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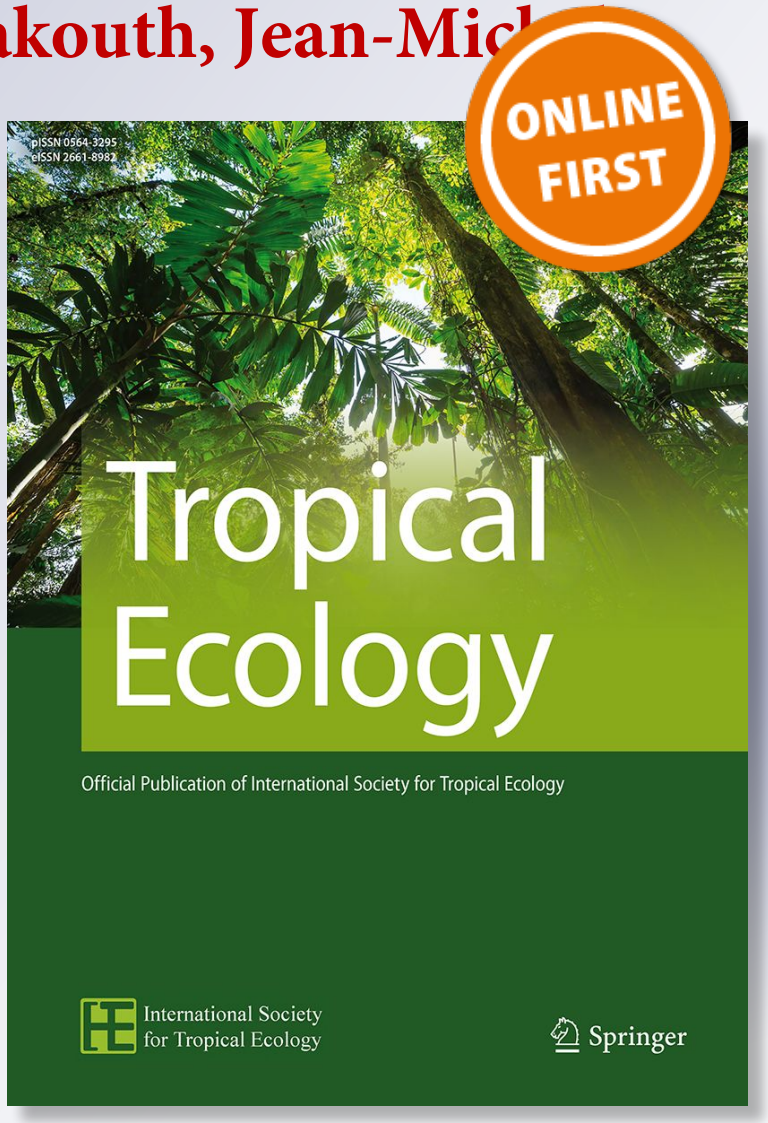

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REVIEW ARTICLE

The baobabs of the Comoro Islands: some biogeographical factors towards the protection and conservation of a neglected asset

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Abstract

This study aims to provide some information about the area of presence and geographical breakdown of baobabs belonging to the *Adansonia digitata* species on the four Comoro Islands. Two of the eight known species of baobabs in the world are present in the Comoro Islands. Whilst they have asset value, a thorough study of their geographical distribution has yet to be produced and there is very little existing action to protect and conserve the asset. An inventory of the *A. digitata* populations on the islands (Grande Comore, Mohéli, Anjouan and Mayotte) and islets of the archipelago was carried out. From this, it was possible to map the geographical breakdown and analyse the spacial distribution of the baobabs. Their distribution seems to be strongly associated to their proximity to the coastline, suggesting the seeds are dispersed by marine hydrochory. The ecological status of this species based on IUCN status assessment, is known from the threats and pressures incurred and its distribution according to their ecological preferences. The species is categorized as Endangered (ER). The data from this study should contribute to improved management and conservation of the *Adansonia* species in the Comoros, a growing requirement in the light of concerns about anthropogenic pressure.

Keywords *Adansonia digitata* · Baobab · Comoros' archipelago · Conservation · Dispersal · Flora · Hydrochory

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Introduction

There are eight species of baobab (*Adansonia* genus) in the world (Fig. 1). *Adansonia digitata* L. is the most common and certainly the most widely studied species (see synthesis by Wickens and Lowe 2008). It is present in its natural state in the Sahelian strip from Senegal to Somalia, in East Africa and Australasia, the Comoro Islands and the north-west of Madagascar (Baum 1995; Wickens 2008; Leong Pock Tsy et al. 2009). A recent study (Leong Pock Tsy et al. 2009) showed that the species originated in West Africa and took a migratory route from the west of the African continent to the east and then to the south and on to Madagascar. A new, possible ninth, species, distinct from *A. digitata* by its degree of ploidy, is thought to have been discovered in East Africa (Douie et al. 2015; Pettigrew et al. 2012) and is named *Adansonia kilima*.

However, a new study (Cron et al. 2016) seems to invalidate this discovery, suggesting that *Adansonia kilima* is synonymous with *A. digitata*, causing a controversy which nonetheless, a priori, does not concern the populations of *A. digit*ata in the Comoro Islands and Madagascar.

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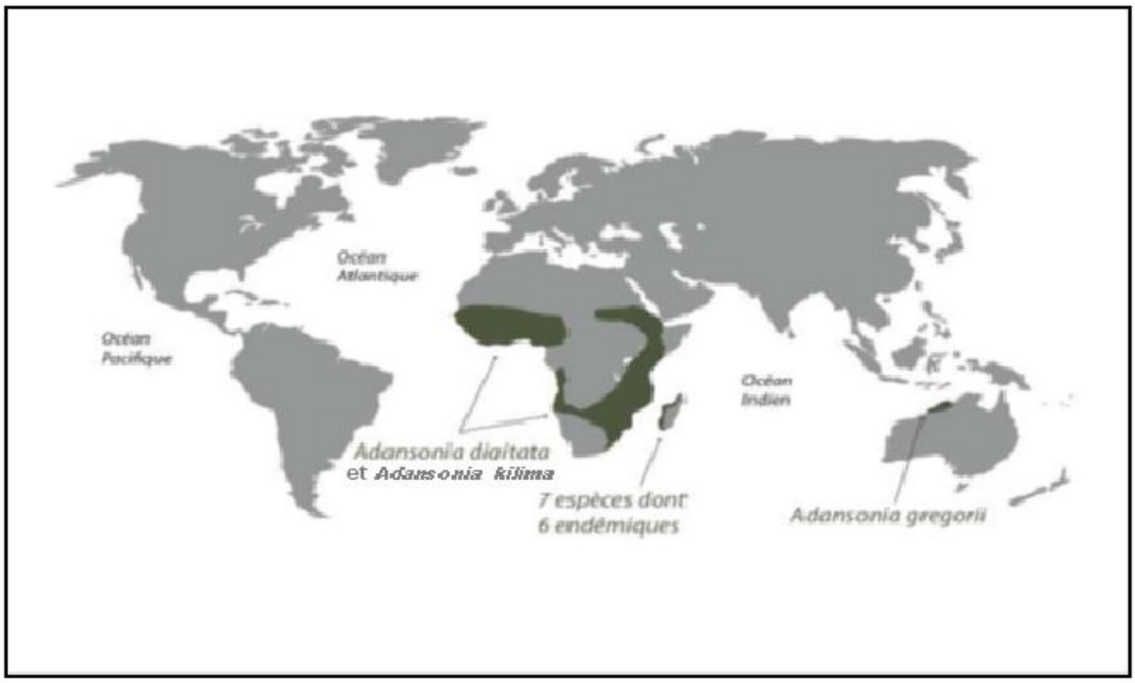


Fig. 1 Distribution species of baobab (*Adansonia* genus) in the world (Wickens 2008)

A. digitata is not currently considered as an endangered species within its entire area of presence and does not feature on the IUCN red list [IUCN (International Union For The Conservation of Nature) 2015, 2019]. As far as the Union of Comoros is concerned (Map 1), whilst there are many baobabs in the Mohéli marine park (the country's largest protected space), *Adansonia digitata* does not feature on the list of protected species published in decree n° 01/031/MPE/CAB of 14 May 2001 relating to the protection of the Comoros' wild fauna and flora (Louette 2004). In Mayotte (Map 1), *A. digitata* does not feature either on the list of protected species, whereas the species *Adansonia madagascariensis*, of which there are a few rare subjects, features (Barthelat et al. 2006; IUCN Comite Français 2013). The natural marine park, created in 2010 ensures the lagoon's protection but its area is limited by the upper foreshore (limit of the publicly-owned seafront). Elements of the land flora, in particular baobabs, are not included. The few specimens on the isle of Mbouzi are protected since the island's 82 hectares of land was designated a natural reserve in 2007. Whilst the baobab is emblematic of the flora of Comoro and Mayotte, it currently receives very little, if any, protection and is threatened by certain human activities, particularly urbanisation (Fig. 2).

This lack of conservation status can be directly related to a gap in the knowledge. The present study aims to fill this gap by providing information on the area of presence and geographic breakdown of baobabs of the *Adansonia digitata* species on the four Comoros Islands. This knowledge should make it easier to define the modes of management and the conservation of baobab population and help to define the zones of ring-fencing taking account of determinants associated with the biology of baobabs, the constraints of dispersal in a context of insularity but also demographic dynamics and urban expansion.

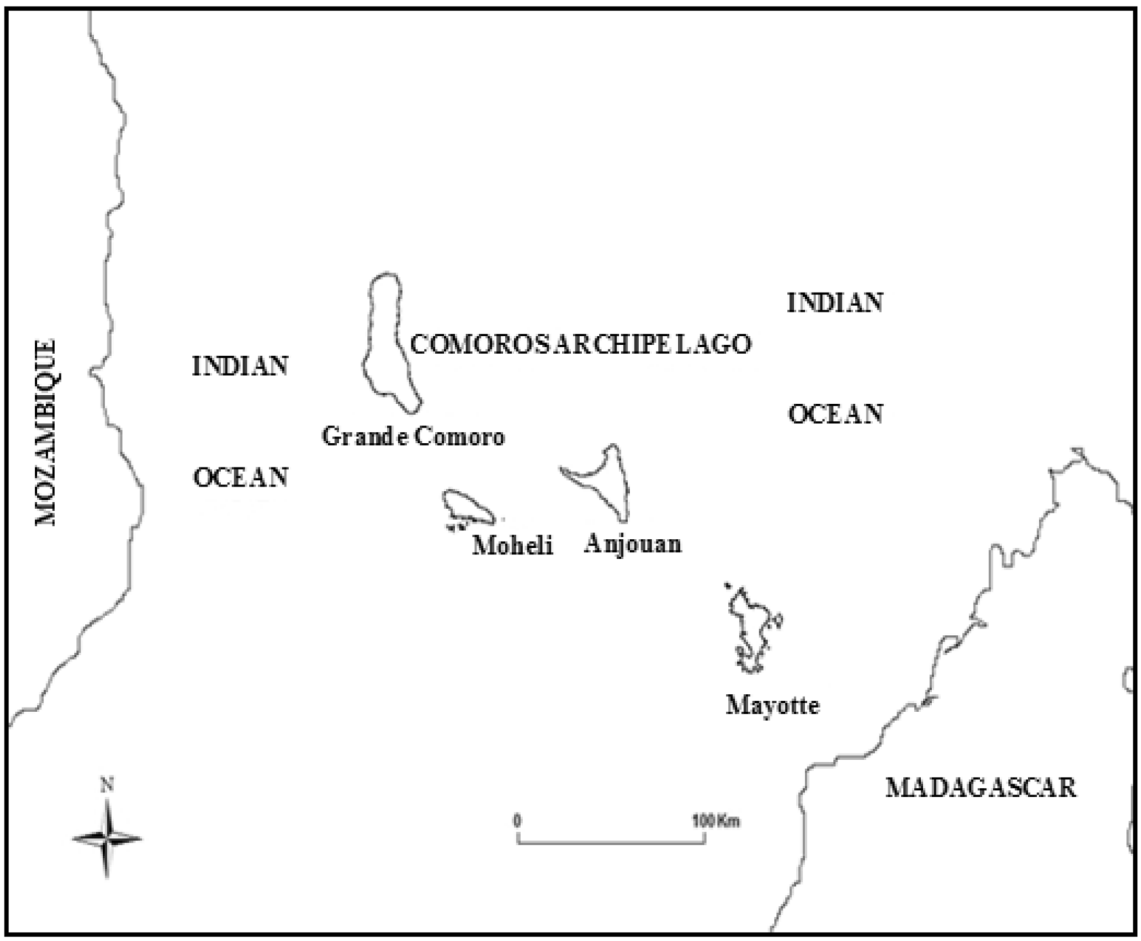
Our approach is based on an inventory of the baobab populations, which is as precise as is possible to enable reference maps of presence and to relate the distribution observed to explanatory factors such as ecological (biology of baobabs and modes of dispersal), geographical (topographical, in particular) and human (demographic and dynamics of urbanisation) factors.

Materials and methods

Inventory methods and measured variables

This study is based on a series of land inventories of baobabs in the Comoro islands that were as exhaustive as possible. A set of data was collated for each including the following:

- geographic coordinates and altitude were measured using GPS;
- diameter at breast height (DBH), taken from measurements of the circumference with a tape measure;
- height of bole (Hf) and total height (Ht) of tree, measured with a clinometer;



Map 1 Location of the Comoro Islands in the Indian Ocean

Fig. 2 Baobab felled to make way for construction of a house at Fomboni

– the shape of each tree was noted and in particular the single-stemmed or multi-stemmed organisation of the bole.

It should be noted that in these inventories, the number of young baobabs (individuals of small calibre with a DHP and/or Hf ≤ 1 m) is very likely underestimated as these individuals are difficult to locate and identify in the context of rugged, overgrown terrain.

Where Mayotte and the surrounding isles were concerned, the inventories were carried out between February and April 2010, and resulted in the localisation of 2007 baobabs on Mayotte (Fadul 2010). This study was based on two prior inventories, which it complemented. The first was carried out in 2006 by the Environmental and Forestry service of Mayotte's Agricultural and Forestry Department (DAF), who collated an inventory and mapped out 776 baobabs in the south east of the island and 31 on the beach at N'Gouja. The second was carried out by the national botanical conservatory of Mascarin (CBNM) on Mayotte, who formulated a distribution map of 699 baobabs.

Concerning the islands of the Union of the Comoros, (Grande Comore, Anjouan and Mohéli), the inventories

were carried out between January 2009 and July 2010 and continuously updated until 2016. They relied on preliminary localisation of the baobabs by photo-interpretation of very high spatial resolution satellite imagery based on and adapted from the method described by Vieilledent et al. (2013) using Quickbird images with a 61 cm spatial resolution.

Analysis of the baobabs spatial organisations

In order to gain a clearer understanding of the geographical breakdown of the baobabs on the four islands and reveal the patterns of spatial organisation, several close relationships were studied using the buffer zone method (Minvieille and Sid-Ahmed 2003).

To calculate the distances of baobabs from the coast, three types of buffer zone were generated:

- a first series covering the first 3000 metres by 1000 m increments;
- a second series of 100 m strips within the first 1000 metres;
- a final covering 10 m intervals within the 100 m strips.

The coastline was defined by the upper limit of the foreshore. The surface area of the buffer zones and the density of baobabs within each buffer zone were calculated for each island. They are expressed as number of individuals km^{-2}.

Similarly, the density of baobabs per altitude band was calculated. The altitude categories retained range from 0 to 200 m in 25 m intervals, without any baobabs present at an altitude exceeding 200 m. In order to illustrate our data better, we used the SRTM digital elevation model ASTER GDEM (GDEM 2), published by NASA and METI in October 2011 who has global precision in the order of 17 metres, a confidence level of 95% and horizontal resolution of around 75 m.

The distribution of baobabs by their DBH was also studied in order to gain an idea on the state of their natural regeneration. The relationship between density of baobab population and that of human population (urbanisation) was established for each administrative district. For Grande Comore, Anjouan and Mohéli, figures from the last population census, carried out from local surveys in 2003 and extrapolated at 2012, were used. For Mayotte, the data from the general census of 2012 was referred to.

Assessment of the threat to *A. digitata* currently, no threat is reported globally by IUCN for *A. digitata*, unlike all other species of the genus, especially Malagasy species (IUCN 2019). Concerning the populations of the Comoros archipelago, the level of threat was estimated according to the IUCN criteria and categories described in the two guides:

- Categories and Criteria of the IUCN Red List: Version 3.1 (2012), (www.uicn.fr/La-Red-Red-of-Species.html).
- Guidelines for the Application of the IUCN Red List Criteria at Regional and National Levels: Version 4.0 (2012) (www.uicn.fr/La-Red-Red-Species.html).

Results

Widely differing population densities from one island to another

A total of more than 3200 baobabs were identified within the entire Comoros archipelago. The average density was 1.8 baobabs km^{-2} (Table 1), however major disparities exist between the islands. Mayotte has the greatest number of baobabs with a total of 2007 individuals. It is also the most densely populated island with 5.35 baobabs km^{-2}. Anjouan has the least baobabs with only 146 baobabs and a low density of 0.34 baobabs km^{-2}. Beyond the four main islands, some of the isles in the archipelago are home to baobabs. In Mayotte, 8 baobabs were identified on Petite Terre, 34 on the isle of M'Bouzi, 7 on M'Tsamboro, 6 on Bandrélé, 3 on Bambao and a single individual on the isle of Handrema. The isle of Wénéfu, off the coast of Mohéli, has 32 baobabs.

Location of baobab populations

Figure 3a, b, c and d show that the baobab populations on each island are mainly spread along the coast. However, this distribution is not homogeneous between the islands (Table 1) but also within the islands: strong densities can be found at the extreme south east of the four islands, as well as the north west of the islands of Grande Comore and Mohéli. In detail, on Grande Comore, two

Table 1 Numbers of baobabs (*A. digitata*) in the islands and isles making up the Comoro Islands and density (expressed in numbers of individuals relative to the surface area of each island)

Islands and isles	Numbers of baobabs	Density of baobabs km^{-2}	Density of baobabs km^{-1} of the coastline
Grande Comore	721	0,70	3,81
Anjouan	146	0,34	0,97
Mohéli and Isle Wénéfu	326 32	0,84	2,61
Mayotte, Petite Terre Isle M'Bouzi Isle M'Tsamboro Isle Bandrélé Isle Bambao Isle Handrema	1941 8 34 7 6 3 1	5,35	10,59
Total	**3225**	**1,58**	**4,85**

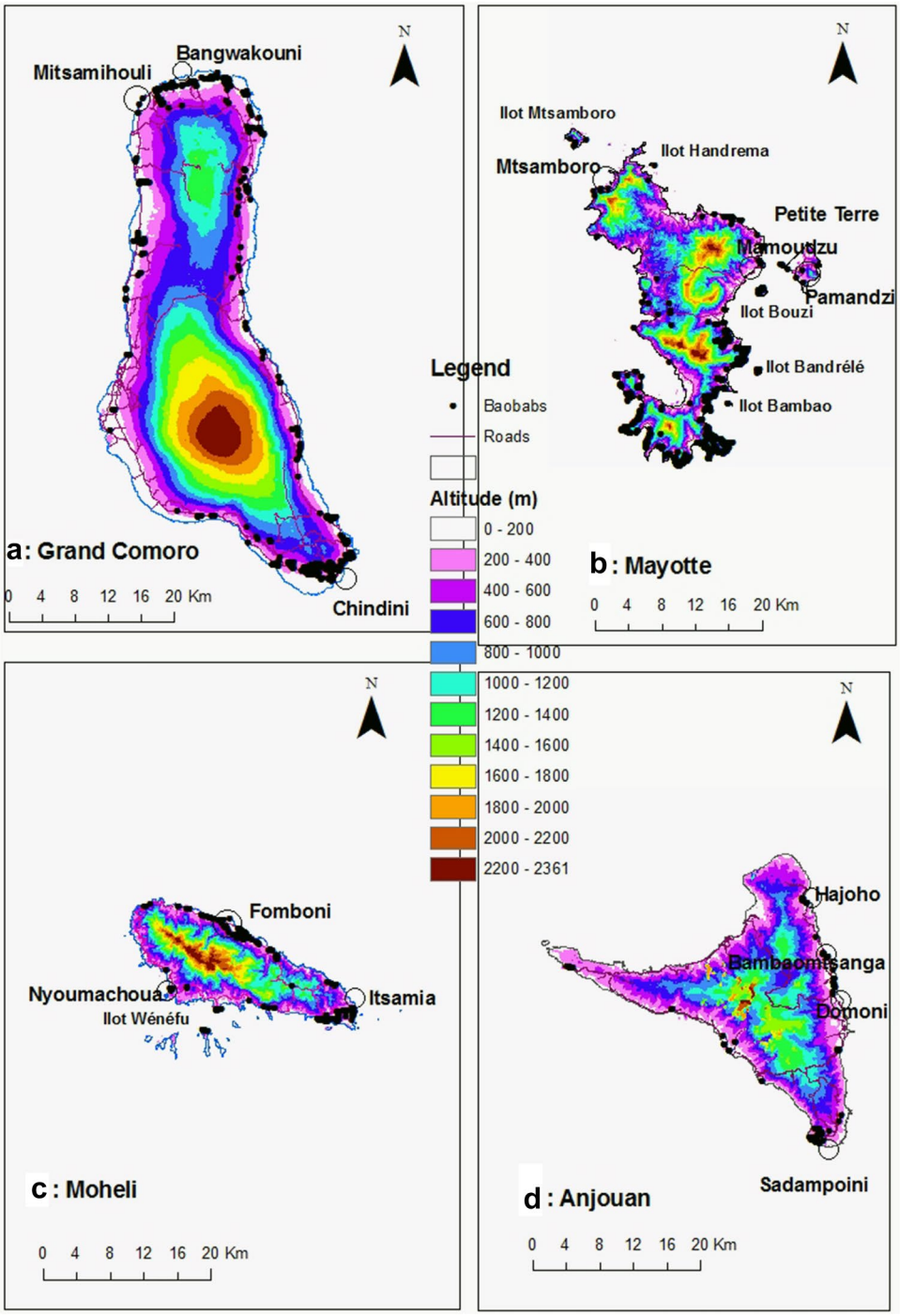
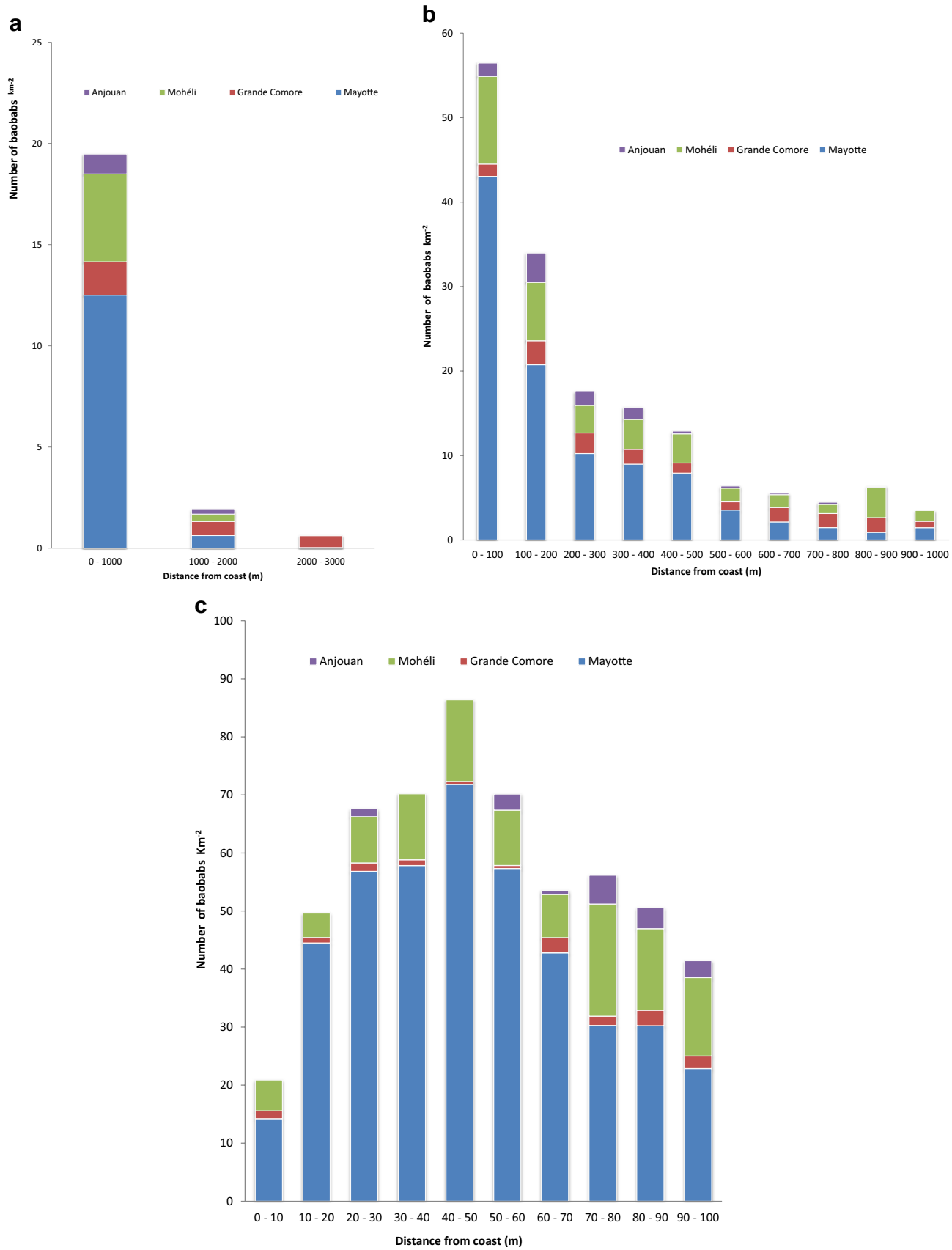


Fig. 3 Location of baobabs (*A. digitata*) on the islands (**a** Grande Comore, **b** Mayotte, **c** Mohéli, and **d** Anjouan) and the isles making up the Comoro Islands in relation to the altitude gradient (expressed by 200 m intervals). Baobabs are represented by black dots

major populations can be distinguished, the greatest is localised in the extreme south-east, close to the town of Chindini, the other is in the north between the towns of Mitsamihouli and Bangwakou. In Mayotte, the greatest concentration is in the south and south-east of the island. The north-west part of the island is sparsely populated. There are two distinct large populations at Mohéli, one on the north coast scattered around the town of Fomboni, the other is more closely assembled, in the south-east around the village of Itsamia. Finally at Anjouan, the largest population is located in the extreme south around the village of Sadampoini. A second more scattered population can be found stretching the length of the coast near the towns of Bambao-mtsanga and Domoni. There are very few baobabs to be found on the rest of the island.



◂**Fig. 4** Density of baobabs (*A. digitata*) on the islands and isles making up the Comoro Islands according to the distance from the sea (expressed in relation to the coastline). **a** Between 0 and 3000 m, with 1000 m intervals; **b** between 0 and 1000 m, with 100 m intervals; **c** between 0 and 100 m, with 10 m intervals

Geographical distribution of the baobabs

All the baobabs are located within 3 km of the coastline and 88% less than a kilometre from the shore (Fig. 4a). Grande Comore is the only island which has baobabs (low density, however) more than 2 km from the coast. On the other four islands, the density of baobabs within the first 1000 metres from the coastline diminishes rapidly further and further inland from the sea. The density is greatest in Mayotte in the 100 m buffer zone with 45 baobabs km^{-2} (Fig. 4b). At the shore, it is common for the trees to have their feet submerged, notably at Nyoumachoua on Mohéli, at Sadampoini on Anjouan, in the south of Mayotte, as well as Hantsindzi on Grande Comore (Figs. 5, 6, 7 and 8). However, a careful analysis (Fig. 4c) shows that the most abundant cohorts are located a few dozen metres from the shoreline (between 20 and 80 m). At less than 30 metres from the sea densities are weaker, and dwindle considerably at 10 metres. They decline likewise after beyond 80 m.

Our observations also show that the largest and often multi-stemmed individuals are present in the the zones closest to the coast (Figs. 5, 6, 7 and 8). This distribution implies that the baobabs are mainly present in low altitude locations: 72% are present in the contours under 50 m and only 27% grow at an altitude over 100 m (Fig. 9).

Allometric distribution of baobabs

Figure 10 shows that breakdown of baobabs according to their DBH reveals a distribution with a maximum for the categories of diameter from 0.5 and 2.5 m. Beyond that, the distribution curve declines gradually (curve "L" or "inverted J" curve). This indicates a dynamic of baobab populations with good natural regeneration (Puig 2001; Bationo et al. 2010; Kebenzikato et al. 2014). For the category of small trees (diametric less than 1 m), Fig. 4 shows a deficit of individuals, as previously indicated by Kebenzikato et al. (2014) relating to the *A. digitata* population in Togo. This deficit could be due to a bias in our sampling (difficulty singling out the youngest individuals) but also, very likely, a real absence of regeneration for which there could be several biological and ecological causes as shown by Venter and Witkowski (2013).

Threats and pressures on *Adansonia digitata* L.

Field observations have shown that, in the archipelago, threats to baobabs and their habitats are of two types: anthropogenic threats (related to baobab uses, destruction of habitats and urbanization) and natural disasters (related to Karthala volcano and cyclones).

Anthropic threats are sometimes linked to the different uses of baobabs, which can be food and fodder, medicinal and aesthetic, artisanal, sociopolitical and legendary (Table 2). The baobab trunk serves as a water reservoir or a "baobab tank" (Fig. 11), especially in the very arid regions of Grande Comore. The interior of the trunk is dug with an adze and then ignites the inside of the cavity with coconut leaves to harden and sterilize the inner wall. This gives a tank with a capacity of 500 to 800 L in which the rainwater can be collected (Fig. 11). Baobabs can also be ecotrocated to provide fiber for ropes (Fig. 12). These practices have been observed on the outskirts of the dry forest of Hamada Ali Rock (Mohéli) and north of Grande Comore. They are spectacular but do not seem to have any harmful consequences on baobab survival.

Natural hazards such as cyclones or storms or coastal erosion (causing a retreat of the coastline in Mayotte and the subsidence of this island) can uproot individuals from baobabs, especially those along the coast, on beaches. Baobab falls have been observed on Nyoumachoua (Mohéli) beach near the sea (Fig. 13). Some baobabs were victims of the lava flows in the Hahaya region and Singani during the last Karthala eruptions at Grande Comore.

But the important threat is linked to the human destruction of baobab habitats. In all the islands, the dry forest, which is the habitat of the baobab, remains in tattered condition, reduced to make way for systems of burning agriculture or expanding areas urban.

The maps in Fig. 14a, b, c, d show the relationship between the densities of baobab populations and those of human settlements. It appears generally that the major baobab populations are located in the least urbanised zones of each island. This is borne out particularly in the districts of Itsahidi in the south of Grande Comore, Bandrelé in the south of Mayotte, Djando in the south of Mohéli and Chaweni in the south of Anjouan. Conversely, the densely urbanised districts have few baobabs except for a few rare exceptions in the districts of Mitsamiouli and Cembenoi Lac Salé in the north of Grande Comore where there are many baobabs in a highly dense urban area. The observations and information gathered on the ground show that baobabs in urban areas are often subject to felling, either for objective reasons (competing for space, risk of uprooted trees falling on homes) (Fig. 2), or for cultural reasons (related to popular beliefs that baobabs are hosts to evil spirits). Baobabs are used as landfills (Fig. 15) in some places. A large number

Fig. 5 Baobabs with feet in water at high tide on the beach at Nyouachoua on Mohéli

Fig. 6 Baobabs with feet in water at high tide on the beach at Sadampoini on Anjouan

of baobabs can be observed along main roads on the four islands (Fig. 16). In total there are around 300 baobabs lining the main roads on the whole archipelago.

Fig. 7 Multi-stemmed baobabs (trees with several offshoots at the base of the trunk, each giving branches) on the coast at Mayotte

Fig. 8 Multi-stemmed baobabs (trees with several offshoots at the base of the trunk, each giving branches) on the coast at Mtsamboro on Mayotte

Discussion

An issue central to the debate amongst biogeographers concerning the origin of fauna and flora in the islands of the Indian Ocean is the fact that many Malagasy, Comoro and Mascarene taxa share characteristics with taxa in Africa, India and even Australia (Buerki et al. 2013; Crowther et al. 2016; Leroy 1978; Pascal et al. 2001; Schatz 1996; Warren et al. 2009; Yoder and Nowak 2006).

The first clue to explain this taxonomic similarity is the vicariance associated with the dislocation of Gondwana, some 160 millions years ago, which began by the separation of the Indo-Madagascan block from East Africa (Schatz 1996; Briggs 2003). However, this hypothesis does not take account of the fact that for many taxa, the divergence

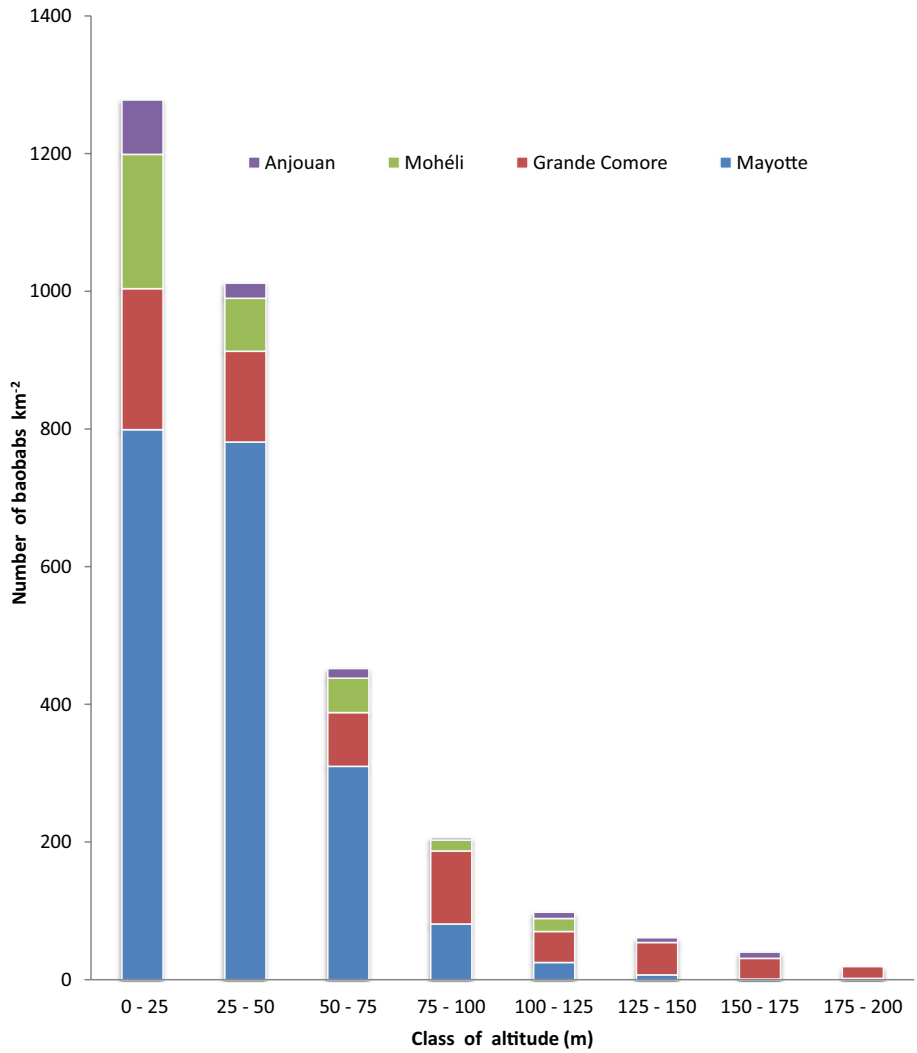


Fig. 9 Density of baobabs (*A. digitata*) on the islands and isles making up the Comoro Islands according to altitude

between the species present in the different regions of the Indian Ocean is for the main part subsequent and could date from the Cenozoic era (De Queiroz 2005; Warren et al. 2009; Yoder and Nowak 2006). The dispersal would then have occurred well after the separation of Madagascar from India and Africa.

It could well have an oceanic origin. Schatz (1996) and Warren et al. (2009) show that these exchanges might have been facilitated by variations in the level of the Indian Ocean which at certain times revealed major islands presently submerged, islands which could have provided a relay between Madagascar and Asia. Schatz (1996), Yoder and Nowak (2006) give greater weight to oceanic dispersal, taking up Simpson's (Simpson 1940, 1952) rafting theory which explains that many animal, as well as plant, species were able to migrate between continents by hitching a ride on fortuitous rafts and with random probability, even if Battistini (1996) and Stankiewicz et al. (2006) showed that this possibility is more probable, now, in the Madagascar/Africa direction.

The current distribution of species of the *Adansonia* genera (a species widely dispersed in Africa, six endemic to Madagascar and one in Australia) raises questions amongst biogeographers (Baum 1995; Baum et al. 1998; Leong Pock Tsy et al. 2009, 2013). Some authors give Gondwanan vicariance as an explanation (Maheshwari 1971; Aubreville 1975; Armstrong 1977). However, this hypothesis has been rejected by Baum et al. (1998) and Baum (2003), who showed by studying a variety of molecular clocks, that the radiation of the genera was much more recent, even for *A. gregorii,* a species currently isolated in Australia, which is thought to date from at the most 17 million years ago, maybe even only seven. The most likely hypothesis is then that of transoceanic dispersal or that of a dispersal by relay of a species now disappeared from the north part of the Indian Ocean (Baum et al. 1998; Baum 2003). It is worth adding that recent human migrations have certainly been involved in the dispersal of *A. digitata* in the Indian Ocean (Aubréville 1950; Miege 1974; Rangan and Bell 2015; Rangan et al. 2015).

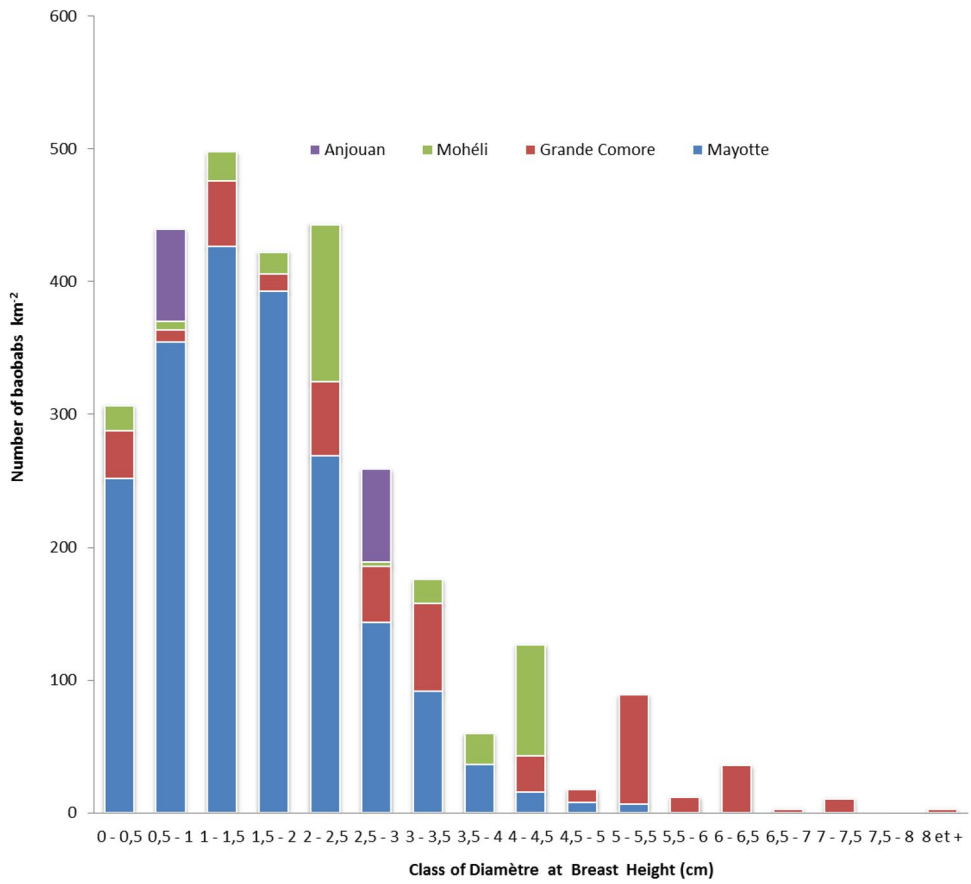


Fig. 10 Density of baobabs (*A. digitata*) on the islands and isles making up the Comoro Islands according to categories of DHB

Table 2 Types of use and part used of *Adansonia digitata*

Types of use	Part used	Use
Food and feed	Leaves and seeds	Food and staple
Medicinal and aesthetic	Leaves, seeds and bark	Against fever, cough and body fatigue
Artisanal, sociopolitical, legendary and others (corderie),…	Whole plant	Art, symbol of strength or vigor and grandeur,…

Fig. 11 Baobab tanker at Domni-lambwani (Grande Comore)

The colonisation of the Comoro islands by *A. digitata* is situated on a more contemporary time-scale as the archipelago's formation began less than 15 million years ago for Mayotte and less than 5 million for the other isles (Battistini 1996; Nougier et al. 1986). Our results show that the baobabs' distribution is limited to a very narrow strip of the coast. Many baobabs are located at the upper limit of the tidal zone almost on the beach, sometimes even on the foreshore. This pattern of spatial distribution strongly bears out the notion of natural introduction from the sea. In the knowledge that the oldest baobabs have been estimated to be more than a thousand years old, and as much as fourteen centuries (Swart 1963: Von Breitenbach 1985; Patrut et al. 2015), it can be estimated that this colonisation took place within the historical period, and does not foresee any in prior periods. This possibility is backed up, on the one hand, by the studies by Baum (1995) and Cornu et al. (2014), who

Fig. 12 Baobab peeled in Hahaya (Grande Comore)

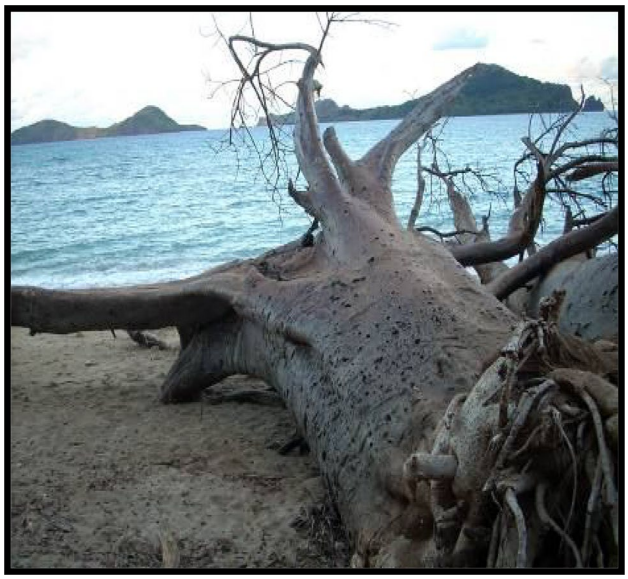


Fig. 13 Baobab uprooted because of erosion in Nyoumachoua (Mohéli)

show (regarding *A. madagascariensis*) that baobab fruits are good floaters and can be dispersed by sea and, on the other hand, by the results of Danthu et al. (1995) and Razanameharizaka et al. (2006), who showed that baobab seeds have a hard, impermeable integument, which affords them a very long latent life capacity before being able to germinate once conditions permit.

This hypothesis does not enable the departure point of fruits (coasts of East Africa or Madagascar) to be determined. The diversity and trajectories of surface sea currents in the Mozambique channel opens up to the possibility of transfer from either the African or Malagasy coasts towards the Comoro (Sætre and da Silva 1984; Donguy and Piton 1991; Battistini 1996), even though the present general disposition of the currents is more favourable to transporting baobabs from Madagascar (Battistini 1996). What is more, this could explain the presence in the tidal zone of Mayotte of a few individuals of *A. madagascariensis*, a species endemic to Madagascar (Charpentier 2006; Cornu et al. 2014).

It is important to note, however, that recent studies by Leong Pock Tsy et al. (2009), which analysed the polymorphism of the length of restriction fragments of chloroplast DNA, revealed that *A. digitata* is a species originating in West Africa, and which has colonised Africa as far as Somalia following a west/east trajectory, then north/south towards southern Africa. Madagascar was colonised from the coastline of Africa. In this context, the pattern by which the Comoro islands were colonised by *A. digitata* deserves to be studied intricately using the tools of molecular biology: questioning whether colonisation occurred by African or "on the way back" from Madagascar? This remains an open question.

Another factor supporting this possibility is the presence of giant trees, most of which are multi-stemmed, by the coast which could be attributable to the washing up onto the beaches of pods containing several viable seeds capable of germinating simultaneously (Chevalier 1906), thus, giving a cluster of individuals able to anastomose and give trees with multiple trunks. This hypothesis has been validated by Patrut et al. (2007, 2015), who showed that the trunks of baobabs can derive from a fusion of a number of neighbouring stems. However, in order to substantiate this hypothesis, it still remains to be seen whether the different stems are those of half-brother individuals.

It is equally important to consider how well this hypothesis of colonisation by marine hydrochory weighs up against the possibility of propagation of *A. digitata* by human intervention during historical times. It is possible that sailors, in particular from Arabia, might have carried on board baobab fruits, reputed for their nutritional qualities (De Caluwe et al. 2010), as food for their journey, and through depositing them at their landing sites may have been responsible for their propagation and subsequent colonisation. This hypothesis, supported by Jumelle and Perrier De La Bathie (1910), Perrier De La Bathie and Hochreutiner (1955) and Miege (1974) has been widely substantiated regarding those individuals of *A. digitata* present in India and the Indian Ocean (Maheshwari 1971; Rangan et al. 2015). However, this means of dispersal by man generally results in a different distribution pattern to that found in the Comoro Islands, a more isolated, more concentrated and less exclusively coastal one.

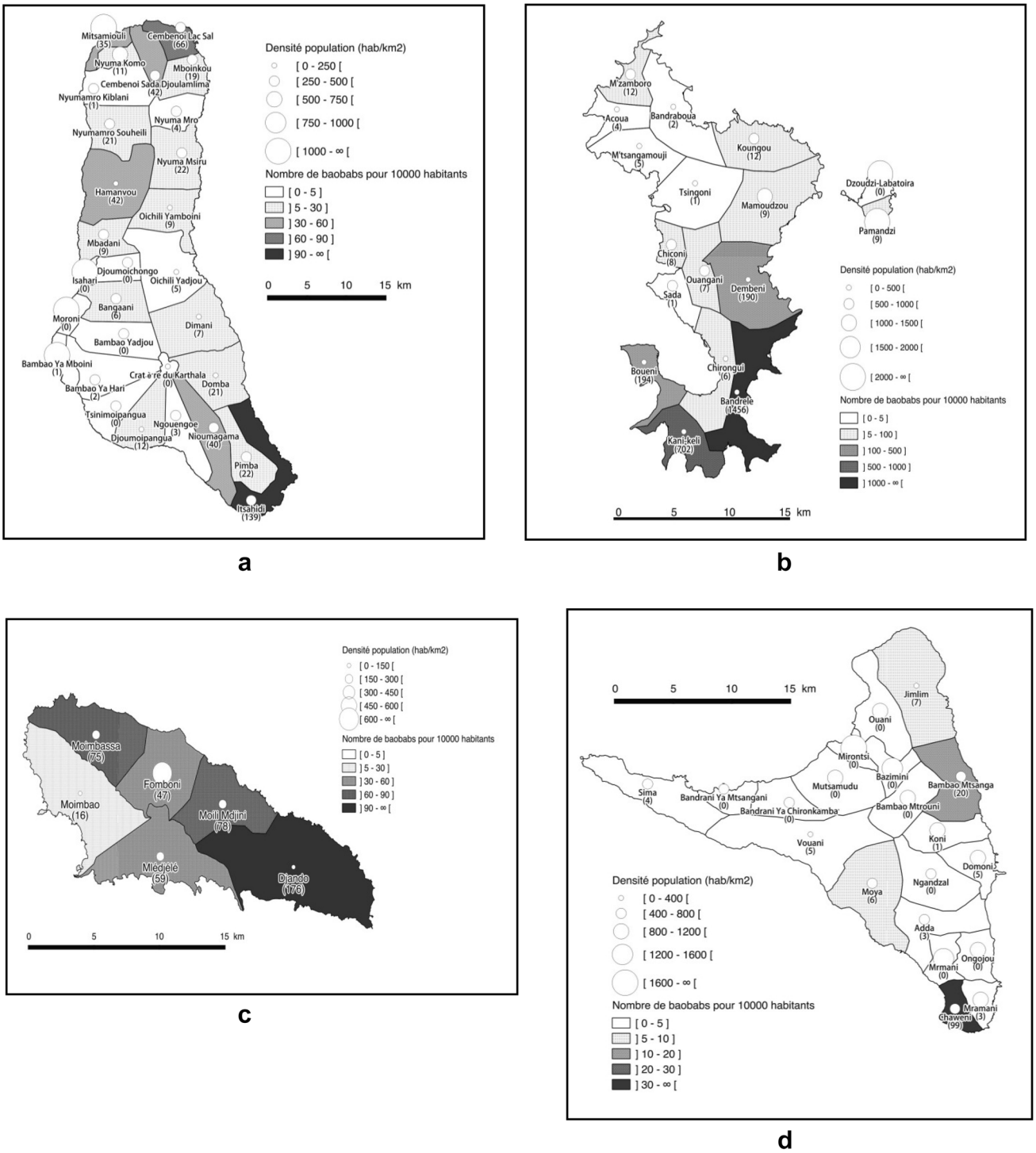


Fig. 14 Density of baobabs (*A. digitata*) on the islands (**a** Grande Comore, **b** Mayotte, **c** Mohéli, and **d** Anjouan) and the isles making up the Comoro Islands in relation to the population density (expressed for each district)

Dispersal inland originating from the coastal trees is probably realised by zoochory through animal dispersers (rats and domestic animals) as suggested by Chevalier (1906) and Wickens and Lowe (2008), and as shown by Andriantsaralaza (2010) and Andriantsaralaza et al. (2015) concerning *A. rubrostipa* and *A. grandidieri,* but also by man, as has been shown by Duvall (2007) and Dhillion and Gustad (2004) for *A. digitata* in Mali and Rangan et al. (2015) in the Indian Ocean. This dispersal

Fig. 15 Baobab stand used as a waste disposal site on Mayotte

Fig. 16 Baobab along the Singani Road (Grande Comore)

occurs seed by seed and results in individuals from a single embryo, which are, therefore, single stemmed.

The question that hangs in the balance is whether this colonisation is entirely complete and if the baobabs are occupying the whole of their potential space, even if this is widely disputed by human activities, in particular urbanisation. Adansonia digitata is not currently recognized by IUCN (2019) as endangered. However, it appears, that in the Comoros archipelago, this biological heritage is under threat while few specific actions are undertaken for its protection. This article, therefore, aims to provide objective elements that can support conservation actions that could include:

- the development of baobab management and conservation plans, steps to register *Adansonia digitata* in the IUCN Red List of Threatened Species in the archipelago, and
- the delimitation or introduction of dry forests, in the strategy for the development of protected areas, the sensitization of national and local authorities and populations on the biological and ecological importance of baobabs and dry forests.

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