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Euryops walterorum, a declining restricted-range endemic of the Greater Gamsberg

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This paper is dedicated to the memory of Dr Thorsten Neckel, astronomer, friend, father and inspirer of this long-term initiative to monitor the population of one of Namibia's very special endemic species on the Greater Gamsberg. Dr Neckel passed away on 8th August 2020.

ABSTRACT

Euryops walterorum is a perennial shrub, endemic to an extremely limited habitat on the plateau of the Greater Gamsberg. The population of this endemic has been shown to be in decline since the early 1980s. The Gamsberg plateau is identified as one of the world's best astronomical observatory sites and has been used as an astronomical base since 1971. Due to its position and favourable atmospheric conditions, the establishment of the Africa Millimetre Telescope is planned here. This development may adversely affect the population of *Euryops walterorum*. In this paper we present information on the ecology and habitat of this plant. We also speculate on possible reasons for the population's decline. Based on this, we propose a long-term monitoring programme on the population health of this restricted-range endemic, as well as further measures for the conservation of the species. Preliminary results from the initial survey show the population stands in their habitat are unevenly distributed and most monitoring plots contained about two plants or less, and many had none. From the current plot data, the estimated total number of mature plants on the plateau was calculated to be about 22 000. Based on the observed reduction in population, as well as both the extremely small Extent of Occurrence and Area of Occupation, the conservation status of the species has been reassessed following IUCN Red List Criteria, and found to be Critically Endangered B1 ab(iii,iv) + 2ab(iii,v).

Keywords: endemic plant; conservation status; *Euryops walterorum*; Gamsberg; monitoring; Namibia; restricted range

INTRODUCTION

At an altitude of 2 347 m, the Greater Gamsberg (Figure 1) is one of the famous landmarks of Namibia. It is located at the edge of the Namib Desert in the Khomas Highland, about 120 km southwest of Windhoek. The plateau harbours a very special plant which, due to the seclusion of the mountain, few people have ever seen: *Euryops walterorum* Merxm. (Figures 2a and 2b). This species is a restricted-range endemic to the Gamsberg plateau (Nordenstam 1966, 1968, Loots 2005). The plateau covers an area of about 220 hectares (Carr & Strohbach 2019, Strohbach 2021), making this an extremely limited habitat. Because of the unique species composition and dominance by *Euryops walterorum*, Strohbach (2021) described the vegetation of the plateau as a unique vegetation association, being the *Digitario erianthae–Euryopietum walterorum.* This association is characterised by the presence of *Panicum lanipes, Euryops walterorum, Eriospermum bakerianum* subsp. *bakerianum, Hypertelis salsoloides, Boophone disticha, Eragrostis nindensis* and *Digitaria eriantha*.

The first herbarium specimens were collected in 1891 by Fleck, followed by Schwerdtfeger in 1953, Merxmüller in 1957 and Nordenstam in 1963 (Nordenstam 1968). Merxmüller described it as a new species in 1955 and named it after the botanists Prof. H. and his wife Dr E. Walter (Giess 1984). In 1963, *E. walterorum* grew in abundance on the stony, flat plateau (Nordenstam 1968), but Giess (1984) observed a severe decline of about 75% of the population in 1983.

Due to its altitude, the dry and clear atmosphere, the very dark night sky and excellent astronomical observation results, the Gamsberg plateau is identified as one of the world's best observatory sites and an astronomical station was built on it after the plateau was bought by the Max Planck Society in 1970 (Elsässer 1989). In 2017, the Netherlands's Radboud University pronounced its intention to construct the planned Africa Millimetre Telescope (AMT) on the Gamsberg plateau (Falcke 2020). Since January 2019, access to the plateau has been restricted only to Max Planck Society partners and

Figure 1*: The north-western aspect of the Greater Gamsberg. The plateau is the habitat of the endemic shrub* Euryops walterorum*. Towards the left margin of the image, the Lesser Gamsberg with its tiny plateau is visible.*

closed to the public (Lemke 2019). Comments on the Environmental Impact Assessment for the proposed establishment of the AMT on Gamsberg were made as part of an Environmental Impact Assessment feedback session in January 2019 at the Namibian Scientific Society in Windhoek. At this meeting, the need for protecting the species from the construction work was stressed and an alternative AMT site was proposed on a different plateau area outside that of the *E. walterorum*'s habitat. A botanical specialist study is part of the EIA, has highlighted the threat to the *E. walterorum* population and made management recommendations. This includes the search for alternative sites.

However, the apparent long-term decline of this limited population and the added pressure that the proposed AMT project will impose, warranted further investigation of the ecology and population dynamics of *E. walterorum*. As a means of obtaining baseline data for this species, studying population dynamics and exploring population trends over time, the National Botanical Research Institute initiated a long-term monitoring project, in cooperation with the Namibia University of Science and Technology (Carr & Strohbach 2019).

EURYOPS WALTERORUM IN A PORTRAIT

Euryops walterorum is one of about 100 *Euryops* species, which mostly occur in Africa, with two species known from the Arabian Peninsula (Ali *et al.* 2016). Most species are confined to southern Africa (Devos *et al.* 2010). The genus *Euryops* in Namibia is common in the southern part of the country, where it is mainly restricted to higher mountainous regions (Nordenstam 1969).

A full description of the species was provided by Suessenguth & Merxmüller (1958) and Nordenstam (1968). *Euryops walterorum* is described as a vigorous glabrous shrub without a subterranean caudex, moderately branching from the base, with erect or ascending branches (Figure 2a). The flowering period with lots of yellow capitula (Figure 2b) starts in mid-winter, generally in July, during the dry period.

Based on morphological characteristics, *Euryops walterorum* seems closely related to *E. lateriflorus*, *E. sulcatus*, *E. ciliatus* and *E. empetrifolius*, the last three of which also have ciliolate leaf-margins. The closest relative appears to be *E. empetrifolius*, which likewise has discoid or shortly radiate capitula. *Euryops walterorum* differs from the latter species mainly by its bigger capitula and larger leaves (Nordenstam 1968). No genetic evidence is available to substantiate these observations, though (Devos *et al.* 2010).

Evolution and endemism in the context of the prehistoric formation of the Greater Gamsberg Mountain plateau

As *E. walterorum* is found only on the Greater Gamsberg plateau (Nordenstam 1968), the question of its origin comes into focus. The endemism can be explained by an insight into the geological formation of the Gamsberg. The present-day Gamsberg formed on intrusive granites, which formed on the southern

Figure 2a: *(left) A mature individual of* Euryops walterorum *in February 2020.* ***Figure 2b:*** *(right)* Euryops walterorum *with buds and capitula (flowerheads) in July 1995.*

edge of the Damara Orogen. Uplift of this orogen formed a high plateau, which was systematically eroded until only the granites remained. Throughout the Karoo sedimentation, this massif remained an island, only to be covered by sands later during the Karoo sedimentation period (Schneider 2004). These sands were partially blown together to form dunes or washed into shallow depressions about 130 million years ago. This wide, sandy plain was not much higher than the sea level at that time, far from its present height (Wittig pers. com. 2020). This is shown by angular holes, up to five cm in size, in the Gamsberg quartzite: Judging by cast rubber fillings, these holes originate from weathered gypsum roses from that period and indicate brackish water (Wittig 1976). At roughly the same time, the African continent began to separate from the South American part of the Gondwana supercontinent. This break-up resulted in the upliftment of the southern African subcontinent through tectonic effects which led to the formation of the Great Escarpment, also in Namibia (Schneider 2004). Over time, the sands solidified into hard quartzite layers forming large table mountains (Schalk 1983). These included the Mount Etjo and Waterberg further north, with the Gamsberg plateau forming an isolated, southernmost occurrence of the Etjo Sandstone (Schneider 2004). By gradually breaking off at the edges (Figure 3a), erosion changed the shape of the table mountains (Schalk 1983) and split the Lesser Gamsberg from the early Gamsberg plateau (Schneider 2004). It is still clearly visible that the same plateau once covered both mountains if observed from a distance (Wittig pers. com. 2020) (Figure 3b).

Nordenstam (1969) regarded the genus *Euryops* as an old and widespread member of the African flora, which differentiated in the Paleogene, about 66 million to 23 million years ago. Recent genetic investigations estimate that differentiation between different clades and species of this genus started some 39 million years ago (Devos *et al.* 2010). This implies that the predecessor to the genus *Euryops* likely already populated the former Gamsberg area during the formation of the Great Escarpment. Through erosion, this population became isolated from other populations further south, and started evolving to the present-day restricted-range endemic species. Unfortunately, *E. walterorum* has not been included in any phylogenetic studies yet (cf. Devos *et al.* 2010, Ali *et al.* 2016), thus its evolutionary history remains unclear. As the Gamsberg plateau was much larger once, the species may also have had a larger habitat, which possibly included the present-day Lesser Gamsberg. Today, the Lesser Gamsberg forms a small plateau remnant with an eroded, unsuitable habitat and no evidence of *E. walterorum*. It is thus likely that the species disappeared from there a long time ago.

GROWING CONDITIONS ON THE GREATER GAMSBERG

Climatic conditions

No weather stations have been installed on the Greater Gamsberg. This means that there are only general climatic data available for the area between the Khomas Highland and the Namib Desert (e.g. Mendelsohn *et al.* 2002). Here the mean annual precipitation is indicated as being between 200 and 250 mm, with a coefficient of variation (CV) of over 50%. Orographic effects of the high plateau are not taken into account.

The development of the CRU-TS 4.03 data set makes modelled historical climatic data available (Harris *et al.* 2014). A down-scaled version of these data, ranging from 1961 to 2018, is available for further climatic studies via the WorldClim data system (Fick & Hijmans 2017). The data have a spatial resolution of 2.5 geographical minutes, or roughly 4.2 x 4.6 km. From these data, monthly historical data have been extracted for the Gamsberg plateau, and have been used to construct climate diagrams (Figure 4). Mean annual precipitation is 287 mm, however, with a high variability (CV of 39.7%).

As the Gamsberg plateau is about 450 m higher than the ground level on the east side and about 1 100 m higher on the west side (Schalk 1983), a strong orographic effect exists. This is especially evident after good rains over consecutive days when the cool and humid plateau can be observed to be covered by clouds in the morning (Figure 5a and 5b), forming a dense fog (Figure 5c), while the sky in the vicinity of the mountain is clear and sunny. In addition, ambient temperatures on the plateau appeared to be several degrees lower compared to the surrounding plains and especially the land below the escarpment to the west. These conditions of lower temperature and higher humidity on the plateau could be a distinct advantage for *E. walterorum* to survive on the Gamsberg.

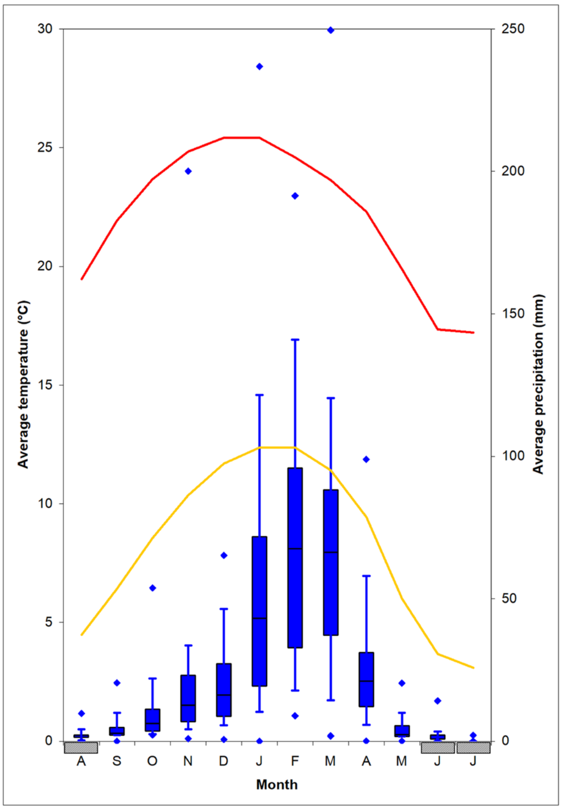

Figure 4: *Climate diagram for the Gamsberg plateau, based on CRU-TS 4.03 data (1961 – 2018) from WorldClim (Fick & Hijmans 2017). Rainfall is indicated as Box-and-Whisker boxes; there the boxes represent the 2nd and 3rd quartile, and the whiskers the 10th percentile (lower whisker) and the 90th percentile (upper whisker). Absolute minimum and maximum precipitation values are indicated as diamonds. The average minimum temperature is indicated as a yellow line, the average maximum temperature as a red line. Frost can occur in the shaded months June, July and August.*

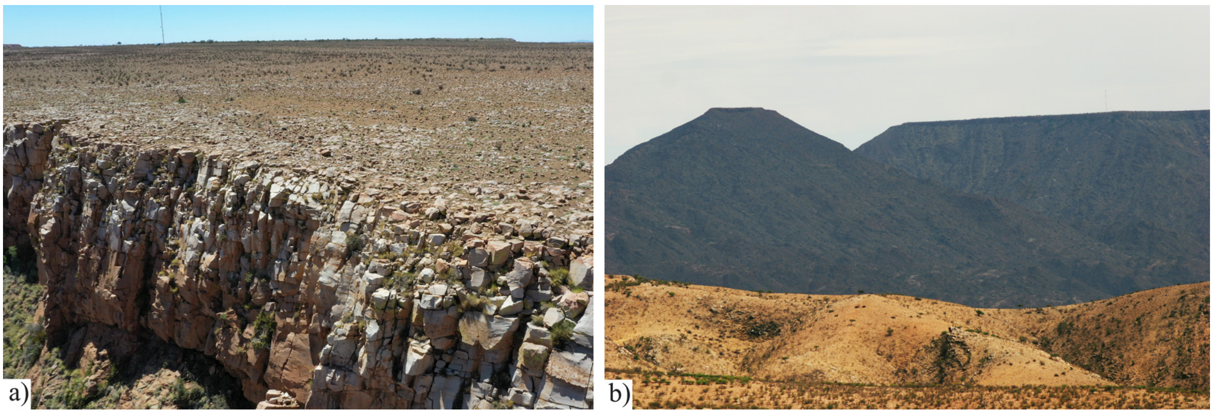

Figure 3a: *(left) The Greater Gamsberg plateau with its 25 to 30 m thick quartzite layer of flat-lying rocks. The edges are eroded and have been breaking off continuously for millions of years (Schalk 1983).* ***Figure 3b****: (right) Lesser and Greater Gamsberg seen from the north east at a distance of 18 km. Both plateaus were once part of the same mountain. This is indicated by nearly the same plateau height of the Greater (2 347 m) and Lesser (2 326 m) Gamsberg (Schalk 1983).*

Figure 5a: *(top left) The cloud covered plateau after exceptional rain in August 1998, seen from the plain south of the Gamsberg.* ***Figure 5b:*** *(top right) The cloudy plateau, as often seen during a good rainy season, recorded from Farm Hakos, about 18 km north east of the Gamsberg, on 1 March 2020 at 09h18. (Photo by Hakos Webcam (Straube et al. 2019)).* ***Figure 5c:*** *(bottom) Dense fog on the plateau in March 2000 enclosed and moistened* Euryops walterorum.

Additionally, casual observations showed the formation of ephemeral wetlands on the plateau. During good rainy seasons in the 1970s, large areas on the plateau were flooded by rain to form pools and puddles, with frogs and fish soon appearing. The frogs came out of cracks in the ground and the fish hatched from eggs in the soil laid by the previous generation (T. Neckel pers. com. 1994). As late as March 2000 (Figure 6a) croaking frogs could be heard from the puddles on the soaked, loamy soil of the plateau after heavy rain. These temporary wetland biotopes have probably been forming for a very long time during good rainy seasons. *Euryops walterorum* plants associated with those areas were observed to be especially lush (Figure 6b), and this points to the possibility that the species may have originated from cooler, more humid conditions.

Observations on autecology and population dynamics

We observed the population intermittently as follows: from 1994 to 1998 on an annual basis, continuing with observations in the years 2000, 2007, 2017 as well as in 2019 and 2020. The following discussion is largely based on these observations.

The species is probably out-crossing (Nordenstam pers. com. 1998). This is confirmed as no seeds were found on shrubs flowering outside the main flowering season, whereas shrubs flowering simultaneously during the season, growing in close proximity (Figure 7), produced plentiful seeds. As many shrubs died over the last almost 50 years, the population density declined and the chances of shrubs in the surrounding area flowering at the same time became less. Additionally, flower production seemed to be minimal or entirely absent after a previously poor

Figure 6a: *(left) After heavy rain in March 2000, the plateau was saturated with water and widely covered by puddles.* ***Figure 6b:*** *(right) Flooded areas in March 2000 within the habitat of* Euryops walterorum*, where plants' condition was especially good.*

rainy season. Similar patterns have been observed with e.g. *Acacia mellifera*, which also only produces viable seeds after normal or good rainy seasons (Joubert *et al.* 2013).

Euryops walterorum seeds and seedlings needed prolonged wet conditions during the rainy season and additional rainfall outside the rainy season for germination and establishment. Seeds germinated after three to five days on wet soil and grew quickly. Survival in their first year depended on water reserves in the soil after an adequate rainy season. This was confirmed by observations in July 1995, when, after frequent and good rainfalls until May, many new seedlings were found on the plateau. One year later, however, due to a poor following rainy season in 1996, most of these were found to be dead. From 2017 onwards seedlings were rarely found. The rainy seasons of recent years were poor, characterised by low precipitation and several weeks of dry spells between rainfall events (Figure 11a). In February 2020, after good rainfalls of December 2019 and January 2020, at least one location with some new seedlings was found. Cocoons of insects were found inside the capitula of a considerable number of *E. walterorum*, which may have played a role in the poor seed production. These insects are still to be identified.

Figure 7: *During the flowering period in July 1995, yellow flowering shrubs on large expanses of the plateau indicated the extent of the* Euryops walterorum *population.*

Euryops walterorum was observed to be able to survive the annual dry period without damage. During a prolonged drought resulting from a delayed or insufficient rainy season, leaves became notably drier and turned to pale green or yellow. After subsequent rainfalls most terminal leaves turned green again and branch tips continued forming new ones. However, this regeneration of the foliage, observed on a regular basis in the past, appears to have diminished from 2017 onwards. Instead, there were many shrubs without leaves, or only brown leaves falling off. Many dead shrubs were still firmly anchored in the ground and may have been standing for years.

Figure 8: Euryops walterorum *grew in abundance on the Gamsberg plateau in 1971. (Photo by T. Neckel).*

Figure 9: *Between 1971 and 2019, large parts of the* Euryops walterorum *population have died. This photograph was taken in February 2019 at the same location with the same viewing direction as the one in Figure 8. (Photo by A. Burke).*

Population decline

In April 1963, *E. walterorum* was found to be abundant in large patches on the plateau, although it did not cover the entire area (Nordenstam pers. com. 1998). This was verified by the astronomer Dr Thorsten Neckel in 1971 and in later years. His photograph taken from the astronomical station in 1971 (Figure 8) shows a vigorous population. Neckel found a considerable part of the population to be dead in the early 1980s (T. Neckel pers. com. 1994). Giess (1984) confirmed this when he visited the Gamsberg in 1983 and roughly estimated a decline of about 75%, as a result of the prolonged drought (Botha 1998). The population did not increase after the loss in 1983, but remained stable (T. Neckel pers. com. 1994). In 1994, Christine Treichel visited Neckel on the Gamsberg for astronomical work and was inspired by him to start her own observations on *E. walterorum* and to continue observations during visits in subsequent years. In 2017, after an absence of ten years, Treichel found an additional, large

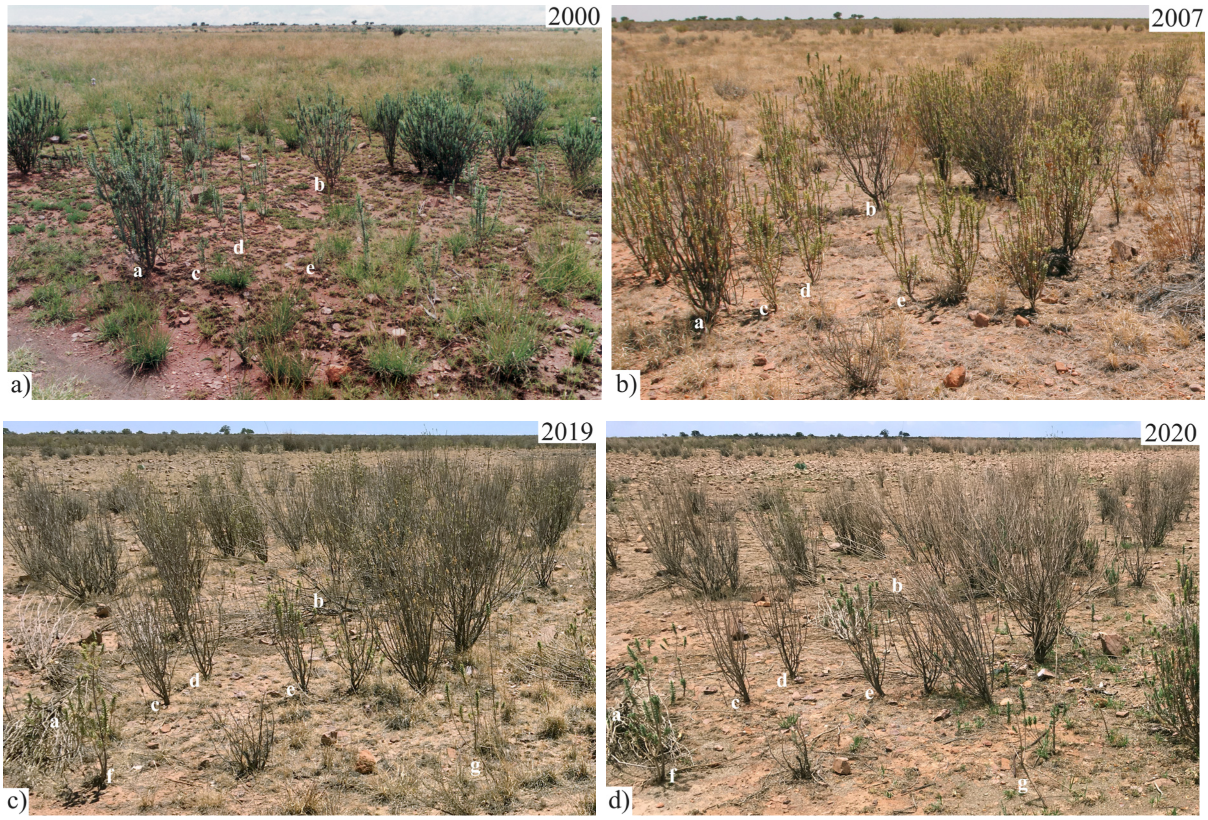

Figure 10: *Repeat photograph series of* Euryops walterorum *from a fixed position over the last 20 years. (a) (top left) March 2000, (b) (top right) January 2007, (c) (bottom left) February 2019, (d) (bottom right) February 2020. For illustration, some exemplary shrubs were marked with letters on the photos: Plants a and b, which already were mature in 2000, grew by 2007, but were found to be dead and fallen over in 2019. Plants c, d and e, which were juvenile in 2000, matured by 2007, but had not significantly grown by 2019. In 2019, c and d were found to be dead whereas e was still alive in 2019 and 2020. There was some recruitment in 2019, as can be seen by markers f and g.*

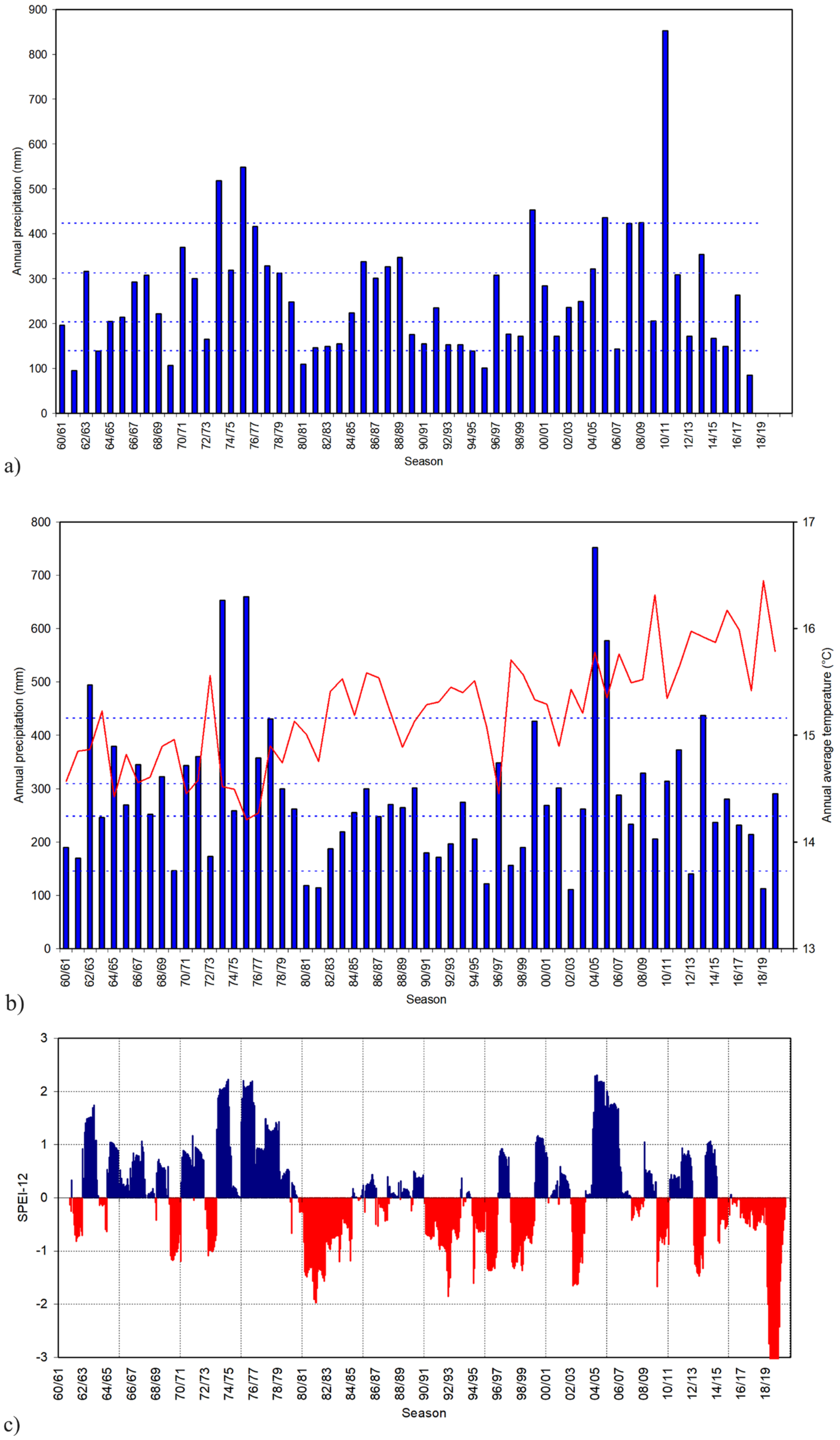

Figure 11: *Long-term climatic trends for the general Gamsberg region. (a) (top): Rainfall observations at Hakos to the north east of the Gamsberg (Straube et al. 2019). This is used to verify general trends of modelled data for the Greater Gamsberg. (b) (middle) Annual rainfall (blue bars) and average annual temperatures (solid red line) for the Greater Gamsberg, based on modelled data from WorldClim and MeteoBlue. For both these graphs, the stippled lines represent the following: from the bottom: 10th percentile of long-term annual rainfall; 40th percentile, 70th percentile and 90th percentile. Seasons with less than the 10th percentile of rainfall are considered as extreme drought years, seasons with less than the 40th percentile as drought years, season with between the 40th and 70th percentile annual rainfall are considered as normal, above the 70th percentile as wet and over the 90th percentile as extreme wet (Botha 1998). (c) (bottom): SPEI index for the Greater Gamsberg, calculated from the same modelled data as used in Figure 11b. For all graphs, the annual values were calculated as seasons from August to July each year, not as calendar years.*

portion of the remaining population to have died. In 2019, this reduction was estimated to be 25% to 30% of the remaining population. In comparison to Neckel's photograph from 1971, another photograph taken in 2019 at the same location and in the same viewing direction by Burke (Figure 9), clearly shows the extent of the decline over the past almost 50 years, with the population having become thinned out and even partly disappearing from the plateau.

Repeat photographs from a fixed position, covering the years between 2000 and 2020, show the process of decline, which is prevalent on large parts of the plateau (Figure 10).

Possible causes of the decline

The reasons for the apparent decline during the past almost 50 years are not yet understood. Beside the observations starting in 1994, satellite images and meteorological data analysed by the authors point to several possible factors that could be mutually reinforcing and may be responsible for or contributing to the perceived reduction and continuing decline. Possible reasons might be the following:

1. Giess (1984) reported a decline of 75% of the population of *E. walterorum* after the drought in the early 1980s. Based on this report, we obtained modelled historical climate data (1961 – 2018) from WorldClim (Harris *et al.* 2014, Fick & Hijmans 2017) for the Greater Gamsberg. These data were augmented with data from MeteoBlue for the 2018/19 season (meteoblue AG 2020), which is not yet included in the WorldClim data set. The WorldClim data set has a spatial resolution of 2.5 geographical minutes (roughly 4.2 x 4.6 km), whilst MeteoBlue only presents their data in a spatial resolution of 30 x 30 km (or quarter degree cells). The basic trends shown by these data were verified against rainfall measurements from the nearby farm Hakos (1 813 m above sea level, about 18 km north east of the Greater Gamsberg) (Figure 11a) (Straube *et al.* 2019). Although not exactly matching, general trends in terms of drought- and wet spells are repeated between Hakos and the Greater Gamsberg, indicating the validity of the modelled data. The quality of in-between seasons, however, varied greatly from each other, likely due to the down-scaling algorithm used by WorldClim (Fick & Hijmans 2017), taking the altitudinal difference also into account (i.e. the orographic effect of the high plateau). The long-term rainfall and mean annual temperature trends at the Greater Gamsberg (based on WorldClim data) are presented in Figure 11b. The quality of the season is indicated on the graphs as four horizontal lines, representing the 10^{th}, 40^{th}, 70^{th} and 90^{th} percentile. All seasons with a total precipitation between the 40^{th} and 70^{th} percentile (at the Greater Gamsberg 261 and 303 mm precipitation annually) are regarded as 'normal', all seasons with a total precipitation below the 10^{th} percentile (less than 166 mm) are regarded as extreme droughts, whilst all seasons with more than the 90^{th} percentile precipitation (more than 429 mm) are regarded as extreme wet seasons (Botha 1998). (For Hakos, the 10^{th} percentile is at 139 mm, the 40^{th} percentile at 203 mm, the 70^{th} percentile at 312 mm and the 90^{th} percentile at 423 mm precipitation annually.) Based on the modelled WorldClim and MeteoBlue data, a Standardised Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano *et al.* 2010) was calculated for the Greater Gamsberg. The SPEI was accumulated for 12 months, thus indicating the quality for any particular month in relation to the quality of the entire season (SPEI-12). The SPEI-12 clearly indicated wet and dry spells (Figure 11c).

The dense population in 1971, as depicted in Figure 8, could be the result of a series of near-normal or above-normal rainy seasons between 1962/63 and 1970/71. Only one drought year was recorded in 1969/70, but was followed by an above-normal season in 1970/71 (in which the picture of Figure 8 was taken). During this period, average temperatures also stayed fairly moderate. The recorded decline in 1983 (Giess 1984) could have been the result of three drought seasons after each other, with two extreme drought years in 1980/81 and 1981/82 (Figures 11b and 11c). During this period, the average temperatures also started rising. With a series of near-normal years between 1984/85 and 1989/90, the population would have stabilised, but not been able to expand. Another prolonged drought period between 1989/90 and 1998/99 would have potentially reduced the population further. A fire in 2016 (see below), coupled with a series of dry years starting in 2013 and cumulating with the severe drought in 2019 (Figures 11b and 11c), could have been the cause for the low population density recorded in Figure 9. The dry conditions were aggravated by a steadily rising average temperature (about 1.6 °C between 1961 and 2020, based on a linear regression of the mean annual temperature ($r^2 = 0.59$), Figure 11b), resulting in higher potential evapotranspiration (PET) and thus a higher net water deficiency. From this it is clear that the shrubs, even though being perennial, are relatively short-lived and the population highly reactive to the quality of the season. Projected long-term climate changes for southern Africa are thus likely to further negatively impact this population.

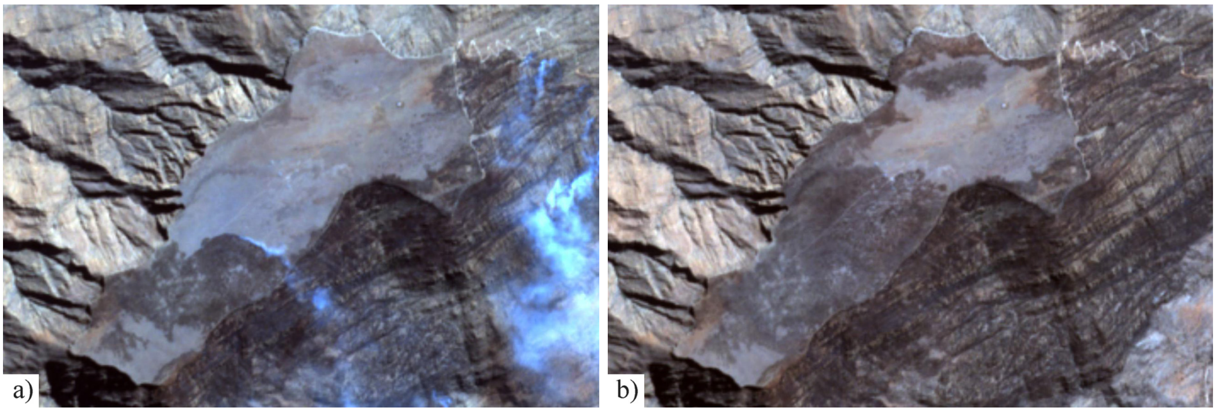

Figure 12: *Progress of the bush fire on the Gamsberg plateau and slopes in August 2016, recorded by the Sentinel-2A satellite. The Gamsberg areas impacted by the fire were (a) (left) on 20 August 2016: The southern plateau, the south-eastern and eastern slopes and the eastern plateau edges, (b) (right) on 30 August 2016: The southern and central plateau, the entire edges of the north-western, northern and north-eastern plateau, a part of the northern plateau, and the eastern and northern slopes. Image sources: Sentinel-2A, Tile T33KXQ dated 20 August 2016 (left) and 30 August 2016 (right). Downloaded from https://scihub.copernicus.eu.*

2. A fire was recorded on the Gamsberg in August 2016, being the only recorded fire during the period November 2000 and June 2020, as evident from the MODIS burned area mapping tool (Giglio *et al.* 2018). This fire started on the south-eastern side of the Greater Gamsberg on 19 August 2016, and spread onto the southern plateau, the south-eastern and eastern slopes and eastern plateau edges over the subsequent day (Figure 12a). It further spread onto the central plateau and the northern edges and was extinguished by local farmers before reaching the astronomy base, leaving most of the northern part of the plateau untouched (Figure 12b). Impacts on the vegetation like charred and burned *E. walterorum* shrubs in the station area and burned *Acacia hereroensis* trees near the northern edge of the plateau, were still visible during a field visit in 2019. Overall, the long-term fire risk for the Gamsberg area is regarded as low (Le Roux 2011).

3. A high mortality rate in older shrubs may have led to a significant decline in the population size, which in turn resulted in reduced seed production or seedling establishment.

4. As the species is out-crossing, the population decline may have led to diminished pollination and seed production and this in turn would have led to a reduction in recruitment, which finally appeared to lead to a further shrinking of the population size.
5. Other species could have colonised the habitat of *E. walterorum. Eriocephalus dinteri* especially can be regarded as a competitor to *Euryops walterorum*, but the dense perennial grass sward dominated by *Digitaria eriantha* could be competing for moisture resources (Strohbach 2021).
6. Pests could have weakened the population through herbivory and inhibiting seed formation.

THE NEED FOR MONITORING OF *EURYOPS WALTERORUM*

The possible effects of climate change as well as the impacts of infrastructure developments are expected to result in a continuing decline of this population, leading to a detrimental effect on the population's viability with extinction in the wild as a possible outcome in the foreseeable future. As there are no empirical data confirming any of the trends observed in the population on the plateau, a long-term monitoring initiative has been initiated by a consortium consisting of the National Botanical Research Institute (Ministry of Environment, Forestry and Tourism), the Biodiversity Research Centre of the Namibia University of Science and Technology, as well as independent lay botanists with a special interest in the project. This initiative is endorsed by the Max Planck Society as the landowners.

The aims of this initiative are:

- to establish a baseline data set on the present-day population
- to establish a monitoring system to monitor the population dynamics in relation to climatic trends and anthropogenic impacts
- to establish a conservation strategy for *E walterorum*, both *in situ* and *ex situ*.
- to determine inter-population genetic relationships (one population or two populations on the northern and southern side of the plateau?)
- to determine phylogenetic relationships with other species of the genus *Euryops.*

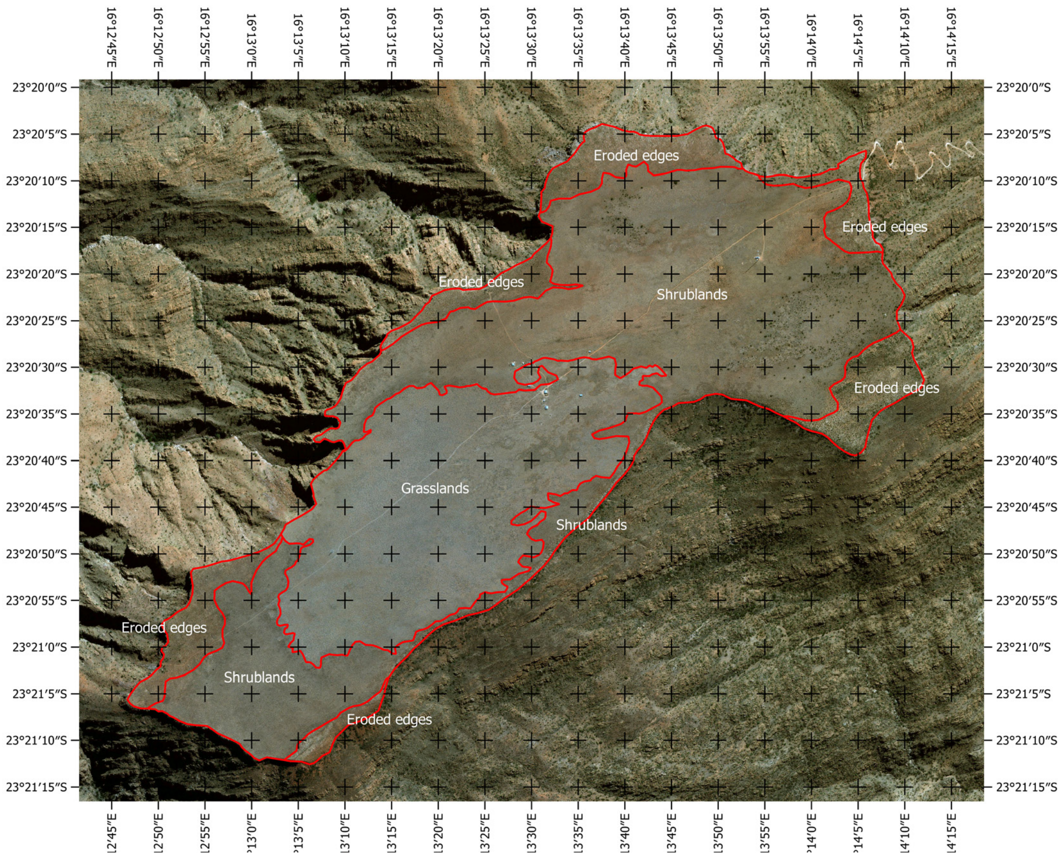

***Figure 13**: Habitats identified and delineated on the Gamsberg plateau, using Google Earth and Microsoft Bing imagery. The shrublands represent likely* Euryops walterorum *habitat.*

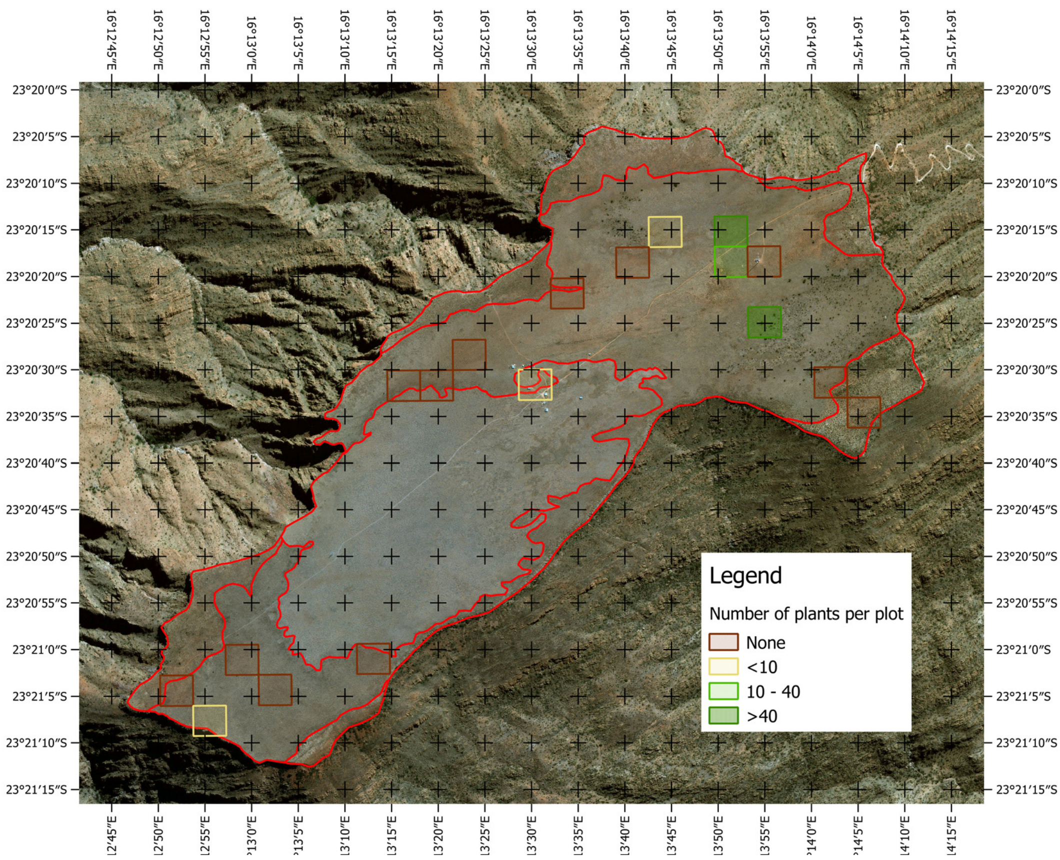

***Figure 14**: Surveyed densities of the* Euryops walterorum *population.*

An initial survey to estimate the population density of *E. walterorum* and obtain baseline data for future monitoring was done during field visits in November 2019 and February 2020. A series of permanent monitoring sites, their lay-out and position pre-determined in a stratified randomised manner following the scheme of the Biodiversity Observatories (Jürgens *et al.* 2012), were set up.

The proposed long-term monitoring programme for *E. walterorum* is described in online Appendix 1.

ESTIMATE OF PRESENT POPULATION OF *EURYOPS WALTERORUM*

Based on the two field visits during November 2019 and February 2020, we can describe the population of *E. walterorum* as follows:

1. The species' occurrence is restricted to the shrublands along the northern, eastern and southern parts of the plateau (about 110 ha), with none occurring in the central grassland, nor along the boulder-strewn eroded edges of the plateau (Figure 13). Within the shrublands, the stands are unevenly distributed.

2. It was evident that the population on the northern and eastern part of the plateau showed a larger amount of live plants than on the southern part of the plateau. This is possibly due to the fire which occurred in 2016 on the southern part of the plateau (Figure 12), but could also have resulted from uneven rainfall distribution over the plateau.

3. In an attempt to explain the difference in habitat, two soil samples were taken from the upper soil layer (10 to 20 cm) at the astronomical station in the shrubland where *E. walterorum* grows, as well as from the survey beacon in the grassland, where it does not occur. The samples were analysed for texture and nutrient values, using standard procedures (Carter & Gregorich 2008). The preliminary soil analysis of shrubland and grassland indicated that the sandy loam was very low in organic material (< 1.5% of organic content). At both locations nitrogen was very low (< 85 mg / 100 g of soil), therefore magnesium (> 57 mg / 100 g of soil), manganese (> 75 mg / kg of soil) and iron (> 95 mg / kg of soil) were very high and the pH value (6.1) was slightly acidic. There were no evident differences between the sites to explain the absence of *E. walterorum* in the grassland.

4. A basic descriptive analysis was done with the collected data and displayed in a geographical information system (GIS) map (Figure 14). In a few plots, over 50 individual plants were counted, but most plots had about two plants or less, and many had none. This is in stark contrast to previous observations, which showed a far denser and far more vigorous population (Figures 8 and 10). Most plants were between 50 and 100 cm high. From the current plot data, the estimated total number of mature plants on the plateau was calculated to be about 22 000.

CONSERVATION STATUS AND STRATEGY

The conservation status of *E. walterorum* on the global IUCN Red List is currently published as 'Least Concern' (LC), reflecting the last global assessment (Craven 2004, IUCN 2012). As a consequence of the apparent threats to the species, resulting in population reductions and decline in the past and foreseen in the future, a review of the conservation status is required and was carried out by the National Botanical Research Institute. *Euryops walterorum* occupies an extremely small Extent of Occurrence (EOO) and Area of Occupancy (AOO). Past reductions in the number of plants were reported as significant and climate data recorded over at least 60 years, suggest a significant plausible threat from the effects of climate change, resulting in a continuing decline in the number of mature individuals and the quality of the habitat. The construction of the planned AMT in the future is predicted to result in further population reduction. The single sub-population is also viewed as a single location because of the significant plausible threats, which limit the spread of the risk of extinction. Although the species qualifies for the Vulnerable D2 category as well as VU A3c and Endangered A2c and A4c, the higher category of Critically Endangered applies in the B category because of the small EOO, AOO, number of locations and the continuing decline in the quality of the habitat and number of mature individuals. The preliminary conservation status is therefore given as CR B1 ab(iii,v) + 2ab(iii,v). The assessment was done using the IUCN categories and criteria (IUCN 2012, IUCN Standards and Petitions Committee 2019) and entered onto the IUCN Species Information System (SIS), from where it will be published as part of the next IUCN global Red List, after a review process approves the assessment.

As a conservation measure, the *ex situ* growing of plants from seeds is planned. This is meant to complement *in situ* conservation measures, aid in preserving a portion of the gene pool and maintain a fallback population of mature plants in case the conditions on the Gamsberg plateau continue to deteriorate. Additionally, excess seeds will be deposited in the National Plant Genetic Resources Centre.

CONCLUSION

Euryops walterorum is a national treasure, growing invisibly to the public on the hard-to-access Gamsberg plateau. The data obtained from the long-term monitoring measures that are now in place will be indispensable and instrumental in revealing population trends in time, such as a further decline in population size, or problems with germination and seedling establishment in this very limited population, and may provide imperative information for understanding and mitigating these effects. A Population Viability Analysis can be conducted once sufficient data have been collected to aid in calculating the risk of extinction.

In times of climate change and biodiversity loss it is in our hands to preserve this extraordinary species.

AUTHOR CONTRIBUTIONS

This paper was initiated and drafted by CT. CT also contributed most of the observations and photographs on *E. walterorum*. BS developed the proposed monitoring system and field-tested this together with SC. BS also provided inputs in the sections 'Climatic conditions' and 'Population decline'. SL provided structural improvements to the sections 'Introduction', 'Observations on autecology and population dynamics' and 'Conservation status and strategy'. SC, SL and AN provided various inputs and insights in this paper.

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