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A checklist of indigenous flora in the Richtersveld National Park confirms high plant diversity in the arid north-western tip of South Africa

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As a basis for conservation planning, a first comprehensive vascular plant species checklist for the core Richtersveld National Park was compiled, based on the collection of more than 3000 new herbarium vouchers and in total studying over 8000 specimens and more than 4000 iNaturalist observations. By the end of April 2024, a total of 1077 indigenous taxa were recorded. The documented indigenous flora included 14 pteridophytes, 3 paleodicots, 246 monocotyledons and 815 dicotyledons. A total of 99 indigenous families and 392 genera were recorded. The largest family was the Asteraceae, and the second largest family was the Aizoaceae. In addition, 44 taxa were identified as invasive or alien flora. Seven species were regarded as extinct; of these, four species disappeared in a context of diamond mining, and three species were no longer found after the recent drought 2014 to 2022. The role of the peculiar biogeographical position and the high diversity of unique habitats within extreme environmental gradients were discussed in a review of published evidence. Reference to distribution and habitat was presented for each species in the appendices.

Conservation implications: The article offers a complete checklist of vascular plants that forms a baseline for monitoring, and which facilitates the identification of additional taxa. In addition, a total of 125 taxa listed on the SANBI Red List and 15 taxa on the International Union for Conservation of Nature (IUCN) Red List were recorded, as well as a total of 170 taxa of conservation concern. Twenty-nine taxa are listed as endangered, and 21 taxa were listed as critically endangered on the South African red list. A total of 38 taxa were regarded as endemic and 101 taxa as near endemic. The identification of these taxa in combination with the information on their habitat preferences and distribution will allow targeted conservation planning.

Keywords: Richtersveld National Park; conservation; succulent Karoo Biome; Gariep Centres; SANBI Red List; IUCN Red List.

Introduction

South Africa is one of 17 megadiversity countries in the world (Conservation International 2020). Exceptional high levels of plant diversity are found in the most arid part of the country, in the Richtersveld region, adjacent to the Southern Namib Desert. The Richtersveld National Park (RNP) has been proclaimed in 1991 because of its placement within the Succulent Karoo Biome with its associated botanical diversity (Jürgens 2004; Richtersveld National Park 2018) and for the astonishing diversity and beauty of the geology (Minnaar 2006) and landscapes (Jürgens 2004). The Succulent Karoo Biome is the only arid region considered to be a global biodiversity hotspot (Mittermeier 1998, 1999). It houses an extremely rich succulent flora with a remarkably high level of endemism (Cowling & Hilton-Taylor 1994; Hilton-Taylor & Le Roux 1989; Jürgens 1991; Mucina et al. 2006; Van Wyk & Smith 2001), with an estimated 2439 endemic plant species (38.4% of the total Succulent Karoo Biome's flora) (Conservation International 2013).

The new park was designed to protect a part of the 'Gariep' centre of plant endemism (Thornton & Odendaal 2006). In addition to high plant endemism and diversity, the park also houses many endemic insects, spiders (Dippenaar-Schoeman & González Reves 2006) and reptiles (Bauer & Branch 2001). A second portion of land was bought at a later stage including the two farms, Klein Duin and Oograbies-west, jointly known as the Klein Duin section of the RNP. Oograbies-west was added to the RNP and proclaimed as a park in 2015; however, because of being geographically

Note: Additional supporting information may be found in the online version of this article as Online Appendix 1, 2 and 3.

divided from the original park in the northern Richtersveld, we have not included this section in this paper (Richtersveld National Park 2018).

According to the Convention on Biological Diversity (2012), one of the strategic actions of the Global Taxonomy Initiative is the 'facilitation of all-taxa inventories in targeted national, regional and sub-regional priority areas', such as biodiversity hotspots and protected areas (Convention on Biological Diversity 2012). Checklists are considered important for conservation areas as they are fundamental to biogeographical analyses and conservation planning (Clark, Barker & Mucina 2011) and can also be used to address aspects such as the presence of threatened and alien species (Spear et al. 2011, 2013).

Each of South Africa's national parks (SANParks) has a management plan approved by the Minister of Environmental Affairs, in which the desired state of the park is stated based on a vision, mission, vital attributes and objectives. One of the RNP vital attributes is:

> [*T*]o ensure the persistence of the uniquely arid adapted biodiversity by maintaining, conserving and restoring ecological processes as well as reducing human impacts within the landscape associated with the Succulent-Karoo- and Desert Biomes of the park. (Richtersveld National Park 2018)

Furthermore, one of the mitigations for the potential impacts of climate change is that the park should have a published plant species list. This will assist RNP 'to ensure the persistence of plant species and plant communities of special conservation by identifying threatened plant species' (Richtersveld National Park 2018). It is therefore an obligation that RNP must have a plant species list to assist in making informed decisions regarding biodiversity programme, proposed development and human activities (Hendricks 2004; McGeoch et al. 2011). Even though new plant species of the RNP are published every year (Al-Shehbaz 2020; Klak, Van Wyk & Bruyns 2023; Manning & Goldblatt 2018; Oberlander, Roets & Dreyer 2014; Steyn & Van Wyk 2015, 2017; Swanepoel, Nanyeni & Van Wyk 2022), the publication of a comprehensive checklist of the vascular plant species is overdue. This first plant species list for the RNP forms the main body of this study. In addition, we report on important contributions to the botanical exploration, and we briefly list and review earlier publications related to the phytogeography, vegetation, ecosystems and evolutionary history of the Richtersveld region (Bezuidenhout & Hendricks 2003; Jürgens 2004).

Study area

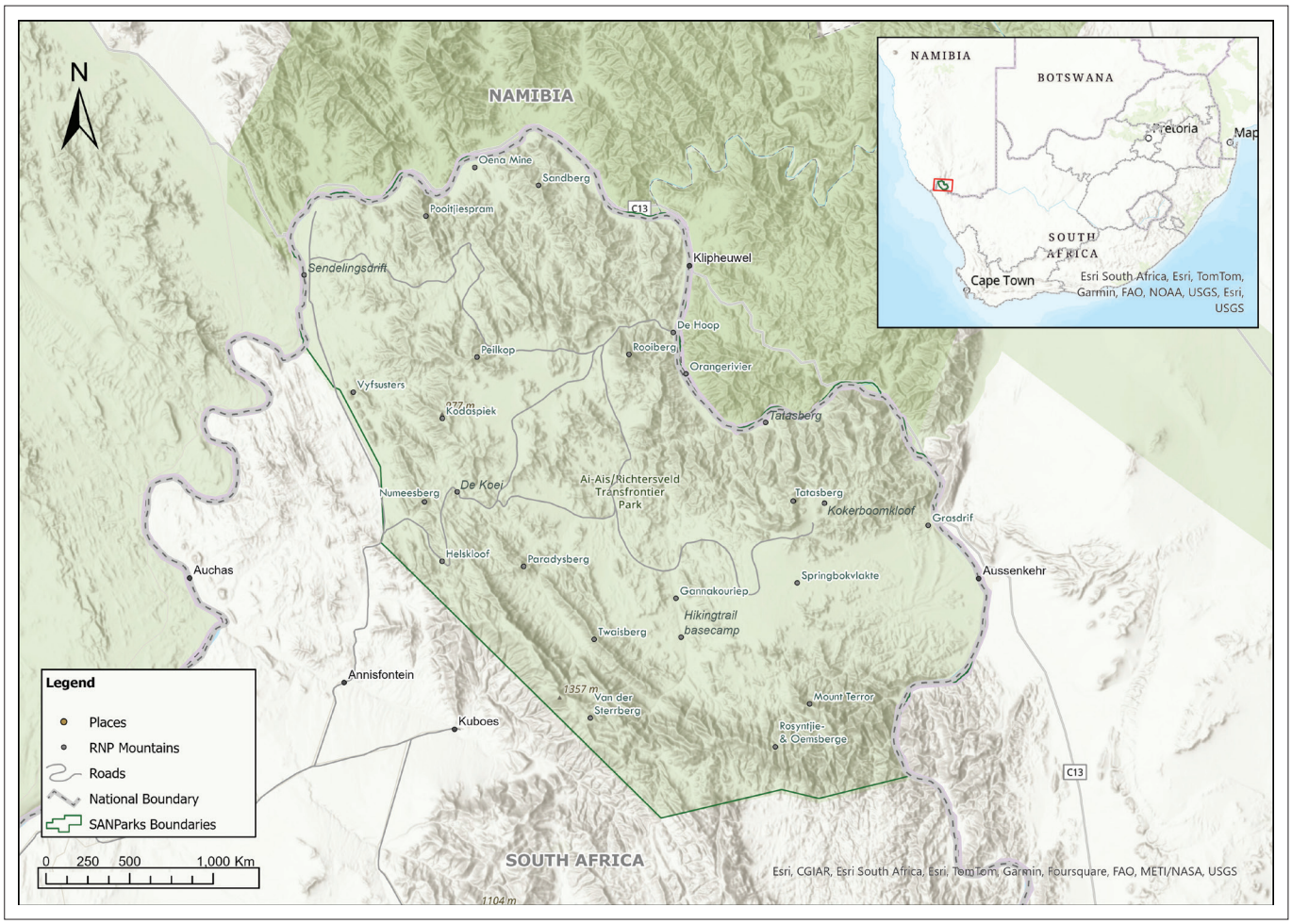
The RNP is located in the Richtersveld Municipality in the Northern Cape Province, South Africa. In total, 170 373 ha have been declared a national park in 1991, while an additional 10 897 ha are in the process of being declared (Richtersveld National Park 2018). Since 1991, the park has been known as the RNP, a contractual park, owned by the Richtersveld Communities and jointly managed by South African National Parks (SANParks) and the Richtersveld Community Management Committee (RGBK) (Richtersveld National Park 2018). In the north and east, the RNP is confined by the border with Namibia along the Orange River, the southern border is formed by the Rosyntjieberg and the western border runs from the Vandersterrberg to the Jakkalsberg (Figure 1).

Geophysical context

The landscapes of the RNP are best described as mountainous terrain with interbedded plains and basins. The mountains consist partly of undulating hills, partly of large steep rocky scarps. The highest point of the park is on the Vandersterrberg Mountain at 1364 metre above sea level (m.a.s.l.). The areas adjacent to the Orange River lie below the 300 m.a.s.l. Labyrinths of deep gorges and ravines in the core mountains converge into dry riverbeds in the broad valleys at their lower reaches. Four main geomorphological landscapes are found in the RNP, namely, (1) the Orange River and adjacent floodplains, (2) gently undulating plains, (3) rolling hills and (4) rugged mountains (Bezuidenhout & Hendricks 2003; RNP 2018).

The geology of the Richtersveld mountains is divers and includes volcanic, igneous and sedimentary rocks as well as their metamorphic equivalents (Macey et al. 2017). The oldest rocks of the Richtersveld are the ca. 2000 million years old volcanic-sedimentary rocks of the Orange River Group, which in the Richtersveld area, are subdivided into two major geological units. These two units are (1) the basal De Hoop Subgroup, which represents the remains of an ancient NW-SE trending belt of island volcanoes, comprising large, irregular bodies of volcanoes and gives rise to the scenic mountains in the east and northeast of the RNP, (2) the De Hoop Subgroup is overlain by the younger Rosyntjieberg Formation, comprising mainly of metasedimentary rocks. The latter forms the prominent 1100 m high mountain range in the south of the park, and also forms part of the NW–trending backbone of the Richtersveld (Macey et al. 2017).

The climate of the Richtersveld is best described by the close juxtaposition of the two dominant climatic regimes of southern Africa. The western parts and the higher, rugged mountain ridges fall within the winter rainfall regime that receives precipitation as rain and fog (and associated high air humidity) predominantly during the winter months by westerly winds in the context of cyclones from the circum-Antarctic west wind zone (Reason et al. 2002). Consequently, the western and higher mountain parts enjoy highly predictable, gentle, winter rains and fog, which support arid-adapted vegetation. In sharp contrast, the more eastern parts of the park lie in the wind shadow of the mountains and receive very little winter rain, while convective thunderstorms bring rains in the form of heavy downpours as rare and isolated events during summer months. These rare, heavy rains in the east



Source: Mr Abel Matsapula, Environmental Control Officer, SANParks, 2024, ©SANParks.

FIGURE 1: Locality of the Richtersveld National Park.

cause predominantly physical weathering, which enforces strong erosion of loose material in the mountains and the formation of sheet wash plains in the eastern valleys (Jürgens 2004). In the west, most of the rock weathering is chemical weathering from vegetation.

Centres of endemism in the Richtersveld National Park

Croizat (1965), Volk (1966) and Nordenstam (1969) were the first botanists to recognise the high number of endemic plant species in the lower reaches of the Orange River, and Croizat (1965) was the first to use the term *Gariep Centre*. Subsequently, the name *Gariep Centre* is used in most relevant taxonomic, biogeographical and ecological publications. In most of these publications, the Richtersveld is portrayed as the core of the *Gariep Centre*. Other authors (e.g. see Van Wyk & Smith 2001) regard a much wider geographical region as the Gariep Centre, including the area from Lüderitz to Port Nolloth to Augrabies. Jürgens (1991, 1997) proposed a subdivision of the southern African arid region (i.e. the entire Karoo and the Southern Namib) into (1) the *Succulent Karoo Region*, forming part of the *Greater Cape Flora* and (2) the *Nama Karoo Region*, forming part of the *Palaeotropis*. In accordance with this proposal, a split of the *Gariep Centre* into a *Western Gariep Centre* and an *Eastern Gariep Centre* was proposed. This division is generally accepted for the Greater Cape Floristic Region (Snijman 2013) and used here for the Gariep Centre. For many taxonomic plant groups, the *Western Gariep Centre* forms either the most important or one of the most important subunits within the Succulent Karoo Biome, including the highest number of genera within Aizoaceae and the largest number of species within the genus *Zygophyllum* (now *Roepera* and *Tetraena*) (Jürgens 1991, 1997; Van Zyl 2000). Within the West Gariep Centre, a very distinct and small but species-rich centre of endemism is the 'West Gariep District' (Jürgens 1991), which includes the desert habitats along the lower Orange River stretching from the western boundary of the RNP towards Alexander Bay (Jürgens 1991, 2006).

Point of contact of several biomes

While the above phytogeographical subdivision is based on the distribution patterns of endemic plants, *biomes* are defined as structural vegetation formations related to ecological functions (Rutherford & Westfall 1986). Following this concept, the *Succulent Karoo Biome* is formed by dwarf shrubs, the *Fynbos Biome* by the combination of

phanerophytes (larger woody plants) and dwarf shrubs, the *Nama Karoo Biome* by the combination of dwarf shrubs and hemicryptophytes (grasses), while the *Desert Biome* is characterised by the dominance of therophytes (annuals and ephemerals) (Rutherford & Westfall 1986). The high botanical diversity of the RNP is partly caused by the fact that several biomes with steep environmental gradients intersect within the park: namely the Succulent Karoo, Fynbos, Desert, and Nama Karoo Biomes (Jürgens et al. 2006). Of these biomes, the Fynbos and Succulent Karoo are being recognised as the two biologically richest and most endangered terrestrial biomes (Mittermeier et al. 1998, 1999).

The spatial patterns of the flora of the Richtersveld are globally unique because nowhere else do two neighbouring plant kingdoms (Cape Flora, now Greater Cape Floristic Region [Jürgens 1991, 1997; Manning & Goldblatt 2012; Snijman 2013] and the Palaeotropical Flora) meet within such a narrow, steep transition zone. In many locations in the RNP (e.g. near the Rooiberg, in the middle Abiekwa River reaches, in the upper Gannakouriep River), a complete turnover of species can be found within 5 km belonging either to the Greater Cape Floristic Region or, alternatively, the Zambezi Region of the Palaeotropis (Jürgens 2017). The Greater Cape Floristic Region is represented by the Fynbos Biome found at altitudes above 1200 m.a.s.l. in the western mountains of the RNP and Richtersveld World Heritage Site.

Furthermore, the Desert Biome is highly diverse and composed of a coastal unit (West Gariep Centre) associated with mild temperatures and high air humidity and an inland unit (East Gariep Centre) with very high temperature maxima and very low air humidity (Jürgens 2017). The climatic zonation from coast to inland, the incision of the Orange River valley within these two centres forms a gateway for both, coastal fog and, sometimes, extreme inland heat, thereby further enhancing diversity within landscapes with strong exposition effects (Jürgens 1986; Nussbaum 2003). Jürgens (2017) proposed that both survival of existing plant species and evolution of new taxa have been enhanced by the roughness of the mountain topography and the close juxtaposition of the two *Gariep Centres,* during periods of drastic climatic oscillations within a very small area (Jürgens 2017).

Small-scale heterogeneity of habitats with phylogenetically distinct species pools

Below the biome level, the vegetation of the RNP shows specific diversity, which is associated with the occurrence of extraordinary environmental conditions in specific habitat types. Examples of such habitats include (1) quartz fields (Schmiedel 2002; Schmiedel & Jürgens 1999, 2002) and (2) habitats frequently subjected to sandstorms on the western plains of the RNP, carrying psammophorous plants (Jürgens 1996). In both habitats, the evolution of specific adaptations led to speciation, and their presence in the RNP adds species to the flora.

The number of species in the landscapes of the RNP is also increased by the high frequency of small-scale habitat-cum-vegetation patterns, which are caused by zoological ecosystem engineers, including the heuweltjies and fairy circles caused by termites (*Microhodotermes viator* and *Psammotermes allocerus*) and the warrens of whistling rat colonies and other soil digging small mammals (Jürgens et al. 2022; McAuliffe et al. 2019, 2023). Best expressed in the well-known heuweltjies, all these vegetation patterns are characterised by steep environmental gradients, associated with strong differences of pH, conductivity, humidity of the soil at a scale of a few metres that are inhabited by quite different species assemblages, which in cumulation increase the density of species and different structures of vegetation (Jürgens et al. 2022).

Furthermore, compared to other arid vegetation types, an unusual fast turnover of species establishment and death has been recorded within the succulent dwarf shrub communities in the RNP (Gotzmann 2002; Jürgens, Gotzmann & Cowling 1999), which also contributes to rapid adaptation to changing environments and to spatial species diversity.

The high species diversity, especially within in the Succulent Karoo Biome of the RNP, despite high aridity, can be exemplified by an early study of the flora of a square kilometre in the valley of Numees in the RNP, where 276 flowering plant species (Angiosperms) were found, although the average rainfall is only ca. 80 mm per year (Jürgens 1986). Another example is the highest mountain in the RNP, Vandersterrberg, where Succulent Karoo, Desert, Nama and Fynbos Biome vegetation contribute to exceptional high species richness for an arid landscape, with a total number of 879 higher plant taxa recorded, to date, for a single mountain (Van Wyk et al., in prep.).

Land use

During historical times, the very close juxtaposition of the winter and summer rainfall region formed the ecological foundation for the traditional transhumance system, which included small stock farming shifting seasonally along the altitudinal and longitudinal gradient, the latter one allowing sequential grazing in the western winter rainfall zone and the eastern summer rainfall zone. The resulting historic mobility patterns of grazing pressure probably had little contribution to the loss of the rich botanical biodiversity of the RNP (Hendricks 2004; Hendricks et al. 2005; Jürgens 2006, 2017), at least compared to the continuous grazing in fenced camps in the southern Richtersveld (Jürgens 2006). It was an important argument during the negotiation phase to establish the RNP, which the – now historical – spatio-temporal pattern of traditional grazing rather alleviated pressure on biodiversity.

However, in recent years (2014–2023), surveys done on endemic flora for the South African Biodiversity Institute and the International Union for Conservation of Nature, within RNP, showed an alarming increase of plant species being threatened by overgrazing. The impacts, if any, on harvesting

of species for medicinal, edible and household use are unknown, but to a small extent still practised by livestock farmers in the RNP. Several mining licences, especially for diamonds, destroyed large areas along the ancient course of the Orange River (Richtersveld National Park 2018). Furthermore, since 2019, there has been a growing demand for rare succulents and bulbs, especially by Middle Eastern Nations, which has already resulted in incidences of illegal harvesting of plants from the RNP. Another growing land use, which poses a growing threat to biodiversity according to RNP annual reports for the past decade, is the harvesting of reeds and firewood by community members from the Aussenkehr Farm in Namibia, which are mostly workers from northern Namibia and Angola employed on the Aussenkehr Farm (Richtersveld National Park 2018). The impacts of tourism on the RNP's biodiversity are unknown, but probably small when compared with the other threats.

Research methods and design

The plant species list of the RNP is based on all available sources of information. Regarding taxonomy, we follow the South Africa National Biodiversity Institute (SANBI). We refer to the concepts published in Volume 2: The Extra Cape Flora, Plants of the Greater Cape Floristic Region (Snijman 2013).

For the compilation of the regional plant list and the annotations regarding distribution and habitat, we filtered the herbarium collections of the Kimberley South African National Herbarium (KSAN), Compton Herbarium (NBG), National Herbarium Pretoria (PRE), Bolus Herbarium (BOL) and the Herbarium Hamburgense (HBG).

In parallel, the following publications were extracted. We made of the Plants of Southern Africa online checklist of NEWPOSA (SANBI 2009), drawing up species lists using Quarter Degree Grids within which the study area falls, also using the Maps of the New Plants of Southern Africa online checklist (South Africa National Biodiversity Institute 2016). We also extracted the spatial information reported in the publications covering the wider Cape Flora (Bond & Goldblatt 1984; Goldblatt & Manning 2000; Levyns 1964; Manning & Goldblatt 2012). With regard to more regional to local publications, we used Van Jaarsveld 1980, 1986; Van Jaarsveld and Nordenstam 2005; Van Wyk 2021; Williamson 2000, the study of one square kilometre in the valley of Numees (Jürgens 1986), and the biogeographical publications by Jürgens and Niebel-Lohmann (1995). We also extracted the updated local species lists that were compiled by Jürgens et al. (2006) for the mapping units in the RNP for the VegMap 2006 project, complemented by GIS-based extracts from the SANBI database (Jürgens 2006; Mucina et al. 2006 [Succulent Karoo Biome]; Rebelo et al. [2006] Fynbos Biome).

The exploration of the flora of the RNP has not yet come to an end. Since 2013, more than 200 new plant species occurrences were recorded, and more than 30 plant species were newly described or their taxonomy resolved (Dreyer, Roets & Oberlander 2013; Goldblatt, Manning & Van Wyk 2015; Klak et al. 2023; Magee, Boatwright & Mucina 2014; Manning & Van Wyk 2021; Oberlander et al. 2014; Roets, Oberlander & Dreyer 2013, 2014; Swanepoel et al. 2022), highlighting how understudied this region is in certain lineages.

Since 2013, we started a systematic new approach to this species list. Data collection of plants was done monthly from October 2013 until April 2024, specifically for this publication, with the purpose not only to find unrecorded species but also to confirm whether species historically recorded still occurs within the RNP. In addition to existing herbarium material, over 3000 herbarium vouchers were made, and more than 2000 living vouchers were collected. Specimens are hosted in the RNP Field Herbarium and Nursery and stored at the KSAN, NBG, BOL and the HBG as well as living collections grown at the Richtersveld Desert Botanical Garden (RDBG). Plant species identification was done by comparing herbarium material at Compton (NBG), Bolus (BOL), Stellenbosch (STEU), KSAN, South Africa National Herbariums (PRE) and HBG. In some cases, dried material for genetic sequencing, as a means of identification, was provided to specialists. In the case of problematic species, second opinions were obtained from several specialists. The KSAN, based at Scientific Services, Kimberley, was visited on several occasions, and lists of more than 500 collections hosted from the RNP and surrounding areas were obtained.

We used the following internet sources:

- Plant Jstore online herbarium – to study type specimens that are hosted outside South Africa
- iNaturalist, including an iNaturalist project that was created to filter data; species with 'research grade' status, confirmed by specialist, was excepted (https://www.inaturalist.org/projects/richtersveld-national-park), which by the end of the research (April 2024) for this publication had a total of 4311 plant observations
- The conservation status was obtained by searching the SANBI Red List for each species (http://redlist.sanbi.org/) and the IUCN Red List for each species (https://www.iucnredlist.org/en) (SANBI Red List, IUCN Red List, April 2024)
- GBIF – https://www.gbif.org/occurrence/search and the South African Protected Areas Database (SAPAD) https://egis.environment.gov.za/protected_and_conservation_areas_database were used to create a shape file of all herbarium collections as well as iNaturalist observations with a research grade.

Ethical considerations

This article followed all ethical standards for research without direct contact with human or animal subjects.

Results

Up to April 2024, over 3000 new collections were made, bringing the total collections to more than 8000 herbarium

vouchers for the RNP, and more than 4000 iNaturalist observations were made of plant species in the RNP. By the end of April 2024, the RNP had a total documented indigenous flora of ca. 1077 taxa (including intraspecific names and plant species identified up to genus level) (Online Appendix 1).

The documented indigenous flora includes 14 pteridophytes (1.3%), 3 palaeodicots (0.2%), 246 monocotyledons (22.8%) and 815 dicotyledons (75.7%). A total of 99 families and 392 genera, which are indigenous, were recorded. The largest family is the Asteraceae, and the second largest family is the Aizoaceae family (Table 1). In addition, 44 taxa (3.9%) invasive or alien flora were also documented (Online Appendix 2).

In total, 125 of indigenous taxa (11.6%) were listed on the SANBI Red List (April 2024), 15 taxa were listed (1.3%) on the IUCN Red List (April 2024) (Table 2), and a total of 171 taxa (15.8%) are of conservation concern (Online Appendix 3). A total of 29 taxa (2.6%) are listed as endangered, and 21 taxa (1.9%) are listed as critically endangered on the South African red list (Online Appendix 3 and Table 2). A total of 38 taxa (3.5%) are endemic (Online Appendix 3 and Table 3), and 101 taxa (9.3%) are near endemic (Online Appendix 3).

Our results confirm that the earlier recorded and monitored taxa *Aloe claviflora* Burch., *Aloe falcata* Baker and *Aloe karasbergensis* (Pillans) Glen & D.S. Hardy have become extinct from the RNP as a result of the extreme drought between 2015 and 2019. *Larryleachia marlothii* (N.E.Br.) Plowes, *Monsonia patersonii* DC., *Oxalis* sp. PC2918 and *Albuca recurva* (Oberm.) J.C.Manning & Goldblatt have become extinct from the RNP as a result of diamond mining between 2018 and 2023, while *Psammophora saxicola* H.E.K. Hartmann might potentially also be extinct because of mining. Furthermore, *Moraea garipensis* Goldblatt, *Strumaria barbarae* Oberm. and *Strumaria barbarae* Jacq. could not be found during this study, and it is thus unconfirmed if they still exist within the RNP.

Discussion

Our study reveals that the indigenous vascular flora of the RNP comprises 1078 taxa. This is an impressive number for the size of the area and the partly extreme aridity.

TABLE 1: Ten largest plant families in Richtersveld National Park (excluding Online Appendix 2 alien species).

Family	No. of genera	No. of taxa	% of flora
ASTERACEAE	49	156	14.4
AIZOACEAE	28	137	12.7
CRASSULACEAE	4	57	5.2
HYACINTHACEAE	11	53	4.9
SCROPHULARIACEAE	23	49	4.5
FABACEAE	22	49	4.5
POACEAE	28	46	4.2
V APOCYNACEAE	21	36	3.3
ASPHODELACEAE	7	35	3.2
IRIDACEAE	11	34	3.1

For comparison, the flora of the Tankwa Karoo NP houses 750 vascular plant taxa in an area of 143 600 ha.

The here shown high plant species richness and the high conservation value, underlined by 38 endemic and 101 near-endemic taxa and 125 indigenous taxa listed on the SANBI Red List, confirm that SANParks' decision to proclaim the RNP as a national protected area is well supported (Steyn & Van Wyk 2015, 2017).

Since the proclamation of the contractual National Park in 1991, access to the park by tourists for camping, fishing and other activities such as off-road driving has been controlled to an extent. Regarding land use, only a limited number of small livestock units are permitted within the RNP (Richtersveld National Park 2018); however, overgrazing has been a major threat to the park in recent years because the number of herds has increased and stocking rates are consistently over the suggested rates, in spite of the still abiding severe degradation caused by the recent extreme drought (2015–2019). Because of illegal hunting, especially with dogs, the diversity and population density of the original fauna are extremely low, compared to similar habitats on the adjacent landscapes north of the Orange River in Namibia. More recently, the illegal collection of rare and endemic plant species in the Namaqualand and Richtersveld regions has become a major threat. While the park is less affected, adjacent areas, especially to the west, are drastically impacted, and this may soon cause negative effects on the diaspore banks of important plant species in the region, including inside the park. Opencast mining remains a great threat to the Richtersveld area, with four species in the list provided in this publication, already lost because of mining activities. One of the *Oxalis* sp. (PC2918) might potentially be extinct in nature, with only one specimen in ex situ collections, after the only known population was destroyed by a mine in 2022.

The plant species checklist presents the current state of botanical diversity in the northern section of the RNP, with the Klein Duin section not being included. A second publication is needed to include the Klein Duin section of the RNP, as pointed out in the management plan of the park (Richtersveld National Park 2018). This section of the RNP, however, has not been included because of insufficient data and limited funding to study this section for this study.

The high plant diversity of the RNP requires continued and even intensified conservation and protection efforts. The lists presented here of endemic and endangered species and the annotations on habitat and distribution will support efficient conservation planning. The above-mentioned cases of populations of rare species, which were recently lost because of mining activities or the recent drought, as well as the continuous detection of new botanical records call for regular updates of the lists. We aim to make such lists available in the web, findable by the search term 'Richtersveld National Park plant species list'.

TABLE 2: Endangered and critically endangered taxa from the Richtersveld National Park (see also Online Appendix 3).

Taxa	National status	National criteria	IUCN status
Acanthopsis ludoviciana H.M. Steyn	EN	B1ab(iii,v)+2ab(iii,v)	-
Acanthopsis tuba H.M. Steyn	EN	B1ab(iii)	-
Aloe pearsonii (Schönland)	CR	A3ce+4ace	CR
Aloidendron pillansii L. Guthrie	CR	A4ace	CR
Aloidendron ramosissimum Pillans	EN	A4ace	EN
Anacampseros herreana Poelln.	EN	B1ab(iii,v)+2ab(iii,v)	-
Anacampseros recurvata Schönland subsp. *buderiana* (Poelln.) Gerbaulet	EN	B1ab(iii,v)+2ab(iii,v)	-
Anacampseros variabilis Poelln.	CR	A2ac; B1ab(ii,iii,v)+2ab(ii,iii,v); C2a(i,ii); D	-
Astridia citrina (L. Bolus)	CR	A2ace+4ace; B1ab(I,ii,iii,iv,v)	-
Astridia herrei L. Bolus	CR	B1ab(iii,v)	-
Astridia longifolia (L. Bolus) L. Bolus	EN	B1ab(iii,v)+2ab(iii,v)c	-
Astridia speciosa L. Bolus	CR	B1ab(iii,v)	-
Babiana lobata G.J. Lewis	EN	B1ab(ii,iii,iv,v)+2ab(ii,iii,iv,v); C2a(i)	-
Cephalophyllum herrei L. Bolus	CR	A2ace+4ace	-
Conophytum ernstii S.A. Hammer subsp. *Ernstii*	EN	A3d	CR
Conophytum jucundum (N.E. Br.) N.E. Br. subsp. *fragile* (Tischer) S.A. Hammer	EN	A4d	-
Conophytum jucundum (N.E. Br.) N.E. Br. subsp. *jucundum*	EN	A4d	EN
Conophytum jucundum (N.E. Br.) N.E. Br. subsp. *ruschii* (Schwantes) S.A. Hammer	EN	A4d	EN
Conophytum loeschianum Tischer	EN	A3d+4c	EN
Conophytum stephanii Schwantes subsp. *helmutii* (Lavis) S.A. Hammer	EN	A4cd	EN
Conophytum taylorianum (Dinter & Schwantes) N.E. Br. subsp. *rosynense* S.A. Hammer	EN	A3cd	EN
Crassothonna opima Merxm.	CR	A2acd	-
Crassula sladenii Schönland	EN	A2a	-
Dracophilus dealbatus (N.E. Br.) Walgate	CR	A4ace	-
Drimia oliverorum J.C. Manning	CR	A3cB1ab(I,ii,iii,iv,v)+2ab(I,ii,iii,iv,v)	-
Eberlanzia schneideriana (A. Berger) H.E.K. Hart.	EN	A2ace+4ace	-
Eriospermum filicaule Marloth ex P.L. Perry	EN	B1ab(iii,v)	-
Eriospermum parvulum P.L. Perry	CR	B1ab(iii,v)	-
Juttadinteria albata (L. Bolus) L. Bolus	CR	B1ab(i,ii,iii,iv,v)	-
Lachenalia nordenstamii W.F. Barker	CR	B1ab(iii,v)+2ab(iii,v)	-
Leipoldtia lunata H.E.K. Hartmann & Rust	EN	B1ab(iii,v)+2ab(iii,v)	-
Mesembryanthemum occidentale Klak	EN	B1ab(iii,v)	-
Mesembryanthemum tomentosum Klak	EN	A4ace	-
Monsonia multifida E. Mey	EN	A4cd	CR
Moraea brevituba (Goldblatt) Goldblatt	EN	B1ab(iii)	-
Namaquanula bruce-bayeri D. Müll.-Doblies & U. Müll.-Doblies	CR	C2a(i)	-
Oedera nordenstamii (K. Bremer) Anderb. & K. Bremer	EN	B1ab(iii,v)+2ab(iii,v)	-
Pachypodium namaquanum (Wyley ex Harv.) Welw	CR	A4acde	-
Portulacaria pygmaea Pillans	CR	A2acd+4acd	-
Psammophora saxicola H.E.K. Hartmann	EN	A4ace	-
Pteronia anisata B. Nord.	EN	B1ab(iii,v)+2ab(iii,v)	-
Rhynchosia emarginata Germish.	EN	B1ab(iii,v)	-
Romulea rupestris J.C. Manning & Goldblatt	EN	D	-
Ruschia glauca L. Bolus	EN	B1ab(iii,v)	-
Ruschia inconspicua L. Bolus	EN	B1ab(ii,iii,v)+2ab(ii,iii,v)	-
Selago diabolica Hillard	CR	B1ab(iii,v)+2ab(iii,v)	-
Stapelia hirsuta L. var. *gariepensis* (Pillans) Bruyns	CR	A2ac+4ac	-
Strumaria barbarae Oberm.	CR	B1ab(iii,v)+2ab(iii,v)	-
Tetraena applanate (Van Zyl) Beier & Thulin	EN	B1ab(iii,v)+2ab(iii,v)	-
Trachyandra aridimontana J.C. Manning	EN	B1ab(iii,v)+2ab(iii,v)	-

EN, Endangered; CR, Critically Endangered; IUCN, International Union for Conservation of Nature.

Conclusion

The plant species checklist confirms an exceptional richness and uniqueness of the flora of the RNP. The conservation of this unique botanical area, located in one of the most arid parts of the country, adjacent to the Southern Namib Desert, in the face of global climate change, will require unprecedented efforts. The challenge for the RNP management team is to ensure the persistence of endemic and rare plant species as well as plant communities of special conservation status, while managing domestic animal use of the area in a sustainable way. This will require effort and consultation with all stakeholders. To tackle these challenges, national and international support will be needed. Furthermore, we recommend that the current conservation status of plant communities within the RNP be reassessed because of the loss of species associated with degradation of habitats.

TABLE 3: Endemic taxa of the Richtersveld National Park (see also Online Appendix 3).

Taxa	Family	Notes
Acanthopsis sp. nov PCV820	ACANTHACEAE	Lower slopes of mountains overlooking Armmanshoek.
Aloe meyeri Van Jaarsv.	ASPHODELACEAE	Cliffs on the southern mountains.
Amaryllis paradisicola Snijman	AMARYLLIDACEAE	Single cliff in the central-western mountains.
Anacampseros recurvata Schönland subsp. buderiana (Poelln.) Gerbaulet	ANACAMPSEROTACEAE	Quartz flats on the western mountains.
Astidia alba (L. Bolus) L. Bolus	AIZOACEAE	Among granodiorite in the northern parts of the park.
Astridia lutata (L. Bolus) Friedrich ex H.E.K. Hartmann	AIZOACEAE	Shale slopes in the north-western part of the park.
Astridia speciosa L. Bolus	AIZOACEAE	Quartz flats in the north-western part of the park.
Bulbine pendens G. Will. & Baijnath	ASPHODELACEAE	Shaded cliffs in the central to southern mountains.
Bulbine sp. nov. PC2663	ASPHODELACEAE	In shade of gneiss rocks, on mountain in the eastern part of park.
Cephalophyllum herrei L. Bolus	AIZOACEAE	Rocky outcrops in the north-western part of the park.
Cephalophyllum numeesense H.E.K. Ha.	AIZOACEAE	Stony slopes and flats from Vyfsusters to Helskloof.
Cheiridopsis angustifolia L. Bolus subsp. *protoparcoides* S.A.H.	AIZOACEAE	Stony flats on upper slopes of southern mountains.
Cheiridopsis sp. 1	AIZOACEAE	On quartz flats around Sendelingsdrif.
Cheiridopsis sp. 2	AIZOACEAE	In loamy soils of the Blokwerf valley, Vandersterrberg.
Cheiridopsis sp. 3	AIZOACEAE	On quartz flats of the Vandersterrberg upper slopes.
Cheiridopsis sp. 4	AIZOACEAE	Stony slopes of Helskloof.
Conophyrum ernstii S.A. Hammer subsp. *ernstii*	AIZOACEAE	Southern slopes of mountains.
Conophytum taylorianum (Dinter & Schwantes) N.E.Br. subsp. *rosynense* S.A. Hammer	AIZOACEAE	South facing cliffs on mountains.
Eriospermum sp. PC3257	RUSCACEAE	In shade of large rocks on the northern mountains.
Heliophila eximia Marais	BRASSICACEAE	South-west facing cliffs of the western and northern mountains.
Heliophila pseudoeximia Al-Shebaz	BRASSICACEAE	Shaded habitats of the Vandersterrberg and Oemsberg.
Hesperantha eremophila J.C. Manning & Goldblatt	IRIDACEAE	In renosterveld on Vandersterrberg and Oemsberg.
Lachenalia nordenstamii W.F. Barker	HYACINTHACEAE	On rocky flats of upper slopes of western mountains.
Lotononis sp. nov. PC 172	FABACEAE	Sand and stony flats in the north-western corner of park.
Oedera nordenstamii (K. Bremer) Anderb. & K. Bremmer	ASTERACEAE	Single limestone outcrop in Helskloof.
Othonna cremnophila B. Nord. & Van Jaarsveld	ASTERACEAE	Steep southern slopes and cliffs of the southern mountains.
Oxalis nivea Roets, Dreyer & Oberl.	OXALIDACEAE	Among rocks in the central to eastern mountains.
Oxalis petricola Dreyer, Roets & Oberl.	OXALIDACEAE	Stony slopes of the central mountains.
Oxalis rosettifolia Dreyer, Roets & Oberl.	OXALIDACEAE	Among granites of Tatasberg to Kookerboomkloof.
Oxalis rubricallosa Dreyer, Roets & Oberl.	OXALIDACEAE	Southern slopes of the central to western mountains.
Oxalis sp. nov. RB2	OXALIDACEAE	Vertical south facing cliffs south of De Hoop.
Pelargonium desertorum Vorster	GERANIACEAE	Southern slopes of the eastern and southern mountains.
Phylica sp. nov. PC376	RHAMNACEAE	Among fynbos patches on sandstone, Vandersterrberg.
Ruschia sp. nov. 1	AIZOACEAE	On quartzite cliffs of Mount Terror.
Ruschia sp. nov. 2	AIZOACEAE	In shade of large boulders, Sandberg.
Ruschia sp. nov. 3	AIZOACEAE	Among granodiorites of the central to northern mountains.
Selago diabolica Hillard	SCROPHULARIACEAE	Southern slopes of mountains in Hellskloof.
Tylecodon ellaphieae Van Jaarsv.	CRASSULACEAE	Shaded side of rocks, southern mountains of the park.

Further research regarding the key threats to individual species is needed to ensure the conservation of unique species. The protection of species in ex situ collections at the RNP's nursery is of great importance to prevent the total loss of species, in a changing environment. Loss of species from a National Protected Area within South Africa is a concern, especially if the cause of degradation is human-induced and needs to be investigated to prevent any further losses of species.

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Competing interests

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arrangements have been reviewed and approved by the affiliated university in accordance with its policy on objectivity in research.

Authors' contributions

P.v.W. contributed to the conceptualisation, methodology, formal analysis, investigation, writing of the article, visualisation, validation, data curation, resources and funding acquisition; H.B. contributed to the conceptualisation, methodology, investigation, writing of the article, visualisation, project administration, validation, resources and supervision; N.J. contributed to the conceptualisation, methodology, formal analysis, investigation, writing of the article, visualisation, validation, resources and supervision.

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Data availability

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

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