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# Impact of poaching on the population structure and insect associates of the Endangered *Encephalartos eugene-maraisii* from South Africa

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**Background:** South Africa is an important centre of cycad diversity in Africa, however, the country's cycads face extinction. Among the primary causes is the poaching of plants from the wild, even within protected areas.

**Objectives:** This study examined poaching patterns in a local population of the Endangered *Encephalartos eugene-maraisii* I.Verd. and how it might affect the population structure, sex ratios, as well as interactions with associated insects.

**Methods:** The population was surveyed in 2008 and 40% of this population was resurveyed between 2021 and 2022. We mapped missing cycads and generated heatmaps. Lastly, we investigated whether the proportion of stems from different size classes, sex ratios and abundance of insect associates varied between areas with a high and low poaching incidence.

**Results:** Poaching, defined as the illegal removal of individuals from the wild, occurred 1.5 times more frequently along the border fence line than areas further away. Medium-sized stems (21–80 cm) are primarily targeted (likely as they can be carried more easily) and low proportions of these stems remain in areas with a high poaching incidence. While *E. eugene-maraisii* exhibits some resilience against poaching through basal suckering, it takes several decades for suckers to mature and replace harvested stems. No effect on sex ratios were recorded in areas with a high poaching incidence, suggesting poachers have not deliberately selected female or male cycads at this site. No pollinating insects were detected on *E. eugene-maraisii*, and no seedlings were observed.

**Conclusion:** Cone production may be too rare in diminished populations to support pollinators that utilise cones as brood sites. The presence of insects that use other plant parts, including leaves, dried leaf stalks and cycad trunks, in the larger population suggests that they are more resilient to diminishing host populations. However, these insects were absent in smaller populations, and their abundances were lower in low-density sites and smaller clump sizes of their host in the larger population. This suggests these insects may be vulnerable to the decline of their host populations due to poaching.

**Keywords:** cycads, conservation areas, herbivore-plant interactions, population decline, impact.

# Introduction

South Africa is a major centre of cycad diversity in Africa, with the monotypic *Stangeria eriopus* (Kunze) Baill. and 37 species of *Encephalartos* Lehm., of which 29 species are endemic to South Africa (Calonje et al. 2023). However, South Africa's cycads face extinction. Many species have limited distributions and small populations, and their numbers are continually declining (Table 1). South African species include four that are already Extinct in the Wild, 11 that

Table 1	. Status and threats	of South African	Encephalartos	species acco	rding to the I	UCN Red List of	Threatened species	s (IUCN 2023)

Species	Status	Individuals (N)	Populations (N)	Threats
E. brevifoliolatus Vorster	EW	0	0	1
E. heenanii R.A.Dyer	EW	0	0	1, 2, 5
E. nubimontanus P.J.H.Hurter	EW	0	0	1
E. woodii Sander	EW	0	0	7
E. inopinus R.A.Dyer	CR (?EW)	1	1	1, 4
E. dolomiticus Lavranos & D.L.Goode	CR (?EW)	0–4	1	1, 4
E. cerinus Lavranos & D.L.Goode	CR (?EW)	0–5	1	1, 4
E. hirsutus P.J.H.Hurter	CR (?EW)	0–10	1	1, 4
E. laevifolius Stapf & Burtt Davy	CR	6–11	3	1, 4
E. cupidus R.A.Dyer	CR	50	1	1,4
E. latifrons Lehm.	CR	70	4	1,4
E. msinganus Vorster	CR	100–200	1	1, 2, 4
E. middelburgensis Vorster, Robbertse & S.van der Westh.	CR	184–200	4	1, 2, 4, 5
E. dyerianus Lavranos & D.L.Goode	CR	350-400	1	1,4
E. aemulans Vorster	CR	600	1	1
E. eugene-maraisii I.Verd.	EN	400-620	3	1,4
E. arenarius R.A.Dyer	EN	850-1500	5	1, 2
E. horridus (Jacq.) Lehm.	EN	Unknown	Unknown	1
E. lebomboensis I.Verd.	EN	5 000	5	1, 3, 6
E. ngoyanus I.Verd.	VU	2 500–5 000	10	1, 2, 5
E. paucidentatus Stapf & Burtt Davy	VU	3 000–5 000	6	1, 2
E. princeps R.A.Dyer	VU	3 500-5 000	6	1, 2, 6
E. altensteinii Lehm.	VU	4 000–10 000	10–15	1, 2, 3
E. ghellinckii Lem.	VU	8 000–10 000	Unknown	1, 5
E. senticosus Vorster	VU	5 000–10 000	12	1, 2
E. humilis I.Verd.	VU	4 500–9 500	10–12	1, 5
E. lanatus Stapf & Burtt Davy	VU	70 000–80 000	8	1
E. lehmannii Lehm.	VU	Unknown	12	1, 2, 6
E. natalensis R.A.Dyer & I.Verd.	VU	Unknown	Unknown	1, 3
E. trispinosus (Hook.) R.A.Dyer	VU	Unknown	8	1, 2
E. friderici-guilielmi Lehm.	NT	5 000–10 000	Unknown	1, 3
E. ferox G.Bertol.	NT	>10 000	Unknown	1, 2, 5
E. caffer (Thunb.) Lehm.	NT	10 000–30 000	12–20	1, 2
E. transvenosus Stapf & Burtt Davy	NT	20 000–50 000	Unknown	1, 2, 3
E. longifolius (Jacq.) Lehm.	NT	Unknown	11–20	1
E. cycadifolius (Jacq.) Lehm.	LC	Stable	Unknown	5
E. villosus Lem.	LC	Stable	Unknown	1, 2

EW – Extinct in the Wild; CR – Critically Endangered; EN – Endangered; VU – Vulnerable; NT– Near Threatened; LC – Least Concern; 1 – Over-collecting/poaching; 2 – habitat destruction for agriculture, livestock impact, etc.; 3 – Harvesting for traditional medicine; 4 – Reduced recruitment; 5 – Natural system modification (e.g., altered fire regimes); 6 – Invasive plant species; 7 – Naturally rare? The last remaining stems were all deliberately removed from the wild. are Critically Endangered, four that are Endangered, 11 that are Vulnerable, and five that are Near Threatened (IUCN 2023). Relatively more cycads in South Africa are Extinct in the Wild or Critically Endangered than in other centres of cycad diversity (Donaldson 2008).

In most regions of the world, the primary cause of the decline in cycad numbers is habitat loss, but in South Africa the poaching of wild plants has played an even greater role, affecting nearly all species (Okubamichael et al. 2016; Table 1). Established cycads from the wild are targeted because cycads are notoriously slow growing and can take decades to reach desirable sizes (Donaldson 2003). Consequently, many plants have been collected for botanical gardens and private collections (Osborne 1995). Those that become rare increase in value, making them even more desirable to collectors and increasing the pressure on species in the wild (Courchamp et al. 2006; Okubamichael et al. 2016). Some species have suffered dramatic declines; for example, in Kaapsehoop, 1 700 Encephalartos laevifolius Stapf & Burtt Davy plants were present in the 1970s, but there are now fewer than five remaining (Government Gazette 2017). Despite various conservation measures, restrictive legislation, and the use of novel technologies (such as microchips and microdots), poaching continues relentlessly because large, rare specimens are in high demand (Donaldson 2003).

South African cycads are also harvested for traditional medicine (Ravele & Makhado 2010; Cousins et al. 2011, 2012, 2013; Williamson et al. 2016; Ndou et al. 2021). Traditional medicine has experienced significant commercialisation in recent years and there has been an increase in the sale of stem sections and bark strips of *Encephalartos* species at traditional markets, which puts more pressure on wild *Encephalartos* populations (Cousins et al. 2011). Intensive harvesting of bark strips and stem sections can be destructive and often result in the death of plants (Donaldson 2003; Bamigboye & Tshisikhawe 2020).

Other threats include the destruction of habitats and invasive plant species. Historically, habitat destruction has contributed to a decline in South African cycad populations. For example, the clearing of dune thicket for agriculture directly reduced *E. arenarius* R.A.Dyer populations (Donaldson 2003). Alien plants such as *Lantana camara* L. have invaded the habitat of cycads such as *E. princeps* R.A.Dyer and *E. lebomboensis* I.Verd. and can potentially affect recruitment by smothering young plants (Donaldson 2003; Government Gazette 2017).

Those involved in illicit trade with cycads often claim that their goal is conservation, even though the illicit collection is the main threat (Torgersen 2017). It is important to conserve cycads not only as part of South Africa's natural heritage but also as a component of ecosystem function. They provide food and shelter for birds and animals (Donaldson 2008), host complex mutualistic relationships with insects (Toon et al. 2020), and host arbuscular mycorrhizae that shape biogeochemical processes in their microhabitats (Marler & Calonje 2020).

Cycads recover slowly from poaching due to their slow growth (Raimondo & Donaldson 2003). Poaching can affect the size of the cycad population, age structure and sex ratio. For example, Cycas circinalis L. populations subjected to pith harvesting completely lacked individuals greater than 50 cm tall (Krishnamurthy et al. 2013). The expected sex ratio for a healthy cycad population is 1:1 but in small populations, male-biased sex ratios are often observed, and it has been speculated that this results from selectively harvesting female plants since they produce seeds (Donaldson 2008). The rarest species are now often represented only by small populations, making them vulnerable to stochastic events (e.g., drought, fire), inbreeding depression and reduced natural recruitment (Donaldson 2003). Cycads and their pollinators exhibit brood-site mutualism, making them vulnerable to coextinction (Toon et al. 2020). There may be too few cones produced by diminished cycad populations to support insect pollinators (Oberprieler 1995). South African species of Encephalartos also have a high diversity of other specialised insects, for example, female cone specialists and leaf consumers, which are also threatened by declining host populations (Oberprieler 1995).

Encephalartos eugene-maraisii I.Verd. is listed as Endangered under Red List criteria A2ad + 4ad; B1ab(v)(IUCN 2023). This species has a limited distribution in the Waterberg range and lacks natural recruitment, making it extremely vulnerable to poaching (Bezuidenhout et al. 2020). The impact of poaching on this cycad has not been studied before. A lack of scientific information constrains decision support systems and the development of management decisions that can effectively ensure the survival of E. eugene-maraisii in the wild (Bezuidenhout et al. 2020). This study aimed to 1) identify poaching patterns of E. eugene-maraisii in one of its last remaining populations, 2) assess its impact on the size class structure and sex ratio of the population, and 3) how this might impact insects closely linked with E. eugene-maraisii.

# Materials and methods

### Study site

*Encephalartos eugene-maraisii* is endemic to the Waterberg range in Limpopo, South Africa (Bezuidenhout et al. 2020). The majority of individuals remain in two main conservation areas, located at either end of its geographical range. Marakele National Park (Marakele) is located at the southwestern extreme of the Waterberg cycad distribution. The Entabeni Safari Conservancy (Entabeni) is at the northeastern edge of its range, where the majority of *E. eugene-maraisii* plants still exist. There have been no reports of cycad poaching in Marakele since its proclamation in 1994 (Bezuidenhout et al. 2020). However, at that time, very few plants (< 50) remained in Marakele and they are extremely difficult to reach (Bezuidenhout et al. 2017). We have also failed to record the presence of any cycad-associated insects in Marakele. Therefore, sampling was confined to Entabeni where the majority of plants remain.

Most plants grow on the rocky mountain plateaus and scarps in the Waterberg-Magaliesberg Summit Sourveld (Gm 29) at high altitudes (1500–1750 m.a.s.l.) (Mucina et al. 2006). The vegetation is characterised by patches of open woodland of *Protea caffra* Meisn. and open shrubland of *Englerophytum magalismontanum* (Sond.) T.D.Penn. and *Ancylobotrys capensis* (Oliv.) Pichon (Steyn & Bezuidenhout 2020). The climate is warm in summer and cold and prone to frost in winter. Historically, fires were frequent in the study areas due to the very high frequency of lightning strikes, and fire scars were visible on the cycads in both populations.

#### Study species

*Encephalartos eugene-maraisii* has aerial stems (up to 4 m long) that become procumbent as they age. Individual plants are multi-stemmed through the production of basal suckers (Figure 1). Individual plants can persist over long periods of time due to vegetative production of suckers and stem longevity. Like all cycads, *E. eugene-maraisii* is dioecious although cones are produced infrequently.

### Patterns of poaching

Poaching was assessed in Entabeni, where the majority of plants remain. The main driver behind the poaching in Entabeni is the horticultural trade, which requires that whole stems are removed. We did not find evidence that plant parts are being harvested for the traditional medicinal trade. This is also supported by previous authors (Bezuidenhout et al. 2020). *Encephalartos eugene-maraisii* has also not been recorded in traditional medicine markets (Cousins et al. 2011, 2012, 2013).

In 2008, Entabeni conducted a cycad census on its property to determine the population size and distribution



Figure 1. Typical architecture of an Encephalartos eugene-maraisii plant. Photographer: P.D. Janse van Rensburg.

within the reserve (De Klerk, 2008). GPS coordinates were provided to facilitate the retracing of individual plants. Given the scattered distribution of plants, it was unlikely to mistake them for those in similar locations. The original census took months to complete and many of the plants are in areas difficult to reach. Given time limitations, we only re-surveyed the most densely populated area between 2021 and 2022. Approximately 40% of the plants identified in the original census (De Klerk 2008) were revisited. The studied plants occurred in a small area ( $\sim$ 8 km<sup>2</sup>), which accounted for approximately 30% of the total area. We recorded plants as present, dead or missing. Remains of dead cycads are visible for a very long period. It was rarely possible to determine the cause of mortality, but common causes include stems falling over, baboon damage and poachers damaging and excavating large stems to get to smaller stems that they could carry. If no remains were found they were classified as missing. Missing cycads were mapped and heatmaps produced. We recorded the number of stems for the plants present, and for each individual stem, we measured its height. The survey areas were also searched for seedlings to confirm the presence or absence of natural recruitment.

### Impact of poaching

The plants grew in areas along the fence line and areas further from the fence. The fence stretches over a distance of approximately 3 km over rocky terrain that is difficult to patrol. Other areas are more easily visible and accessible from roads within the reserve. It appears that plants have been poached from across the entire population. However, poaching has historically been more intense along the fence line (Entabeni reserve manager, pers. comm.). Therefore, analyses were conducted by categorising areas along the fence line as 'high poaching incidence' and areas further from the fence line as 'low poaching incidence'. A ridgeline divides the two areas. The high poaching incidence area consists of plants along the fence line and the western slope of the ridgeline, which faces the fence. The low poaching incidence area consists of plants on the eastern slope of the ridgeline and further away.

All analyses were done using SPSS version 28 (IBM Corp 2021). To assess the impact of poaching on the size structure of the population we compared the distribution of stem height of individual stems in areas with high and low poaching incidence using the Kolmogor-ov-Smirnov test for goodness of fit (e.g., Botha et al. 2004a, 2004b). The studied plants occurred in a small area and experienced similar climatic conditions and fire regimes. Additionally, cycad stem growth is positively correlated with stem height, therefore shrinkage of stems is ruled out (Griffiths et al. 2005; Marler et al. 2020).

Medium-sized stems seemed to be primarily targeted because large stems may be too heavy to carry over the large distances that poachers need to cover over neighbouring properties (Entabeni reserve manager, pers. com.). To test this, we investigated whether the proportion of stems from different size classes varied between areas with high poaching incidence and low poaching incidence. We classified all stems into five size classes based on their length: suckers (no visible stem); visible stems (> 0 cm); small stems (1–20 cm); medium-sized stems (21-80 cm) and large stems (> 80 cm). The proportion of each size class in the areas of high and low poaching incidence was compared using Chi-square analyses ( $\chi^2$ ). Finally, to show how the clump size of individual plants might be affected by poaching we tested for significant differences with a Kruskal-Wallis test, between the mean number of stems per plant for each category in areas with high vs low poaching incidence.

During the 2008 census, a small proportion of plants were sexed. To gather more data, we examined cycad plants for cone material to determine the sex of the plants. A binomial test was conducted to see if the proportion of male and female plants are different from the expected 1:1 sex ratio in cycads. To test whether poaching affects the sex ratio through selective harvesting of female plants, we compared the proportions of male and female plants between areas with a high poaching incidence and low poaching incidence using Chi-square analysis. We also tested for significant differences in the mean number of stems between male and female plants using a Kruskal-Wallis test.

### Insect abundance

We recorded three insect species associated with *E. eugene-maraisii* in Entabeni (Figure 2), but, as per previous extensive surveys, none of these are pollinators. Reference collections (accession numbers: *PDJVR Morpho 6* and 7) are stored at the Biosystematics Division, South African National Collection of Insects (SANC), Agricultural Research Council, Pretoria, South Africa.

Amorphocerus cf. setosus Boheman, 1838 (Coleoptera: Curculionidae) bore into the trunk of *E. eugene-maraisii*. The trunks exhibit characteristic emergence holes made by beetles. All stems except those out of reach or pinned between rocks were assessed for beetle emergence holes. This was done by placing a 10 cm wide piece of clear plastic, from top to bottom on each stem and counting the number of exit holes made by *A*. cf. *setosus* adults. The number of holes per square centimetre was calculated by dividing the number of holes by the area recorded (the length of the stem  $\times$  10 cm).

Apinotropis verdoornae Jordan, 1945 (Coleoptera: Anthribidae) breed in dead leaf stalks of *E. eugene-maraisii*. It has overlapping life history stages and so it is



Figure 2. Insects associated with Encephalartos eugene-maraisii in Entabeni: A, B, Amorphocerus cf. setosus; C, D, Apinotropis verdoornae; E, F, Zerenopsis lepida. Photographs: P.D. Janse van Rensburg.

usually possible to find adults and larvae within the same leaf stalk at any time of the year (personal observations). If dead leaf stalks were present, five dead leaves were randomly selected from each stem, cut off and dissected after which the numbers of larvae and adults were determined.

Larvae of Zerenopsis lepida (Walker, 1854) (Lepidoptera: Geometridae) consume new leaf flushes (Janse van Rensburg et al. 2023). Herbivory damage was used as an estimate of the abundance of Z. lepida. To determine the level of damage, the percentage of leaf area removed for each leaf was visually estimated using different damage classes: 0%, 1–25%, 26–50%, 51–75%, and > 75%. We calculated the percentage of leaf area consumed by larvae by multiplying the number of leaves from each damage class with the midpoint of each damage class category, e.g., 13% for the 1–25% class. The values of all classes were then summed and divided by the total number of leaves per stem. Only new leaf flushes are damaged and only a small portion of plants flush leaves each season. For a more complete sample of the entire population, we combined leaf damage estimates from consecutive years, 2021 and 2022.

Kruskal-Wallis tests were used to determine whether there were significant differences in mean insect abundances between plant sex, altitude and aspect. Additionally, we recorded whether the stems had fire scars and tested for significant differences between the abundance of insects on the burned and unburned stems. To assess the potential impacts of poaching we compared insect abundance between high poaching

incidence and low poaching incidence areas. Also, because poaching can lead to lower plant densities and smaller clump sizes due to removed stems, we compared insect abundance between different densities of E. eugene-maraisii and analysed correlations between the abundance of insects and the clump size (number of visible stems) of E. eugene-maraisii using Spearman rank correlation analysis. Using heat maps of existing plants, we rated areas with dense plant density (dark spots on the heatmap), sparse plant density (light spots on the heatmap), and intermediate plant density (areas between dense and sparse areas).

#### Ethical considerations

Ethics approval (no.: NWU-01552-20-A9) for this study was granted by the North-West University, Faculty of Natural and Agricultural Sciences Ethics Committee (FNASREC). A permit (no.: ZA/LP/111179) to do research on plants in the Limpopo province of South Africa was granted by the Limpopo Department of Economic Development, Environment and Tourism (LEDET).

## Results

### Patterns of poaching

We were unable to find any seedlings in the survey areas. A total of 297 plants recorded in 2008 were revisited. Out of those, 246 (83%) plants were still present, eight ( $\sim$ 3%) plants were dead and 43 ( $\sim$ 14%) plants could not be relocated. This represents a reduction of ~17% (51 plants) in 14 years, equivelant to an annual intrinsic population growth rate of -0.013. The estimation is based only on completely missing plant individuals and does not include missing stems from plant individuals that were still present. Most of the missing plants were those that occurred adjacent to the border fence of the conservation area and are assumed to have been removed from the wild by poachers (Figure 3).

### Impact of poaching

The Kolmogorov-Smirnov test for goodness of fit only indicated a marginally significantly different stem size distribution between areas with high poaching incidence (n = 70) and low poaching incidence (n = 176)(K-S = 1.443, p = 0.031). Chi-square analysis indicated that there was a higher proportion of stemless suckers in areas with high poaching incidence (35.8%) compared to areas with low poaching incidence (24.3%) ( $\chi^2$ = 10.457, df = 1, p = 0.001) (Table 2). There was a higher proportion of visible stems (> 0 cm) in the areas with low poaching incidence (75.7%) than areas with a high poaching incidence (64.2%) ( $\chi^2 = 10.805$ , df = 1, p = 0.001). Of the visible stems, the frequency of medium-sized stems was lower in the areas with a high poaching incidence (18.7%) compared to areas with a low poaching incidence (28.5%) ( $\chi^2 = 5.596$ , df = 1, p = 0.018). The proportions of small stems ( $\chi^2 = 0.454$ , df = 1, p = 0.500) and large stems ( $\chi^2$  = 0.006, df = 1, p = 0.937) did not differ significantly between areas.



Stem length (cm)	Relative frequ	encies (%) of h	eight classes	eight classes Mean (range) number of stems of class per plant		
	High poaching incidence	Low poaching incidence	Chi Squared	High poaching incidence	Low poaching incidence	Kruskal- Wallis
Stemless suckers (0)	35.83	24.27	0.001	0.96 (3)	0.76 (4)	0.042
Visible stems $(> 0)$	64.17	75.73	0.001	1.73 (6)	2.38 (7)	0.003
Small stems (1–20)	15.51	17.70	0.500	0.41 (2)	0.55 (4)	0.287
Medium-sized stems (21-80)	18.72	28.47	0.018	0.50 (3)	0.89 (3)	< 0.001
Large stems (> 80)	29.95	29.56	0.937	0.80 (3)	0.92 (4)	0.433
All	100	100	-	2.61 (6)	3.09 (7)	0.080

Table 2. The relative frequency of stems from different height classes of *Encephalartos eugene-maraisii*, and the mean number of stems per plant for each height class, in areas with high poaching incidence and low poaching incidence

The range indicates the difference between the lowest and highest values.

This was further reflected by a significantly higher mean number of medium-sized stems (21–80 cm) and lower stemless suckers (0 cm) per plant in areas with a low poaching incidence (Table 2).

#### Sex ratios

We were able to determine the sex of 90 (39.3%) of the remaining plants, of which 52 were male and 38 were female. A two-tailed binomial test indicated that the observed proportion of female plants did not differ significantly from the expected value 0.50 (p = 0.142). There were no differences in the frequency of male and female plants between areas ( $\chi^2 = 0.552$ , p = 0.457). We found no difference between the mean number of visible stems and suckers between female (2.83) and male plants (2.85) (H = 0.029, p = 0.865) and the mean numbers of medium-sized stems (primarily targeted for harvesting) between female (0.33) and male plants (0.69) (H = 1.216, p = 0.270).

#### Insect abundance

There was no significant association between the abundance of insects and aspect, altitude and the sex of plants (Tables S1, S2; Supplementary material). A total of 78% of stems had visible fire scars. This did not significantly affect the abundance of *A. verdoornae* or herbivory by *Z. lepida*. However, the mean number of *A.* cf. setosus exit holes was significantly higher on burned stems (0.018 holes/cm<sup>2</sup>) than on unburned stems (0.005 holes/cm<sup>2</sup>) (p < 0.001).

The mean number of *A. verdoornae* individuals were higher in areas with a low poaching incidence, but not significantly so (Table 3). The abundance of *A. verdoornae* was significantly lower in areas with low plant density, and plants with smaller clump sizes also had a lower abundance of *A. verdoornae* (Table 3). The level of herbivory from *Z. lepida* was significantly higher in areas with a low poaching incidence and decreased significantly with decreasing plant density and decreasing

**Table 3.** The relationship between density and clump size of *Encephalartos eugene-maraisii* and the abundance of *Amorphocerus* cf. *setosus* (measured by the number of exit holes on the cycad trunk), *Apinotropis verdoornae* (measured by the number of individuals in dead leaf stalks) and *Zerenopsis lepida* (measured by the level of herbivory)

Insects	Mean (range) area	abundance be	tween	Mean (range) abundance between plant density					Correlation with clump size	
	High poaching incidence	Low poaching incidence	р	Sparse	Intermediate	Dense	p	<i>r</i> <sub>s</sub>	p	
Amorphocerus cf. setosus	0.016 (0.05)	0.017 (0.06)	0.399	0.017 (0.05)	0.015 (0.06)	0.019 (0.06)	0.137	0.067	0.305	
Apinotropis verdoornae	2.72 (13)	3.49 (22)	0.138	2.46 (11) <sup>a</sup>	2.81 (13) <sup>a</sup>	4.49 (22) <sup>b</sup>	0.010	0.158	0.018	
Zerenopsis lepida	6.12 (50.29)	12.12 (88)	< 0.001	5.57 (29.96)ª	10.50 (88) <sup>ab</sup>	13.20 (88) <sup>b</sup>	0.024	0.406	< 0.001	

The range indicates the difference between the lowest and highest values.

clump sizes of *E. eugene-maraisii* (Table 3). We did not record any significant difference in the number of exit holes of *A.* cf. *setosus* between the areas nor any correlation with the density or clump sizes of *E. eugene-maraisii* (Table 3).

# Discussion

This is the first investigation into poaching patterns in a local population of the Endangered E. eugene-maraisii and how it might affect its population structure and interactions with associated insects. Supporting the observations made by the reserve manager, a slightly higher intensity of poaching was observed along the border fence line of the conservation area. Areas along the border fence line had a low proportion of medium-sized stems (21-80 cm), which seems to be the primary target for poachers. We found no difference in the sex ratios between areas with high poaching incidence and low poaching incidence and found no evidence for selective harvesting of female plants. The abundance of A. verdoornae and herbivory by Z. lepida decreased in lower densities and clump sizes of E. eugene-maraisii, indicating they may be sensitive to the decline of their host plant.

Poaching of *E. eugene-maraisii* has been a major problem for the past 30 years, with estimates suggesting a 50% reduction in the population (Government Gazette 2017). As a result, the distribution has shrunk, and the remaining subpopulations can be found mostly in Entabeni and Marakele (formally protected area managed by SANParks) (Bezuidenhout et al. 2020). There have been no reports of cycad poaching in Marakele since its proclamation in 1994 (Bezuidenhout et al. 2020). There were, however, very few plants left by then. Entabeni's plants were some of the most difficult to reach. The eradication of cycads in most areas in the Waterberg, caused by poaching, has led to an increase in poaching incidents in Entabeni.

Although sampling only 40% of the population was a limitation, we concentrated on the locations with the highest density of plants that were most often targeted by poachers. Other plants on the reserve are more randomly distributed and harder to reach. In this study, a slightly higher poaching rate (1.5 times) was observed along the border fence line. Besides being the first cycads encountered, it also falls in a difficult-to-patrol area with many places for poachers to hide. The majority of medium-sized stems (21-80 cm) had been intensively harvested. Cycads are generally removed indiscriminately of size (Okubamichael et al. 2016). While larger stems fetch higher prices, smaller stems are also targeted because they are easier to transport (Okubamichael et al. 2016). The reason for targeting medium-size stems in Entabeni may be case specific. To reach cycads, poachers must walk long distances (up to 12 km) through neighbouring properties, and larger stem sizes are often too heavy to carry. However, large stems are sometimes damaged or excavated to reach the smaller stems that can be carried with relative ease (Figure 4).

The selective harvesting of medium-sized stems, in this case, has led to significantly different size class distribution of stems between areas with a high poaching incidence and low poaching incidence. Poachers often only target a subset of individuals in a population, for example, individuals with the largest tusks in the case of elephants (Chiyo et al. 2015) or selective harvesting of certain tree species in higher size classes (e.g., Botha et al. 2004a, 2004b). Selective harvesting may result in changes to the population structure, possibly causing declines. Poaching is the main threat to cycads in South Africa (Table 1); however, it is also very difficult to detect in populations that are not closely monitored. The stem size structure may potentially be used as a flexible and cost-effective indicator to track changes in wild populations of cycads and provide insight into the status of poaching. For example, C. circinalis populations subjected to pith harvesting have resulted in a complete absence of plant individuals taller than 50 cm (Krishnamurthy et al. 2013).

As evidenced by the large number of stemless suckers produced by plants in the areas targeted by poachers, *E. eugene-maraisii* has been able to survive despite severe poaching pressures and the absence of natural recruitment because it reproduces vegetatively. Cycads grow extremely slowly, with reports generally indicating around 1–3 cm per year (Vovides 1990; Cabrera-Toledo et al. 2019; Marler et al. 2020). Consequently, cycads are not particularly resistant to poaching because suckers will take a long time to reach the size of their poached counterparts. Modelling different poaching scenarios for two South African species with contrasting life histories revealed that poaching even small numbers of adult plants can cause rapid population declines (Raimondo & Donaldson 2003).

Moreover, *E. eugene-maraisii* lacks natural recruitment and has a complete lack of subadults, which suggests that the absence of natural recruitment has been a long-standing problem. Even in the presence of natural recruitment, species such as *E. cycadifolius* (Jacq.) Lehm. that have highly persistent adult plants and infrequent recruitment events are unable to recover within a reasonable time frame (< 100 years) even from small losses of adult plants (Raimondo & Donaldson 2003). Reinforcement (adding individuals to an existing population) efforts have been made in a proactive attempt to limit the decline of *E. eugene-maraisii* (Bezuidenhout 2019; Bezuidenhout et al. 2020). However, rare opportunities to hand-pollinate female cones and the slow growth of reintroduced seedlings



Figure 4. Large Encephalartos eugene-maraisii stem that was pushed over by poachers. Photographer: P.D. Janse van Rensburg.

have not been able to stem the tide of poaching (Bezuidenhout et al. 2020).

Limited conclusions can be drawn on the sex ratios because only 39% of the plants could be sexed. The sex ratio was slightly male-biased; however, female plants are less likely to be identified because they cone less frequently. If a larger proportion of the population was sexed the sex ratio may have been closer to 1:1. We found no evidence that female plants are selectively harvested. Due to the slow coning rate of *E. eugene-maraisii*, there is little material (live cones, dry cone material and seeds) poachers can use to sex plants. The destruction of cones, especially female cones, by baboons also removes evidence of coning. Moreover, individual stems are usually harvested rather than whole multi-stemmed plants, which will maintain the sex ratio.

No pollinators have been recorded on *E. eugene-maraisii* despite extensive surveys. Cycad pollinators are dependent on cones for reproduction and the time between coning events can become too long for pollinators to be sustained in diminished host populations (Oberprieler 1995). The presence of other insects on *E. eugene-maraisii* may indicate higher resilience to decreasing host populations because they depend on more abundant plant parts (Figure 2). However, herbivory by Z. lepida and abundance of A. verdoornae decreased at lower plant densities and smaller clump sizes of E. eugene-maraisii, indicating that they are still sensitive to the decline of their host. South Africa hosts a rich diversity of insects associated with cycads (Oberprieler 1995). However, several cycad species are now only represented by single populations containing few individuals (Table 1). Several cycad species also exhibit reduced reproductive success, which might indicate rarity or absence of their pollinators (Table 1). Specialist herbivores are often absent in small host populations due to the higher probability of herbivore extinction (Kéry et al. 2001; Colling & Matthies 2004). Chance events (droughts, floods, fires, etc.) puts small insect populations at greater risk of extinction (Thomas & Jones 1993). Smaller ranges have fewer patches (refuges) that escape disturbance from where insect populations can recolonise cycad host plants.

Apinotropis verdoornae is of particular interest. It is a detritivore that feeds on dead leaf stalks and dried cone material. It is the only genus of Anthribidae exclusively associated with cycads (Oberprieler 1999). Entabeni is the only known locality where *A. verdoornae* occurs, as we have not recorded it from other *E. eugene-maraisii* population or closely related species such as *E. middelburgensis* Vorster, Robbertse & S.van der Westh. and *E. dyerianus* Lavranos & D.L.Goode. To conserve *E. eugene-maraisii*  and its associated insects, it is crucial to maintain as many refuges of suitable habitat as possible.

# Conclusion

This study examined poaching patterns in one of the last remaining populations of E. eugene-maraisii and its impact on population structure and insect interactions. Higher poaching incidence was observed along the border fence line, primarily targeting medium-sized stems. These findings can inform decision making processes, helping determine areas that require increased patrolling and prioritise stem sizes for interventions like micro-dotting. Lower insect abundance in areas with lower host densities and smaller clump sizes of their host highlights the potential impact of poaching, emphasising the need for protection against poaching. Conserving E. eugene-maraisii in the wild will require several actions that may include increased protection from poaching, species recovery techniques (reinforcement and reintroductions), identifying other threats (e.g., climate change) and further research on the disappearance and reintroduction of pollinators.

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### Author contributions

All authors contributed to the study's conception and design. Data collection and analysis were performed by PDJvR with assistance from JvDB and HB. The first draft of the manuscript was written by PDJvR and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

#### Disclaimer

The views expressed in the submitted article are our own and not an official position of the institution or funder.

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# Supplementary material

Table S1. Kruskal-Wallis results indicating the impact of aspect, altitude and plant sex on the abundance of Amorphocerus cf. setosus and Apinotropis verdoornae, and level of herbivory by Zerenopsis lepida

Insect species	Asp	oect	Altit	ude	Plant sex		
	Н	Р	Н	Р	Н	Р	
Amorphocerus cf. setosus	0.304	0.983	4.108	0.128	0.391	0.532	
Apinotropis verdoornae	2.777	0.596	4.222	0.121	0.317	0.573	
Zerenopsis lepida	8.237	0.083	0.113	0.945	0.116	0.734	

Plant number	Stem number	Stem height (cm)	Area	Plant density	Plant sex	Mean number of <i>Amorphocerus</i> cf. <i>setosus</i> exit holes/ cm <sup>2</sup> per plant	Mean Apinotropis verdoornae per plant	Mean Zerenopsis lepida leaf herbivory per plant
1	1	148	1	2	F	0.007432	3	0
	2	0						
	3	0						
	4	0						
2	5	76	1	2		0.003947	2	0
	6	69						
3	7	145	1	2	F	0	0	46.4375
	8	6						
4	9	112	1	2	М	0.003571	5	27.27073
	10	102						
	11	0						
	12	0						
5	13	98	1	2		0.030612	3	0
	14	0						
	15	0						
6	16	146	1	2		0.024051	2.5	3.150327
	17	156						
	18	150						
	19	14						
	20	6						
	21	39						
7	22	187	1	2	М	0.017792	1	2.830688
	23	60						
	24	32						
8	25	107	1	2		0	4.5	25.42857

Plant number	Stem number	Stem height (cm)	Area	Plant density	Plant sex	Mean number of <i>Amorphocerus</i> cf. <i>setosus</i> exit holes/ cm <sup>2</sup> per plant	Mean Apinotropis verdoornae per plant	Mean Zerenopsis lepida leaf herbivory per plant
	26	6						
	27	0						
9	28	197	1	2		0	4	0
10	29	78	1	2	М	0.003968	2.5	24.47869
	30	242						
11	31	200	1	2	F	0	3	50.28571
	32	0						
12	33	84	1	2		0.020238	0	0
	34	0						
13	35	57	1	2		0.026316	0	0
	36	0						
14	37	340	1	2	М	0	1	3.171171
	38	170						
	39	45						
15	40	220	1	2	М	0.011818	6	0
	41	15						
16	42	260	1	2		0.000513	1	0
	43	14						
	44	18						
17	45	180	1	2	М	0.012222	1	0
18	46	236	1	2	М	0.029429	2	15.13499
	47	62						
	48	0						
	49	0						
	50	61						
19	51	62	1	2	F	0.022177	1.5	0
	52	60		_				
20	53	230	1	2		0.021014	3.5	22.37235
	54	138						
	55	0						
21	56	16	1	1		0	0	0
	57	0						
22	58	227	1	1		0	0	10.65688
	59	0						
	60	0						
	61	0						

Plant number	Stem number	Stem height (cm)	Area	Plant density	Plant sex	Mean number of <i>Amorphocerus</i> cf. <i>setosus</i> exit holes/ cm <sup>2</sup> per plant	Mean Apinotropis verdoornae per plant	Mean Zerenopsis lepida leaf herbivory per plant
23	62	89	1	1		0.008989	4	12.95172
	63	0						
24	64	6	1	1			10.5	11.60455
	65	0						
	66	3						
	67	0						
	68	0						
25	69	14	1	1		0.011688		15.1
	70	0						
	71	0						
	72	11						
	73	0						
26	74	61	1	2		0.011475	0	17.95249
	75	0						
	76	0						
27	77	26	1	1		0		8.6875
	78	0						
	79	0						
	80	0						
28	81	31	1	1		0.041935		0
	82	0						
29	83	192	1	1	F	0.015104	0	0
30	84	114	1	1	М	0.05209	3.5	7.916667
	85	17						
_	86	0						
31	87	150	1	1	М	0	2	7.111111
	88	11						
32	89	98	1	1		0.011224	0	0
	90	0						
33	91	249	1	1		0.035352	1.5	0
	92	57						
	93	0						
34	94	75	1	1		0	1	0
	95	10						
35	96	135	1	1		0	4	0
36	97	0	1	1				0

Plant number	Stem number	Stem height (cm)	Area	Plant density	Plant sex	Mean number of Amorphocerus cf. setosus exit holes/ cm <sup>2</sup> per plant	Mean Apinotropis verdoornae per plant	Mean Zerenopsis lepida leaf herbivory per plant
	98	0						
	99	0						
37	100	12	1	1		0	0	0
	101	0						
38	102	99	1	1		0.037374	2	0
	103	0						
39	104	73	1	1		0.024658	3	0
	105	0						
40	106	30	1	1		0.013333	2	0
	107	18						
41	108	105	1	1		0.022024	6	0
	109	16						
	110	8						
	111	0						
42	112	132	1	1	М	0.023485	0	0
	113	0						
43	114	242	1	1		0	7	0
44	115	0	1	1				0
45	116	0	1	1				0
46	117	158	1	1	М	0.026461	3	1.857143
	118	117						
	119	0						
47	120	0	1	1				0
48	121	155	1	1	F	0.026452	6	0
	122	0						
49	123	171	1	1	F	0		10.82937
	124	17						
	125	0						
	126	0						
50	127	300	1	1	F	0.016667	1	3.320755
	128	107						
	129	6						
	130	6						
51	131	278	1	1	F	0.017648	4.5	0
	132	97						
	133	20						

Plant number	Stem number	Stem height (cm)	Area	Plant density	Plant sex	Mean number of <i>Amorphocerus</i> cf. <i>setosus</i> exit holes/ cm <sup>2</sup> per plant	Mean Apinotropis verdoornae per plant	Mean Zerenopsis lepida leaf herbivory per plant
	134	0						
	135	0						
52	136	160	1	1	F	0.043072	3	6.45614
	137	40						
	138	39						
	139	0						
53	140	180	1	1		0.0175	5	0
	141	60						
	142	0						
	143	8						
	144	2						
54	145	19	1	1		0.036842		29.96591
	146	0						
	147	0						
	148	0						
55	149	202	1	1	F	0.011139	3	4.195652
	150	6						
56	151	181	1	1		0.024309	0	0
	152	0						
	153	0						
57	154	181	1	1	М	0.011602	2	9.087719
	155	0						
	156	0						
58	157	32	1	2		0.028125	6	0
59	158	39	1	2		0.020513	0	14.5294
60	159	53	1	2	М	0.032415		1.537879
	160	66						
	161	0						
	162	18						
61	163	55	1	2	_	0.02	3	0
	164	0						
62	165	109	1	2		0.010092	1	0
	166	0						
63	167	30	1	2		0.050417	13	2.043478
	168	40						
	169	0						

Plant number	Stem number	Stem height (cm)	Area	Plant density	Plant sex	Mean number of <i>Amorphocerus</i> cf. <i>setosus</i> exit holes/ cm <sup>2</sup> per plant	Mean Apinotropis verdoornae per plant	Mean Zerenopsis lepida leaf herbivory per plant
64	170	149	1	2		0.020418	3	0
	171	0						
	172	52						
65	173	199	1	2		0.012141	9	19.75987
	174	28						
	175	0						
66	176	160	1	2		0.02211	1.5	12.2107
	177	190						
	178	46						
	179	0						
67	180	250	1	2		0.015733	3	0
	181	70						
	182	30						
68	183	108	1	2		0.00463	0	0
69	184	127	1	2	F	0	0	0
	185	0						
70	186	107	1	2		0.007477		0
71	187	100	2	2	F	0	0	0
72	188	0	2	2				0
	189	0						
	190	6						
73	191	160	2	2	М	0.010545	0	4.454586
	192	26						
	193	17			-			
	194	35						
	195	48						
	196	310						
74	197	112	2	2	-	0.017857	4	0
75	198	170	2	2	F	0.023855		5.423377
	199	32						
	200	51						
	201	70						
	202	2						
76	203	210	2	2	М	0	3.5	7.9375
	204	67						
77	205	62	2	3	М	0.035484	6	0

**Table S2:** Recorded plant traits and insect abundance data of *Encephalartos eugene-maraisii* between 2021 and 2022. Areas are categorised as 1) areas with a high poaching incidence and 2) low poaching incidence. Plant densities are classified as 1) sparse, 2) intermediate and 3) dense (continued)

Plant number	Stem number	Stem height (cm)	Area	Plant density	Plant sex	Mean number of Amorphocerus cf. setosus exit holes/ cm <sup>2</sup> per plant	Mean Apinotropis verdoornae per plant	Mean Zerenopsis lepida leaf herbivory per plant
78	206	285	2	3	F	0.02162		8.911974
	207	112						
	208	41						
	209	6						
	210	40						
	211	170						
	212	114						
_	213	20						
	214	0						
79	215	160	2	3		0.020069	0	4.153846
	216	15						
	217	12						
80	218	98	2	3	М	0.010703		8.573775
	219	87						
	220	86						
	221	17						
	222	50						
	223	0						
81	224	74	2	3		0.010811	21	0
82	225	71	2	3		0.010664	7	67.99947
	226	42						
83	227	330	2	3		0.017652	1	4.605652
	228	86						
	229	78						
_	230	18						
	231	9						
84	232	40	2	3		0.0075	10	0
	233	0						
85	234	144	2	3		0.020985		19.14874
	235	104						
	236	60						
	237	85						
	238	98						
86	239	147	2	3		0.002268	2	30.36134
	240	6						
	241	3						

Plant number	Stem number	Stem height (cm)	Area	Plant density	Plant sex	Mean number of <i>Amorphocerus</i> cf. <i>setosus</i> exit holes/ cm <sup>2</sup> per plant	Mean Apinotropis verdoornae per plant	Mean Zerenopsis lepida leaf herbivory per plant
	242	17						
87	243	210	2	3		0.019538	12	11.36932
	244	41						
	245	34						
	246	46						
88	247	235	2	3	F	0.011874	2	0.597701
	248	52						
	249	45						
89	250	150	2	3	М	0.002972	0	1.588889
	251	128						
	252	6			-			
90	253	214	2	3	F	0.006128	3	4.656917
	254	91			-			
	255	68						
91	256	287	2	3	М	0.025784	0	0
	257	112						
	258	17						
92	259	146	2	2		0.015068	2	0
	260	0						
	261	0						
	262	0						
	263	0						
93	264	145	2	2		0.02069	4	27.5
	265	0						
94	266	148	2	2	М	0	2	13.14583
	267	10						
	268	0						
95	269	88	2	2		0	0	8.03268
	270	0						
	271	0						
96	272	30	2	2		0.013333	0	6.888889
	273	0						
	274	0						
97	275	50	2	2		0.046346	0	21.375
	276	52						
98	277	3	2	2		0.006522	4	0

Plant number	Stem number	Stem height (cm)	Area	Plant density	Plant sex	Mean number of <i>Amorphocerus</i> cf. <i>setosus</i> exit holes/ cm <sup>2</sup> per plant	Mean Apinotropis verdoornae per plant	Mean Zerenopsis lepida leaf herbivory per plant
	278	0						
	279	184						
99	280	160	2	2		0	5	0
	281	0						
100	282	127	2	2	М	0.028346	0	3.203125
	283	0						
	284	0						
	285	0						
101	286	170	2	2		0.01794	12	11.45195
	287	145						
	288	13						
	289	0						
	290	11						
102	291	213	2	2		0.001408	0	3.478261
	292	6						
	293	0						
103	294	56	2	2		0.025794	4	0
	295	6						
	296	3						
104	297	112	2	2		0.002679	4	4.846154
	298	0						
	299	25						
105	300	90	2	3	F	0.022222		8.84783
106	301	37	2	3		0.035135	5	0
107	302	51	2	3		0.038133	5	4.041667
	303	77						
	304	0						
108	305	190	2	3		0.028889	2	10.40345
	306	25						
	307	6						
109	308	0	2	3		0.013656	0	0
	309	0						
	310	0						
	311	0						
	312	227						
110	313	130	2	3		0.006923		0

Plant number	Stem number	Stem height (cm)	Area	Plant density	Plant sex	Mean number of Amorphocerus cf. setosus exit holes/ cm <sup>2</sup> per plant	Mean Apinotropis verdoornae per plant	Mean Zerenopsis lepida leaf herbivory per plant
111	314	124	2	3		0.022581		16.83333
	315	0						
	316	0						
112	317	211	2	3		0	0	0
113	318	50	2	3		0.020254	1.5	10.86275
	319	21						
	320	15						
114	321	219	2	2	М	0.017294	3.5	1.105263
	322	59						
	323	12						
115	324	76	2	2	F	0.019737	1	4.53333
116	325	24	2	2		0		16.00706
	326	12						
	327	6						
	328	203						
	329	59						
117	330	183	2	2	F	0.062061	7	0.727273
	331	7						
	332	0						
	333	0						
	334	0						
118	335	57	2	2		0.02807	1	0
	336	0						
119	337	57	2	2	F	0.007212	5	88
	338	131						
	339	0						
120	340	233	2	2	F	0.023646	2	3.984615
	341	34						
	342	34						
	343	3						
	344	79						
121	345	130	2	1	М	0.026355	4	20.38333
	346	63						
122	347	310	2	2	F	0	4	23.3383
	348	110						
	349	15						

Plant number	Stem number	Stem height (cm)	Area	Plant density	Plant sex	Mean number of <i>Amorphocerus</i> cf. <i>setosus</i> exit holes/ cm <sup>2</sup> per plant	Mean Apinotropis verdoornae per plant	Mean Zerenopsis lepida leaf herbivory per plant
	350	8						
	351	6						
123	352	65	2	1		0.010769	6	0
124	353	46	2	1		0.027464	1.5	0
	354	45						
	355	0						
	356	0						
125	357	118	2	1	М	0.017797	0	4.573333
	358	0						
	359	0						
126	360	77	2	1		0	5	4.511111
127	361	80	2	3	М	0.013276	0	1.039414
	362	191						
	363	0						
	364	0						
128	365	175	2	3		0.003354	9	34.39175
	366	180						
	367	18						
129	368	92	2	3	М	0.034783	2.5	0
	369	0						
130	370	137	2	3		0.023122	5	27.26236
	371	17						
131	372	165	2	3		0.024848	5	9.803571
	373	0						
132	374	170	2	3		0	6	88
133	375	61	2	3		0.034426		0
134	376	40	2	3	F	0.01	7	0
135	377	80	2	3		0.01625	0	0
136	378	118	2	3		0.018968	8	8.668023
	379	12						
	380	17						
	381	0						
	382	0						
137	383	197	2	3		0.03212	2.5	4.883721
	384	74						
138	385	150	2	3	М	0.005561	5	10.93401

Plant number	Stem number	Stem height (cm)	Area	Plant density	Plant sex	Mean number of Amorphocerus cf. setosus exit holes/ cm <sup>2</sup> per plant	Mean Apinotropis verdoornae per plant	Mean Zerenopsis lepida leaf herbivory per plant
	386	127						
	387	42						
	388	6						
	389	27						
	390	0						
139	391	91	2	3		0.021978	4	29.1894
140	392	110	2	3		0.011096	16	0
	393	17						
141	394	127	2	3		0.013386	6	12.35021
	395	12						
	396	6						
	397	17						
142	398	68	2	3		0.019678	14	5.792683
	399	193						
143	400	30	2	3		0.026667	0	0
144	401	80	2	3		0.037222	8	6.428111
	402	80						
	403	30						
145	404	43	2	3		0.009432	3	9.3375
	405	6						
	406	12						
	407	0						
146	408	181	2	3		0	0	0
	409	61						
	410	0						
147	411	21	2	3		0.063571	1.5	43.25833
	412	30						
148	413	140	2	3	М	0.047527	8	1.894258
	414	42						
	415	30						
	416	26						
149	417	236	2	2	М	0.00374	6	9.736488
	418	112						
	419	99						
	420	0						
	421	2		_				

**Table S2:** Recorded plant traits and insect abundance data of *Encephalartos eugene-maraisii* between 2021 and 2022. Areas are categorised as 1) areas with a high poaching incidence and 2) low poaching incidence. Plant densities are classified as 1) sparse, 2) intermediate and 3) dense (continued)

Plant number	Stem number	Stem height (cm)	Area	Plant density	Plant sex	Mean number of Amorphocerus cf. setosus exit holes/ cm <sup>2</sup> per plant	Mean Apinotropis verdoornae per plant	Mean Zerenopsis lepida leaf herbivory per plant
150	422	107	2	2		0.043925	4	16.5385
151	423	120	2	2		0.002222	2	41.10632
	424	17						
	425	0						
	426	40						
152	427	115	2	2	М	0.023921	1	12.35606
	428	56						
	429	0						
	430	0						
	431	0						
	432	0						
153	433	278	2	2		0.033351	2	16.08912
	434	31						
	435	15						
	436	17						
154	437	33	2	2		0.004545	0	12.66667
	438	6						
155	439	136	2	2		0.009559	0	0
156	440	87	2	2	М	0.006897	4	5.263889
	441	0						
	442	0						
	443	0						
157	444	25	2	2		0.019783	5	0
	445	46						
158	446	135	2	2	М	0.00963		0
159	447	58	2	2		0.011207	4	0
	448	0						
	449	6						
	450	12						
160	451	97	2	2	F	0.018557	3	0
161	452	114	2	2		0	2	0
	453	17						
162	454	91	2	2	М	0.022955	3.66	6.595238
	455	78						
	456	294						
163	457	95	2	2		0.023158	2	0

Plant number	Stem number	Stem height (cm)	Area	Plant density	Plant sex	Mean number of <i>Amorphocerus</i> cf. <i>setosus</i> exit holes/ cm <sup>2</sup> per plant	Mean Apinotropis verdoornae per plant	Mean Zerenopsis lepida leaf herbivory per plant
164	458	77	2	2		0.038961	4	11.17328
	459	0			_			
	460	0						
165	461	49	2	2		0.024567	0	21.17544
	462	22						
	463	8						
	464	0						
	465	12						
	466	0						
166	467	182	2	2		0.030769	9	0
167	468	55	2	2		0.016292	0	20.98148
	469	0						
	470	5						
	471	55						
	472	95			-			
	473	28						
168	474	119	2	2	_	0.012131	2	7.115217
	475	65						
	476	12						
169	477	40	2	3		0.045357	4	0
	478	42						
	479	0						
	480	0						
170	481	180	2	3	-	0.013653	4	6.728889
	482	58						
	483	30			-			
	484	60						
	485	95						
	486	0						
171	487	180	2	3	F	0.030556	1	0
	488	0						
172	489	170	2	3		0.000606	6	4.571429
	490	0						
	491	0						
	492	0						
	493	0						

Plant number	Stem number	Stem height (cm)	Area	Plant density	Plant sex	Mean number of Amorphocerus cf. setosus exit holes/ cm <sup>2</sup> per plant	Mean Apinotropis verdoornae per plant	Mean Zerenopsis lepida leaf herbivory per plant
	494	30						
	495	220						
173	496	71	2	2		0.013651	0	23.15476
	497	250						
174	498	35	2	2	М	0.025714	0	0
175	499	180	2	2	М	0.02132	2	10.37517
	500	44						
	501	0						
	502	0						
	503	0						
	504	0						
	505	12						
	506	65						
176	507	118	2	2		0.011299	4	0
	508	12						
177	509	102	2	2		0.044608	0	25.97549
	510	12						
	511	0						
	512	21						
178	513	80	2	2		0.00875	0	0
179	514	370	2	2	М	0.01629		18.30393
	515	135						
	516	160						
	517	24						
	518	34						
	519	0						
180	520	148	2	2	F	0.018946	4	30.28832
	521	100						
	522	0						
181	523	91	2	2		0.005249	3	6.419815
	524	82						
	525	0						
	526	2						
	527	0						
182	528	253	2	2		0.020059	8	14.19576
	529	46						

**Table S2:** Recorded plant traits and insect abundance data of *Encephalartos eugene-maraisii* between 2021 and 2022. Areas are categorised as 1) areas with a high poaching incidence and 2) low poaching incidence. Plant densities are classified as 1) sparse, 2) intermediate and 3) dense (continued)

Plant number	Stem number	Stem height (cm)	Area	Plant density	Plant sex	Mean number of Amorphocerus cf. setosus exit holes/ cm <sup>2</sup> per plant	Mean Apinotropis verdoornae per plant	Mean Zerenopsis lepida leaf herbivory per plant
183	530	93	2	2	М	0.009005	3	0
	531	12						
184	532	185	2	2		0.011755	1	37.96697
	533	57						
	534	17						
	535	15						
	536	8						
185	537	68	2	2		0	6	0
186	538	141	2	2	F	0.030083	9	11.22222
	539	12						
	540	6						
187	541	125	2	2		0.0128	0	10.79279
	542	0						
	543	0						
188	544	49	2	3		0.013025	0	8.277778
	545	17						
189	546	251	2	3		0.01903	1.5	36.10498
	547	40						
	548	54						
190	549	170	2	3	F	0.028157	2	40.2472
	550	75						
	551	0						
191	552	25	2	3		0.056		0
192	553	115	2	3		0.011833	5	51.14618
	554	34						
	555	0						
	556	0						
	557	6						
193	558	282	2	3	F	0.024069	3	17.97643
	559	145						
	560	48						
	561	48						
194	562	242	2	3		0.05286	4	23.25926
	563	21						
	564	18						
195	565	78	2	3		0.014505	9	19.2381

Plant number	Stem number	Stem height (cm)	Area	Plant density	Plant sex	Mean number of <i>Amorphocerus</i> cf. <i>setosus</i> exit holes/ cm <sup>2</sup> per plant	Mean Apinotropis verdoornae per plant	Mean Zerenopsis lepida leaf herbivory per plant
	566	14						
	567	10						
196	568	259	2	3		0.01945	10	75.43377
	569	0						
	570	20						
197	571	92	2	3		0.028125	6	2.5375
	572	48						
	573	0						
	574	0						
	575	0						
198	576	160	2	3		0.015	6	8.96774
199	577	127	2	3	М	0.006299	0	0
200	578	79	2	3		0.011392	2	0
	579	0						
	580	0						
	581	0						
201	582	226	2	3	F	0.027655	1.5	4.063889
	583	22						
	584	16						
202	585	245	2	3		0.004592	4	13.6667
	586	105						
	587	12						
	588	98						
	589	0						
	590	0						
203	591	81	2	3		0.024027	22	60.72222
	592	26						
	593	0						
204	594	67	2	1	М	0.01194	1	18.25
	595	0						
	596	0						
205	597	130	2	1	М	0	0	13.95833
	598	0						
206	599	125	2	2	М	0.0092	1.5	5.654828
	600	125						
	601	6						

Plant number	Stem number	Stem height (cm)	Area	Plant density	Plant sex	Mean number of <i>Amorphocerus</i> cf. <i>setosus</i> exit holes/ cm <sup>2</sup> per plant	Mean Apinotropis verdoornae per plant	Mean Zerenopsis lepida leaf herbivory per plant
	602	0						
	603	6						
207	604	124	2	2		0.007279	2	22.96032
	605	13						
	606	6						
208	607	108	2	2	М	0.028704	1	0
	608	6						
209	609	148	2	2	F	0.017657	5	14.5976
	610	88						
	611	50						
	612	5						
	613	24						
	614	17						
	615	6						
	616	7						
210	617	54	2	2		0.009259	3	7.200311
	618	6						
	619	0						
	620	0						
211	621	293	2	2	М	0.016864	3	9.049829
	622	149						
	623	25						
	624	60						
	625	12						
212	626	143	2	2		0	2	17.29032
	627	16						
	628	0						
213	629	285	2	2		0.006316	6	6.97619
	630	40						
214	631	48	2	2		0.03125	5	0
	632	0						
215	633	69	2	2	F	0.002899	0	5.886364
	634	12						
216	635	125	2	2	М	0.011767	2	51.53628
	636	86						
	637	70						

Plant number	Stem number	Stem height (cm)	Area	Plant density	Plant sex	Mean number of <i>Amorphocerus</i> cf. <i>setosus</i> exit holes/ cm <sup>2</sup> per plant	Mean Apinotropis verdoornae per plant	Mean Zerenopsis lepida leaf herbivory per plant
	638	0						
	639	0						
217	640	183	2	2	М	0	4.5	18.5625
	641	30						
	642	0						
218	643	73	2	2		0.014578	9	51.86147
	644	54						
	645	54						
	646	0						
	647	0						
219	648	170	2	2		0.007647	2	16.73529
	649	0						
220	650	230	2	1	F	0.011812	0	29.25556
	651	42						
	652	0						
221	653	78	2	2		0.020513	3	0
222	654	122	2	2	F	0.031987	3.33	23.38477
	655	17						
	656	10						
	657	10						
	658	7						
	659	27						
223	660	79	2	2	М	0.010127	4	3.960317
	661	0						
	662	0						
224	663	160	2	2	F	0.018826	0	21.05729
	664	37						
	665	0						
	666	0						
225	667	77	2	2		0.028571	4	0
	668	0						
	669	0						
226	670	137	2	3		0.026141	3	27.86111
	671	21						
	672	12						
	673	0						

Plant number	Stem number	Stem height (cm)	Area	Plant density	Plant sex	Mean number of <i>Amorphocerus</i> cf. <i>setosus</i> exit holes/ cm <sup>2</sup> per plant	Mean Apinotropis verdoornae per plant	Mean Zerenopsis lepida leaf herbivory per plant
227	674	131	2	3	F	0.005344	1	28.6746
	675	14						
	676	0						
228	677	200	2	3	М	0.017158		2.970588
	678	295						
	679	47						
	680	22						
	681	20						
229	682	115	2	3		0.004348	2	6.41667
230	683	189	2	3	F	0	4	10.69231
	684	0						
231	685	250	2	3		0.0112	3	8.72
232	686	33	2	3		0.004545	7	0
	687	6						
233	688	113	2	3		0.002655	0	0
234	689	128	2	3	М	0.028013	1	26.08056
	690	64						
	691	0						
	692	0						
	693	21						
	694	0						
235	695	178	2	3		0.017301	2.5	7.275983
	696	6						
	697	37						
	698	78						
236	699	75	2	3	М	0.059333	3	31.4011
	700	4						
	701	0						
237	702	85	2	3		0.009412	4	0
238	703	59	2	2		0.011864	1	0
	704	0						
239	705	45	2	2	М	0	3	39.75
240	706	26	2	2		0.038462	0	0
	707	0						
241	708	128	2	2		0.001042	1.5	24.84286
	709	32						

Plant number	Stem number	Stem height (cm)	Area	Plant density	Plant sex	Mean number of Amorphocerus cf. setosus exit holes/ cm <sup>2</sup> per plant	Mean Apinotropis verdoornae per plant	Mean Zerenopsis lepida leaf herbivory per plant
	710	0						
	711	0						
	712	26						
242	713	0	2	1		0.015908	0	2.515152
	714	54						
	715	56						
	716	0						
	717	0						
	718	60						
243	719	41	2	1		0.026829	2	0
	720	0						
	721	0						
244	722	25	2	1	М	0.02	0	28.8333
245	723	107	2	2	М	0.004862		2.918154
	724	25						
	725	223						
	726	108						
246	727	225	2	2		0.01064	2	13.24661
	728	82						
	729	112						
	730	160						
	731	4						
	732	30						
	733	0						