cabbage	*lehlomane-le-leholo*	Terrestrial	Herb	Medicinal	Least Concern	Common
Senecio macrocephalus DC. sens. lat.		*sebea-mollo*	Terrestrial	Herb	Medicinal	Least Concern	Common
Senecio othonniflorus DC.		*lehlomane*	Terrestrial	Herb	Medicinal	Least Concern	Common
Senecio rhomboideus Harv.		*lelutla-la-pula*	Terrestrial	Herb	Medicinal	Least Concern	Common
[1]*Senecio seminiveus* Wood&Evans		*khotolia-ea-noka*	Aquatic	Dwarf shrub	Medicinal	Least Concern	Common
Silene bellidioides DC.			Terrestrial	Herb		Least Concern	Common
Solanum retroflexum Dunal	Sobosobo berry	*limomonyane*	Terrestrial	Herb		Least Concern	Common
Stachys rugosa Aiton		*taraputsoe*	Terrestrial	Herb	Herbal tea	Least Concern	Common
Stoebe plumosa (L.) Thunb.	Bankrupt bush	*sehalahala*	Terrestrial	Shrub	Firewood	Least Concern	Common
Striga bilabiata subsp. *bilabiata* (Thunb.) O.Kuntze	Small witchweed		Terrestrial	Herb	Parasitic	Least Concern	Common
**Tagetes minuta* L.	Khakiweed	*monkhane, lechuchutha*	Terrestrial	Forb	Dye	Not evaluated	Common
**Taraxacum officinale* Weber sensu lato	Common dandelion	*lenyoka*	Terrestrial	Herb	Medicinal	Not evaluated	Very common
Tarchonanthus camphoratus L.	Wild camphor bush		Terrestrial	Shrub	Firewood	Least Concern	Not common
[3]*Tenaxia disticha* (Nees) N.P.Barker & H.P.Linder var. *disticha*	Copper wire grass		Terrestrial	Grass		Least Concern	Very common
[3]*Thamnocalamus tessellatus* (Nees) Sonderstrom & Ellis	Drakensberg bamboo	*leqala, tsehlanyane*	Terrestrial	Grass	Thatching	Vulnerable	Very common
Themeda triandra Forssk.	Red grass	*seboku*	Terrestrial	Grass	Grazed	Least Concern	Very common
Thesium costatum A.W.Hill		*marakalle*	Terrestrial	Shrublet		Least Concern	Common
**Tragopogon dubius* Scop.	Yellow goat's beard	*moetse-oa-pere*	Terrestrial	Forb	Vegetable	Not evaluated	Common
Trichoneura grandiglumis (Nees) Ekman			Terrestrial	Grass	Grazing	Least Concern	Common

[*]exotic;[1]DMC (EMR) endemic; [2]Lesotho endemic; [3]declared legally protected in the country

Table 1. Plant species recorded in the first proposed Biosphere Reserve of Lesotho (continued)

Taxon	Common names	Vernacular (Sesotho) names	Habitat	Growth Form	Uses	IUCN Conservation Status	Abundance
Trifolium burchellianum Ser.	Wild clover	*moroko*	Aquatic	Forb	Medicinal	Least Concern	Common
**Trifolium repens* L.			Aquatic	Forb	Grazing	Not evaluated	Common
Tristachya leucothrix Trin. ex Nees	Hairy trident grass		Terrestrial	Grass	Grazing	Least Concern	Common
Tulbaghia acutiloba Harv.	Wild garlic	*moelela*	Aquatic	Herb	Medicinal	Least Concern	Common
Typha capensis (Rohrb.) N.E.Br.		*motsitla*	Aquatic	Forb	Hat	Least Concern	Common
**Urtica urens* L.		*bobatsi*	Terrestrial	Herb	Vegetables	Not evaluated	Common
[1]*Valeriana capensis* Thunb.	Cape valerian	*seliba/Motetele*	Aquatic	Herb	Medicinal	Least Concern	Very common
**Verbena bonariensis* L.	Tall verbena, purple top		Terrestrial	Forb		Not evaluated	Common
Veronica anagallis-aquatica L.			Aquatic	Herb		Least Concern	Very common
Wahlenbergia krebsii Cham. subsp. *krebsii*	Fairy bell-flowers	*moopetsane*	Terrestrial	Herb	Medicinal	Least Concern	Common
Withania somnifera (L.) Dunal	Ashwagandha	*moferangope*	Terrestrial	Herb	Medicinal	Least Concern	Common
[1]*Woodsia montevidensis* (Spreng.)Hieron.			Terrestrial	Fern		Least Concern	Not Common
[1]*Wurmbea burttii* B.Nord.			Aquatic	Herb		Least Concern	Not Common
Xerophyta viscosa Baker	Small black-stick lily	*lefiroane*	Aquatic	Herb	Ropes	Least Concern	Common
[3]*Xysmalobium involucratum* (E. Mey.) Decne.	Scented xysmalobium		Terrestrial	Herb	Medicinal	Least Concern	Not Common
Xysmalobium parviflorum Harv. ex Scott Elliot	Octopus cartwheel	*leoto-la-khoho*		Herb	Medicinal	Least Concern	Not common
[3]*Xysmalobium stockenstromense* Scott Elliot	Mountain uzura		Terrestrial	Herb	Medicinal	Least Concern	Not common
Zaluzianskya microsiphon (O.Kuntze) K.Schum.	Short-tubed drumsticks		Terrestrial	Forb		Least Concern	Common
Zaluzianskya pulvinata Killick		*lebohlollo, theleli*	Terrestrial	Herb		Least Concern	Common
Zantedeschia aethiopica (L.) Spreng.	White arum lily	*mohalalitoe*	Terrestrial	Herb	Medicinal	Least Concern	Common
Zantedeschia albomaculata (Hook.) Baill.	Arrow-leaved arum	*mohalalitoe*	Terrestrial	Herb	Medicinal	Least Concern	Common
**Zinnia peruviana* (L.) L.	Redstar zinnia	*pilopilo*	Terrestrial	Forb	Whistles	Not evaluated	Very common

[*]exotic;[1]DMC (EMR) endemic; [2]Lesotho endemic; [3]declared legally protected in the country

rosehip (*Rosa rubiginosa* L.). Even though some of the exotic species are invasive, such as yellowcress (*Rorippa nudiuscula* Thell.) and khakiweed (*Tagetes minuta* L.), some of these exotic species are of commercial importance. For example, rosehip is consumed for its edible fruits and is also used for medicinal purposes. In fact, Lesotho is currently exporting rosehip fruits to Germany for making tea and jam, as well as for the production of essential oils used in the cosmetics industry. The residue from the plant is reported to induce fertility in animals (Kobisi et al. 2019). Sixty of the 380 recorded species are endemic to the DMC. Two of the recorded species are endemic to Lesotho namely *Glumicalyx lesuticus* Hillard & Burtt and spiral aloe (*Aloe polyphylla* Schönl. ex Pillans, Figure 3C), whereas *Othonna burttii* B.Nord. and Lesotho lily (*Gladiolus saundersii* Hook.f., Figure 3D) are near endemic. Spiral aloe is the national flower of Lesotho and is under threat due to illegal trade. Some natural populations are now extinct from certain areas in the country where the plant used to be abundant (pers. obs.). However, it is surprising that spiral aloe is listed as Vulnerable, whereas *G. lesuticus* and *O. burttii* have an IUCN conservation status of Least Concern, despite their limited distribution and population in the country. On the other hand, *G. lesuticus* and *O. burttii* have not previously been recorded by authors who documented the flora of Lesotho (e.g. Phillips 1917; Jacot Guillarmod 1971; Schmitz 1982; Kobisi 2005), even though these plants have been listed as Lesotho endemics (NES 2000) and are Red Listed (Talukdar 2002).

A notably conspicuous but locally uncommon fern, known as bracken (*Pteridium aquilinum* (L.) Kuhn, Figure 3F), which has a narrow distribution in Lesotho, was also recorded in TNP. Cooper-Driver et al. (2008) stated that even though bracken is a common weedy plant worldwide, it is surprisingly rare in Lesotho. Bracken was found forming a colony within a thicket of oldwood in TNP at an elevation of 2 037 masl, at GPS coordinates of S 28°55′ 28.5″, E 028°26′ 44.8″. The only other records of this plant in the country are Ha Ntsi, on the way to Mohale Dam, and Ha Mamokoaqo in the Leribe District, collected by Dieterlen in 1903 (Cooper-Driver et al. 2008). The fern is unique in that it is very large compared to other common fern species occurring in the country, growing to a height of 1.5 m.

Fauna

Even though a majority of wild species of fauna has been hunted down close to extinction in different parts of the country, a number of species still exist in the proposed BR, particularly birds and mammals. As a result, many of these species are declared legally protected in the country, and these include antelope, baboons, monkeys, bearded vultures, other birds of prey, cranes, storks and herons. A number of species have been recorded in the current study for the five classes of vertebrates (mammals, birds, fish, reptiles and amphibians), and these are discussed in more detail in the sections that follow.

Mammals: A total of 16 mammal species were recorded in the proposed BR, including rodents, jackal, antelope, dassies, rabbits and baboons (Table 2). Seven of the 16 recorded species are declared legally protected, and these include African clawless otter (*Aonyx capensis* Schinz, 1821), Cape porcupine (*Hystrix africaeaustralis* Peters, 1852), chacma baboon (*Papio ursinus ursinus* (Kerr, 1792)), grey rhebok (*Pelea capreolus* (Forster, 1790)) and common eland (*Tragelaphus oryx* (Pallas, 1766)). The common eland seems to have been previously widespread in the country, as evidenced by the many occurrences of rockart (Figures 3H, I). However, the species was locally extirpated mainly due to hunting prior to being reintroduced into TNP following declaration of the area as a PA. In comparison, LHDA (1998a, 1998b) reported 11 mammals in BNR and 12 in TNP, based on reports from field staff in the area. Even though a limited number of mammals have been recorded in the current study, archaeological records indicate that several species of mammals were historically (during the Holocene) widespread in the country (Grab & Nash 2020). These include aardwolf (*Proteles cristata* Sparrman, 1783), African wild cat (*Felis lybica* Forster, 1780), black-backed jackal (*Canis mesomelas* Schreber, 1775), black wildebeest (*Connochaetes gnou* (Zimmermann, 1780)), blesbok (*Damaliscus pygargus phillipsi* Harper, 1939), Cape fox (*Vulpes chama* (A.Smith, 1833)), common genet (*Genetta genetta* (Linnaeus, 1758)), scrub hare (*Lepus saxatilis* F.Cuvier, 1823), klipspringer (*Oreotragus oreotragus* (Zimmermann, 1783)), mountain reedbuck (*Redunca fulvorufula* (Afzelius, 1815)), red hartebeest (*Alcelaphus buselaphus* (Pallas, 1766)), rock hyrax (*Procavia capensis* (Pallas, 1766)), slender mongoose (*Galerella sanguinea* (Rüppell, 1835)), springbok (*Antidorcas marsupialis* (Zimmermann, 1780)), Cape porcupine (*H. africaeaustralis*), steenbok (*Raphicerus campestris* (Thunberg, 1811)) and common warthog (*Phacochoerus africanus* (Gmelin, 1788)) (Grab & Nash 2020). Given the drastic extinction rate of fauna species in Lesotho, the recording of six of these species in the current study, namely African wild cat, black-backed jackal, common genet, scrub hare, rock hyrax and Cape porcupine, adds to the biodiversity value of the proposed BR. However, absence of some of these species currently reveals a major loss of fauna in Lesotho over the past 200 years as discussed by Grab and Nash (2020).

Birds: Fifty-three bird species were recorded in the proposed BR, 13 of which are declared legally protected in the country (Table 3). It is important to note that two of the 13 protected species, namely Cape Vulture (*Gyps coprotheres* (Forster, 1798)) and Bearded Vulture (*Gypaetus barbatus* (Linnaeus, 1758)), have a limited distribution and are globally listed as Endangered and Near Threatened respectively (Hockey et al. 2006). Indeed LHDA (1998a, 1998b) reported a total of ten

Table 2. Mammals species recorded in the first proposed Biosphere Reserve of Lesotho

Taxon	Common names	Vernacular (Sesotho) names	IUCN Conservation Status	Habitat	Abundance
[3]*Aonyx capensis* Schinz	African clawless otter	*qibi*	Near Threatened	Aquatic	Not Common
Canis mesomelas Schreber	Black-backed jackal	*Phokojoe*	Least Concern	Terrestrial	Not Common
[3]*Caracal caracal* Schreber	Caracal	*Thoalere*	Least Concern	Terrestrial	Not Common
Cryptomys hottentotus Lesson	Common african mole-rat	*Mokunyane*	Least Concern	Terrestrial	Common
Felis lybica Schreber	African wild cat		Least Concern	Terrestrial	Not Common
[3]*Galerella pulverulenta* Wagner	Small grey mongoose	*Mochalla*	Least Concern	Terrestrial	Common
Genetta genetta L.	Small-spotted genet	*Qoako*	Least Concern	Terrestrial	Not Common
[3]*Hystrix africaeaustralis* Peters	Cape porcupine	*Noko*	Least Concern	Terrestrial	Not Common
Ictonyx striatus Perry	Striped polecat	*Nakeli*	Least Concern	Terrestrial	Not Common
Leptailurus serval Schreber	Serval		Least Concern	Terrestrial	Not Common
Lepus saxatilis F. Cuvier	Scrub hare	*Mutlanyana*	Least Concern	Terrestrial	Common
Mystromys albicaudatus Smith	White-tailed rat		Vulnerable	Terrestrial	Not Common
Otomys sloggetti Thomas	Sloggett's ice rat	*Leboli-leqhoa*	Least Concern	Terrestrial	Very Common
[3]*Papio cynocephalus ursinus* Kerr	Chacma baboon	*Tsoene*	Least Concern	Terrestrial	Not Common
[3]*Pelea capreolus* Forster	Grey rhebok	*Letsa*	Near Threatened	Terrestrial	Common
Procavia capensis Pallas	Rock dassie	*Pela*	Least Concern	Terrestrial	Very Common
Pronolagus rupestris A.Smith	Red rock rabbit	*Thlolo*	Least Concern	Terrestrial	Common
[3]*Tragelaphus oryx* Pallas	Common eland	*Phoofu*	Least Concern	Terrestrial	Not Common

[3]Declared legally protected in the country

Red-listed bird species, including the Cape Vulture and Bearded Vulture in both BNR and TNP. Even though their common breeding sites are the high elevation cliffs in Lesotho, the two bird species occassionally migrate to neighbouring countries such as South Africa, Botswana, northern Namibia and southern Zimbabwe (Hockey et al. 2006). Lesotho has also legally protected the two bird species (under Legal Notice No. 36 of 1969, as amended by Legal Notice No. 93 of 2004 and No. 38 of 2006), as well as listing them under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

Lesotho is reported to be the main breeding ground to the rare Bearded Vulture in southern Africa (NES 2000). A study by Donázar et al. (1993) revealed that elevation and ruggedness of the topography probably influence the existence of adequate breeding places for the Bearded Vulture, as is the case in the proposed BR, however, human disturbance negatively affects the breeding success of the bird. In fact, the population of the species has declined drastically, mainly due to hunting of adults and robbery of eggs and chicks, as well as fire, decline in food supply, gin traps and collection of the birds for skins and plumage. In addition, since the Bearded Vulture is a specialised species in terms of its habitat requirements and food choice, Colahan (2004) suggested establishment of partnerships between conservation organisations for management and conservation of the population. Several efforts are currently being undertaken by the Department of Environment in Lesotho (of the Ministry of Tourism, Environment and Culture) together with South Africa, under a bilateral programme targeted towards enhanced breeding of the species. A Bearded Vulture Management Plan has also been developed for conservation of the species.

The decline of Bearded Vulture populations has also been observed in other parts of the world. For example, the decline is reported to have started in the mid-nineteenth century in Europe and North America,

Table 3. Bird species species recorded in the first proposed Biosphere Reserve of Lesotho

Taxon	Common names	Vernacular (Sesotho) names	Form	IUCN Conservation Status	Habitat	Abundance
Anas sparsa Eyton	African Black Duck	*letata*	Fish eater, aquatic insect	Least Concern	Aquatic	Not Common
Anthus hoeschi Stresemann	Mountain Pipit	*tšaase-ea-loti*	Insects-eater	Near Threatened	Terrestrial	Common
[3]*Aquila verreauxii* Lesson	Black Eagle	*moja-lipela*	Birds of Prey	Least Concern	Terrestrial	Not Common
[3]*Ardea cinerea*	Grey Heron	*kokolofitoe*	Birds of Prey	Least Concern	Aquatic	Common
[3]*Bostrychia hagedash* Latham	Hadeda Ibis	*lengangane*	Insects and frogs eater	Least Concern	Terrestrial	Not Common
Bubo capensis Smith	Cape Eagle-owl		Medium-sized mammals and birds	Least Concern	Terrestrial	Common
[3]*Buteo rufofuscus* Forster	Jackal Buzzard	*khajoane*	Birds of Prey	Least Concern	Terrestrial	Common
Chaetops aurantius Layard	Drakensberg Rockjumper	*mamolisa-lipela*	Rock Jumper	Near Threatened	Terrestrial	Common
[3]*Columba guinea* L.	Speckled Rock Pigeon	*leeba-la-thaba*	Seeds-eater	Least Concern	Terrestrial	Common
Corvus albicollis Latham	White-necked Raven	*lekhoaba*	Birds of Prey	Least Concern	Terrestrial	Not Common
Cossypha caffra L.	Cape Robin-chat	*sethoena-moru*	Insects-eater	Least Concern	Terrestrial	Common
Coturnix coturnix L.	Common Quail	*khoale*	Seeds-eater	Least Concern	Terrestrial	Common
Emberiza capensis L.	Cape Bunting	*maborokoane*	Seeds-eater	Least Concern	Terrestrial	Common
Emberiza flaviventris Stephens	Golden-breasted Bunting	*maborokoane*	Seeds-eater	Least Concern	Terrestrial	Common
Emberiza tahapisi Smith	Cinnamon-breasted Bunting	*maborokoane*	Seeds-eater	Least Concern	Terrestrial	Common
Estrilda melanotis Temminck	Swee Waxbill		Seeds-eater	Least Concern	Terrestrial	Not Common
Euplectes ardens Boddaert	Red-collared Widowbird		Seeds-eater	Least Concern	Terrestrial	Common
[3]*Falco biarmicus* Temminck	Lanner Falcon	*phakoe*	Birds of Prey	Least Concern	Terrestrial	Not Common
[3]*Falco rupicolis* Dupont	Rock Kestrel	*seotsanyana*	Birds of Prey	Least Concern	Terrestrial	Not Common
[3]*Geronticus calvus* Boddaert	Southern Bald Ibis	*mokhotlo*	Insects-eater	Vulnerable	Terrestrial	Common
[3]*Gypaetus barbatus* L.	Bearded Vulture	*ntsu-kobokobo*	Birds of Prey	Near Threatened	Terrestrial	Not Common
[3]*Gyps coprotheres* Forster	Cape Vulture	*lenong, letlaaka*	Bird of Prey	Endangered	Terrestrial	Not Common
Hirundo albigularis Strickland	White-throated Swallow	*lekabelane*	Insects-eater	Least Concern	Terrestrial	Common
Hirundo cucullata Boddaert	Greater Striped Swallow	*lehaqasi*	Insects-eater	Least Concern	Terrestrial	Common

[3]Declared legally protected in the country

Table 3. Bird species species recorded in the first proposed Biosphere Reserve of Lesotho (continued)

Taxon	Common names	Vernacular (Sesotho) names	Form	IUCN Conservation Status	Habitat	Abundance
Lamprotornis bicolor Gmelin	African Pied Starling	*leholi*	Insects-eater	Least Concern	Terrestrial	Common
Lanius collaris L.	Common Fiscal	*tšemeli*	Bird of Prey	Least Concern	Terrestrial	Common
Melaenornis silens Shaw	Fiscal Flycatcher	*tšemeli*	Birds of Prey	Least Concern	Terrestrial	Common
Monticola explorator Vieillot	Sentinel Rock Thrush	*mohetle*	Insects-eater	Near Threatened	Terrestrial	Common
Motacilla capensis L.	Cape Wagtail	*motjoli*	Insects-eater	Least Concern	Terrestrial	Common
Nectarinia famosa L.	Female Malachite Sunbird	*taletale*	Insects-eater and nectar	Least Concern	Terrestrial	Common
Numida meleagris L.	Helmeted Guinea Fowl	*khaka*	Seeds-eater	Least Concern	Terrestrial	Common
Onychognathus morio L.	Red-Winged Starling	*letsomila*	Insects-eater	Least Concern	Terrestrial	Common
Passer domesticus L.	House Sparrow	*seroebele*	Seeds-eater	Least Concern	Terrestrial	Common
Passer melanurus Statius Müller	Cape Sparrow	*seroebele*	Seeds-eater	Least Concern	Terrestrial	Common
Petronia superciliaris Blyth (= *Gymnoris superciliaris*)	Yellow-throated Bush Sparrow	*seroebele*	Seeds-eater	Least Concern	Terrestrial	Common
Phalacrocorax lucidus Lichtenstein	White-breasted Cormorant	*seinuli*	Fish-eater	Least Concern	Aquatic	Common
Ploceus capensis L.	Cape Weaver	*letholoptjoe*	Seeds-eater	Least Concern	Terrestrial	Common
Prinia maculosa Boddaert	Karoo Prinia	*motinyane*	Insects-eater	Least Concern	Terrestrial	Common
Pternistis swainsonii Smith	Swainson's Spurfowl	*khoale*	Seeds-eater	Least Concern	Terrestrial	Common
Ptyonoprogne fuligula Lichtenstein	Rock Martin	*lekabelane*	Insects-eater	Least Concern	Terrestrial	Common
Pycnonotus nigricans Vieillot	African Red-eyed Bulbul	*hlakahlothoana,*	Insects-eater	Least Concern	Terrestrial	Common
[3]*Sagittarius serpentarius* J. F. Miller	Secretarybird	*mamolangone*	Birds of Prey	Vulnerable	Terrestrial	Not Common
Saxicola torquata L.	African Stonechat	*tlhatsinyane*	Seeds-eater	Least Concern	Terrestrial	Common
[3]*Scopus umbretta* Gmelin	Hamerkop	*mamasianoke*	Frogs, crabs	Least Concern	Terrestrial	Not Common
Serinus canicollis Swainson	Cape Canary	*tsoere*	Seeds-eater	Least Concern	Terrestrial	Common
Sphenoeacus afer Gmelin	Cape Grassbird	*nkhonoa-litali*	Insects-eater	Least Concern	Terrestrial	Common

[3]Declared legally protected in the country

Table 3. Bird species species recorded in the first proposed Biosphere Reserve of Lesotho (continued)

Taxon	Common names	Vernacular (Sesotho) names	Form	IUCN Conservation Status	Habitat	Abundance
Streptopelia capicola Sundevall	Cape Turtle Dove	*molala-motso*	Seeds-eater	Least Concern	Terrestrial	Common
Streptopelia senegalensis L.	Laughing Dove	*mofubetsoana*	Seeds-eater	Least Concern	Terrestrial	Common
Telophorus zeylonus L.	Bokmakierie	*pijemptjete*	Insects-eater	Least Concern	Terrestrial	Common
Turdus libonyana Smith	Kurrichane Thrush			Least Concern	Terrestrial	Common
[3]*Tyto capensis* Smith	African Grass-Owl	*sephooko*	Bird of Prey	Least Concern	Terrestrial	Not Common
Vidua macroura Pallas	Pin-tailed Whydah	*molepe*		Least Concern	Terrestrial	Common
Vidua paradisaea L.	Long-tailed Paradise Whydah	*tjobolo*	Seeds-eater	Least Concern	Terrestrial	Common
Zosterops virens Sundevall	Cape White-Eye	*mahloanalitsepe*		Least Concern	Terrestrial	Common

[3]Declared legally protected in the country

causing the populations to approach extinction (Ogada et al. 2012). A similar observation has also been made in the Middle East, as well as Central and South America (Ogada et al. 2012). According to Di Vittorio et al. (2018), vulture populations in West Africa are also undergoing dramatic decline, particularly due to factors such as environmental changes, poisoning and bioaccumulation of toxic substances from agricultural products, pesticides, and veterinary drugs used in cattle livestock. In addition, the vultures are subject to direct persecution for the trade of products used in traditional medicine (Di Vittorio et al. 2018). The proposed BR would assist in creating a platform for enhanced breeding of the species to increase the population size. In addition, raising awareness of the biodiversity wealth of the area amongst all residents and role-players could potentially result in reduced utilisation of natural resources specifically within the core areas. Interestingly, Birdlife International categorises the Lesotho Highlands (under which the proposed BR falls) as an Endemic Bird Area of high priority and lists the Drakensberg Rockjumper (*Chaetops aurantius* Layard, 1867), Mountain Pipit (*Anthus hoeschi* Stresemann, 1938) and Drakensberg Siskin (*Crithagra symonsi* (Roberts, 1916)) to be of particular global interest (LHDA 1998a, 1998b). Therefore the proposed BR has potential to become a popular spot for birders who are interested in high elevation species, and thus enhance tourism in the area.

Fish: Only two fish species were recorded in the current study namely Maloti minnow or Maloti redfin (*Pseudobarbus quathlambae* (Barnard, 1938)), (Figure 3G) and rainbow trout (*Oncorhyncus mykiss* (Walbaum, 1792)), as summarized in Table 4. It is reported that Maloti minnow was first discovered in the headwaters of the uMkhomazana River in Kwazulu-Natal, South Africa (Barnard 1938), but was subsequently feared extinct (Jubb 1971). The fish was rediscovered at Sehlaba-thebe in Lesotho in 1970 (Jubb 1971). However, although the South African population was feared to be certainly extinct, the species was recently rediscovered in the Mzimkhulu River system in KwaZulu-Natal (Kubheka et al. 2017) and therefore considered near endemic in Lesotho. The recording of Maloti minnow in the Bokong River during this survey adds tremendous clout to the biodiversity rationale of the proposed BR, particularly because the species is Lesotho's only known endemic vertebrate. However, rainbow trout have been introduced in the country. Indeed, LHDA (1998b) indicated that there was circumstantial evidence that rainbow trout were previously introduced into the Tšehlanyane River, and that a residual population existed downstream of TNP. Therefore, the occurrence of the two fish species in two separate rivers, minimises the possibility of one species being a threat to the other (feeding on the other).

Reptiles: A total of seven reptiles were recorded in the proposed BR, comprising four snakes and three lizards (Table 5). Some of the snakes are venomous, namely

Table 4. Fish species recorded in the first proposed Biosphere Reserve of Lesotho

Taxon	Common names	Vernacular (Sesotho) names	IUCN Conservation Status	Abandance
**Oncorhynchus mykiss* Walbaum	Rainbow trout	*trautu*	Not Evaluated	common
[2]*Pseudobarbus quathlambae* Barnard	Maloti minnow	*thoboshana*	Endangered	common

[*]Introduced species; [2] Lesotho endemic

berg adder (*Bitis atropos* (Linnaeus, 1758)), puff adder (*Bitis arietans* (Merrem, 1820)) and rinkhals (*Hemachatus haemachatus* (Bonnaterre, 1790)). Berg adder is known from high elevations in the Maloti–Drakensberg, but also occurs at lower elevations in the Cape Fold Mountains of the Western Cape of South Africa (Barlow et al. 2019). On the other hand, LHDA (1998a, 1998b) previously reported six lizards and four snakes in both BNR and TNP, including the Essex's mountain lizard (*Tropidosaura essexi* Hewitt, 1927), which is known only from the summit slopes of the KwaZulu-Natal Drakensberg, the adjacent Free State province and the Lesotho Highlands.

Amphibians: Three amphibian species were recorded, two of which are aquatic, namely Drakensberg frog (*Amietia delalandii* (Duméril & Bibron, 1841) and Maloti River Frog (*Amietia vertebralis* (Hewitt, 1927)), as well as one terrestrial Bufonid, called Gariep toad or mountain toad (*Vandijkophrynus gariepensis* (Smith, 1848)), summarised in Table 6. *Ametia delalandii* and *A. vertebralis* are reported as near endemic in the country (NES 2000). A study by LHDA (1998a, 1998b) reported seven amphibian species in both BNR and TNP. These are African clawed frog (*Xenopus laevis* Daudin, 1802), Gray's stream frog (*Strongylopus grayii* (Smith, 1849)), Natal ghost frog (*Heleophryne natalensis* (Hewitt, 1913)) and ranger's toad (*Amietophrynus rangeri* Hewitt, 1935), as well as the three species recorded in the current study. Generally, Lesotho is reported to have a total of 19 amphibian species, with only two near-endemic species (NES 2000). Amphibians are reported to be one of the most sensitive group of animals in the world which react rapidly to substantial changes in their environments (Saber et al. 2017). As a result, they are useful indicators of pollution and climate change.

Other biophysical aspects (wetlands)

Three major wetlands were observed in the core area of the proposed BR, and four others in the transition zone. These wetlands do not only provide habitats for certain flora and fauna species, but also provide water for many river basins in the country as well as transboundary rivers. As a result, these wetlands play a major role in the ecology and hydrology of downstream systems including the provision of water to the Katse Dam, which supplies water to Gauteng province in South Africa. In addition, the wetlands provide water for livestock drinking and domestic use to surrounding communities. However, it was observed that wetlands in the transition zone lack effective management systems and are vulnerable to degradation and consequent reduction of ecosystem services. Some sections within the wetlands are intact while other patches are degrading due to erosion, thus threatening the intact portions. The long-term productivity of these ecosystems is threatened by encroachment through ploughing in surrounding fields and poor road construction practices. In addition, a majority of wetlands in the transition zone are under threat due to cropfield encroachment, roads/paths that go through them, as well as grazing. Similarly, a study

Table 5. A list of recorded reptiles

Taxon	Common names	Vernacular (Sesotho) Names	IUCN Conservation Status	Form
Agama atra Peters	Southern rock agama	*mankhoshepe*	Least Concern	Agama
Bitis arietans Merrem	Puff adder	*marabe*	Not Evaluated	Adder
Bitis atropos L.	Berg adder	*qooane*	Least Concern	Adder
Duberria lutrix lutrix Linnaeus	Common slug-eater		Least Concern	Snake
Hemachatus haemachatus Bonnaterre	Rinkhals	*masumo*	Least Concern	Cobra-like Snake
Pseudocordylus melanotus A. Smith	Drakensberg crag lizard	*checheiki*	Least Concern	Lizard
Trachylepis punctatissima Smith	Montane speckled skink	*mokholutsoane*	Least Concern	Skink
Tropidosaura essexi Hewitt	Essex's mountain lizard		Least Concern	Lizard

Table 6. A list of recorded amphibian species

Taxon	Common names	Vernacular (Sesotho) names	Form	Habitat	IUCN Conservation Status
Amietia delalandii Duméril and Bibron (= *A. dracomontana* Channing)	Drakensberg frog	*seqaqana*	Frog	Aquatic	Least Concern
Amietia vertebralis Hewitt	Maluti river frog	*letlametlu*	Frog	Aquatic	Least Concern
Vandijkophrynus gariepensis A. Smith	Gariep toad Mountain toad	*marokolo*	Toad	Terrestrial	Least Concern

by Chatanga et al. (2020) indicated that wetlands in the Maloti–Drakensberg region are generally intensively utilised and degraded, with very high anthropogenic pressures, particularly in the highlands of Lesotho. The wetlands are also a habitat for Sloggett's ice rat, which is endemic to southern Africa, being confined to South Africa and Lesotho. However, the species causes damage to the wetlands by digging holes that destroy the vegetation (Figures 3J, K). A study by Mokotjomela et al. (2009) revealed that the damage caused by Sloggett's ice rat through soil erosion and loss exceeds effects of domestic livestock. This mammal species is also found in rocky habitats and alpine grassland, both wet and dry, at elevations of more than 2 000 m (6 600 ft). It is reported in the Drakensberg Mountains of the Eastern Cape and KwaZulu-Natal provinces of South Africa, as well as Lesotho (Monadjem et al. 2015).

Notable plant species recorded in the wetlands include: copper wire grass (*Merxmuellera macowanii* (Stapf) Conert), which is used for making crafts (brooms, baskets, traditional Basotho hats) and thatching, as well as mild rhubarb (*Gunnera perpensa* L.), water mint (*Mentha aquatica* L.), and wild clover (*Trifolium* L. spp), used for medicinal purposes. In addition, Lesotho red-hot poker (*Kniphofia caulescens* Baker) adds beautiful scenery to high elevation valleys of the Maloti–Drakensberg, particularly in summer (Figure 3E). This plant is endemic to the Maloti–Drakensberg region, even though it is reported to be relatively rare on the South African side (being found in Eastern Cape and KwaZulu-Natal). A study by Chatanga et al. (2019) reported a total of 16 wetland types associated with the Maloti–Drakensberg region, and these include *M. macowanii* wetland, *G. perpensa* wetland, *K. caulescens* wetland and *Mentha longifolia–Juncus inflexus* wetland. The study also discussed the classification, description and environmental factors of montane wetland vegetation of the Maloti–Drakensberg region.

Conclusion

The current study provides findings of a rapid biodiversity survey undertaken in Lesotho's first proposed Biosphere Reserve, the core area of which comprises Bokong Nature Reserve and Tšehlanyane National Park. The survey recorded a total of 380 plant species, 60 of which are endemic to the Drakensberg Mountain Centre (formerly known as Drakensberg Alpine Centre), whereas 30 are declared legally protected in the country. Two plants endemic to Lesotho have been documented in the area namely spiral aloe and *Glumicalyx lesuticus*. The former is the national flower of Lesotho, which is under immense pressure in the wild due to illegal trade. The near-endemic (confined to South Africa and Lesotho) Drakensberg bamboo was found widespread in Tšehlanyane National Park, and it is reported to provide a habitat for the Red-listed Endangered butterfly species known as *Metisella syrinx*. However, the search for this butterfly during the survey was not successful.

In the case of fauna, 16 mammalian species were recorded, seven of which are declared legally protected in the country. These include Sloggett's ice rat, which is endemic to southern Africa, being confined to South Africa and Lesotho. This species is however, causing damage to the wetlands, which provide ecosystem services such as water and livestock grazing. These wetlands supply water to the Katse Dam of the Lesotho Highlands Water Project, which in turn provides water to parts of Gauteng in South Africa. A total of 53 bird species were documented, 13 of which are declared legally protected. Among these are the Cape Vulture and Bearded Vulture, which are IUCN listed as Endangered and Near Threatened respectively, and have limited distribution being endemic to southern Africa. Lesotho is currently the main breeding ground for the Bearded Vulture in southern Africa. Two fish species were recorded namely Maloti minnow and rainbow trout, with the former being Lesotho's only known true endemic vertebrate species. A total of seven reptiles were recorded, three of which are venomous snakes namely puff adder, berg adder and rinkhals. In addition, three amphibian species were recorded, two of which are reported as near endemic in the country, namely *Amietia delalandii* and *A. vertebralis*.

The survey has filled some gaps by providing valuable information on the biodiversity (particularly regarding the flora and avifauna) of the proposed Biosphere Reserve.

The presence of important species, i.e. some being endemic to Lesotho, endemic to the Maloti–Drakensberg area, Red Data-listed, or declared legally protected in the country, contribute tremendously to the biodiversity value of the proposed BR. Therefore, the findings of the current study will contribute towards justification of the area to be nominated as Lesotho's first Biosphere Reserve under the UNESCO MAB Programme. However, management plans of the proposed Biosphere Reserve should be developed, to address, amongst others, the challenges of managing invasive species and fire that may negatively affect the biodiversity of the area.

Acknowledgements

The authors are grateful to UNESCO and the Lesotho Government for financial support to undertake the study. We thank the two anonymous reviewers for their useful suggestions to improve the manuscript.

Competing interests

The authors declare that they have no competing interests.

Authors'contributions

LSK drafted the manuscript, KK and KM collected the data, and RPS edited the manuscript and added valuable information.

Funding

The study was financed by UNESCO viz; the UNESCO MAB Programme in Paris, the German Commission for UNESCO and the Lesotho National Commission for UNESCO, as well as the Lesotho Government through the Ministry of Tourism, Environment and Culture (MTEC).

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BOTHALIA – African Biodiversity & Conservation
ISSN: (Online) 2311-9284, (Print) 0006-8241

Rediscovery of *Scarabaeus sevoistra* Alluaud, 1902 (Coleoptera: Scarabaeinae): biological notes and IUCN Red Listing

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Dates

Submitted: 23 November 2020
Accepted: 4 August 2021
Published: 5 November 2021

How to cite this article:

Deschodt, C.M., Harrison, J. du G & Sole, C.L., 2021, 'Rediscovery of *Scarabaeus sevoistra* Alluaud, 1902 (Coleoptera: Scarabaeinae): biological notes and IUCN Red Listing', *Bothalia* 51(2), a14. http://dx.doi.org/10.38201/btha.abc.v51.i2.14

Scarabaeus sevoistra Alluaud, 1902 was previously thought to be extinct. While identifying Scarabaeinae species on the iNaturalist website, photos posted by citizen scientists were discovered and identified as this species by the authors. The importance of the rediscovery of the species is presented here. We provide new biological notes for the species and a key to separate the species from its congeners. Additionally, we formally give a conservation status for the species.

Keywords: *Scarabaeus sevoistra*, iNaturalist, rediscovery, biological notes, conservation status.

Introduction and taxonomic history

The tribe Scarabaeini is one of four dung beetle tribes that occur on Madagascar (Philips, Pretorius & Scholtz 2004; Monaghan et al. 2007), where it is represented by only three species of *Scarabaeus* Linnaeus, 1758. These species are morphologically distinct from one another and from other *Scarabaeus* and, consequently, as discussed below, have had an unstable taxonomic history (Sole et al. 2011). Of these three species, *Scarabaeus sevoistra* Alluaud, 1902 is rare and was only collected from two localities in southern Madagascar: Analavondrove in Antanimora (1901) and Marovato (1939). Tree felling and harvesting and the invasion by *Opuntia* Mill. has greatly reduced the natural habitat in those areas (https://www.worldwildlife.org/ecoregions/at1311). The species has not been collected or recorded during the last 82 years and was thought to be extinct or functionally extinct (Rahagalala et al. 2009).

The holotype of *S. sevoistra*, the only specimen of the type series, was collected by Dr J. Decorse, a French botanist and entomologist, who was collecting xerophytes (*Aloe, Euphorbia* and *Sarcostemma*) in Madagascar between 1898 and 1900 (Eggli & Newton 2010). Alluaud (1902: 250) described it as *Scarabaeus sevoistra* Alluaud, 1902 and noted that the specimen was collected on the 'Androy plateau, in the north of the country of Sevoïstra, on a bush trail in the Analavondrove region, in February 1901' (our translation from French). Thereafter, Gillet (1911) erected the new genus *Neateuchus* for *S. sevoistra* together with the African continental species *Scarabaeus rixosus* Péringuey, 1901 and *Scarabaeus proboscideus* (Guérin-Meneville, 1844) (type species of the genus by original designation).

The defining features of *Neateuchus* as provided by Gillet are brief and include: '*the very close intermediate coxae, leaving an almost linear gap between them, and by the mentum offering a strong tooth perpendicular to its surface. The arrangement of the intermediate coxae places this genus closer to*

Mnematium *MacLeay and* Mnematidium *Ritsema*' (translation from (Gillet 1911)). Janssens (1938), on the other hand, believed that *S. sevoistra* differed enough from the two continental species to be placed in its own monotypic genus and erected *Neomnematium* Janssens, 1938 to accommodate it as *Neomnematium sevoistra* (Alluaud, 1902).

In hindsight, and presumably unknown to Janssens (1938), the characters used for the erection of *Neomnematium* relate to the species' modified morphology due to it being flightless, unlike the flying *S. rixosus* and *S. proboscideus*, and to its psammophilous adaptations (e.g., broad, spade-like clypeus) for digging into sand (Scholtz 1981, 2000). Paulian and Lebis (1960) and Ferreira (1961) followed this same generic placement. Mostert and Holm (1982) synonymised *Neomnematium* with *Scarabaeus* based on it having a similar protuberance on the mentum as *Scarabaeus zambesianus* Péringuey, 1901 and a similarly symmetrical aedeagus as is seen in *Scarabaeolus scholtzi* (Mostert & Holm, 1982) and *Scarabaeolus rubripennis* (Boheman, 1860). Harrison and Philips (2003), Harrison, Scholtz and Chown (2003) and Forgie, Philips and Scholtz (2005) agreed with this decision following the first morphological phylogenies for the Scarabaeini. Forgie, Philips and Scholtz (2005) stressed that, despite the difficulty to obtain specimens of *S. sevoistra* and all the allied flightless Scarabaeini, it would be important to find more of them for further molecular and morphological studies and to gain a better knowledge about their biology.

Here, we update and discuss the known geographic records for *Scarabaeus sevoistra*, summarise its taxonomic history, expand on its natural history, and provide an IUCN Red listing to highlight its need for conservation and to facilitate the latter. In addition, we provide an identification key to differentiate the three known species of Madagascan Scarabaeini from one another.

Materials and Methods

iNaturalist (iNat) (https://www.inaturalist.org/home) is a website open to all where natural history images can be uploaded and stored with accompanying biological information. Specialists then voluntarily identify (where possible) the taxa in the photographs. Both the data and photos are accessible to scientists. Recently, C.M.D was making routine Scarabaeinae identifications on the iNat website and came across a peculiar-looking flightless scarabaeine beetle from Madagascar (Figure 1A–F). After consultation with J.duG.H. and C.L.S. and comparing the iNat photos with images of the holotype of *Scarabaeus sevoistra* Alluaud, 1902 housed in the Muséum national d'Histoire naturelle (MNHN), the identities of the listed iNat records are confirmed here to be *S. sevoistra* (Figure 2A–C).

Taxonomy from photographs is a contentious issue (Epstein 2017). Although we use photographs as a basis for this current paper, we believe that the necessary characters to identify the species are visible. The images are from three independent sources and thus most probably authentic. As this is a species of conservation concern, we do not need to collect specimens for the purpose of this paper.

Results and discussion

These new records of *S. sevoistra* constitute the first and only confirmed observations of this species in about 80 years. This rediscovery is of extreme importance as the species can now formally be protected and some of its biology inferred.

Sexual dimorphism

As can be seen in Figures 2A and C, the holotype of *Scarabaeus sevoistra* has some obvious differences from the specimen illustrated and identified with this same name by Paulian and Lebis (1960). The differences concern several features in the shape of the protibiae that, in other better-known species of Scarabaeini and dung beetles in general, are related to sexual dimorphism. More specifically, the holotype has the protibiae ending bluntly, as the proximal inside and outside denticles of the protibia ends in a T-shape; moreover, the inner edge of the protibiae is strongly serrated (Figure 2A). These features are typical of male dung beetles. Paulian and Lebis's specimen (Figure 2C), in turn, lack the denticle in the inner edge of the protibiae and, therefore, they do not end in a T-shape; furthermore, the serration on the inner protibial edge, is also lacking. These characters are typically female. Unlike the holotype, Paulian and Lebis's specimen also has the protibial outer teeth quite large, a condition that is also usually related to females and presumably function in the making of dung balls and for digging into sand. The original description does not mention the sex of the holotype but based on the features discussed above, we confidently conclude it is a male, whereas Paulian and Lebis's specimen is a female. Like other *Scarabaeus*, therefore, the protibiae of *S. sevoistra* are highly sexually dimorphic.

Natural history and new biological notes of *Scarabaeus sevoistra*

Harrison and Philips (2003) and Harrison, Scholtz and Chown (2003) made a detailed morphological analysis of the mouthparts of all known flightless species of Scarabaeini. They predicted that *Scarabaeus sevoistra* would be a wet dung feeder as it does not exhibit the mouthpart morphology ubiquitous to all species

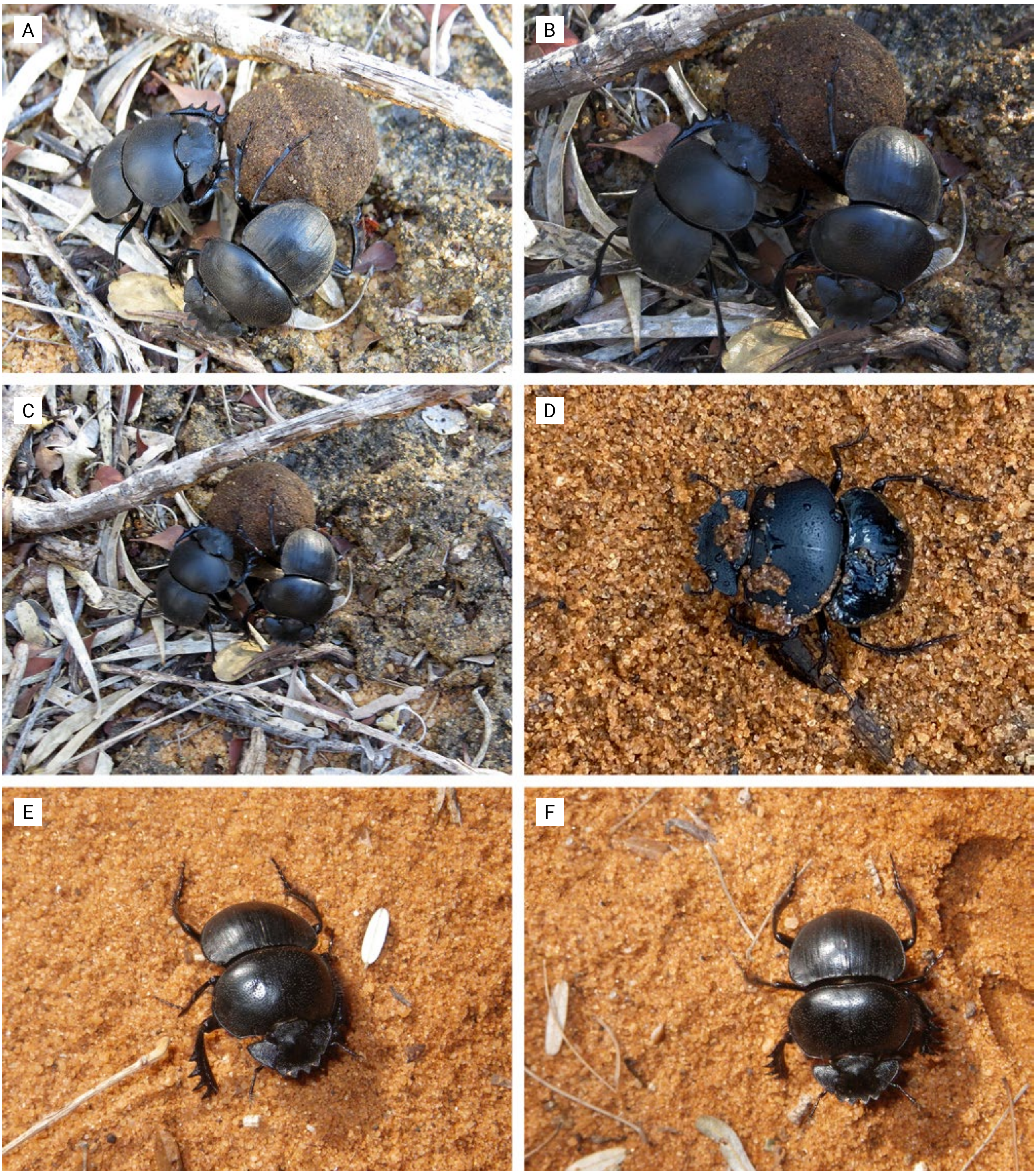

Figure 1. A–F, Recent photographic observations of *Scarabaeus sevoistra* Alluaud, 1902. A, B, C, photographed by Joseph Thompson, 04 November 2015; D, photographed by Bitty Roy, 17 November 2019; E, F, photographed by Maxim Nuraliev, 01 August 2015.

of *Pachysoma* Macleay, 1821, where dry dung and detritus feeding is the norm (Scholtz, 1989; Harrison, Scholtz and Chown (2003).

From the series of pictures of the three records found on iNat (Figure 1A–F), the following new biological notes for *S. sevoistra* can be inferred.

It can be confirmed that the species does indeed feed on wet dung as predicted by Harrison, Scholtz and Chown (2003), based on the data about mouthpart morphology compiled by Harrison and Philips (2003).

It is known that when most ball-rolling Scarabaeini species pair up at the dung source, the male will roll it with the female clinging to the side of the ball as in *Kheper* and *Scarabaeus* or she will follow from behind as in *Scarabaeolus* (Davis, Frolov and Scholtz, 2008). It is apparent from the photos (Figure 1A–C) that this species makes spherical dung balls that they roll backwards

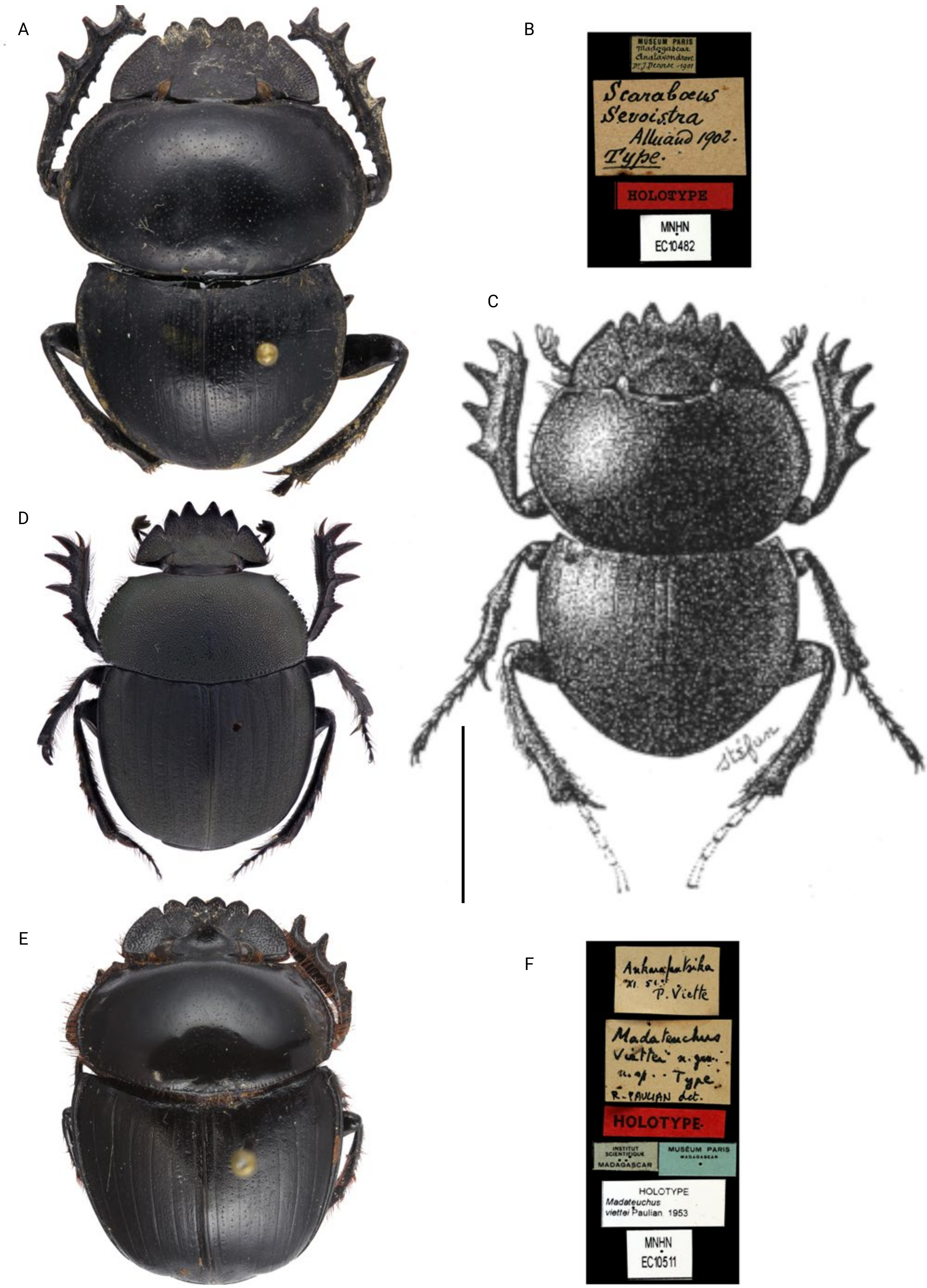

Figure 2. A–G, Madagascan Scarabaeini species. A, B, holotype male of *Scarabaeus sevoistra* Alluaud, 1902 and the associated labels from the MNHN; C, habitus drawing of a female *S. sevoistra* (from Paulian & Lebis (1960: 14)) for comparison; note the dimorphism in the shape and form of the protibiae of the male (A) and female (C); D, *Scarabaeus radama* Fairmaire, 1895; E, F, *Scarabaeus viettei* (Paulian, 1953), holotype female and the associated labels from the MNHN. Scale bar is 10 mm.

while working as pairs, but it is unclear if the female intends to sit on top or cling to the side of the ball. We are aware that some species of ball rolling dung beetle can steal dung balls made by other telecoprid species, but the photographic evidence suggests that *S. sevoistra* does, at least, roll its own dung balls.

In all the available iNat photos, they are photographed on sandy soil, as occurring in all other known flightless Scarabaeini (all reviewed in Harrison, Scholtz and Chown (2003)). This is in accordance with the previous collecting record by J. Decorse, who, as explained above, also originally collected the species while searching for xerophilic genera of plants (Eggli & Newton 2010). This constitutes further independent evidence for the association between arid areas with sandy soil and the evolution of flightlessness among the Scarabaeini (Scholtz 2000).

All the iNat specimens were observed in the Madagascan spiny thicket ecoregion, suggesting this to be their preferred habitat type (Figure 3). Both Verreaux's sifaka (*Propithecus verreauxi* Grandidier, 1867) and the ring-tailed lemur (*Lemur catta* Linnaeus, 1758) are relatively large primates (weighing about 2–4 kg) that occur in the Madagascan spiny thicket ecoregion (LaFleur & Gould 2020; Louis et al. 2020). Although *S. sevoistra* may be able to switch back to utilising cattle dung, as tentatively suggested by Rahagalala et al. (2009), for the Malagasy Scarabaeini as a whole, it is possibly on the dung of these indigenous primates that the species naturally feeds and survives on.

Of the photographed specimens (Figure 1E–F), only one of the photographers (Maxim Nuraliev) noted soil and climate data. That specimen was observed on sandy soils on a cool, cloudy and wet morning, after a night of rain (Maxim Nuraliev, pers. com.). Paulian and Lebis (1960) include this biological note for the species: *'The species seems to be very localised and to have only a very brief period of appearance, probably linked to the rains'* (our translation from the original French).

Key to the Madagascan species of Scarabaeini

The three species of Scarabaeini that occur on Madagascar are believed to have arrived there naturally (i.e. by non-human means) (Rahagalala et al. 2009; Sole et al. 2011)) and are thereby considered indigenous and endemic. Though this has not been recorded so far, all three species of Scarabaeini may potentially occur sympatrically. We thus provide a key to separate them from one another.

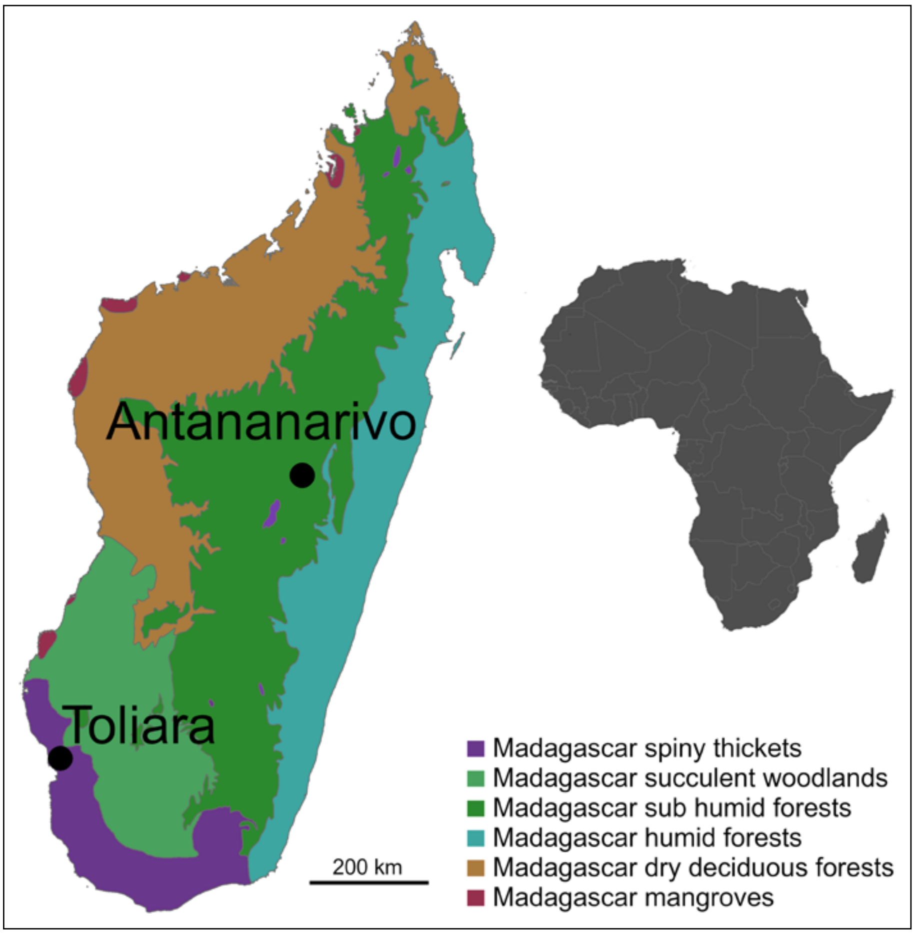

Figure 3. Map showing the ecoregions of Madagascar with the Madagascan spiny thickets in the southwest.

1a	Flightless. Elytra strongly rounded anteriorly. Southwest of Madagascar . . . . . . *Scarabaeus sevoistra* Alluaud, 1902 (Figures 1A–F and 2A, C)	
b	Flight capable. Elytra narrowing anteriorly, but not strongly rounded	2
2a (1b)	Pronotum and elytra smooth, with small punctures. South and southwestern Madagascar. . . . . . *Scarabaeus viettei* (Paulian, 1953) (Figure 2E)	
b	Pronotum and elytra granulate. West coast of Madagascar . . . . . . *Scarabaeus radama* Fairmaire, 1895 (Figure 2C)	

Conservation status

Recently quite a few specimens of *Scarabaeus cancer* (Arrow, 1919), a related and similarly enigmatic species from Angola, ended up for sale within the insect trade. To keep the rediscovery of *S. sevoistra* from hobbyist-collectors, Joseph Thompson, the citizen scientist who posted the first pictures, was asked to remove them by one of the authors here. However, two subsequent postings of *S. sevoistra* were made by different citizen scientists and we realised that a different approach was needed as news of its rediscovery would eventually reach these collectors. We thus decided to formally give this enigmatic species a Red Data List status as a measure of protection. Additionally, the authorities in the area where the species was photographed can now be informed of the scarcity and vulnerability of this species to poaching and be on the lookout for any suspect collecting activities.

Available distribution evidence suggests that *S. sevoistra* is geographically restricted to the already Critical/Endangered (https://www.worldwildlife.org/ecoregions/at1311) Madagascar spiny thicket ecoregion in the south of the country (Figure 3). The ecoregion is known to support an exceptionally high level of endemism while encompassing some smaller centres of endemism within the ecoregion (https://www.worldwildlife.org/ecoregions/at1311). We specifically have not indicated on the map where the specimens were photographed, but the area that *S. sevoistra* was photographed in is a small area in the south of Madagascar with less than 100 ha that is afforded protection.

With only about 3% of this ecoregion formally protected, the most important threats to its survival are habitat destruction for livestock pasture, agriculture and conceivably poaching (https://www.worldwildlife.org/ecoregions/at1311) (Lindenmayer & Scheele 2017). Although widespread, the Verreaux's sifaka is considered Critically Endangered (Louis et al. 2020) and the ring-tailed lemur is considered Endangered (LaFleur & Gould 2020) and thus the food source of *S. sevoistra* is probably also very limited. This dung beetle species should thus be assessed as Endangered B2ab (see IUCN (2012) for an explanation of the criteria), but future assessments might elevate the threat category to Critically Endangered.

Acknowledgements

We would like to thank Mario Cupello (Federal University of Paraná), and two anonymous reviewers for their invaluable comments that improved the earlier version of this manuscript and Joseph Thompson, Maxim Nuraliev (Lomonosov Moscow State University) and Bitty Roy (University of Oregon) for their keen observations and their permission to use their photographs. Christophe Rivier (MNHN) is thanked for imaging the holotype specimens of *Scarabaeus sevoistra* Alluaud, 1902 and *Scarabaeus viettei* (Paulian, 1953). We also thank the iNat website for allowing us to use the data. C.M.D. thanks the University of Pretoria for continued PhD bursary funding.

Competing interests

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this article.

Authors' contributions

C.M.D. (University of Pretoria) was the project coordinator, J.duG.H. (University of the Witwatersrand) conceived the paper and C.M.D. (University of Pretoria), J.duG.H. (University of the Witwatersrand) and C.L.S. (University of Pretoria) wrote the paper together.

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BOTHALIA – African Biodiversity & Conservation
ISSN: (Online) 2311-9284, (Print) 0006-8241

Dung beetle conservation in a heterogeneous landscape of the Maputaland Centre of Endemism

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Dates

Submitted: 26 September 2020
Accepted: 17 August 2021
Published: 5 November 2021

How to cite this article:

Escobar, F., Davis, A.L.V., Deschodt, C.M. & Scholtz, C.H., 2021, 'Dung beetle conservation in a heterogeneous landscape of the Maputaland Centre of Endemism', *Bothalia* 51(2), a15. http://dx.doi.org/10.38201/btha.abc.v51.i2.15

Background: Maputo Special Reserve (MSR) in Mozambique lays within the Maputaland Centre of Endemism (MCE) and protects the biota of a habitat mosaic dominated by coastal dune forest and inland sand forest patches of different sizes surrounded by natural grassland.

Objectives: To determine the importance of woody versus grassland vegetation for supporting endemic east coast versus widespread savanna dung beetles in the MCE in the face of increased accessibility and exploitation of woody vegetation in southern Mozambique, especially by charcoal burners.

Method: We used general linear mixed models, additive partitioning of diversity and ordination to analyse species abundance and occurrence across a mosaic of three major habitats in the MSR (grassland, sand and dune forest).

Results: High compositional heterogeneity was found between habitat types and study sites so that beta diversity was mostly higher than alpha diversity. Three distinct scarabaeine dung beetle assemblages defined from ordination were largely centred on the three habitat types. Out of a total of 61 species, greater numbers were associated with grassland (38) than sand (17) and dune forest (6) although abundance was greater in both dune forest and grassland than in sand forest. Biogeographical classification indicated that >40% of the species are endemic to the east coast of southern Africa with the remainder centred in adjacent savanna. Endemic east coast species were well represented in both forest (15) and grassland (11). Savanna species were better represented in grassland (27) than forest (8). Proportions of grassland species and their abundance declined across increasing patch sizes of sand forest becoming lowest in dune forest.

Conclusions: Conservation of endemic, east coast dung beetle species requires the preservation of both natural grassland and sizeable patches of forest in an undisturbed habitat mosaic. As the east coastal system is relatively small in extent with the MCE widely transformed in South Africa, the MSR is an important contributor to regional conservation of endemic species.

Keywords: conservation; dung beetles; endemism; Maputo Special Reserve; Maputaland; Mozambique; Scarabaeinae, South Africa.

Introduction

The southeast coastal region of Mozambique and South Africa is biogeographically distinct and may be divided into southern (Pondoland) and northern (Maputaland) centres of endemism based on floral and vertebrate distribution (van Wyk 1994; Perera et al. 2011). The southeast coast also comprises the smallest of six regional centres of dung beetle distribution defined for southern Africa (Davis & Scholtz 2020) in an area characterised by rain falling mainly during summer (60–80%). The greatest numbers of summer rainfall dung beetle species restricted to the southeast coast are concentrated in the MCE in northeast KwaZulu-Natal and southeast Mozambique (Davis & Scholtz 2020) where they are known primarily from quaternary deep coastal sands (Davis et al. 2020). Some past (Davis et al. 2003, 2013; Jacobs et al. 2010) and present studies on these sands have recorded from 57 to 63 species in each local assemblage of which ± 42–52% were endemic to the east coast with some restricted to Maputaland.

A variable degree of protection is offered to endemic species of the deep coastal sands in the MCE. In South Africa, a narrow coastal strip is formally protected southwards from the Mozambique border as the Kosi Bay Nature Reserve, iSimangaliso World Heritage Site and Mapelane Nature Reserve. At the inland edge of the coastal sands on the South African border with Mozambique, the Tembe Elephant Park and Sileza Nature Reserve also protect mixed savanna woodland and patches of sand forest as well as dung beetles (van Rensburg et al. 1999; Botes et al. 2006). However, the remainder of the region is unprotected farmland or local conservancy. Furthermore, the coastal dunes to the south of Mapelane have been subjected to dredge mining for titanium bearing sands although 33% of this area is under restoration as dune forest (van Aarde et al. 1996). Within Mozambique to the south of Maputo, the MSR protects grassland, dune and sand forest patches from the coast to approximately 20 km inland. Although the extreme southeast corner of the country remains formally unprotected, the inland edge of MSR continues southwards as a corridor for elephant movement along the Futi River as far as the South African border where it abuts Tembe Elephant Park. As a result, the area of protected coastal belt vegetation on deep sands of the MCE is much larger in southeast Mozambique than in South Africa where its conservation status (Maputaland Coastal Belt – CB1; Maputaland Wooded Grassland – CB2) is rated as vulnerable to endangered (Mucina & Rutherford 2006).

The dung beetle fauna on deep sands of the MCE has been well studied in South Africa (van Rensburg et al. 1999; Davis et al. 2002, 2003, 2013; Botes et al. 2006) but only to a lesser extent in southeast Mozambique (Jacobs et al. 2010). Since composition of dung beetle assemblages shows clear differences in response to habitat disturbance by elephants and humans in and around Tembe Elephant Park (Botes 2006), the study of Jacobs et al. (2010) suggested further research should address questions on the effects of relative habitat continuity, isolation, patch size, and levels of disturbance in and around MSR. This is now more urgent as threats to the region around the reserve have recently increased along with greater accessibility (Makhaye & Mkhize 2019), development (Peace Parks Foundation 2020), and in particular, clearance of sand forest by farmers and charcoal burners (Tokura et al. 2020). Therefore, we examined: (1) differences in species abundance patterns, diversity and rarity of dung beetles between grassland, dune forest and three patch sizes of sand forest (large, medium, small) for the entire, heterogeneous, habitat mosaic of a study area in the MSR; (2) associations of species assemblages with each of the five habitat/patch sizes; (3) bias in associations of species with each of the five habitat/patch sizes; (4) patterns resulting from the overlay of biogeographical affiliations (east coast, savanna or sandy savanna) onto species habitat associations; (5) how habitat type and forest patch size influenced the occurrence of both east coast endemics and species also found in the adjacent savanna. This approach was designed to demonstrate the importance of the reserve and its environmental mosaic for conservation of the forest and endemic, east coast component of the dung beetle fauna given the greater transformation of the MCE in South Africa.

Methods

Study area

The MCE is roughly consistent with both the Maputaland Coastal Forest Mosaic ecoregion of Olson et al. (2001) and the northern part of the Indian Ocean Coastal Biome of Mucina and Rutherford (2006) including the edge of the adjoining Savanna Biome. Although the biomes of Mucina and Rutherford (2006) were defined for just South Africa, they continue over the border into southeast Mozambique. In northeast KwaZulu-Natal, South Africa, the sandy coastal part of the MCE comprises the eastern part of the Savanna Biome (vegetation unit: Tembe Sandy Bushveld – SVl18) and the northern part of the Indian Ocean Coastal Biome (dominant vegetation units: Maputaland Coastal Belt – CB1; Maputaland Wooded Grassland – CB2; with embedded patches of Northern Coastal Forest – FOz7) (Mucina & Rutherford 2006). The dominant mixed woodland savanna of the Tembe Sandy Bushveld continues northwards into Mozambique and surrounds the protected Licuati sand forests to the west of MSR that is, itself (Figure 1), situated within a 35 km wide coastal strip representing a northern continuation of the Indian Ocean Coastal Biome from South Africa (Mucina & Rutherford 2006).

Proclaimed in 1960, the MSR (800 km^2 from 1960 to 2011; ± 1500 km^2 from 2011 to present by addition of the Futi corridor) protects the flora and fauna in a region characterised by a mosaic of habitats (Smith & Leader-Williams 2006). Within the original 800 km^2 reserve, these habitats are dominated by hygrophilous or woody grassland with patches of sand forest and sand thicket plus water bodies. In particular, the naturally fragmented sand forest and sand thicket comprises patches of different sizes (<1 ha to ± 2000 ha) immersed mainly in a matrix of natural grassland. Other habitats

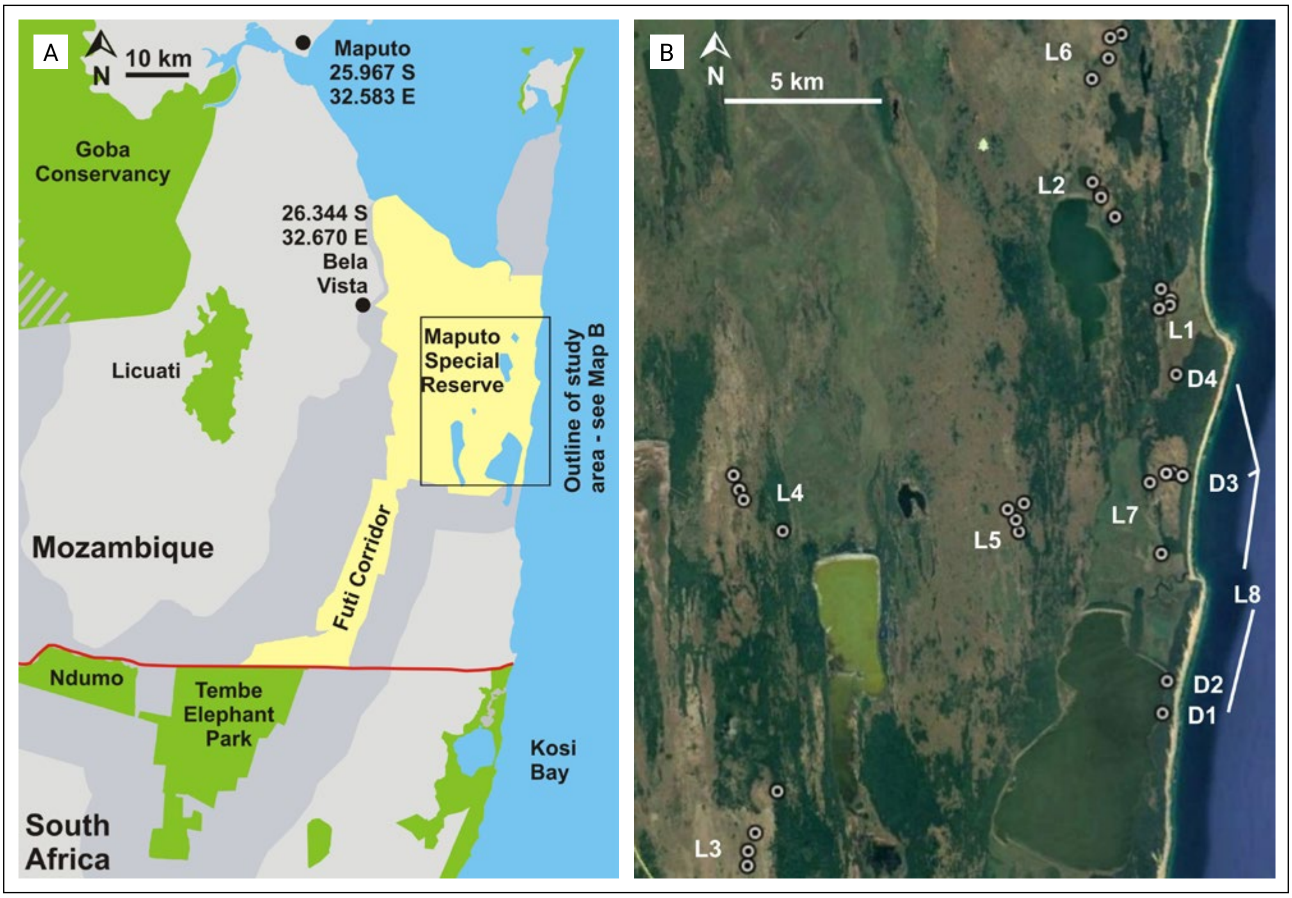

Figure 1. A, map outlining the study area and showing the position of Maputo Special Reserve (MSR) in relation to land usage in the surrounding area of southeast Mozambique and northeast KwaZulu-Natal, South Africa (nature and game reserves are marked by green and yellow, darker grey outlines the Lubombo Conservancy, unprotected areas are pale grey, Indian Ocean, inlets and lagoons are blue) (redrawn from Peace Parks Foundation 2020); B, position of sampling localities in MSR plotted onto Google Earth; L1–L7 = study sites at each locality in large, medium and small sand forest patches plus grassland; L8, DF1–DF4 = dune forest study sites. Position of most forest sites was measured at the point of entry as the GPS could not detect satellites under the canopy.

are more limited in extent and include fringing coastal dune forest, *Terminalia* woodland, grass and sedge swamp in addition to plantations (Smith & Leader-Williams 2006).

Sampling protocol

Sampling was conducted in three major habitats (grassland, sand forest/thicket, dune forest) and in three patch sizes of sand forest/thicket (large, medium, small) within the confines of the original 800 km^2 reserve. This combination of habitats and patch sizes is, hereafter, considered as five different habitat types. To determine habitat associations, dung beetles were sampled at eight localities across the reserve (Figure 1). Each of localities 1–7 included single study sites in grassland, plus small (< 3.8 ha), medium (8 to 53 ha) and large (> 137 ha) patches of sand forest/thicket (= 28 study sites in total separated by 2.30 to 0.10 km at each locality; sand forest at localities 3 and 4; sand thicket at the other localities; hereafter, all cited as sand forest). Locality 8 was defined from widely scattered study sites in a 10.35 km, more-or-less continuous band of dense dune forest (0.35 to 1.25 km wide at sampling points) along the coastline (= 4 study sites in total separated by 1.0 to 6.3 km). At each of the 32 study sites, four pitfall traps were placed at least 50 m apart with distances from forest edges dictated by patch size (dune forest 200 m; large, medium and small sand forest patches: 100 m, 50 m and ±25 m, respectively). This amounted to a total of 128 traps, 16 in dune forest (Locality 8) and 28 in each of the more extensive grassland plus large, medium and small sand forest patches (localities 1–7).

Pitfall traps comprised five-litre plastic buckets (top diameter, 23 cm; depth, 17.5 cm) dug into the sand so that the rims were level with the soil surface. Pig dung was selected as bait since it was readily available and is a good attractant for many dung beetle species (Marsh et al. 2013). Each bait comprised ± 200 ml of fresh pig dung wrapped in thin cloth that was supported at ground level across the top of the buckets by two strong wires. Water plus detergent was placed at the bottom of each pitfall to immobilise the catch.

Sampling was conducted on a single 48 h occasion at each locality between 08 and 24 November 2006.

Samples were collected every 24 h and placed in 99% ethanol for later identification. Fresh baits were placed on the traps at the beginning of sampling and then replaced three times with fresh baits after ± 12 h, either early in the morning or late in the afternoon. This protocol presented fresh dung for attracting both diurnal and nocturnal fliers and yielded a total of 256 samples (32 study sites × 4 traps × 2 days). Representative material was originally deposited in the reference collection at the University of Pretoria that has now been donated to the IZIKO South African Museum, Cape Town.

Data analysis

Completeness of sampling

Coverage-based rarefaction (Chao & Jost 2012) was used to estimate if sampling effort at each study site was sufficient to provide a complete inventory of the species assemblage represented within the whole community. This was determined using the equation: $\hat{C}n = 1 - f_1 / n\,[(n - 1)f_1 / (n - 1)f_1 + 2f_2]$, where f_1 and f_2 are, respectively, the numbers of species with one (singletons) and two individuals (doubletons) in the sample and n is the number of individuals. Sample completeness ($\hat{C}n$) indicates the proportion of the entire community represented by the trapped species (Chao & Jost, 2012). When $\hat{C}n \approx 100\%$ (or '1' on a 0–1 scale), sampling is complete in terms of the effort and capture technique used. Therefore, the diversity values can be compared directly (Chao & Jost 2012). Sample coverage was calculated using the iNEXT package for R (Hsieh et al. 2016).

Species abundance patterns

General linear mixed effects models (GLMM) with poisson error distributions were used to examine how numbers of species and abundance were affected by habitat type and between–study site heterogeneity within each habitat. Due to high over-dispersion detected for abundance, the quasi-poisson error distribution was used (Crawley 2013). Habitat type was considered as a fixed factor and study sites as a random factor. Traps (128 in total) were nested within study sites; study sites were the replicates. For analyses of deviance and tests of contrasts, we used the Type II Wald Chi square test. For the adjustment of *P* values in the contrasts, we used the Tukey method. Analyses were carried out using the 'lme4' (Bates et al. 2020), 'multcomp' (Hothorn et al. 2017), and 'MASS' (Ripley et al. 2019) packages in R v. 3.5.3 (R Core Team 2019).

Diversity and rarity

Additive partitioning of total species richness (gamma - γ) (Veech et al. 2002; Crist et al. 2003) was used (1) to determine the proportion of species occurring within (alpha – α) and between study sites (beta – β_1) in each of the five habitats ($\gamma = \alpha + \beta_1$ study sites) and (2) to determine overall proportion of diversity occurring within (α) and between study sites (β_1) and between habitat types (β_2) ($\gamma = \alpha + \beta_1$ study sites $+ \beta_2$ habitat types). This approach permitted a direct comparison between numbers of species attributable to the alpha and beta components of gamma diversity.

We calculated a species rarity index based on species distribution across sampling sites. This was calculated as $1 - (n_i / N)$, where n_i is the number of sites at which species *i* was present, and n is the total number of sites (N = 32). Based on the index values, frequency of species occupation at the 32 sites determines the proportion of species with restricted occurrence across the study area.

Habitat and biogeographical associations

Factor analysis and hierarchical analysis of oblique factors (Tibco Software Inc. 1987–2014 – Statistica 13.3.) were used to analyse local distribution patterns across the 32 study sites. The 32 × 61 data matrix represented mean abundance per sample at 32 study sites for each of 61 species of dung beetles. The data were 4th root transformed before factor analysis using varimax-normalised rotation of factors. Hierarchical analysis of oblique factors was used to identify clusters of sites with similar faunal composition (default setting of 0.7) and determine the amount of shared and unique variance between clusters represented by extended factors.

Non-metric multi-dimensional scaling (NMDS) (Tibco Software Inc. 1987–2014 – Statistica 13.3.) and a minimum spanning tree (MST) were used to analyse bias in spatial distribution of dung beetle species between five habitat types. The 61 × 5 data matrix represented mean abundance per sample of 61 species in grassland, dune forest and the three different patch sizes of sand forest. The data were square root transformed and converted to a correlation matrix before NMDS analysis. The distance matrix was used to fit a minimum spanning tree to the ordination biplot for dimensions 1 and 2. Distances between species pairs were first placed in rank order. A search then determined the shortest distances between each species pair until all data points were connected by a complete tree. Dotted lines were used to represent the greatest distances (> 0.7) on the MST to assist defining clusters with similar habitat bias.

Habitat bias was combined with measurements of biogeographical bias. That shown by 50 of the 61 species was defined using the classification in Davis and Scholtz (2020 – three patterns, east coast, savanna or sandy savanna). Biogeographical bias shown by *Onthophagus juvencus* Klug and ten unnamed or undescribed species

Table 1. Species numbers and abundance of dung beetles in three habitats and three patch sizes of sand forest in Maputo Special Reserve (f_1 / f_2 = number the numbers of species with one (singletons) and two individuals (doubletons) in the sample; $\hat{C}n$ = sampled coverage (Chao and Jost 2012)

Diversity data and coverage	Dune forest	Sand forest			Grassland	All habitats
		Large	Medium	Small		
Total species ± 95% CI	21 ± 4.3	33 ± 2.9	30 ± 2.9	40 ± 3.9	49 ± 4.8	61 ± 4.2
Total abundance	13873	8405	9500	5172	20177	57127
f_1 / f_2	5 / 1	3 / 1	3 / 2	9 / 4	8 / 4	8 / 2
$\hat{C}$n	0.9996	0.9996	0.9983	0.9997	0.9996	0.9996

also conformed to these three patterns according to known distribution patterns (pers. obs. ALVD).

Results

Completeness of sampling

A total of 57 127 individuals, belonging to 61 species and 23 genera, was captured in the five habitat types. In all cases, completeness of sampling ($\hat{C}$n) was close to '1' with a sampling deficit of less than 0.2% (Table 1). These results indicate that our comparisons of richness species, abundance and species composition are reliable. Overall, nine species (15%) accumulated around 74% of total abundance: *Proagoderus aciculatus* (Fahraeus) (27%) more typical of dune forest; followed by three species biased to grassland, *Mimonthophagus ambiguus* (Péringuey) (13%), *Proagoderus aureiceps* (d'Orbigny) (7%), *Kurtops signatus* (Fahraeus) (6%); and five species biased to sand forest, *Sisyphus oralensis* Daniel & Davis (5%), *Onthophagus lacustris* Harold (5%), *Catharsius pandion* Harold (4%), *Onthophagus* sp. 1 (4%), *Onthophagus giuseppecarpanetoi* Tagliaferri & Moretto (3%) (Table S1). However, about 23% of the total species (14) were restricted to less than two study sites and about 59% (36) to less than eight sampling sites (Figures 2, S1).

Species abundance patterns

GLMM indicated differences in species numbers and abundance between habitat types ($\chi^2_{\text{species number}}$ = 75.31, df = 4, P <0.001; $\chi^2_{\text{abundance}}$ = 63.39, df = 4, P <0.001) and significant spatial heterogeneity between study sites within habitats ($\chi^2_{\text{species number}}$ = 11.44, df = 5, P = 0.041; $\chi^2_{\text{abundance}}$ = 11.78, df = 5, P = 0.037). The median number of species was significantly higher in grassland than in dune forest and sand forest patches of different sizes where values were relatively similar and did not differ significantly (Figure 3A). The greatest, between-site heterogeneity in number of species was found within grasslands and small sand forest patches (Figure S2A). Median abundances in dune forest and grassland did not differ significantly but were significantly higher than those in sand forest patches (Figure 3B). The greatest, between-site variation in abundance, was found within grasslands followed by dune forest (Figure S2B).

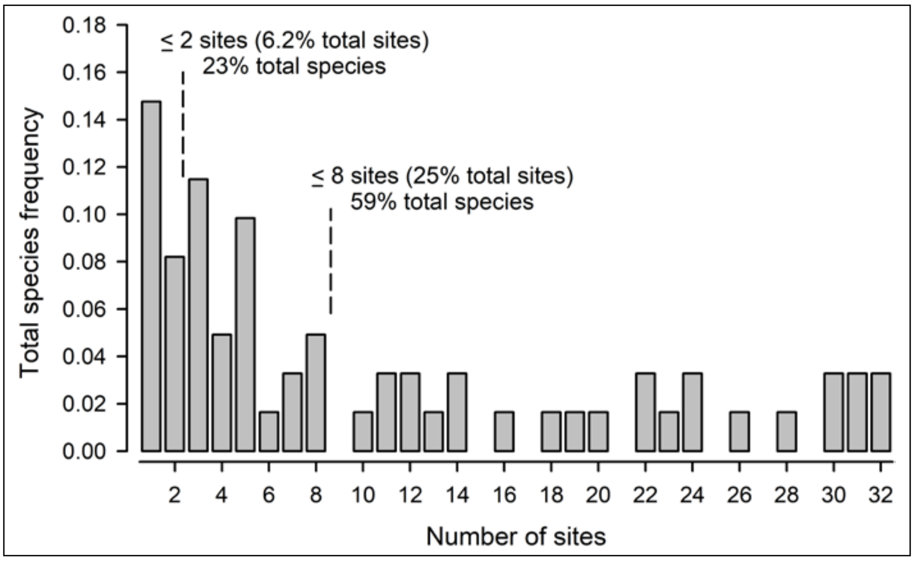

Figure 2. Frequency distribution for proportions of species recorded at 32 study sites in MSR (n = 4 in dune forest; n = 7 in grassland and each of three patch sizes of sand forest). Dotted lines delineate the relative incidence of rarer species at study sites. Note that a high percentage of the total species are found only in 25% of the sampled sites. See Figure S1 for values of the species rarity index.

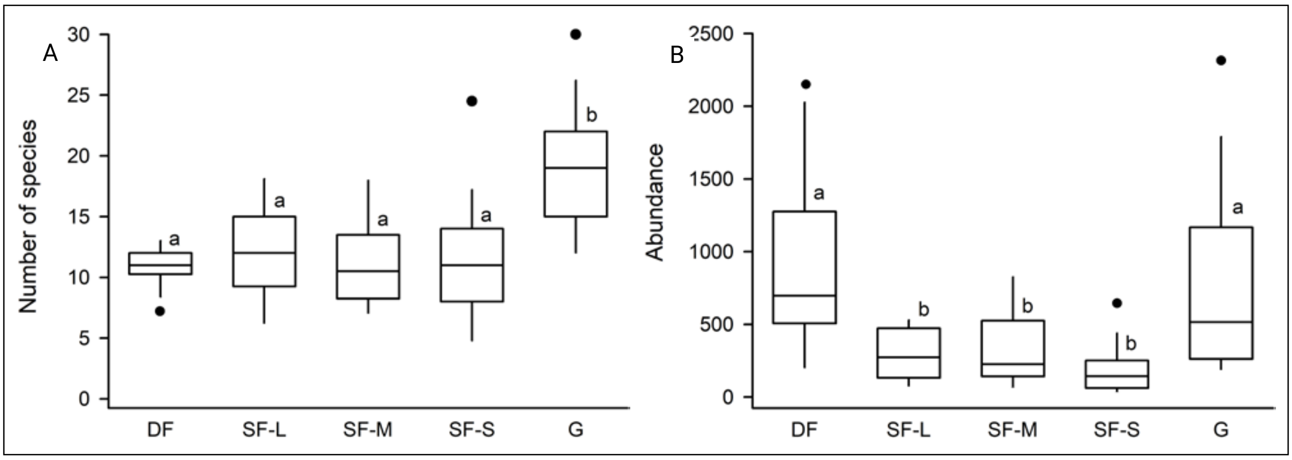

Figure 3. Box plots comparing number of species (A) and abundance (B) in each habitat type (DF = dune forest, SF-L, SF-M, SF-S = large, medium and small sand forest patches, G = grassland). Within each box, the mid-line represents the median whereas the lower and upper extents of the box represent the interquartile range Q_1 = 25th percentile and Q_3 = 75th percentile, respectively. Whiskers are minimum and maximum values. Black points represent outliers. Different letters indicate statistical differences at $P < 0.05$.

Relative proportions of total species and individuals (Table 1) also differed between habitats. The overall highest proportions of species (80.3% of 61) and individuals (36.3% of 57127) was found in grasslands. Although the lowest proportion of individuals (9.1%) was recorded in small sand forest patches, species richness was relatively higher (65.7%) than in the medium and large patches (49.1%, 54.1%) with relative abundance of 16.6% and 14.7%, respectively. Dune forest showed the lowest proportions of species (34.5%) but higher relative abundance (24.3%) than other forest habitats despite the lower number of study sites.

Several other trends in heterogeneity were noted across the reserve. These include a decline in abundance northwards along the coastline in dune forest (Locality 8: study sites 1–4) and higher species numbers and abundance in grassland at inland localities 3 and 4 plus coastal Locality 7 that are partly paralleled in sand forest at those localities (Figure S2). Mostly lower numbers were recorded at study sites in localities 1, 2, 5 and 6.

Diversity and rarity

In an additive manner, gamma diversity (γ) across the study area in MSR was expressed as: 61 = 15.6 [α within study sites] + 34.6 [β_1 between sites] + 11.1 [β_2 between habitat types] (Figure 4). Proportionally, overall diversity was divisible into only 25% generated by alpha diversity within study sites and 57% generated by beta diversity between study sites at different localities with 18% generated by beta diversity between habitats. On the habitat scale, sand forest and grassland accounted for the highest values of beta diversity between study sites at different localities (55 to 62%) while dune forest showed the lowest beta diversity values between study sites (40%). The slightly greater contribution of beta diversity in small sand forest and grassland (62% and 57%, respectively) is reflected by greater numbers of rarer species (larger f_1 / f_2 values – Table 1) and the higher contribution of alpha diversity in dune forest is reflected by dominance of a single species (*Proagoderus aciculatus*, 70.1% – Table S1).

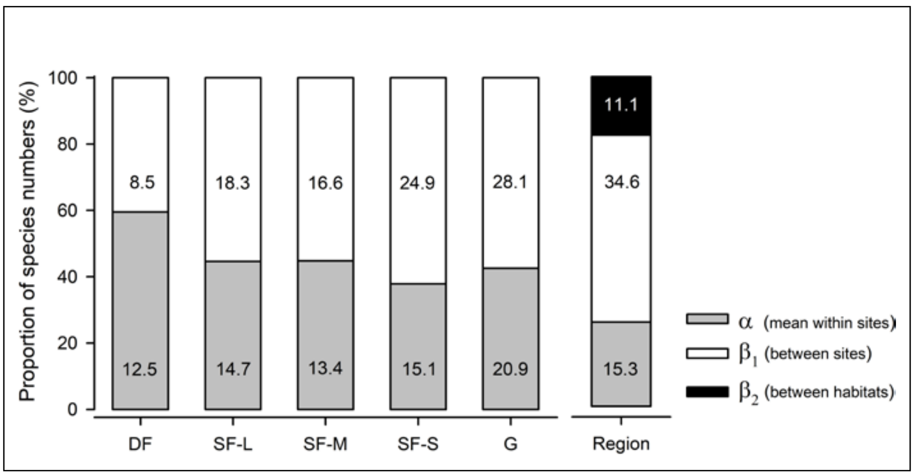

Figure 4. Contribution of each spatial component (habitat and patch size) to total species numbers sampled in the entire reserve (gamma diversity, n = 61 species); alpha (α) = diversity contributed by study sites; beta (β_1) = diversity between study sites; beta (β_2) = diversity between habitats. Proportions contributed by alpha and beta diversity are shown by the divisions within the bars whereas numbers of species are shown inside the bars (see methods). DF = dune forest; SF-L, SF-M, SF-S = large, medium and small sand forest patches; G = grassland.

Habitat and biogeographical patterns

Factor analysis and hierarchical analysis of oblique factors defined three differing spatial patterns in MSR accounting for 84.7% of the overall variance between mean species abundance data at 32 study sites (Figure 5A). The dung beetle faunas of grassland sites (93% unique variance) showed strong differences to those at forest study sites. The dung beetle faunas of dune and sand forest sites were structurally close (83% or 77% shared variance). There was some inconsistency in initial habitat classification as the 'sand forest faunas' at Locality 7 (large, medium and small patches) and Locality 5 (medium patch) were classified with the dune forest study sites. However, no difference was detected between most sand forest and sand thicket faunas.

NMDS ordination and a MST indicated three groups of species showing a local bias to either dune forest (6 spp.), patches of sand forest (17 spp.) or grassland (38 spp.) (Figure 5B, Table S1). These species groups also showed differing degrees of bias to either east coast, savanna or sandy savanna distribution patterns at biogeographical scale. Species with distributions centred on the east coast (26 spp.) occurred in all three studied habitat types although there were slightly more in natural forest (15 spp.) than in natural grassland (11 spp.). Species with distributions centred in sandy savanna and savanna were heavily biased to grassland (27 spp.) as opposed to forest occurrence (8 spp.) although this was less true of small sand forest patches (Table 1). Overall endemism to the east coast amounted to 42.6% in terms of total species numbers and 80.6% in terms of mean abundance per sample, of which 61.3% comprised abundance contributed by east coast forest endemics.

Penetration of grassland species into sand forest varied according to patch size, which accounted for the

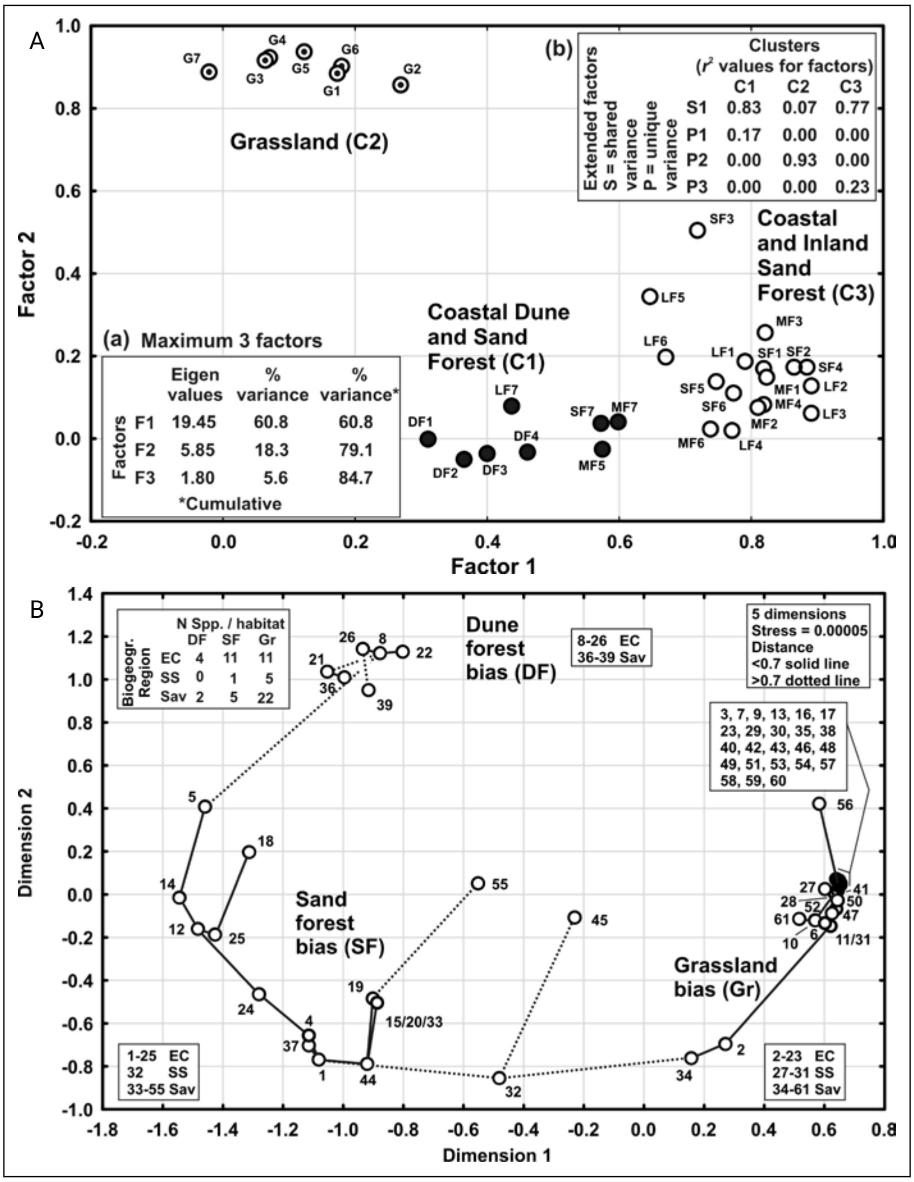

Figure 5. A, factor analysis ordination biplot showing three statistically defined clusters with, (a) a table of eigenvector values for each factor with proportional contribution to variance, and (b) r^2 values for the relationship between clusters and secondary (S) or primary (P) extended factors derived from hierarchical analysis of oblique factors (data points for study sites: G = grassland, DF = dune forest, LF, MF, SF = large, medium and small sand forest patches); B, NMDS ordination biplot with minimum spanning tree representing the habitat and biogeographical bias of 61 dung beetle species from Maputo Special Reserve (See Table S1 for key to species; EC = east coast species, SS = sandy savanna species, Sav = savanna species).

Table 2. Dung beetle species numbers, abundance, and proportions of grassland species in three habitats and three patch sizes of sand forest in Maputo Special Reserve.

Habitat associations	Dune forest	Sandforest			Grassland
		Large	Medium	Small	
Total N forest species ^	14	20	18	19	12
Total N grassland species ^	7	13	12	21	37
% N grassland species ^	33.3	39.4	40.0	52.5	75.5
Average. abundance/sample forest spp. ^	430.5	133.5	135.2	71.3	9.2
Average abundance/sample grass spp. ^	3.0	16.6	34.5	21.1	357.7
% abundance grassland species ^	0.7	11.1	20.3	22.9	97.5

^ See Figure 5 and SI plus Table 1 for classification of species habitat associations.

greater total numbers in small patches compared with medium and large patches (Tables 1, 2). Proportional representation by grassland species increased from dune forest across large and medium patches of sand forest becoming much larger in small sand forest patches (Table 2). Proportional average abundance of grassland species per sample also increased from dune forest to large sand forest patches becoming appreciably greater in both medium and small patches but much lower than in unshaded grassland.

Discussion

We first discuss some peripheral problems associated with defining scale of endemism along the east coast as well as outlining some of the climatic and faunal variation within the deep sand region of the MCE. We then discuss influences on species abundance patterns, associations with habitat and patch size, as well as outlining how recent threats illustrate the importance of MSR for conservation of east coast endemics, particularly in the light of current clearance of forest outside and within other nearby reserves.

Endemism on the east coast

Centres of endemism have been recognised along the east coast of southern Africa for various biota including flora, mammals and dung beetles (van Wyk 1996; Perera 2011; Davis et al. 2003, 2013; Jacobs et al. 2010). Although many dung beetle species are currently considered to be endemic to either the Pondoland or Maputaland centres (Davis et al. 2020), biogeographical classification relies on the quality of survey data. Whilst the dung beetle fauna of the MCE has been well studied (Davis et al. 2002, 2003, 2013; Jacobs et al. 2010) that to the south in Pondoland is less well studied and that to the north in the Southern Zanzibar–Inhambane Coastal Mosaic is very poorly known. Thus, although some papers have defined species distributions as widespread savanna and Maputaland or east coast endemics (Davis et al. 2003, 2013; Jacobs et al. 2010), the known distributional extent of some species has subsequently changed. For instance, *Sisyphus neobornemisszanus* cited as *S. bornemisszanus* is not restricted to the MCE as it is now known from Pomene further north along the east Mozambique coast in the Southern Zanzibar–Inhambane Coastal Mosaic. Furthermore, *Sisyphus* (*Neosisyphus*) *mirabilis* cited as *Neosisyphus mirabilis* is, also, not restricted to the MCE as it is now also known from far to the south in the Eastern Cape, South Africa. Thus, in the present work the most recent classification developed by Davis and Scholtz (2020) is used to describe biogeographical patterns shown by most of the dung beetle fauna of MSR (savanna, sandy savanna or east coast distribution). Unnamed and possibly undescribed species were also allotted to these three categories according to known distributions (pers. obs. ALVD).

Within the area encompassed by the Maputaland Coastal Forest Mosaic of Olson et al. (2001), annual rainfall is lower inland (± 600–650 mm) compared to the moister coastal band where annual temperature and rainfall vary from the warm but dryer centre around MSR (± 22.4ºC, 760–800 mm) to a little cooler and moister at the southern extreme (± 21.5ºC, 900–950 mm) and a little warmer and moister at the northern extreme (± 22.8ºC, 830–860 mm). Of 93 species recorded by four quantitative studies along the coastal part of the MCE (Davis et al. 2002, 2003, 2013; Jacobs 2010; present study), 28 are known only from the east coast. Of these, 25 are protected in the MSR with three recorded only to the south. However, six species recorded in the reserve were not recorded to the south in studies conducted in natural dune forest or in early succession grassland and woodland that replaced cleared dune forest after dredge-mining around Richards Bay (Davis et al. 2002, 2003, 2013). Notably, the reserve does not protect two flightless forest endemics showing restricted east coast distributions. One has been recorded at the northern edge of its range near Richards Bay, South Africa (*Gyronotus carinatus* (Boheman)), in the south of the MCE. The other is known from only four museum specimens and is, apparently, restricted to the moist area at the unprotected northern edge of the MCE in Mozambique (*Canthodimorpha lawrencei* Davis, Scholtz & Harrison).

Species abundance patterns in the MSR

GLMM results and high beta diversity indicate extensive variation in species abundance composition between study sites and habitats, which may be ascribed to a complex of spatial and temporal factors. These include: (1) different microclimates in grassland sand forest and dune forest habitats; (2) different patch sizes of forests, possibly with increased effects of edges in smaller patches; (3) day-to-day weather variation during sampling; (4) variability in local availability of suitable dung types for feeding and breeding; and (5) possibly, different levels of disturbance by elephants influencing habitat microclimate. Some of these factors may be responsible for trends in spatial patterns.

Differences in species abundance composition in unshaded grassland and shaded woodland or forest habitats of the MCE are known to be strongly correlated to microclimatic factors including light intensity, radiant and ambient temperature (Davis et al. 2002, 2003, 2013). Presumably, these factors were responsible for the three main assemblage structures recorded in MSR. Grassland and forest assemblages showed extreme differences that would parallel extreme differences in microclimate. Differences in assemblage structure between dune and sand forest were limited but significant. However, the driving factors are unclear as no measurements were made of likely differences in percentage canopy cover and underlying microclimate, nor of possibly greater edge effects in smaller patches of sand forest. Nevertheless, it is clear that differences in patch size of sand forest influences the numbers of species and individuals but has not driven any consistent differences in species abundance composition. However, it is unknown if the configuration of patches of different sizes had any effect, particularly after 14 years since data collection.

It is known that weather influences day-to-day variation in activity by dung beetles (Davis 1995, 2002; Davis et al. 2014), primarily the effects of sunshine, cloud or incidence of rainfall on diel temperatures and light intensity although wind may also be a factor, particularly in some coastal regions. Although there were clear differences in Day 1 and Day 2 results at many study sites that were possibly due to weather variation, microclimatic parameters could not be monitored at the 32 study sites for logistical reasons. Furthermore, as the workload demanded that sampling at some localities should be conducted on different days to that at others, it was not possible to standardise weather effects for the entire data set. However, this omission is not thought to have adversely influenced reliability of principal results for diversity and composition.

Over 400 elephants were recorded by the last census in the ± 1 500 km^2 of MSR (Peace Parks Foundation 2020), up from an earlier census of 180 (de Boer et al. 2000) when the reserve comprised just 800 km^2. Although no measurements are available for the effects of past or present elephant damage in the forests of the reserve, past research on dung beetles in Tembe Elephant Reserve and Sileza Nature Reserve showed that assemblage structure in elephant-disturbed sand forest differed to that in undisturbed sand forest (Botes et al. 2006). In and around the reserves, assemblage structure showed even greater differences in human-disturbed sand forest and the surrounding matrix of mixed woodland savanna (Botes et al. 2006), to which sand forest is converted after excessive disturbance (van Rensburg et al. 1999). Thus, size and effect of the elephant population should be monitored in MSR, particularly as sand forest harbours many neo-endemic plant species (van Wyk & Smith 2000).

Although frequency distribution of dung is known to influence local species abundance composition of dung beetle assemblages (Lobo et al. 2006), distribution of dung types and their amounts remain unknown for the sampling period in MSR. However, close to this time, tracking the movement of five elephants showed that they were primarily utilising the sand forest and hygrophilous grassland along the Futi floodplain (Ntumi et al. 2005) in the northeast of the current reserve, a similar pattern to that recorded from earlier tracking and dung counts (de Boer et al. 2000). The Futi floodplain is closest to localities 3 and 4 where large samples of dung beetles were recorded in sand forest and woody grassland. Observations of elephants and their dung during sampling also indicated that elephants visit some sand thicket patches closer to the coastline whereas, currently, frequent observations are made of elephants on the floodplains and in dense dune forest (Peace Parks Foundation 2020). Such differences in the concentration of elephant distribution in relation to water and forage availability could contribute to the differences in local abundance of dung beetles that were recorded across the overall landscape of the reserve.

Biogeographical plus habitat and patch size patterns in MSR

Within the MSR, biogeographical affiliations, associations with habitat and effects of patch size may be considered to reflect those for dung beetles across the entire region of coastal sands within the MCE. The reserve does not protect all of the east coastal sand species in the region but does include the bulk of the known endemics (see above). Ordination of site data suggests that classification into either dune or sand forest faunas was not entirely accurate as those in all patch sizes of sand forest' at Locality 7 clustered with dune forest. This probably reflects its greater proximity to the coastline and coastal dune forest than other sites that clustered as sand forest. Nevertheless, the clusters showed limited but significant differences in structure that are reflected by habitat bias to either sand (17 spp.) or dune forest (6 spp.) in 23 species of which 15 are east coast endemics. Despite the heterogeneity in abundance and species data between localities, study sites and sampling days, results suggest that small sand forest patches are less effective in conserving the forest dung beetle fauna. This owes to lower overall abundance than larger patches and greater penetration of species biased to grassland habitat, which is also true of medium patches based on proportional abundance data. Furthermore, the greater representation of savanna taxa in natural grassland suggest that reduction in the extent of forest areas would result in greater prominence of savanna taxa in the east coastal zone. Although 11 out of 38 grassland-biased species were identified as having east coastal centres of distribution, it should be noted that two of these 11 species showed a wider but unique distribution pattern from the east coast into savanna up the Zambezi valley to the Okavango delta and north Namibia (*Copris puncticollis*, *Mimonthophagus ambiguus*).

Endemism, threats and conservation

Within MSR, some clear trends shown by analyses of local habitat and species distribution data suggest that protection of natural grassland and both large patches of dune and sand forest would be necessary to adequately conserve the endemic east coastal dung beetle fauna. Threats to this fauna were limited at the time of data collection in 2006 when the southeast corner of Mozambique was only accessible by 4×4. However, a new tarmac road was officially opened in November 2018. This reduced the travel time from Kosi Bay (South Africa) to Maputo (capital of Mozambique) from 6 hours via 4×4 tracks to only 90 minutes. Although the new road skirts the entrance to MSR, which has been upgraded (Peace Parks Foundation 2020), the ease of regional access on tarmac has generated a much greater volume of traffic (Makhaye & Mkhize 2019), which may lead to increased future regional disturbance. For instance, the new road cuts across the Futi corridor, proclaimed as part of the reserve in 2011 to protect elephant movement along the Futi River towards South Africa. Also, a recent report describes increased deforestation for production of charcoal and agricultural lands around and, even within, the nearby Licuati sand forest (Tokura et al. 2020). Furthermore, the road system of MSR has been upgraded and new lodges on the coastline have been created or are under construction for development of ecotourism from which local communities will benefit (Peace Parks Foundation 2020). Nevertheless, under such management, the results suggest that MSR should remain a valuable asset for conservation in the MCE as long as the large patches of sand and dune forest remain preserved within a natural grassland matrix.

Acknowledgements

The study was supported by the University of Pretoria and the Conservation Ecology Research Unit (CERU), Department of Zoology & Entomology, University of Pretoria, through the 'Project for Maputaland Biodiversity Assessment: Threats and Opportunities', financed by the Mozal Community Development Trust and Billiton's HSEC. We thank Prof. Dr Cornelio P. Ntumi for organising and facilitating permission to sample dung beetles in Maputo Special Reserve under the auspices of this project.

Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

Design and field execution of the research (FE, CMD), identification of samples (ALVD), data analysis and writing (FE, ALVD), input into writing (CMD, CHS).

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Supplementary Material

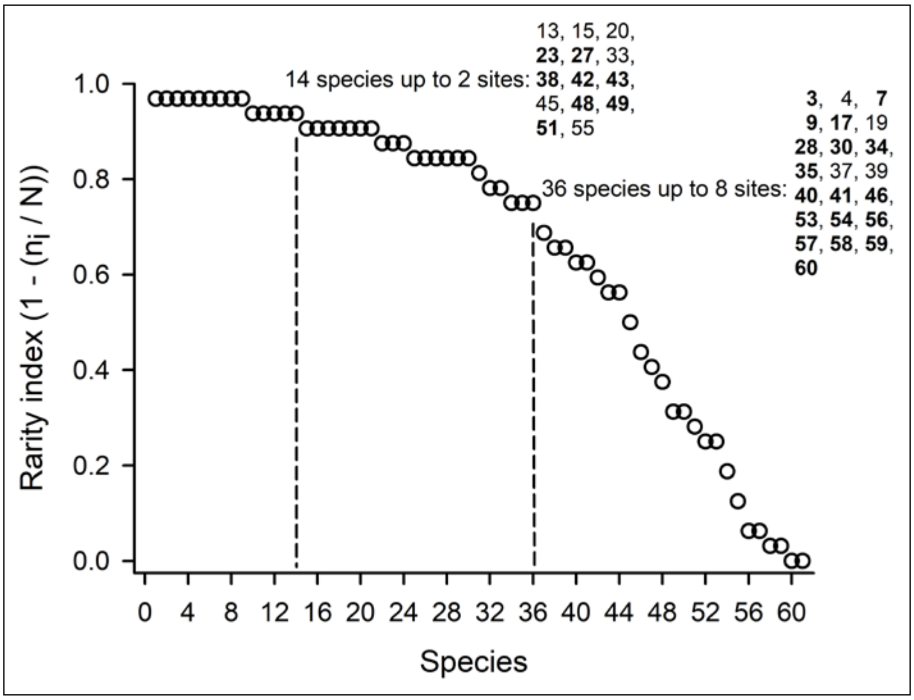

Figure S1. Rarity index values for each species ranked from highest to lowest. Dotted lines show rare species found at up to two sites and indicate the high proportion of the total species (~60%) found at eight sites or less (key to blocks of species numbers in Table S1; species in bold biased to grassland occurrence).

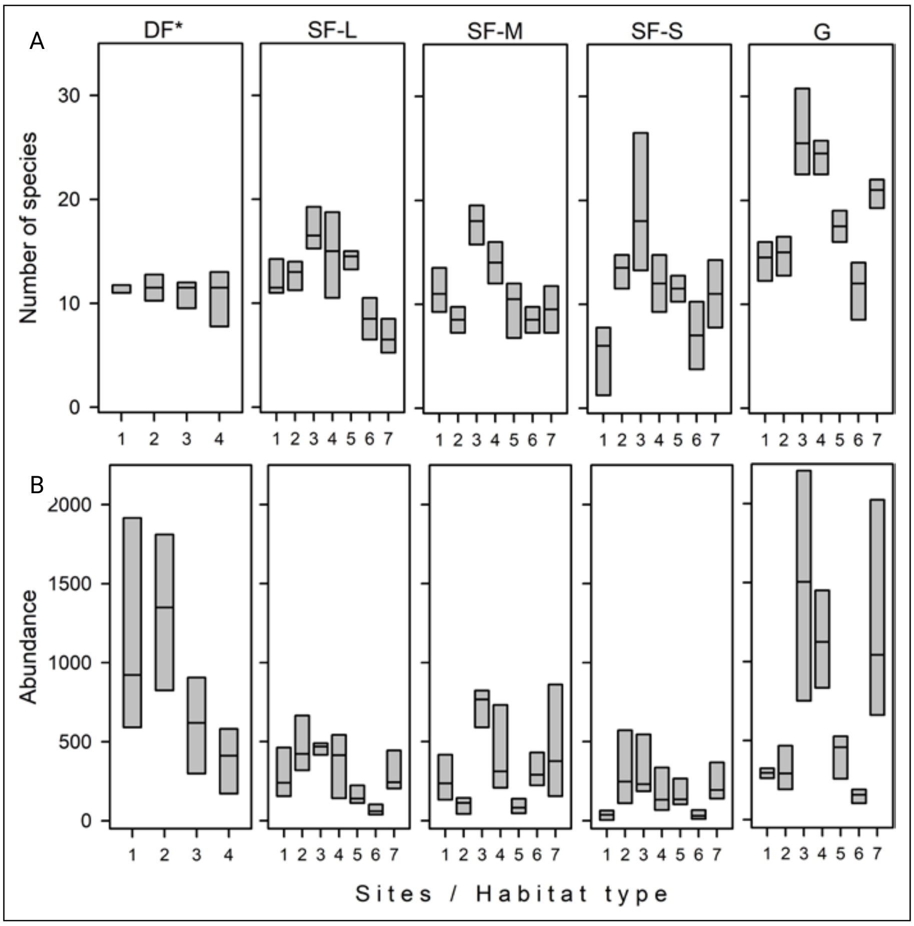

Figure S2. Box plots comparing number of species (A) and abundance (B) at each study site (1–7, except DF* = 1–4) within each habitat type. Within each box, the mid-line represents the median whereas the lower and upper extents of the box represent the interquartile range: Q_1 = 25th percentile and Q_3 = 75th percentile, respectively. DF = dune forest, SF-L, SF-M, SF-S = large, medium and small sand forest patches, G = grassland.

Table S1. Average numbers of 61 dung beetle species in three different habitats (DF = dune forest, SF = sand forest, G = grassland) and three patch sizes of sand forest in Maputo Special Reserve with a classification of biogeographical (see Davis and Scholtz 2020) and habitat bias (see Figure 5 and methods*) with rarity index values (see SI Figure 1 and methods**) for wide (0) or restricted (1) coverage

N	Biogeographical centre* and species		Average abundance / sample				Habitat	Rarity
		Dune forest	Sand forest			Grass-land	Bias*	Index**
			Large	Medium	Small			
EAST COAST CENTRE								
1	*Caccobius* sp. 1^ (M)	0.47	15.52	8.59	5.02	0.98	SF	0.063
2	*Caccobius* sp. 3^ (M)	0.03	5.89	3.54	3.29	11.76	G	0.125
3	*Catharsius harpagus* Harold (M)	0	0	0	0	3.49	G	0.875
4	*Catharsius laticeps* Boheman (M)	0	1.18	0.75	0.05	0	SF	0.844
5	*Catharsius pandion* Harold (M)	15.78	13.75	9.91	4.54	0.65	SF	0.031
6	*Copris inhalatus* Quedenfeldt ssp. *sanctaluciae* Ferreira (M)	0	0.09	0.11	0.04	2.71	G	0.625
7	*Copris puncticollis* Boheman	0	0	0	0.04	1.16	G	0.906
8	*Garreta caffer* (Fahraeus)	24.59	0.52	0.95	0.11	0	DF	0.500
9	*Metacatharsius zuluanus* (Balthasar)	0	0	0	0	1.33	G	0.813
10	*Mimonthophagus ambiguus* (Péringuey)	1.81	4.68	23.02	7.91	97.71	G	0.031
11	*Onthophagus giuseppecarpanetoi* Tagliaferri & Moretto (M)	0.03	1.09	1.86	2.70	30.55	G	0.313
12	*Onthophagus lacustris* Harold	6.59	16.43	19.59	7.18	0	SF	0.250
13	*Onthophagus ursinus* d'Orbigny	0	0	0	0	0.02	G	0.969
14	*Onthophagus* sp. 1^ (M)	9.72	16.71	14.43	7.66	0.09	SF	0.188
15	*Onthophagus* sp. 2^ (M)	0	0.02	0	0	0	SF	0.969
16	*Onthophagus* sp. 3^ (M)	0.03	0.09	0.02	0.41	24.85	G	0.594
17	*Onthophagus* sp. 4^ (M)	0	0	0	0	3.44	G	0.906
18	*Onthophagus* sp. 5^ (M)	2.34	1.41	6.54	2.54	0.02	SF	0.281
19	*Onthophagus* sp. 6^ (M)	0	0.05	0	0.04	0	SF	0.906
20	*Onthophagus* sp. 7^ (M)	0	0.45	0	0	0	SF	0.938
21	*Proagoderus aciculatus* (Fahraeus)	303.8	41.23	38.68	24.25	2.25	DF	0.000
22	*Scarabaeus bornemisszai* zur Strassen (M)	16.81	0.43	0.20	0.05	0.04	DF	0.656
23	*Sceliages gagates* Shipp (M)	0	0	0	0	0.04	G	0.969
24	*Sisyphus (Neosisyphus) mirabilis* (Arrow)	0.53	4.43	4.04	0.70	0.05	SF	0.438
25	*Sisyphus oralensis* Daniel & Davis (M)	4.97	12.66	21.20	11.14	0	SF	0.250
26	*Sisyphus neobornemisszanus* Daniel & Davis	34.75	0.38	3.57	1.88	0	DF	0.406
SANDY SAVANNA CENTRE								
27	*Allogymnopleurus splendidus* (Bertolini)	0	0	0	0.02	0.09	G	0.938

^ Species with biogeographical pattern derived from observations. Endemic east coast species, currently, still known only from Maputaland marked by '(M)' although some may have wider distributions.

Table S1. Average numbers of 61 dung beetle species in three different habitats (DF = dune forest, SF = sand forest, G = grassland) and three patch sizes of sand forest in Maputo Special Reserve with a classification of biogeographical (see Davis and Scholtz 2020) and habitat bias (see Figure 5 and methods*) with rarity index values (see SI Figure 1 and methods**) for wide (0) or restricted (1) coverage (continued)

N	Biogeographical centre* and species		Average abundance / sample				Habitat	Rarity
		Dune forest	Sand forest			Grass-land	Bias*	Index**
			Large	Medium	Small			
SANDY SAVANNA CENTRE (continued)								
28	*Kheper lamarcki* (Macleay)	0	0	0.09	0.04	2.27	G	0.781
29	*Kurtops signatus* (Fahraeus)	0	0.05	0	0.64	58.35	G	0.563
30	*Metacatharsius troglodytes* (Boheman)	0	0	0	0	2.18	G	0.781
31	*Pachylomera femoralis* (Kirby)	0	0.57	1.07	1.21	21.36	G	0.313
32	*Scarabaeus goryi* (Castelnau)	0.03	0.71	1.05	0.52	0.49	SF	0.375
SAVANNA CENTRE								
33	*Afrodrepanus impressicollis* (Fahraeus)	0	0.04	0	0	0	SF	0.938
34	*Caccobius histerinus* (Fahraeus)	0	0.02	0.02	0.02	0.04	G	0.844
35	*Caccobius nigritulus* (Klug)	0	0	0	0	1.07	G	0.906
36	*Chalconotus convexus* Boheman	9.94	6.20	5.32	5.23	4.56	DF	0.000
37	*Cleptocaccobius postlutatus* (d'Orbigny)	0	0.20	0.05	0.02	0	SF	0.844
38	*Catharsius tricornutus* DeGeer	0	0	0	0	0.18	G	0.938
39	*Copris fidius* (Olivier)	0.09	0	0.02	0.07	0	DF	0.906
40	*Gymnopleurus virens* Erichson	0	0	0	0.02	0.40	G	0.750
41	*Metacatharsius opacus* (Waterhouse)	0	0.02	0	0.07	6.82	G	0.750
42	*Onitis viridulus* Boheman	0	0	0	0	0.02	G	0.969
43	*Oniticellus planatus* Castelnau	0	0	0	0	0.02	G	0.969
44	*Onthophagus aeruginosus* Roth	0	1.18	0.18	0.25	0.04	SF	0.688
45	*Onthophagus beiranus* Péringuey	0	0	0.09	0	0.02	SF	0.938
46	*Onthophagus juvencus* Klug ^	0	0	0	0.02	7.56	G	0.750
47	*Onthophagus obtusicornis* Fahraeus	0	0.07	0.16	0.55	7.96	G	0.656
48	*Onthophagus pullus* Roth	0	0	0	0	0.02	G	0.969
49	*Onthophagus* sp. 8 ^	0	0	0	0	0.02	G	0.969
50	*Pedaria segregis* Péringuey	0	0.07	0.04	0.41	10.91	G	0.625
51	*Pedaria* sp. 1 ^	0	0	0	0	0.02	G	0.969
52	*Proagoderus aureiceps* (d'Orbigny)	1.03	3.48	4.55	3.61	55.75	G	0.063
53	*Proagoderus bicallosus* (Klug)	0	0	0	0	0.24	G	0.906
54	*Proagoderus chalcostolus* Péringuey	0	0	0	0.02	0.35	G	0.844
55	*Proagoderus dives* (Harold)	0	0	0	0.02	0	SF	0.969

^ Species with biogeographical pattern derived from observations. Endemic east coast species, currently, still known only from Maputaland marked by '(M)' although some may have wider distributions.

Table S1. Average numbers of 61 dung beetle species in three different habitats (DF = dune forest, SF = sand forest, G = grassland) and three patch sizes of sand forest in Maputo Special Reserve with a classification of biogeographical (see Davis and Scholtz 2020) and habitat bias (see Figure 5 and methods*) with rarity index values (see SI Figure 1 and methods**) for wide (0) or restricted (1) coverage (continued)

N	Biogeographical centre* and species		Average abundance / sample				Habitat	Rarity
		Dune forest	Sand forest			Grass-land	Bias*	Index**
			Large	Medium	Small			
	SAVANNA CENTRE (continued)							
56	*Scarabaeus geminogalenus* Davis & Deschodt	0.03	0	0	0	0.27	G	0.906
57	*Scarabaeolus clanceyi* (Ferreira)	0	0	0	0.07	0.91	G	0.844
58	*Scarabaeolus planipennis* (Davis & Deschodt)	0	0	0	0.02	0.31	G	0.875
59	*Sisyphus* (*Neosisyphus*) *confrater* (Kolbe)	0	0	0	0	0.35	G	0.875
60	*Sisyphus* (*Neosisyphus*) *fortuitus* (Péringuey)	0	0	0	0	0.24	G	0.844
61	*Sisyphus sordidus* Boheman	0.06	0.48	0.04	0.02	2.91	G	0.563

^ Species with biogeographical pattern derived from observations. Endemic east coast species, currently, still known only from Maputaland marked by '(M)' although some may have wider distributions.

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BOTHALIA – African Biodiversity & Conservation
ISSN: (Online) 2311-9284, (Print) 0006-8241

Otholobium outrampsii (Psoraleeae, Fabaceae) – a new species from the Western Cape, South Africa

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Dates

Submitted: 27 July 2020
Accepted: 13 January 2021
Published: 10 August 2021

How to cite this article:

Stirton, C.H. & Du Preez, B., 2021, '*Otholobium outrampsii* (Psoroleeae, Fabaceae) – a new species from the Western Cape, South Africa', *Bothalia* 51(2), a5. http://dx.doi.org/10.38201/btha.abc.v51.i2.5

Otholobium outrampsii (Psoraleeae, Fabaceae) – a new species from the Western Cape Province, South Africa, is described and illustrated. This species is closely related to *O. curtisiae* but can be morphologically distinguished by it having semi-conduplicate, minutely glandular, softly pilose leaflets (versus flat, prominently glandular, glabrous leaflets); leaflet apex attenuate (versus leaflet apex shortly apiculate); calyx accrescent (versus calyx non-accrescent). The description of this new species further highlights the value of citizen science and by giving it the specific epithet 'outrampsii', we honour an incredible group of citizen scientists, namely the Outramps CREW group.

Keywords: Psoraleeae, Fabaceae, *Otholobium,* new species, taxonomy.

Introduction

Otholobium C.H.Stirt. (Fabaceae: Psoraleeae) is a genus endemic to southern Africa and most diverse in the Greater Cape Floristic Region (GCFR), where over 69 species are known to occur (Manning & Goldblatt 2012; Stirton 1989). This paper describes a highly localised new species, *Otholobium outrampsii*, from the northern slopes of the Outeniqua Mountains in the Western Cape. It is a prostrate to semi-erect resprouting shrublet up to 20 cm tall with sparsely glandular, green hairy stems bearing semi-conduplicate, minutely glandular, softly pilose, narrowly elliptic to narrowly obovate leaflets with sparsely pilose margins. Inflorescences are terminal, pseudo-capitate and borne on short seasonal shoots and comprising 3–4 triplets of flowers. Fruiting calyces are accrescent.

Materials and methods

Permission to collect plant material in protected areas was provided by the Western Cape Nature Conservation Board (Permit: AAA 008-00222-0028). The morphological description was made based on herbarium specimens and fresh material collected in the field.

Results

1. Otholobium outrampsii C.H.Stirton & B.du Preez sp. nov., closely allied to *O. curtisiae* C.H.Stirt. & Muasya from which it differs in having green hairy stems with sparse, small, round, yellowish glands (versus purplish-green, hispid stems encrusted with prominent orange, urn-shaped pustules); semi-conduplicate, minutely glandular, pilose, narrowly elliptic to narrowly obovate leaflets, apex attenuate (versus flat, prominently glandular, glabrous, oblanceolate to oblong leaflets, apex apiculate); sessile pseudo-capitate 9–12-flowered terminal inflorescences borne on short seasonal shoots (versus capitate shortly pedunculate 3–6-flowered inflorescences borne in upper axils); flower triplets subtended by a flabellate bract (versus oblong bract); and accrescent calyx (versus non-accrescent calyx). TYPE: SOUTH AFRICA, **Western Cape**, lower northern slopes of Fouriesberg in Outeniqua Mountains, 3321DD, [33°48′20.002″S / 21°55′5.001″E, 530 masl], 13 Dec. 2013, *Viviers & Vlok 367* (holotype PRE!).

Prostrate to semi-erect shrublet 15–20 cm tall, resprouter. Stems 1 to many, branching along the prostrate stems, branches smooth, hairy when young, glabrous when older, flowering shoots clustered in the upper axils of the new season's growth, softly pilose, without urn-shaped pustules concentrated below leaves. Stipules 2.5–3.0 × 1.0 mm, persistent, appressed to recurving, subulate, hairy. Leaves digitately trifoliolate, inserted spirally, semi-erect, shortly petiolate; petioles 1.0–1.5 mm long, petiolule 0.4–0.5 mm long, hairy; leaflets 8–10 × 2.0–2.4 mm, the later produced leaflets slightly smaller and more densely hairy, rigid, semi-conduplicate, arching, narrowly elliptic to narrowly obovate, apex attenuate, base cuneate; terminal leaflet longer than laterals, symmetrical, laterals asymmetrical, glands sunken, scarcely visible with a 10× lens. Inflorescences pseudo-capitate in axils of short seasonal shoots, flowers in triplets, shorter than subtending leaves, comprising 3–4 triplets of flowers; each triplet subtended by a single 3 × 12 mm long, flabellate, oblong, multi-veined bract, narrowing towards the apex, caducous; peduncle absent. Flowers white, pedicel 2.8–3.0 mm long; each flower subtended by a narrowly lanceolate hairy bract up to 3.5 mm long. Calyx 5 mm long, accrescent; lobes subequal, vexillar teeth shortest, lanceolate, carinal tooth 2–3× wider, broadly lanceolate, dark green and strongly ribbed, with 3 prominent dark green veins, teeth sparsely glandular, densely white pilose along margins, hairs patent; tube 2 mm deep, pale green. Standard 6.5–7.2 × 5.5–6.0 mm, glabrous, broadly ovate, emarginate, white, nectar guide an arc of dark purple flecks near base of blade, appendages present on lower inner face, low, parallel and separate; claw short ± 0.5 mm long. Wing petals 5.5–6.0 × 1.8–2.2 mm, blade broadly cultrate, white, scarcely auriculate, petal sculpturing present, upper basal and upper central comprising low parallel trans-costal ridges; claw ± 2 mm long, ribbon-like. Keel 4.2–4.5 × 1.5–1.6 mm, white with a dark purple discolouration on almost half of inner face of blade; claw ± 2 mm long, ribbon-like; Androecium ± 3.8 mm long, vexillar stamen free and bent at base; anthers alternately basifixed and medi-fixed; small nectarial ring present. Pistil ± 3.5 mm long, glabrous, ovary ± 0.9 mm long, 1-ovulate, covered in a few recurved stalked glands; style ribbon-like, glabrous, entasis broadest before the point of flexure; stigma penicillate. Fruits and seeds unknown. Figures 1 and 2.

Etymology

The specific epithet *outrampsii* honours the members of the Outramps Group of the Custodians of Rare and Endangered Wildflowers (CREW) Programme, who have done much to champion the protection of the rare and threatened plants of the southern Cape, and who made a number of special trips to find flowering material of this rare species.

Diagnostic characters

Otholobium outrampsii is a post-fire resprouter and can be diagnosed by a combination of its prostrate to semi-erect spreading habit up to 20 cm tall, with scarcely pustulate, greyish hairy branches with persistent stipules, semi-conduplicate spreading minutely glandular, softly pilose, narrowly elliptic to narrowly obovate leaflets with an arching attenuate apex, asymmetrical lateral leaflets shorter than the terminal leaflet, leaflets glabrous except for sparsely softly pilose margins, glabrous when mature, and accrescent calyx with subequal lobes and large broadly lanceolate carinal lobe.

Distribution and habitat

Otholobium outrampsii is a rare and highly localised species known from the farm Paardebont, at the foot of Fouriesberg, west of the Robinson Pass on the northern side of the Outeniqua Mountains (Figure 3). This species occurs between the elevations of 430 and 550 m asl. The vegetation at this location is North Outeniqua Sandstone Fynbos (FFs18) as described by Mucina and Rutherford (2006). It favours dry, rocky and well-drained sandy soil derived from Table Mountain Sandstone in full sun on a southwest facing slope. Flowering only occurs after fire from late September to November.

Conservation status

Otholobium outrampsii is known only from a single location in the Outeniqua Mountains. The population size is estimated to be roughly 100 mature individuals. This species is threatened by the presence and spread of *Hakea sericea* Schrad. & J.C.Wendl in and around the area from which this species is known. There is a potential threat from *Acacia mearnsii* De Wild. which is infesting the valley below. As the area is generally poorly explored and, given that the plants are small and inconspicuous when not in flower and only flower in the first year after fire, it is likely that other populations may be present on the surrounding hillslopes.

Figure 1. *Otholobium outrampsii*. A, habit of plant, 1/10th life size; B, fruiting shoot showing accrescent calyces, 10×; C, upper surface of terminal leaflet, 10×; D, lower surface of old leaflet, 8×; E, transverse section of leaflet, 20×; F, calyx opened out, outer face, 7.5×; G, side view of calyx, 8×. [*Viviers & Vlok 367* (PRE)]. Artist Charles Stirton.

Figure 2. *Otholobium outrampsii*. A, flower front view; B, flower side view; C, flower ventral view; D, seasonal leaf adaxial surface; E, whole plant in habitat; F, flowering shoot. Photographs: B. du Preez.

Based on available data from surveys by members of the Outramps Group of CREW, a Red Data List status of Critically Endangered is recommended for *O. outrampsii* according to the IUCN categories and criteria (IUCN 2012).

Additional specimens examined

SOUTH AFRICA. **Western Cape**: 3 km south of Paardebont Farm, [33°48′22.5″S / 21°55′6.527″E, 530 masl], 06 Nov. 2013, *Outramps s.n.* (BOL); Lower northern slopes of Fouriesberg in Outeniqua Mountains, [33°48′22.5″S / 21°55′6.527″E, 530 masl], 23 Sept. 2019, *B. du Preez 744* (BOL).

Acknowledgements

We wish to thank Jan Vlok and Mike Viviers, who first drew the first author's attention in 2013 to some sterile specimens they thought might be a new species. However, it was through the efforts of the Outramps CREW Group and the second author who eventually rediscovered the locality and collected flowering material that confirmed it as new. We wish to thank Abubakar Bello for helping in the making of our map figure. We also wish to thank Mr Cornel Fourie from the farm Paardebont for granting permission to access his property to visit the *O. outrampsii* population. We thank the two anonymous reviewers for their constructive comments.

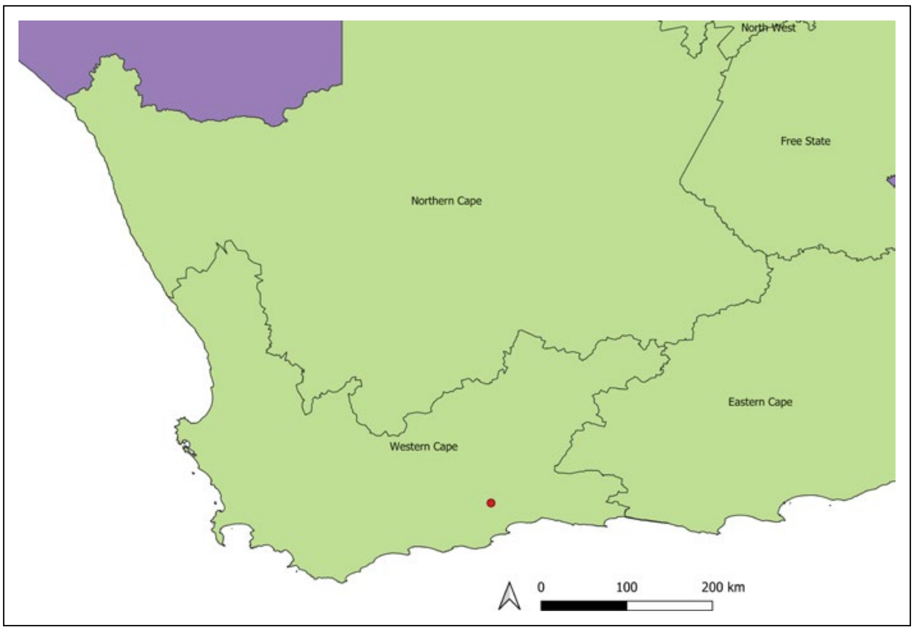

Figure 3. Known distribution of the endemic species *Otholobium outrampsii* in South Africa.

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BOTHALIA – African Biodiversity & Conservation
ISSN: (Online) 2311-9284, (Print) 0006-8241

New records of alien and potentially invasive grass (Poaceae) species for southern Africa

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Dates

Submitted: 3 July 2020
Accepted: 5 November 2020
Published: 8 July 2021

How to cite this article:

Sylvester, S.P., Soreng, R.J., Sylvester, M.D.P.V., Mapaura, A. & Clark, V.R., 2021, 'New records of alien and potentially invasive grass (Poaceae) species for southern Africa', *Bothalia* 51(2), a1. http://dx.doi.org/10.38201/btha.abc.v51.i2.1

Background: The grasses (Poaceae) of the Flora of Southern Africa (FSA) region (i.e. Botswana, Eswatini, Lesotho, Namibia and South Africa) are relatively well documented, for both native and non-native species. Visiting taxonomic expertise nevertheless reveals new FSA and in-country records, particularly of non-native species. Such records provide an opportunity for improving biosecurity relating to potentially invasive but hitherto undetected non-native Poaceae in the FSA region.

Objectives: To improve floristic data for non-native Poaceae occurring in the FSA region.

Method: Field collections were made, herbarium collections, databases and relevant literature were studied.

Results: New records are presented for non-native grasses that were encountered as locally common populations in the Drakensberg Mountain Centre of Floristic Endemism (DMC, Lesotho and South Africa). *Festuca rubra* and *Agrostis capillaris* are newly reported for sub-Saharan Africa and southern Africa and are also the first verified specimens reported for the African continent, with previous reports from northern-most Africa (Morocco, Algeria and/or Tunisia) uncertain. *Jarava plumosa*, introduced from South America and previously known for the whole of Africa from a single population in the Western Cape of South Africa, is newly reported from the border between the Eastern Cape, South Africa and Lesotho. The ecological implications, including the potential to become invasive, are discussed for each species, with taxonomic notes given to help differentiate them from closely resembling taxa.

Conclusion: These new records of alien grass species raise concerns over their potential ecological impact, particularly as they are found in an area of conservation importance, the DMC. Future efforts to monitor their distribution are of utmost importance.

Keywords: exotic grasses; non-native grasses; Gramineae; Drakensberg Mountain Centre of Floristic Endemism; Lesotho; South Africa

Introduction

The grass family Poaceae is relatively well-documented for the Flora of Southern Africa (FSA) region (comprising Botswana, Eswatini, Lesotho, Namibia and South Africa), with old and recent country-level treatments (e.g. Gibbs Russell et al. 1990; Fish et al. 2015) that incorporated efforts of numerous researchers who focused on different individual genera (Fish et al. 2015, see references therein), as well as more recent treatments of individual genera e.g. *Anthoxanthum* L. (Mashau 2016); *Festuca* L. (Sylvester et al. 2020a); *Poa* L. (Soreng et al. 2020).

In many countries, grasses have become the most damaging of invasive plants (D'Antonio & Vitousek 1992; D'Antonio et al. 2011; Gaertner et al. 2014), with knowledge of the distribution and ecology of these non-native grasses crucial for effective habitat management (e.g. Gaertner et al. 2014; Visser et al. 2017; Monnet et al. 2020). Visser et al. (2017) notes that there is much uncertainty regarding the identity, numbers of species, distributions, abundances and impacts of alien grasses in the FSA region, with only 37 of the known 256 non-native species in the region considered to be invasive. Despite this lag in non-native Poaceae knowledge, South Africa has some of the most progressive invasive species legislation in the world, including for known invasive Poaceae: 18 species are listed in the National Environmental Management: Biodiversity Act's Alien and Invasive Species Lists (2016).

Even less known is the impact of invasive or alien grasses in the high-elevation Drakensberg Mountain Centre of Floristic Diversity and Endemism (DMC) of southern Africa (Carbutt 2019). The DMC, covering some 40 000 km^2, contains the only true alpine region in Africa south of Mount Kilimanjaro (Carbutt 2019). These high-elevation Afromontane and alpine areas are renowned for their high levels of plant diversity and endemism, with the DMC hosting ± 2 520 angiosperm species (Carbutt & Edwards 2004) of which 227 are endemic (Carbutt & Edwards 2006; Carbutt 2019). This high importance for biodiversity is matched by the socio-ecological importance of these ecosystems, with a significant rangeland-based agrarian community relying on the DMC for their livelihoods (subsistence-based livestock herding being the dominant land-use). Any potential threat to this, such as that posed by potentially invasive alien plants, should be taken very seriously.

During extensive field collecting and ecological research by the authors in the DMC area, new records of alien grass species were discovered that add a further three species to the known flora of the DMC (Carbutt & Edwards 2004, 2006; Carbutt 2019), and raise concerns over their potential ecological impact.

Materials and Methods

The new records were collected during extensive fieldwork conducted by SPS, RJS, MDPVS and AM in the DMC between 1 Feb. and 9 Mar. 2020, with specimens deposited in the PRE, NU and US [exported, awaiting accession] herbaria (Herbarium acronyms follow Thiers [continuously updated]). Herbarium study was also conducted at PRE between 13 and 20 Mar. 2020.

Ethical considerations: Permits

Collecting permits were kindly granted by the Eastern Cape Department of Economic Development, Environmental Affairs and Tourism (DEDEAT), Ezemvelo KZN Wildlife (EKNZW), and the Lesotho Ministry of Tourism, Environment and Culture – Department of Environment.

Taxonomic Treatment

Agrostis capillaris *L.*, Sp. Pl. 1: 62 (1753). *Agrostis polymorpha* var. *capillaris* (L.) Huds., Fl. Angl. 1: 31 (1778). *Trichodium capillaris* (L.) Roth, Nov. Pl. Sp. 41 (1821). Type: [Habitat in Europae pratis], *Herb. A. van Royen s.n.* (lectotype, designated by Widén 1971: 65: L0052645 left-hand specimen [image!]; isolectotype: L [not seen]) (Figures 1, 2).

= *Agrostis tenuis* Sibth., Fl. Oxon. 36 (1794). *Agrostis capillaris* Huds., Fl. Angl.: 27 (1762), hom. illeg., non L., 1753. Type: ENGLAND (not located).

Many other heterotypic synonyms (POWO 2020).

Distribution: Of Eurasian origin; introduced into many other temperate areas of the World (POWO 2020, and references therein). This is the first report of the species for sub-Saharan Africa and the FSA region; it may also be the first verified specimen from the African continent, as it is noted with '?' for Morocco and Tunisia by Dobignard and Chatelain (2010: 213) (Figure 2).

New record: SOUTH AFRICA. **Eastern Cape**: Tiffindell Ski Area, on path to Ben Macdhui summit, S30.6516648 E27.92767, 2745 m alt., side of dirt road through alpine grassland (specifically, Mucina and Rutherford 2006's Lesotho Highland Basalt Grassland vegetation unit in the Grassland Biome), 10 Feb. 2020, *S.P. Sylvester et al. 3451* (NU, PRE, US).

Common vernacular names: bent grass (USA); brown top (UK, USA); colonial bent (USA); common bent (UK).

Notes: *Agrostis capillaris* is generally not considered invasive in the areas where it has been introduced and naturalised, and is not included in the IUCN Global Invasive Species Database (http://www.iucngisd.org/gisd/). Nevertheless, given the current perceived fragility of the alpine sub-centre of the DMC (Global Mechanism of the UNCCD 2018, 2019; Bentley et al. 2019; Carbutt 2019), the demographics and spatial extent of this species should be examined, and its behavior closely monitored (by e.g. the South African National Biodiversity Institute's (SANBI) Invasive Species Programme). The species was found to be locally frequent and occurs alongside *Festuca rubra*, also detailed in this paper, and may have been sown as a lawn mix by the Tiffindell Ski Resort to ensure adequate cover of their ski slopes. Other native species such as *Lachnagrostis barbuligera* (Stapf) Rugulo & A.M.Molina or *Poa binata* Nees, which were found in the vicinity, and are just as capable of forming a close sward, should rather be

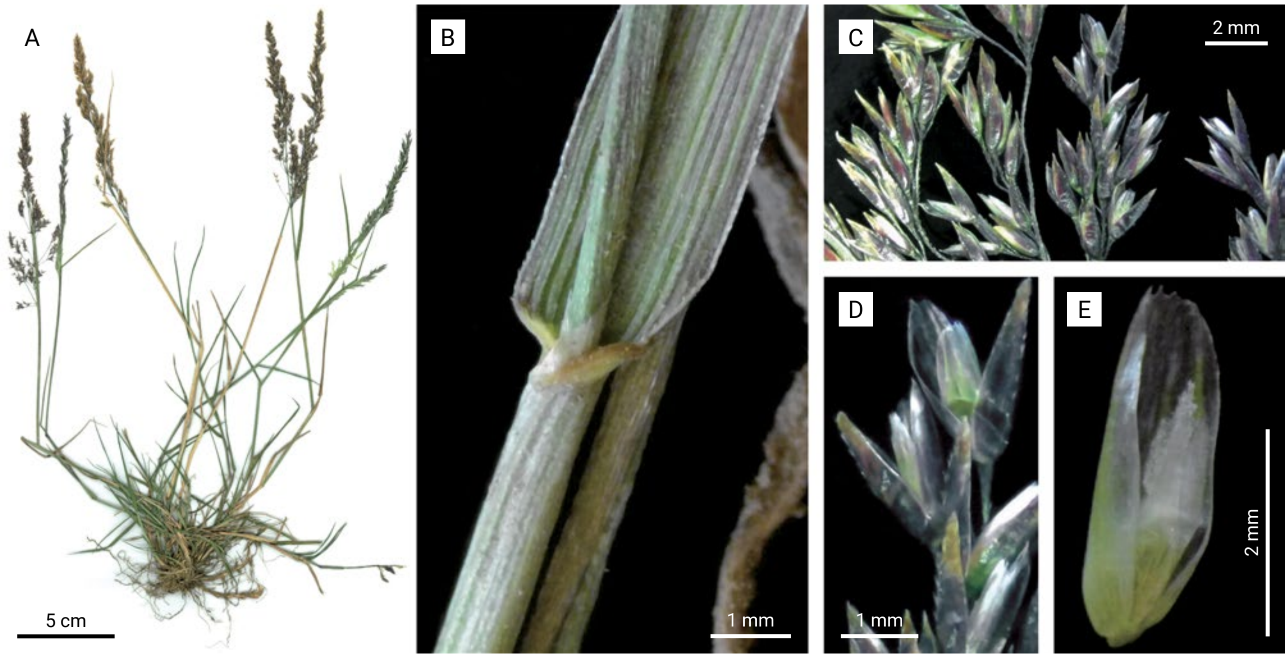

Figure1. *Agrostis capillaris*; A, whole plant; B, junction of sheath and blade of a tiller [sheath should be expanded to see clearly that the ligule is shorter than broad]; C, inflorescence close-up; D, spikelets, lateral view; E, floret, ventral view, showing the well-developed palea. Image A of *S.P. Sylvester et al. 3451* (US), B–E of *S.P. Sylvester et al. 3451* (PRE).

used in seeding projects as opposed to these non-native species.

Similar species: *Agrostis gigantea* Roth, an alien species now naturalised in the FSA region (Fish et al. 2015), is closely related and similar in terms of: plants always with extensively creeping rhizomes, usually without stolons; leaf blades generally flat (*A. capillaris* often with basal blades involute and culm blades flat); panicles open or only partially contracted after flowering, generally > 5 cm long (sometimes as short as 3 cm in *A. capillaris*); primary panicle branches without branchlets at least in the proximal half; floret notably shorter than the glumes, usually $\frac{1}{3}$–$\frac{3}{4}$ the length of the glumes, without a rachilla prolongation; paleas reaching ($\frac{2}{5}$–)$\frac{2}{3}$–$\frac{3}{4}$ the length of the lemma; lemmas muticous or with an awn of varying length, ranging from a short straight awn, 0.2–1.0 mm long, to a long geniculate and twisted awn to 4 mm long, inserted basally, medially or in the upper half of the lemma, not surpassing or greatly surpassing the glumes.

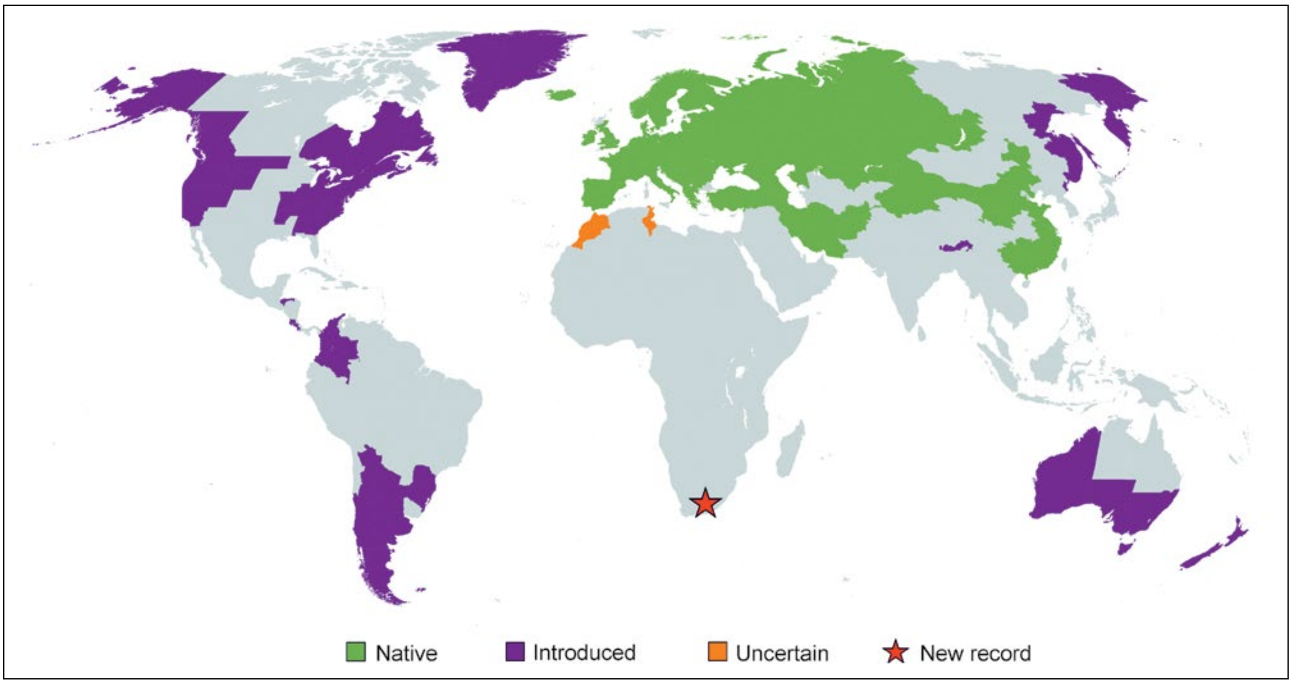

Figure 2. *Agrostis capillaris* global distribution map, with country- or regional-level shading, taken and modified from POWO (2020).

Agrostis capillaris is primarily differentiated from *A. gigantea* by the ligule of the tiller leaves being distinctly shorter than wide [sheath should be expanded to be able to see this clearly] and ≤ 1 mm long (Figure 1B) (vs. as long as or distinctly longer than wide, 1–3 mm long in *A. gigantea*), ligules of culm leaves 0.5–1.5(–2.9) mm long, shorter to sometimes longer than wide (vs. 2–8 mm long, as long as or distinctly longer than wide in *A. gigantea*). *Agrostis capillaris* can also usually be readily distinguished from *A. gigantea* by its shorter size, culms being 10−75(−90) cm tall, and thinner blades of culm leaves (0.6−)1.0−4.0(−5.0) mm wide as opened out which are sometimes inrolled (Figure 1) (vs. culms 40−100(−120) cm tall, blades of culm leaves (2−)3−8 mm wide, always flat in *A. gigantea*) although there are smaller variants of *A. gigantea* with thinner leaves which can superficially resemble *A. capillaris*. In these cases of ambiguity, the ligule will always settle the identity (also see notes and key in Sylvester et al. 2020b).

Agrostis stolonifera L., a species not known from southern Africa, but which is native in temperate Eurasia and northern Africa reaching as far south as Chad, and which is widely introduced elsewhere (POWO 2020, and references therein), also bears similarities to *A. capillaris*. *Agrostis stolonifera* is primarily differentiated from *A. capillaris* by the ligule of tillers 1–3 mm long and culm leaves 2.0–6.5 mm long, always distinctly longer than broad. The habit also differs, with *A. stolonifera* usually extensively stoloniferous with stolons 5–100(–200) cm long [these often not collected as part of herbarium specimens], rhizomes usually absent (vs. extensively rhizomatous, sometimes also stoloniferous, in *A. capillaris*). Cope and Gray (2009) and Harvey (2007) differentiate *A. stolonifera* from *A. capillaris* and *A. gigantea* mainly based on panicle characteristics, e.g. Cope and Gray (2009) state *A. stolonifera* has primary panicle branches often bearing branchlets more-or-less from the extreme base but sometimes bare in the lower ¼–⅓, panicle tightly closed after flowering (vs. primary panicle branches bare of branchlets at least in the lower half, panicle open or only partially contracted after flowering in *A. capillaris* and *A. gigantea*). However, in the case of *A. capillaris*, panicle contraction after flowering is seen as a somewhat ambiguous differentiating character as it can vary from contracted to open both before and after anthesis. Thus, the form of the ligule is found to be a much more reliable distinguishing character for differentiating these species (also see updated description and key in Sylvester et al. 2020b).

Festuca rubra *L.*, Sp. Pl. 1: 74 (1753). *Festuca ovina* var. *rubra* (L.) Sm., Engl. Fl. 1: 139 (1824). *Festuca duriuscula* var. *rubra* (L.) Alph. Wood, Amer. Bot. Fl. 2: 399 (1871), nom. illeg. hom. Type: SWEDEN [Hab. in Europa sterilibus siccis]. In paludosis prati regii Upsalia, sin coll. s.n. (lectotype, designated by Jarvis et al. 1987: 301: GB [not seen]) (Figures 3, 4).

Many heterotypic synonyms (POWO 2020).

Distribution: Native range is sub-arctic and temperate Northern Hemisphere (Figure 4). The native range of *F. rubra* s.l. is noted to extend into northern Africa by POWO (2020), although the subspecies or varieties of *F. rubra* described from high-elevation Morocco and Algeria have been re-assigned to other species of *Festuca* (Dobignard 2010). Thus, it is unclear whether *F. rubra* occurs naturally, or has been introduced, in northern Africa: Dobignard and Chatelain (2010: 296) note '?' for Morocco and the Madeira islands. Our collection from South Africa is therefore possibly the first verified specimen from the African continent. It does, however, occur on sub-Antarctic Marion Island (one of South Africa's two islands in the Prince Edward Islands group), where it is recorded as a major invasive species (Greve et al. 2017). *Festuca rubra* has also been introduced to Australia, New Zealand, and South and Central America (POWO 2020, and references therein) where it has become naturalised, but is not considered invasive.

New record: SOUTH AFRICA. **Eastern Cape**: Tiffindell Ski Area, next to ski lift, S30.650718 E27.925683, 2781 m alt., alpine grassland (specifically, Mucina and Rutherford 2006's Lesotho Highland Basalt Grassland vegetation unit in the Grassland Biome), annually burnt, appears to be seeded with alien species, 11 Feb. 2020, *S.P. Sylvester et al. 3455* (NU, PRE, US).

Common vernacular names: red fescue (Canada, UK, USA); strong creeping red fescue (UK).

Notes: *Festuca rubra* is generally not considered invasive in the areas where it has been introduced and naturalised (except for Marion Island), and is not included in the IUCN Global Invasive Species Database (http://www.iucngisd.org/gisd/). It was found to be locally common and is likely to have been sown in a seed mixture for maintenance of the Tiffindell ski slopes, which has subsequently spread into nearby alpine grassland (see notes under *Agrostis capillaris* above).

Traditional circumscription of infraspecific taxa within *F. rubra* has been brought into question (Saikkonen et al. 2019); although our specimen keys fairly solidly to *F. rubra* subsp. *rubra* in the treatments by Hubbard (1984), Cope and Gray (2009), and Darbyshire and Pavlickf (2007), we prefer to present the new record at the species rank here.

Similar species: *Festuca rubra* is quite distinct and differs from other *Festuca* s.l. taxa in the FSA region by having the combination of: rhizomes present, very slender, extensively creeping, tillers extravaginal, with cataphylls present (Figure 3B) (vs. extensive creeping rhizomes absent, tillers intravaginal, cataphylls absent in *F. africana* (Hack.) Clayton [= *Pseudobromus silvaticus* K. Schum.], *F. arundinacea* Schreb. [= *Lolium*

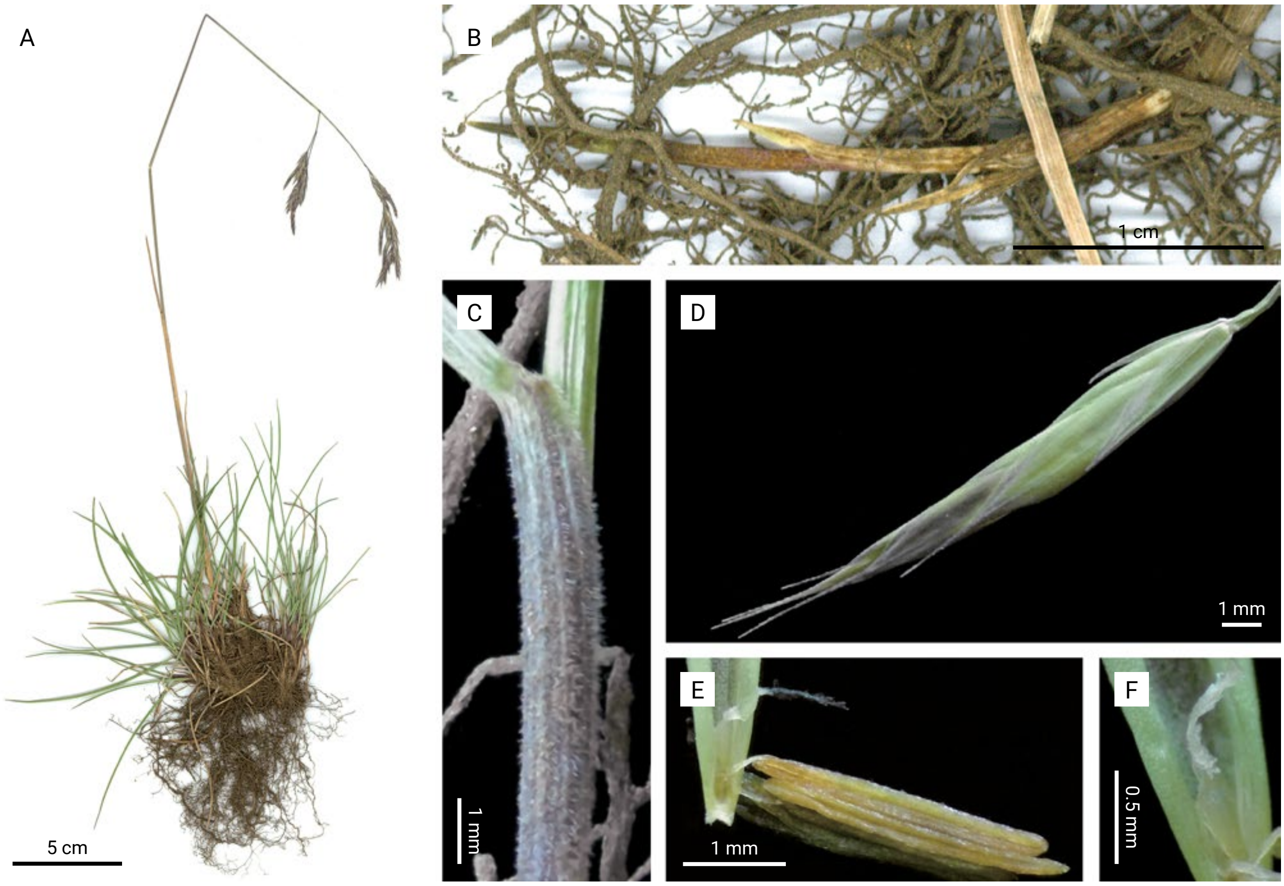

Figure 3. *Festuca rubra*; A, whole plant; B, lateral-tending rhizome covered in cataphylls; C, leaf sheath and junction with blade of a tiller showing strigose hairs; D, spikelet; E, base of palea with lemma removed to reveal the ovary and stamens; F, close-up of glabrous ovary apex. Images A and B of *S.P. Sylvester et al. 3455* (US), C–F of *S.P. Sylvester et al. 3455* (PRE).

arundinaceum (Schreb.) Darbysh.], *F. caprina* Nees, *F. costata* Nees, *F. killickii* Kenn.-O'Byrne, *F. vulpioides* Steud.); basal sheaths entire or splitting into narrow parallel threads (vs. coarsely fibrous in *F. costata*), usually strigose-hairy (Figure 3C), rarely glabrous (vs. glabrous or scabrous in most; white velvet-hairy in *F. scabra* Vahl); ligules 0.1–0.5 mm long (vs. > 1 mm long in most apart from *F. caprina, F. dracomontana* H.P.Linder,

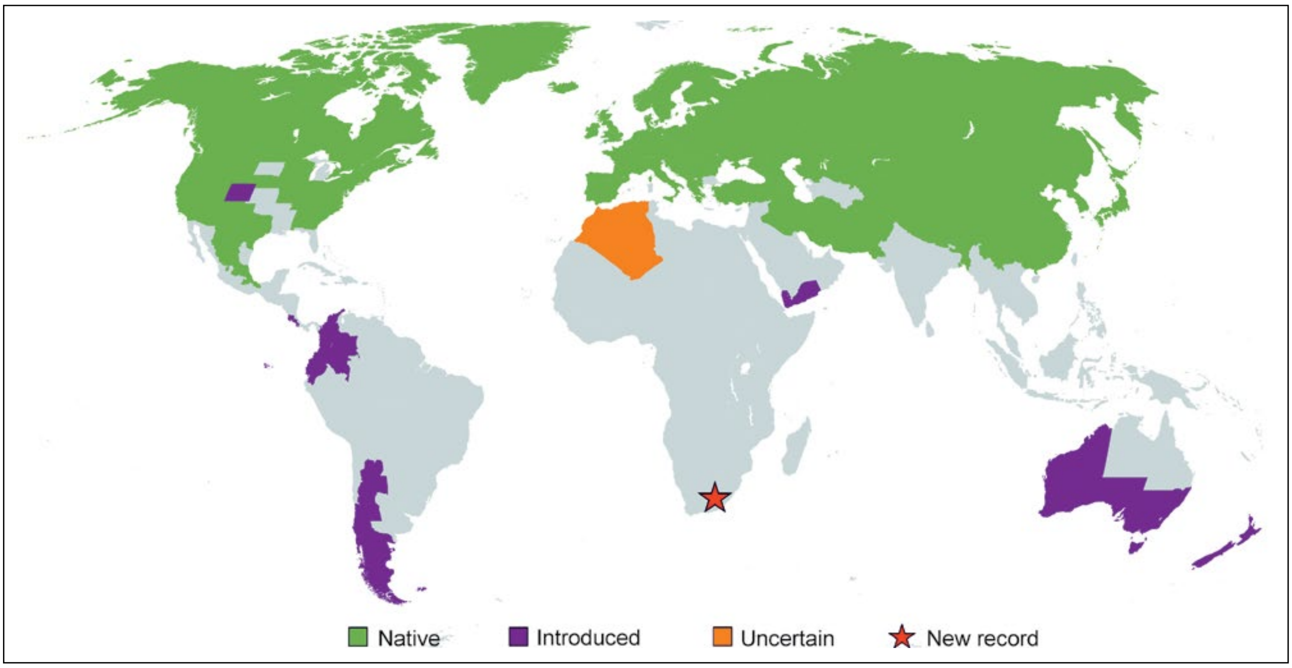

Figure 4. *Festuca rubra* global distribution map, with country- or regional-level shading, taken and modified from POWO (2020).

F. drakensbergensis Sylvester, Soreng & M.D.P.V. Sylvester [Sylvester et al. 2020a], *F. exaristata* E.B. Alexeev, *F. vulpioides*); collars non-auriculate (vs. auriculate in *F. arundinacea* [= *Lolium arundinaceum*], *F. dracomontana*, *F. vulpioides*); blades narrow, conduplicate or rolled, 0.3–1.5(–2.5) mm wide in diameter (vs. flat or relatively broad, [2–]3–15 mm wide in diameter in most [rarely narrower in *F. scabra*] apart from *F. caprina*, *F. drakensbergensis*, *F. exaristata*); panicles open or contracted (vs. very open, candelabrum-shaped, in *F. longipes* Stapf, open or contracted in other taxa); spikelets 3- to 10-flowered (vs. 1-flowered in *F. africana* [= *Pseudobromus silvaticus*]; sometimes 2-flowered in other taxa); awns (0.1–)0.4–4.5 mm long (Figure 3D) (vs. 10–20 mm long in *F. africana*); anthers 1.8–4.5 mm long (Figure 3E) (vs. 0.8–1.8 mm long in *F. drakensbergensis*, *F. exaristata*, and rarely *F. killickii*); ovary apex glabrous (Figure 3F) (vs. hairy in most taxa apart from *F. exaristata*, *F. arundinacea* [= *Lolium arundinaceum*]; incompletely known in *F. africana* [= *Pseudobromus silvaticus*]).

Jarava plumosa (Spreng.) S.W.L.Jacobs & J.Everett, Telopea 7(3): 301 (1997). *Calamagrostis plumosa* Spreng., Syst. Veg., ed. 16 [Sprengel] 1: 253 (1824). *Arundo plumosa* (Spreng.) Schult., Mant. 3 (Schultes & Schultes f.) 604 (1827). *Stipa papposa* Nees, Fl. Bras. Enum. Pl. 2(1): 377 (1829). *Stipa papposa* Delile, Ind. Sem. Hort. Monsp. 7 (1849). *Stipa delilei* Steud., Syn. Pl. Glumac. 1(2): 126 (1854). *Achnatherum papposum* (Nees) Barkworth, Phytologia 74(1): 11 (1993). Type: [URUGUAY] MONTEVIDEO. *F. Sellow s.n.* (holotype: B [not seen]; isotypes: US00141669 [image!]) ex herb. Berol., HAL0106794 [image!] ex herb. Berol.) (Figures 5, 6).

= *Stipa tenuiflora* Phil., Linnaea 33(3-4): 281. 1864. Type: CHILE. Prov. Colchagua: prope Llico, Dec. 1861, *L. Landbeck s.n.* (holotype: not located; isotypes: BAA00002961 [image!], SGO000000750 [image!]).

= *Stipa papposa* fo. *major* Speg., Anales Mus. Nac. Montevideo 100. 1901. Type: not designated.

= *Stipa papposa* fo. *minor* Speg., Anales Mus. Nac. Montevideo 100. 1901. Type: not designated.

Distribution: For the entire African continent, *J. plumosa* was previously known from a single population on the University of Cape Town (UCT) campus collected in 1963 and 1980 (Gibbs Russell et al. 1990; Fish et al. 2015). Our collection in the Eastern Cape extends the species range c. 950 km eastward. It is also feasible to say that the species has likely established in adjacent Lesotho, which was less than 100 m away on the opposite bank of the Telle River. *Jarava plumosa* has its native range in austral South America, covering central and eastern Argentina, Chile, Uruguay, to as far north

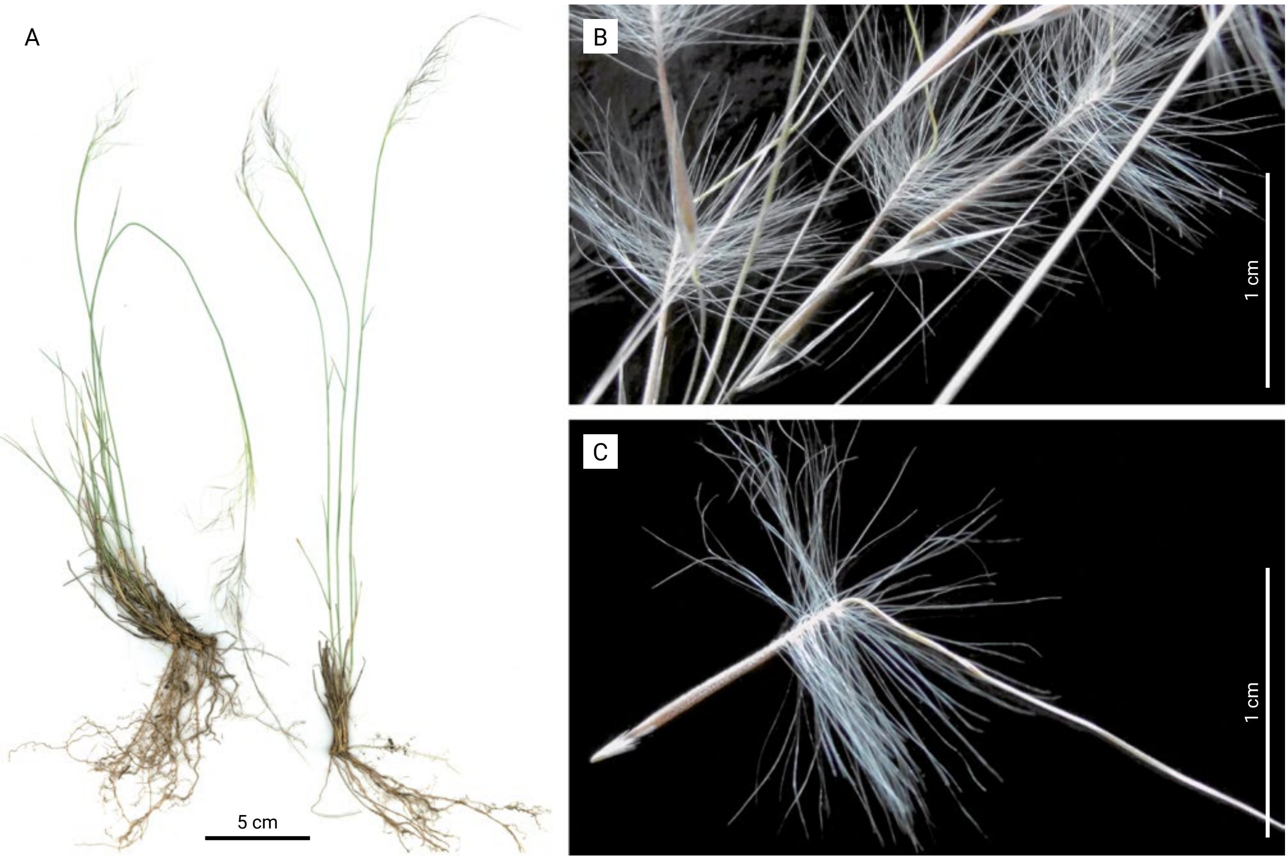

Figure 5. *Jarava plumosa*; A, whole plant; B, inflorescence close-up; C, floret. Image A of *R.J. Soreng et al. ZA-30* (US), B and C of *R.J. Soreng et al. ZA-30* (PRE).

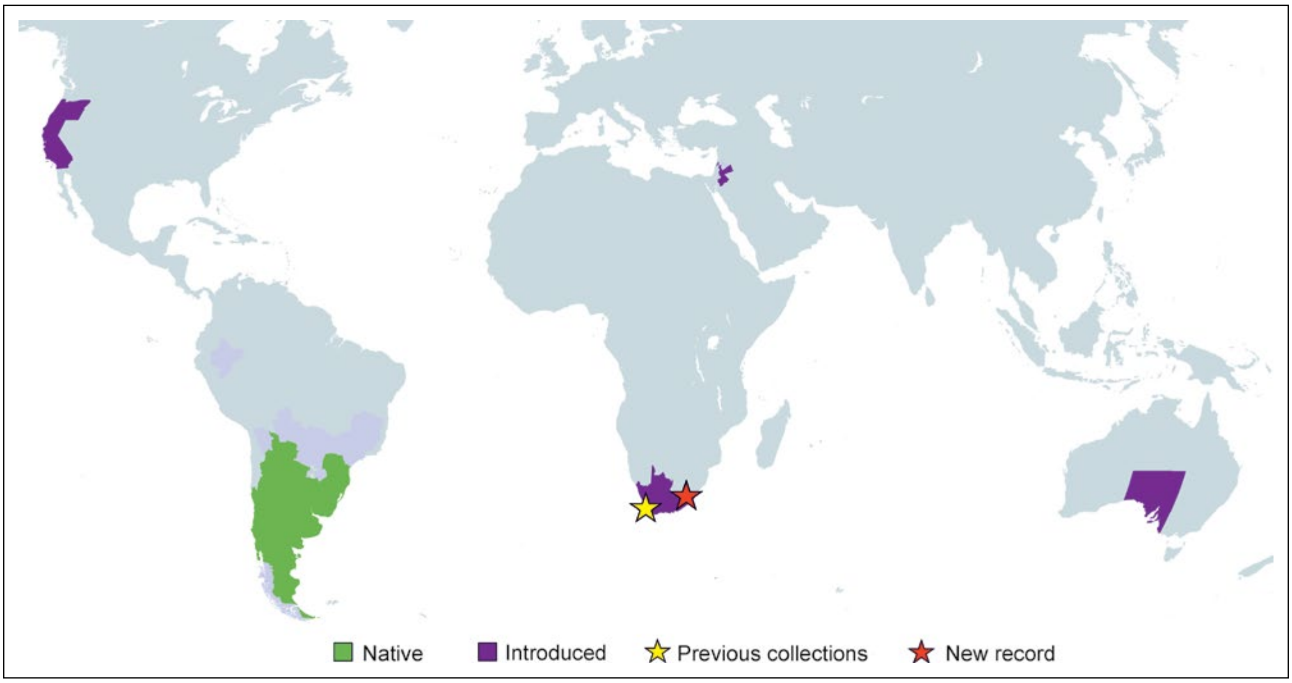

Figure 6. *Jarava plumosa* global distribution map, with country- or regional-level shading, taken and modified from POWO (2020).

as southern Brazil (Zuloaga et al. 2008; Longhi-Wagner 2015; Figure 6). The species has also been documented as becoming naturalised in Adelaide, Australia (Gardner et al. 1996; Wilson 2009), as well as California, USA (Arriaga 2007), and Palestine (Danin 2004).

New record: SOUTH AFRICA. **Eastern Cape**: by Telle river on road to Lundeans Nek, near village of Bebeza [or 'Emqheyen' in https://earth.google.com/], S30.518347 E27.649831, 1460 m alt., under *Eucalyptus* trees by roadside, 9 Feb. 2020, *R.J. Soreng et al. ZA-30* (NU, PRE, US, QWA).

Common vernacular names: *flechilla mansa*, *flechilla* (Argentina).

Notes: Gardner et al. (1996) noted the vigorous nature of *Jarava plumosa* and how, despite efforts to remove the plant since as far back as 1968, it continued to establish at the Botanic Gardens of Adelaide and was subsequently found in the South Parklands bordering Adelaide. The first record of *J. plumosa* outside of its natural range comes from South Africa, from collections made in the UCT campus in 1963 and 1980 (Gibbs Russell et al. 1990). Our discovery of an abundant population of *J. plumosa* by the side of the Telle River, Eastern Cape, South Africa, points to the likelihood that this species has a wider distribution than previously realised, and has been overlooked. The species exhibits certain traits pointing to its potential to become invasive, such as the apical pappus highly adapted to anemochory, and long awns that easily attach to clothing, fur etc. to aid in zoochory. Closely related species in the genera *Nassella* (Trin.) É.Desv. and *Stipa* L. exhibit similar traits, and have successfully become naturalised in many parts of the world, with a few – e.g. *Nassella neesiana* (Trin. & Rupr.) Barkworth, *N. tenuissima* (Trin.) Barkworth, *N. trichotoma* (Nees) Hack. & Arechav – that are known invasives causing ecological havoc in many parts of the world, including South Africa (Visser et al. 2017; Mapaura et al. 2020; IUCN Global Invasive Species Database, http://www.iucngisd.org/).

Similar species: In southern Africa, *J. plumosa* could be mistaken for *Stipagrostis anomala* De Winter, which also has a pappus-like plume of long hairs, 4–8 mm long, emerging from the apex of the lemma and/or lower part of the awn. *Jarava plumosa* can be differentiated from *S. anomala* by the pappus-like hairs being found on the apex of the lemma and base of the awn (vs. hairs restricted to just base of awn in *S. anomala*), callus being obtuse (vs. pungent), and a perennial habit (vs. annual) (Figure 5B–C).

Conclusions

Three new non-native grass species are added to the flora of the DMC and the FSA: two (*Agrostis capillaris* and *Festuca rubra*) in the alpine sub-centre, and one (*Jarava plumosa*) in the montane sub-centre. Although still apparently highly localised, the unique alpine habitat in southern Africa – with the closest ecological comparison in South Africa and FSA being the Prince Edward Islands – suggests that *F. rubra* in particular could become a species of concern, and should be monitored with the intention of eradication while still localised. Similarly, the presence of the potentially highly invasive species *J .plumosa* in the highly degraded and stressed xeric rain-shadow region of Telle Bridge requires further population assessment to determine abundance and distribution. All three of these grasses should be looked out for across the DMC for additional undetected populations.

Acknowledgements

We wish to gratefully thank Nanjing Forestry University, China, and the Afromontane Research Unit (University of the Free State, South Africa) for financial and logistical support; Caroline Mashau, Lyn Fish, and PRE staff for access to the PRE herbarium, discussions of taxa, and supplying collecting paper; and Ralph and Nadine Clark for providing an operations base in South Africa (including during lockdown). We also wish to extend grateful thanks to the permitting authorities and landowners for the relevant permits and permissions to undertake the fieldwork: Ezemvelo KZN Wildlife (uKhahlamba-Drakensberg Park & UNESCO World Heritage Site), Eastern Cape Parks & Tourism Authority, Eastern Cape Department of Economic Development, Environmental Affairs & Tourism, the Kingdom of Lesotho Department of Environment, and Witsieshoek Mountain Lodge/Batlokwa Tribal Authority.

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SANBI
Biodiversity for Life
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BOTHALIA – African Biodiversity & Conservation
ISSN: (Online) 2311-9284, (Print) 0006-8241

The correct author citation for taxa in *Strumaria* and changes to subgenera in *Strumaria* and *Hessea* (Amaryllidaceae: Amaryllideae), with a synopsis of the actinomorphic-flowered genera of subtribe Strumariinae

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Dates

Submitted: 25 August 2020
Accepted: 17 August 2021
Published: 10 September 2021

How to cite this article:

Snijman, D.A. & Manning, J.C., 2021, 'The correct author citation for taxa in *Strumaria* and changes to subgenera in *Strumaria* and *Hessea* (Amaryllidaceae: Amaryllidaceae), with a synopsis of the actinomorphic-flowered genera of subtribe Strumaria', *Bothalia* 51(2), a9. http://dx.doi.org/10.38201/btha.abc.v51.i2.9

Aspects of the nomenclature and classification of the subtribe Strumariinae are corrected and emended as follows: *Hessea* subgenus *Myophila* (Snijman) Snijman and *Strumaria* subgenus *Carpolyza* (Salisb.) Snijman are described, and *Strumaria* section *Gemmaria* (Salisb.) Snijman is validated; the correct author citations for several names in *Strumaria* that were invalidly published by Jacquin are established; and a complete infrageneric synopsis for the actinomorphic-flowered taxa of subtribe Strumariinae is provided.

Keywords: Africa; classification; Jacquin; new taxa; nomenclature; taxonomy; Willdenow.

Introduction

The predominantly African tribe Amaryllideae (Amaryllidaceae) includes four subtribes, of which Strumariinae Traub ex D.Müll.-Doblies & U.Müll.-Doblies (Müller-Doblies & Müller-Doblies 1985) are endemic to southern Africa (Meerow & Snijman 2001). The complexity of relationships among the actinomorphic-flowered genera of Strumariinae is reflected in the differing taxonomic treatments of *Carpolyza* Salisb., *Hessea* Herb., *Namaquanula* D.Müll.-Doblies & U.Müll.-Doblies and *Strumaria* Jacq. ex Willd. sensu lat. by Müller-Doblies and Müller-Doblies (1985) and Snijman (1994), based largely on these authors' interpretation of the group's floral morphology. Arising from the more recent molecular phylogenetic studies of Weichhardt-Kulessa et al. (2000) and Meerow and Snijman (2001, 2006), further taxonomic changes were implemented in the group. The monotypic *Carpolyza* was subsumed under *Strumaria* (Meerow & Snijman 2001) and the genus *Namaquanula* was reinstated from its former rank as a subgenus in *Hessea* (Snijman 2005).

These changes necessitated a revision of the subgeneric classification of *Hessea* and *Strumaria* and the necessary adjustments are completed here. We recognise a new subgenus to accommodate *Carpolyza spiralis* (L'Hérit.) Salisb. within *Strumaria* and we validate the new section *Gemmaria* (Salisb.) Snijman within subgenus *Gemmaria* of *Strumaria*. We also formalise the change in rank of section *Myophila* Snijman to subgenus within *Hessea*. Further, we provide a synopsis of the current infrageneric classification for the actinomorphic-flowered Strumariinae, incorporating the taxonomic changes made since 1985 by Duncan and Voigt (2020), Weichhardt-Kulessa et al. (2000), Meerow and Snijman

(2001), Müller-Doblies and Müller-Doblies (1992), and Snijman (1999, 2005).

We also correct the author citations of some species in *Strumaria*. The name *Strumaria* was first published by Jacquin (1795) in his *Icones plantarum rariorum* for five species of Amaryllideae from southern Africa's winter-rainfall region. Although the individual species were described, no separate generic description or diagnosis was included, either then or later in his *Collectaneorum supplementum* (Jacquin 1797). This lack of a diagnosis for his new genus, which included more than a single species at the time, renders the generic name invalid (Turland et al., 2018: Art. 38.1, 38.5), and this in turn renders the names of the five species published by Jacquin under that genus also invalid (Turland et al., 2018: Art. 35.1). These names were all validated by Willdenow (1799) in the *Species plantatum*, fortunately without any change in their priority.

Nomenclature

Corrections to author names

Accepted names are in **bold** and synonyms in *italics*.

Strumaria *Jacq. ex Willd.*, Species plantarum 2: 31 (1799). Lectotype: *Strumaria truncata* Jacq. ex Willd., designated by Phillips, Genera of South Afrcan Flowering Plants, ed. 2: 201 (1951).

Strumaria angustifolia Jacq. ex Willd., Species plantarum 2: 32 (1799). [*Strumaria angustifolia* Jacq.: 13 (1795), Jacq.: 48 (1797), invalid name, without generic description]. Type: illustration in Jacq.: t. 359 (1795).

Note: This taxon is considered to be conspecific with **S. truncata** *Jacq. ex Willd*. (Snijman 1994).

Strumaria filifolia Jacq. ex Willd., Species plantarum 2: 32 (1799), nom. illeg. superfl. pro *Leucojum strumosum* Sol. ex Aiton (1789). [*Strumaria filifolia* Jacq.: 14 (1795), invalid name, without generic description]. Type: as for *Leucojum strumosum* Sol. ex Aiton.

Note: Although Snijman (1994) considered this to be a legitimate name and typified it against the illustration in Icones plantarum rariorum 2: t. 361 (Jacquin, 1795), Jacquin (1795) clearly stated that he was coining it as a preferred replacement name for *Leucojum strumosum* ["melius quam *Leucojum strumosum"*] with a direct reference to Aiton (1789), and it is therefore correctly treated as an illegtimate superfluous name for that taxon, with the same type. It is considered to be conspecific with **S. tenella** *(L.f.) Snijman* (Snijman 1994).

Strumaria linguifolia Jacq. ex Willd., Species plantarum 2: 31 (1799). [*Strumaria linguifolia* [as '*linguaefolia*'] Jacq.: 13 (1795), Jacq.: 45 (1797), invalid name, without generic description]. Type: illustration in Jacq.: t. 356 (1795).

Note: This taxon is considered to be conspecific with **S. truncata** *Jacq. ex Willd*. (Snijman 1994).

Strumaria rubella Jacq. ex Willd., Species plantarum 2: 31 (1799). [*Strumaria rubella* Jacq.: 13 (1795); Jacq.: 46 (1797), invalid name, without generic description]. Type: illustration in Jacq.: t. 358 (1795).

Note: This taxon is considered to be conspecific with **S. truncata** *Jacq. ex Willd*. (Snijman 1994).

Strumaria truncata *Jacq. ex Willd.*, Species plantarum 2: 31 (1799). [*Strumaria truncata* Jacq.: 13 (1795), Jacq.: 47 (1797), invalid name, without generic description]. Type: illustration in Jacq.: t. 357 (1795).

Strumaria undulata *Jacq. ex Willd.*, Species plantarum 2: 32 (1799). [*Strumaria undulata* Jacq.: 14 (1795), Jacq.: 50 (1797), invalid name, without generic description. Type: illustration in Jacq.: t. 360 (1795).

Note: The identity of this taxon is uncertain (Snijman 1994).

New subgenera and sections

Strumaria *Jacq. ex Willd.*, Species plantarum 2: 31 (1799).

Subgenus **Carpolyza** (*Salisb.) Snijman*, stat. nov. *Carpolyza* Salisb., Paradisus Londinensis 1: 63 (1807). Type: *Carpolyza spiralis* (L'Hérit.) Salisb. = *Strumaria spiralis* (L'Hérit.) Aiton

Section **Gemmaria** *(Salisb.) Snijman*, sect. nov. [*Strumaria* subg. *Gemmaria* sect. *Gemmaria*, invalid name without author, Snijman: 106 (1994)]. *Gemmaria* Salisb., The Genera of Plants: 127 (1866). Type: as for *Gemmaria* Salisb.

Hessea *Herb.*, Amaryllidaceae: 289 (1837).

Subgenus **Myophila** *(Snijman) Snijman*, stat. nov. *Hessea* subgenus *Namaquanula* section *Myophila* Snijman in Contributions from the Bolus Herbarium 16: 76 (1994). Type: *Hessea mathewsii* W.F.Barker

Synopsis of infrageneric taxa in Strumaria, Hessea and Namaquanula

Strumaria *Jacq. ex Willd.,* Species plantarum 2: 31 (1799). Lectotype: *Strumaria truncata* Jacq. ex Willd., designated by Phillips, Genera of South African Flowering Plants, ed. 2: 201 (1951).

Subgenus **Strumaria**

Bulb tunics parchment-like, whitish. *Cataphyll* present, sometimes exserted. *Foliage leaves* (2)3 or

4(6), erect, spreading laterally in a fan, lorate, glabrous, rarely sticky. *Scape* persisting beyond seed release. *Flowers* funnel-shaped, rarely hypocrateriform or campanulate, pedicels more-or-less as long as perianth, tepals free, filaments usually connate into a tube with outer whorl adnate to style, anthers dorsifixed, style 3-angled or -winged towards base, rarely uniformly swollen. *Chromosome base number x* = 10.

8 spp.: *S. barbarae* Oberm. [as '*barbariae*' Oberm.], *S. bidentata* Schinz, *S. hardyana* D.Müll.-Doblies & U.Müll.-Doblies, *S.luteoloba* Snijman, *S. phonolithica* Dinter, *S. prolifera* Snijman, *S. speciosa* Snijman, *S. truncata* Jacq. ex Willd.

Subgenus **Carpolyza** (*Salisb.) Snijman* [validated above]. *Carpolyza* Salisb.: 63 (1807). Type: *Carpolyza spiralis* (L'Hérit.) Salisb.

Bulb tunics thinly fibrous, whitish. *Cataphyll* absent. *Foliage leaves* 4 to 6, spreading, filiform, glabrous. *Scape* ± spirally twisted proximally, persisting beyond seed release. *Flowers* funnel-shaped, pedicels shorter to much longer than perianth, tepals connate into a short tube basally, filaments decurrent on perianth tube with inner whorl shortly adnate to style, anthers subcentrifixed, style somewhat 3-angled. *Chromosome base number x* = 10.

1 sp.: *S. spiralis* (L'Hérit.) Aiton

Subgenus **Tedingea** *(D.Müll.-Doblies & U.Müll.-Doblies) Snijman* in Contributions from the Bolus Herbarium 16: 86 (1994). *Tedingea* D.Müll.-Doblies & U.Müll.-Doblies: 45 (1985). Type: *S. tenella* (L.f.) Snijman

Bulb tunics softly fibrous, whitish. *Cataphyll* present or absent. *Foliage leaves* 2 to 6, spreading, filiform, glabrous. *Scape* often proximally flexed or spirally twisted, usually persisting during seed release. *Flowers* stellate, rarely somewhat campanulate, pedicels much exceeding perianth length, tepals free, filaments separate, both whorls adnate to swollen style base, anthers dorsifixed. *Chromosome base number x* = 10.

2 spp.: *S. pygmaea* Snijman, *S. tenella* (L.f.) Snijman subsp. *tenella*, *S. tenella* subsp. *orientalis* Snijman

Subgenus **Gemmaria** *(Salisb.) Snijman* in Contributions from the Bolus Herbarium 16: 105 (1994). *Gemmaria* Salisb.: 127 (1866). Type: *Gemmaria gemmata* (Ker Gawl.) Salisb. ex D.Müll.-Doblies & U.Müll.-Doblies = *S. gemmata* Ker-Gawl.

Bulb tunics parchment-like, whitish or yellowish. *Cataphyll* present or rarely absent. *Foliage leaves* 2(3), spreading to prostrate, lorate to elliptic, plane, more-or-less pubescent or pustulate, at least in juveniles. Scape mostly detaching basally at seed set. Flowers stellate to funnel-shaped, pedicels shorter or longer than perianth, tepals free, filaments separate, both whorls adnate to swollen style base, anthers subcentrifixed. *Chromosome base number x* = 10.

Note: The phylogenetic study of Meerow and Snijman (2001), using nrDNA ITS sequences and morphology, shows weak support for the currently recognised sections of subgenus *Gemmaria*. The results, however, are based on less than a third of the species of the subgenus. Accordingly, until a more complete analysis of the clade becomes available, we retain the sections recognised in Snijman (1994).

Section **Gemmaria** *(Salisb.) Snijman* [validated above]. *Gemmaria* Salisb.: 127 (1866). Type: as for subgenus.

Bulb tunics whitish or yellowish. *Cataphyll* present. *Foliage leaves* 2(3). *Flowers* stellate, pedicels at least twice as long as perianth, filaments attached to broad style base, style distinctly widest at base.

11 spp.: *S. argillicola* G.D.Duncan, *S. chaplinii* (W.F.Barker) Snijman, *S. discifera* Marloth ex Snijman subsp. *discifera*, *S. discifera* subsp. *bulbifera* Snijman, *S. gemmata* Ker Gawl., *S. karooica* (W.F.Barker) Snijman, *S. karoopoortensis* (D.Müll.-Doblies & U.Müll.-Doblies) Snijman, *S. leipoldtii* (L.Bolus) Snijman, *S. massoniella* (D.Müll.-Doblies & U.Müll.-Doblies) Snijman, *S. merxmuelleriana* (D.Müll.-Doblies & U.Müll.-Doblies) Snijman, *S. unguiculata* (W.F.Barker) Snijman, *S. villosa* Snijman

Section **Bokkeveldia** *(D.Müll.-Doblies & U.Müll.-Doblies) Snijman* in Contributions from the Bolus Herbarium 16: 131 (1994). *Bokkeveldia* D.Müll.-Doblies & U.Müll.-Doblies: 27 (1985). Type: *Bokkeveldia watermeyeri* (L.Bolus) D.Müll.-Doblies & U.Müll.-Doblies = *S. watermeyeri* L.Bolus

Bulb tunics whitish or yellowish. *Cataphyll* present. *Foliage leaves* 2(3). *Flowers* more-or-less funnel-shaped, pedicels slightly shorter or longer than perianth, filaments adnate to style for 2.5 to 4.0 mm above base, style more-or-less evenly thickened in proximal half.

5 spp.: *S. aestivalis* Snijman, *S. perryae* Snijman, *S. pubescens* W.F.Barker, *S. salteri* W.F.Barker, *S. watermeyeri* L.Bolus subsp. *watermeyeri*, *S. watermeyeri* subsp. *botterkloofensis* (D.Müll.-Doblies & U.Müll.-Doblies) Snijman

Section **Cryptomeria** *Snijman* in Contributions from the Bolus Herb. 16: 105 (1994). Type: *S. picta* W.F.Barker

Bulb tunics whitish. *Cataphyll* absent or rarely present. *Foliage leaves* usually more than 3, only 2 exserted above ground, shortly ciliate. *Flowers* weakly campanulate, pedicels somewhat longer than perianth, minutely pubescent, filaments thickened and ventrally ridged in proximal half, attached to style base, style narrowly ovoid, 6-grooved proximally, tapering distally.

1 sp.: *S. picta* W.F.Barker

Hessea *Herb.*, Amaryllidaceae: 289 (1837). Type: *Hessea stellaris* (Jacq.) Herb.

Subgenus **Hessea**

Hessea subgenus *Kamiesbergia* (Snijman) Snijman: 71 (1994); Snijman: 109 (1999). *Kamiesbergia* Snijman: 125 (1991). Type: *Kamiesbergia stenosiphon* Snijman = *H. stenosiphon* (Snijman) D.Müll.-Doblies & U.Müll.-Doblies

Bulb tunics parchment-like. *Cataphyll* present. *Foliage leaves* 2, glabrous or rarely minutely pilose. *Flowers* stellate, somewhat funnel-shaped or rarely hypocrateriform, tepals often adnate to filaments, filaments connate proximally into a short to long tube, rarely inner and outer whorls dissimilar, smooth, anthers centrifixed, ovary dome flattened. *Chromosome base number* $x = 11$.

11 spp.: *H. breviflora* Herb., *H. cinnamomea* (L'Hérit.) T.Durand & Schinz, *H. incana* Snijman, *H. monticola* Snijman, *H. pilosula* D.Müll.-Doblies & U.Müll.-Doblies, *H. pusilla* Snijman, *H. speciosa* Snijman, *H. stellaris* (Jacq.) Herb., *H. stenosiphon* (Snijman) D.Müll.-Doblies & U.Müll.-Doblies, *H. tenuipedicellata* Snijman, *H. undosa* Snijman

Subgenus **Myophila** (*Snijman*) *Snijman* [validated above]. *Hessea* section *Myophila* Snijman: 76 (1994). Type: *H. mathewsii* W.F.Barker

Bulb tunics softly fibrous. *Cataphyll* present. *Foliage leaves* 2(3), glabrous. *Flowers* stellate, tepals free to base, filaments free or shortly connate basally, densely papillate adaxially and each bearing a curved blunt hook arching over central disc, anthers subcentrifixed, ovary dome raised into 3 trichome-covered green pulvini between style and inner whorl. *Chromosome base number* $x = 11$.

2 spp.: *H. mathewsii* W.F.Barker, *H. pulcherrima* (D.Müll.-Doblies & U.Müll.-Doblies) Snijman

Namaquanula D.Müll.-Doblies & U.Müll.-Doblies in Botanische Jahrbücher 107: 20 (1985); Snijman: 155 (2005), emend. *Hessea* subgenus *Namaquanula* (D.Müll.-Doblies & U.Müll.-Doblies) Snijman: 74 (1994), excluding section *Myophila* Snijman. Type: *N. bruce-bayeri* D.Müll.-Doblies & U.Müll.-Doblies

Bulb tunics brittle, tan-coloured. *Cataphyll* absent. *Foliage leaves* (1)3 or 4, glabrous. *Flowers* stellate, tepals shortly connate or free, filaments proximally papillate on adaxial surface, anthers dorsifixed. *Chromosome base number* $x = 11$.

2 spp.: *N. bruce-bayeri* D.Müll.-Doblies & U.Müll.-Doblies, *N. bruynsii* Snijman

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BOTHALIA – African Biodiversity & Conservation
ISSN: (Online) 2311-9284, (Print) 0006-8241

Chlorophytum boomense (Agavaceae) is a synonym of *C. namaquense* from southern Namibia and the Northern Cape, South Africa

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Dates

Submitted: 30 October 2020
Accepted: 16 August 2021
Published: 12 October 2021

How to cite this article:

Manning, J.C. & Van Wyk, P.C., 2021, '*Chlorophytum boomense* (Agavaceae) is a synonym of *C. namaquense* from southern Namibia and the Northern Cape, South Africa', *Bothalia* 51(2), a11. http://dx.doi.org/10.38201/btha.abc.v51.i2.11

Chlorophytum boomense (Agavaceae), a local endemic from southern Namibia, is found to be morphologically indistinguishable from *C. namaquense*, which ranges from southern Namibia to central Namaqualand, and is consequently synonymised in that species.

Keywords: Greater Cape Floristic Region; Namaqualand; Namibia; Taxonomy

Introduction

Chlorophytum Ker Gawl. (Agavaceae) (sensu APGII 2003; Manning & Goldblatt 2012) includes 150–200 species of rhizomatous perennials distributed widely through the Old World tropics and subtropics, with its centre of diversity in Africa (Conran 1998; Manning 2017). The genus is well represented in southern Africa, with 40 species currently recorded from the subcontinent, twelve of which are endemic to the winter-rainfall parts of the Greater Cape Floristic Region (Manning & Goldblatt 2012; Snijman 2013; Kativu & Bjorå 2016; Manning 2017).

The southern African species were last revised some years ago by Obermeyer (1962) [see Archer and Kativu (2001) for nomenclatural corrections], but the Namibian species were more recently treated by Kativu et al. (2012). Since these publications, two additional species have been described from South Africa (Van Jaarsveld 2014; Manning 2017) and another from southern Namibia (Kativu & Bjorå 2016). The latter, *C. boomense* Kativu, was described from a single population from Ai-Ais Hotsprings Game Park just east of Rosh Pinah in southern Namibia. We are unable to distinguish it from *C. namaquense* Schltr. ex Poelln. from the Northern Cape, South Africa and southern Namibia, and formally synonymise it here.

Materials and Methods

All relevant material was examined in BOL, NBG, PRE and SAM (abbreviations following Thiers (2016)), the herbaria containing significant holdings of southern African flora. Author names are abbreviated according to the International Plant Names Index (https://www.ipni.org).

Taxonomy

Chlorophytum boomense is known from a single population along the Boom River near its confluence with the Orange River ± 30 km east of Rosh Pinah

Table 1. Summary of taxonomically useful characters in *C. boomense* (from Kativu & Bjorå (2016)) and *C. namaquense* (from Obermeyer (1962) plus additional specimens cited)

	Roots	Rhizome	Leaves	Inflorescence	Pedicels	Tepals	Filaments
C. boomense	Swollen at base, without tubers	Short, with fibrous leaf bases	Subdistichous, linear to lanceolate, 8–12 mm wide, glabrous	Simple	Articulated below middle, ± 9 mm long in fruit	10 mm long	Sparsely papillate
C. namaquense	Slender, without tubers	Short, with fibrous leaf bases	Subdistichous (in an elongated rosette), linear to lanceolate, 8–25 mm wide, glabrous	Simple or with 1 or 2 ascending branches	Articulated at or shortly below middle, 10 mm long in fruit	10–12 mm long	Scabrid

in southern Namibia. It was recognised as new through comparison with other species recorded from central and southern Africa, and was diagnosed against the tropical African *C. subpetiolatum* (Baker) Kativu on the basis of their similar roots, tapering to the tips, but is otherwise morphologically different from that taxon, and the two are evidently only distantly related (Kativu & Bjorå 2016). *Chlorophytum boomense* is otherwise unremarkable among the southern African members of the genus with pedicels articulated at or below the middle in having glabrous, subdistichous, linear to narrowly lanceolate leaves 8–12 mm wide, and a simple, racemose inflorescence of moderately large flowers with sparsely papillate filaments.

Chlorophytum namaquense, which was described from plants from Springbok in northern Namaqualand, was considered for a long time to be a relatively rare endemic from the immediate area (Obermeyer 1962) but is now known to occur more widely, ranging from Rosh Pinah in southern Namibia through the Richtersveld as far as Soebatsfontein in central Namaqualand, South Africa (Snijman 2013). It is diagnosed by its slender roots, elongated rosette of glabrous, lanceolate leaves to 25 mm wide with unthickened, sparsely setulose margins, and ± simple raceme of moderately large flowers with scabrid filaments, and pedicels articulated near the middle (Obermeyer 1962). Although the roots were described as slender, Obermeyer (1962) suggested that they were probably soft and spongy when young, and this is borne out in more recent collections, which have slender, tapering roots indistinguishable from *C. boomense*. The similarity between these two species, as well the occurrence of *C. namaquense* in Namibia, was overlooked by Kativu and Bjorå (2016).

A summary of taxonomically useful features in the two species (Table 1) fails to reveal any significant differences between them and we accordingly reduce *C. boomense* to synonymy.

Nomenclature

Chlorophytum namaquense *Schltr. ex Poelln.* in Berichte der Deutschen Botanischen Gesellschaft 61: 207 (1943). Type: South Africa, Northern Cape, Springbok (2917): Namaqualand, Vogelklip, (–DB), Oct 1897, *Schlechter 11295* (B†, holo.; PRE, iso.!).

Chlorophytum boomense Kativu in Kativu and Bjorå in Plant Ecology and Evolution 149: 342 (2016), *syn. nov.* Type: Namibia, Chamaites (2717): Ai-Ais Hotsprings Game Park, Orange River Mountain (Boom River), (–CC), 12 Sep 2012, *Nanyeni 380* (WIND, holo.–image!; SRGH, WIND, iso.).

Additional representative specimens examined

Namibia. **2717 (Chamaites):** Rosh Pinah, hills E of Danimub Reserve, (–CC), 4 Sept 2000, *Bruyns 8871* (NBG).

South Africa. NORTHERN CAPE. **2816 (Oranjemund):** Richtersveld National Park, (–BB), 7 Nov 1995, *G & F Williamson 5841* (NBG). **2817 (Vioolsdrift):** Kliphoogte, (–CD), 11 Sept 1929, *Herre STE11482* (NBG); Kouefontein, (–CD), 15 Aug 1979, *Van Berkel 108* (NBG). **2917 (Springbok):** Kourkammaberg, (–CD), 25 Aug 1999, *Desmet 266* (NBG); Spektakel, (–DA), 9 Sept 1950, *Barker 6729* (NBG); 3.5 km E of Nababeep and 1.5 km N of Divide Copper Mine, (–DB), 18 Aug 1987, *Hilton-Taylor 2104* (NBG); 10 mi [16 km] N of Komaggas, (–DC), 4 Sept 1951, *Compton 22799* (NBG); Misklip [Mesklip], (–DD), 28 Aug 1935, *Compton 5869* (NBG); 25 Aug 1941, *Barker 1883* (NBG). **3017 (Hondeklipbaai):** Boskloof, Kookfontein farm, 10 km NE of Soebatsfontein, (–BA), 2 Sept 1986, *Hilton-Taylor 1346* (NBG).

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BOTHALIA – African Biodiversity & Conservation
ISSN: (Online) 2311-9284, (Print) 0006-8241

Othonna koos-bekkeri Van Jaarsv. is a synonym of *Othonna cerarioides* Magoswana & J.C.Manning (Asteraceae: Othonninae)

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Dates

Submitted: 19 October 2020
Accepted: 6 July 2021
Published: 18 October 2021

How to cite this article:

Magoswana, S.L., Boatwright, S.J., Magee, A.R. & Manning, J.C., 2021, '*Othonna koos-bekkeri* Van Jaarsv. is a synonym of *Othonna cerarioides* Magoswana & J.C.Manning (Asteraceae: Othonninae)', *Bothalia* 51(2), a12. http://dx.doi.org/10.38201/btha.abc.v51.i2.12

Othonna koos-bekkeri Van Jaarsv. is recognised as a synonym of *O. cerarioides* Magoswana & J.C.Manning.

Keywords: Greater Cape Floristic Region; nomenclature; priority; succulent; taxonomy.

Introduction

The genus *Othonna* L. (Asteraceae: Senecioneae: Othonninae) comprises ± 90 species of succulent or sub-succulent perennial herbs or shrubs with more-or-less dorsiventrally flattened leaves and radiate or disciform capitula with female sterile disc florets and female marginal florets with a beige or reddish pappus that is sometimes accrescent. The genus is concentrated in the Greater Cape Floristic Region (GCFR) of South Africa but extends into southern Namibia, southern Angola and Zimbabwe (Manning 2013; Magoswana et al. 2019, 2020).

The genus was last revised by Harvey (1865) and is in urgent need of a modern taxonomic revision, although the preliminary floristic treatments by Manning and Goldblatt (2012) and Manning (2013), along with the recent taxonomic revision of the geophytic species of the genus by Magoswana et al. (2019), constitute a valuable contribution to a complete revision of the genus in the Greater Cape Floristic Region. Among the species included by Manning (2013) in his treatment of the Namaqualand members was an unnamed taxon, *Othonna* sp. A from the Richtersveld and northern Namaqualand, characterised by erect, rod-like stems 1–2 m tall, with ascending branches bearing spur-shoots terminating in disciform capitula.

This species was subsequently and almost simultaneously described and published by Magoswana et al. (2020) and Van Jaarsveld (2020). *Othonna cerarioides* Magoswana & J.C.Manning (Magoswana et al. [March] 2020) was characterised as an erect shrub with rod-like stems and branches, bearing numerous spur-shoots with obovate-oblanceolate leaves clustered at the tips, and up to nine disciform capitula per spur-shoot; and *Othonna koos-bekkeri* Van Jaarsv. (Van Jaarsveld [June] 2020) as a succulent shrub distinguished by its ascending, rod-like stems and lateral spur-shoots bearing sub-umbellate clusters of yellow capitula.

In Magoswana et al. (2020) the flowering time was erroneously given as 'April to August' although citing a specimen flowering in September. Following examinations of specimens available to us and those cited in Van Jaarsveld (2020), it is evident that this was an error and the correct flowering period for this species is in autumn from March to May.

Manning (2013: 314) in his treatment of *Othonna* suggested that *Senecio crassicaulis* Hutch. was possibly conspecific with *Othonna* sp. A (now *O. cerarioides*). The latter was a typographical error for *O. cyclophylla* Merxm., as was clearly indicated later (Manning 2013: 328).

Of the nine paratypes cited by Van Jaarsveld (2020), six were also examined and cited in Magoswana et al. (2020). *Othonna cerarioides* and *O. koos-bekkeri* quite clearly represent the same species, for which the name *O. cerarioides* has nomenclatural priority (Turland et al. 2018: Art. 11.3) having been published three months before *O. koos-bekkeri*, and we formally synonymise the latter. We have since seen a collection of *O. cerarioides* from southern Namibia (*Bruyns 7320* (BOL), cited below, along with additional collections from BOL), which extends the known distribution range of the species just north of the Richtersveld onto the hills just north of the Orange River near the junction with the Gamkab River.

Nomenclature

Othonna cerarioides *Magoswana & J.C.Manning* in Nordic Journal of Botany 38(3): 1 (21 March 2020). Type: South Africa, Northern Cape, Springbok (2917): Brandberg, near O'kiep, (–DB), 13 May 1978, *Hugo 1214* (NBG!, holo.; PRE, iso.!).

Othonna koos-bekkeri Van Jaarsv. in Bradleya 38: 225 (26 June 2020), *syn. nov.* Type: South Africa, Northern Cape, Springbok (2917): Tafelberg near Kosies (Steinkopf, Richtersveld) (–BA), without date, *Van Jaarsveld and Combrink 27729* (NBG!, holo.).

Additional specimens examined

NAMIBIA. Vioolsdrif (**2817**): Aussenkehr, hills west of Marinkas Quellen, 8 Jul. 1997, *Bruyns 7320* (BOL).

SOUTH AFRICA. Northern Cape, Vioolsdrif (**2817**): Ploegberg above Black Hills, 10 Jul. 1997, *Bruyns 7322* (BOL). Springbok (**2917**): Steinkopf, Kosies, 5 Sept. 2002, *Bruyns 9238* (BOL); Steinkopf, 13 Jul. 2006, *Pole-Evans 2353* (BOL); 5 km N. of Concordia, 20 Jun. 1992, *Bruyns 5158* (BOL).

Acknowledgements

We thank Nick Helme for bringing to our attention the publication of *Othonna koos-bekkeri* Van Jaarsv. This work is based on research supported by the National Research Foundation of South Africa (Grant Number 118597) awarded through the Foundational Biodiversity Information Programme (FBIP), a joint initiative of the Department of Science and Technology (DST), the National Research Foundation and the South African National Biodiversity Institute. Additional funding was provided by Elizabeth Parker of Elandsberg. Thank you to Dr Cornelia Klak of the Bolus Herbarium for alerting us of the Namibian and additional collections of the species.

Competing interests

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this article.

Authors' contributions

SLM and JCM were the project leaders, ARM and JSB made conceptual contributions.

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ISSN: (Online) 2311-9284, (Print) 0006-8241

Validation of two previously described species of *Annesorhiza*

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Dates

Submitted: 20 November 2020
Accepted: 6 July 2021
Published: 12 October 2021

How to cite this article:

Magee, A.R., 2021, 'Validation of two previously described species of *Annesorhiza*', *Bothalia* 51(2), a10. http://dx.doi.org/10.38201/btha.abc.v51.i2.10

Two species of *Annesorhiza*, *A. laticostata* Magee and *A. radiata* Magee, are here validated with reference to the previously and effectively published descriptions and diagnoses.

Keywords: *Annesorhiza laticostata*; *Annesorhiza radiata*; Greater Cape Floristic Region; new species; nomenclature; South Africa.

Introduction

Annesorhiza Cham. & Schltdl. (Apiaceae) is a South African endemic genus centred in the Greater Cape Floristic Region (Magee et al. 2012; Magee 2013; Van Wyk et al. 2013). Twelve species were recognised in the last revision of the genus by Tilney and Van Wyk (2001), but the number of species has since nearly doubled to 22 species (Magee & Manning 2010; Van Wyk & Tilney, 2010; Magee et al. 2011; Magee 2015). A large addition to the genus came as a result of the re-assessments of the polymorphic genus *Peucedanum* L. in Africa (Winter et al. 2008). The African species of *Peucedanum* have been shown to be only distantly related to the type of the genus and subsequently accommodated in seven genera (Winter et al. 2008; Magee et al. 2011). Two of these, *Peucedanum filicaule* (Eckl. & Zeyh.) B-E.van Wyk & Tilney and *P. triternatum* Eckl. & Zeyh., together with five undescribed but closely related species, were as such transferred to *Annesorhiza* by Magee et al. (2011) based on morphological (fruit with a narrow commissure and leaves hysteranthous (Vessio 2001)) as well as molecular sequence data (Calviño et al. 2006). The validity of two of the five new species described within the *Annesorhiza triternata* group by Magee et al. (2011) have since been brought into question. The type collection for both species were made when the plants were in their reproductive phase with inflorescences and fruit evident, but vegetatively sterile. Subsequently, leaf material was added to these collections in the spring of the same year and indicated as such on the specimen label. In the type citation of these two species (Magee et al. 2011) more than one gathering was inadvertently indicated by the inclusion of a statement that the leaf collections had been added to the reproductive collections, without specifically excluding them, rendering the names invalid (ICBN Art. 40.2, Turland et al. 2018). These two names are therefore validated here with reference to the previously and effectively published descriptions and diagnoses (ICBN Art. 38.1, Turland et al. 2018).

Nomenclature

Annesorhiza laticostata *Magee* sp. nov. *Annesorhiza laticostata* Magee *nom. inval.*, Systematic Botany, 36(2): 513 (2011). Type: SOUTH AFRICA. Western Cape, Worcester (3319): Hills between the Breede River and the Brandvlei Dam, S of Worcester next to the road to Rawsonville (–CB), 15 February 2010, *Magee*

& Le Roux 188 (excluding leaves, added on 16 August 2010) (NBG-NBG0266670!, holo.; K-K000975897!, NBG- NBG1460469!, PRE-PRE0998616!, iso.).

Annesorhiza radiata *Magee,* sp. nov. *Annesorhiza radiata* Magee *nom. inval.*, Systematic Botany, 36(2): 514 (2011). Type: South Africa. Western Cape, Worcester (3319): Worcester, Karoo Desert National Botanical Garden, clay soils near the bottom of the reserve (–CB), 20 April 2010, *Magee 242* (excluding leaves, added on 16 August 2010) (NBG-NBG0266683!, holo.; K-K000975895!, NBG- NBG0266671!, PRE-PRE0998615!, iso.).

Acknowledgements

This work is based on research supported by the National Research Foundation of South Africa (Grant Number 90646).

Competing interests

The author declares that he has no financial or personal relationship(s) that may have inappropriately influenced him in writing this article.

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ISSN: (Online) 2311-9284, (Print) 0006-8241

Clarification of the confusion surrounding the generic name *Bryomorphe* Harv. (Asteraceae: Gnaphalieae), and the new genus *Muscosomorphe* J.C.Manning

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Dates

Submitted: 8 February 2021
Accepted: 20 July 2021
Published: 10 September 2021

How to cite this article:

Manning, J.C. & Govaerts, R., 2021, 'Clarification of the confusion surrounding the generic name *Bryomorphe* Harv. (Asteraceae: Gnaphalieae), and the new genus *Muscosomorphe* J.C.Manning', *Bothalia* 51(2), a8. http://dx.doi.org/10.38201/btha.abc.v51.i2.8

The monotypic genus *Bryomorphe* Harv. is found to be homotypic with *Klenzea lycopodioides* Sch.Bip., which is considered to be a later synonym of *Dolichothrix ericoides* (Lam.) Hilliard & Burtt, and *Bryomorphe* is thus a synonym of *Dolichothrix*. The new genus *Muscosomorphe* J.C.Manning is proposed to accommodate the species previously included in *Bryomorphe* as *B. aretioides* (Turcz) Druce, along with the new combination *M. aretioides* (Turcz) J.C.Manning.

Keywords: Africa; classification; illegitimate superfluous name; nomenclature; taxonomy.

Introduction

The genus *Bryomorphe* Harv. (1863) was established for a single, dwarf species of Gnaphalieae (Asteraceae) from the mountains of the Western Cape, with a characteristic cushion-forming habit, ericoid foliage and radiate capitula. The new name *B. zeyheri* Harv. (1863) provided for the only (thus type) species in his new genus is unfortunately an illegitimate superfluous name for both *Helichrysum aretioides* Turcz. (1851) and *Klenzea lycopodioides* Sch.Bip. (1843) since Harvey (1863) cited both of these names in synonymy (Turland et al. 2017: ICN, Art. 52). The first of these names is typified by *Zeyher 2908*, which was rather vaguely said to come from the Table and Hottentots Holland mtns, and the latter by *Krauss s.n.* [*610*] from the mountains (possibly the Kammanassie Mtns) inland of George. In the protologue to *Bryomorphe*, Harvey (1863) also cited a third specimen, *Roser 42* from the Riviersonderend Mtns above Genadendal.

Druce (1911) recognised that *B. zeyheri* was a superfluous name for *H. aretioides* since both names cited *Zeyher 2908* as the type and he therefore provided the combination *B. aretiodes* (Harv.) Druce, overlooking the nomenclatural issues raised by Harvey's (1863) inclusion of the earlier *K. lycopodioides* in synonymy. The nomenclatural priority of *K. lycopodioides* was finally identified by Levyns (1942), who concurred with Harvey (1863) that all three names seemed to apply to the same species and accordingly provided the combination *B. lycopodioides* (Sch.Bip.) Levyns as the correct name for the taxon.

This is where matters remained until Koekemoer (2011) realised that not one but two quite distinct species were involved, and that the type of *K. lycopodioides* was in fact conspecific with *Dolichothrix ericoides* (Lam.) Hilliard & Burtt (1981). The confusion between *K. lycopodioides* and *H. aretioides* is difficult to explain as the former has appressed, scale-like leaves and discoid capitula, as was highlighted by Koekemoer (2011), who also provided detailed descriptions of both taxa. Koekemoer (2011) accordingly placed *K. lycopodioides* in synonymy under *D. ericoides* and recognised the later combination *B. aretioides* (Harv.) Druce as the correct name for the illegitimate *B. zeyheri* Harv., and the type of the genus *Bryomorphe*.

Unfortunately, Koekemoer (2011) incorrectly identified *Roser 42* (TCD) as the holotype of *B. zeyheri* and so overlooked the nomenclatural implications for the genus *Bryomorphe* of the illegitimacy of the name *B. zeyheri*. These were identified by Rafaël Govaerts, principal contributor to the World Checklist of Selected Plant Families at Kew, and are addressed here.

Results and nomenclature

Firstly, the type of *Bryomorphe* is not *B. aretioides* but is in fact *B. zeyheri* and thus *K. lycopodiodes*. This is by reason of *B. zeyheri* being an illegitimate superfluous name for *K. lycopodioides* (Turland et al. 2017: ICN, Art. *52.1*). A name, unless conserved (Art. *14*) or sanctioned (Art. *15*), is illegitimate and is to be rejected if it was nomenclaturally superfluous when published, i.e. if the taxon to which it was applied, as circumscribed by its author, definitely included the type of a name that ought to have been adopted, or of which the epithet ought to have been adopted, under the rules. The possible argument that Harvey (1863) excluded the type of *K. lycopodioides* from his circumscription of *B. zeyheri* and thus from *Bryomorphe* (Turland et al. 20l7, ICN: Art. 7.5) is refuted by his words “Schultz (Bip.) places this plant in his genus *Klenzea* …..” (Harvey 1863: line 34). The type of both *B. zeyheri* and thus of the genus *Bryomorphe* is thus *Krauss 610*, which is the type of *K. lycopodioides*. In consequence of this, the genus *Bryomorphe* becomes a nomenclatural synonym of *Dolichothrix*.

Furthermore, the name *Bryomorphe* Harv. (1863) is antedated by the very similar *Bryomorpha* Kar. & Kir. (1842) (Caryophyllaceae), which, although not strict homonyms, might be considered confusingly similar (Turland et al. 2017, ICN: Art. *53.2* Ex. 8). Harvey (1863) was evidently unaware of this when he described *Bryomorphe*, but although he pointed it out later (Harvey 1894), the implications on the legitimacy of the name have escaped attention until now.

Molecular analyses (Bayer et al. 2000; Bengston et al. 2011) place *Dolichothrix* in a clade with *Lachnospermum* Willd., *Metalasia* R.Br., *Phaenocoma* D.Don. and other satellite genera, whereas *Bryomorphe aretioides* is retrieved as a member of a separate clade that includes *Amphiglossa* DC., *Disparago* Gaertn., *Elytropappus* Cass. and *Stoebe* L. Following the current taxonomy, therefore, it is necessary to recognise a new genus for *B. aretioides*, and the generic name *Muscosomorphe* is proposed here, along with the new combination *M. aretioides*.

The new genus *Muscosomorphe*

Muscosomorphe J.C.Manning, *gen. nov. Bryomorphe* sensu Koekemoer in Bothalia 41: 325 (2011), non Harv. (1863). Type species: *M. aretioides* (Turcz.) J.C.Manning

[*Bryomorphe* sensu Harv., Thesaurus Capensis 2 : 33 (1863), pp., excluding type *Klenzea lycopodioides*]

Dwarf, cushion-forming shrublets. *Leaves* ascending-incurved, imbricate, linear, adaxial surface tomentose with longitudinally striate hairs, adaxial surface lachnate. *Capitula* heterogamous, terminal, 1 to 3 at branch tips, partially concealed among leaves. *Involucral bracts* multiseriate, outer bracts ovate, foliaceous distally, inner bracts linear to narrowly oblong, scarious, rounded apically with large lateral wings clasping florets. *Receptacle* alveolate. *Ray florets* 6 or 7, female, lamina 3-lobed, white. *Style branches* obtuse, sweeping hairs not tufted. *Disc florets* 7 to 9, bisexual, corolla purple. *Anthers* basally tailed. *Style branches* truncate, sweeping hairs tufted. *Cypselas* terete, laevigate; pappus setae ± 15 to 30, free, barbed in lower four fifths, densely plumose distally, occasionally interspersed with clavate cells.

M. aretioides (Turcz) J.C.Manning, *comb. nov. Helichrysum aretioides* Turcz. in Bulletin de la Sociéte Impériale des Naturalistes de Moscou 24: 79 (1851). *Bryomorphe aretioides* (Turcz.) Druce in Second Supplement to Botanical Society & Exchange Club of the British Isles, Report for 1916, 4: 611 (1917). Type: South Africa, Western Cape: summits of Table and Hottentots Holland mtns, *Zeyher 2908* (KW-1000916, holo.-image!; K-415093-image!, P-21335 and 21336-images!, PRE!, S-06-14625-image!, SAM!, TCD, iso.).

Etymology: From the Latin *muscosus* moss-like, alluding to the cushion-forming habit and to the generic name *Bryomorphe* that was previously used by Harvey (1863).

New synonyms in *Dolichothrix*

Dolichothrix Hilliard & Burtt in Botanical Journal of the Linnean Society 82: 221 (1981). Type species: *D. ericoides* (Lam.) Hilliard & Burtt

Bryomorphe Harv., Thesaurus Capensis 2 : 33 (1863) [non *Bryomorpha* Kar. & Kir. (1842)], *syn. nov*.; Harv. in Flora Capensis 3: 277 (1894). Type: *B. zeyheri* Harv., nom. illeg. = *B. lycopodioides* (Sch.Bip.) Levyns

D. ericoides (Lam.) Hilliard & Burtt in Botanical Journal of the Linnean Society 82: 221 (1981). *Xeranthemum ericoides* Lam., Encylopédie méthodique. Botanique 3: 240 (1789). Type: South Africa, Western Cape: Cape of Good Hope, *Sonnerat s.n.* (P-LAM, holo.). [For full synonymy see Koekemoer (2011: 325).

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ISSN: (Online) 2311-9284, (Print) 0006-8241

Mushroom art in South Africa and Zimbabwe – Emil Holub: 1847–1902

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Dates

Submitted: 27 November 2020
Accepted: 20 May 2021
Published: 18 October 2021

How to cite this article:

Sharp, C. & Burrett, R.S., 2021, 'Mushroom art in South Africa and Zimbabwe – Emil Holub: 1847–1902', *Bothalia* 51(2), a13. http://dx.doi.org/10.38201/btha.abc.v51.i2.13

Emil Holub was a nineteenth century, Austro-Hungarian Czech, medical doctor with wide-ranging interests in ethnography and the natural sciences. During visits to southern Africa in the 1870s, he meticulously recorded everything that he encountered. Amongst his vast collection of artifacts, natural history specimens and notes were several sketches of fungi. These illustrations are reproduced here to document this valuable historical knowledge, tentatively identifying them in the context of the habitats through which Holub travelled.

Key words: southern African history; macro-fungi; South Africa; Zimbabwe; natural history; artistic records.

Introduction

The late 19th century era saw many adventurers visiting Africa in search of ethnological or natural history curiosities. Emil Holub was one. He was born on 7 October 1847 in Holice (Holitz), eastern Bohemia, in what is now the Czech Republic. As a youngster he exhibited a remarkable passion for natural history, geography and archaeology, and was an avid reader of many of the leading travelogues of that period. As a result of the writings of David Livingstone, Holub became obsessed with the African continent, and it was his avowed ambition to follow in Livingstone's footsteps. To this end, he explored southern Africa twice: most extensively in 1872–1879 and again from 1883 to 1887 (Burrett & Olša jr 2006; Burrett 2006).

Holub studied medicine at Charles University, Prague, and left for South Africa in May 1872. Arriving at Cape Town on 1 July, he spent a short time in Port Elizabeth (Gqeberha) before making his way to the Diamond Fields where he set himself up at Dutoitspan. Holub worked hard and lived frugally, saving his money to fund his proposed travels into the interior. These journeys are well documented, and it is the English translations of his books that are referred to in this paper (Holub 1881; Holy 1975).

In early February 1873, Holub undertook his first excursion into the west of the old Transvaal Republic. This lasted two months, during which he collected about 1 500 dried plants and an enormous quantity of other natural history specimens, including over 3 000 insects. A short while later, November 1873 to April 1874, Holub was again on the move, this time travelling to Shoshong in what is today Botswana (Kandert 1998). Holub's third expedition began on 2 March 1875. This time he set out for the Zambezi River by way of the 'Salt Pan Road'. During this 21-month long journey, Holub passed through the arid wilderness between Botswana's Makgadikgadi Salt Pans and the Zambezi River. At the end of July 1875, he reached Pandamatenga, a key pre-colonial trading centre. With the support of trader George Westbeech, Holub received permission to cross the Zambezi to spend time in the Lozi (Barotse) Kingdom of Western Zambia. In December 1875, Holub had a disastrous mishap when his canoe overturned in the Zambezi, losing provisions, medicines and many of his notes and specimens (Holub 1881 – Vol.2; Burrett 2006). This forced him to turn back, and he finally returned to Kimberly in November 1876.

On 5 August 1879, Holub left Cape Town and returned to Prague via London, spending the next four years writing up his travels, giving lectures and presenting displays of his collections in many European cities. In 1883 he returned to Africa accompanied by his wife Rosa, and in June 1884 they embarked on an ambitious attempt to travel far beyond the Zambezi River. This journey, funded by the Austro-Hungarian State, was a disaster, and by April 1886 the expedition was aborted after the death of several of his companions and the loss of all his equipment and accumulated field-notes. Holub finally returned to Europe in 1887 and died in February 1902 as a result of the accumulated long-term effects of malaria. Today Emil Holub is considered one of the national folk-heroes of the Czech Republic and one of the greatest scientific travellers of the 19th century.

Clearly Holub had an uncommon passion for natural history as well as an eye for detail, and his fascinating mushroom drawings are uncommon since fungi were rarely noticed by most likeminded travellers. We hope that this publication, a historical review of these early southern African fungi sketches, will give recognition to the valuable pioneer contribution of Emil Holub to mycological knowledge in southern Africa and encourage further research.

Materials & Methods

Most of Holub's observations have remained unpublished, so it was a privilege for one of us in 2007 to be granted permission to see Holub's drawings in the Náprstek Museum in Prague, as part of a general heritage project funded by the Czech Embassy, Harare. This was facilitated by the then Czech Ambassador to Zimbabwe, Jaroslav Olša Jnr. Subsequently, Bohumil Hamrsmid of the Czech Embassy in Lusaka, Zambia, was approached for assistance with translation of the annotations alongside the sketches. Contrary to our expectations, he found that most of the text was not written in Czech, but in archaic German, with only a smattering of Czech here and there. Hamrsmid found the German very difficult to read, let alone translate and we approached Helga Landsmann who is familiar with the old Sütterlin script and old style of handwriting. On many pages there are several styles of writing and pen quality/size. We believe that additions were made later by the curatorial staff in the Museum, but they add little to the nature of the illustrations and original annotations and are therefore not discussed further.

Holub's two 1881 volumes were read to provide some insight into the background of the various mushroom sketches, so enabling us to understand general habitat and timing of the journey when these fruiting bodies were illustrated. Unfortunately, it was not always possible to match the sketches with the published texts, and the exact localities of the illustrations are often obscure, using old geographical names no longer in use, or they are a distorted version of what he thought was said in Cape Dutch or various African languages. In addition, we have found that the official English translation, done by Ellen E. Frewer, has many variations to the original text. A fair amount of the natural history detail was dropped as Frewer believed that they would have little appeal to the general English reader. This has made it difficult to correlate the published text with some of the annotations in Holub's original field-notes. Nonetheless it appears that the mushroom drawings come from three general areas, and it is on this basis that we discuss his sketches (Figure 1).

The original sketches, scanned by the staff of the Náprstek Museum in Prague, are in sepia, but they are reproduced here in black-and-white to enhance their finer details. The drawings were done on whatever paper Holub had on hand as paper was a rare commodity at that time. His original numbering is retained. Measurements of size on the sketches were given in the old imperial style and Holub, in his characteristically precise manner, used the 'triple primes', i.e., three apostrophe signs (''') to denote a twelfth of an inch.

It is appreciated that the exact determination of a species cannot always be achieved by illustration alone. It is not known whether Holub's fungi collections survived the journeys, and it would be interesting to confirm the tentative identifications below with relevant voucher specimens in the Náprstek Museum. Nonetheless, Holub's attention to detail is such that the genus, and sometimes a species name, can be allocated to his sketches. Obviously, some of our interpretations may be open to dispute, because by its very personal nature, any work of art is very individualistic and influenced by the knowledge and experience of the artist. Equally, interpretation is influenced by the knowledge and experience of the reviewing eye. The nomenclature used in this paper is according to *Index Fungorum* (2020).

In late December 2018, a field trip was undertaken by the first author and Judy Ross to explore the sites along the Pandamatenga–Leshumo Valley trail as described by Holub in his publications. Our intention was to verify the vegetation present, which would assist in naming the illustrated fungi. Unfortunately, the rains were very late that season, and no mushrooms were seen during our week-long excursion.

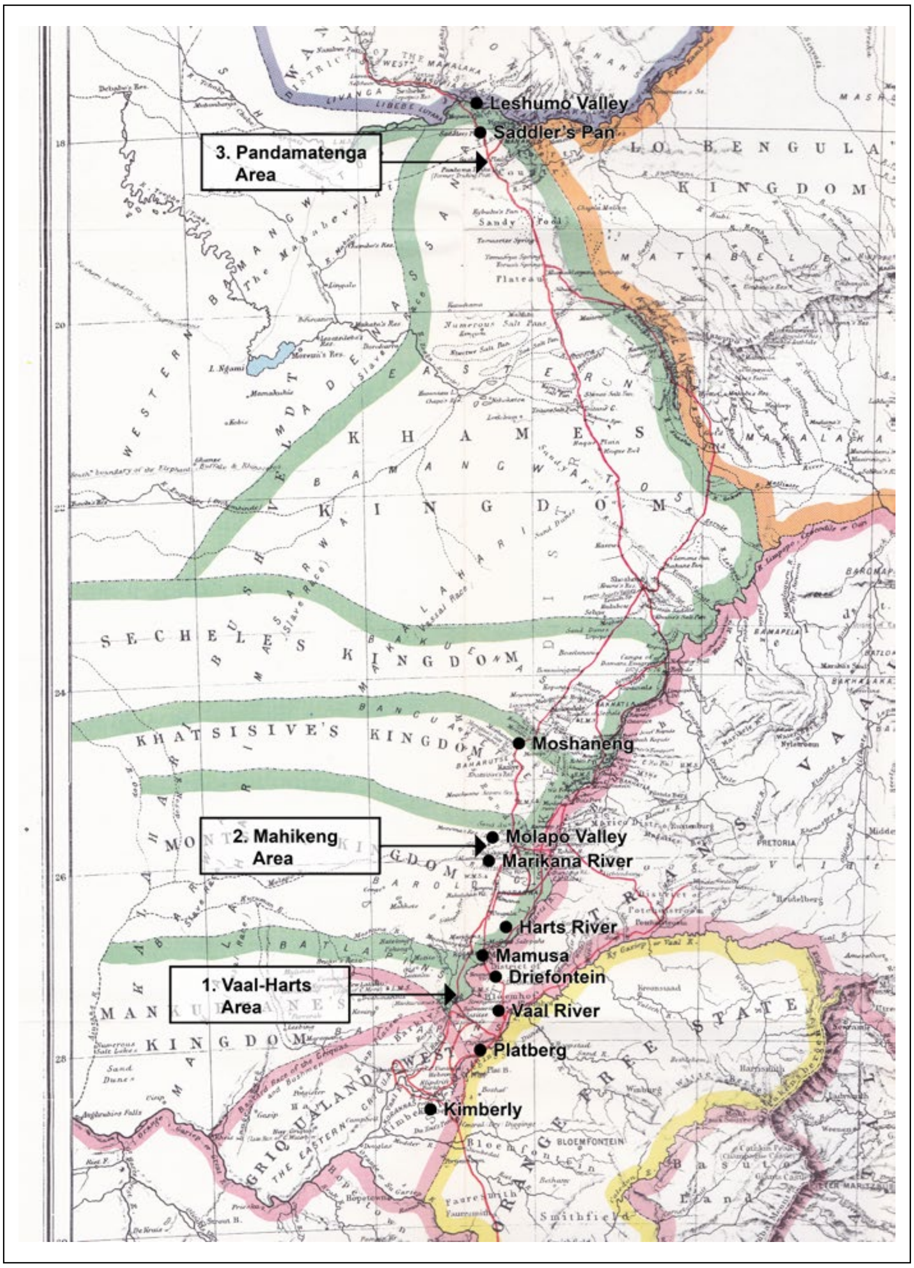

Figure 1. Holub's map showing three main areas from where fungi were illustrated. (Map scanned from Vol.1 of Holub 1881).

At the end of this paper, we include two written records of fungal collections from southern Africa attributed to Holub that have come to light in more recent literature. These may be only part of his forgotten legacy. It is possible that there are additional mushroom illustrations archived in the Náprstek Museum.

Results and Discussion

Holub's first published mention of 'funguses' is on 26 July 1875 in Volume 2 of his travelogues (Holub 1881), together with a note about explosive seed pods. This latter phenomenon applies to *Brachystegia*, *Julbernardia* and *Baikiaea* trees, which Holub encountered at that time of year while travelling north 'through very monotonous sandy forest' towards the settlement of Pandamatenga. These trees are in the Caesalpinioideae sub-family of legumes, and the first two genera are dominant in miombo woodland and have ectomycorrhizal associations with many fungi. They often co-exist with *Baikiaea plurijuga* Harms, the Zambezi teak tree, which is dominant in many of the Kalahari Sand areas. It is unlikely that there were fungi fruiting at that time of year, except for bracket fungi, which Holub apparently did not illustrate, but he collected 'a good many plants, and some varieties of seeds, fruits and funguses'.

The next mention of fungi is made during Holub's stay in the Upper Leshumo Valley where he was recovering from a particularly bad bout of 'fever'. On 19 January 1876 he was well enough to take a short walk and botanised in the immediate vicinity of the wagons – 'Of such funguses as I could neither press nor dry, I took sketches…'.

The annotations to his sketches, unlike the published text, mentions 'mushroom' using the old German term 'Schwamme' ('sponge mushrooms'), a name with which he would have been familiar back home, although in using this word he meant more than 'bolete' fungi to which this common name is now applied in Zimbabwe. It is interesting that he also mentions lichens in his books, for example in rocky areas north of Moshaneng. This suggests that he knew that they, and probably also fungi, were separate from plants. Unfortunately, his descriptions of the lichens are not detailed enough to identify those he encountered.

The drawings and translations of the annotations to Holub's field sketches are documented and our identifications follow below. These are summarised in Table 1.

1. The Gariep (Vaal)–Harts River Region, South Africa, 1873.

Holub collected various natural history specimens in the western and central areas of the former Transvaal, including the modern provinces of Gauteng, Limpopo and North West as well as in the immediate vicinity of Kimberly. These collections date to 1873 and January 1874. The general habitat of these river valleys where he did considerable work is described as 'desert scrub' (Pole-Evans 1936) or part of the savanna biome in the Eastern Kalahari Bushveld Bioregion (Mucina & Rutherford 2011).

In March 1873 Holub found *Phellorinia herculeana* (Pers.) Kreisel 1961 (syn. *Phellorinia strobilina, Phellorinia*

Table 1. List of fungi illustrated by Emil Holub on his travels in southern Africa. Uncertain identification is indicated by a question mark (?)

Holub's Number	Mushroom name
4	*Phellorinia herculeana* (Pers.) Kreisel 1961
22, 23, 24	*Termitomyces*
39, 40	'Puffball' in Agaricaceae
41, 42	*Agaricus*
44	*Agaricus*
45	*Agaricus*
46, (47)	*Coprinus comatus* (O.F.Müll.) Pers. (1797)
47, 48, 49, 50	*Termitomyces*
52	*Amanita pleropus*? (Kalchbr, & MacOwan) D.A. Reid
433	*Parasola plicatilis* (Curtis) Redhead,Vilgalys & Hopple 2001
434	*Russula*? *Clitocybe*?
435, 436	*Macrolepiota*
437	*Lentinus/Panus* (*Panus neostrigosus*? Drechsler-Santos & Wartchow 2012)
438	*Laccaria*?
439	*Cantharellus*
440	*Laccaria*?
444	*Agaricus*
445	*Laccaria*?*Cantharellus*? *Lepista*?
446	*Marasmius/Collybia*
447	*Entoloma*? *Marasmius*?
458, 459, 460	*Agaricus trisulphuratus* Berk. 1885
461	*Podoscypha*? an Ascomycete?
462	*Leucoagaricus*
466	*Pluteus*? *Entoloma*? *Mycena*?

inquinans), (Figure 2, Holub No.4), 'along the way in the grass between Driefontein and …. (near Platberg)'. The unknown name in the annotation cannot be deciphered despite reference to his map. There follows a description of colour of the specimen which could be any one of the following – whitish, yellowish or brownish. The writing is unclear, hindering translation. Unfortunately, little else of the text can be read. The sizes recorded by Holub fit the species well and he has captured the exact character of this fungus. There are several records of this species in South Africa, two of which were recorded in Fauresmith and one along the Vaal River (Doidge 1950), which would seem to fit the location where Holub encountered it. There are three records from Zimbabwe in the private collection of Cathy Sharp, all found in heavy, alluvial soil along major rivers (collections CS699 and CS1069 and ZSES17). There is a chance that this sketch (and the Zimbabwean collections) may be *Dictyocephalos attenuatus* (Peck) Long & Plunkett 1940, a species very similar to *P. herculeana* both macro- and microscopically (Dios et al. 2002) and previously collected in Hwange, Zimbabwe (Doidge 1950).

Figure 2. Holub no. 4: *Phellorinia herculeana*.

Figure 3 (Holub numbers 22, 23, 24), shows a characteristic termite fungus, *Termitomyces*. The details of the rough cap surface suggest that this is possibly *Termitomyces sagittiformis* (Kalchbr. & Cooke) D.A.Reid 1975 (Van der Westhuizen & Eicker 1994), although *Termitomyces umkowaan* (Cooke & Massee) D.A.Reid 1975 may also develop a cracked cap with age. Both species have a swollen base to the stipe before narrowing into a black pseudorrhiza as shown in Holub's illustration. A more precise identification to species is therefore not possible. The location of this specimen is given as 'Found in the sand of the swampy tributary… [west…] Dr Moffat's salt pans'. These pans are marked on Holub's map, west of the Harts River near Mamusa. 'The biggest figure is a fully grown sponge, the white of the mushroom blending into yellowish…the gills are white…grows with termite mounds.' Unfortunately, the rest of the annotation is indecipherable.

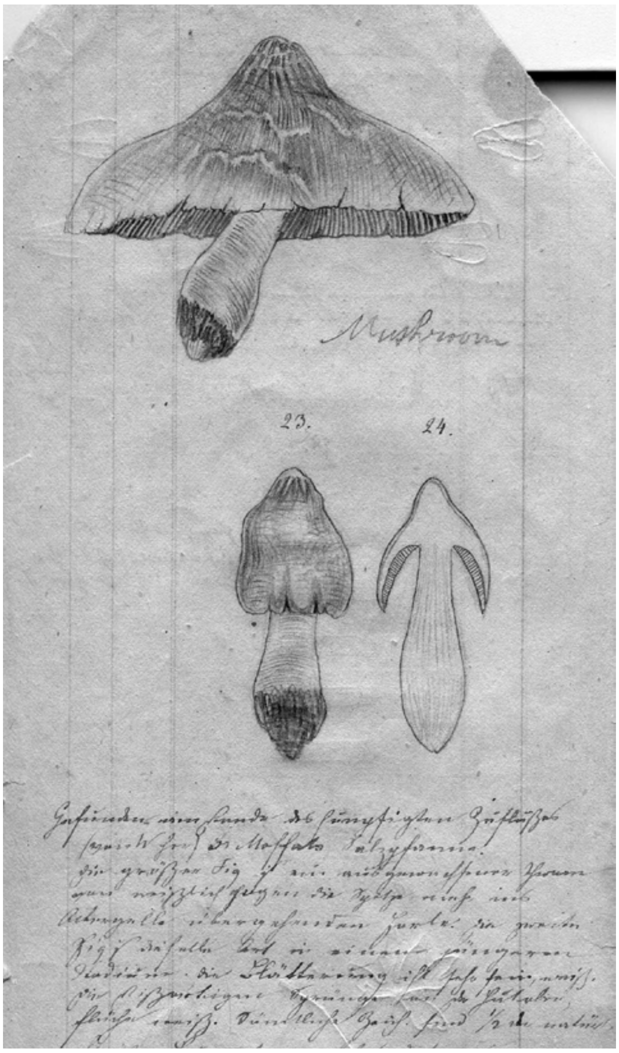

Figure 3. Holub numbers 22, 23 and 24: *Termitomyces*; no. 22: fully grown; no. 23: unopened; no. 24: cross-section.

2. The Mahikeng (previously Mafeking) area, South Africa, 1875.

In North West Province, South Africa, Mahikeng is close to South Africa's northwestern border with Botswana. Its habitat is open *veld* comprised of short mixed grass with low scrub along the banks of the Molapo River (Pole-Evans 1936). Mucina and Rutherford (2011) classified the area as being on the edge of Savanna and Grassland biomes.

The illustration in Figure 4 (Holub numbers 39 and 40), is possibly one of the 'puffballs', perhaps a *Calvatia* with the typically crimped folds underneath. This group of

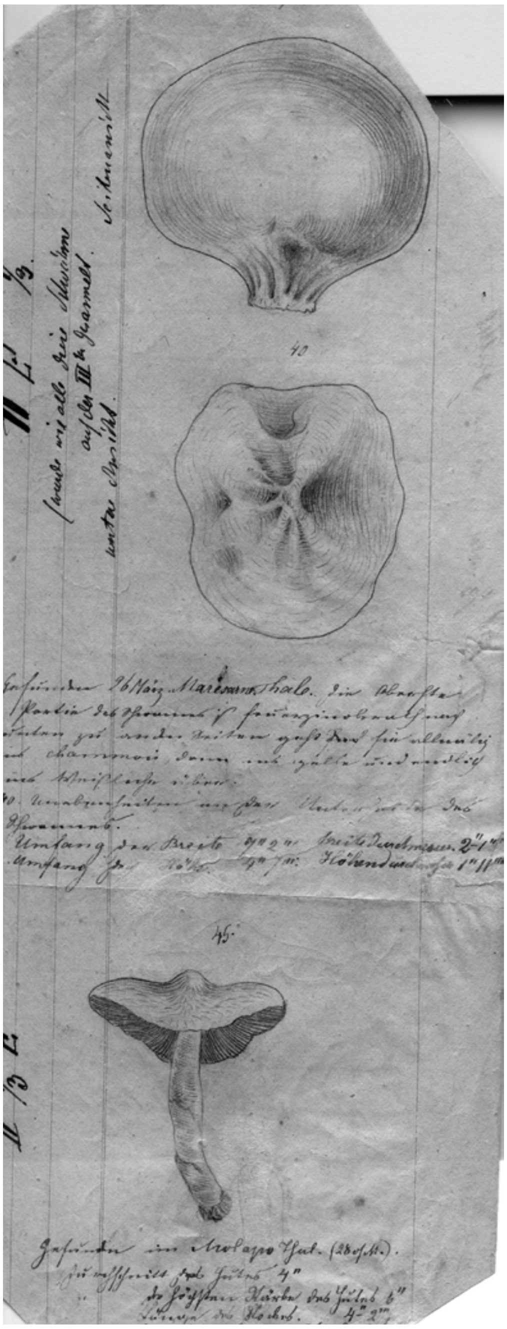

Figure 4. Holub numbers 39 and 40: a 'puffball'; no .45: *Agaricus*.

fungi were formerly in their own family called Lycoperdaceae but are now in Agaricaceae. Holub shows the 'side-view' (no. 39) and 'under-view' (no. 40). 'As all sponge mushroom…on the third…Found on 26th of March….' If the translation is correct, it is not clear which measurements Holub took of the fruiting bodies: 'circumference of the width 7" 2''' cross-section of width 2" 1''' circumference of the height 4" 7''' diameter 1" 11'''.'

The *Agaricus* (Figure 4: Holub no. 45) was 'found in Molapo Valley on 28th October.' The Molapo River forms the southern border of Botswana. The mushroom noted by Holub measured as follows: 'cross-section of the closed cap is 4", cross-section of the open cap is 6", cross-section height of the cap is 4" 2''' circumference of cap is 11'''. It is not clear whether there is more to the last measurement as the page is damaged. Of interest is the date when this mushroom was found and illustrated. October is usually very hot and dry, and one would not expect fruiting at this time, although thunderstorms do occur, and temporary moisture and humidity may well encourage growth of these mushrooms.

Figure 5 shows another *Agaricus*. Holub no. 44 has a rather obscure caption written in a different language, possibly Czech or Slovak – 'page 25 in diary.' We assume that this refers to one of Holub's personal diaries, which we have not seen. The half-fraction shown alongside appears to refer to this same specimen, suggesting that it is a very large species.

Illustration no. 46 looks to be *Coprinus comatus* (O.F.Müll.) Pers. 1797. It is shown as a third of life-size and was 'found in the Molapo Valley.' However, there are some species of *Agaricus* that look like this in the young stage, and it may represent the same fungus in the adjacent illustrations. However, because Holub allocated a different number to this drawing, we assume it to be a different mushroom.

In Figure 6, Holub numbers 41 and 42 look like young *Agaricus* fruiting bodies. They are annotated 'Found in

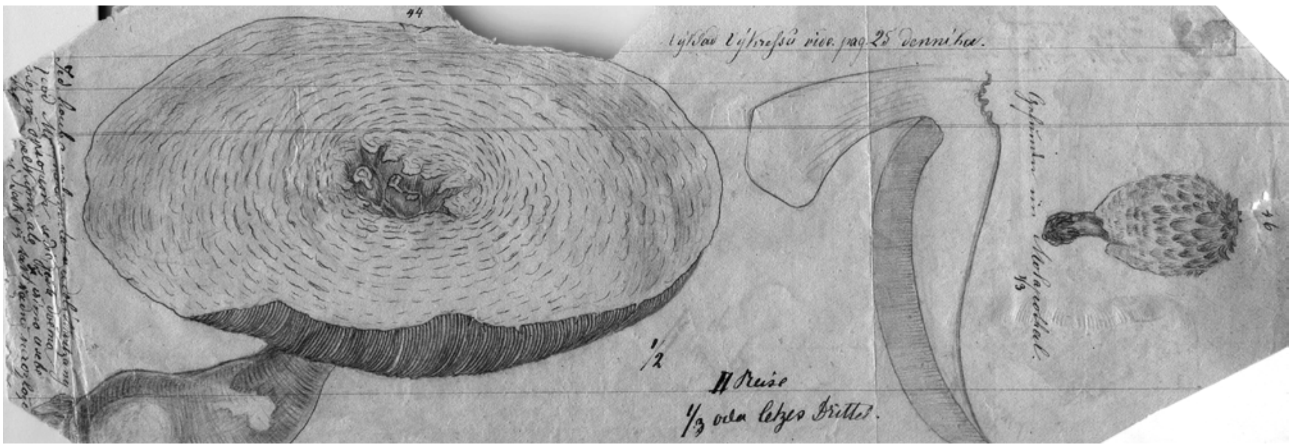

Figure 5. Holub no. 44: *Agaricus* (including cross-section); no .46: *Coprinus comatus*.

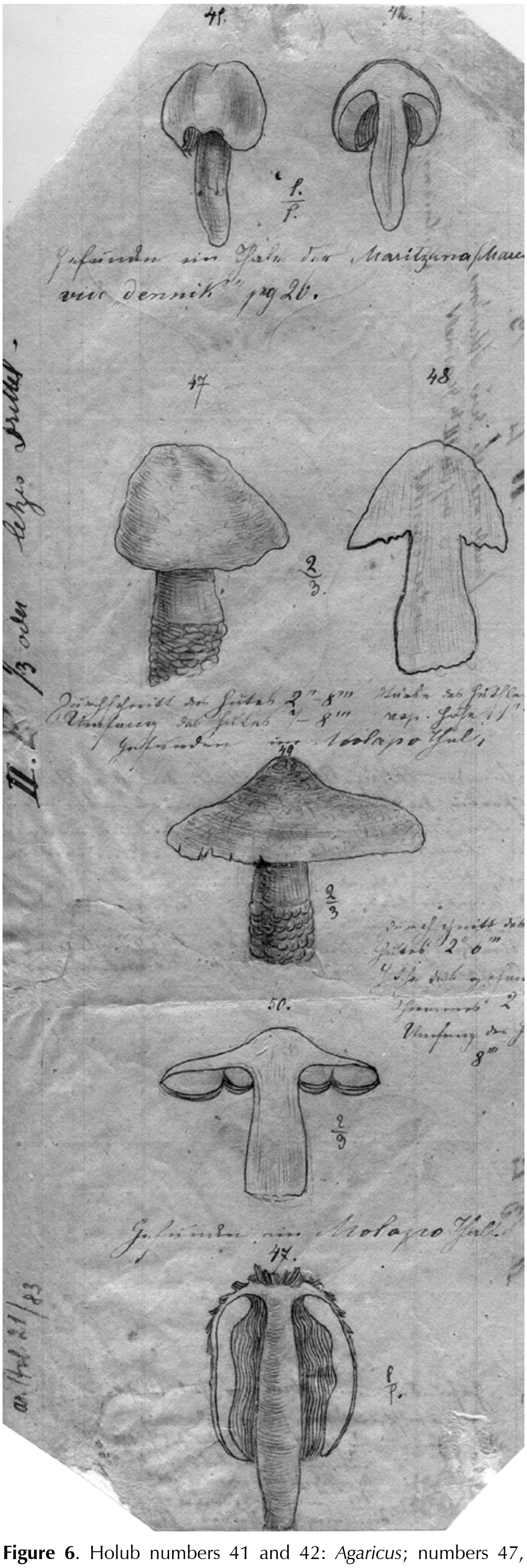

Figure 6. Holub numbers 41 and 42: *Agaricus*; numbers 47, 48, 49 and 50: *Termitomyces*; duplicated no. 47: *Coprinus comatus*.

the valley of Maritzana/ …. [Marikana?]', 'from diary page 26.' It is not certain what the 'fraction' represents, but it possibly means life-size. The next four pictures (numbers 47, 48, 49 and 50), show another *Termitomyces*, possibly *Termitomyces schimperi* (Pat.) R.Heim 1942, judging from the details of the stipe and its general robust habit. The first two are labelled 'Cross-section of cap 2" 8''', circumference of cap 7" 8'''…1" 6'''. Found in the Molapo Valley.' The note between pictures 49 and 50 reads 'Cross-section of cap 2" 6'''. Height of the found mushroom 2"…Circumference of the cap…8''' found in the Molapo Valley.' Unfortunately, the right-hand side of the scanned image is missing.

The picture at the bottom of Figure 6 has a duplicated 'no. 47' and looks like a cross-section of the *C. comatus*, which appeared in Figure 5. There are no notes pertaining to this sketch, but the annotation on the left-hand side may be a brief cross-reference to Holub's notes e.g., 'Hol. 21/83.' Perhaps it alludes to a page in his diary or a collection item no. 21. Similar annotations are to be found on many of Holub's sketches.

Figure 7 (Holub no. 52) shows the meticulous detail of what we believe to be the non-mycorrhizal *Amanita pleropus* (Kalchbr. & MacOwan) D.A.Reid. It is labelled 'found in the Molapo Valley. Circumference of the cap 16" 6'''. Cross-section through the cap 5" 2'''. Length of the '…rundes' 6" 4''' ". The last sentence cannot be deciphered, but the size of the feature (6''') may refer either to the ring on the stipe or to the basal structure. The latter is very interesting and must have been remarkable enough for Holub to make a point of illustrating it. First impression suggests a small volva or volval remains typical of an *Amanita*, but mycelia tufts may

Figure 7. Holub no. 52: possibly *Amanita pleropus*.

also be present at the base of *Macrolepiota* species (pers. observation Cathy Sharp), a feature not often noticed unless the substrate litter is carefully brushed off.

3. Pandamatenga, Zimbabwe, 1875–1876.

The historical site of Pandamatenga occupied the crest of a low hill overlooking riverine vegetation and open grassland at the headwaters of the Matetsi River, a tributary of the Zambezi (G. Macdonald pers. comm.). The vegetation further north along the trail is predominantly Kalahari sand teak woodland with scattered *Brachystegia boehmii* Taub. and *Julbernardia globiflora* (Benth.) Troupin. It is in this woodland that ectomycorrhizal fungi were encountered by Holub and some of his drawings depict these genera (Figures 8 & 9). Additional patches of mopane (*Colophospermum mopane* (Benth.) J.Léonard) grow on black clay and cut across the sand in an east–west direction, often forming pans and vlei areas, which are water-logged in the rainy season.

Figures 8, 9 and 10 illustrate some of the fungi that Holub encountered in the 'Leshomo' Valley, north of Pandamatenga. The Upper Leshumo Valley is stony and dominated by *Combretum* vegetation and te upper reaches of the Leshumo River are flanked by teak woodland on sand, with some *Brachystegia* species and *J. globiflora*. This area is within easy walking distance of where Holub would have been camped away from the tsetse fly during January and February of 1876, and the ectomycorrhizal mushrooms that he sketched would have been fruiting at that time.

Dropping into the valley northwards, the current habitat is *Vachellia tortilis* (Forssk.) Galasso & Banfi woodland growing on grey alluvial soil, although remnants of huge *Faidherbia albida* (Delile) A.Chev., seen in 2018, suggest that these trees may have been more prevalent in Holub's time. Towards the confluence of the Leshumo and Zambezi rivers the vegetation opens out into clumps of *Boscia* spp. and regenerating *Vachellia* and *Senegalia* species. These low-lying plains became impassable during the rains and were in a belt that had tsetse fly, hence Holub and the traders and missionaries who came this way were forced to leave their wagons up-country in the Upper Leshumo Valley.

The following is Holub's description of the Leshumo Valley: "…slightly hilly, only several hundred metres wide, covered with high grass and park-like woods and is bordered on both sides by high laterite ridges. At the end of Valley a spur of the left laterite ridge stretches towards the right one. This heavily wooded spur was supposed to be the remaining tsetse area whereas flat part covered with grass, bush and shrubs was supposed to be free of tsetse from spurs to Chobe and Zambezi rivers….'

Figure 8 is labelled: 'Sponge mushrooms of the upper Leshoma Valley and its immediate surroundings.' It shows a range of five species. Number 433 is *Parasola plicatilis* (Curtis) Redhead, Vilgalys & Hopple 2001, which is commonly found on old dung or well-rotted wood. Number 434 looks like an ectomycorrhizal *Russula* or it could be a *Clitocybe* with its slightly twisted stipe. Numbers 435 and 436 are two stages of development of *Leucoagaricus*, possibly *Leucoagaricus meleagris* (Gray) Singer 1949, (syn. *Leucocoprinus meleagris*). The drawing shows a particular attachment to an unknown substrate, but in real life they are usually found on dead wood. Number 437 is a *Lentinus*/*Panus*, possibly *Panus neostrigosus* Drechsler-Santos & Wartchow 2012 (syn. *Lentinus strigosus*), which is very common and has a characteristically short stipe. Number 438 could be *Laccaria*, another ectomycorrhizal species, but this is usually associated with *Eucalyptus* trees, none of which would likely have been in that area in Holub's time. More recently there have been a few collections that might be indigenous species, but this genus has been little-studied in Africa.

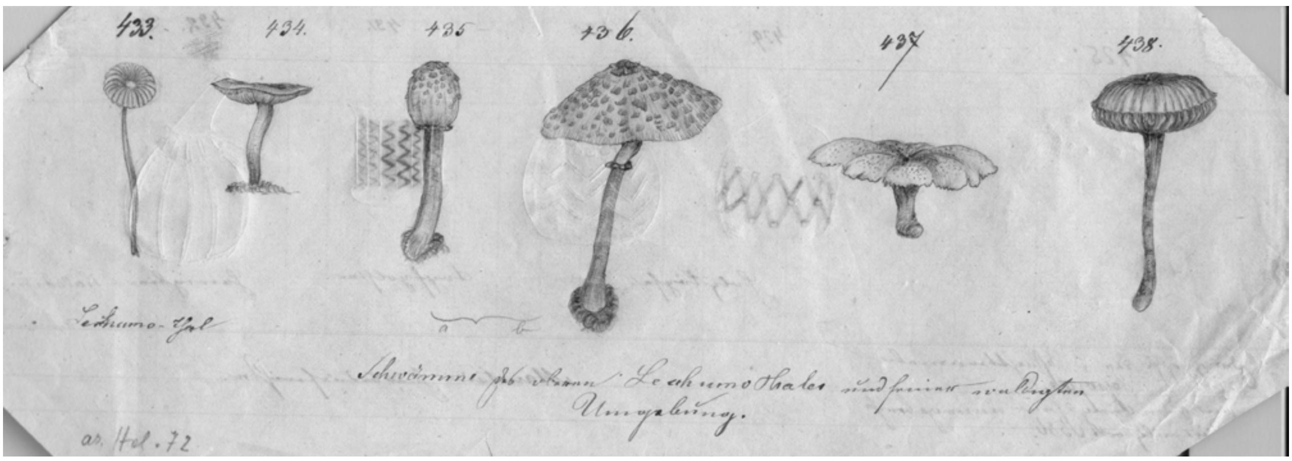

Figure 8. Holub no. 433: *Parasola plicatilis*; no. 434: *Russula*? *Clitocybe*?; numbers 435 and 436: *Leucoagaricus*; no. 437: *Lentinus/Panus*; no. 438: *Laccaria*?

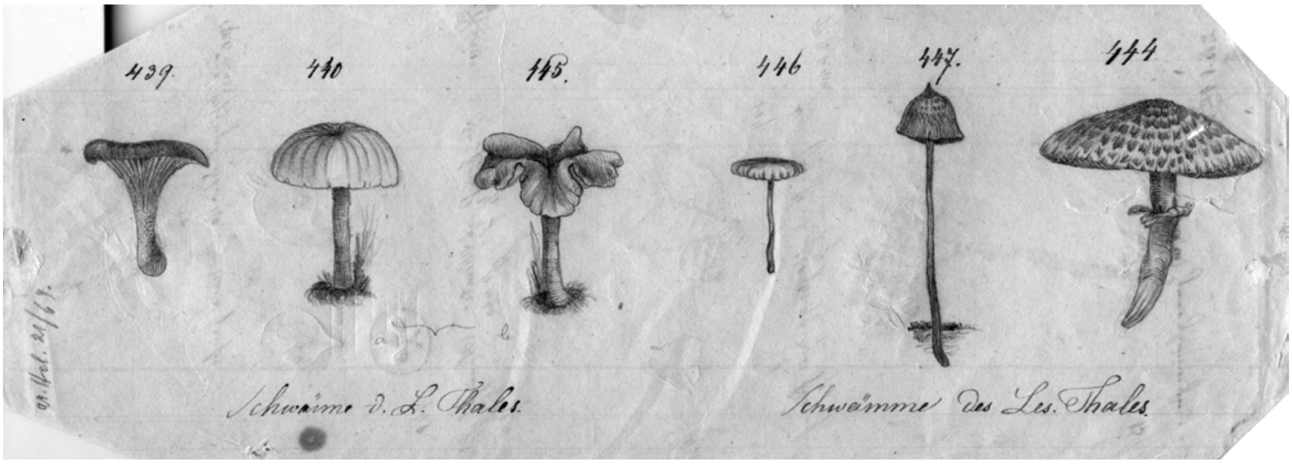

Figure 9. From left to right, Holub no. 439: *Cantharellus*; no. 440: *Laccaria*?; no. 445: *Laccaria*? *Cantharellus*? *Lepista*?; no. 446: *Marasmius*/ *Collybia*; no. 447: *Entoloma*? *Marasmius*?; no. 444 *Agaricus*.

Figure 9 shows six different species of 'Sponge mushrooms of the Leshoma Valley.' Number 439 looks like the ectomycorrhizal *Cantharellus miomboensis* Buyck & V.Hofst. 2012 with a roughly textured stipe. The mushroom depicted as no. 440 is possibly another *Laccaria* in mid-stage of growth. As Holub linked numbers 440 and 445 with curled brackets and 'a'–'b', these may be the same mushroom at different stages. This genus is known to be very variable in Europe (A. Verbeken, pers. comm.) but there is limited information on the indigenous species (Sharp, unpublished). On its own, no. 445 has similarities to *Cantharellus platyphyllus* Heinem. 1966 or *Cantharellus splendens* Buyck 1994 and to *Lepista*, so it is hard to ascertain the precise identity. Number 446 with its twisted stipe is likely to be *Marasmius* or *Collybia*. Number 447 is possibly an *Entoloma* or *Marasmius,* while no. 444 is an *Agaricus*.

Figure 10 shows another range of mushrooms from 'Leshoma Valley'. *Agaricus trisulphuratus* Berk. 1885 is clearly illustrated in three stages of growth, (Holub numbers 458, 459 and 460). This striking orange species is found in open patches of bare, clay-enriched, damp ground. Number 461 may be a tiny species of *Podoscypha*, which is associated with sedges and fine grass species. It is often encountered in open, damp grassland or wetlands, and is common throughout Zimbabwe. However, it may be an *Ascomycete* (A. Verbeken, pers. comm) or an *Omphalina*-like species, none of which have been fully studied in Africa. Number 462 is *Leucoagaricus* sp., which is common in open grass habitats. Number 466 could be any one of three genera: *Pluteus*, *Entoloma* or *Mycena*.

A summary of the species shown in Holub's drawings with their localities is shown in Table 2.

While visiting Victoria Falls (September 1875 or October 1885), Holub collected a rust-fungus on one of the *Dracaena* species (Dracaenaceae), growing along the Zambezi River, probably in the rain forest. Many years later this was identified and named by Ethel Doidge as a new species in the Pucciniaceae rust family, *Uromyces holubii* Doidge 1941 (Doidge 1941).

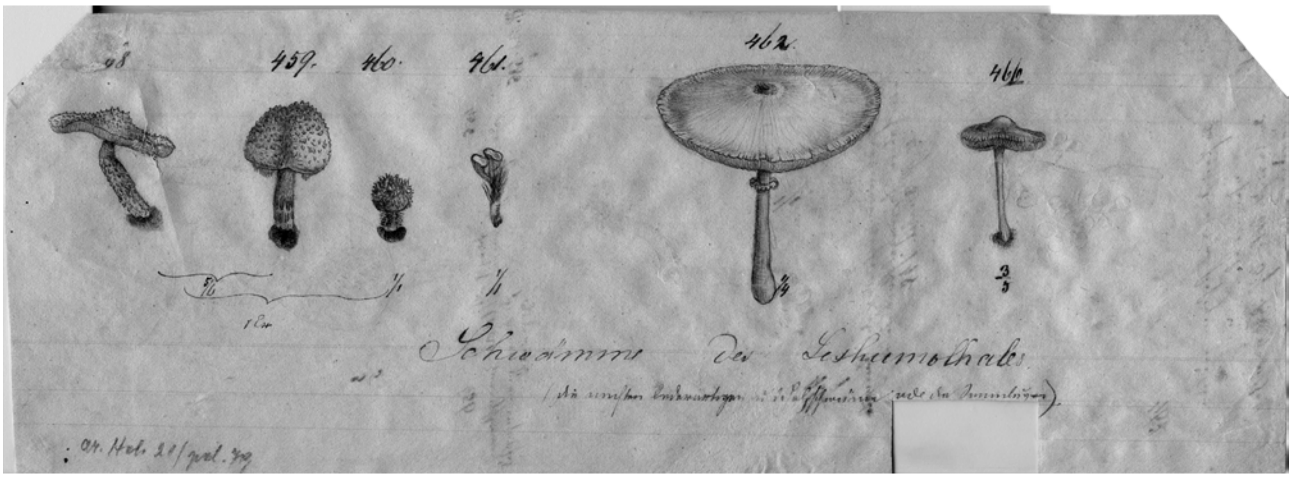

Figure 10. From left to right, Holub Numbers 458, 459 and 460: *Agaricus trisulphuratus*; no.4 61: *Podoscypha*? Ascomycete? *Omphalina*-like?; no. 462: *Leucoagaricus*; no. 466: *Pluteus*? *Entoloma*? *Mycena*?

Table 2. Summary of the figures with number of drawings, number of species depicted and their respective localities. SA = South Africa; Zim = Zimbabwe

Fig. no.	No. of drawings	No. of species	Country
2	1	1	SA – Vaal–Harts rivers
3	3	1	SA – Kimberly area
4	3	2	SA – Mahikeng
5	3	2	SA – Mahikeng
6	7	3	SA – Mahikeng
7	1	1	SA – Mahikeng
8	6	5	Zim – Leshumo
9	6	6	Zim – Leshumo
10	6	4	Zim – Leshumo
Results:	Total of 36 drawings	Total of 24 species (one duplicated in a separate figure)	SA – 9 species Zim – 15 species

Some of Holub's fungi collections appear to have been sent to Germany, because discovered amongst them was a new species that was named *Broomeia ellipsospora* Höhn. 1905 (von Höhnel 1905; Doidge 1950). It is unknown when or where Holub collected this particular specimen, but the species has since been found in both South Africa and Zimbabwe.

Conclusion

Emil Holub's mushroom drawings constitute a valuable collection of natural history records. They give us insight into the finer details of the ecosystems through which he passed in the nineteenth century. Unlike most travellers of that time, he was more than a hunter and trader, and brought with him a sound knowledge and genuine interest in a variety of natural and social sciences.

This paper exposes some of the fascinating fungi illustrations that can be found in Holub's hitherto unanalysed papers in Prague. Undoubtedly some of these illustrations are of his specimens that are possibly now housed in one of the many museums across Europe in which he deposited collections. With these illustrations alone we have a valuable contribution to science, but it would be ideal to link them with their voucher specimens.

This alerts us to the probable existence of many inadequately documented collections housed in herbaria and museums throughout the world that hold valuable information, which needs to be studied and published. Revealing these mushroom drawings done by Emil Holub in the 1870s, and exploring their content, is a start to bringing this information to light.

Acknowledgements

The Czech Embassy in Harare facilitated the visit of one of us to the Náprstek Museum in Prague during which time these sketches, amongst many other fascinating subjects, were identified. We must thank Ambassador Jaroslav Olša, Jr for his interest in encouraging us to explore the forgotten legacy of Emil Holub. Helga Landsmann is thanked for the time-consuming translation of Holub's notes accompanying the mushroom drawings. Gordon Macdonald, Roger Parry and Armston Tembo kindly provided information about the Pandamatenga, Leshumo and Kazuma areas respectively. Judy Ross's assistance on the field trip in 2018 was invaluable. Martin Sanderson is thanked for his efforts in deciphering Holub's measurements. We are grateful for Annemieke Verbeken's assessment of the identity of the mushrooms. Wild Horizons staff, particularly Richard Nsinganu, are thanked for their interest and support during the 2018 field trip. We are grateful for comments and advice from anonymous reviewers.

Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

CS (Natural History Museum of Zimbabwe) was project leader for a series of articles on Mushroom Art in Zimbabwe, RSB (Natural History Museum of Zimbabwe) recognised the value of Holub's drawings and requested copies while on an independent visit to Prague.

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ISSN: (Online) 2311-9284, (Print) 0006-8241

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FORMATTING

Manuscripts must be submitted as a MS Word document. Documents compiled in other software, including Google Documents, cannot be accepted.

Low resolution versions of figures and tables can be inserted into the document. High resolution of figures must, however, also be included separately, with each figure as a separate, appropriately labelled file (see details of requirements for figures below).

Please do not use hidden formatting, including character styles in the manuscript. Also avoid nested tables and text boxes. Many of these cause corruptions in the design software, and can usually be avoided if authors refrain from copying and pasting from various sources, including other MS Word documents.

- **Language:** Manuscripts must be written in British English. Avoid Americanisms (e.g. use 's' and not 'z'). Consult the Oxford English Dictionary when in doubt and remember to set your version of Microsoft Word to UK English.
- **Line numbers:** Insert continuous line numbers.
- **Font:**
  - **Font type:** Times New Roman
  - **General font size:** 12pt
- **Line spacing:** 1.15
- **Headings:** Ensure that formatting for headings is consistent in the manuscript.
  - First headings: normal, bold and 14pt
  - Second headings: normal, bold and 12pt
  - Third headings: normal, underlined and 12pt
  - Fourth headings: normal, bold, running-in text and separated by a colon, and 12pt.

Scientific names: Names of genera and infrageneric taxa are italicised, with the author citation not italicised. Exceptions include specific cases in taxonomic treatments (see details of such manuscripts below); new taxa in the abstract; and in checklists where the position is reversed – correct names are not italicised and synonyms are italicised. Names above generic level are not italicised. The complete scientific name of a species as well as the author citation should be given at the first mention in the text. The generic names should be abbreviated to the initial thereafter, except where references to other genera with the same initial could cause confusion.

Authors of botanical names are abbreviated according to Authors of Plant Names (Brummitt & Powell 1992, Royal Botanic Gardens, Kew).

In names covered by the International Code of Zoological Nomenclature, the date of publication should be separated from the authority by a comma (e.g. *Anthomyza bellatrix* Roháçek, 1984). When a species or subspecies is transferred to a genus other than that in which it was first classified, the original authority, including the date, is placed in parentheses.

Adjectives and nouns derived from genus names become Roman with a lower case initial (e.g. *Felis*→feline, *Libellula*→libellulids, *Streptococcus*→streptococcal infection).Those derived from higher taxonomic groups also begin with a lower case letter and are presented in Roman (e.g. Ostracoda→ostracods, Cactaceae→cacti).

A scientific name given at its first mention after a vernacular name should be separated from it by a comma if the two names are exact synonyms (e.g.…the two-spotted cricket, *Gryllus bimaculatus*,…), but not if the vernacular name may apply to more than one species (e.g. the starfish *Asterina pectinifera*, the medaka *Oryzias latipes*).

Abbreviations should be used sparingly but consistently. No full stops are placed after abbreviations ending with the last letter of the full word, after units of measure, after compass directions, after countries and after well-known institutions.

FIGURES AND TABLES

The word Figure should be written out in full and should begin with a capital F, in both the text and captions.

Figures (original or electronic submissions):

- Figures should be planned to fit, after reduction, into a width of either 80, 118 or 165 mm, with a maximum vertical length of 230 mm. Allow space for the caption in the case of figures that will occupy a whole page.
- Graphics, i.e. drawings, graphs or photographs, should be submitted as separate files. Low resolution copies of the figures should be included in the manuscript for review purposes.
- If extensive changes to image files are proposed by the editor, the author will be contacted and the specific image file will have to be re-submitted after the indicated corrections have been implemented.
- Scale bars or scale lines should be used on figures where relevant.
- Captions should not be added as part of the figure file. Number captions clearly and correctly and include either in the main text close to where the figure should be inserted or as a list of captions at the end of the text; not as a separate document.
- Authors wishing to use illustrations already published elsewhere must obtain written permission before submitting the manuscript and provide this to the editor at the time of submission, along with appropriate acknowledgements.
- Do not resample low resolution images to a higher resolution.
- Mosaics should be submitted as separate photographs as TIF/JPG files at 600 dpi or higher. A mockup of the layout should also be submitted. Final layout of the mosaic will be done by our graphics department. Do not number the original images, but do include a scale bar. Indicate the lettering on the mockup and not on the original photographs.
- Manuscripts for which the figures, including line drawings, photographs, graphs and histograms, and maps, do not comply will be rejected for design and layout, even though the paper was accepted for publication, until such time that the authors can provide suitable images. This can significantly delay publication.

Line drawings:

- The original artwork should be in jet-black Indian ink, on fine art paper, 200 gsm. Lines should be clear enough to accommodate reduction. Do not use draughtman's film.
- Drawings in pencil will not be accepted.
- Provide original drawings electronically as bitmap TIF files, 1200 dpi.
- At the request of the author, the Graphic Design Section of SANBI will assist with the scanning of original material. Authors wishing to have the originals of figures returned must inform the editor in writing and mark each original 'To be returned to author'.

Photographs:

- Provide photographs electronically as either TIF or JPG files, 600 dpi or higher.

Graphs and histograms:

- The typeface for all graphs and histograms is Arial.
- Provide graphics originated in CorelDraw (version 16 or lower), as a .CDR file.
- Graphs and histograms generated in MS EXCEL or MS Word, should be provided as is. File conversion into the correct format will be accommodated by SANBI Graphics.
- Images generated in other programmes should be submitted as TIF or JPG files at a resolution of 600 dpi or as encapsulated postscript files (.EPS). If graphs and histograms are submitted in colour, please ensure that the shading used is easily discernible once the file is converted to grayscale.

Maps:

- It is strongly recommended that taxonomic articles include dot maps as figures to show the distribution of taxa. If maps will be reduced to column width (80 mm), the symbols and numbers used must be large enough to accommodate the reduction. The maps should show: numbered grid lines of latitude and longitude; the provinces of South Africa; and a scale line. Maps of neighbouring countries should be treated in the same way, with bordering states clearly labelled. For orientation purposes, a small inset map should appear in a corner of the figure.
- Submit maps electronically as either TIF or JPG files, 600 dpi or higher.
- ArcView GIS maps are acceptable. The layout representing all the appropriate themes (including grid lines) should be submitted as an encapsulated postscript file (.EPS).
- If maps are submitted in colour, please ensure that the shading used is easily discernible once the file converted to grayscale.

Tables:

- Tables should be drawn up in MS Word and not copied and pasted from other software such as MS Excel.
- Avoid copying and pasting text into the table as this often result in nested tables that are problematic to format and edit. Type in all text from scratch.

- Do not submit tables as text with separators such as tabs or commas, submit as MS Word standard tables.
- Do not include text boxes in table cells, type text directly in the primary table cell.
- Use Times New Roman 12pt if possible. However, should the width of the columns and the amount of text make this difficult, the size of the font may be reduced to no less than 9pt.
- If possible, present tables in portrait format. However, if tables must be presented in landscape format, use section breaks before and after the tables to separate it from the main text.
- Do not stretch the table to beyond the size of the paper on screen.
- Use the background fill function to shade cells if necessary. Do not use text highlights.

STRUCTURE OF YOUR ARTICLE

Page 1:

The format of the compulsory cover letter forms part of your submission and is on the first page of your manuscript and should always be presented in English. You should provide all of the following elements:

- **Article title:** Provide a short title of 50 characters or less.
- **Full author details:** Provide title(s), full name(s), position(s), affiliation(s) and contact details (postal address, email, telephone and cellular number) of each author.
- **Corresponding author:** Identify to whom all correspondence should be addressed to.
- **Authors' contributions:** Briefly summarise the nature of the contribution made by each of the authors listed.
- **Summary:** Lastly, include a list containing the number of words, pages, tables, figures and/or other supplementary material with the submission.

Page 2 and onwards:

Title: The article's full title should contain a maximum of 95 characters (including spaces).

Abstract: The abstract, written in English, should be no longer than 250 words and must be written in the past tense. The abstract should give a succinct account of the background, objectives, methods, results and significance of the findings/conclusion

Do not cite references in the abstract and do not use abbreviations excessively in the abstract.

The following points serve as a guide for presenting your manuscript in a well-structure format:

Introduction: The introduction contains two subsections, namely the background section and the literature review.

- **Background:** This section should be written from the point of view of the readers, including those without specialist knowledge in that area and must clearly state and illustrate the introduction to the research and its aims in the context of previous work bearing directly on the subject. The Background section to the article normally contains the following five elements:
  - **Key focus:** A thought-provoking introductory statement on the broad theme or topic of the research.
  - **Context:** Provide the context to the study, which can include the conceptual framework or explain the role of other relevant key variables in this study.
  - **Trends:** Cite the most important published studies previously conducted on this topic or that have any relevance to this study (provide a high-level synopsis of the research literature on this topic).
  - **Objectives:** Indicate the most important controversies, gaps and inconsistencies in the literature that will be addressed by this study. In view of the above trends, state the core research problem and specific objectives that will be addressed in this study.
  - **Contribution to field:** Explanation of the study's academic (theoretical and methodological) or practical merit and its importance (provide the value-add or rationale for the study).
- **Literature review:** The literature review is the second subsection under the Introduction and provides a brief and concise overview of the literature under a separate second-level heading, e.g. literature review. A synthesis and critical evaluation of the literature (not a compilation of citations and references) should at least include or address the following elements (ensure these are in the literature review):
  - Definitions of all key concepts.
  - A critical review and summary of previous research findings (theories, models, frameworks, etc.) on the topic.
  - A clear indication of the gap in the literature and for the need to address this void.
  - A clearly established link that exists between formulated objectives and theoretical support from the relevant literature.

Research method and design (first-level heading):

The methods should include:

- **Materials (second-level heading):** Describe the type of organism/s or material/s involved in the study.
- **Study site (second-level heading):** Describe the site and setting where your study was conducted.
- **Design (second-level heading):** Describe your experimental design clearly. Note: Additional details can be placed in the online supplementary location.
- **Procedure or Methods (second-level heading):** Describe the protocol for your study in sufficient detail (with a clear description of all interventions and comparisons) so that other scientists could repeat your work to verify your findings.

- **Analysis (second-level heading):** Describe how the data were summarised and analysed. Additional details can be placed with the online supplementary information. Do not include lists here as they will be published as supplementary material.

Ethical considerations (first level heading):

- **Ethical clearance (second-level heading):** Articles based on the involvement of animals and/or humans must have been conducted in accordance with relevant national and international guidelines. Approval must have been obtained for all protocols from the author's institutional or other relevant ethics committee and the institution's name and any ethics certificate number/s should be provided at submission.
- **Risks or negative impacts associated with research and mitigation (second-level heading):** This section should consider any risks or negative impacts to the subjects caused by the project (the subject may be a human individual or a population of plants or animals). What precautions were taken to minimise any negative impacts of the research on the subject/s?
- **Permitting (second-level heading):** Projects that required permits for collection, transport or provision of material must provide all relevant permit details.
- **Recruitment and informed consent (second-level heading):** In the case where human subjects were involved, how were subjects recruited? Was there any sense in subjects being obliged to participate or were volunteers recruited. Authors must include how informed consent was handled in the study.
- **Data protection (second-level heading):** Authors must include, in detail, the way in which data protection was handled.

Results (first-level heading):

Results should be presented as follows:

- Present the results of your experiment(s) or research data in a sequence that will logically support (or provide evidence against) the hypothesis, or answer the questions / address the objectives, as stated in the introduction.
- Present the body of the results section in text with the key findings that include references to each of the tables and figures. Report statistical test summaries (test name, p-value) parenthetically (that is, inserted as a parenthesis in brackets) together with the biological results they support. Use the SI unit.
- All units should conform to the SI convention and be abbreviated accordingly. Metric units and their international symbols are used throughout, as is the decimal point (not the decimal comma).

Discussion (first-level heading):

This section normally contains the following four elements. It is suggested that subheadings are used in this section:

- **Outline of the results (second-level heading):** Restate the main objective of the study and reaffirm the importance of the study by restating its main contributions; summarise the results in relation to each stated research objective or research hypothesis; link the findings back to the literature and to the results reported by other researchers; provide explanations for unexpected results.
- **Practical implications (second-level heading):** Reaffirm the importance of the study by restating its main contributions and provide the implications for the practical implementation your research.
- **Limitations of the study (second-level heading):** Point out the possible limitations of the study and provide suggestions for future research.
- **Recommendations (second-level heading):** Provide the recommendations emerging out of the current research.

Conclusion (first-level heading):

This should state clearly the main conclusions of the research and give a clear explanation of their importance and relevance, with a recommendation for future research (implications for practice). Provide a brief conclusion that restates the objectives, the research design and the results with their meaning.

Acknowledgements (first-level heading):

If, through your study, you received any significant help in conceiving, designing or carrying out the work, or received materials from someone who did you a favour by supplying them, you must acknowledge their assistance and the service or material provided. *Authors should always acknowledge outside reviewers of their drafts and any sources of funding that supported the research.*

- **Competing interests (second-level heading):** A competing interest exists when your interpretation of data or presentation of information may be influenced by your personal or financial relationship with other people or organisations that can potentially prevent you from executing and publishing unbiased research. Authors should disclose any financial competing interests, but also any non-financial competing interests that may cause them embarrassment were they to become public after the publication of the manuscript.

  > *Where an author gives no competing interests, the listing will read:*
  >
  > 'The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this article.'

- **Authors' contributions (second-level heading):** This section is necessary to give appropriate credit to each author, and to the authors' applicable institution/s. The individual contributions of authors should be specified with their affiliation at the time of the study and completion of the work. An 'author' is generally considered to be someone who has made substantive intellectual contributions to a published study. Contributions made by each of the authors listed, can follow the example below (please note the use of author initials):

> J.K. (University of Pretoria) was the project leader, L.M.N. (University of KwaZulu-Natal) and A.B. (Stellenbosch University) were responsible for experimental and project design. L.M.N. performed most of the experiments. P.R. (Cape Peninsula University of Technology) made conceptual contributions and S.T. (University of Cape Town), U.V. (University of Cape Town) and C.D. (University of Cape Town) performed some of the experiments. S.M. (Cape Peninsula University of Technology) and V.C. (Cape Peninsula University of Technology) prepared the samples and calculations were performed by C.S. (Cape Peninsula University of Technology).

References (first-level heading):

Begin the reference list on a separate page with no more than 60 references for full length articles and 30 references for short notes. The *Bothalia – African Biodiversity & Conservation* Journal uses the **Harvard referencing style**. Note: no other style will be permitted.

If you use any reference editor to add citations in the text, <u>remove all data fields and replace with normal text before submission</u>.

For journal articles, provide DOIs for as many as possible (usually all papers published in or after 2000). The DOI reference can be provided after a comma at the end of each reference.

TAXONOMIC PUBLICATIONS

Bothalia – African Biodiversity & Conservation publishes taxonomic findings where these align with the scope and focus of the journal (see Scope and Focus of *Bothalia – African Biodiversity & Conservation*). For such works the following headings should be used:

The Abstract and Introduction must follow the guidelines for full length articles, as described above.

Research method and materials (first-level heading):

- **Materials (second-level heading):** Briefly explain from which institutions material was studied, and whether any fresh material was collected as part of the study. If field collecting did take place explain where this was carried out, over what time period and how samples were collected.
- **Procedure (second-level heading):** Explain how observations, measurements and illustrations were done, and what equipment was used.

Taxonomic treatments (first-level heading):

This section serves as a guide to understand and standardise the presentation of taxonomy in research articles and short communications.

More details of rules that must be adhered to can be obtained from:

- The International Plant Names Index at http://www.ipni.org/
- International Association for Plant Taxonomy at http://www.iapt-taxon.org/
- The International Commission for Zoological Nomenclature (http://www.iczn.org)

The following sequence and format must be followed for taxonomic treatments in *Bothalia – African Biodiversity & Conservation*:

Species treatments:

- Basionym (the first name validly published, which has priority over other names later given to the same species): **Name** (bold, not italicised), *author citation* (italicised), author/s of paper in which basionym stated (if different from original author, not italicised).
- Name of the journal/publication written out in full (not italicised), volume: page number/range (date of publication), fig/s.
- Type locality: COUNTRY (upper case), as provided in the original description. Type specimen/s: date of collection, *collector (italicised), collector number* (italicised) (where available), institution code (using global acronym), catalogue number (where available), status (holotype, isotype/syntype, lectotype). If specimen was examined, this is indicated by a '!' after the specimen status.
- Additional references, in chronological order, with author: page (year of publication), figure number/s reflected (e.g. Boris et al.: 14 (1966); Boris: 89 (1967), fig. 9.).
- List of synonyms in chronological order, arranged in groups of nomenclatural synonyms (i.e. homotypic synonyms (based on the same type), followed by heterotypic synonyms (based on a different type), arranged chronologically), with references cited as author, page (year of publication), and figure number/s listed in chronological order.
- Identification of illegitimate names in the nomenclatural component must be accompanied by an appropriate indication of the reason for their illegitimacy. The type details for each heterotypic synonym should be included (institution code followed by catalogue number where available and type status), and those specimens examined by the author/s

must be indicated by an exclamation mark. The full reference for citations must be included in the Reference List.

Examples:

1. **Eremiolirion amboense** (*Schinz*) *J.C.Manning & C.A.Mannheimer* in Bothalia 35: 117 (2005), fig. 4. Type: South West Africa [NAMIBIA], Amboland [**Ovamboland**], Ongangua [Ondongwa], without date, *Ruatanen 344* (Z.holo!).
2. **Walleria gracilis** (*Salisb.*) *S.Carter* in Kew Bulletin 16: 189 (1962). *Androsyne gracilis* Salsb.: 61 (1866). Type: SOUTH AFRICA, **Western Cape**, *William Marsden* [BM, holo!; drawing in Salisbury mss.8: 818 (BM)].

   W. armata Scltr. & K.Krause in Krause: 235 (1921). Type: SOUTH AFRICA, [**Western Cape**, near Klawer], [Farm] Windhoek, 8 July 1896, *R. Schlechter 8074* (B, holo [not seen]; BM!, BR!, COI!, GRA!, K, MO!, PRE!, S!. iso).
3. **Plagiotaphrus improvisus** *(Attems 1934) Hoffman* in Revue de Zoologie et de Botanique Africaines, 83 (3–4): 209 (1971), fig. 2. *Megaskamma improvisa:* Attems: 16: 13 (1934), figs 14–17. Type: **ANGOLA**, near Cuanza River, Biėi District, Jan. 1932, *F. Haas* (SMF 1694, holo. [not seen] 1 male).

- Lectotypes or neotypes should be chosen for correct names without a holotype. It is not necessary to lectotypify synonyms. When a lectotype or neotype is newly chosen, this should be indicated by using the phrase "here designated". If reference is made to a previously selected lectotype or neotype, the name of the designating author and the literature reference should be given. In cases where no type was cited, and none has subsequently been nominated, this may be stated as "not designated".

Description of new taxa:

- All newly described taxa and newly proposed synonyms and new combinations should be explicitly designated as such, e.g. fam. nov., trib. nov., gen. nov., sp. nov., nom. nudem., syn. nov., comb. nov.

  Name (bold, not italicised) sp. nov. authority (if different to the authors of the manuscript)

  TYPE/S: (holotype followed by paratype/s) (COUNTRY (upper case), **province** (bold), locality as given by original collector (if in foreign language or using archaic or outdated place names then these must be placed in inverted commas, with modern equivalent of collecting locality in square brackets (if relevant)), geographic co-ordinates (if the geographic co-ordinates were not provided on the specimen label or provided by the collector, and were identified by the author using a gazetteer or Google Earth, this must be indicated by including the co-ordinates in square brackets, altitude, habitat or other available, relevant collecting details, date of collection, *collector's name (italicised), collector's number (italicised*) (if available), (institution where specimen is housed (using global acronyms for these), catalogue number (if available), number of specimens by male and female (where relevant)).

  Examples

1. **Lasiosiphon rigidus** J.C.Manning & Boatwr., sp. nov.

   TYPES: SOUTH AFRICA, **Northern Cape**, Tankwa [Tangua] Karoo National Park, SW foot of Leeuberg, along drainage lines, [32°18,2'S / 20°0.3'E, 414 masl], 20 Jun. 2012, *Manning 3363* (NBG, holo., MO, PRE, iso).
2. **Doratogonus microsetus** sp. nov.

   TYPES: SOUTH AFRICA, **Mpumalanga**: Wakkerstroom, 27.36670°S / 30.01670° E, 20 Dec, 2000, *D. Forbes (*NMSA 21786, 1 male holo.; NMSA 21787, 2 males, 1 females, para.).

Second-level headings for taxonomic treatments:

- Description (with third-level headings if required, and according to diagnostic characters for the particular taxon)
- Distribution and habitat
- Ecology
- Etymology
- Local name/s
- Uses / economic value
- Diagnosis and relationships
- Conservation status – comment on whether included in existing Red Lists, or whether the species would potentially qualify as threatened and describe current and potential threats.
- Other material examined (country (upper case), province (bold): locality as given by original collector, modern equivalent of collecting locality in square brackets (if relevant), co-ordinates (degrees, minutes

decimal) (in square brackets if gazetteer or Google Earth used by author), approximate altitude, date of collection, *collector's name (italics), collector's number* (italics) (if available) (institution where specimen is housed (using international acronym or code for these), catalogue number (if available), number of specimens by male and female (where relevant)).

- List of specimens must be arranged alphabetically by country, and within countries, by province in alphabetical order, and within provinces, alphabetically by locality name, and as far as possible keeping those specimens from the same locality together, then in chronological order by collection date.
- Herbarium acronyms follow Index Herbariorum [Thiers, B. [continuously updated]. Index Herbariorum: A global directory of public herbaria and associated staff. New York Botanical Garden's Virtual Herbarium. http://sweetgum.nybg.org/ih/]. The accepted acronyms for other institutions can be obtained from the Global Registry of Biorepositories (GRBio) (http://grbio.org).
- Original locality information in a foreign language or using archaic/outdated place names should be indicated using inverted comas, with any relevant corrections for modern usage, including conversions to metric units, added in square brackets.

  The date of collection is to be presented as day, month of the year (abbreviated as Jan., Feb., Mar., Apr., May, Jun., Jul., Aug., Sept., Oct., Nov., Dec.), and year in full.

  Geographic co-ordinates must be presented as taken from a GPS, or from an online gazetteer or georeferencer in degrees, decimal minutes (DDM). Records must also indicate the hemisphere (E or W and N or S, and the estimated/approximate altitude. If the geographic co-ordinates and approximate altitude were not provided on the specimen label or provided by the collector, and were identified by the author, this must be indicated by including the co-ordinates in square brackets.

  For species that may be threatened by over-collecting, the co-ordinates can be degraded to reflect only the degrees and minutes. In the case of old specimens where the exact locality is unknown the degree and minutes or equivalent, or the degree or quarter degree grid square can be provided.

  Examples:

  1. SOUTH AFRICA. **Western Cape**: Near Eendekuil, western foot of Piekenierskloof Pass, [32°37.136'S / 18°57.525'E 476masl], 28 Aug. 2009, *Magee, Boatwright, Manning and Goldblatt 161* (NBG, PRE, K, BOL); roadside near Gouda, [33°37.136'S / 19°2.044'E, 85masl], 09 Sept. 1951, *Esterhuysen 18840* (BOL [3 sheets], K, PRE).Tulbagh, 33°17.126'S / 19°8.257"E, 162masl, Sept. 1919, *Bolus 16734* (BOL);
  2. SOUTH AFRICA: **KwaZulu-Natal:** Nkandhla Forest, in forest along dirt road, 28º43'38.592"S / 31º07'58.281"E, 1121 masl, 19 Nov, 2001, *A. Armstrong & H. Murray* (NMSA 21970 [1 male, 1 female]).

Language for these sections must be as concise as possible, using principles instead of verbs.

The remaining first-level headings (Discussion, Conclusions, Acknowledgements, Competing interests, Authors' contributions and References) must follow the same format as for full length articles, as detailed above.

Images – low resolution version in the text file; high resolution files – correctly labelled – as separate JPG, TIF or EPS files.

Identification keys: Dichotomous keys must use sequential numbering, with the two parts of the couplet numbered 1a, b; 2a, b etc. New species included in keys must be bolded and not italicised, and sp. nov. must be stated, while other species names must not be bolded, must be italicised, and must include the species authority in the correct format.

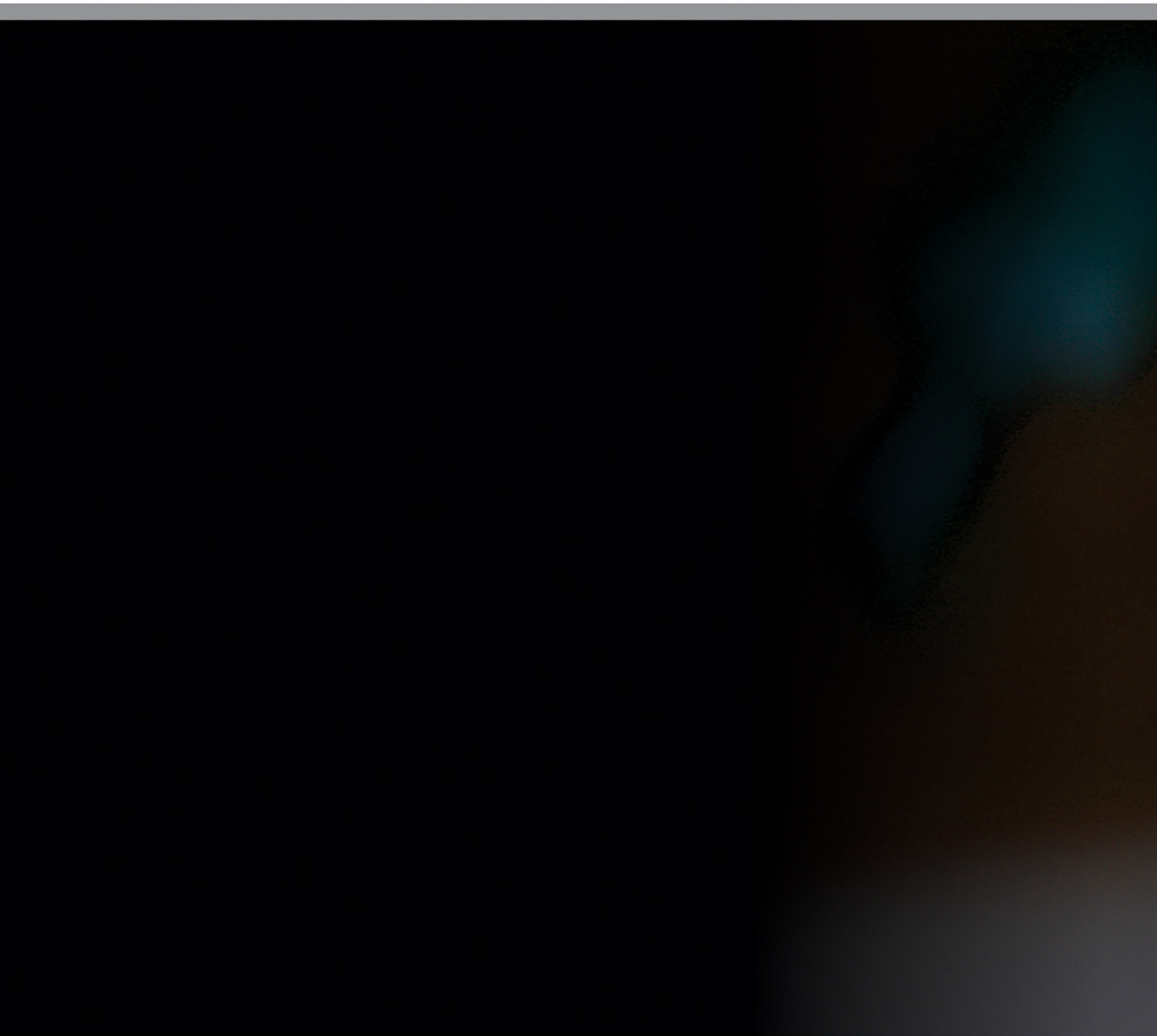
Illustrations for taxonomic works: Descriptions of new plant species should include a photograph of the holotype specimen, unless there is a good reason for not providing this. For all taxa, descriptions of new species and taxonomic revisions should include annotated illustrations that clearly show and indicate diagnostic characters.

Nomenclatural changes

Bothalia – African Biodiversity & Conservation will accept notes on nomenclatural changes. Authors are encouraged to include all name changes into a single manuscript and not to split these into separate manuscripts. Note that where a nomenclatural changes are a formality, and not based on research findings presented, the manuscript may not be subjected to a full review process. In such cases the publication will clearly state that the paper has not been peer reviewed.

Range extensions / new distribution records

Bothalia – African Biodiversity & Conservation will accept new distribution records where these have an impact on the conservation status of a species, or they represent a new country record. Single new distribution records will only be considered for publication where these are of major significance, and authors are encouraged to compile all new distribution records into a single manuscript and not to split these into several papers.



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