ARTICLE

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Bark harvesting: a potential threat for the Grandidier's baobab *Adansonia grandidieri* in western Madagascar

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ABSTRACT
The Grandidier's baobab conveys the image of Madagascar worldwide. Locally, these trees have multiple uses with all parts of the plant being exploited by the population. We investigated the patterns of bark harvesting on the Grandidier's baobab in three districts in the Menabe Region: Mahabo, Manja and Morondava. Following 103 transects of 1 km each, we found that 54.0% of the baobab trees had been subject to bark extraction. The mean total area exploited per tree was 3,1 ± 0.2m2. Between April 2013 and January 2014, we also monitored four markets that regularly sell baobab products: Bemanonga, Mahabo, Morondava and Analaiva. Bemanonga revealed to be the largest market for the baobab bark with 21,594 straps and 34,517m of ropes recorded during the observation period. We estimate that some 9800 Grandidier's baobab trees have been affected by debarking to supply the demands recorded over the ten months monitoring period. If this demand remains constant, all baobab trees in Menabe would be debarked within the next 39 years. Since most baobab trees have been located in hard-to-reach areas and in protected areas, bark extraction may intensify in accessible sites and populations without protected status may disappear locally. This would result in local extinction of the species within a short period. To ensure sustainable management of the Grandidier's baobab, we recommend enriching the population by planting young baobabs, regulating access to the resources through local management structures and promoting alternatives to baobab ropes.

RÉSUMÉ
Le baobab de Grandidier est une espèce emblématique de Madagascar. Il évoque la Grande Île dans le monde entier. Dans sa zone d'occurrence, c'est une espèce à usage multiple pour les riverains qui utilisent toutes les parties de ce baobab. La présente étude porte sur l'exploitation de l'écorce du baobab de Grandidier dans la région Menabe, plus particulièrement dans les districts de Mahabo, Manja et de Morondava. Pour estimer l'étendue de l'exploitation des écorces sur les pieds de baobabs, des observations ont été réalisées sur 103 transects de 1 km de long entre avril 2013 et janvier 2014. Pour évaluer l'importance des écorces de baobab pour les riverains, des observations ont été conduites au niveau de quatre marchés de la région dans les villes de Bemanonga, Mahabo, Morondava et Analaiva au cours de la même période. Au total, 21 594 lanières d'écorce et 34 517 m de corde de baobab ont été recensés dans les quatre marchés. La plus importante quantité d'écorce de baobabs commercialisée a été enregistrée à Bemanonga. À partir des données récoltées, il est estimé que près de 9800 pieds de baobabs à écorcer sont nécessaires pour couvrir les besoins des riverains pendant la seule période d'études de 10 mois. Si la demande devait se maintenir à ce niveau, tous les pieds de baobab de la région Menabe, dont la population avait été estimée à environ un million d'individus, seraient écorcés au cours des 39 prochaines années. Comme la plupart des pieds de baobab ont été localisés dans des zones difficiles d'accès et dans les aires protégées, l'extraction des écorces pourrait s'intensifier dans les sites accessibles et les populations qui ne bénéficient d'aucun statut de protection pourraient disparaître localement. Pour assurer la gestion durable du baobab de Grandidier, il est ainsi recommandé de renforcer la population existante par la plantation de jeunes plants, la régulation de l'accès aux ressources par des structures locales de gestion et la promotion d'alternatives aux cordes réalisées avec les écorces de baobab.

INTRODUCTION

Madagascar has a unique biodiversity that places the country among the world's conservation priorities (Myers et al. 2000, Brooks et al. 2002). Considering the vascular plants only, 11,220 species were recorded in Madagascar, of which 82% are endemic (Callmander et al. 2011). The eastern Malagasy rainforest is among the centres of species richness with more than 3000 species per 10,000 km^2 (Mutke et al. 2011). The western tropical dry forest has a lower species richness but is famous for the iconic baobabs, which have important functions for people and the ecosystem

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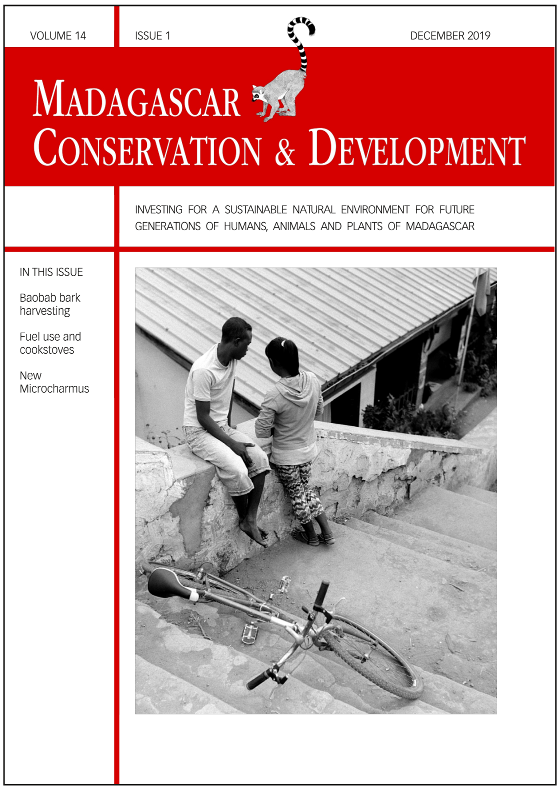

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and are facing multiple threats (Miles et al. 2006, Graf et al. 2009, Ehrensperger et al., 2013, Grinand et al. 2013, Zinner et al. 2013).

Eight species of baobabs are known worldwide, six of which are endemic to western Madagascar (Cron et al. 2016, Karimi et al. 2019). According to Cuni Sanchez (2010), the baobab tree has a multitude of use in Africa and Australia. Besides utilizing the fruit, bark and leaves, the size and shape of the tree lends itself to spaces for water storage, prisons, toilets, burial grounds, sleeping places, shelters, ritual sites and venues for prayers (Mukamuri and Kozanayi 1999, Wickens and Lowe 2008). Malagasy baobabs have multiple functions and uses. The Grandidier's baobab *Adansonia grandidieri* stands out because of its iconic image representing Madagascar on most documentaries and advertisements. The Allée des Baobabs in Morondava attracts many tourists and is a major source of income for the Region (Scales 2014).

Non-timber forest products (NTFPs) are important resources for people in western Madagascar. Bushmeat, medicinal plants, materials for construction, weaving and other handicrafts are collected from the wild (Garcia and Goodman 2003, Norscia and Borgognini-Tarli 2006, Randrianandrianina et al. 2010, Scales 2012). These resources are collected for household consumption, but also sold on markets as a source of income. NTFPs often provide economic buffers to the Malagasy rural populations when crops fail and can help provide additional seasonal income when the benefits of other economic activities are reduced (Neudert et al. 2017).

NTFPs significantly contribute to livelihood security in the Menabe Region and have traditionally been used by rural communities for subsistence and trade (Ramohavelo and Sorg 2008). Tubers from *Dioscorea maciba* and *Tacca pinnatifida*, *Tenrec ecaudatus* bushmeat (a mammal species), and honey are important NTFPs for local livelihoods (Ramohavelo and Sorg 2008). Grandidier's baobab *Adansonia grandidieri* trees also provide locally important NTFP products, mainly for consumption (fruits, seeds, leaves and bark as infusion) and construction (Baum 1996, Marie et al. 2009). The Grandidier's baobab is listed as Endangered on the IUCN Red List of Threatened Species; the major threat is poor regeneration (IUCN 2016). This species is the most heavily exploited of Madagascar's baobabs (Perrier de la Bâthie 1924, Bond 2002, Rakotondrazanany 2016, pers. comm.). The fruits and seeds are collected for food and extraction of cooking oil, the bark is used to make ropes, and the spongy wood is dried and sold for thatch. However, the greatest threat to Grandidier's baobab comes from the conversion of its habitat into agricultural land. Mature trees are left standing, presumably because of their cultural importance and the value of the fruit, bark and wood. The impacts of local exploitation of NFTPs from this species remains poorly understood, limiting our ability to define appropriate conservation measures, especially in areas of conservation importance from where sustainable extraction is permitted.

In this article, we focus on the activity of bark collection from the Grandidier's baobab. We aim to understand the importance of this activity to rural communities in the Menabe Region and the potential impacts of bark harvesting on the species population. This information helps designing targeted conservation strategies for the Grandidier's baobab.

METHODS

STUDY AREA. This study was carried out in the Menabe Region, in the western region of Madagascar, an area identified as priority for conservation (Kremen et al. 2008, Wilmé et al. 2012). We focused on five communes in the three districts, where the Grandidier's baobab is frequently observed in the wild and derivates found for sale at local markets (Figure 1).

BAOBAB SURVEYS. We used T-square sampling to estimate baobab density within seven different areas (Ankoba, Ampataka, Bepeha, Andoviana, Benato, Tanambao Sara and Bekonazy) between August 2009 and November 2011 (Krebs 1999, Greenwood and Robinson 2006). Following a random 1 km transect, the survey team stopped every 100 m—this is the observation point O, measured the distance xi from the observation point to the nearest Grandidier's baobab (B1) and the distance y_i from B1 to its nearest neighbour with the condition that the angle OB1B2 is more than 90°. Baobab density was calculated using the formula:

$$D = \frac{n^2}{2.828 \sum x_i \sum y_i}$$

where D is the density and n is the total number of random points (Krebs 1999).

For each baobab tree, we estimated the trunk height, measured the circumference at breast height and if there are signs of bark removal, measured the area removed. Trunk height was measured based on the trigonometric method by West (2009), in which a team member held a horizontal T-shaped stick of 1 m at eye-level. The observer walked back until they can observe the base of the tree and the tip of the trunk. The distance between the observer and the base of the trunk, which is equivalent to the height of the tree, was then measured. Circumference at breast height (1,30 m) was measured with a tape measure. Considering that baobab barks are put in a rectangular shape after harvesting, we used the trunk height (h) and circumference (c) to calculate the surface of bark available (s) (s = h * c). Similarly, if the barks have been removed from the tree, we measured the height (h1) and width (w) of the area without bark to calculate the surface of bark removed (s1 = h1 * w). The proportion of surface exploited is the ratio between the total surface removed and the total surface available (p = s1 / s). During the surveys, we collected information on baobab harvesting methods from our guides and the use of bark.

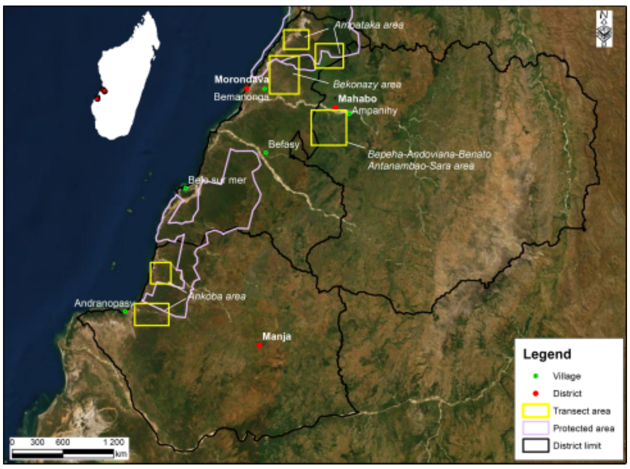

Figure 1. Study area.

MARKET MONITORING. Between April 2013 and January 2014, we employed four local observers to record baobab products available for sale at four markets: Morondava, Mahabo, Bemanonga, Analaiva (Figure 1). This method allowed us to estimate the supply of various baobab products (fruits, straps, ropes, barks, bark parts or pieces for infusion and powder), prices, provenance and quantity. The observers recorded data weekly with a logbook to ensure data are recorded in a similar way. We used Kruskall-Wallis test to compare monitoring efforts between markets and the frequency of observation of the different products.

For the barks and derived products, observers recorded the number of straps (strips of baobab bark) observed per vendor and estimated the length of the ropes made from baobab bark. They also recorded the price per strap and per meter of rope. Strap dimensions varied between 25–30 cm in width and 2–2.5 m in length. In the analysis, we assumed that all straps were 25 cm wide and 2 m long, and that the same dimensions of baobab bark are extracted. Open discussions with rope makers revealed that 1 m of rope can be produced with one strap. Using these data, we calculated the total surface of baobab barks needed to produce the products available on the market (surface = width * length). Using the unit cost of each product, we calculated the price of baobab bark per square meter.

RESULTS

PATTERNS OF BARK HARVESTING. We recorded a total of 1247 *Adansonia grandidieri* trees, of which 54.0% have been subject to bark extraction. Baobab density varied between our study sites and was highest in Analaiva and Andranopasy and lowest in Ampanihy and Bemanonga. In contrast, levels of bark extraction were highest in Bemanonga and Befasy and were lowest in Andranopasy and Ampanihy (Table 1). Large trees with a total bark surface of 14.8 ± 0.3 m^2 were preferred for bark extraction (Mann-Whitney, U = 141 981, Z = -2.981, p = 0.0003). Smaller trees with a total bark surface below 13.2 ± 0.4 m^2 were left intact. In general, only parts of the barks are removed, with an average height of 0.7 m and 0.9 m width on each tree. This was described as the traditional way to harvest the barks by the local guides. We also observed 41 baobab trees that had been deliberately felled for bark extraction, of which 16 were in Andranopasy, 14 in Ampanihy, 7 in Analaiva and 4 in Befasy. This practise was described as unusual and due to the increasing demands for baobab ropes. In 2010, we also found eight baobabs that were felled naturally by cyclones in Befasy. Barks of fallen and cut trees were extracted from the entire trunk.

PATTERNS OF BAOBAB BARK TRADE. We made 1240 observations of baobab products from the four local markets. Although monitoring effort varied between sites (n = 103, 71, 70 and 52 days, respectively: 6.7 ± 0.7 days per month), up to 80% of baobab products were observed in Bemanonga despite this site only accounting for 35% of our monitoring effort. Observations of baobab products in the other three markets never represented more than 8% of the records from Analaiva, Mahabo and Morondava.

Three baobab species were reported in the markets: *Adansonia grandidieri* (91%), *A. za* (9%) and *A. rubrostipa* (only one record). Baobab products found in the markets included ropes made of fibres (36.0%), fruits (31.5%), thin straps made from fibres and used as twine (21.5%), bark pieces for infusion (4.6%), fungi collected from dead trees (5.1%), thick straps used for roofing and walls (1.0%), and seeds as well as leaves (0.1% each).

Observation of *Adansonia grandidieri* straps and ropes was significantly more frequent in Bemanonga with 58.6 ± 8.0 records per month compared to 2.1 ± 0.4 records for the other markets (Kruskall Wallis test: H_3= 25.271, p < 0.001). In total, 21,594 straps and 34 517 m of rope were recorded from Bemanonga compared to less than 1500 straps and 1500 m of ropes in Analaiva, Mahabo and Morondava (Table 2). Only straps were available in Morondava, where it is more expensive compared to the other markets (Table 2). This is probably because 45.6 % of the straps in this market are from Andranopasy (Table 3), a commune 126 km away from Morondava. In Mahabo, ropes were twice as expensive as the straps (Table 2), although individual bark workers reported that a strap (generally of 0.25 cm wide and 2 m long) can make 1m of rope.

Straps are sold at $US0.10 ± 0.002 per unit while ropes are sold at $US0.17±0.003 per meter. All straps sold in Mahabo market were from Ampanihy, a commune within the district and only 5.5% of the ropes are from outside the district (Table 3). Analaiva is the only market where ropes are cheaper than the straps (Table 2). This suggests that the demand for ropes in this market is low. Ropes not sold locally are sold in Bemanonga (Table 3) where the price is higher. Straps and ropes from Befasy and Belo-sur-Mer are also found in Bemanonga market (Table 3).

BARK TRADE AND HARVESTING. We estimated the number of baobab trees partially debarked between April 2013 and January 2014 to make the total quantity of ropes recorded (34,517m) to vary between 5230 and 5991. Estimations of strap and exploited bark surface area per one meter of rope are based on: (i) A typical strap being approximately 25 cm wide and 2 m long (0.5 m^2); (ii) the mean surface exploited per baobab tree being 3.1 ± 0.2 m^2.

According to our calculations, 62.3% of the trees could be from Bemanonga, 26.4% from Analaiva, 5.6% from Befasy, 3.3% from Ampanihy and 2.5% from Andranopasy and Belo-sur-Mer. Analaiva and Bemanonga have the lowest estimated baobab den-

Table 2. Baobab fibers in the markets. Quantities of straps and ropes recorded during the monitoring between March 2013 and January 2014 and the mean (± SE) per product at each market.

Market	N observation days	N straps	Price strap (MGA/unit)	Total length of ropes (m)	Price rope (MGA/m)
Analaiva	71	760	287.5 ± 54.9	640	203.3 ± 15.0
Bemanonga	103	21.594	190.2 ± 3.3	34.517	336.5 ± 5.3
Mahabo	70	632	241.7 ± 22.9	1.45	534.6 ± 11.0
Morondava	52	1.315	500.0 ± 21.8	-	-

Table 1. Estimated densities of *Adansonia grandidieri* at the five communes surveyed in Menabe Region between 2008 and 2010 and patterns of bark harvesting.

Commune	Area (km^2)	N transects	N trees	Density/km^2	% trees harvested	Surface harvested (± SE m^2)	% total bark surface (± SE)
Ampanihy	1.602	34	399	209.4	48.4	2.5 ± 0.3	2.1 ± 0.2
Analaiva	546	12	66	173.4	56.1	5.7 ± 1.2	4.7 ± 0.9
Andranopasy	1.718	20	439	485.5	44.9	3.9 ± 0.5	4.0 ± 0.4
Befasy	640	20	246	429.1	63.4	4.2 ± 0.4	3.5 ± 0.3
Bemanonga	1.113	17	97	107.4	96.9	3.0 ± 0.7	1.2 ± 0.3

sity (Table 1) but have the highest bark harvesting rate (2.7 and 5.1% of the populations, respectively).

DISCUSSION

This study showed that more than half of the Grandidier's baobab trees in the wild have been subject to bark extraction. Since only part of the bark has been removed, the trees are still standing many years after the extraction. However, we started to observe intensive harvesting which consists in cutting down the trees to remove all the bark. If this practise continues, it will cause the decline of the species in the short term.

Ropes made with baobab barks are used as harnesses for the cattle and for attaching canoes (Wickens and Lowe 2008, Marie et al. 2009). They are preferred to the nylon ropes because of their low cost but also, they last longer and do not harm the cattle. In villages where the palm *Bismarckia nobilis* is growing, it is also used in place of the baobabs for making ropes (Mamilaza 2009). However, people would still prefer using baobab ropes and straps if those were available. Selling 10m of ropes per day would be necessary for a person living only on baobab rope trade to reach the poverty line of $US2 per day (World Bank 2014). Although baobab bark harvesting and making ropes does not represent a major activity in the Menabe, it can be an important source of income for some. This aspect should be considered when developing rules related to bark harvesting. Planting the palm *Bismarckia nobilis* is an alternative measure to be promoted as it is a fire-resistant fast-growing species with similar use by local populations as the baobabs.

This study could not solve the 'dispute' between local communities and scientists regarding the impact of bark harvesting on the baobab trees. On one hand, community members argue that bark removal do not harm the baobab trees while they agree that bark does not regenerate. However, in the wild, the baobabs are still standing. On the other hand, scientists advocate that bark harvesting might represent a threat to the trees as they are more exposed to ecological and climatic threats (Wickens and Lowe 2008). In the Allée des Baobabs, lower barks have been removed on almost all the trees but they are still standing (Wickens and Lowe 2008). In order to determine if the Grandidier's baobab barks can be sustainably managed and how, in-depth studies on the impact of bark harvesting is required (Ticktin 2004). In fact, trees may recover from bark harvesting depending on the species, the technique used and the environmental conditions (Delvaux et al. 2009). Bark harvesting also has different impacts on tree growth or fruit production and hence on population sizes (Gaoue and Ticktin 2008, Schumann et al. 2010, Schmidt et al. 2011).

The most recent population estimation of the Grandidier's baobab is at one million trees (Vieilledent et al. 2013). During a period of 10 months, we recorded 34 517m of baobab ropes at the four markets monitored. Assuming that these ropes came exclusively from the partially debarked baobabs, they would come from 5230–5991 trees. By extrapolation, there should be enough baobab bark stock for 1912 months (159 years) of baobab barks in the wild. However, we also found that 54% of the baobabs we found during the field surveys have already been debarked. As a result, if the demand remains constant, there is stock only for about 73 years (159 years * 46%).

Other studies in Africa reported that bark harvesting affects negatively the survival of baobab trees (e.g., Hall and Bawa 1993, Peters 1994, Cunningham 2001). Survival is threatened because the extraction of barks could make the individual more susceptible to pathogen attacks or could expose stem cortex tissue, impairing the flow of water and nutrients, hence reducing survival rates (Cunningham 2001). Botha et al. (2004) also found that on other tree species, bark removal affected fruit production. In the wild, we have seen that some Grandidier's baobab had fruits while others did not. Bark harvesting might be a factor contributing to this variation.

Effective management of the protected areas will play a central role to ensure conservation of the Grandidier's baobab. The Menabe region, where the Grandidier's baobab is most abundant, has four protected areas: Kirindy-Mitea National Park (72 200 ha), Andranomena (6420 ha) and Ambohijanahary Special Reserves (27 650 ha) and the Menabe-Antimena Reserve (125 000 ha) (Gardner 2011, Waeber et al. 2019). These protected areas represent 36% of the Menabe terrestrial ecosystems. If these protected areas also had 36% of the baobab population—bark harvesting is prohibited in protected areas—people will have access to only 640 000 baobab trees, providing barks for some 40–47 years using the traditional method (i.e., removing the bark without sophisticated, modern tools at heights not exceeding that of the exploiter). After this period, risks of felling trees to meet the demands of the market will increase in accessible areas (Marie et al. 2009). We thus recommend the establishment of local management structures that can monitor and regulate exploitation of baobab barks outside of protected areas by following the rights transfer system by which communities can regulate access to natural resources in their territory, including the baobabs (Antona et al. 2004). In this case, it is necessary that the governement who gives the rights builds the capacity of the communities to do so and support them until they can independently manage the resources and get benefits.

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Table 3. Origin of the baobab bark products available at the markets monitored. (Numbers indicate the percentage of products in the market coming from the Commune)

Market	Ampanihy	Analaiva	Andranopasy	Befasy	Belo-sur-Mer	Bemanonga
Straps						
Analaiva	-	36.8	-	-	-	63.2
Bemanonga	-	0.6	-	9.1	2.9	87.4
Mahabo	100	-	-	-	-	-
Morondava	-	-	45.6	5.7	-	48.7
Ropes						
Analaiva	-	100	-	-	-	-
Bemanonga	-	43.3	-	3.9	0.9	52.0
Mahabo	94.5	5.5	-	-	-	-

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SUPPLEMENTARY MATERIAL

Table S1. Starting points of transects in the Menabe Region.