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Criteria for biodiversity special value zones in the Sperrgebiet – plant endemism and species richness measures in practice

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ABSTRACT

Zoning protected areas for management purposes usually requires a base layer representing biodiversity and ecological criteria. This study illustrates a systematic process of assigning special value zones within the Tsau||Khaeb (Sperrgebiet) National Park. Clearly defined criteria resulted in fourteen areas of very high biodiversity importance. These are the Kowis mountains, Lüderitz peninsula, Tsaukhaib-Haalenberg inselbergs, Grillental-Pomona corridor, Boegoeberg, Klinghardt mountains, Tsaus mountain, Heioab-Aurus mountain range, Chamnaub inselbergs, Rooiberg-Nudavib mountains, Skorpion inselbergs, Obib mountains, Schakalsberge and the Orange River valley.

Keywords: Aurus mountains; conservation planning; Namibia; protected area; range-size; southern Namib; Sperrgebiet; Succulent Karoo Biome

INTRODUCTION

Zoning protected areas uses criteria related to biodiversity and ecological functioning as the base layer. In this context plants are often used as indicators (Pearman & Weber 2007; Mandelik *et al*. 2010; Ferreira *et al*. 2013). As primary producers they form the basis for most terrestrial ecosystems. Relatively evenly spread spatial data are more readily available for them than for most other groups of taxa. This is certainly the case in the Tsau||Khaeb (Sperrgebiet) National Park, where the park was recently zoned for management purposes. This article focuses on the biodiversity component of this zoning exercise. In addition to data availability, plants have an even greater importance in this park, as this is the northern tip of the Succulent Karoo Biome, a world-renowned biodiversity hotspot. This hotspot was assigned on the basis of plant species richness and endemism as well as threats to the biome (Mittermaier *et al*. 2004). Plant species richness, endemism and protection status were therefore used as the prime criteria for identifying biodiversity special value zones (Ministry of Environment & Tourism 2019) within the park. The objective of this article is to document the reasoning for assigning biodiversity special value zones based on clearly defined criteria.

Study area

The park is situated in the south-western most corner of Namibia and the northern-most tip of the Succulent Karoo Biome. Historically created as a buffer zone for the diamond mining industry, the area has been virtually inaccessible since 1908 to anybody except for staff and services related to the mining industry. Less than 1 % (approximately 0.7 %) of this vast area (some 2.1 million hectares) has been directly disturbed by mining, but exploration and service infrastructure, largely inside the mining licence areas along the Orange River and the coast, tell a story of over hundred years of man's quests for diamonds. Large areas away from these diamond deposits are nearly pristine. Today they present the only large, continuous section of Succulent Karoo Biome which has not been altered by livestock grazing; except for areas along the eastern boundary of the park, which were used for emergency grazing until the early 1980s.

The park harbours over 1,000 plant species which is nearly one quarter of the entire flora of Namibia (Burke & Mannheimer 2004). A healthy population of brown hyena is present in the park which shows behavioural patterns different from other brown hyenas in southern Africa, due to the cool, coastal environment and reliance on seals as the main food source (Wiesel 2010). Although large mammal diversity is lower than in most other parks, large populations of gemsbok and springbok occur, as well as a largely unstudied and expected to be varied reptile, small mammal and invertebrate fauna. The Orange River Mouth is a declared Ramsar site supporting wetland bird populations which also extend to and move along the coastal section of the park.

The climate of the study area is arid with a largely moderate temperature regime. Average annual

rainfall ranges between zero and approximately 80 mm. The annual mean rainfall at Lüderitz is 17 mm, at Oranjemund and Rosh Pinah around 50 mm, and at Aus, just to the east of the Sperrgebiet, 85 mm. Higher mountain areas in the Sperrgebiet receive more rain than surrounding lowlands, and annual averages at high altitudes may well exceed 100 mm (Burke *et al*. 2004). The Sperrgebiet falls within a transitional zone between winter and summer rain. Hence rains may fall at any time of the year. A rainfall gradient of decreasing rain from southwest to northeast, related to winter rains originating in the Cape, is indicated within the Sperrgebiet (Burke *et al*. 2004). Summer rains become increasingly more important towards the northeast, winter rains towards the southwest.

Another important source of moisture is fog. It is an almost daily occurrence along the coast. Its frequency decreases eastwards (Olivier 1995). The Orange River provides an important conduit for fog, as it often moves eastwards along the valley and reaches as far as Rosh Pinah, well over 60 km inland from the coast. Although no data on fog precipitation exist for the Sperrgebiet, the fog belt in the central Namib extends approximately 30 km inland and on average brings about 64 mm of moisture per annum at the coast, decreasing to about 35 mm at the eastern edge of the fog belt (Hachfeld & Jürgens 2000). At the coast, fog precipitation therefore exceeds rainfall.

Temperature regimes in the study area are comparatively moderate. Although daily means are expected to only range between 14 and 18 °C at the coast (e.g. Lüderitz) and from 10 to 24 °C further inland (e.g. Aus) (Pallett *et al*. 1995), maximum temperatures of 40 °C have been reported in both areas. Frosts are frequent in winter in the Aus area, but the remaining area at lower altitudes only rarely experiences frost.

Apart from aridity, wind is the most critical climatic factor affecting biodiversity and habitats in this area. Strong, southerly coastal winds prevail throughout the year, abating slightly as one moves eastwards. Constant daily winds at Pomona, for example, range between 30 and 50 km/hr in summer (Pallett *et al*. 1995), but often reach 100 km/hr. In winter, easterly 'berg' winds related to high pressure cells over the southern African interior can occasionally generate equally high wind speeds and impose hot, desiccating conditions on biota.

METHODS

Data sources

Landform-based mapping during 2003-2006 which delineated broad habitat units and associated vegetation types in the park (Burke 2006) was revisited and cross-checked with additional data from the National Botanical Research Institute in Windhoek and the author's own observations. More available data resulted in minor adjustments to some vegetation types (e.g. on the Lüderitz peninsula and the Klinghardt mountains). This was verified during workshops with key stakeholders such as the National Botanical Research Institute, the Ministry of Environment & Tourism, the Namparks project and environmental staff of mining licence holders.

Defining criteria

To enable a transparent assignment according to biodiversity importance, measurable criteria were developed which were backed by available data and reflected conservation importance and management-related objectives. Plant endemism, protection status and species richness are measurable criteria and were used directly to develop a 4-scale assignment. Plant endemism and protection status are species-based and occurrence in a particular mapping unit was used as indicator. Species richness was applied directly by counting the number of plant species occurring in a mapping unit.

Red list criteria were initially considered, but not incorporated. The reasons are: (1) To be applicable systematically across the entire park, the information would need to be reasonably complete. This means all plant species occurring in the park would need to have been evaluated against red list criteria. This is unfortunately not the case, as only a portion of the species has so far been evaluated with the focus on endemic plants and plant collector's items. Using this criterion would therefore be skewed towards the areas where plants occur that have been assessed. (2) The majority of species listed in a threatened category in the Sperrgebiet are either endemic or protected (e.g. all *Aloe* and *Crassula* species) and thus already included as a criterion. This would therefore be a duplication of information used as criteria.

Other biodiversity components such as landscape and fauna were not directly used in the assessment of biodiversity importance. These were assigned the category 'special management' (Ministry of Environment & Tourism 2019), based on existing features (e.g. natural monuments) and expert-driven identification during workshops. The main natural springs and wetlands in the park which attract a multitude of wildlife, and breeding and/or feeding areas of flagship animals were assigned as 'special habitats' in this study. Brown hyena (*Parahyaena brunnea*) and Damara Tern (*Sterna balaenarum*) were identified by the wildlife experts as flagship species and their breeding and/or feeding areas were therefore delineated as 'special habitats'.

Plant endemism, range size and protection status

As abundance data and detailed information on the status of plant populations are not available in the park, range sizes provide an approximation of a plant's risk to extinction. The more restricted a plant's range, the higher is the extinction risk, as even small disturbances could result in the elimination of a species (Smith *et al*. 1991; Burgess *et al*. 2006; Collins *et al*. 2009; Cadotte & Davies 2010; Davies *et al*. 2011). In the context of this study three range sizes were considered appropriate as key criteria: (1) species restricted to a mapping unit (broad habitat or vegetation type), (2) species endemic (i.e. restricted) to the park and (3) species endemic to the Namib Desert. Plants legally protected in Namibia (Nature Conservation Ordinance 4 of 1975 and Government Notice 247 of 1977, Forest Act 12 of 2001 and Government Notice 170 of 2015) also served as indicators, if they were not already included as endemic.

Plant species richness

Thresholds for plant species richness were assigned purely on numerical principles: 150, 100 and 50 were used as cut-off points. These proved appropriate when applied to the distribution of the park's plant species richness. Although plant distribution data are considered the most complete spatial information on biodiversity for the park, there are still some inaccessible areas which have been poorly surveyed. Expert opinion, without field data to back this, was only applied in the latter case. Expectation of occupancy by protected species or Namib endemics was then used as a criterion to rate this mapping unit of 'medium' conservation importance.

Once these criteria were defined, rules were developed for assigning biodiversity importance (Table 1). Where more than one criterion applied to a species (e.g. *Conophytum taylorianum* is a park endemic and protected), the species was only counted in one category. Also all mapping unit endemics are automatically park endemics, but were not counted as park endemics. This means each plant species was assigned only one categorical criterion.

RESULTS AND DISCUSSION

Of the over 1,000 plant species occurring in the park (Burke & Mannheimer 2004), some 30 plant species are strictly endemic to the park, another approximately 30 almost restricted to the park. These and, in addition, protected species combined with species richness served as indicators to define areas of particular biodiversity importance. This includes all mountains and most inselbergs, but also rocky areas and sand plains along the coast and the Orange River (Figure 1). The scale of mapping around mountains and inselbergs includes foothills and plains near these mountains. These habitats are therefore also included in 'special value zones'

The park is richest in one of the most difficult groups of plants to identify, the family Aizoaceae or Mesembryanthemaceae. The confusion already starts at higher taxonomic order, as some taxonomists consider this the family Aizoaceae, others Mesembryanthemaceae (Herre 1971; Bittrich & Hartmann 1988; Germishuizen & Meyer 2003; Snijman 2013). The fact that this group is evolutionary relatively young is one of the reasons for this confusion. It is one of the fastest evolving groups of plant species on earth (Klak *et al*. 2004).

Table 1: *Criteria for assigning biodiversity importance based on plant indicators in the Tsau‖Khaeb (Sperrgebiet) National Park.*

Biodiversity importance	Criteria	Rules
Very high	≥ 1 plant species endemic to mapping unit ≥ 150 plant species ≥ 5 park endemics ≥ 10 protected species	At least two criteria apply
High	≥ 100 plant species ≥ 5 park endemics ≥ 5 protected species	At least two criteria apply
Medium	≥ 50 plant species ≥ 1 Namib endemic ≥ 1 protected species poor data, but protected or Namib endemics expected	One criterion applies
Low		None of the criteria apply
Special habitat	Important habitats for flagship species, e.g. feeding or breeding sites, special habitat for wildlife or providing essential ecosystem function (e.g. wetland)	Recognised of national importance
Natural monument	Natural feature of outstanding importance	Recognised of national importance

This, together with improved techniques (e.g. molecular studies), and more field data has resulted in continuous revisions in this group. New genera are created, new species described, others are combined to one species, genera are sunk and then re-created again when yet another study provides new information (e.g. Hartmann & Dehn 1989; Klak & Linder 1998; Klak *et al*. 2007; Snijman 2013). It makes it difficult even for experienced botanists to keep up-to-date with the latest developments.

More field surveys will change the information on distribution of species and add more species to some mapping units. It may also change the status of endemics. All this will then affect the statistics such as number of endemics and protected species and

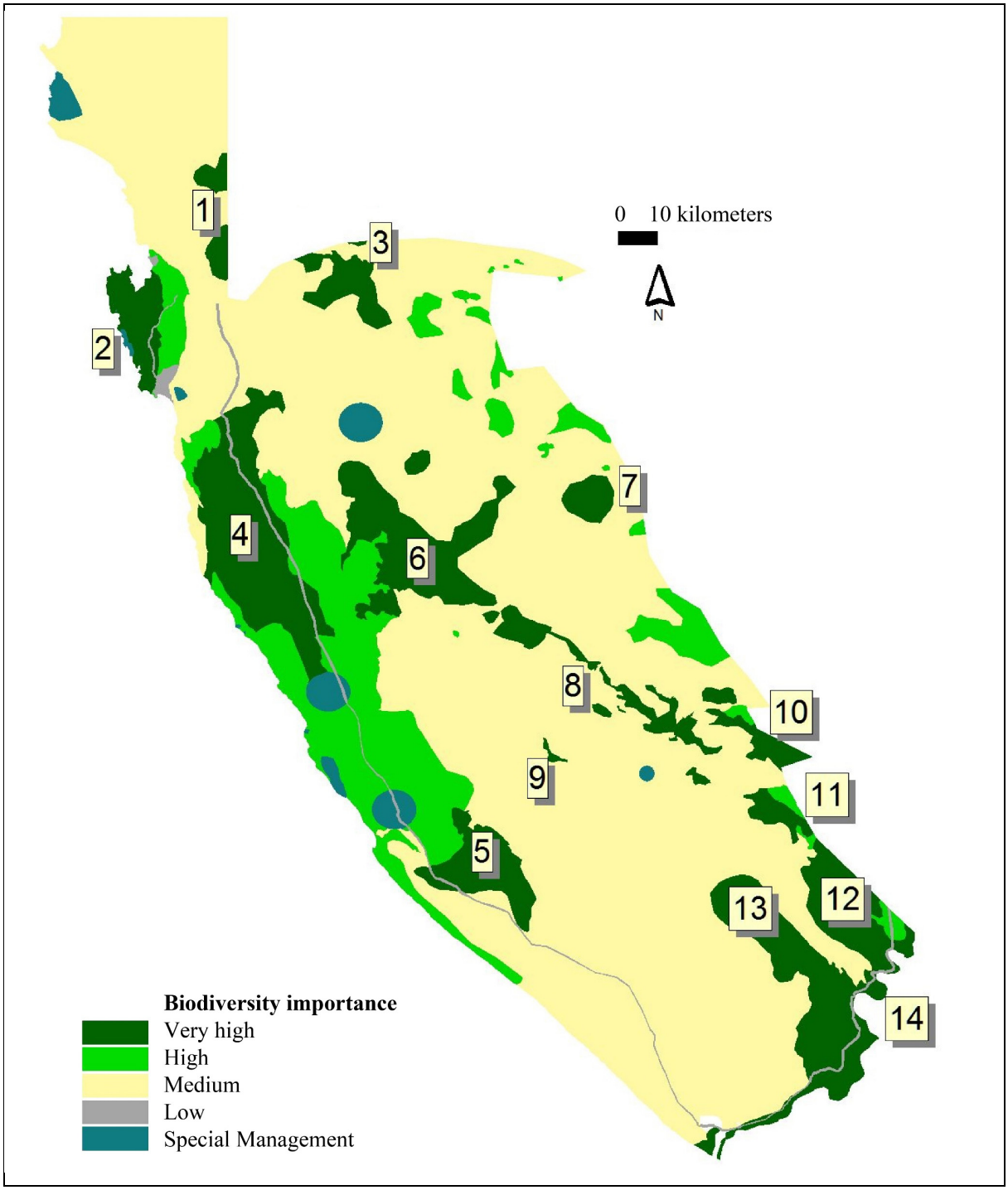

Figure 1: *Biodiversity importance of mapping units in the Tsau||Khaeb (Sperrgebiet) National Park. The labels correspond to the heading numbering in the text (1 Kowis mountains, 2 Lüderitz peninsula, 3 Tsaukhaib-Haalenberg inselbergs, 4 Grillental-Pomona corridor, 5 Boegoeberg, 6 Klinghardt mountains, 7 Tsaus, 8 Heioab-Aurus mountain range, 9 Chamnaub inselbergs, 10 Rooiberg-Nudavib mountains, 11 Skorpion inselbergs, 12 Obib, 13 Schakalsberge, 14 Orange River valley).*

overall species richness. The figures provided in this paper have to be seen in this context and provide the best approximation available at the time.

Areas of very high biodiversity importance

Fourteen mapping units of 'very high' biodiversity importance based on the criteria above were assigned in the Tsau||Khaeb (Sperrgebiet) National Park. The reason for this is explained in the following section, describing the mapping units from north to south. The heading numbering corresponds to the map (Figure 1).

1. Kowis mountains

Some 20 km east of Lüderitz, ridges of metamorphic rocks (metasediments, schist and gneiss) of the Namaqua Metamorphic Complex (Miller 2008c) rise to some 250 m above the surrounding plains (highest point at 656 m above mean sea level (amsl)). They are positioned in a sand corridor and most plants are continuously exposed to sand-blasting (Figure 2). Just over 100 plant species have been recorded, including one possible endemic to this inselberg (*Juttadinteria kovisimontana*), at least four park endemics (e.g. *Amphiglossa thuja*, *Drimia secunda*, *Juttadinteria simpsonii* and *Namibia ponderosa*), and over ten protected species (e.g. *Acanthosicyos horridus*, *Aloidendron dichotomum*, *Commiphora capensis*, *Conophytum saxetanum*, *Crassula ausensis*, *C. elegans*, *Eberlanzia clausa*, *E. sedoides*, *Lithops karasmontana* and *Psammophora modesta*).

The status of the potential endemic *Juttadinteria kovisimontana* is not entirely clear as it could be a hybrid between *Namibia ponderosa* and *Juttadinteria simpsonii* (Mannheimer 2006). Whatever the outcome of more detailed studies may reveal, it is still a very rare plant. *Namibia ponderosa* and *Juttadinteria simpsonii* are only known from the Kowis mountains and Haalenberg, some 14 km to the east of the Kowis mountains.

2. Lüderitz peninsula

The peninsula is largely rocky terrain dissected by a network of sandy washes and pans. Rocks are largely gneiss and metasediments such as schist of the Namaqua Metamorphic Complex, with a few isolated granite outcrops and an amphibolite ridge in the northern part of the peninsula (Miller 2008c). The lichen fields near Grosse Bucht are also included in this mapping unit. Proximity to the coast guarantees a regular, though meagre moisture supply.

Over 100 plant species have been recorded. Park endemics are represented by at least five species, including *Eremothamnus marlothianus*, *Fenestraria rhopalophylla*, *Lithops optica*, *Pelargonium cortusifolium* and *Pteronia spinulosa*; protected species are at least ten (e.g. *Cephalophyllum ebracteatum*, *Conophytum saxetanum*, *Crassula elegans*, *Crassula muscosa*, *Juttadinteria deserticola*, *Lavrania marlothii*, *Ruschia deminuta* and *Tylecodon schaeferianus*). Higher plant diversity was reported in previous studies for the quarter degree square into which this mapping unit falls (Burke 2006). However, this proved to be a data error. Historic records in the National Botanical Research Institute's specimens database for "Lüderitz District", which covers the entire Sperrgebiet, were lodged in this quarter degree square (2615CA).

A rare red mutant of *Lithops optica* which used to be more abundant in the past, occurs on the peninsula, called 'rubra' and is considered a different form by some succulent specialists (Tischer 1925). It is highly sought after by collectors (Krainz 1948; Heine 2004). *Lithops optica* is in the process of being merged with *Lithops herrei* based on molecular studies and may therefore no longer be considered a park endemic (Loots *et al*. in prep.). However the 'rubra' form was not included in this revision, because of lack of material (Loots, pers. comm. August 2019).

Figure 2: *The dunes along the southern end of the Kowis mountains (left) are a testimony of the sand-blasting the gneiss outcrop receives regularly, resulting in relatively low plant cover (right).*

3. Tsaukhaib-Haalenberg inselbergs

Outcroppings of granodiorite gneiss of the Namaqua Metamorphic Complex form the Tsaukaib-Haalenberg inselbergs at the northern border of the park (Miller 2008c). The Haalenberg section extends north into the Namib-Naukluft Park. The highest peak is 1068 m amsl and rises some 250 m above the plains.

One dwarf succulent (*Conophytum halenbergense*) and a bulb (*Eriospermum halenbergense*) are endemic to these inselbergs, possibly also *Lithops francisci* and *Juttadinteria simpsonii*, depending on the outcome of further taxonomic studies. Over 150 plant species are recorded here and these include more than ten protected species (e.g. *Adromischus* species, *Aloidendron dichotomum*, *Amphibolia saginata*, *Boscia albitrunca*, *Commiphora capensis*, *Crassula ausensis*, *Crassula muscosa*, *Dracophilus delaetianus*, *Eberlanzia clausa* and *E. sedoides*) and three park endemics (*Juttadinteria simpsonii*, *Lithops francisci* and *Namibia ponderosa*).

4. Grillental-Pomona corridor

This encompasses the largest, contiguous mapping unit of 'very high' conservation importance. It consists of a variety of rock types and outcrops from dolomites near Grillental, syenite at Drachenberg and Dreizackberg to the volcanic cone at Schwarzer Berg, dolomite outcrops around Pomona, outcrops near Bogenfels to the sedimentary rocks of Buntfeldschuh in the south of this mapping unit (Miller 2008a). Various inselbergs and rocky outcrops dot the landscape in between. Not all these have been studied. Those that have either harbour plant species only occurring in this mapping unit, such as *Namibia cinerea*, and/or more than five park endemics (e.g. *Antimima dolomitica*, *Eremothamnus marlothianus*, *Fenestraria rhopalophylla*, *Frankenia pomonensis*, *Marlothiella gummifera*) (Figure 3) and/or at least ten protected species (e.g. *Cephalophyllum ebracteatum*, *Conophytum saxetanum*, *Crassula deceptor*, *C. mesembrianthemopsis*, *C. muscosa*, *Eberlanzia clausa*, *E. sedoides*, *Juttadinteria deserticola*, *Larryleachia* species, *Lithops optica*, *L. karasmontana* and *Psammophora modesta*). Well over 150 plant species are recorded in this mapping unit.

Although this study focused on describing quantifiable biodiversity indicators, the Grillental-Pomona corridor gains additional significance by containing important fossil sites (e.g. at Elizabethfelde, Grillental, Bogenfels corridor and Buntfeldschuh) (Pickford & Senut 1999). The well-known natural monument Bogenfels also falls into this mapping unit.

5. Boegoeberg

This is the closest inselberg to the coast in the park and rises some 200 m above its surrounding. The highest peak is at 540 m amsl. Metavolcanics, quartzite and phyllite of the Gariep Complex are the main rock types (Miller 2008b). Apart from the inselberg and associated outcrops this mapping unit also includes a lichen field to the west of the inselberg and the plains in between. The inselberg is frequently shrouded in fog and the lichen field is on a slight rise, thus also receiving more moisture.

Just over 150 plant species have been recorded. These include at a minimum five park endemics such as *Antimima buchubergensis*, *Antimima dolomitica*, *Fenestraria rhopalophylla*, *Frankenia pomonensis* and *Pteronia spinulosa*. Protected species in this mapping unit are well over ten and include *Cephalophyllum ebracteatum*, *Conophytum saxetanum*, at least seven *Crassula* species, *Eberlanzia sedoides*, *Stoeberia beetzii* and *Tylecodon schaeferianus*. The elusive geophyte *Eriospermum buchubergense* is believed to occur only on this inselberg; elusive because it has only been recorded once and was never found again (Dinter 1932; Perry 1994).

Figure 3: *Two Sperrgebiet endemics:* Namibia cinerea *at Grillental (left) and* Marlothiella gummifera *at Bogenfels (right).*

6. Klinghardt mountains

This mountain complex consists of a range of inselbergs of medium height, rising up to 300 m above the plains. The highest peak is Höchster which reaches 1114 m amsl. Complex geology, with outcroppings of quartzite, phyllite, dolomite and limestone of the Gariep complex, interspersed with phonolite intrusions of more recent origin (Miller 2008b), and the mosaic of inselbergs, dunes, gravel and sand plains provide a great diversity in habitats (Figure 4). This mapping unit also includes Münzenberg to the north-east of the Klinghardt mountains.

Over 300 plant species have been recorded to date, more than five of these endemic to the Sperrgebiet and two only occurring in the Klinghardt mountains. *Conophytum taylorianum* subsp. *taylorianum* has so far only been recorded from one locality in these mountains (Hammer 2002) and *Blepharis meyeri* has only been recorded here (Vollesen 2000). Park endemics include *Amphiglossa thuja*, *Antimima dolomitica*, *A. buchubergensis*, *Conophytum klinghardtense*, *Drimia secunda*, *Eriocephalus klinghardtensis* and *Hoodia officinalis*. The flora also contains an additional over 30 protected plant species, including *Adromischus montium-klinghardtii*, *Aloe erinacea*, *Aloidendron dichotomum*, *A. ramosissimum*, *Amphibolia saginata*, *Astridia velutina*, *Cephalophyllum ebracteatum*, *Cheiridopsis robusta*, *Conophytum pageae*, *Dracophilus dealbatus*, *Eberlanzia sedoides*, *Ficus cordata*, *Larryleachia* species, *Psammophora modesta*, *P. nissenii*, *Quaqua mammillaris*, *Ruschia muelleri*, *Stapelia similis*, *Tylecodon paniculatus* and well over ten *Crassula* species. Also found on these inselbergs are the Gariep centre endemics *Delosperma klinghardtianum*, *Pelargonium klinghardtense* and *Lachenalia klinghardtiana*. The fact that so many plant species are named after these mountains indicates their importance as a locality where these were first collected, even if they were subsequently found elsewhere.

7. Tsaus mountain

This mountain is positioned in the central eastern section of the park. It is comprised of black limestone, sandstone, conglomerate and shale of the Nama Group, underlain by gneiss of the Namaqua Metamorphic Complex (Miller 2008c). The gneiss outcrops are at the north-eastern section of the mountain. These rocks form a flat-topped mountain with a plateau of about 9 km in length and 8 km wide, which gently slopes from 1226 m amsl at the highest point in the north to about 879 m in the south. The mountain rises on average about 400 m above the surrounding plains.

The more uniform landscape and rock types and greater aridity support less plant species than many other inselbergs in the park. However nearly 150 species have been recorded to date. Although no strict park endemics are recorded, a number of Gariep endemics occur such as *Euphorbia namibensis*, *Jamesbrittenia bicolor*, *Lessertia acanthorachis*, *Pteronia pomonae* and *Stipagrostis lanipes*. More than five protected species also occur (e.g. *Acacia erioloba*, *Aloidendron dichotomum*, *Boscia albitrunca*, *Crassula muscosa*, *Dracophilus dealbatus*, *Hoodia gordonii*, *Juttadinteria attenuata* and *Larryleachia* species). The main reason for its assignment of 'very high' biodiversity importance is the occurrence of *Lithops hermetica* which only grows on the Tsaus mountain (Cole 2000). The rare shrub *Euclea asperrima* which is only recorded from limestone in the Huns mountains, central escarpment and one other inselberg in the Sperrgebiet, also grows on the Tsaus mountain.

Figure 4: *A great variety of habitats supports a diverse flora in the Klinghardt mountains.*

8. Heioab-Aurus mountain range

This very large mapping unit in the central east has the highest habitat diversity in the park. It includes high and low mountain ridges, inselbergs and low outcrops of various geology (metasediments and metavolcanics such as gneiss, granite, quartzite, phyllite, conglomerate and dolomite) of the Namaqua Metamorphic and Gariep Complexes, but also quartz gravel and sandy plains, semi-vegetated dunes as well as a section of the dry Uguchab river. Heioab, at 1121 m amsl, is the highest peak, followed by the Aurus peak at 1084 m amsl. The Aurus mountains form a horseshoe towards the east and slope gently to the eastern plains and Uguchab river, but rise steeply for some 480 m above the plains to the west. The southern ridges of the Aurus mountains form a protective barrier against the constant southerly winds. Therefore the densest permanent plant cover and the highest plant diversity in the park are found here (Figure 5). This mapping unit also includes the inselbergs to the west of the Aurus range and Buschmannberg with a peak of 984 m, rising some 290 m above the surrounding (it is marked as Wasserkuppe on some maps).

Some 400 plant species have been recorded in this mapping unit, and this includes at least five park endemics (*Antimima aurasensis*, *Conophytum klinghardtense* ssp. *klinghardtense*, *Crassula aurusbergensis*, *Eriocephalus klinghardtensis* and *Pteronia spinulosa*) and, in addition, another over 50 protected plants. The two dwarf succulents *Tylecodon aurusbergensis* and *T. aridimontanus* are endemic to this mapping unit (Williamson 1995). *Tylecodon aurusbergensis* has only been recorded on south- to west-facing slopes of the Aurus range, while *T. aridimontanus* is recorded from the Heioab mountain. Both are restricted to the mountains in this mapping unit. Another species worth mentioning is the recently described elusive geophyte *Moraea thermarum*, which has only been recorded from two localities so far: on a mountain near the Orange River in the Ai-Ais Richtersveld Transfrontier Park and in the Aurus mountains (Goldblatt & Manning 2013).

Protected species include some 20 species of *Crassula*, *Adromischus marianiae*, *Adromischus montium-klinghardtii*, *Aloe erinacea*, *A. microstigma*, *Aloidendron dichotomum*, *A. ramosissimum*, *Amphibolia saginata*, *Cephalophyllum confusum*, *Cheiridopsis robusta*, *Conophytum pagae*, *Holothrix filicornis*, *Eberlanzia sedoides*, *Hoodia gordonii*, *Juttadinteria deserticola*, *Psammophora modesta*, *Quaqua incarnata*, *Ruschia muelleri*, *R. odontocalyx*, *Stoeberia gigas*, *Tylecodon paniculatus* and many more.

9. Chamnaub inselbergs

Positioned more or less half way between Boegoeberg and the Aurus mountains, this group of inselbergs is largely composed of quartzite, shale and schist of the Gariep Group (Miller 2008b). The inselbergs rise some 110 m to 160 m above the surrounding vegetated dunes. The highest peak is 690 m amsl.

Close to 100 plant species have been recorded on these isolated inselbergs and this includes at least five park endemics and well over ten protected species. Park endemics include *Amphiglossa thuja*, *Antimima buchubergensis*, *Crassula aurusbergensis*, *Eriocephalus klinghardtensis* and *Pelargonium cortusifolium*. In addition, protected species include *Aloidendron ramosissimum*, *Amphibolia saginata*,

Figure 5: Aloe microstigma *at Heioab (left) and remarkably dense perennial vegetation in the eastern section of the Aurus mountains (right).*

Aridaria noctiflora, *Cephalophyllum ebracteatum*, *Conophytum* sp., at least another five *Crassula* species, *Eberlanzia sedoides*, *Larryleachia* species and *Stoeberia beetzii*.

10. Rooiberg – Nudavib mountains

The Rooiberg and associated inselbergs which stretch towards the Nudavib mountains extend south-east from the southern end of the Aurus mountain chain. They are comprised of diverse rock types from gneiss to mixtite and metasedimentary rocks. This also includes the low conglomerate (diamictite) inselberg to the north of Rooiberg, called Kegelberg on some maps, Schwarzkuppe on others. Rooiberg is by far the highest of these and rises some 325 m above the plains reaching 1125 m amsl. Kegelberg (Schwarzkuppe) is 847 m amsl.

Over 170 plant species were recorded on Rooiberg alone and this includes well over ten protected species. Most remarkable is the occurrence of at least one endemic to this mapping unit, *Conophytum klinghardtense* subsp. *baradii* which is found on Rooiberg and mixtite outcrops in the vicinity of Rooiberg (Young *et al*. 2019). Although the rich flora does not include any other strict park endemics, there are many Gariep endemics such *Aloe erinacea*, *Amphibolia saginata*, *Antimima quarzitica*, *Eriocephalus giessii*, *Lachenalia pearsonii* and *Pteronia pomonae*. Protected species include, amongst other, *Adromischus montium-klinghardtii*, *Astridia velutina*, *Boscia albitrunca*, *Cephalophyllum confusum*, *Conophytum saxetanum*, eight *Crassula* species, *Ruschia muelleri*, *Stoeberia frutescens*, *S. gigas* and *Tylecodon paniculatus*.

11. Skorpion inselbergs

Complex geology in the south-eastern part of the park created a range of inselbergs and exposed different rock types. These include dolomite, mixtite, phyllite, quartzite, rhyolite, shale and schist outcrops of the Gariep Complex and Orange River Group, many formations interspersed with quartz veins. The higher inselbergs rise approximately 100 m above the surrounding.

Although no high altitudes are reached, these inselbergs are very diverse in plants and over 200 species have been recorded in this mapping unit (Burke 2009). At least one park endemic occurs, *Eriocephalus klinghardtensis*. There are also many Gariep endemics; amongst others *Bulbine rhopalophylla*, *B. namaensis*, *Justicia cuneata* and *Manulea namibensis*. The number of protected species reaches well beyond the threshold of ten, which is made up by over ten *Crassula* species alone. In addition to these, other protected species in this mapping unit are, for example, *Adromischus montium-klinghardtii*, *Aloe garipensis*, *Aridaria noctiflora*, *Boscia albitrunca*, *Cheiridopsis robusta*, *Conophytum taylorianum* subsp. *ernianum*, *C. saxetanum*, *Eberlanzia schneideriana*, *Ebracteola derenbergiana*, *Hoodia gordonii*, *Psammophora nissenii*, *Ruschia muelleri*, *R. tumidula* and *Tylecodon paniculatus*.

12. Obib mountains

This mapping unit in the south-eastern corner of the park contains the Obib mountains and Gomtsawibberge and comprises the most formidable mountain range in the park. The highest point, Obib peak, is 908 m amsl. Peaks rise on average approximately 300 m above the surrounding. The highest peak of the Gomtsawibberge, Gumchavib, is only 668 m amsl, but rises almost 500 m above the valley of the Orange River. Metasediments and sedimentary rocks such as dolomite, limestone, schist, quartzite and conglomerate of the Gariep formation provide most of the substrate (Miller 2008b).

Plant diversity is extraordinary in these mountains and over 400 species have been recorded to date, so it is not surprising that this contains well over 30 protected species, and one plant endemic to the Obib mountains. The elusive herb *Heliophila obibensis* (Schreiber 1979) has so far only been recorded in these mountains. Although only two other strict park endemics, *Eriocephalus klinghardtensis* and *Psammophora saxicola* (Hartmann 2002) have been recorded, many Gariep endemics occur. *Amphibolia saginata*, *Senecio giessii*, *Sarcocaulon inerme*, *Trachyandra lanata* and *Stipagrostis garubensis* are some of these. At least 15 different *Crassula* species grow in these mountains, which are all protected, as well as the protected *Adromischus filicaulis*, *A. alstonii*, *A. marianiae*, *Aloe gariepensis*, *A. pachygaster*, *Aloidendron dichotomum*, *A. ramosissimum*, *Amphibolia obscura*, *Anacampseros filamentosa*, *Boscia albitrunca*, *Cephalophyllum compressum*, *C. ebracteatum*, *Cheiridopsis robusta*, *Eberlanzia ebracteata*, *E. schneideriana*, *Haworthia venenata*, *Hoodia gordonii*, *Larryleachia* species, *Ruschia muelleri*, *Psammophora modesta*, *Stoeberia gigas*, *Tylecodon paniculatus* and more.

13. Schakalsberge

Stretching over some 30 km, these north-northwest to south-southeast trending ridges of greenschist, phyllite, dolomite, marble, breccia and greywacke of the Gariep formation (Miller 2008b) extend up to the Orange River. The highest peak, at 625 m amsl, rises some 220 m above the surrounding. These mountains also include the Rooilepel outcrop and Skilpadberg in their southern reaches.

Plant diversity is high, with over 150 plant species. This includes the local park endemic bulb *Bulbine francescae* and at least three broader park endemics

(*Astridia hallii*, *Euphorbia angrae* and *Fenestraria rhopalophylla*) and in addition more than 20 protected species (e.g. *Aloe ramosissima*, *Astridia velutina*, *Cephalophyllum ebracteatum*, *Conophytum pageae*, *C. taylorianum* subsp. *ernianum*, at least ten *Crassula* species, *Dracophilus dealbatus*, *Eberlanzia clausa*, *E. sedoides*, *Juttadinteria deserticola*, *Larryleachia* species, *Psammophora modesta*, *Ruschia odontocalyx*, *Stapelia similis*, *Stoeberia gigas* and *Tylecodon paniculatus*. Skilpadberg near the Orange River is a particularly diverse and exceptional area, as a number of additional species of conservation importance occur here, such as the range-restricted *Aloe pearsonii* (only known from Namuskluft, some outcrops along the Orange River and a few localities in the Richtersveld), *Amphibolia obscura*, *Euphorbia herrei*, *Portulacaria pygmaea* and *Sarcocaulon multifidum*.

14. Orange River valley

The Orange River valley from Sendelingsdrif to Hohenfels comprises a diverse landscape with the permanently-flowing river, river banks, islands, and dry rivers, plains, dunes and mountains flanking both sides of the Orange River. A variety of rock types of the Gariep formation such as schist, mixtite, breccia and dolomite are exposed (Miller 2008b). Where north-south-trending mountain chains such as the Gomtsawibberge and Schakalsberge meet the Orange River, steep slopes and gullies provide a great variety of habitats. Terraces of former courses of the Orange River are exposed at various places. Some of these not only harbour diamonds but also provide a unique habitat. The habitat changes from Hohenfels to the Orange River mouth in that there are no longer mountains, but dunes and sand plains on the north-bank. Fog regularly moves upriver and precipitates on slopes and outcrops facing the river. Such sites are particularly rich in plant species and harbour a number of Orange River endemics (Figure 6).

The perennial river supports woodlands, in many places with dense undergrowth, grassy flood plains, reed beds and a variety of aquatic plant communities. These support diverse fish, amphibian and aquatic invertebrate communities. They are feeding and breeding grounds for a variety of water and other birds as well as mammal and reptile fauna.

Rocky slopes, gullies and ancient gravel terraces are particularly rich in plant species and over 170 plant species have been recorded along this stretch of river. This includes at least two park endemics (*Astridia hallii* and *Fenestraria rhopalophylla*) and over 20 protected plant species (e.g. *Aloe pearsonii*, *Aloidendron dichotomum*, *A. ramosissimum*, *Astridia velutina*, *Amphibolia obscura*, *Cephalophyllum herrei*, *Crassula muscosa*, *Crassula subaphylla*, *Conophytum saxetanum*, *Larryleachia* species, *Lithops herrei*, *Portulacaria pygmaea* and *Tromotriche pedunculata*). The significance of the outcrop Skilpadberg, which can be considered the southern-most extension of the Schakalsberge is described above.

Due to the proximity to the Richtersveld, one of South Africa's biodiversity hotspots (Cowling & Pierce 2000), there are also a number of Orange River plant endemics which only occur along this stretch of river, but on both sides in Namibia and South Africa. These include *Hartmanthus pergamentaceus*, *Juttadinteria albata*, *Sarcocaulon inerme*, *S. multifidum* and *Tylecodon buchholzianus*.

Downriver of Hohenfels species richness and occurrence of plants of conservation importance decreases, except at Swartkop. However, the Orange River valley here becomes part of a Ramsar site, an area of international importance for wetland birds. Although the Ramsar site does not include Pink Pan, the pan is also included as an area of very high

Figure 6: *Outcrops along the Orange River support range-restricted species such as* Aloe pearsonii *on Skilpadberg (left) and* Cheiridopsis verrucosa *on Swartkop near Oranjemund (right).*

conservation importance in this mapping unit. The valley west of Hohenfels could either be categorised as of 'very high biodiversity importance' (based on rare and protected plants at Swartkop) or mapped as a special habitat during zoning of the park.

Areas of high biodiversity importance

Areas of 'high' biodiversity importance are the remaining, more significant inselbergs in the park as well as the areas adjoining the Lüderitz peninsula and Grillental-Pomona corridor to the east. There are no plant species endemic to these mapping units, but they are nevertheless species rich and harbour at least five park endemics and/or protected species each. This also includes the northern section of mined areas in Namdeb's high security area. Here a number of protected and endemic species have either recolonised the disturbed landscape or remain in small pockets of undisturbed ground in between (Burke 2007).

It is important to note that not all range-restricted park endemics, such as *Polemanniopsis namibensis* which is only known from a few localities (van Wyk *et al*. 2010), occur in areas assigned 'very high' or 'high' biodiversity status. This is due to their disjointed distribution. There are possibly more plant species which do not automatically receive adequate protection based on the overall biodiversity assignments, for the same reason.

Implications for conservation planning and management

This study forms the basis for management zones in the park. It needs to be supplemented by information of important historic sites and sites of special scientific interest such as fossil sites and sites of geological importance. Fauna-based indicators could be considered in future once adequate spatial information is available for certain groups of taxa and the habitats they occupy. Information on plant distribution changes and new discoveries could lead to up- or downgrading biodiversity importance of certain species which may also affect the overall biodiversity importance of a mapping unit. This study should therefore be reviewed and updated when an adequate body of new information becomes available (e.g. linked to comprehensive biodiversity surveys).

Although the area was divided into 56 vegetation types based on prevailing landform, in many instances this is still not sufficiently detailed mapping for management purposes. Large mapping units for example contain pockets of critical areas of exceptionally high diversity, or populations of species with an extremely limited range. These are very vulnerable to disturbance. Mountain peaks and the Aurus saddle are some examples. But there are also populations of vulnerable species on south- to west-facing slopes (e.g. *Crassula aurusbergensis*, *Tylecodon aridimontanus*, *T. aurusbergensis*), particular substrates (e.g. *Namibia cinerea* on dolomite) and isolated for some other reason (*Conophytum klinghardtense* subsp. *baradii*, *Polemanniopsis namibensis*). These need to be identified, mapped and zoned as exceptional sites within their respective zones of biodiversity importance.

The scale of mapping invariably influences the level of biodiversity importance. A larger mapping unit such as the Grillental-Pomona corridor harbours more plant species and with this also a greater chance of species of particular conservation importance because of the mapping units large extent. More detailed mapping to subdivide this large unit would help to better guide management, but requires intensive surveys during a good vegetation season.

CONCLUSION

With some 30 plant species strictly endemic to the park, the Tsau||Khaeb (Sperrgebiet) National Park by far exceeds the level of endemism encountered in any other protected area in Namibia. However, this level of endemism does reflect the high level of endemism of the Succulent Karoo Biome overall which, with 26 % plants endemic to this biome (Driver *et al*. 2003), supports one of the most unique arid floras in the world.

Although this study is a descriptive account of plant diversity and distribution in the Sperrgebiet, it is evident that species richness mirrors habitat diversity. The Klinghardt mountains with their varied geology and landforms, the Heioab-Aurus range and associated inselbergs, as well as the Obib mountains are by far the most species-rich landscapes. Where special bioclimatic conditions prevail, for example associated with the influence of fog in the coastal areas, many species restricted to these areas evolved (Burke 2004).

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