African Journal of Ecology

Climate change and the African baobab (*Adansonia digitata* L.): the need for better conservation strategies

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Abstract

The baobab tree, with more than 300 uses and commercial value in EU and United States, has been identified as one of the most important trees to be conserved and domesticated in Africa. A decline in baobab populations because of changes in climate could have a negative effect on African livelihoods. Therefore, it is important to study the potential future distribution of this species and determine strategies for conservation. We used Maxent, 480 geo-referenced records, present and future climatic and soil layers. Different general circulation models and scenarios were selected. Models were simulated for (i) All records, (ii) East Africa and (iii) West Africa species records. For each combination, the proportion of the present habitat that might remain suitable in the future was determined. These habitat proportions were compared with the Protected Areas in Africa. Although potential future distributions were different depending on model, scenario and records used, in all cases only a percentage of the present distribution was predicted to remain suitable in the future. Some countries were found to have no suitable habitat in the future. Recommendations for different conservation strategies include *in situ* conservation in Protected Areas; *ex situ* conservation in seed banks; and conservation through 'sustainable utilization'.

Key words: conservation strategies, distribution, future climate, Protected Areas, sustainable utilization, The baobab tree

Résumé

Le baobab, pour lequel on connaît 300 utilisations et valeurs commerciales dans l'UE et les U.S.A., a été identifié comme l'un des arbres dont la conservation et la domestication sont les plus importantes en Afrique. Un déclin des populations de baobabs dû aux changements climatiques pourrait avoir un impact négatif sur les moyens de subsistance des Africains. Il est dès lors important d'étudier la future distribution potentielle de cette espèce et de déterminer des stratégies pour sa conservation. Nous avons utilisé Maxent, 480 données géoréférencées, des couches de données sur l'étude et la prédiction du climat, ainsi que sur les sols. Nous avons choisi différents modèles de circulation générale et différents scénarios. Nous avons créé des modèles pour (i) l'ensemble des données et (ii) les données sur l'espèce en Afrique de l'Est et (iii) en Afrique de l'ouest. Pour chaque combinaison, la proportion de l'habitat actuel qui pourrait rester propice à l'avenir a été déterminée. Ces différentes proportions ont été comparées avec les aires protégées africaines. Bien que les distributions futures potentielles soient différentes selon les modèles, les scénarios et les données utilisées, l'on prédisait dans tous les cas que seul un certain pourcentage de la distribution actuelle resterait adapté à l'avenir. Pour certains pays, on a trouvé qu'il ne resterait aucun habitat propice dans le futur. Les recommandations en matière de stratégies de conservation incluent : la conservation *in situ* dans des aires protégées, la conservation *in situ* dans des banques de semences et la conservation par une 'utilisation durable'.

Introduction

Predicted changes in atmospheric CO_2 and climate are likely to affect the distribution and abundance of most species (Araujo *et al.*, 2005; Schroter *et al.*, 2005). Tropical biodiversity is foreseen to be critically threatened not only by climate change, but also by land-use changes (Bradshaw, Sodhi & Brook, 2009). Climate assessments

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show that Africa is likely to experience marked climatic changes over the 21st century with drying and warming in most subtropical regions and slight increases in precipitation in the tropics (Boko *et al.*, 2007). Christensen *et al.* (2007) estimated that regions across Africa will experience temperature increases between 3 and 4°C with drier tropical regions experiencing more warming than the wetter tropical regions. Africa is also one of the most vulnerable continents because of lack of adaptive ability and challenges such as poverty, infrastructural and technological challenges, political conflicts and degradation of ecosystem functioning (Boko *et al.*, 2007). Sub-Saharan Africa also maintains the highest proportion of malnourished populations in the world, with one in three people being chronically hungry (FAO, 2008).

A few studies have addressed the potential consequences of the future climate changes on biodiversity in Africa. McClean *et al.* (2005) predicted that more than 5000 African plant species would experience losses of climatically suitable habitat by 2085. Thuiller *et al.* (2006) predicted that up to 40% of African mammals would be critically endangered by 2080 owing to the loss of suitable habitat. Although a small number of studies have addressed the potential consequences of the future climate changes on plant biodiversity in Africa, only some suggest management strategies (e.g. Bomhard *et al.*, 2005).

Among the taxa most vulnerable to reductions in suitable habitat are those that have delayed maturation and low reproductive rate (reducing their ability to recover from population reductions), low dispersal rates (making it difficult to colonize new suitable areas) and/or that are already under anthropogenic pressure (Araujo, Thuiller & Pearson, 2006; Penman *et al.*, 2010).

The baobab tree *Adansonia digitata* L. (Family Malvaceae) meets these three criteria. This tree is a long-lived species (1200 years, Patrut *et al.*, 2007), which takes up to 23 years to start fruiting (Wickens & Lowe, 2008). It is naturally dispersed by animals (mainly elephants and baboons), and it is under considerable human pressure: bark, fruits and leaves are harvested for different purposes (Wickens & Lowe, 2008). Dovie (2003) stated that bark harvesting was being carried out unsustainably in Zimbabwe. Mutilation because of leaf harvesting which affects fruit production is carried out unsustainably in some areas of West Africa (Dhillion & Gustad, 2004; Schumann *et al.*, 2010).

The baobab tree has been identified as one of the most important edible savannah trees to be conserved, domesticated and valorized in Africa (Eyog Matig, Gaoue & Dossou, 2002). Among others, the tree provides nutritious food (Nordeide *et al.*, 1996), livestock fodder, material for hunting and fishing, medicine, shade, veterinary and spiritual services for local people in Africa (Sidibe & Williams, 2002). Many baobab products are sold in markets and are an important source of income for people (Diop *et al.*, 2006). Especially in West Africa, rural people rely on a variety of nutritional and medicinal products provided by the baobab (Buchmann *et al.*, 2010). Baobab fruit pulp is also commercialized in Europe and in the United States (CEC, 2008; FDA, 2009). The tree also acts as an important source of food, water and shelter for a wide range of animals (Fenner, 1980), and it improves site conditions in the savannah (Amundson, All & Belsky, 1995). Thus, declining baobab populations owing to climate change would have a negative effect not only in the society (local people could lose an important part of their diet and an essential pharmaceutical resource) but also on the ecosystems where baobabs exist.

The aim of this research is to study the potential future baobab tree distribution in Africa using a predictive modelling approach, thereby contributing to the selection of effective conservation sites and other conservation strategies.

Materials and methods

Species data

Localities (n = 480) for *A. digitata* were assembled from herbarium records and fieldwork (Table 1). Some of the herbarium records contained geographical coordinates representing presence locations but others had to be georeferenced using the gazetteers of the Flora Zambesiaca (Pope & Pope, 1998), the Flora of Tropical East Africa (Polhill, 1988), the Geographic Names Data Base (GNS – National Geospatial-Intelligence Agency, 2005) and Google Earth (Google, 2008). Herbarium records classified as 'cultivated specimen' by the Herbarium or with controversial 'cultivation' origin by Sidibe & Williams (2002) were also eliminated.

Although there is only one species of baobab tree growing in continental Africa (*A. digitata*) and no subspecies or varieties are officially accepted, a recent study has shown that there are genetic differences between populations from West and East Africa (Pock Tsy *et al.*, 2009). To account for this, we studied baobab potential future

Table 1 Source, number, type of record and geographical location of baobab presence records used in the study

Source	No. and type of records	Geographical location
Arhus Herbarium[a]	2 H	Senegal, Tanzania
Botanic Garden and Botanical Museum Berlin-Dahlem[a]	4 H	Mali, Tanzania, Kenya
Cuni Sanchez A.	23 F	Benin, Malawi, Mozambique
DADOBAT Project	20 F	Senegal, Mali
Database Schema for UC Davis[a]	1 H	Niger
De Smedt S.	11 F	Mali
Dhillion & Gustad (2004), Duvall (2007)	2 F	Mali
Frankfurt Herbarium	23 H	Burkina Faso, Benin, Nigeria
KEW Herbarium	48 H	Several countries all over Africa
Larsen A.S.	21 F	Several countries all over Africa
Marine Science Institute, UCSB[a]	1 H	Tanzania
Missouri Herbarium[a]	7 H	Tanzania
Paris Herbarium	20 H	Several countries all over Africa
Phytotrade Africa database	58 H, F	Malawi, Zambia, Mozambique, Zimbabwe
Pock Tsy *et al.* (2009)	51 F	Several countries all over Africa
PRECIS database	40 H	South Africa, Namibia, Botswana
Schumann K.	19 F	Burkina Faso, Benin
Uppsala Herbarium[a]	2 H	Kenya, Eritrea
Wagningen Herbarium[a]	1 H	Cameroon
Wickens & Lowe (2008)	126 H	Several countries all over Africa

H, herbarium record; F, field work record.
[a]The occurrence data were accessed through GBIF Data Portal (http://www.gbif.net).

distribution using all 480 presence records and using the East (307) and West African (173 records) records separately based on Pock Tsy *et al.* (2009) (Fig. 1). These are referred to as the 'All Records', the 'East African' and the 'West African' model, respectively.

Predictor variables

We used nineteen climatic variables from the WorldClim data set (Hijmans *et al.*, 2004, 2005) and one soil variable (soil type) from the Harmonized World Soil Database (HWSD) (FAO/IIASA/ISRIC/ISSCAS/JRC, 2008). The climatic variables are derived from monthly temperature and rainfall recorded worldwide (period 1950–2000) and are often used in ecological niche modelling (e.g. Blach-Overgaard *et al.*, 2010; Penman *et al.*, 2010). The same variables have already been used to model baobab tree distribution (Cuni Sanchez, Osborne & Haq, 2010).

There are currently at least 24 different atmosphere-ocean general circulation models (GCM) being used to project climatic changes for more than ten different greenhouse-gas emissions scenarios (PCMDI, 2007). In this study, we selected three GCM (HadCM3, CCCma-CGCM2 and CSIRO-MK2) that have been commonly used in recent studies dealing with the impacts of climate change on biodiversity (e.g. Araujo, Thuiller & Pearson, 2006; Mika *et al.*, 2008; Buisson *et al.*, 2010). For each GCM, two scenarios were examined: A2a and B2a. Both scenarios are intermediate scenarios representing regional development and slow economic growth, B2a being more moderate than A2a. The spatial resolution of all layers was 5 min.

Predicting modelling

Species distribution modelling was implemented using the maximum entropy approach (Maxent) of Phillips, Anderson & Schapire (2006) because of its high performance compared with other predictive algorithms (Elith *et al.*, 2006; Pearson *et al.*, 2007) and because it avoids commission errors (i.e. when a model predicts the presence of a given species in particular area although it is known that

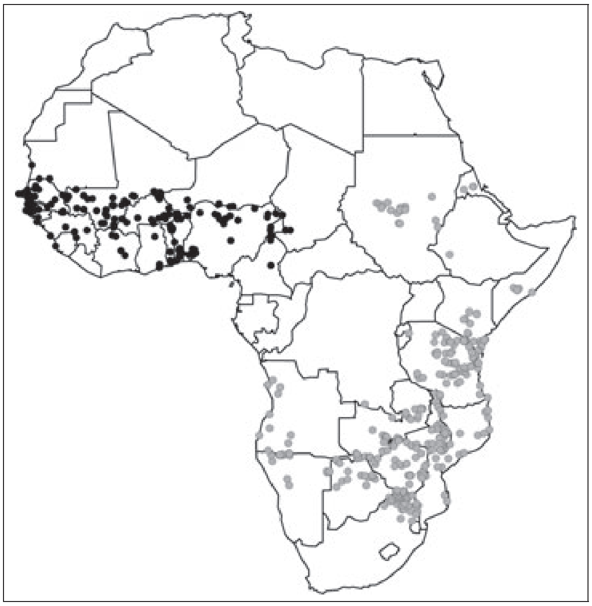

Fig 1 Geographical distribution of the baobab presence records used in the study. Black dots: West Africa records, grey dots: East Africa records, as defined by Pock Tsy *et al.* (2009)

this species is not present there) that is preferred in conservation studies (Loiselle *et al.*, 2003; Phillips, Anderson & Schapire, 2006).

Model performance was evaluated using the methods described in Cuni Sanchez, Osborne & Haq (2010). The default settings for Maxent were used. The Maxent set-up was as follows: the environmental layers of present conditions were used to create three models for the baobab tree (All records, East Africa and West Africa models), and then, these models were projected into the future using different sets of environmental layers depending on the GCM and the scenario. The soil layer was always the same. In total, the All records, the East Africa and the West Africa models were each projected six times (three GCM and two scenarios).

Areas with clamping are sites where one or several environmental variables used for model projection (the future) are found to be outside their range within the study area used to build the model (present conditions in Africa). Caution should be taken if these areas are predicted to have very suitable conditions (S. Phillips, pers. comm.). Therefore, areas where clamping was high (more than 40%) were removed from the potential future suitable habitat. As suggested by Liu *et al.* (2005), the threshold 'Equal training sensitivity and specificity' was used to convert the probability of baobab presence (which is a continuous variable going from 0 to 1) to a Boolean variable of presence/absence.

Further analyses

Seed dispersal and the associated patterns of plant migration are considered to be a significant uncertainty in projecting climate change impacts on plant species ranges (Thuiller *et al.*, 2008). Most studies on potential future plant distribution have considered two scenarios: 'unlimited dispersal' that represents an unrealistic best case scenario and 'no dispersal', the worse case scenario (Engler & Guisan, 2009). Baobab seeds are dispersed by animals (mainly elephants, baboons and elands) and humans (Wickens & Lowe, 2008). Considering the lack of natural regeneration observed by several authors in different countries in Africa (Romero *et al.*, 2001; Assogbadjo *et al.*, 2005; Edkins *et al.*, 2007), we decided to assess only the 'no dispersal' scenario for three reasons: (i) elephants are less common and widespread than they used to be centuries ago; (ii) baobabs fruits are highly exploited by humans and it is unlikely that many fruits are left on the trees; and (iii) even when seeds germinate, there are many constrains for seedling survival. The main constraints for baobab seedling survival are fire, livestock browsing and clearing of fields (Wickens & Lowe, 2008). It seems unlikely that without human intervention baobabs will colonize new suitable habitat. Thus, we did not consider 'potentially colonisable habitat' (the area a species could occupy given unlimited dispersal ability) but only the percentage of the present habitat that might still be suitable in the future. These percentages were calculated using ArcGIS 9.2 (Environmental Systems Research Institute, Inc., Redlands, CA, USA).

We also compared these percentages with a GIS layer of the Protected Areas in Africa in 2009, obtained from the World database on Protected Areas (WDPA) (http://www.wdpa.org/). With the aim of reducing prediction uncertainty, only the Protected Areas having present suitable habitat predicted to remain suitable under all GCM and scenarios were considered as areas for high-priority conservation.

Results

Model performance and variable contribution

All models performed well. All records, West Africa and East Africa models had high area under the ROC curve

(AUC) values (0.90, 0.93 and 0.95, respectively). The AUC is a measure of model performance, the closer the AUC value to 1 the better (see Cuni Sanchez, Osborne & Haq, 2010). The predicted present distributions also showed good agreement with data from the literature.

The variables that were the most important predictors in each model were different. Temperature seasonality and annual precipitation were the most important predictors for the All records model. Mean temperature of the warmest 4 months and precipitation of the wettest 4 months were the most important predictors for the West African model, while mean temperature of the coldest 4 months and temperature seasonality were the most important predictors for the East African model.

Present and future distributions

For the All Records model, Maxent predicted the baobab tree to occur in most of the Sahel (except Chad) and in much of the mopane savannah in south-eastern Africa (grey colour, Fig. 2). While estimated present distribution for the East Africa model included much of the mopane savannah in south-eastern Africa (grey colour, Fig. 3), the West Africa model included most of the Sahel with Chad but excluding Sudan (grey colour, Fig. 4). Results for the All Records model differed from a combination of the results of the West Africa and East Africa models.

Estimated potential future distributions for all models were different depending on the GCM and scenario used (Figs 2–4). In all cases, only a percentage of the present distribution was predicted to be suitable in the future, with predictions for scenario B2a, in general, being smaller in extension than those for scenario A2a (Table 2). For the All records model, the percentage of present distribution predicted to be suitable in the future ranged from 5% to 69%, while for the East Africa model it ranged from 27% to 91% and for the West Africa model from 5% to 48%.

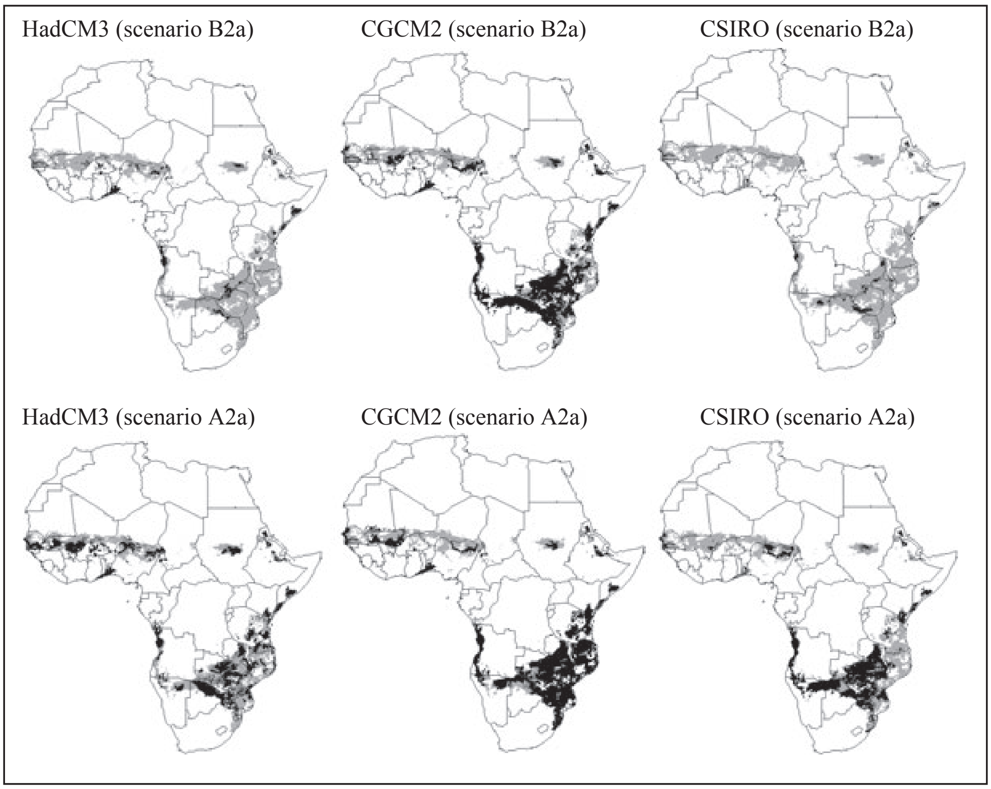

Fig 2 Estimated potential future distributions for the All records model. Grey indicates suitable conditions for the baobab tree in the present. Black indicates suitable areas in the present predicted to remain suitable in the future for the mentioned general circulation models (GCM) and scenario

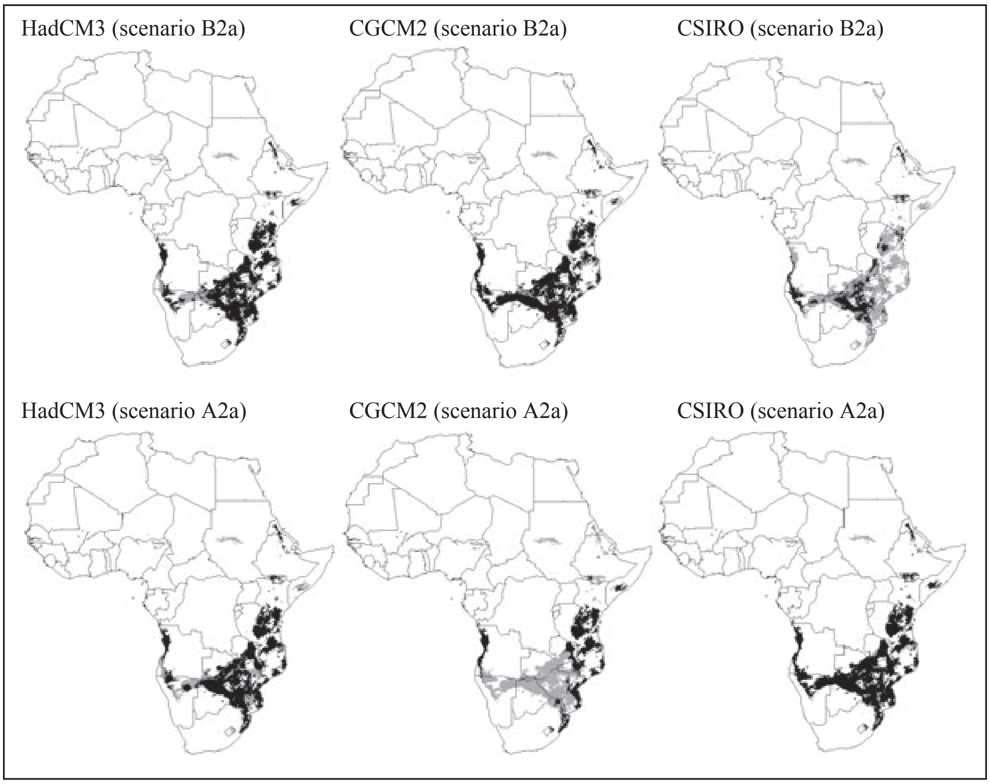

Fig 3 Estimated potential future distributions for the East Africa model. Grey indicates suitable conditions for the baobab tree in the present. Black indicates suitable areas in the present predicted to remain suitable in the future for the mentioned general circulation models (GCM) and scenario

Some countries within the present range were found to have no suitable habitat for the baobab tree in the future. This was the case of Sudan, Namibia, Botswana, Somalia and Ivory Coast (Figs 3 and 4).

Potential sites for conservation

Some areas that were predicted to have suitable habitat in both the present and the future are not known to have baobabs (e.g. southern Ethiopia and eastern Chad). Thus, these two areas cannot be considered as a potential site for baobab conservation.

For the East Africa model, 36% of the area predicted to remain suitable in the future (under all GCM and scenarios) is within Protected Areas. In total, nineteen Protected Areas could be considered as potential areas for high-priority conservation (Table 3). For the West Africa model, only 5.3% of the area predicted to remain suitable in the future (under all GCM and scenarios) is within Protected Areas (Table 3). Information on baobabs being present in these Protected Areas could only be found for some (Table 3). Elephant damage on baobab seedlings and/or mature trees has been reported from some of the Protected Areas (Table 3).

Discussion

Different sets of records

Our analyses showed that the use of different sets of records (All records, East Africa and West Africa models) gives different potential present and future distributions, with predictions for All records model being different from the combination of East Africa and West Africa models. Similar results were obtained by Cuni Sanchez, Osborne & Haq (2010). Observed differences in the main environmental factors limiting the distribution of the baobab tree by different models are also in agreement with Cuni

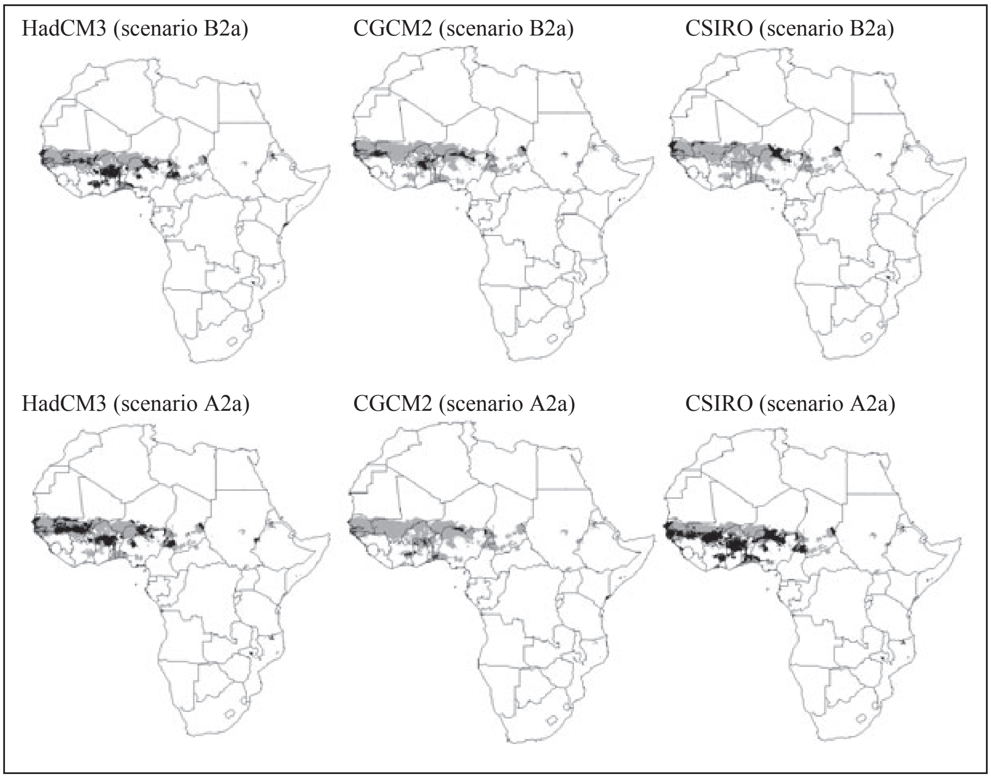

Fig 4 Estimated potential future distributions for the West Africa model. Grey indicates suitable conditions for the baobab tree in the present. Black indicates suitable areas in the present predicted to remain suitable in the future for the mentioned general circulation models (GCM) and scenario HadCM3 (scenario B2a) CGCM2 (scenario B2a) CSIRO (scenario B2a)

Table 2 Percentage of the present potential distribution estimated to remain suitable in the future for the All records model, East Africa model and West Africa model under different general circulation models (GCM) and scenarios

	Scenario A2a (%)			Scenario B2a (%)		
	HadCM3	CGCM2	CSIRO	HadCM3	CGCM2	CSIRO
All records model	44	69	41	9	55	5
East Africa model	76	39	91	76	80	27
West Africa model	5	33	48	12	30	10

Sanchez, Osborne & Haq (2010). Although it is possible that these differences in the main environmental factors limiting the distribution of the baobab tree only reflect differences in the available environment (West Africa being drier than East Africa, in general), and baobab trees from East Africa could survive in drier habitats (habitats not found in East Africa under current climatic conditions), it is also possible that West and East African baobab trees have different ecological requirements owing to genetic differences. Preliminary results from a drought seedling experiment support this later idea (S. De Smedt 2010, pers. comm.). When the genetic variation between isolated populations of a species is not well documented, we suggest that different sets of records are considered and results compared to maximize the effectiveness of the selected conservation strategies.

Table 3 Protected Areas predicted to have present suitable habitat for the baobab tree that will remain suitable in the future under all general circulation models and scenarios, and information on baobab presence and reported elephant damage in the Protected Areas

Model used	Country	Type of Protected Area	Name	Remarks
East Africa model	Angola	National Park	Quiçãma	Baobabs reported
	Eritrea	Wildlife Reserve	Nakfa	
	Kenya	National Park	Tsavo East	Baobabs reported; elephant damage (Wickens & Lowe, 2008)
		National Park	Tsavo West	Baobabs reported; elephant damage (Wickens & Lowe, 2008)
	Malawi	Wildlife Reserve	Vwaza Marsh	
	Mozambique	National Park	Zinave	
	South Africa	National Park	Kruger	Baobabs reported; elephant damage (Edkins *et al.*, 2007)
		Private Nature Reserve	Klaserie	
		Game Farm	Selati	
	Tanzania	National Park	Ruaha	Baobabs reported; elephant damage (Barnes, Barnes & Kapela, 1994)
		Forest Reserve	Itulu Hill	
		Game Reserve	Mkomazi	Baobabs reported
		Game Reserve	Muhezi	
		Game Reserve	Kizigo	
		Game Reserve	Rungwa	
		Game Reserve	Lunda-Mkwabi	
		Game Reserve	Usangu	
	Zambia	National Park	North Luangwa	Baobabs reported; elephant damage (Robertson-Bullock, 1960)
		Game Reserve	Musalangu	
West Africa model	Senegal	UNESCO Biosphere Reserve	Delta du Saloum	Baobabs reported
		Forest Reserve	Foret de Bandia	Baobabs reported
		Forest Reserve	Foret de Thies	Baobabs reported
	Nigeria	Forest Reserve	Gwiwakorel	
		Forest Reserve	Zamfara	
		Forest Reserve	Barawa	
		Forest Reserve	Dan Babba	
		Forest Reserve	Mawulli	

Future distribution

One question that rises while studying the potential future distribution of a species is the validity and/or accuracy of the GCM and scenarios commonly used for this purpose. However, to date, this is the best data available, and it is still commonly used to study the potential effect of climate change on species' distributions (e.g. Buisson *et al.*, 2010; Marini *et al.*, 2010). The fact that there is uncertainty about predicted changes in climate does not justify the lack of actions; it is better to use the data that are available and carry out the studies required to make recommendations for conservation.

Regardless of the set of records used, modelling suggests that the geographical distribution of the baobab tree will shrink under predicted levels of climate warming. Much of the area that is currently suitable environmentally will not remain suitable in the future. In these future unsuitable habitats, local extinction is the most likely outcome. Adult trees, with an extensive shallow rooting system and a large trunk that accumulates water (Sidibe & Williams, 2002), might survive for a period of time. However, as seedlings are less resistant to drought than adults (Wickens, 1982), seedlings might not be able to establish.

Alternatively, one possibility is that the baobab tree is capable of adapting to future local conditions by phenological or physiological means. Another possibility is that microclimate conditions not captured in the scale of this study allow the survival of some baobab populations. If so, the change in extension of suitable habitat may not be as pronounced as projected here. However, it is also possible that, as suggested by Midgley *et al.* (2003), the combined impact of future land transformation and climate change will reduce suitable habitat even more than predicted here. Another option that should also be considered is the potential increase in future utilization pressures on the baobab tree, as other plant species fail to cope with predicted changes in climate (as suggested for the African ivory nut palm *Hyphaene petersiana*, Blach-Overgaard, Svenning & Balslev, 2009). This could cause the extinction of some baobab populations existing in present suitable habitat predicted to remain suitable in the future. Although it is possible that the change in extension of suitable habitat may not be as projected, results from this study support the view that the baobab tree is threatened by climate change (Wickens & Lowe, 2008) and indicate that better conservation strategies are urgently needed.

Conservation strategies: Protected Areas

One strategy often considered in conservation studies is the presence of National and International Protected Areas. However, not many Protected Areas were predicted to have suitable habitat for the baobab tree in the future (especially in West Africa), and in some of them, baobab presence could not be confirmed. Surveys are needed in these Protected Areas.

Moreover, it seems that current levels of protection within a Protected Area might not be enough for the baobab tree. Elephants have been reported to damage and even kill baobab trees (both adults and seedlings) in Protected Areas (Barnes, Barnes & Kapela, 1994; Edkins *et al.*, 2007). Another issue is that human pressure (fruit, bark and leaf harvesting) on baobab trees in some Protected Areas remains considerable, e.g. Burkina Faso (Schumann *et al.*, 2010). On the other hand, results from a study on population structure carried out in Burkina Faso showed that recruitment is higher inside the Protected Area than outside, despite human utilization and elephant presence in the Park (Schumann *et al.*, 2010). Although this might not be the case for all Protected Areas, it shows that Protected Areas do offer some degree of protection to this species.

High priority should be given towards more effective protection of the baobab tree, especially in the Protected Areas predicted to remain climatically suitable under all GCM and scenarios. Although baobab tree protection from elephants is difficult (Barnes, Barnes & Kapela, 1994), baobab seedlings could be protected from other herbivores (e.g. through fencing) and/or baobab seedlings could be planted. In areas where baobab is widely used by local communities living around the Protected Area, baobab utilization could be limited to fruit harvesting.

Other conservation strategies

Another potential conservation strategy, especially for areas at high risk of habitat loss (e.g. Sudan), might be *ex situ* conservation in germplasm collections or orchards. The predicted extinction in Sudan already seems to be happening: Wickens (1982) stated that many baobabs in the drier parts of Sudan died during and following the Great Drought of the late 1960s. Baobab populations in Sudan (which are isolated from both West Africa baobabs and East Africa baobabs and are at the most northern limit of the East Africa range) might be an interesting genetic pool for future baobab domestication. Hampe & Petit (2005) pointed out at the importance for conservation of the populations at the rear edge of shifting ranges. Considering that baobab seeds have been reported to remain viable for years (Sacande *et al.*, 2006), seeds from Sudanese populations could be collected and preserved in Seed Banks.

Monitoring of the existing baobab populations is the recommended strategy for countries predicted no longer to have suitable habitat for the baobab tree in the future under some GCM and scenarios (e.g. Namibia, Botswana, Ivory Coast). If existing populations are found to be continuously declining, *ex situ* conservation in germplasm collections might be the most feasible solution.

Another *in situ* conservation strategy that might be considered is the possibility of introducing a forestry law to limit access rights to baobab trees. However, results from northern Benin showed that this strategy was not as successful as was expected (Buchmann *et al.*, 2010). Farmers in northern Benin reported that they now remove baobab seedlings from their fields because they would need to buy permits for their use in the future. Moreover, if restricted access is introduced, today's 300 different baobab uses may no longer be employed (Buchmann *et al.*, 2010). Translocation, another conservation strategy often considered, does not seem to be cost-effective for the baobab tree (mechanical diggers and even helicopters might be needed, see Wickens & Lowe, 2008).

To help maintain viable baobab populations, especially in areas predicted to remain suitable in the future, 'conservation through utilization' could be a more effective strategy. If people use the baobab tree, and appreciate it, they are more likely to be interested in preserving it. Training workshops on sustainable fruit, leaf and bark harvesting could be organized as suggested by Buchmann *et al.* (2010). In Namibia, similar training has successfully guided local harvesters towards sustainable harvest methods of the Devil's Claw, *Harpagophytum procumbens* (Nemarundwe, Ngorima & Welford, 2008). Training could also include seedling identification and protection and management of sick trees. Giving value to the baobab tree and promoting its conservation could also help preserve the ecosystem where the baobab tree lives and the plant and animals that feed, shelter or live in it.

Conclusion

Only a small part of the current range of the baobab tree will retain suitable environmental conditions for viable baobab populations in the future. Therefore, conservation action is urgently needed. Several conservation strategies could be used to preserve the baobab tree and, therefore, maintain not only the diet, pharmaceutical and income resources of many local people in Africa, but also the ecosystem where the baobab tree lives. One option is *in situ* conservation in Protected Areas predicted to have suitable habitat in the future. Another option, especially for countries where baobab is predicted to become extinct, is *ex situ* conservation in Seed Banks. 'Conservation through utilization' could also be a successful conservation strategy for the baobab tree.

Acknowledgements

We thank all baobab tree locality data providers, particularly the PhD students De Smedt S., Larsen A.S. and Schumann K. We express our gratitude to the support given by A. Overgaard, M. Greve and G.E. Wickens. This research was supported by DADOBAT (Domestication and Development of Baobab and Tamarind) – EU funded project (Project No. 032217).

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(*Manuscript accepted 30 December 2010*)

doi: 10.1111/j.1365-2028.2011.01257.x