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Ecological characterization and evolution of *Elaeis guineensis* Jacq. traditional parklands in Lower Casamance (Senegal)

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Abstract This study is a contribution to the characterization of traditional agroforestry parklands in Lower Casamance. It aims at determining the diversity of species and the tree size structure in these parklands, as well as at identifying the threats to their sustainability, in order to assist decision making on natural resource conservation. To this end, 45 plots of 50 × 50 m size were inventoried. In each plot, an exhaustive inventory of trees was performed, including species identification, height measurement and estimates of regeneration and mortality rates. Additionally, 116 stakeholders were interviewed about their management practices, the revenue they obtained from agroforestry parklands, and their opinion on the future of these parks. A total of 2739 *Elaeis guineensis* palm trees and 3948 trees from other species were observed in the 11.25 ha studied. Hence a relative density of 40.96 individuals of *E. guineensis* ha^{-1}. The 63 species belonged to 51 genus within 23 botanical families. The analysis of tree communities indicated a strong role of human management on the species composition of parklands, with cultural value trees near the villages and wood production trees further away, and with some sites having more trees with medicinal uses. The distribution of tree sizes of *E. guineensis* and estimates of mortality and regeneration rates indicated that the population of palm trees is ageing and regeneration is too low to compensate mortality. Based on interviews, palm production is decreasing in the area, and causes of decline identified by the farmers were salinization, drought, illegal cutting, and bush fires, i.e., both natural and anthropogenic causes. In view of the importance of these parklands for the local economy and food security, better management of *E. guineensis* parklands is required to ensure their sustainability.

Keywords Agroforestry parkland · *Elaeis guineensis* · Lower Casamance · Natural regeneration

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Introduction

The Lower Casamance is located in the south of Senegal. It has enormous economic potentialities due to its dense river system, its relatively fertile lands, and the presence of agricultural, aquaculture and of forest resources (wood, fruits, honey, medicinal plants…). For generations, farmers in the Sahel have maintained several species of trees and shrubs within their agricultural land. These traditional land use systems where woody species are deliberately associated with agriculture and animal husbandry in a dispersed spatial arrangement (Bonkoungou et al. 1997) are known as "wooded parklands" or, more recently, "parklands" (Boffa 2000).

Besides their diverse ecological functions, these parklands can be an important source of many products: food, fodder, medicines, firewood, construction wood, etc. For the poorest farmers, the contribution of these agroforestry products to the nutritional and economic stability of their families and their participation in mitigating the risks of climate fluctuations are of paramount importance for survival (Bonkoungou et al. 2002). Unfortunately, the biodiversity of woody parkland is threatened. Over the last decades, many parklands have become degraded under the combined effects of social, economic, political and environmental factors (Boffa 2000). The aging of trees in these parklands, associated with the decrease in the density of tree cover and a depletion of the number of tree species, raise some fears for the survival of these systems. The main objective of this study was to determine the diversity, the structure and the regeneration potential of trees in these parklands in order to identify meaningful management methods to ensure the sustainability of these vulnerable parklands. The study focused on *Elaeis guineensis* parklands, which associate upland rice cultivation with oil palm and other trees, the type of parklands most representative of parklands in the Lower Casamance.

Materials and methods

The study area

The study was conducted in Ouonck (12°42′36″ North, 16°03′20″ West) in the Department of Bignona, Ziguinchor (Fig. 1). It is part of the Kalounayes Municipality Area, which also encompasses the Kalounayes Classified Forest. Four villages characterized by a high potential for production of palm oil were selected in this municipality: Diagho, Diaghour, Kigninding and Togho. Just like all the Lower Casamance, this area has enormous agricultural potential with its fertile land and the south soudano-coastal climate with a strong maritime influence (Sagna 2005), providing good rainfall although rains are unevenly distributed throughout the year and display a high inter-annual variability. Casamance also has enormous economic potentialities thanks to its forest resources. Among the forest species of the area, *E. guineensis* is the most exploited for its numerous services and products. In spite of its importance, oil palm tree production faces real threats due to natural as well as anthropological factors.

The climate of Lower Casamance is dominated by two seasons: a dry season, which runs from November to mid-June and a rainy season from mid-June to October, during which agricultural activities are carried out. During the dry season, temperatures can sometimes be very high (35–40 °C). Rainfall has been very variable between years over the last 30 years, with an average of 1322 mm year^{-1}. The largest surplus year was 1999 with 1947 mm while 2002 showed the largest deficit with 811 mm (Fig. 2). In the last 10 years (2005–2015), the trend is an increase in rainfall with only two deficit years (2007 and 2011).

Timber inventory

The *E. guineensis* parklands of the four villages were inventoried, with 9–12 vegetation inventories in each village, giving a total of 45 vegetation inventories. Each inventory was performed on a 50 m × 50 m square plot, a size that is often used for parkland inventories (Diedhiou et al. 2014; Diédhiou 2013; Dan Guimbo et al. 2010). In each plot, an exhaustive inventory of trees species was done, and the diameter at breast height (1.3 m) and tree height were measured for each adult tree. Regeneration potential of *E. guineensis* was estimated by counting young palm trees measuring less than 1.3 m. Mortality rates were estimated by counting the number of *E. guineensis* stumps. The illustrated flora of Senegal (Berhaut 1967) was used for species identification.

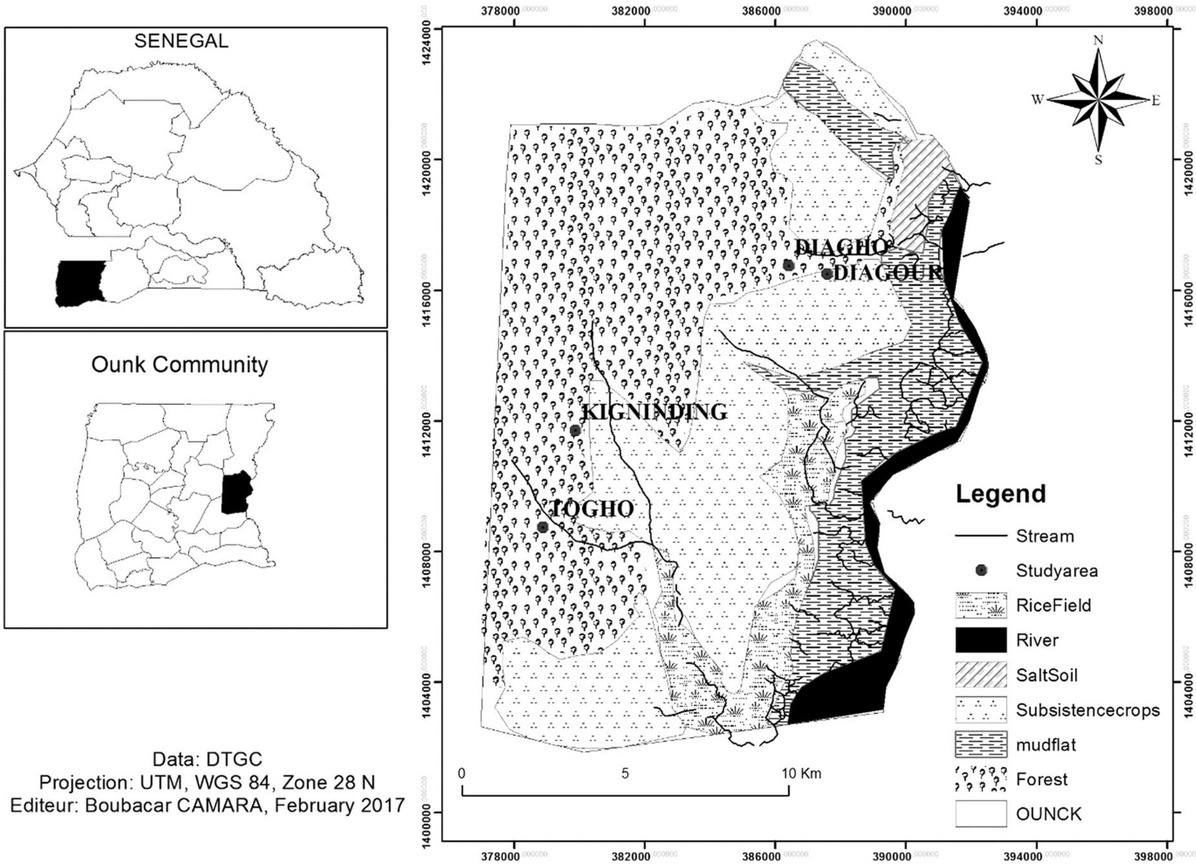
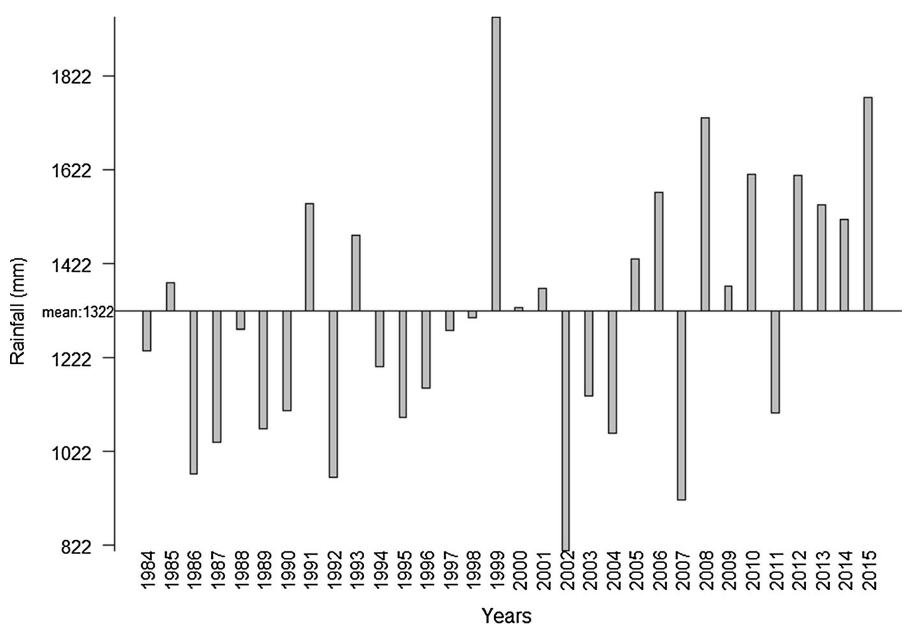


Fig. 1 Location map of the study sites

Fig. 2 Evolution of annual rainfall from 1984 to 2015 in the region



Farmers' interviews

A survey of farmer's practices and beliefs was conducted through interviews with the people of the four villages using directional type of questionnaires and focus groups. These questionnaires were conducted on 116 individuals aged more than 18 among whom 32.8% of women. In each village, a sample of the population was chosen according to their sector of activity in the Palm grove (harvesters of palm bunch, processors, sellers, the group's leaders) but also the customary leaders of each village and the state development agents or representatives of non-governmental organizations accompanying the population in the management of natural resources.

The questions were mainly focused on the dynamics, the management of parks and the different products, and associated revenue, from palm groves.

Statistical analyses

Species diversity was analyzed using the Shannon–Weaver diversity index, Pielou's equitability index, the dissimilarity index of Jaccard and species richness.

The Shannon–Weaver diversity index is calculated with the equation:

$$H' = -\sum_{species\ i} p_i * Log_2(p_i),$$

where p_i is the frequency of species i, H' is equal to 0 if all individuals of the population belong to a single species, the index is maximum when all individuals are distributed equally over all species (Frontier and Pichod-Viale 1995). This index is used to calculate the diversity of groups compared to the maximum diversity (Hmax) which is the base 2 logarithm of the number of species (S);

$$H\max = Log_2(S).$$

The equitability index or R of Pielou (1966) also called equipartition's index (Blondel 1979 quoted by Faye 2005) or regularity, which represents the ratio of the observed H on Hmax: R = H'/Hmax. This represents the level of achievement of maximum diversity (Faye 2005).

The dissimilarity index of Jaccard is used in statistics to compare the dissimilarity between samples. It is calculated by the relation $D_J(j_1, j_2) = 1 - \frac{C}{(A+B+C)}$, where C is the number of species common to both J_1 and J_2 sites, A is the number of species specific to J_1 site and B is the number of species specific to J_2 site. The Jaccard index varies from 0 to 1. It is designed to be zero if the two sites are identical, and it is 1 if the two sites have no species in common.

A principal component analysis was performed on the abundances of species that were present in more than 10% of the plots (i.e., *E. guineensis* and 27 associated species). The PCA analysis was performed on scaled data using function PCA of package FactoMineR of R statistical software. As we used this analysis to describe the community of associated trees, we considered *E. guineensis* as a supplementary variable, i.e., not active in the analysis. Village was added as a qualitative supplementary variable, to determine whether or not the associated tree communities were different between villages. We also used the distance to the village as a quantitative supplementary variable.

The mortality ratio of *E. guineensis* was calculated as follows

$$Mortality\ ratio = \frac{\#\ Elaeis\ guineensis\ stumps}{\#\ living\ Elaeis\ guineensis}.$$

The percentage of mortality caused by human action (cutting and/or fire marks) was calculated as follow:

$$Mortality\ caused\ by\ humans = \frac{\#\ Elaeis\ guineensis\ stumps\ from\ cutting\ or\ fire}{\#\ Elaeis\ guineensis\ stump} \times 100.$$

The regeneration ratio of *E. guineensis* was calculated as follows

$$Regeneration\ ratio = \frac{\#\ Elaeis\ guineensis\ saplings}{\#\ living\ Elaeis\ guineensis}.$$

Although those ratios are not exactly mortality and fecundity rates relative to time, we are confident that they represent the dynamics of *E. guineensis* in the parklands, because *E. guineensis* stumps (used to calculate the mortality ratio) usually disappear within a decade, while young trees (used to calculate the regeneration ratio) also take a decade to become mature.

Analysis of variance was performed on the density, relative abundance, regeneration ratio and mortality ratio of *E. guineensis* in order to test the effect of village on these variables. Multiple comparisons between villages were performed using Tukey's honest significant difference test.

The farmers' interviews were transcribed and the resulting text was processed with the software Sphinx Plus, which performs univariate and bivariate analyzes of variance.

Results

Tree communities in *Elaeis guineensis* parklands

We identified 6687 trees in the 45 inventories, giving a tree density in agroforestry parklands in the study area of 594 trees ha^{-1}. The floristic diversity of the study area was rich with 63 species belonging to 51 genera within 23 botanical families. The most important families of accompanying trees were Fabaceae and Moraceae with respectively 16 and 13% of all individuals. Apocynaceae and Rubiaceae were next with 10% of all individuals. Combretaceae, Meliaceae and Mimosaceae were respectively represented by 8, 6 and 5% of all individuals. Annonaceae, Arecaceae, Chrysobalanaceae, Bignoniaceae each represented 3% of individuals. The remaining families, i.e., Agavaceae, Anacardiaceae, Bombacaceae, Connaraceae, Euphorbiaceae, Hymnocardiaceae, Lythraceae, Rutaceae, Sapindaceae, Sapotaceae, Sterculiaceae and Verbanaceae each represented 2% of individuals.

In terms of diversity, Shannon index was 2.69 on average. The equitability index of Pielou was 0.56 on average, indicating a more or less equitable distribution of species between inventories. However it must be noted that the villages of Togho and Kigninding were more diversified with a higher equitability index (Table 1).

The dissimilarity index of Jaccard (Table 2) reveals some floristic similarity between the four study villages. This can be explained by the proximity between villages but also by the fact that parklands of *E. guineensis* share the same favorite areas, that is to say, the fringe area between the lowlands and plateau.

In the PCA analysis, plots Kigninding 1 and Kigninding 9 were considered as supplementary individuals, because otherwise these two plots were causing most of the variance and all other plots were grouped in the middle of the graph. In this PCA, the first plane represents 27.3% of the variance (Fig. 3). Axis 1 separates plots with few trees from plots with many trees, while axis 2 separates different tree species. The species positively correlated with axis 2 (*Allophyllus africanus*, *Ekebergia senegalensis*, *Holarrhena floribunda*, *Uvaria chamae*, *Zanthoxylum senegalense*, *Guiera senegalensis*, *E. guineensis*, *Newbouldia laevis*, *Voacanga thouarsii* and *Khaya senegalensis*) are all species that are used for production (e.g., production of wood fuel, fence pickets, food, ropes, etc,…), while species negatively correlated with axis 2 (*Albizia adianthifolia*, *Ceiba pentandra* and *Ficus sycomorus* ssp. *gnaphalocarpa*) have low quality wood but sometimes have spiritual value. The distance from the plot to the nearest village, added as illustrative variable, came out strongly correlated with axis 2, indicating that trees used for wood are grown far from the village, while trees with spiritual values are kept close to the village. Species that are correlated with axis 1 and are uncorrelated with axis 2 (e.g., *Hymenocardia acida*, *Cassia sieberiana* and *Antiaris africana*) have medicinal uses.

The map of individuals on the principal plane (Fig. 4) shows that plots in Kigninding and Togho are more spread out (i.e., less similar) than plots in Diagho and Diaghour villages. Villages differ significantly along axis 1 ($p = 0.002$), with Kigninding positively associated with axis 1 (many trees), but villages are not significantly different along axis 2.

Table 1 Shannon diversity index (H′) and Pielou's equitability index (R) in each of the four villages

	H′	R
Diagho	2.5	0.53
Diaghour	1.81	0.36
Kigninding	3.64	0.63
Togho	2.79	0.53
Means	2.69	0.56

Table 2 Jaccard's dissimilarity Index

Diaghour	0.50		
Kigninding	0.64	0.56	
Togho	0.55	0.48	0.40
	Diagho	Diaghour	Kigninding

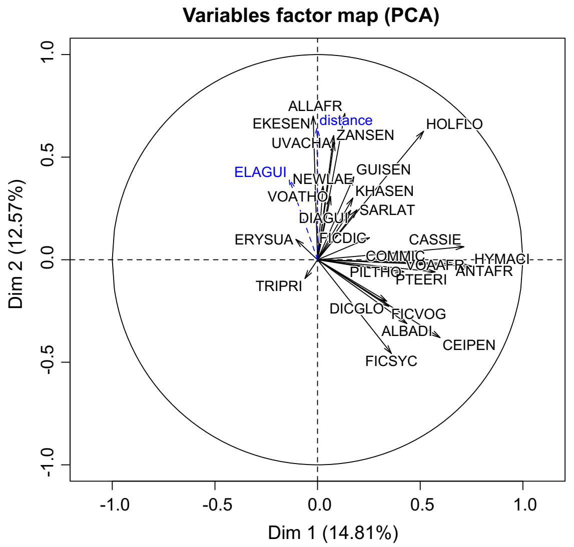


Fig. 3 Variables factor map of the PCA based on species that are present in more than four plots [*Elaeis guineensis* and distance to the village (in blue) are used as illustrative variables]. (Color figure online)

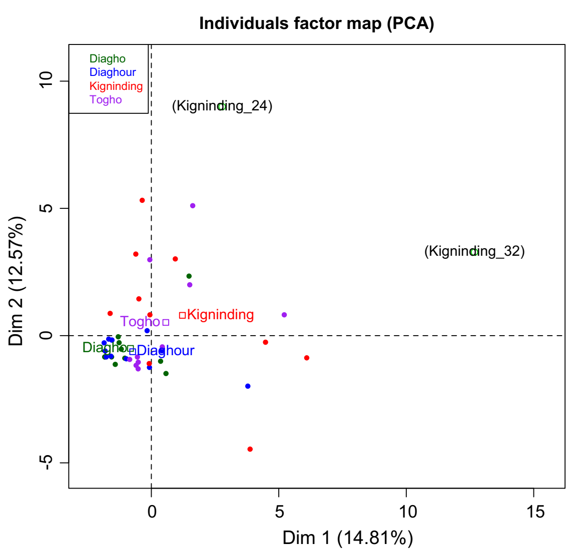


Fig. 4 PCA map of the individual inventories based on species that are present in more than four inventories, colored by village. (Color figure online)

Characteristics of *Elaeis guineensis* populations

The average density of *E. guineensis* was 243.45 individuals ha^{-1}. The comparison of *E. guineensis* densities among villages shows a significant ($p < 0.001$) effect of village, with less individuals in Diagho than in other villages (Fig. 5a). The relative abundance of *E. guineensis* was significantly different between villages ($p < 0.001$), with more relative abundance in Diagho and Diaghour villages compared to Kigninding and Togho (Fig. 5b).

The height of *E. guineensis* was used as a proxy to estimate the age of the trees. In all four villages, the most represented height classes are intermediate classes, i.e., the classes [10; 15] and [15; 20] with respectively 44.1 and 34.2% (Fig. 6).

The regeneration ratio was very low in all four villages (6.4 saplings for 100 adult trees in average), without any significant difference between villages (Fig. 7a). Furthermore, we observed a mortality ratio of 12.3 stumps for 100 adult trees in our inventories (Fig. 7b, no significant differences between villages), with 43% of the dead trees being attributable to the work of man, i.e., anarchic logging and fires. Several factors account for this low regeneration and high mortality: on one hand, the exploitation mode of the species prevents regeneration because oil extraction is done by cooking the seeds, furthermore, the nut is used to feed pigs and the almond is also used to extract palm kernel oil. Moreover, the saplings are victims of bad agricultural practices and other kind of anthropological pressure. On the other hand, high mortality of palm trees is due to excessive cuttings and the climatic variability of these last decades, with the salinization of lands. This was confirmed by farmers during the interviews.

Farmer's interviews

According to 76% of the respondents to the farmers' interviews, the palm groves of the area are declining. However, 20% of the respondents thought palm groves are progressing, and 4% thought they are stable. The interviews clearly reinforce the observations made in the field (e.g., figure), which showed that the parklands of *E. guineensis* are aging. Among the causes of decline, salinization of land was the main cause, identified by 67% of respondents, followed by drought with 29%, clear cutting with 22%, and hydro-agricultural structures with 18% and finally bushfires with 13% (Fig. 8).

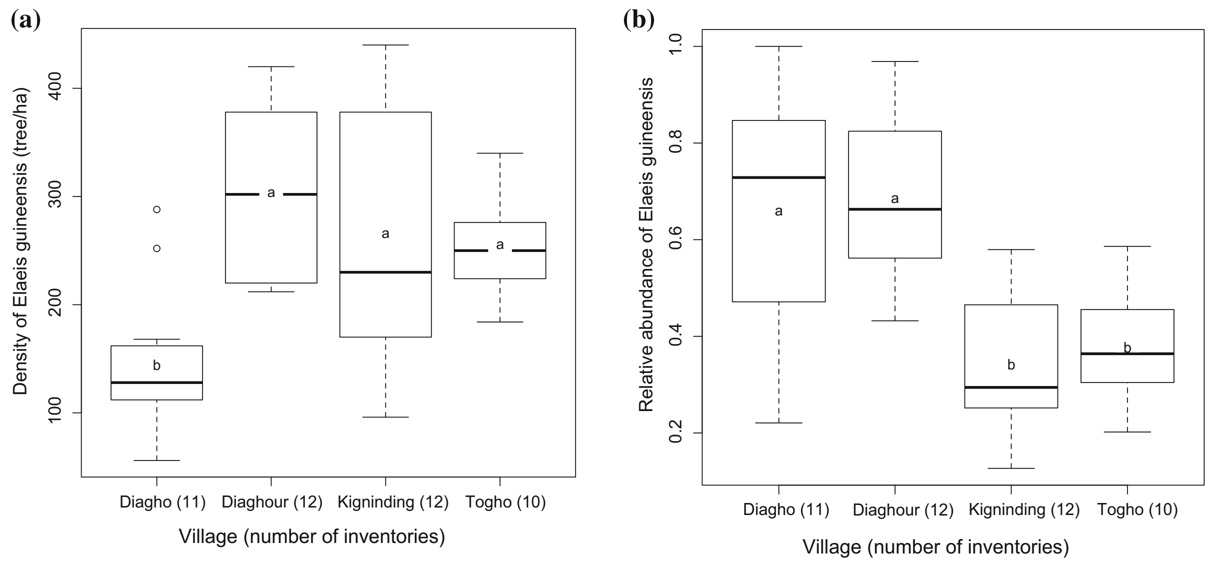


Fig. 5 Density (**a**) and relative abundance (**b**) of *Elaeis guineensis* in four villages in Senegal. The letters indicate the mean, and means with different letters are significantly different ($\alpha = 0.05$)

Discussion

To our knowledge, after consulting the literature, we think that this is the first report of the species composition and age structure of *E. guineensis* parklands in Lower Casamance. With 63 observed species, our results show a greater diversity than was previously observed in agroforestry parklands in other parts of western Africa: in the Prefecture of Doufelgou (Togo), Wala et al. (2005) found 9 species (with Shannon diversity index of 1.7) in parklands of *Parkia biglobosa* (Jacq.) R. Br. ex G. Don and 21 species (Shannon index = 0.5) in the only parklands of *E. guineensis* that was surveyed. Boffa (2000) found between 40 and 50 species in agroforestry parklands in Burkina Faso. Diedhiou et al. (2014) encountered 54 species distributed in 24 families and 43 genera in the parklands of Mar Fafaco's island in Senegal. The diversity found by Kebenzikato et al. (2014) in *Adansonia digitata*'s parkland in Togo was 52 species distributed in 45 genera and 23 families (the dominant families being Fabaceae and Moraceae, i.e., the same as in our study). Regarding tree density in agroforestry parklands, our results also show a larger tree density in Lower Casamance than in other regions in West Africa: Kebenzikato et al. (2014) found a density of 9.42 trees ha^{-1} in a parklands of *A. digitata* in Togo. Boffa (2000) found a density of 40 trees ha^{-1} in the parklands of the Town of Tokombéré in Cameroon. Wala et al. (2005) found a density of 150 trees ha^{-1} in the parklands of *E. guineensis* of Défalé and Niamtougou in Ghana. The much higher density found in our study at the Ouonck Municipality in Senegal (594 trees ha^{-1}) is allowed by the high soil fertility of the region but most importantly by the importance of forest trees for the local people, as stated during the interviews.

The importance of anthropogenic factors in the maintenance of these parklands is also illustrated by the results of the PCA of the abundance of tree species (Fig. 3): tree species are grouped by main uses (wood, medicinal products, spiritual aspects). This correlation between species, combined with the correlation with the distance to the village (sacred woods are kept close to the village, while trees used for wood production are further away), indicate the important role of management on the species composition of parklands.

However these parklands are at risk because of the current trends in agricultural activities. Our results show an ageing population of *E. guineensis* (Fig. 6), with a rate of mortality much higher than the rate of regeneration (Fig. 7). This risk is confirmed by the experience of the farmers expressed during the interviews: 76% of respondents considered that *E. guineensis* parklands are declining. This situation is not specific to our study region: Lamien et al. (2004)

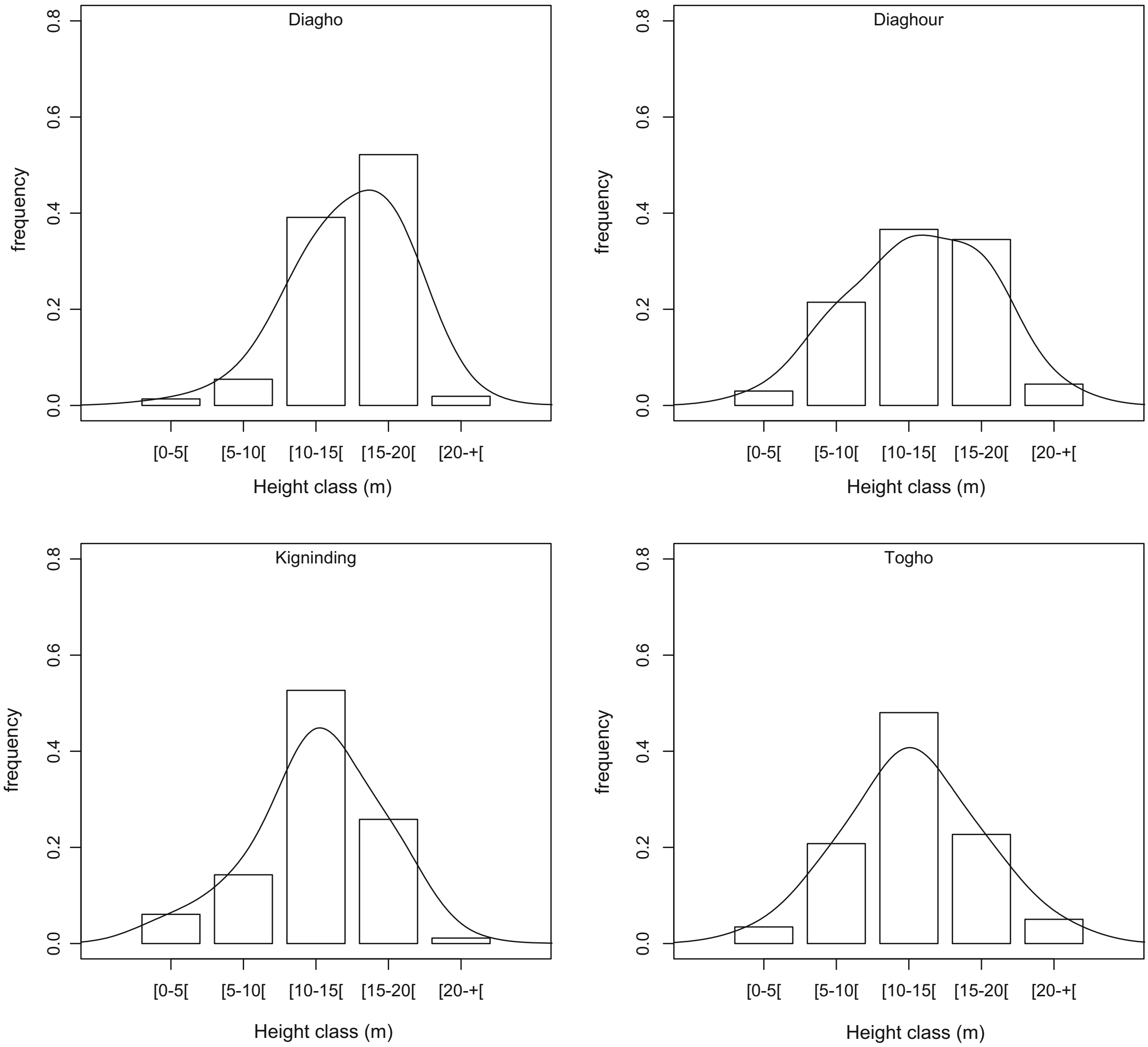


Fig. 6 Distribution of *Elaeis guineensis* by height class (bars represent the actual frequency in each class and the line is the estimated density distribution)

also found a dominance of individuals belonging to the middle diameter classes in a *Vitellaria paradoxa*'s parkland in Burkina Faso. Wala et al. (2005) also found the same pattern in a mixed parkland with *P. biglobasa–V. paradoxa* and in a parkland of *E. guineensis* in the Prefecture of Doufelgou in Togo. The same pattern was observed by Zomboudre (2009) in a parkland of *Faidherbia albida* and another parkland of *V. paradoxa* in the west of Burkina Faso.

The main causes of this degradation are salinization, drought, cuts, bad planning of hydro-agricultural structures and bushfires. The same causes have been identified by several authors (Gnangle et al. 2012; Dianda et al. 2009; Dah-Dovonon and Gnangle 2006) who highlighted that the aging of several parklands was caused by poor agricultural practices. Akpo et al. (2004), Tappan et al. (2004) Tiffen and Mortimore (2002), and also observed a reduction in wood density in agroforestry systems, mentioning drought as the main cause. Faye et al. (2002) indicated the anarchic exploitation of timber as the cause of degradation. Dan Guimbo et al. (2016) identified intensive exploitation of the ligneous resources as the main driver of the current dynamics of the plant communities in

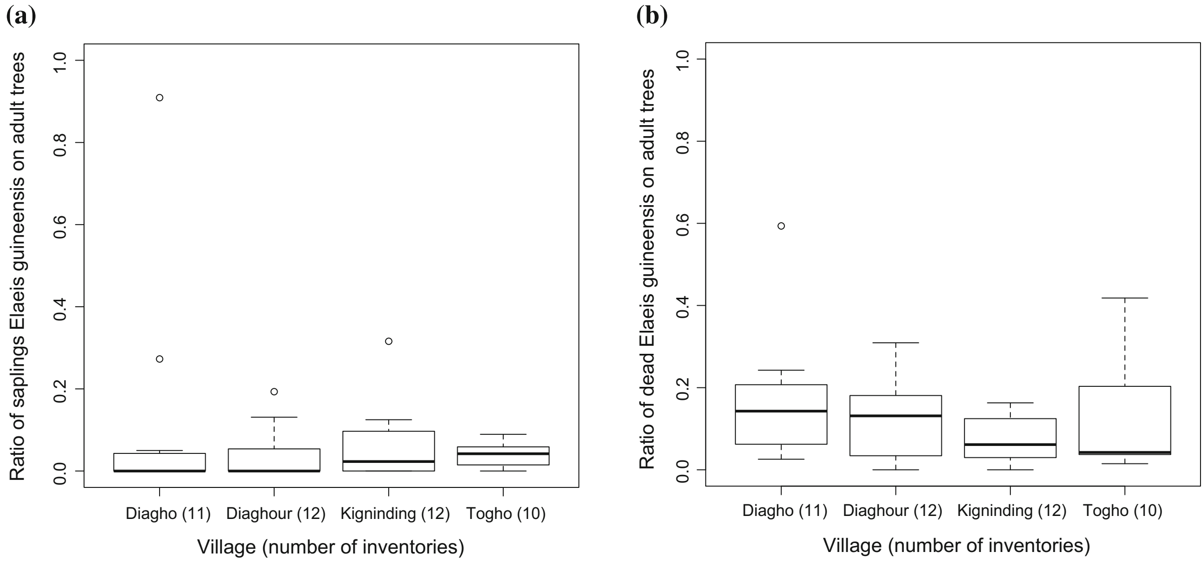


Fig. 7 Regeneration (**a**) and mortality (**b**) ratios of *Elaeis guineensis* in the four villages

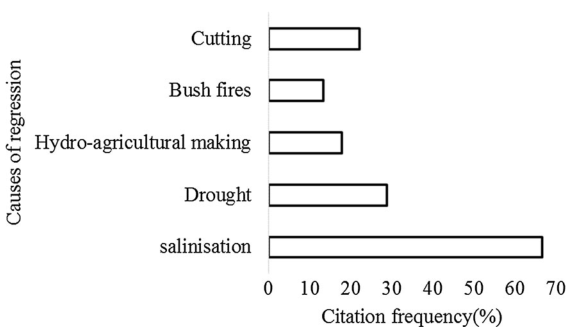


Fig. 8 Causes of the regression of the *Elaeis guineensis* parklands identified by farmers

agroforestry parklands. In the case of Ouonck's *E. guineensis* parklands, the other causal factor is the procedure of palm oil processing. Seeds are transported outside of the parklands to the places of processing and cannot be brought back to ensure regeneration because nuts are cooked whole for palm oil extraction, rather than separating the pulp from the kernel, and germination is almost impossible after cooking the seed. Furthermore, kernels are also used for palm kernel oil production.

Conclusion

This study is the first attempt to describe the *E. guineensis* parklands in Lower Casamance, which are characterized by a high diversity of accompanying trees, as well as a high density of trees. The species composition of the accompanying trees seemed affected mainly by human decisions to protect different species for different uses as a function of the distance to the village. Due to the small number of saplings and the high mortality of *E. guineensis* trees, aging of these parklands raises concerns about their survival. As most of the causes of decline are anthropogenic (i.e., excessive logging and inappropriate cultural practices), there is hope that raising public awareness of the fragility of these parklands could promote the conservation of those secular systems through protection of existing trees, promotion of natural regeneration or even reforestation.

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