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RUNNING TITLE

Climate change impacts on desiccation-tolerant vascular plants of West Africa

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ABSTRACT

Background and aims

Climate change affects global biodiversity, and species such as desiccation-tolerant vascular plants (DT plants) remain largely neglected in conservation objectives and individual initiatives, West Africa is no exception. Our study aims to assess the impact of climate change on DT plant distribution and diversity in West Africa.

Material and methods

In this study, we use all DT plants described to West Africa and their occurrences, and employ species distribution models to depict changes in their distribution and diversity when comparing present and future climate change conditions.

Key results

We identified a consistent contraction of DT plants' distribution ranges and a significant shrinkage of their centres of diversity and endemism.

Conclusion

It is imperative that future research and on-the-ground conservation efforts should focus on species-specific conservation needs, including closely monitoring DT species with small distribution ranges and assessing the conservation requirements of DT species with broad distribution ranges. It should also be stressed the urgency of integrating climate projections into the conservation planning of DT plants worldwide to ensure that effective conservation strategies include the expansion of protected areas specifically designed to improve stewardship of conserved DT plants.

KEYWORDS

Climate change, Conservation, Desiccation tolerance, Diversity, Endemism, Resurrection plants

INTRODUCTION

Climate change affects global biodiversity both positively and negatively, leading to changes in species distribution, altering current diversity patterns, and affecting ecosystem processes upon which humans depend (Root et al. 2003; Parmesan 2006; Urban 2024). However, its impact is idiosyncratic and thus depends on species' capacities to cope with environmental changes and concomitant exposures to shifts in climate (Dawson et al. 2011). This complexity makes the development of effective strategies to mitigate negative climate change complicated, and reinforces the need to understand more profoundly the range of impacts of climate change on biodiversity.

A large fraction of biodiversity remains overlooked in conservation planning (Guénard et al. 2025), and desiccation-tolerant vascular plants (DT) from West Africa are a good example of this predicament (Seidou et al. 2025). DT plants are characterised by a remarkable capacity to withstand the near complete loss of relative water content in dry periods (Porembski and Barthlott, 2000). Because of the desiccation tolerance response, DT plants are perceived as plants little impacted by climate change, despite empirical studies that demonstrate that DT plants are sensitive to shifts in environmental variables (Marks et al. 2021). That means that, despite the ability to tolerate desiccation, DT plants should be vulnerable to climate change. This oversight is problematic because many DT plants are endemic to rock outcrops that act as island-like ecosystems (Porembski 2007; Porembski et al. 2016); because of these insular characteristics, the ability of DT plants to migrate to new suitable habitats has shown to be limited (de Paula et al. 2020; Vanschoenwinkel et al. 2024). In short, the conservation of DT plants is particularly concerning in West Africa, where climate change is projected to cause warming scenarios exceeding 1.5–2.5 °C by 2085 that are expected to cause as much as to 90% of habitat loss for some plant species (Boko et al. 2007; Busby et al. 2012).

This study aims to conduct the first assessment of how climate change affects the distribution and diversity patterns of DT plants in West Africa. We first conducted species distribution modelling for all known DT plants with occurrences in West Africa and used future climatic projections to estimate contractions or expansions in species distribution under different climate change scenarios. Second, we identified DT species' centres of diversity and endemism in West Africa and evaluated changes in species and endemism richness from a biogeographical perspective. Our findings provide the first comprehensive evaluation of the impact of climate change on West Africa's DT plants, identifying priority species and areas for conservation that support more effective conservation planning on these species.

MATERIAL AND METHODS

Study area

In this study, we followed the Encyclopædia Britannica (Fage and McCaskie 2025) and considered West Africa a biogeographic region encompassing 20 countries from Senegal in the west to Equatorial Guinea in the east. Despite not being typically included as West African countries, we also included Cameroon, Chad, and Equatorial Guinea because they represent an ecological and floristic continuum of West African ecosystems and biodiversity.

Four distinct vegetation zones are found in West Africa: Guineo-Congolian Zone, Guineo-Congolian/Sudanian Zone, Sudanian Zone, and Sahel Zone, where the annual rainfall ranges from 250 mm in the Sahel Zone to 3000 mm in the Guineo-Congolian Zone (Sinsin et al. 2010). In this region, the Guinean Coastal forest stands out as one of the global biodiversity hotspots due to its biodiversity singularities and anthropogenic pressures (Myers et al. 2000; Mittermeier et al. 2011).

Species list and distribution models

To compile a list of DT plants from West Africa, we conducted a systematic literature review using four search engines: (1) Scopus, (2) Web of Science, (3) Academia, and (4) Google Scholar, and the key-words: “desiccation tolerant” OR “resurrection” AND angiosperm* OR pteridophyte* OR lycophyte* OR vascular OR plant*” for the period between 1950 and 2024. We initially retrieved a total of 1657 documents (243 documents from Scopus, 567 from Web of Science, 36 from Academia, and 811 from Google Scholar), of which 549 were duplicates and thus removed. Only species described as desication-tolerant and native to West African countries according to Plants of the World Online (POWO 2025) were included. We did not include infraspecific taxa. Nomenclature follows the Tropicos taxonomic backbone (Tropicos 2025). In total, we found 49 DT plant species from 11 families, within 30 genera and three major’ plant groups' encountered in West Africa (Table S1).

To produce species distribution hypotheses for every DT species (used in our further analyses), we retrieved occurrence records for each DT species using datasets with preserved specimens from the Global Biodiversity Information Facility (GBIF 2025, Table S1) and Tropicos (Tropicos 2025). We remove duplicate records and data with geographic inconsistencies (e.g., country centroids or occurrences beyond species' native occurrence range; see Table S2 for the R packages used in this study). We included occurrences without coordinates but with a precise collection site description by using its geographic entity or the centroid of the closest municipality. To avoid sampling bias, we reduced multiple records for the same species within an area of 1 km radius to only one occurrence.

Using the resulting occurrence records, we conducted two modelling approaches: a niche-based approach in which we conducted the Maximum Entropy (MaxEnt) technique under a climate niche perspective (MaxEnt; Phillips *et al.* 2004), and a spatial-based technique, i.e., the inverse-distance weighted (IDW; Shepard 1968) by interpolating the known occurrence points for each species. The MaxEnt approach was chosen because of its ability to identify suitable areas of occurrence even for species with small sampling sizes (Elith et al. 2011). On the other hand, the IDW technique was chosen for providing alternative hypotheses to niche-based approaches, which can overestimate species distribution to areas beyond the species' dispersal capacity (Diniz-Filho et al. 2003; Pearson and Dawson 2003; Elith et al. 2011).

We used current climatic conditions to calibrate the MaxEnt models by retrieving the 19 bioclimatic variables available at CHELSA database v2.1 (Karger et al. 2021; Table S3). These variables represent the mean values of 30-year monthly climatic data from 1981 to 2011 as recommended by World Meteorological Organization (https://public.wmo.int/). To avoid overfitting and multicollinearity among the bioclimatic variables, we removed variables that showed a relative contribution lower than 5% to explain species distribution models, determined by a jackknife test, and with a variation inflation factor (VIF) < 10.

Both MaxEnt and IDW techniques were evaluated by the Area Under the Receiver Operating Characteristic Curve (AUC) and True Skill Statistics (TSS) methods via a k-fold cross-validation (k = 5). We used 100, 1000, or 10000 random background points depending on the presence points being < 100, between 100 and 300, or > 300, respectively (Barbet-Massin et al. 2012). The final distribution hypotheses of species were produced by the agreement between the binary output (i.e., presence-absence predictions) of each MaxEnt and IDW distribution hypothesis, which were generated from the 50% consensus across five modelling routines (including different random cross-validation) for which a minimum score of 0.8 for AUC and 0.6 for TSS was achieved. The binary output for each individual model was produced using the individual model's thresholds, minimising omission rates for true positives and true negatives (i.e., best sensitivity and specificity). We applied a spatial unit of 2°30" x 2°30", extending the scale by 5° of latitude and longitude beyond the species' utmost occurrence points.

We could not conduct MaxEnt and IDW for two species. *Afrotrilepis jaegeri* J.Raynal and *Coleochloa domensis* Muasya & D.A.Simpson had less than five valid occurrences, so they were not included in this study. Although native to West Africa, our model outputs did not include West Africa in the distribution hypotheses of *Actiniopteris semiflabellata* Pic.Serm., *Cheilanthes coriacea* Decne., *Oropetium capense* Stapf, *Sporobolus stapfianus* Gand., and *Craterostigma plantagineum* Hochst. due to their low number of valid occurrences in the region. Therefore, these species were also not used in this study.

Assessment of the impact of climate change on the distribution of desiccation-tolerant vascular plants

To assess how climate change may affect DT plants' distribution, we compared the area (in km²) of the species' distribution hypotheses in the present with their estimated areas (in km²) of their distribution hypotheses under different climate change scenarios. Future contractions in species' distribution would describe a negative impact of climate change, while expansions in species' distribution would describe a positive impact of climate change.

Two global climate models under the Coupled Model Intercomparison Project Phase 6 framework (Coupled Model Intercomparison Project 2025) were used: GFDL-ESM4.1 (Dunne *et al.* 2020) and UKESM1 (Sellar *et al.* 2019; equilibrium climate sensitivity of 3.4 and 5.4 K, respectively). From those global climate models, we used climate datasets corresponding to two distinct shared socioeconomic pathways. One reflected the most optimistic scenario (SSP1, sustainable path, with environmental boundaries, low greenhouse gas emission) and another reflected the most pessimistic scenario (SSP5, very high greenhouse gas, with fossil-fueled development). Three future time-series intervals were considered: years 2011–2040, 2041–2070**,** and 2071–2100.

The same climatic variables used to calibrate species' distribution models for the present were used for future projections of their distribution. Although the IDW technique does not consider the effects of climate change, it was used to evaluate a species' capacity to disperse to new suitable areas. We used the consensus between the two global climate models (i.e., GFDL-ESM4.1 and UKESM1) to facilitate the interpretation of our results, and used contrasting global climate models and shared socioeconomic pathways to obtain a more comprehensive view of the potential impact of climate change on species distribution.

Assessment of the impact of climate change on the diversity and endemism patterns of desiccation-tolerant vascular plants

To assess how climate change may affect DT plants' diversity patterns, we identified the current centres of diversity and endemism of DT plants in West Africa and re-estimated them using the species distribution hypotheses under different climate change scenarios. Centres of diversity were based on species richness, our operational variable to describe the diversity of DT plants, while the centres of endemism were based on endemism richness, our operational variable to describe the endemism of DT plants.

To estimate the species richness, we overlapped the distribution hypotheses of every species and counted the number of species per grid cell. We attributed the same weight to every species to calculate species richness (i.e., every species counted as 1). To estimate the endemism richness, we overlapped the distribution hypotheses of every species. However, unlike for species richness, we attributed a different weight to each species before counting the number of species per spatial unit. The weight for each species was calculated based on their inverse range size (Kier et al. 2009). We used the absolute values of the log-transformed scores to reduce the effect of the fine spatial resolution, which produces a strong lognormal distribution of endemism richness scores. By this method, we gave a higher contribution of species with a smaller distribution to identify the centres of endemism for DT plants in West Africa.

Regions with higher species richness describe a higher diversity of DT plants, while regions with higher endemism richness describe a higher endemism of DT plants. The species and endemism richness approaches were chosen because, although both metrics focus on the taxonomic facet of diversity, they offer alternative views when considering whether or not species have a more restricted distribution.

We repeated the same routine using the species distribution hypothesis for each future scenario. Reductions in diversity per grid cell would describe a negative impact of climate change by possibly promoting species loss, while increases in diversity per spatial unit would describe a positive impact - assuming that higher diversity is positive - of climate change on species by favoring the occurrence of a higher number of species. On the other hand, changes in endemism should be interpreted in a less straightforward way. While reductions in endemism per spatial unit could describe species loss, it could also describe expansions in species' climatically suitable areas because the weight of a species in the index is inversely proportional to its geographic extent. The opposite is also true. Increases in endemism per spatial unit could describe the gain of species, but it could also describe reductions in species' climatically suitable areas. Although we recognise the existence of important constraints to species distribution on smaller scales (e.g., biotic interactions and stochasticity; Pearson and Dawson 2003), they were not taken into account in this study.

We used a Jenks natural breaks optimisation to create five different interval classes for diversity patterns from both taxonomic and endemism perspectives, recognising areas of low, very low, moderate, high, and very high diversity or endemism (see Table S4). We considered centres of diversity and endemism the regions with high or very high diversity and endemism, respectively. In this study, all the analyses and graphical representations were conducted in the R 4.4.2 software (R Core Team 2025).

RESULTS

The impact of climate change on the distribution of desiccation-tolerant vascular plants

Most of the DT plants in this study will be negatively impacted by climate change, as revealed in both the most optimistic and pessimistic scenarios. *Cheilanthes inaequalis* (Kunze) Mett. (Pteridaceae), *Microchloa kunthii* Desv. (Poaceae), and *Craterostigma yaundense* (S.Moore) Eb.Fisch., Schäferh. & Kai Müll. (Linderniaceae) are the most negatively affected species by climate change in all future scenarios (Fig. 1; Table S5; supplementary material). Our models predicted *C. inaequalis* and *C. yaundense* to become extinct in West Africa in some future scenarios. Species that would experience a positive impact of climate change were few and not restricted to any specific taxonomic group. *Selaginella njamnjamensis* Hieron. (Selaginellaceae) was the species most positively affected by climate change in all future scenarios, followed by *Crepidomanes chevalieri* (Christ) Ebihara & Dubuisson (Hymenophyllaceae) and *Microchloa indica* (L. f.) P. Beauv.

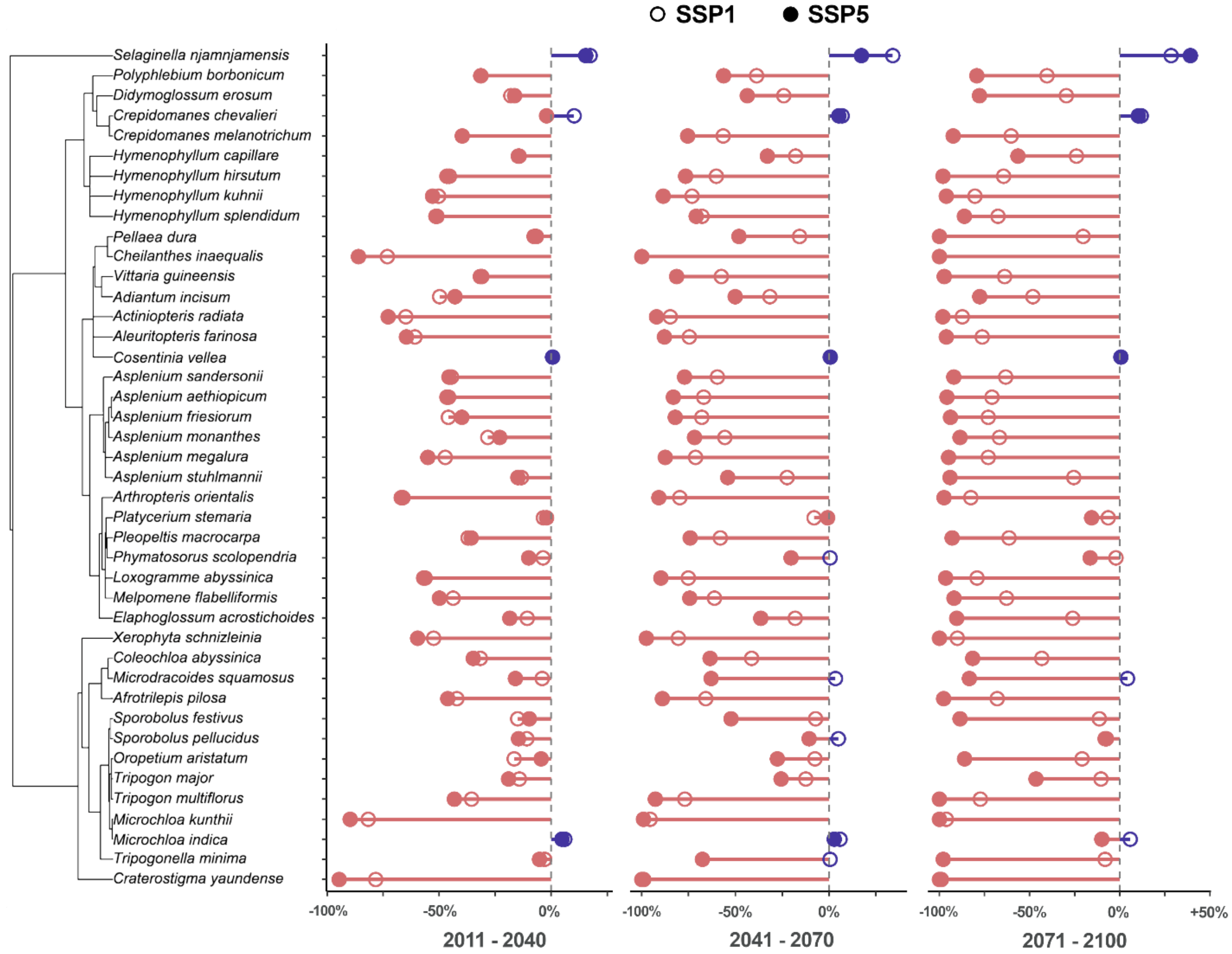

Fig. 1. Projected changes in distribution of desiccation-tolerant vascular plants in West Africa under the most optimistic (SSP1; open circles) and pessimistic (SSP5; filled circle) scenarios, across different time-series intervals. A value of 0% indicates no change in distribution, while negative and positive values represent the percentage of contraction and expansion in species distribution due to climate change, respectively.

The impact of climate change on the diversity and endemism patterns of desiccation-tolerant vascular plants

We identified as current centres of diversity for DT plants areas (1) in the Guinea highlands, which also includes montane locations in Sierra Leone, Liberia, and Côte d'Ivoire; (2) in the Togo Mountains; (3) along the Cameroon volcanic line, which also includes the islands Bioko and Sao Tomé et Príncipe; (4) a region extending from central Cameroon to most parts of continental Equatorial Guinea; besides (5) small enclaves along the coastline of South-South of Nigeria and Cameroon (Fig. 2).

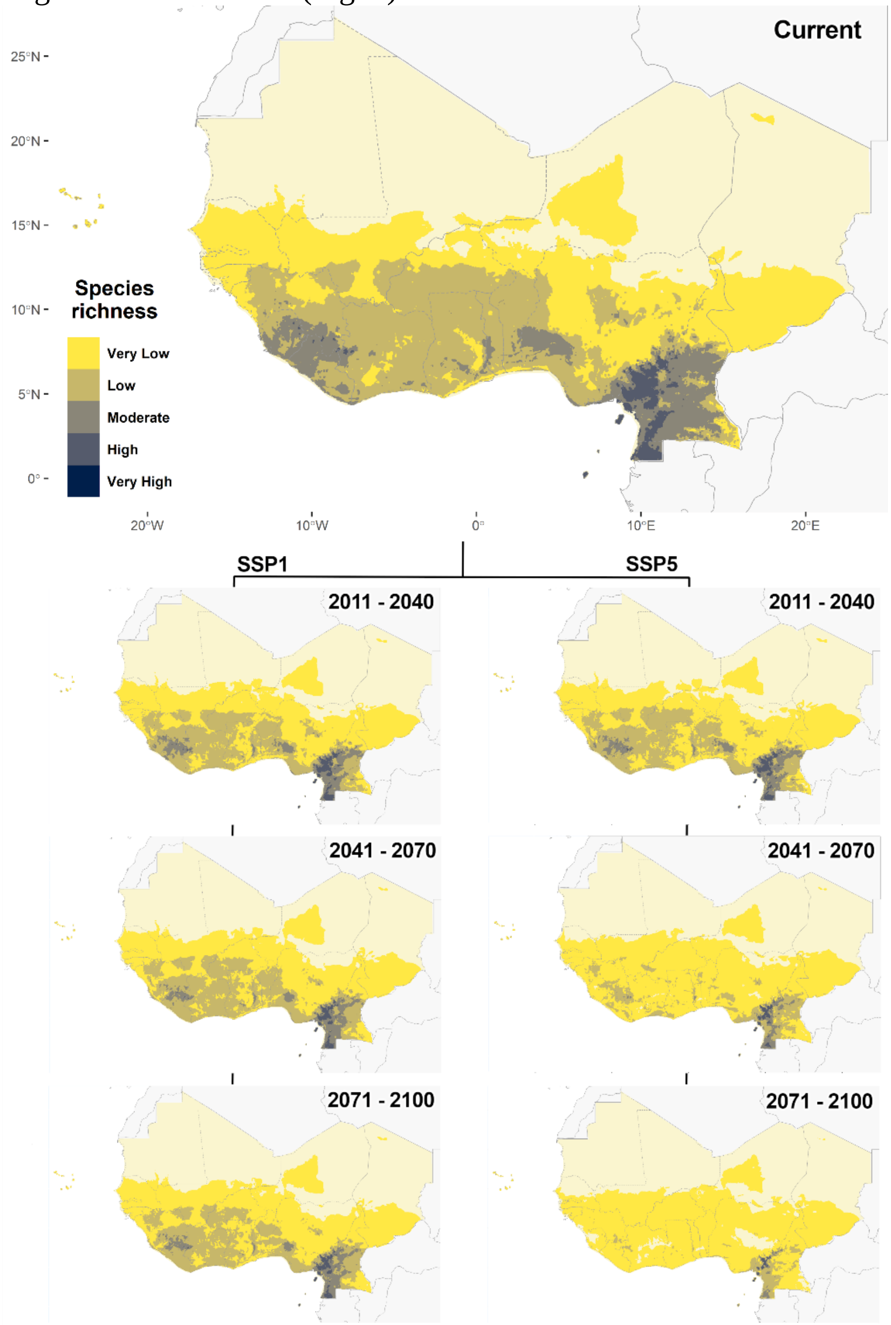

Fig. 2. Diversity patterns of desiccation-tolerant vascular plants in West Africa and the impact of climate change on the current diversity patterns. The impact of climate change was evaluated considering the most optimistic (SSP1) and pessimistic (SSP5) scenarios across different time-series intervals.

We identified as current centres of endemism for DT plants areas (1) in Cabo Verde islands; (2) in Guinea highlands, including montane locations in Sierra Leone, Southern Liberia, and Western Côte d'Ivoire; (3) in Southern Ghana (Volta region) and Togo Mountains; (4) in Kaduna State in north-west region of Nigeria (5) Aïr Massif in Northern Niger; (6) along the Cameroon volcanic line, which also includes the islands Bioko and Sao Tomé et Príncipe; (7) in the region extending from Southern Cameroon to continental parts of Equatorial Guinea; besides (8) enclaves along the West African coastline, from Senegal to Cameroon (Fig. 3).

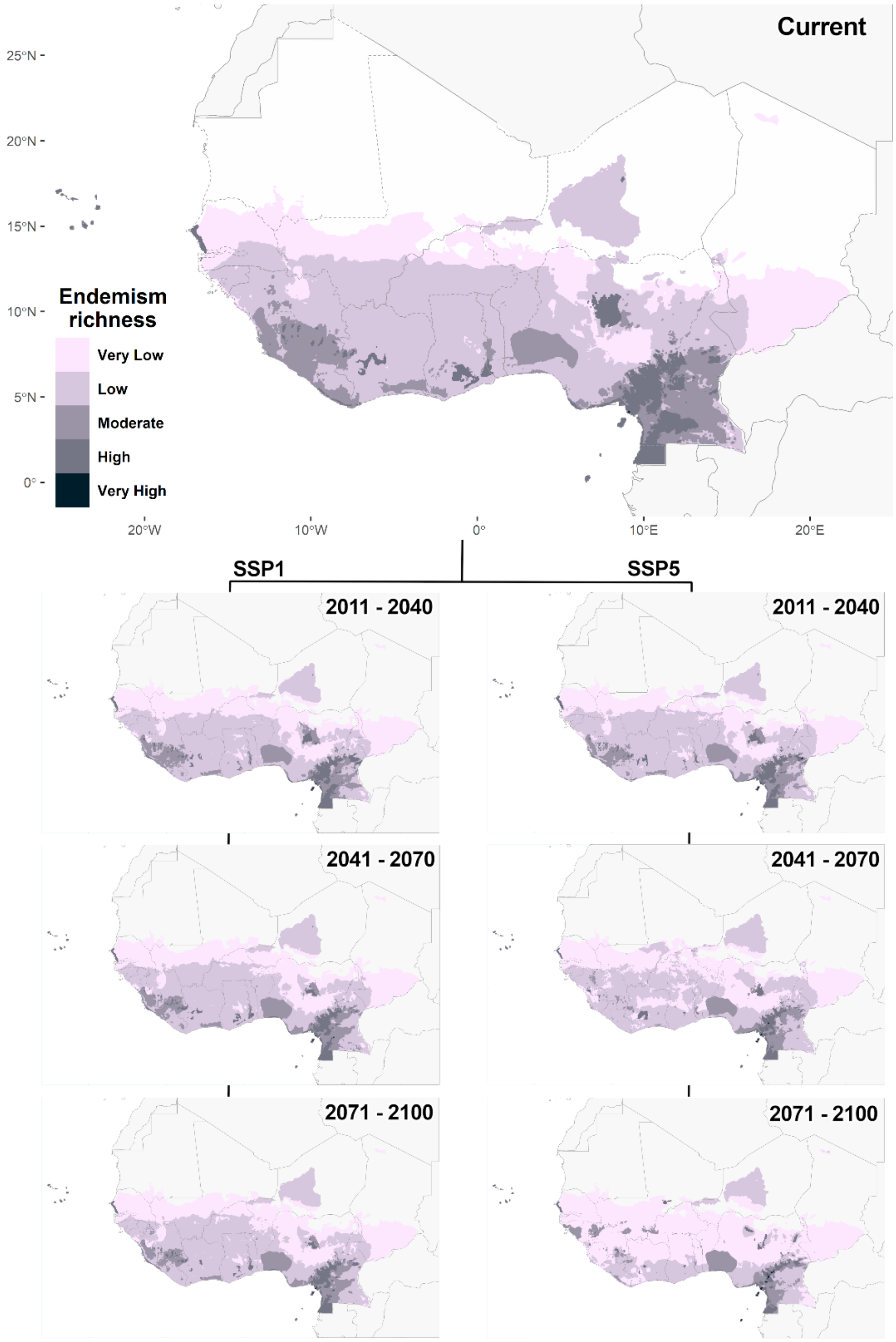

Fig. 3. The endemism patterns of desiccation-tolerant vascular plants in West Africa and the impact of climate change on the current diversity patterns. The impact of climate change was evaluated considering the most optimistic (SSP1) and pessimistic (SSP5) scenarios across different time-series intervals.

Our projections show that the current centres of diversity for DT plants will contract under future climate change, with the extent of this contraction growing more severe under the most pessimistic scenario when compared to the most optimistic scenario (Fig.2; Table 1; Table S6). The contraction of the centres of diversity becomes particularly pronounced by 2071-2100 where only disjunct patches along the Cameroon volcanic line are predicted to exhibit a high diversity of DT plants. Our projections suggest that current centres of endemism are also likely to shrink under future climate scenarios, with the degree of reduction more marked under SSP5 than SSP1 (Fig.3; Table 1; Table S6). However, while areas of high endemism of DT plants will be reduced, areas of very high endemism will increase in size.

Table 1. Area shifts of diversity and endemism patterns of desiccation-tolerant vascular plants in West Africa owing to climate change. The impact of climate change was evaluated using the most optimistic (SSP1) and pessimistic (SSP5) scenarios across different time-series intervals. Negative values describe the contraction of areas of a given class of diversity and endemism, while positive values describe the expansion of areas of a given class of diversity and endemism.

	SSP1			**SSP5**		
	2011-2040	**2041-2070**	**2071-2100**	**2011-2040**	**2041-2070**	**2071-2100**
Species richness						
Very low	+20 %	+23 %	+27 %	+21 %	+64 %	+63 %
Low	-10 %	-10 %	-17 %	-11 %	-63 %	-86 %
Moderate	-43 %	-56 %	-59 %	-49 %	-83 %	-95 %
High	-29 %	-50 %	-55 %	-36 %	-74 %	-90 %
Very High	+25 %	-100 %	-100 %	-100 %	-100 %	-100 %
Endemism richness						
Very low	+39 %	+39 %	+44 %	+28 %	+53 %	+119 %
Low	-8 %	-4 %	-6 %	-2 %	-5 %	-48 %
Moderate	-19 %	-21 %	-26 %	-22 %	-48 %	-42 %
High	-20 %	-35 %	-40 %	-26 %	-48 %	-61 %
Very High	+628 %	+694 %	+710 %	+1313 %	+1251 %	+3765 %

DISCUSSION

The impact of climate change on the distribution of desiccation-tolerant vascular plants

Based on our results, we suggest the inclusion of DT plants in future conservation studies and efforts for several reasons. First, as expected, the magnitude of the negative effects of climate change on species distribution is predicted to be higher under the most pessimistic climate scenario. But the consistently high impact of climate change on species distribution by 2071-2100 in the most pessimistic scenario is concerning. Thirty-three out of 42 West African DT species (78%) are predicted to undergo a 75% loss of their current habitat. Some of these species, including *Craterostigma yaundense*, *Cheilanthes inaequalis*, *Pellaea dura*, *Tripogon multiflorus*, and *Xerophyta schnizleinia*, are predicted to either go extirpated or become extinct in the same scenario. These species should be carefully monitored in West Africa.

The tenuous long-term persistence of these species is even more concerning when we consider that, even if we adopt a globally more sustainable future scenario, we will not be able to reverse the impact of climate change on DT plants. Thirty-seven out of 42 West African DT species (88%) will still be negatively impacted by climate change by 2071-2100 in the most optimistic scenario, with some species being more critically impacted than others. For example, *Cheilanthes inaequalis* is predicted to become extirpated by 2100 under every scenario.

We also recommend that future studies and efforts focus on species conservation needs rather than on specific taxonomic groups or species distribution. By affecting many species, climate change is likely to affect a large array of ecosystem functions and services, especially considering that species number is expected to correlate positively with functional diversity (Tilman et al. 2014; Brown and Anand 2022). West African DT species belong to taxonomic groups with different evolutionary histories; threats to phylogenetic diversity also threaten the evolutionary potential of DT plants in West Africa because evolutionary potential increases with phylogenetic diversity (Winter et al. 2013). That is, loss of phylogenetic diversity results in the loss of species' potential to evolve, as their populations adapt to environmental changes (Hall 1999). We believe that conservation attention to different taxonomic groups could reduce the risks of losing functional and phylogenetic diversity of DT plants.

It might also feel tempting to scientists and conservationists to focus primarily on the conservation of species with a small distribution. Species with smaller distributions are expected to be more sensitive to environmental change due to their narrower niche breadth (Gaston 1996; Saupe et al. 2015), but it is also important to note that anthropogenic drivers can cause the rarity of species, regardless of other constraints to species distribution (Fiedler and Ahouse 1992). Climate change is expected to affect DT plants with both small and broad distributions (Fig. 4), including the fragmentation of species distributions. This suggests that populations of locally restricted as well as widely distributed species will remain in small, suitable patches. The problem is that, all else being equal, small patches cannot support a greater number of individuals (i.e., lower carrying capacity; MacArthur and Wilson 1967; Hanski 1998), and populations in these patches become more prone to local extinction due to demographic and environmental stochasticity (Fahrig 2003; Ovaskainen and Hanski 2004). Additionally, habitat fragmentation can be followed by a loss of connectivity between and among populations, reducing the likelihood of immigration of individuals to avoid local extinctions and inbreeding depression. For example, both *Asplenium stuhlmannii* and *Tripogonella minima* are widely distributed in two large disjunct areas in West Africa. By 2071-2100, the most pessimistic scenario, they are projected to lose up to 94% and 98%, respectively, with their distribution reduced to multiple small, geographically separated patch populations (Table S5).

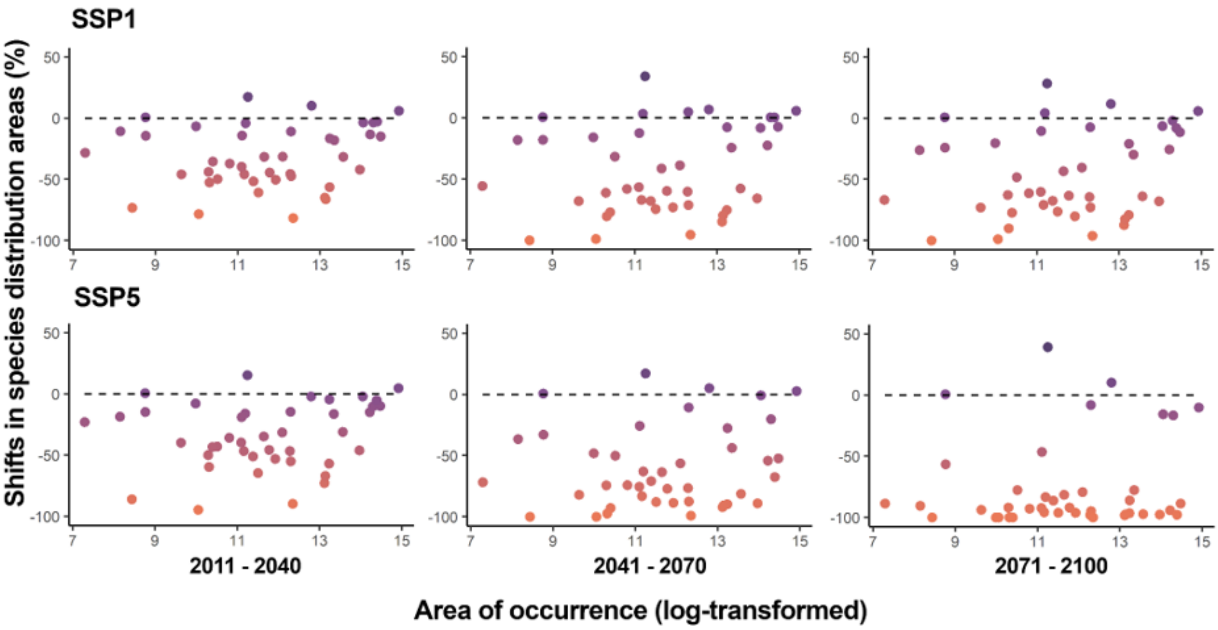

Fig 4. Shifts in species distribution by species area of occurrence in the most optimistic (SSP1) and pessimistic (SSP5) scenarios, across different time-series intervals. Dashed line represents the threshold where shifts in species distributions are either negative or positive, in case of contraction or expansion. Colour gradient from red illustrates contraction and to blue for expansion.

In general practice, species with smaller distributions should be prioritised for conservation efforts because their populations are likely to be already found close to patch size thresholds to maintain minimum viable populations. For example, *Asplenium monanthes* and *Sporobolus festivus* were the species with the most restricted and broad distribution in our study, respectively. Both are predicted to lose up to 89% of their geographic areas by 2071-2100 in the most pessimistic scenario. Importantly, this number represents a remaining area of 167 km² for *Asplenium monanthes*, a geographic extent far smaller than the remaining area of 221878 km² for *Sporobolus festivus*. The extirpation of *Asplenium monanthes* in continental parts of West Africa is also predicted, leaving this fern occupying a small region on Bioko Island in the Gulf of Guinea. It is noteworthy to mention that some endemic species, like *Afrotrilepis jaegeri* and *Coleochloa domensis* were not evaluated in this study and may be similarly imperiled. In sum, geographically restricted species deserve to be closely monitored to avoid possible extirpation in West Africa.

The impact of climate change on the diversity and endemism patterns of desiccation-tolerant vascular plants

Priority areas for the conservation of DT plants also support a disproportional diversity and endemism of vascular plants as a whole (CEPF 2000; Myers et al. 2000; Barthlott et al. 2005; Kier et al. 2009; Cai et al. 2023). Only 11% of the priority areas for the conservation of DT plants are found in currently protected areas (Fig. 5), which is low considering that these locations will either lose many species or show an increase in endemism due to species distribution contractions owing to climate change. The Guinea Highlands, for example, currently exhibit a high diversity of DT plants, but in the most pessimistic scenario by 2071-2100, it is predicted to exhibit a low diversity of DT plants. On the other hand, the terrestrial parts of the

Cameroon Volcanic Line are predicted to play an important role as ecological refuges against climate change, maintaining both high diversity and endemism of DT plants even under the pessimistic scenario. That means that key regions for the conservation of DT plants in West Africa are still below the Aichi Biodiversity Targets to 2020 (i.e., Target 11, ≥17% of protected areas by 2020) and distant to the Aichi Biodiversity Targets to 2030 (i.e., Target 3, ≥17% of protected areas by 2020; Convention on Biological Diversity 2025a; 2025b).

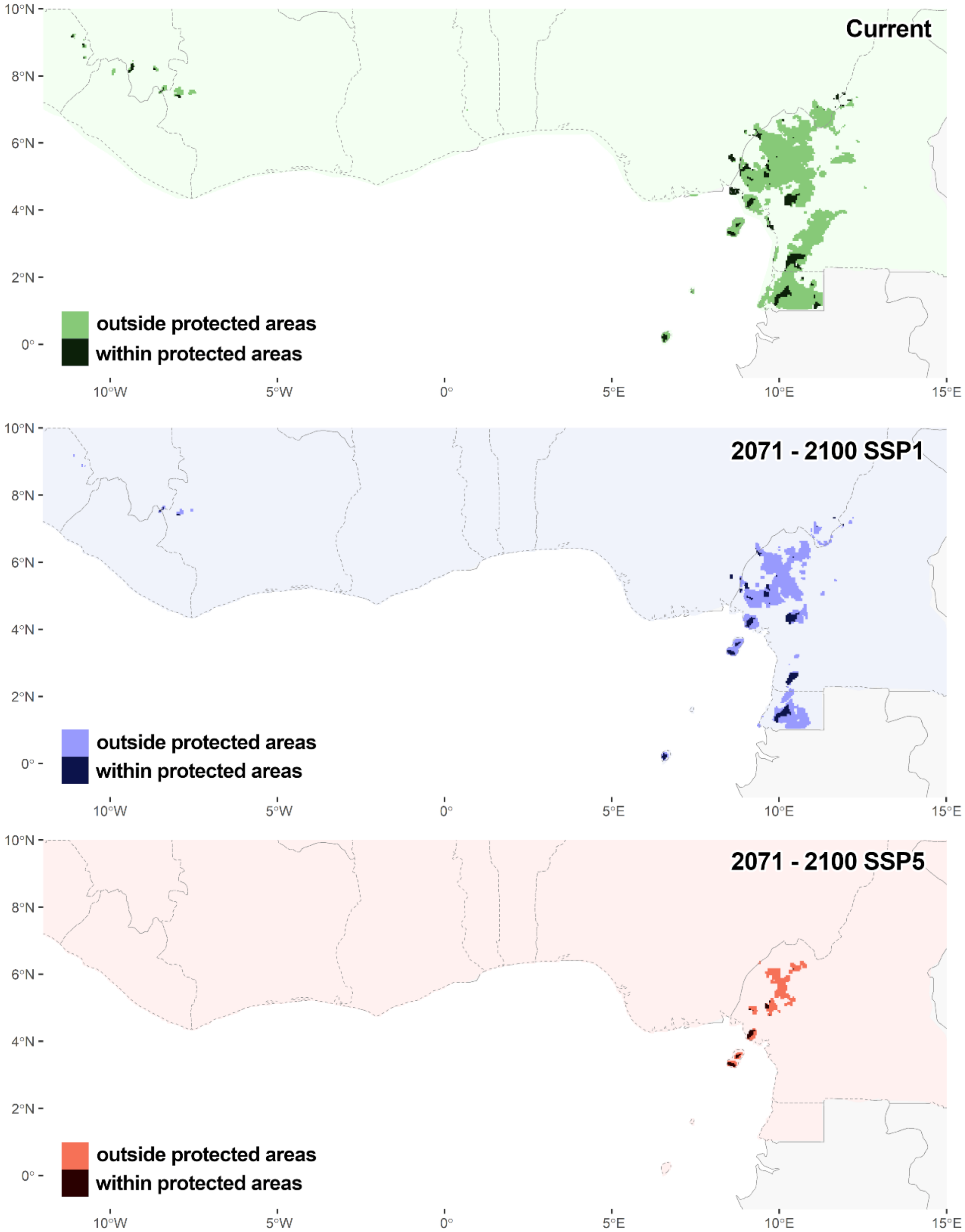

Fig. 5. Priority areas for the conservation of desiccation-tolerant vascular plants within and outside protected areas from West Africa in the present and by 2071-2100 under the most optimistic (SSP1) and pessimistic (SSP5) scenarios.

While increasing the number of protected areas is an important goal, we recognise that many current protected areas are not effectively managed. For instance, Mount Cameroon was established in 2010 as a priority conservation area for DT plants, and it benefits from legal protection, but its boundaries are not yet fully defined nor are sustainable management strategies implemented (Bergl et al. 2007; Forboseh et al. 2011). Thus, a strategic area for biodiversity conservation is left susceptible to ongoing exploitation (Bergl et al. 2007; Forboseh et al. 2011), with climate change refuges for DT plants likely threatened by other anthropogenic drivers, increasing the extinction risks of these species. This predicament is not exclusive to Mount Cameroon in West Africa. Even where protection exists, the enforcement is weak and the management is poor due to unclear legal boundaries or minimal conservation activities (Blom et al. 2004; Oates et al. 2004; Bergl et al. 2007; Cronin et al. 2014).

It is noteworthy to mention that most centres of diversity and endemism for DT plants in West Africa are in mountainous regions. Their topographic complexity begets environmental heterogeneity, which supports a higher number of species that are ecologically more distinct from each other (Körner 2007; Stein et al. 2014; Stark et al. 2017; Harrison and Noss 2017; Rahbek et al. 2019). This links taxonomic and functional diversity, and implies that by protecting these mountainous regions, we would preserve a high diversity of DT plans and the ecosystems' functions and services they provide (Laureto et al. 2015; Brown and Anand 2022). Besides, the fact that mountains concentrate a great number of species with small distributions reinforced our claim for the protection of these regions. Despite mountains creating elevational environmental gradients in which species could migrate up or downhill in response to climate change, small-ranged species might be more sensitive to changes and/or have a lower dispersal capacity (Gaston 1996). That means there is no guarantee that these species will successfully track new suitable habitats.

Yet, many DT plans also occur on lowland inselbergs (Porembski and Barthlott 2000). It is not clear if, by exhibiting lower elevation gradients when compared to mountains, lowland inselbergs could produce enough environmental gradient to allow species to move to different altitudes. If not, the whole lowland inselberg would become unsuitable for species due to climate change and might not play a role as climate change refuges for DT plants. This can be exemplified by the local extinction of *Craterostigma yaundense* and *Xerophyta schnizleinia*, which are mostly related to lowland inselbergs in West Africa. Managing ecological processes in protected areas, rather than solely protecting these areas (see Pickett et al. 1992), could be the solution to minimising the effects of climate change in those areas. Ensuring suitable conditions in lowland inselbergs can be important, not only for the persistence of species, but also to keep ecological corridors (e.g., as stepping stone patches) that allow species to track new suitable locations under unavoidable climate change scenarios.

Other factors (e.g., velocity of climate change, species dispersal limitations, and negative biological interactions) not considered here must still be better understood before the implementation of strategies seeking the management and landscape integration of lowland inselbergs. Future studies could, for example, evaluate how the topographic complexity of lowland inselbergs contributes to decouple some habitats (e.g., clefts and crevices or monocotyledoneous mats; Porembski et al. 2007) from large-scale shifts in climate and thus lessen the impact of climate change on DT plants. Also important is that other anthropogenic drivers of biodiversity loss (e.g., land-use change or alien invasive species) will interact with climate change in additive ways (Jaureguiberry et al. 2022), intensifying climate's effect on DT plants' diversity. We believe that a more comprehensive understanding of climate change is a necessary next step to support effective conservation efforts for DT plants in West Africa.

CONCLUSIONS

Our study identified the possible severe impacts of climate change on both species distribution and diversity patterns. We observed a consistent contraction of species distribution and habitat fragmentation, which might cause a reduced carrying capacity and rescue effects. Conservation studies and efforts should focus on species conservation needs, closely monitoring species with small distribution and assessing the conservation aspects of species with broad distribution. On the other side of the same coin, we show a significant shrinkage of both centres of diversity and endemism, threatening the diversity of DT plants in West Africa and the ecosystem functions they perform. Our findings stress the urgency of integrating climate projections into conservation planning, ensuring that conservation strategies include the expansion of protected areas and are designed to improve their management and network. We believe that such practices would safeguard not only individual species but also the ecological and evolutionary processes that sustain DT plants' biodiversity.

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Table 1. Area shifts of diversity and endemism patterns of desiccation-tolerant vascular plants in West Africa owing to climate change. The impact of climate change was evaluated using the most optimistic (SSP1) and pessimistic (SSP5) scenarios across different time-series intervals. Negative values describe the contraction of areas of a given class of diversity and endemism, while positive values describe the expansion of areas of a given class of diversity and endemism.

Fig. 1. Projected changes in distribution of desiccation-tolerant vascular plants in West Africa under the most optimistic (SSP1; open circles) and pessimistic (SSP5; filled circle) scenarios, across different time-series intervals. A value of 0% indicates no change in distribution, while negative and positive values represent the percentage of contraction and expansion in species distribution due to climate change, respectively.

Fig. 2. Diversity patterns of desiccation-tolerant vascular plants in West Africa and the impact of climate change on the current diversity patterns. The impact of climate change was evaluated considering the most optimistic (SSP1) and pessimistic (SSP5) scenarios across different time-series intervals.

Fig. 3. The endemism patterns of desiccation-tolerant vascular plants in West Africa and the impact of climate change on the current diversity patterns. The impact of climate change was evaluated considering the most optimistic (SSP1) and pessimistic (SSP5) scenarios across different time-series intervals.

Fig 4. Shifts in species distribution by species area of occurrence in the most optimistic (SSP1) and pessimistic (SSP5) scenarios, across different time-series intervals. Dashed line represents the threshold where shifts in species distributions are either negative or positive, in case of contraction or expansion. Colour gradient from red illustrates contraction and to blue for expansion.

Fig. 5. Priority areas for the conservation of desiccation-tolerant vascular plants within and outside protected areas from West Africa in the present and by 2071-2100 under the most optimistic (SSP1) and pessimistic (SSP5) scenarios.