Supporting Information for

Not all species will migrate poleward as the climate warms: the case of the seven baobab species in Madagascar

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Supplementary Figures

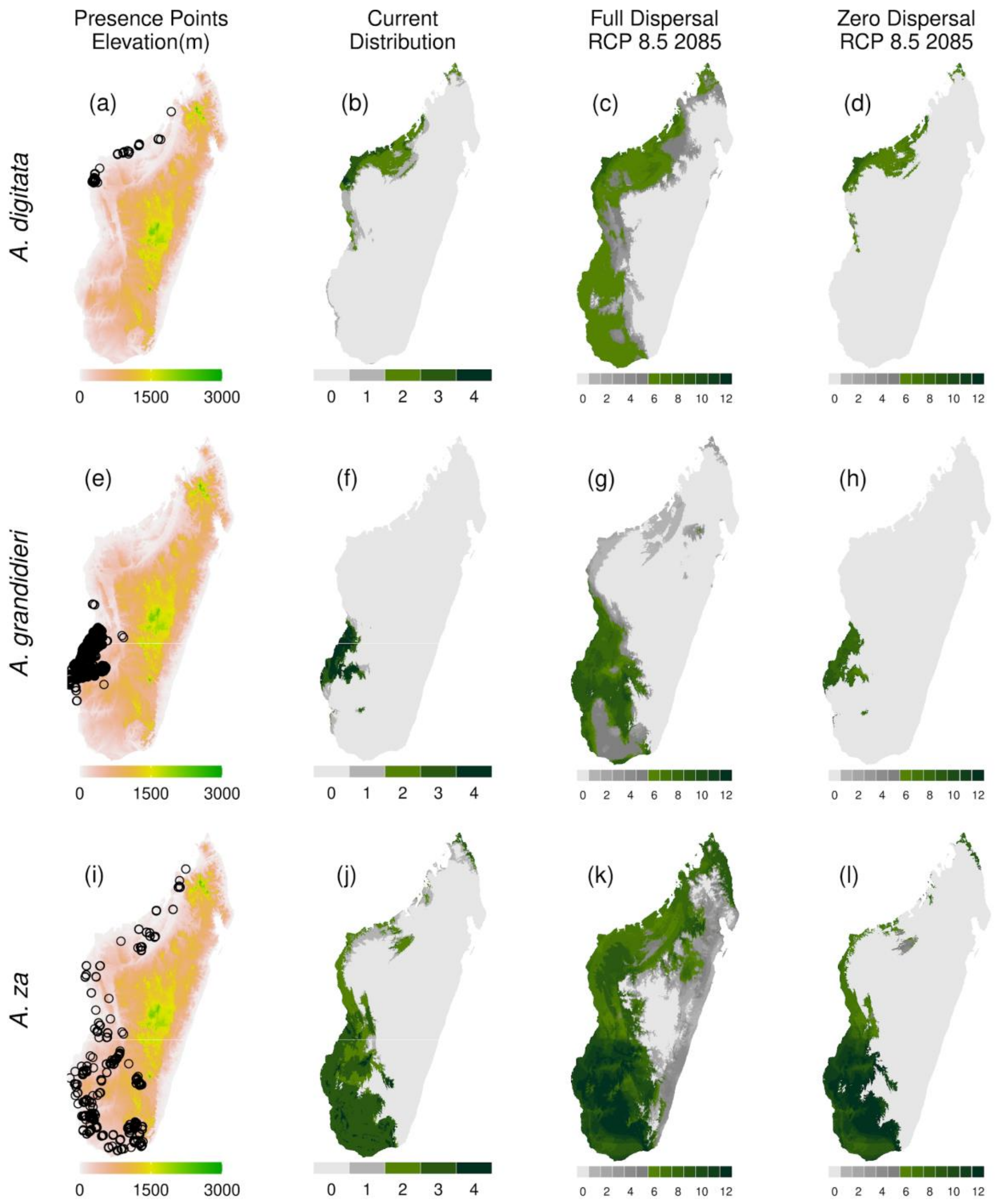
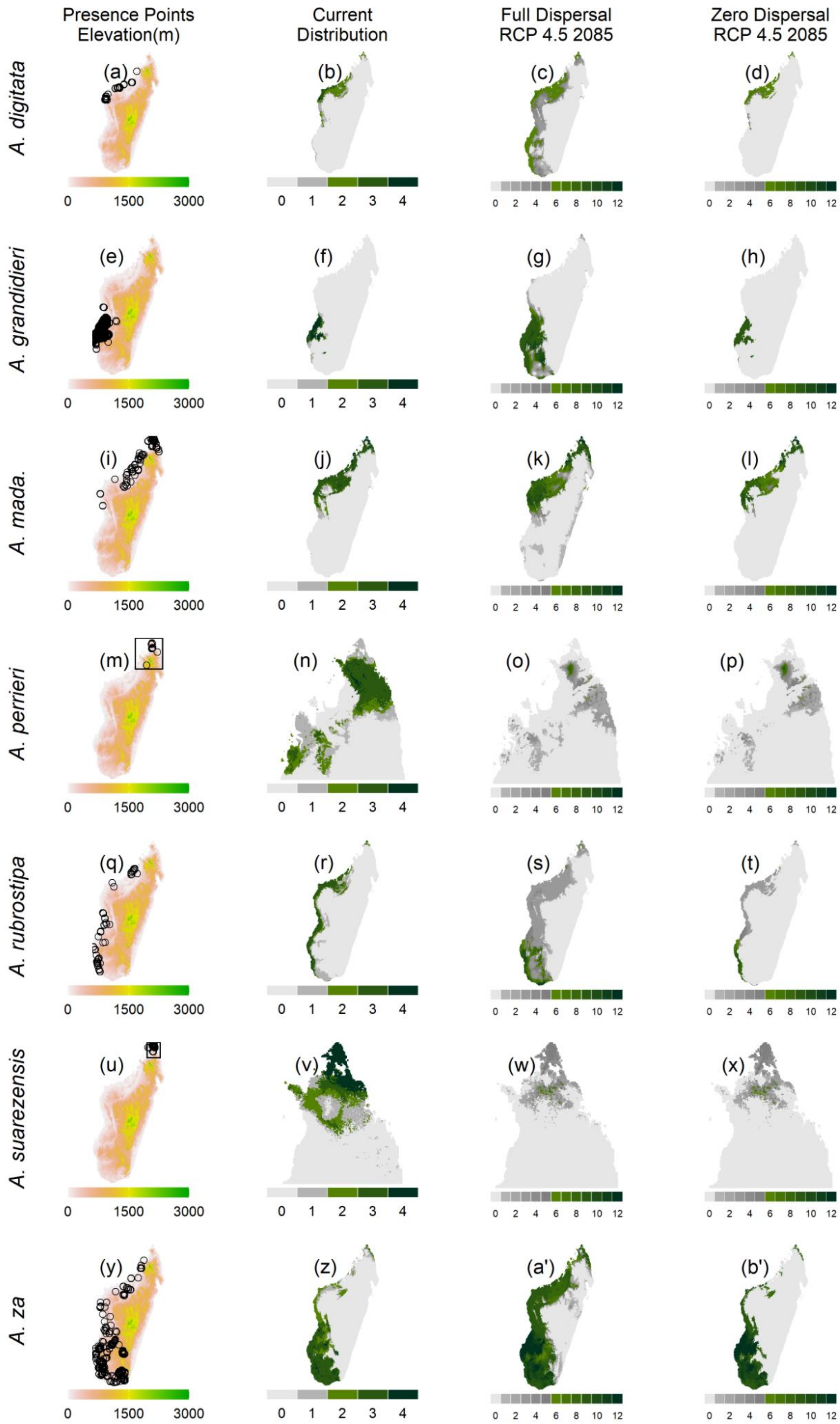


Figure S1. Species range shifts under climate change for the three resilient baobab species under RCP 8.5. The three species are *A. digitata*, *A. grandidieri*, and *A. za* (one species per row). **(a, e, i)** Occurrence points over Madagascar elevation map (elevation in m); **(b, f, j)** Current predicted species distribution. Legend indicates the number of models (0-4) predicting the species presence **(c, g, k)** Projected species distribution in 2085 under scenario RCP 8.5 and the full-dispersal hypothesis. Legend indicates the number of models (0-12) predicting the species presence **(d, h, l)** Projected species distribution in 2085 under scenario RCP 8.5 and the zero-dispersal hypothesis. Legend indicates the number of models (0-12) predicting the species presence. For the distribution maps, the species is assumed to be present (green areas) when a majority of models predicts a presence (votes >= 2 in the present, and >= 6 in the future). The species is considered absent (grey areas) when no model (votes = 0), or a minority of models (votes < 2 in the present, and < 6 in the future), predicts a presence.



Presence Points Elevation(m)
Current Distribution
Full Dispersal RCP 4.5 2085
Zero Dispersal RCP 4.5 2085
A. digitata
A. grandidieri
A. mada.
A. perrieri
A. rubrostipa
A. suarezensis
A. za
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)
(k)
(l)
(m)
(n)
(o)
(p)
(q)
(r)
(s)
(t)
(u)
(v)
(w)
(x)
(y)
(z)
(a')
(b')
0 1500 3000
0 1 2 3 4
0 2 4 6 8 10 12

Figure S2. Species range contraction under climate change (RCP 4.5) for all baobab species. The seven species are *A. digitata*, *A. grandidieri*, *A. madagascariensis* (*A. mada.*), *A. perrieri*, *A. rubrostipa*, *A. suarezensis*, and *A. za* (one species per row). **(a, e, i, m, q, u, y)** Occurrence points over Madagascar elevation map (elevation in m); **(b, f, j, n, r, v, z)** Current predicted species distribution. Legend indicates the number of models (0-4) predicting the species presence; **(c, g, k, o, s, w, a')** Projected species distribution in 2085 under scenario RCP 4.5 and the full-dispersal hypothesis. Legend indicates the number of models (0-12) predicting the species presence; **(d, h, l, p, t, x, b')** Projected species distribution in 2085 under scenario RCP 4.5 and the zero-dispersal hypothesis. Legend indicates the number of models (0-12) predicting the species presence. For the distribution maps, the species is assumed to be present (green areas) when a majority of models predicts a presence (votes >= 2 in the present, and >= 6 in the future). The species is considered absent (grey areas) when no model (votes = 0), or a minority of models (votes < 2 in the present, and < 6 in the future), predicts a presence. Maps for *A. perrieri* and *A. suarezensis*, two species distributed at the extreme North of Madagascar, have been zoomed in (black squares).

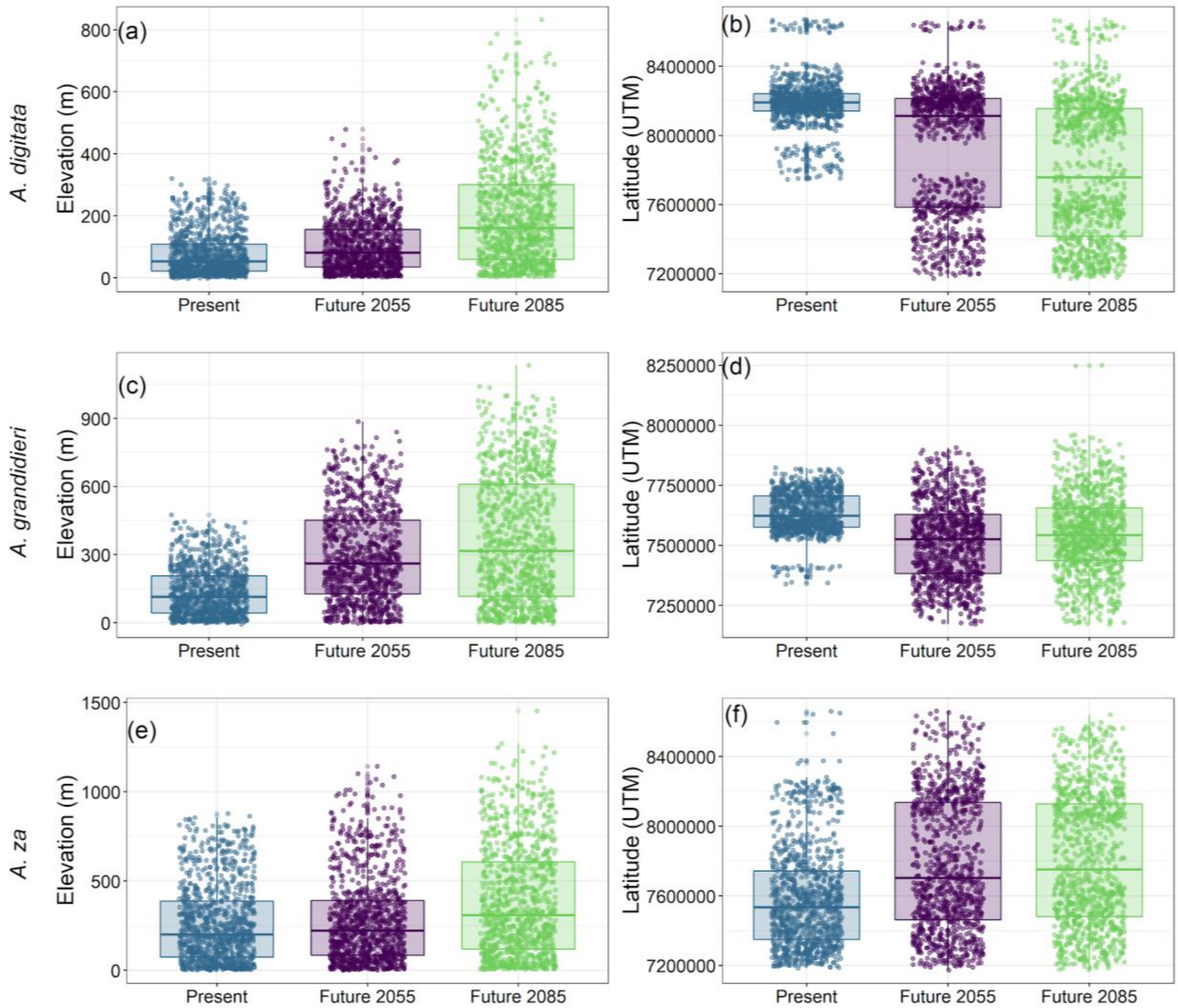


Figure S3. Change in elevation and latitude for the climate-resilient baobab species. We randomly sampled 1000 points inside the species predicted occurrence area in the present and in the future under RCP 8.5 scenario and full-dispersal hypothesis. **(a, b)** For *A. digitata*, the species should maintain stable its average elevational and latitudinal gradient from the current projection until 2085. **(c, d)** *Adansonia grandidieri* might move to higher elevations and shift its latitudinal range to lower latitudes. **(e, f)** *Adansonia za* could slightly shift its elevational gradient to more elevated areas in 2085 and higher latitudes, i.e. equatorward, from the present to 2085.

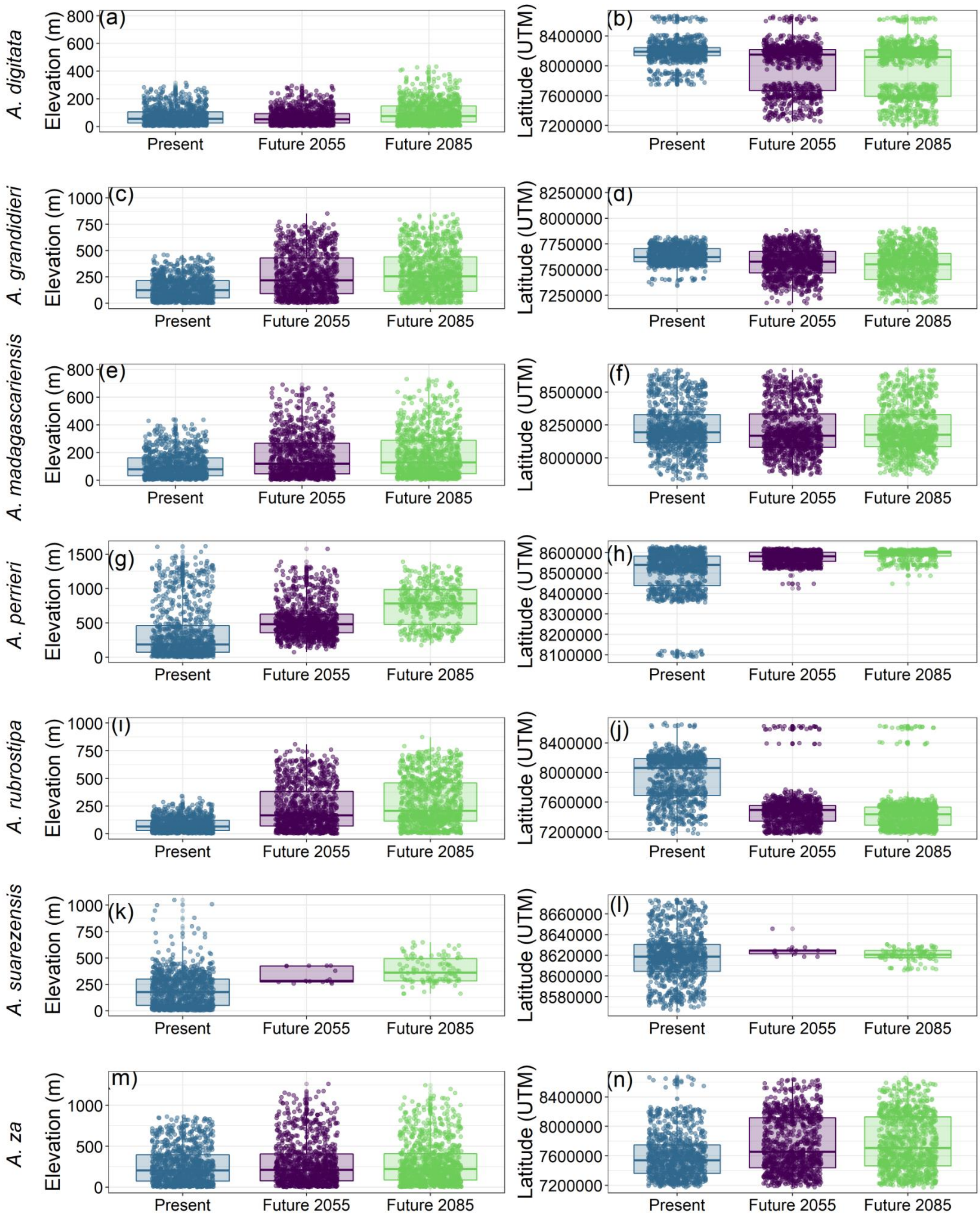


Figure S4. Change in elevation and latitude for the all baobab species under RCP 4.5 in the present and under two future scenarios (2055 and 2085). We randomly sampled 1000 points inside the species predicted occurrence area in the present and in the future (due to the extremely reduced distribution area for *A. perrieri* and *A. suarezensis*, we only sampled 416 and 105 points, respectively for year 2085, and another 15 points for *A. suarezensis* in 2055). **(a, c, e, g, i, k, m)** All species showed a tendency to maintain their current elevational range in the future or move upwards in 2055 or 2085 considering elevation. **(b, d, j)** Considering latitude distributional range, *A. digitata*, *A. grandidieri*, and *A. rubrostipa* are expected to move polewards in the future, while (**h, l, m)** *A. perrieri*, *A. suarezensis*, and *A. za* are expected to move equatorward, and **(f)** *A. madagascariensis* might keep stable its current latitudinal range in 2055 and 2085.

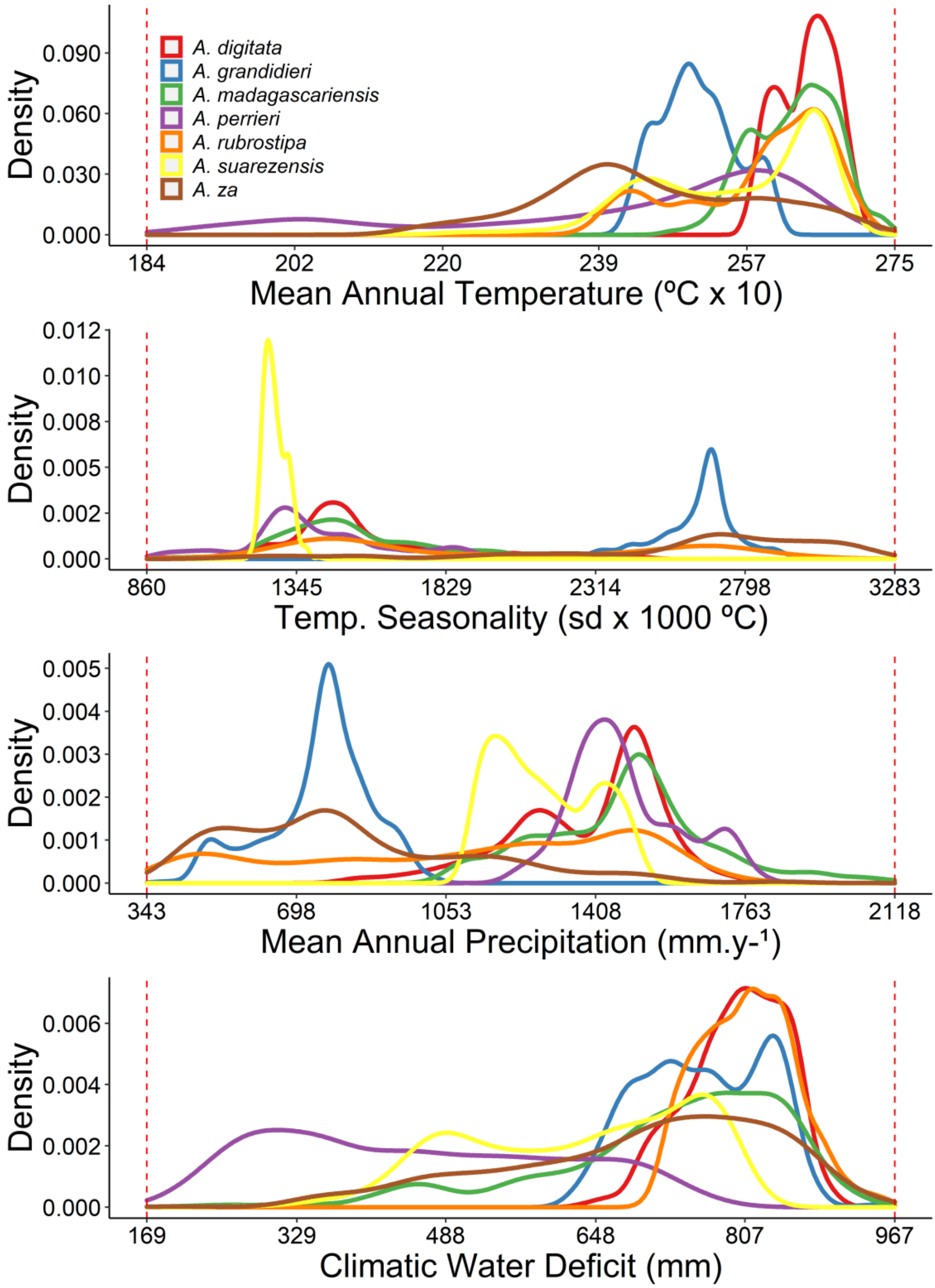


Figure S5. Bioclimatic niche of the seven baobabs species found in Madagascar. We computed species bioclimatic niche by randomly sampling 1000 points within each species distribution area for the four climatic variables selected in this study: annual mean temperature, temperature seasonality, mean annual precipitation, and climatic water deficit. Dashed lines (red) represent the climatic conditions through Madagascar. Baobab niche breadth indicates difference between species' climatic niche, with climatic specialist ones (*A. digitata* and *A. madagascariensis* – adapted to warmer temperatures –; *A. grandidieri* – adapted to higher seasonality in temperature and drier climate –; *A. perrieri* and *A. suarezensis* – adapted to lower seasonality in temperature), and generalist/ubiquitous species (*A. rubrostipa* and *A. za*), with a wider climatic niche which encompass almost every other baobab species bioclimatic niche.

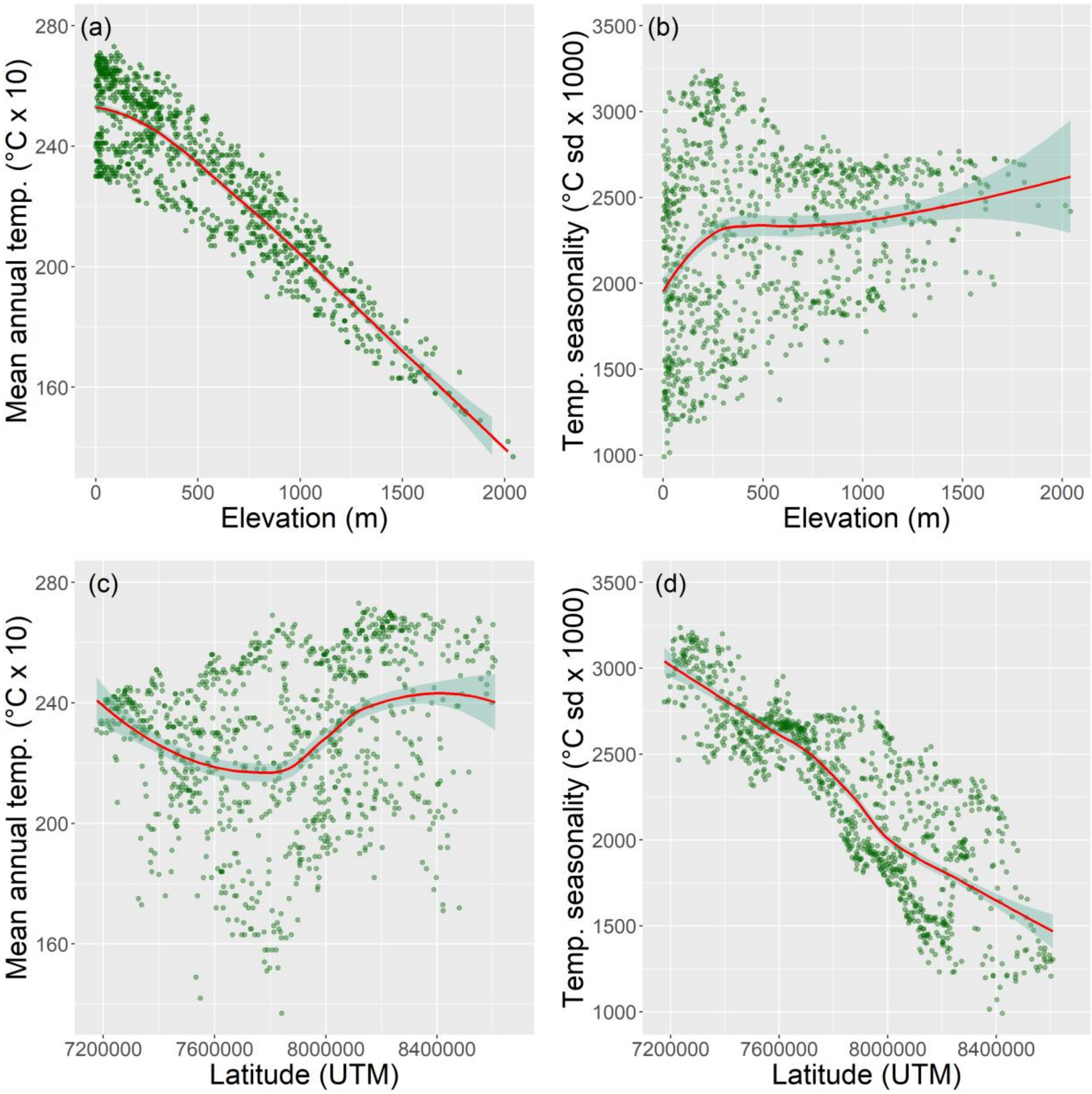


Figure S6. Relationship between climatic, elevational, and latitudinal gradients in Madagascar. We sampled 1000 random points through Madagascar extent. **(a)** Mean annual temperature is significantly lower as elevation increases. **(b)** Temperature seasonality remains stable as elevation increases, however, as elevation is > 1500 m, temperature seasonality might increase. **(c)** The mean annual temperature variation according to latitude in Madagascar. Mean annual temperature ranges between 22 °C to 25 °C across the entire country. **(d)** The temperature seasonality variation according to latitude in Madagascar. We see a decrease in seasonality from South (7200000 UTM) to North Madagascar (8400000 UTM). Shaded area surrounding the red line represents the smooth fitting values of the 1000 random points sampled.

Supplementary Tables

Table S1. Presence data-set used for the species distribution modeling (SDM). We computed the number of presence points with GPS coordinates for each species. Considering a 1-km² spatial grid covering Madagascar, we identified the cells including at least one presence point for each species independently. Doing so we obtained a presence data-set at 1-km² resolution for each species. We removed cells with incomplete associated bioclimatic data from the presence data-set.

Species	Number of initial presence points with GPS coordinates	Number of 1-km² cells with presence data	Number of 1-km² cells with presence data in Madagascar and complete bioclimatic data
A. digitata	1854	151	62
A. grandidieri	128 609	3772	3770
A. madagascariensis	1222	159	153
A. perrieri	150	21	21
A. rubrostipa	794	93	90
A. suarezensis	1686	174	170
A. za	2970	460	460

Table S2. Performance of the four statistical models in predicting species presence–absence. AUCc and TSSc indicate the mean of the Area Under the ROC Curve and the True Skills Statistics respectively after a 5-fold cross-validation procedure (data were split into 70% of the training data and 30% of test data). AUC full and TSS full indicate the Area Under the ROC Curve and the True Skills Statistics calculated for the full data-set (100% of the data).

Species	Model	AUC full	AUCc	TSS full	TSSc
A. digitata	GLM	0.972	0.955	0.900	0.903
	GAM	0.989	0.974	0.977	0.949
	Random Forests	1	0.969	0.999	0.927
	Maxent	0.970	0.967	0.859	0.875
A. grandidieri	GLM	0.991	0.991	0.951	0.951
	GAM	0.991	0.990	0.950	0.951
	Random Forests	1	0.994	0.988	0.965
	Maxent	0.989	0.989	0.936	0.936
A. madagascariensis	GLM	0.961	0.958	0.834	0.834
	GAM	0.966	0.963	0.834	0.837
	Random Forests	1	0.964	0.993	0.839
	Maxent	0.959	0.958	0.812	0.819
A. perrieri	GLM	0.993	0.954	0.967	0.913
	GAM	0.991	0.941	0.981	0.887
	Random Forests	1	0.960	1	0.917
	Maxent	0.987	0.987	0.924	0.946
A. rubrostipa	GLM	0.959	0.961	0.839	0.856
	GAM	0.962	0.963	0.831	0.858
	Random Forests	1	0.967	0.999	0.891
	Maxent	0.951	0.953	0.783	0.841
A. suarezensis	GLM	0.998	0.998	0.993	0.991
	GAM	0.999	0.998	0.995	0.993
	Random Forests	1	0.996	0.999	0.989
	Maxent	0.949	0.960	0.992	0.917
A. za	GLM	0.881	0.870	0.631	0.621
	GAM	0.893	0.880	0.676	0.655
	Random Forests	0.999	0.944	0.992	0.742
	Maxent	0.881	0.870	0.638	0.622

Table S3. Performance of the ensemble model based on committee averaging. Values of the threshold-dependent indices True Skill Statistics (TSS), Sensitivity, and Specificity are described below. Almost all TSS values were >= 0.83 except for *A. za*, where the TSS was 0.672 due to a relatively lower specificity. The performance metrics thus indicate good performance of the ensemble model by correctly predicting species presence/absence on committee averaging method.

Species	TSS	Sensitivity	Specificity
A. digitata	0.92	1.00	0.92
A. grandidieri	0.95	0.99	0.96
A. madagascariensis	0.83	0.99	0.84
A. perrieri	0.97	1.00	0.97
A. rubrostipa	0.85	0.97	0.87
A. suarezensis	0.99	1.00	0.99
A. za	0.67	0.94	0.72

Table S4. Baobabs' vulnerability to climate change and elevational range shift in 2085 under scenario RCP 4.5. We calculated the species distribution area (km²) in the present (SDAp) and future (SDAf) to describe the change in the species distribution area (Change SDAp SDAf %) according to two dispersal hypotheses (full and zero-dispersal).

Baobab species IUCN status	SDAp (km²)	Current mean elevation (m)	Dispersal hypothesis	SDAf (km²)	Future mean elevation (m)	Change SDAp f (%)
Adansonia digitata Not assessed by IUCN	47 872	76	Full	91 692	100	+92
			Zero	38 293	68	-20
A. grandidieri Endangered A2c*	27 651	135	Full	101 727	285	+268
			Zero	27 651	135	0
A. madagascariensis Near threatened	92 311	105	Full	123 913	184	+34
			Zero	85 023	108	-8
A. perrieri Critically endangered C2a(i)	14 872	377	Full	427	762	-97
			Zero	427	762	-97
A. rubrostipa Least concern	74 194	77	Full	53 367	283	-28
			Zero	15 636	277	-79
A. suarezensis Endangered B1ab (i,ii,iii,iv,v) + B2ab (i,ii,iii,iv,v)	3347	194	Full	100	393	-97
			Zero	100	393	-97
A. za Least concern	170 625	265	Full	304 482	294	+78
			Zero	170 622	265	0

Table S5. **Climate change within the current species distribution areas.** We computed the climatic variables' mean and 95% quantiles within the current species distribution areas for the current and future climates. For the future climate, we considered the mean of the climatic projections of three GCMs (GISS-E2-R; HadGEM2-ES; NorESM1-M) for the year 2085 under RCP 8.5. Abbreviations: $Temp_{pf}$ for mean annual temperature (in °C x 10); $Tseas_{pf}$ for temperature seasonality (in °C sd x 1000); $Prec_{pf}$ for mean annual precipitation (in mm.y^{-1}); Cwd_{pf} for climatic water deficit (in mm) in the present (p) and future (f).

Baobab species	Confidence interval	$Temp_p$	$Temp_f$	$Tseas_p$	$Tseas_f$	$Prec_p$	$Prec_f$	Cwd_p	Cwd_f
A. digitata	**Mean**	*264*	298	*1525*	1612	*1390*	1205	*800*	1680
	2.5%	*258*	291	*1136*	1267	*953*	937	*691*	1372
	97.5%	*270*	306	*2246*	2208	*1665*	1454	*882*	1926
A. grandidieri	**Mean**	*251*	286	*2649*	2729	*746*	715	*764*	1670
	2.5%	*243*	277	*2338*	2402	*467*	474	*642*	1447
	97.5%	*260*	296	*2887*	3045	*956*	895	*877*	1978
A. madagascariensis	**Mean**	*263*	296	*1510*	1623	*1485*	1298	*724*	1546
	2.5%	*253*	282	*1133*	1269	*1110*	986	*399*	980
	97.5%	*272*	308	*2008*	2101	*1953*	1733	*890*	1989
A. perrieri	**Mean**	*243*	272	*1391*	1539	*1483*	1257	*465*	962
	2.5%	*192*	223	*948*	1117	*1262*	1063	*230*	436
	97.5%	*267*	300	*1890*	2108	*1764*	1483	*738*	1563
A. rubrostipa	**Mean**	*258*	292	*1972*	2046	*1088*	969	*808*	1678
	2.5%	*240*	273	*1224*	1335	*413*	395	*719*	1455
	97.5%	*270*	306	*2898*	2921	*1650*	1451	*913*	1914
A. suarezensis	**Mean**	*255*	283	*1275*	*1389*	*1288*	1103	*629*	1242
	2.5%	*233*	259	*1221*	*1333*	*1121*	932	*402*	724
	97.5%	*267*	295	*1357*	*1479*	*1498*	1303	*794*	1653
A. za	**Mean**	*245*	280	*2583*	2668	*830*	760	*689*	1488
	2.5%	*220*	256	*1282*	1406	*430*	388	*378*	870
	97.5%	*270*	307	*3183*	3229	*1524*	1363	*902*	2010