

CLIMATIC CHANGES MAY NOT AFFECT THE DISTRIBUTION RANGE OF SOUTH AFRICAN ENDEMIC *ENCEPHALARTOS* SPECIES (CYCADALES)

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Abstract: In recent decades climate change has emerged as one of the major forces driving biodiversity loss and species extinction. Cycads are highly threatened species and previous studies have revealed they are also being affected by climate change. In this study we tested the possible response to climate change of four rare cycad taxa (*Encephalartos* species) endemic to South Africa, displaying a low but reasonable number of natural occurrences. Maximum Entropy model (MaxEnt) was used in carrying out the predictions based on eight environmental variables. Our results revealed no range contraction but a slight spread in the distribution of these taxa. Temperature seasonality, vegetation types and landforms are by far the most important predictors of the species modelled. On the contrary, the mean annual temperature and precipitations showed very low contributions in all models. We conclude that climate change may not determine a reduction in range size of the *Encephalartos* species studied. Possible decline in South African cycads may still occur through anthropogenic influences.

Keywords: *Encephalartos* species, Environmental predictors, Maximum Entropy (MaxEnt), Niche modelling, Species distribution

Introduction

Human anthropogenic activities, the spread of invasive species and habitat destruction have been factors responsible for species extinction in the past 400 years with an extinction rate over a thousand times higher than the past extinction episodes the Earth has ever witnessed [2, 35]. This extinction crisis has wiped out one quarter of all species that have been assessed and there is a possibility of continuity of these trends in decades to come [17]. But in the 21st century, climate change has emerged as a major force promoting the species extinction crisis, resulting in ecosystem disruption and loss of genetic diversity [13, 24, 28, 31, 34]. Climate change also interacts with other ecological forces to promote the species extinction crisis [4]. For instance, interaction with land cover change has been shown to exacerbate biodiversity loss [20, 33, 36]. This interaction has been found to also promote habitat loss and fragmentation, resulting in heightened susceptibility of fragmented species population to extinction [6, 20, 33].

Among flora that have been assessed globally, the order Cycadales (representing all extant cycads) contains the largest percentage of threatened plant species [16, 17, 41]. Taxa belonging to this plant group are facing threat everywhere they occur [10]. South Africa contains the third largest number of cycads in the world [18] with the majority of them being highly threatened and some already extinct in the wild [9]. A major decline in African cycad populations in recent times increased the extinction risk in cycads endemic to South Africa [1]. A wide range of ecological

and anthropogenic forces are responsible for this extinction crisis of cycads in South Africa, which include: illegal harvest for medicinal and horticultural uses, habitat fragmentation, disease infestation, invasive plant species competing with them in their natural habitats and also climate change [7, 8, 10].

Suitable habitats for threatened species are determined by species distribution models [22, 14, 5]. This study modelled some South African *Encephalartos* species under some climatic scenarios to determine the response of these taxa to climatic conditions. We selected four, well sampled cycad taxa endemic to South Africa and predicted their future distribution under different climatic predictions suggested by the latest (5th) IPCC report.

Methodology

Records of all South African cycads including 37 *Encephalartos* species and *Stangeria eriopus* were obtained from the South African National Biodiversity Institute (SANBI). We generated a quarter degree grid species richness map for all South African cycads using ArcGIS 9.2 (www.esri.com/arcgis/). MaxEnt 3.3.3k [30] was used to model both the current and future distribution of four taxa using their distribution records after first preparing and projecting to Albers equal area projection for Africa, the species occurrence and environmental predictor layers in ArcGIS 9.2 at the same resolution of 30 arc seconds. In particular, Maximum Entropy (MaxEnt) has been proved to be more effective in niche modelling compared to models such as GARP, DOMAIN and ENFA [11]. MaxEnt is also suitable for modelling species that have small numbers of distribution records [29, 38, 14, 19, 32, 5, 25, 12] and it has been used in modelling cycads in some studies [23, 3]. Analyses were conducted using R version 3.0.3 within RStudio Version 0.98.501 and the following packages: raster, dismo, rgdal, rjava and maptools. Duplicates from the same grid were removed. Presence records were split as follows: 70% for training and 30% for testing. Five replicates were run using cross validation, and median probabilities were reported. Otherwise, standard defaults were used in MaxEnt runs.

Due to limited records for South African cycads, only four reasonably well-sampled species were analysed, *Encephalartos natalensis* (n=15, reduced to 7 after removal of duplicates), *Encephalartos lehmannii*, (n=22, reduced to 12 after removal of duplicates), *Encephalartos altensteinii* (n=35, reduced to 12 after removal of duplicates) and *Encephalartos friderici-guilielmi* (n=22, reduced to 9 after removal of duplicates). In order to prevent problems of over-fitting or under-fitting, we selected the background using a 100 km buffer mask for each species based on a polygon circumscribed to all occurrence points. In order to display binary maps of predictions from continuous probability data, we used the equal training sensitivity and specificity thresholds.

Following Laidlaw et al. (2012), four Bioclim climatic variables i.e., Bio01 (Annual Mean Temperature), Bio04 (Temperature Seasonality), Bio12 (Annual Precipitation) and Bio14 (Precipitation of the Driest Month), were obtained from the Worldclim database [www.worldclim.org; 15]. Additional four categorical environmental predictors, thought to be important for defining the ecological niche of cycads, were employed: landform [40], lithography [40], topographic roughness (calculated using SDMTTools in ArcGIS from the GTOPO30 digital elevation model) and SANBI vegetation types [26]. The importance of these variables to the *Encephalartos* species modelled in our study was confirmed based on their habitat and ecology as reported in relevant IUCN Red List accounts and also due to their correlation with environmental predictors used for modelling *Encephalartos latifrons* in a recent study [3]. MaxEnt models were

first trained based on all eight predictor variables, using climatic data for the current climate scenario and then projected to two future representative concentration pathways scenarios of RPC +26 (a more conservative emission scenario) and RPC +85 (a more severe scenario), based on the latest projections contained in the Fifth Assessment Intergovernmental Panel on Climate Change (IPCC) report (<https://www.ipcc.ch/report/ar5/>) with years projection between 2080 and 2100 (between 60 to 80 years from now). Bioclim data for these two future scenarios were also obtained from the Worldclim database. The MPI (Max Planck Institute for Meteorology) model was selected for these projections.

Results

The area of maximum species richness of cycads occurs in the Eastern Cape and KwaZulu-Natal provinces of South Africa (Figure 1). There is no reduction in habitat suitability for the taxa modelled based on our future climatic predictions (Figure 2). All models performed well based on the AUC values varying from 0.779 to 0.978 (Figure 3). The lack of response to climate change in our species models is not surprising given the very low contributions of Mean Annual Temperature (Bio1) and Annual Precipitation (Bio12) in all our models (Figure 3). Instead, temperature seasonality (Bio4), SANBI vegetation types, and landforms are by far the most important variables for the species modelled in MaxEnt (Figure 3). The studied species prefer more seasonably stable climates nearer the Eastern Cape coast, based on the species distribution map generated.

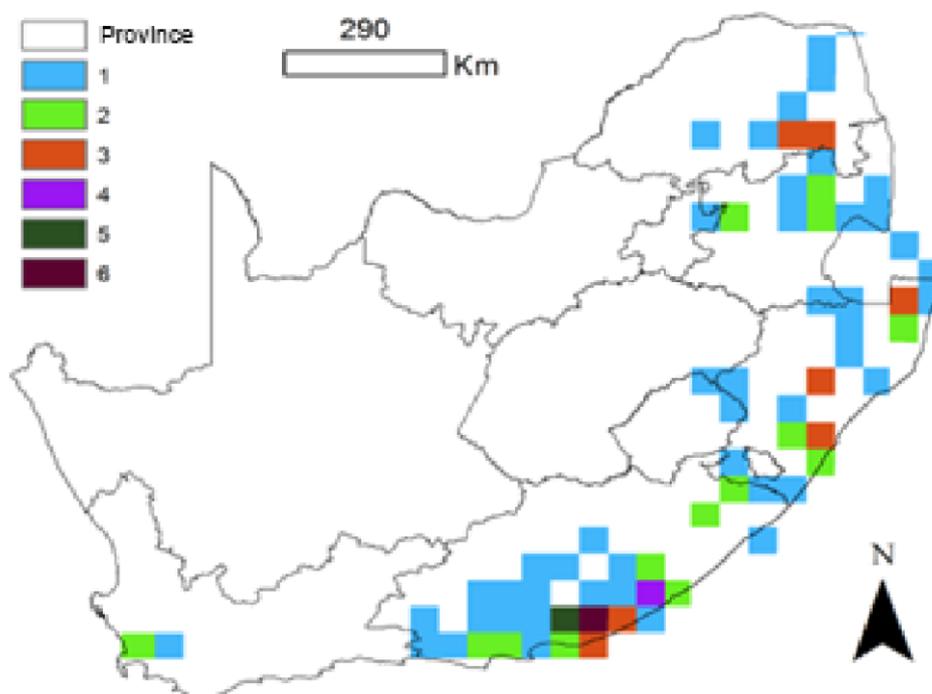


Fig. 1: Quarter degree grid map of species richness considering all South African cycad taxa (37 *Encephalartos* species plus *Stangeria eriopus*)

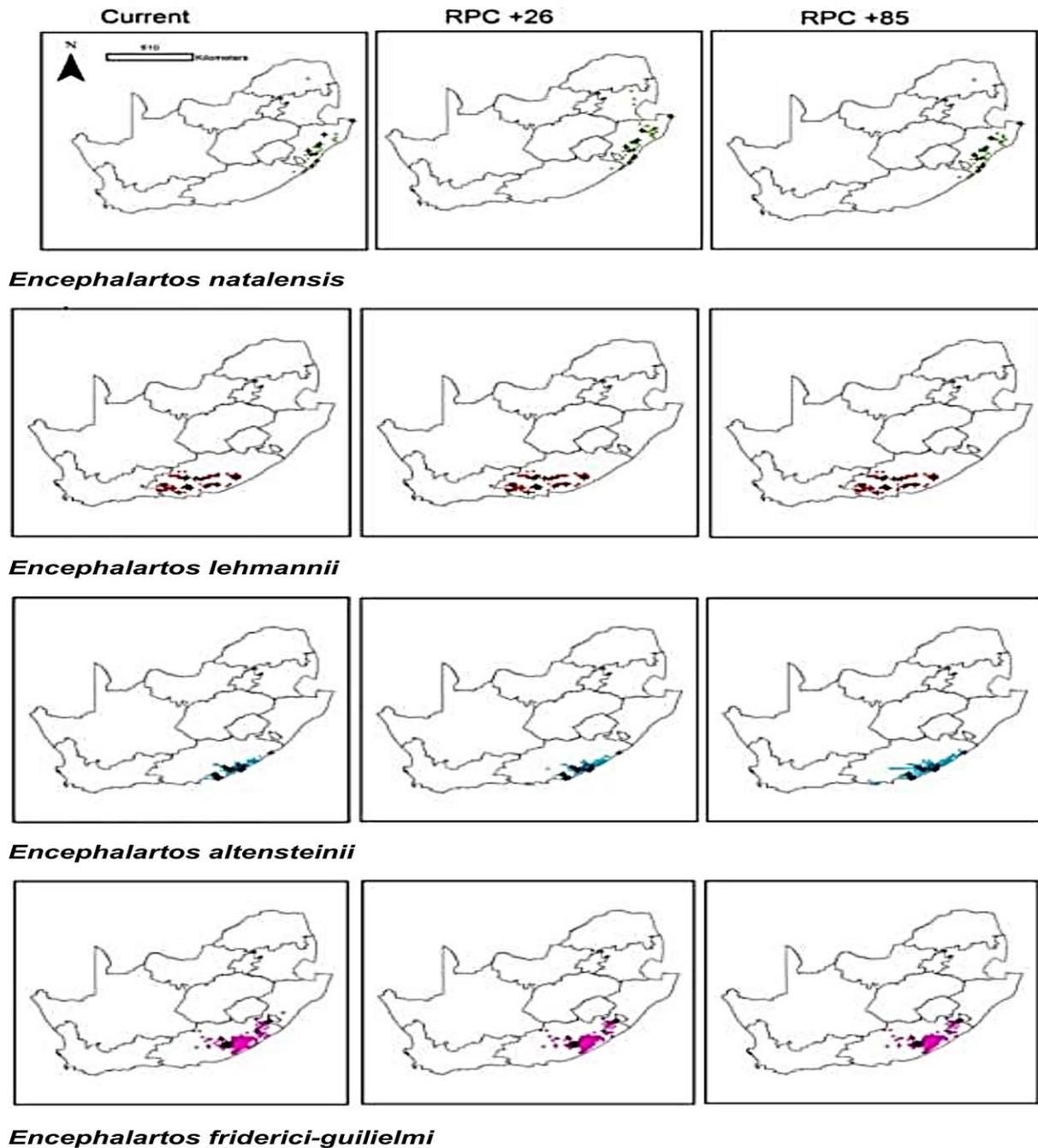


Fig. 2: MaxEnt models (based on median probabilities from 5 replicates) showing the predicted distributions of *E. altensteinii*, *E. friderici-guilielmi*, *E. lehmannii* and *E. natalensis* using 100 km buffer masks as background for each species and eight predictor variables

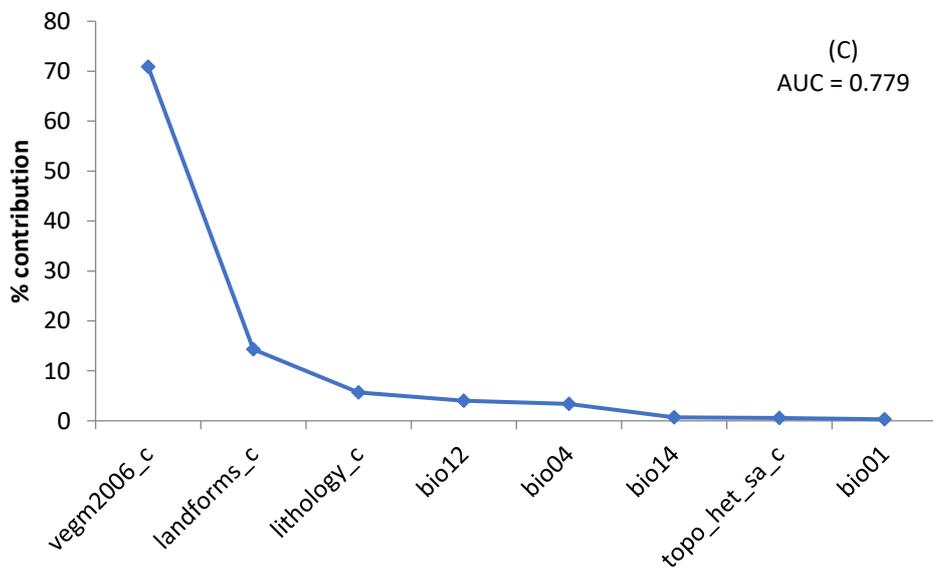
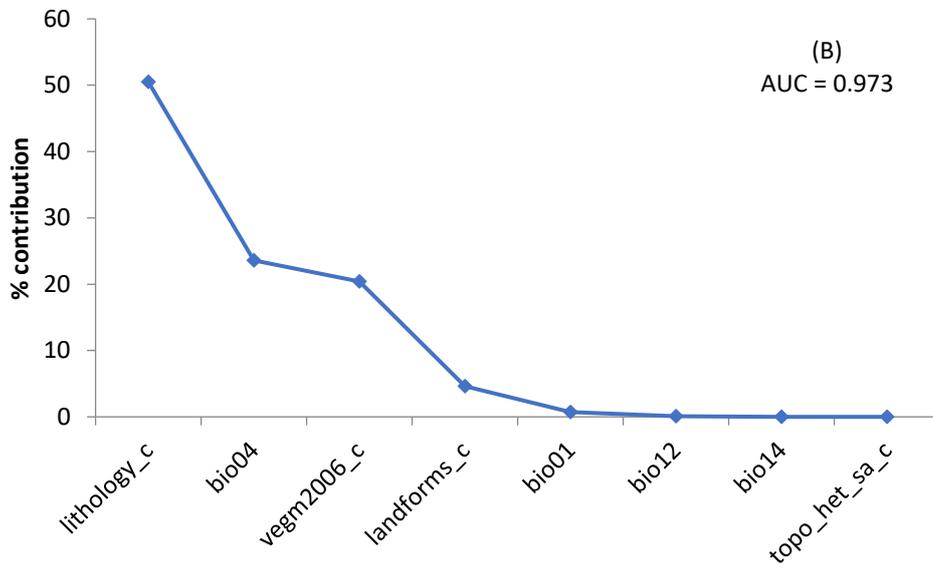
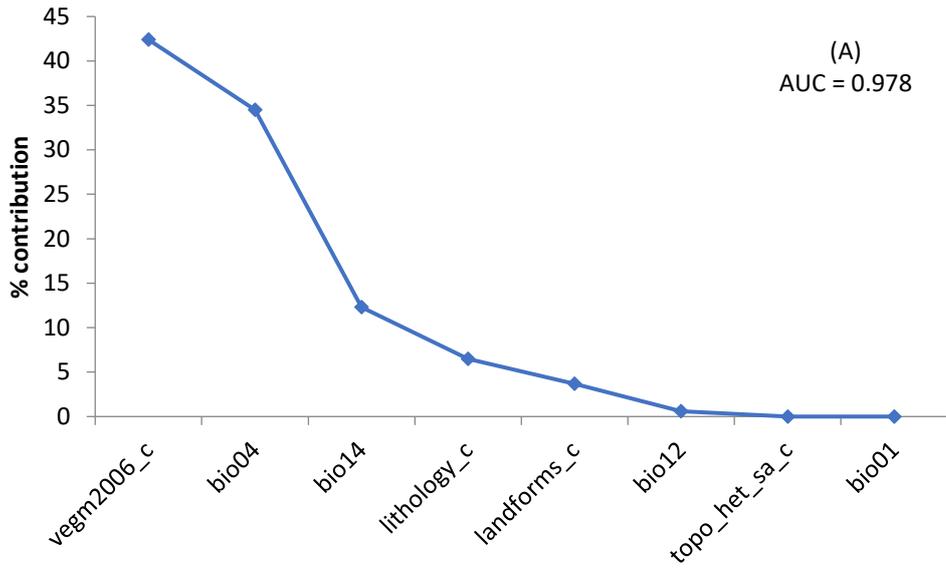
Discussion

In the four South African *Encephalartos* species modelled in this study, future predicted changes in temperature, precipitation and temperature seasonality do not result in decreased ranges and accelerated extinction risks, but rather show a slight spread under favourable conditions in their future distribution compared to the present distribution. There is therefore a possibility that

these taxa may not to be affected by changes in climatic conditions in the future. Although the number of taxa modelled represent about 10% of the total number of South African cycads, it is still possible to draw inferences based on the similarity in ecological and habitat preferences between all South African cycads [37]. Mean annual temperature and minimum precipitation have little influence of the MaxEnt models. Temperature seasonality (Bio4) is an important variable, but future predictions for the study area do not show changes in this variable. The four taxa we modelled are all represented in Eastern Cape or KwaZulu-Natal, which is the main centre of diversity of cycads in South Africa (see Figure 1). Also drawing support from a study conducted by Yessoufou et al. [39] on evolutionary history of African cycads, there might be a possibility of all *Encephalartos* species having similar response towards climate change. The dated phylogenetic tree reconstructed by Yessoufou et al. [39] showed that all known *Encephalartos* species in South Africa are monophyletic, i.e. they share the same ancestral lineage. The study also showed that all South African cycads originated in the Pliocene, an epoch characterized by cooler and drier condition and the majority of South African *Encephalartos* species possess an underground stem as an adaptation to aridity and high temperatures. This may also support the hypothesis according to which all South African *Encephalartos* species are likely to share the same response in relation to climate change. Konning [21] grouped South African cycads based on their life history and traits. But the grouping does not show significant difference in the response of South African cycads to environmental factors. Most South African cycads have the same response to different environmental factors such as precipitation, mean annual temperature and geology [21]. In a recent study by Carin et al. [3] on modelling habitat suitability of *Encephalartos latifrons*, the environmental predictors used for the modelling were climate, geology, vegetation and topography. Their study revealed that geology contributed more to the MaxEnt model than the rest of the predictors. These correlate with the results of our model in which vegetation and lithology contributed more than the rest of the environmental predictors. This further show similarities in response of *Encephalartos* species to climatic conditions.

However, Laidlaw et al. [23] conducted a study on some *Macrozamia* cycad taxa in Queensland (Australia) using climatic predictions to determine how these taxa will respond to climate change in future. They found that the expected change in climatic conditions in between 2030 to 2100 will result in cycads declining in Queensland. By considering the phytogeographic and taxonomic differences between *Encephalartos* and *Macrozamia* groups, we can infer the reason for the difference in the outcomes of these two studies. Nagalingnum et al. [27] showed that *Macrozamia* and *Encephalartos* originated in two different quaternary oscillation seasons and that these two genera might have different experiences in response to climate change. Our study thereby predicts that in these two cycad hotspots (Australia and South Africa) there might be divergent responses of different lineages of cycads in relation to climate change.

The low occurrence records of the species considered here was one *a priori* constraint against reaching a robust predictive power of the species distribution. This is an acknowledged limitation of this study. However, our results can give some rough insight into the possible response of South African *Encephalartos* to environmental changes.



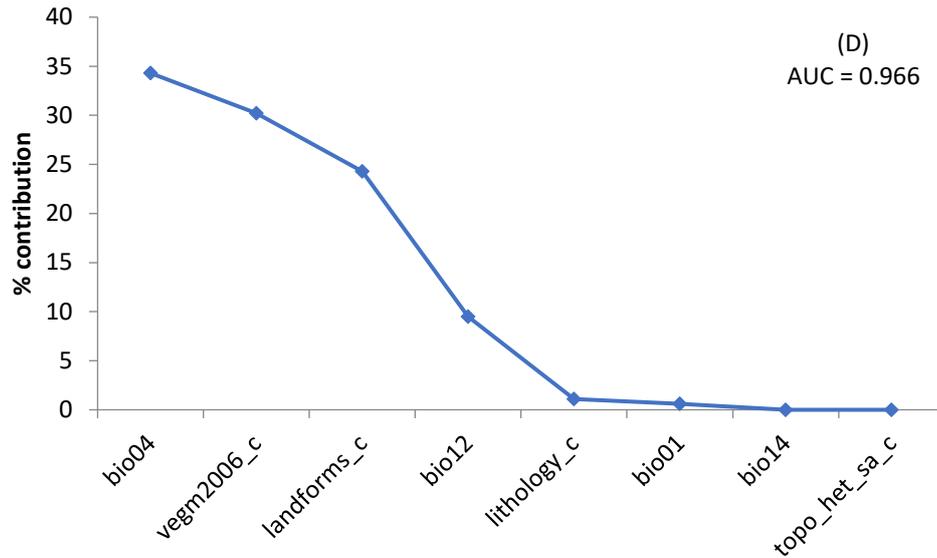


Fig. 3: Contribution of environmental predictors to the MaxEnt models used to predict the distribution of four *Encephalartos* species: *E. altensteinii* (A), *E. friderici-guilielmi* (B), *E. lehmanii* (C) and *E. natalensis* (D). AUC – area under the curve; topo_het_sa_c - topographic roughness; vegm2006_c - vegetation type. Other abbreviations as in Methodology section

Conclusions

Lithology and vegetation are the two major environmental/biotic predictors that contributes greatly to the species distribution model employed in this study. The second predictor (vegetation) may not be compositionally stable but could change due to anthropogenic pressure. Although climate change is an important factor to consider in conservation, our results suggest that the control of anthropogenic influences should be a central focus in cycads conservation in South Africa.

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SCHIMBĂRILE CLIMATICE POT SĂ NU AFECTEZE AREALUL DE DISTRIBUȚIE AL SPECIILOR DE *ENCEPHALARTOS* (CYCADALES) ENDEMICE ÎN AFRICA DE SUD

(Rezumat)

În ultimele decenii, schimbările climatice au reprezentat o forță majoră ce a condus la pierderea biodiversității și la dispariția speciilor. Cycadalele sunt specii foarte amenințate, iar studiile anterioare au arătat că sunt, în mare măsură, afectate de schimbările climatice. În acest studiu am testat răspunsul posibil la schimbările climatice pentru patru taxoni rari de cycadale (specii de *Encephalartos*) endemice în Africa de Sud, care prezintă un număr scăzut, dar rezonabil, de indivizi spontani. Modelul de Maximă Entropie (MaxEnt) a fost utilizat în realizarea predicțiilor bazate pe opt variabile de mediu. Rezultatele noastre nu au evidențiat nicio scădere a arealului actual al indivizilor, ci o ușoară creștere a distribuției acestor taxoni. Sezonalitatea temperaturii, tipurile de vegetație și formele de relief sunt de departe cei mai importanți predictorii ai speciilor studiate. Dimpotrivă, temperatura medie anuală și precipitațiile au fost de importanță foarte scăzută în toate modelele analizate. Concluzionăm că este posibil ca schimbările climatice să nu determine o reducere a arealului speciilor de *Encephalartos* studiate. Posibilul declin al cycadalelor din Africa de Sud poate apărea, însă, din cauza influențelor antropice.

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