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Survey of *Loxodonta africana* (Elephantidae)-caused bark injury on *Adansonia digitata* (Malavaceae) within Pendjari Biosphere Reserve, Benin

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Abstract

This study assessed the level of bark damage on baobab trees (*Adansonia digitata*) as caused by elephants (*Loxodonta africana*), and the possibility of finding refuges where baobab could escape bark damage within the Pendjari Biosphere Reserve (PBR). Distributions of elephants and baobab trees within the PBR were compared using presence records of both species taken along transect lines. Two sites (National Park vs. hunting zone) that differ in elephant density were compared for intensity of bark damage and correlations between the intensity of bark damage and stem size of the baobab trees and population structure of the baobab trees. Elephants and baobabs showed co-occurrence in PBR suggesting that there is nowhere to hide for baobabs. The intensity of bark damage was positively correlated with elephant density and baobab girth. Baobab population girth classes were not significantly different in areas with and without bark damage. Future studies should test whether there are certain baobab genotypes that can resist elephant damage. It could also be tested whether effective conservation of elephants in the PBR has resulted in a bull-biased population over its carrying capacity.

Key words: bark damage intensity, bio-reserves, distribution, tree girth class distribution, West Africa

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Résumé

Cette étude a évalué les dommages causés aux écorces de baobabs (*Adansonia digitata*) par les éléphants (*Loxodonta africana*) ainsi que la possibilité de trouver des refuges où les baobabs pourraient éviter ces dommages dans la Réserve de Biosphère de la Pendjari (RBP). La distribution des éléphants et celle des baobabs dans la RBP ont été comparées en utilisant les relevés de présence des deux espèces le long de transects. Deux sites (parc national *vs* zone de chasse) où la densité des éléphants est différente ont été comparés en ce qui concerne les dégâts causés aux écorces et la corrélation entre l'intensité de ces dégâts, la circonférence des troncs de baobabs et la structure de la population de baobabs. Les éléphants et les baobabs coexistent dans la RBP, ce qui laisse penser qu'il n'y a pas d'endroit où les baobabs sont à l'abri. L'intensité des dommages causés aux écorces était positivement liée à la densité des éléphants et à la circonférence des baobabs. Les classes de circonférence de la population de baobab n'étaient pas significativement différentes dans les zones avec ou sans dégâts. Les futures études devraient vérifier s'il existe certains génotypes de baobabs capables de résister aux dégâts des éléphants. On pourrait aussi voir si la conservation efficace des éléphants dans la RBP n'a pas conduit á 'une population biaisée en faveur des mâles et qui dépasse sa capacité de charge.

Introduction

Elephant (*Loxodonta africana* Blumenbach) populations within many natural reserves and protected areas have been suggested as responsible for altering the structure of native vegetations (Mapaure & Campbell, 2002). This is particularly the case, when elephant populations are relatively high as is the case with the Pendjari Biosphere Reserve (PBR) (869 individuals in the whole reserve or approximately 1 individual per 6 km²) (Bouché *et al.*, 2011). Within the PBR (located in the Sudanian zone of Benin), the elephants are responsible for the conversion of tree-dominated savannahs into grass-dominated savannahs (B. Fandohan, Université d'Abomey Calavi, unpubl. data.). The impact of elephants on woody vegetation has led to concerns about possible extirpation of some plant species from the PBR as elsewhere in Africa (Ihwagi *et al.*, 2010). For example, elephant damage has resulted in dramatic changes in the population structure of *Acacia tortilis* Hayne (Pellew, 1983), *A. elatior* Brenan (Ihwagi *et al.*, 2010) and *Adansonia digitata* L. (Edkins *et al.*, 2008).

The baobab tree (*A. digitata*) is of conservation importance not only in the PBR but in Africa in general because of the important ecosystem function it plays, due to its weak ability to self-regenerate, its sensitivity to drought and the genetic degradation its populations are facing across its natural distribution range (Assogbadjo *et al.*, 2006; Kyndt *et al.*, 2009; Schumann *et al.*, 2010). Baobab trees provide food to bats (pollen; Wickens & Lowe, 2008), human and other primate species (fruit; Assogbadjo *et al.*, 2006) and elephants (bark; O'Connor, Goodman & Clegg, 2007). Within the PBR, like elsewhere, individuals and populations of the baobab trees are vulnerable to damage by elephants (Swanepoel, 1993; Barnes, Barnes & Kapela, 1994). The elephants cause damage to the trees by stripping off tree barks (Napier-Bax & Sheldrick, 1963). The damage often leads to collapse and mortality of the trees, with the small-sized trees suffering higher mortality (Barnes, Barnes & Kapela, 1994; Edkins *et al.*, 2008). The impacts of elephants on baobab trees can be influenced by terrain. For example, in Lake Manyara National Park (Tanzania), resident baobab populations within the southern part are less heavily damaged than those found in the northern part (Weyerhaeuser, 1985). This has been attributed to the steeply terrain of the southern escarpment, which restricts elephant access to the baobab trees (Wall, Douglas-Hamilton & Vollrath, 2006). Similar observations were reported in the Kruger National Park in South Africa where habitats with a rocky or steeply topography were said to be acting as refuges for baobab trees against elephants' damage (Edkins *et al.*, 2008).

Thus far, most of the studies on relationship between elephant and baobab trees have been undertaken in Southern and Eastern Africa. As such, very little information on such relationships is available from West Africa. The objectives of the present study were to (i) check for possible refuges for baobab trees to escape elephants' damage, (ii) assess the levels of elephant-induced bark damage on baobab trees and (iii) determine the relationship between girth of the baobab trees and the intensity of bark damage they have undergone. The following research questions were addressed: (i) Is there a discontinuous distribution of elephants within the PBR that leave gaps within which baobab trees can escape bark damage? (ii) Is the intensity of bark damage correlated with site type (National Park vs. hunting zone)? (iii) Is the intensity of bark damage correlated with girth of baobab trees? (iv) Is the population structure of baobab trees (girth class distributions) dependent upon the intensity of bark damage? Providing answers to these questions would give insights into better conservation and management of both the elephants and baobab trees, which are keystone species within the PBR (Blanc *et al.*, 2007; Hermy *et al.*, 2007).

Apart from the Atakora Mounts Chain (400–513 m above sea level) in its southern limit, most of the PBR has a flat topography (150–200 m above sea level) (Delvingt, Heymans & Sinsin, 1989), with no physical barrier to movements of the elephants. Thus, it was hypothesized that baobab populations across the PBR are all accessible and hence vulnerable to bark damage by elephants. It was also hypothesized that baobab populations located within the integrally protected zone of the PBR (the National Park) would experience more intense bark damage because of the higher density of elephants within the Park (Bouché *et al.*, 2004). It was further hypothesized that small-stemmed baobab trees would undergo higher intensity of bark damage than the large-stem trees because the former have softer barks that would be easier to remove. Finally, it was hypothesized that the structure of baobab populations would be dependent upon bark damage.

For the first hypothesis, the niches (i.e. distribution) of elephants and baobabs were compared using presence records of both species spanning the entire range of the PBR. The three latter hypotheses were tested by collecting and collating data on intensity of bark damage on individual baobab trees in the National Park and the hunting zone within the PBR.

Material and methods

Study area

The study was undertaken within the PBR located in the Sudanian zone of Benin, West Africa (10°40′–11°28′N and 0°57′–2°10′E; Fig. 1). The study covered the two zones in the PBR: the National Park of Pendjari (which is integrally protected) and the hunting zones (where sport hunting is the only human activities allowed) (Fig. 1). Hunting activities use to take place during the dry season (from December to May). Of these two zone types, the National Park hosts a greater density of elephants than the hunting zones (Bouché *et al.*, 2004). According to Bouché *et al.* (2011), the elephant population in the PBR has slightly increased from 826 individuals in 1985–1991 to 869 individuals in 2005–2010. Native vegetation in the area is dominated by woodlands, tree and shrub savannahs. Annual rainfall averages 900–1000 mm and shows a unimodal regime (from May to November). A recent study indicated significant increase in mean temperature (+1°C; from 27 to 28°C) and perceptible decline of the rainfall (−5.5 mm year^{-1}; from 1220 to 1000 mm), and the number of rainy days per year (−45 days; from 115 to 70 days)

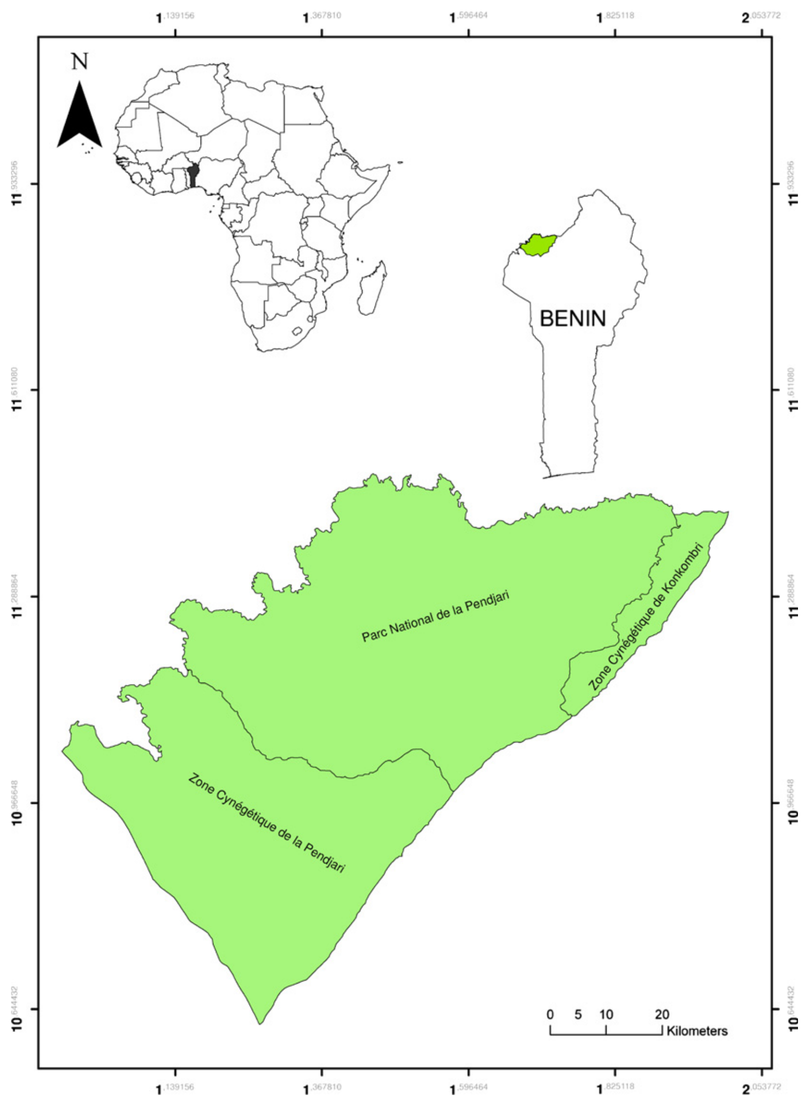

Fig 1 Map showing the study area (Biosphere Reserve of Pendjari)

between 1960 and 2008 (Gnanglè *et al.*, 2011). Soils are mainly ferruginous.

Assessment of distribution of baobabs and elephants in PBR

To assess the distribution of the baobab trees and the elephants spanning the entire PBR, geographical coordinates (longitude and latitude) of location of both species were gathered from extensive field work survey (February–April 2011) along transect lines across PBR (Fig. 2). For areas that we were not able to scrutinize during the field survey, geographical coordinates were retrieved from location records of both species in reports and scientific literature on fauna and flora of the study area (Bouché *et al.*, 2004, 2011; Sokpon *et al.*, 2008). For field surveys (conducted on the basis of the vegetation map of PBR and depending on accessibility), twelve 15 × 0.2 km transects were delineated (Fig. 2). Along each transect, latitude and longitude of every contact point with either species was recorded using a GPS receiver (GARMIN 60, Liberty House, Southampton, UK; precision 3 m). When an elephant was not physically observed at a given location but indications of it presence (dung, foot prints or bark damage) were observed, such indications were used as a proxy record of an elephant. Distribution maps for elephants and baobabs were generated (using ArcMap 9.3) from the species records. The maps were then merged to check for possible refuges where baobab could escape bark damages.

Assessment of impact of elephant-caused bark damage on the population structure of baobabs

Locating baobabs within the PBR is relatively complex because the adult trees are sparely distributed while the

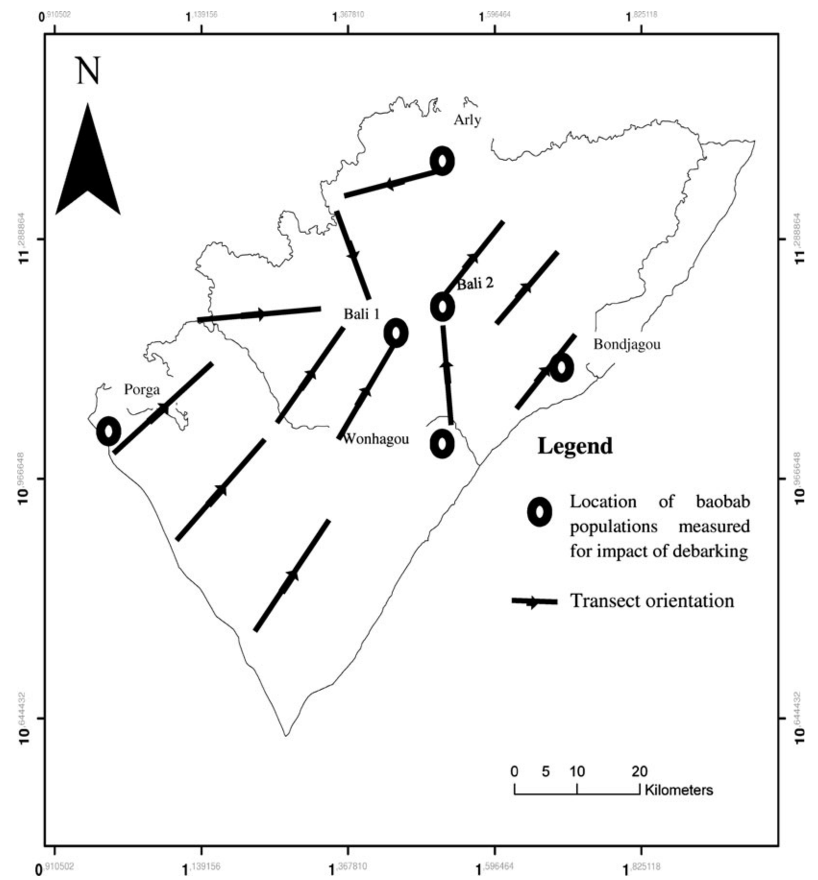

Fig 2 Location of surveyed baobab tree populations. Porga and Wohangou are within the hunting zone of Pendjari; Bali 1, Bali 2, Bonjagou and Arly are within the core integrally protected National Park of Pendjari). The arrows indicate pedestrian transect lines for baobab and elephant location records

small trees are inconspicuous. This, therefore, invalidates random sampling techniques (Edkins *et al.*, 2008). Hence, a nonprobability sampling technique was adopted. Six major baobab populations were selected along survey transects. Four populations fell within the National Park, while two others occurred within the hunting zone of Pendjari (Fig. 1). Within each population, individual counts and girth measures of each tree at 130 cm above the ground (G130) were taken. The sampling effort was limited to 200 ha (2 × 0.1 km) per population. The percentage bark removal (hereafter referred to as bark damage) from the trunk of each baobab tree (from the base up to a height of 3 m) was visually estimated. This was carried out for only trees with signs of recent bark damage (where the baobab's fibrous tissue could still be seen; Plate S1). Estimation of bark damage was limited to 3 m height to reduce errors of appreciation. Bark damage was scored on a seven-level scale, from the lowest to the highest intensity (Ihwagi *et al.*, 2012): undamaged (0), tusked (1), 1–25% debarked (2), 26–74% debarked (3), 75% debarked (4), 76–99% debarked (5) and ring debarked (6). Zone type was coded according to increasing elephant density and level of protection within the PBR: 1 (hunting zone) and 2 (integrally protected National Park). To this end, elephant densities around studied baobab populations were determined based on available inventory data (Bouché *et al.*, 2004). According to this report, elephant density ranged from one individual per 3 km^2 to one individual per km^2 around baobab populations located within the integrally protected National Park. Contrastingly, it was zero to one individual per 5 km^2 around baobab populations within the hunting zone. A Spearman's rank correlation test was performed to determine the correlations between (i) zone type (protection level) and intensity of bark damage and (ii) girth of the baobab tree and intensity of bark damage. The proportion of ring-barked trees and the proportion of undamaged trees per population were estimated. Data on girth of each individual tree were further used to build girth class distribution histograms for each baobab population. The coefficient of skewness (g1) of the observed distributions was used to describe girth class distributions (GCDs) of the six populations (Feeley *et al.*, 2007). A log-linear analysis was performed to check for dependence between the distribution of girth class and intensity of bark damage. As primary data on tree girth did not fulfil some requirements for log-linear analysis (i.e. the number of trees for each cell of the contingency table must be >0, and at least 20% of the classes should have more than five individuals), five trees were added to each cell to resolve this (Caswell, 2001).

Results

Distribution of elephants and baobab trees

There was an overlap in the distributions of the elephants and baobab trees for most of the PBR, making it improbable to find refuges within most of the PBR where baobab trees could escape elephants damage (Fig. 3). Nevertheless, there was an overlap in distributions of the elephants and the baobab trees only in a few patches within the hunting zone (Fig. 3).

Impact of elephants on baobab tree populations

A total of 252 baobab trees were distributed among the six populations as follows: Arly (70), Bali1 (41), Bali2 (21), Bondjagou (52), Porga (31) and Wohangou (37). All baobab population showed a bell-shaped girth class distribution indicating little recruitment in both reserve and hunting zone. They were very few individuals in size 1–40 cm. The intensity of bark damage was positively correlated with level of protection and elephant density ($r = 0.38$; $P < 0.0001$) (Table 1). The relative proportion of undamaged trees was lower in populations within the National Park than in the hunting zone (7.77% ± 4.69; Fig. 4a–d vs. 47.82% ± 41.37; Fig. 4e,f). While only 8.07% ± 11.40 of trees in populations within the hunting zone faced more than 75% debarking, 22.82% ± 4.03 of trees within the National Park faced the same level of debarking (Table 2).

The intensity of bark damage was also positively correlated with girth for the combined data ($r = 0.45$; $P < 0.0001$) or when the girth data were broken down to zone type ($r = 0.35$; $P < 0.0001$ in the National Park and $r = 0.75$; $P < 0.0001$ in the hunting zone) (Table 1). Some noticeable discrepancies were, however, observed when the six baobab populations were considered separately. Irrespective of zone type, some populations (i.e. Bali 1, Bondjagou and Porga) exhibited nonsignificant correlations between girth and damage intensity, while others (Wohanga, Arly and Bali 2) exhibited significant correlations (Table 1).

The GCDs were skewed to the right (positive distribution curves; $g1 > 0$; Table 2), suggesting higher ratio of large-stemmed trees to small-stemmed trees in all populations. GCDs did not significantly changed with the intensity of bark damage (log-linear $\Delta G^2 = 26.40$; $P > 0.10$).

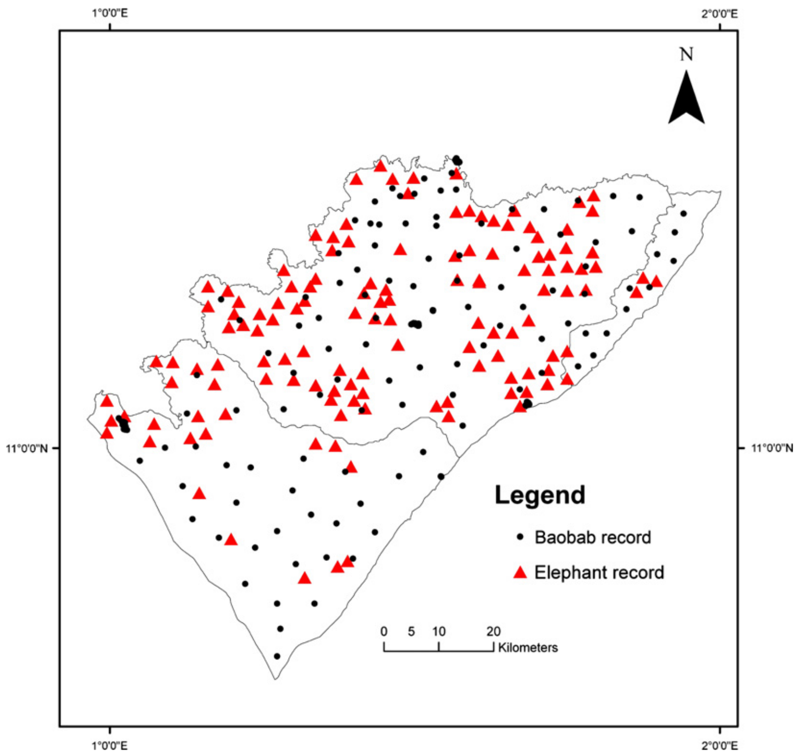

Fig 3 Distribution of baobab trees and elephants in the Pendjari Biosphere Reserve

Table 1 Spearman's rank correlation between intensity of bark damage and: (1) elephant density and protection level; (2) girth size of baobab trees for six populations selected in two sites

	Bark damage intensity	Significance (*P* value)
Elephant density and protection level	0.38	<0.0001
Girth size		
Arly	0.51	<0.0001
Bali 1	0.23	0.1459
Bali 2	0.52	0.0152
Bondjagou	0.02	0.8898
Overall National Park	0.35	<0.0001
Porga	0.31	0.0896
Wohangou	0.36	0.0311
Overall hunting zone	0.75	<0.0001
Global	0.45	<0.0001

Table 2 Skewness and percentage of baobab trees with more than 75% of debarking

Zone	Population	Skewness	Baobab trees (%) with more than 75% debarked
National Park	Arly	1.46	11.43
	Bali 1	1.84	41.46
	Bali 2	0.14	9.52
	Bondjagou	0.41	28.85
Hunting zone	Porga	0.46	16.13
	Wohangou	0.54	0

Discussion

In support of the first hypothesis above, the overlaps in distributions of elephants and the baobab trees within most of the PBR indicate that the trees do not have refuges where they can escape elephant attacks. This implies that continued existence of the baobab trees within the PBR would depend on the ability of baobabs to survive various level of debarking. Long-term monitoring programme on response of baobabs to different level of debarking is required to address the likelihood of their survival in the study area.

Although the overlap between elephants and the baobab trees within the hunting zone occurred in only a few patches, there are no reasons to believe that the trees in

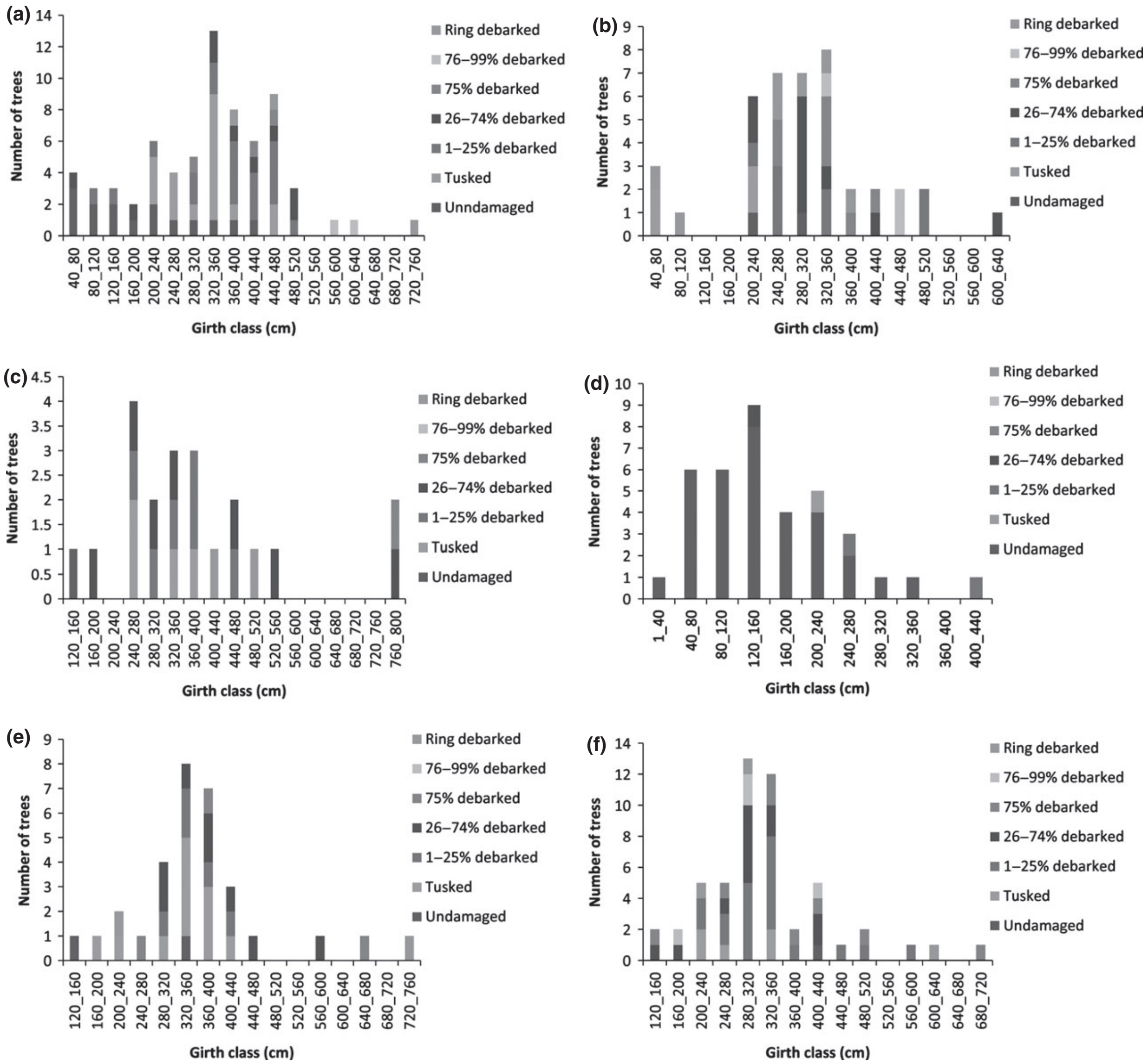

Fig 4 Girth class distribution and distribution of the intensity of bark damage relative to the size class of baobab trees in six populations: (a) Arly, (b) Bali 1, (c) Bali 2, (d) Bondjagou (National Park); (e) Porga, (f) Wohangou (hunting zone)

the hunting zone will always suffer only limited damage by the elephants. Some reasons may explain our findings: on the one side as our field survey corresponded to the dry season and the hunting period, elephants may have moved to the more secure and noiselessly areas as the national park, and in where water resource is more available (Bouché *et al.*, 2004). According to Hema, Barnes & Guenda (2011) proximity of water represents one of the factors determining elephant distribution in the dry season. The abovementioned reasons are thus even more probable as our data collection on debarking damage only took into account recent injuries. On the other side, elephants are also known in several places for incursions outside Protected Areas and into farmlands for crop raiding despite the risk of poaching (e.g. Kenya, Sitati, Walpole & Leader-Williams, 2005; Burkina Faso, Hema, Barnes & Guenda, 2011; W National Park, B. Fandohan, field observ.).

Lack of juvenile baobabs (1–40 cm girth) could be seen as an indicator of declining populations irrespective of zones. However, this argument main not hold for long-lived species such as *A. digitata* (Venter & Witkowski, 2010). Our data support the second hypothesis that the baobab populations would suffer higher bark damage within the National Park because of greater density of elephants in the park relative to the hunting zone. As previously explained, sport hunting activities and little water resource in the hunting zone during the period of field survey are potential factors that could explain the observed differences.

The significant positive correlation between girth and intensity of bark damage do not support the third hypothesis. The tendency of elephants to debark large-stem trees has been reported previously in East Africa (Ihwagi *et al.*, 2010). Nevertheless, this was not consistently confirmed when the data are broken down to each population. Elephant preference for debarking particular size class trees could be influenced by many factors including girth range of target populations, relative availability of different girth class stems (Edkins *et al.*, 2008).

The results do not support the fourth hypothesis as the log-linear test shows that girth class distributions of the baobab girth are independent of intensity of bark damage. Previous studies on impact of elephant bark damage on individual populations have yielded disparate findings. While some studies reported significant negative effect (e.g. Barnes, 1985; Edkins *et al.*, 2008; Ihwagi *et al.*, 2010), other studies observed no significant change in population structure as resulting from bark damage (Weyerhaeuser, 1985). A comprehensive understanding of the impact of bark damage on individual species' demography would require multiyear census.

High intensity of debarking by elephants could lead to high mortality rates of the target plants and eventually alter vegetation structures (Ihwagi *et al.*, 2010). A key question that remains is, what factors influence the debarking pressure by elephants? Several hypotheses have been proposed in attempts to address this question. One such hypothesis posits that the relative ratio of male to females within a herd of elephants will influence the intensity of damage (O'Connor, Goodman & Clegg, 2007). More specifically, because of their greater body size and thus greater nutritional requirement, adult male elephants cause more damage to trees than female adults, juveniles or calves (Barnes, Barnes & Kapela, 1994; Hiscocks, 1999). Thus, elephant herds with high proportions of adult males are likely to cause more bark damage than herds with low proportions of adult males (Smallie & O'Connor, 2000; O'Connor, Goodman & Clegg, 2007). Another factor likely to influence elephant damage on baobab trees is the frequency of occurrence of severely dry seasons. As the frequency of severely dry seasons increases, so does the decrease in amount of food available from herbs; hence, the elephants face nutritional stress and resort to consuming barks of trees (Styles & Skinner, 2000; Osborn, 2004; Birkett & Stevens-Wood, 2005). Indeed, a positive correlation between the intensity of bark damage and the duration of the dry season has been reported (Ihwagi *et al.*, 2010, 2012). Hence, a change in climate characterized by more severe dry seasons would exacerbate the debarking pressure on baobab trees by elephants. This hypothesis is congruent with rainfall decline and temperature rise recently illustrated in the study area (Gnanglè *et al.*, 2011).

In the course of the current study, it was noticed that baobab trees that were only tusked, all shared the characteristic of having a cracked trunk irrespective of zones (Plate S2). Hence, it is plausible to hypothesize that certain trees have barks that are relatively harder to damage, indicating existence of baobab genotypes that can resist elephant damage. Genetic differences within baobab populations have been highlighted by several authors (Kyndt *et al.*, 2009). It was also observed that some trees had signs of complete recovery after ring-debarking (Plate S3). As such, some baobab trees could be resilient to severe debarking damage by elephants. On the basis of previous works that highlighted that increasing elephant debarking behaviour is linked to increased number of adults in elephants herds (O'Connor, Goodman & Clegg, 2007), it could be also hypothesized that effective conservation of elephants in PBR could have led to increase in their population size and decline in the carrying capacity of PBR for elephants; which may be an underlying cause of increasing debarking behaviour. It would be of interest to explicitly test these hypotheses with a view to advancing our understanding of the factors influencing debarking pressures on the baobab trees.

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Supporting information

Additional Supporting Information may be found in the online version of this article:

Plate S1 Recent bark damage to a baobab tree.
Plate S2 Tusked baobab tree with a cracked trunk.
Plate S3 A Baobab tree that had undergone debarking but later recovered: points (a) are parts which were previously damaged; point (b) freshly damaged parts.