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Effects of climatic variability and local environment patterns on the ecology and population structure of the multipurpose plant species, *Vitex doniana* Sweet (Lamiaceae) in Benin

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Abstract: We assessed impacts of climatic variability, land cover and proximity of river on the ecology and population structure of *Vitex doniana* Sweet in Benin (West Africa) in order to provide relevant information for its sustainable management and conservation in the context of global change. Numbers of contacts and numbers of adult individuals per contact of the species along transects revealed through negative binomial model that even though the species is present in all climatic zones, it does not show preference to a particular zone, but it is more frequent in mosaics of croplands and fallows (MCF) and in areas at less than 500 m to river. Analyses of floristic composition, suggested that *V. doniana* occurs globally in different woody plant communities regarding climatic zones, land cover types and distance to the closest river. Significant interaction effects of climatic zone and land cover type were noted on structural parameters (mean diameter and basal area) of *V. doniana* with the highest values in the Sudanian MCF (46.11±23.83 cm and 3.35±3.07 m^2 ha^{-1}). Moreover, diameter structures revealed globally a predominance of relatively young individuals (dbh ≤ 20 cm) of the species. Although studied environmental factors do not have significant effect on densities of the species (adult and regeneration), the relatively low values recorded may lead to a rapid decline of its populations in future. Sustainable management practices should be thought to favour and preserve the regeneration of the species for it conservation.

Key words: Agroforestry species, conservation, global change, plant ecology, population patterns, *Vitex doniana*, wild fruiting trees.

Introduction

Forest resources have been of great importance for human well-being since early stages of humanity and lot of people are still dependant (MEA 2005). Among these forest resources, fruiting tree species play significant roles for humankind (Atato *et al.* 2011; Becker 1983; Lykke *et al.* 2004) and because of that, some of them have been maintained in agricultural lands during land clearing building up then agroforestry systems (Akinnifesi *et al.* 2008). These species, previously considered as less useful and underutilized products, are becoming more and more important and considered in many policies worldwide generally and particularly in developing countries (Oladélé 2011). This is mainly because they provide several goods and services to local people enhancing

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then their capacity to face food shortage (Atato *et al.* 2011), help in poverty alleviation (Akinnifesi *et al.* 2008; Oladélé 2011) and also enhance biodiversity conservation (Vodouhê *et al.* 2011). Unfortunately, habitat and population of these species are facing increasing pressures due to the rapid human population growth (MEA 2005; Nacoulma *et al.* 2011) and climate change (FAO 2012; IPCC 2007).

Indeed, there are evidences that global change including mainly climate and land cover changes is affecting ecosystems and they may no longer be able to provide goods and services for the growing human population (FAO 2012; Sala *et al.* 2000). In West Africa for instance, forests ecosystems are already facing impacts of climate change and climate variability with increases in trees mortality, and decreases in forest species richness and trees density (IPCC 2007; Kalame *et al.* 2009). In the same time, anthropogenic pressures (wood, bark, roots, leaves and fruits harvesting) have been reported to affect the population structure and survival of several plant species (Delvaux *et al.* 2009; Mensah *et al.* 2014; Nacoulma *et al.* 2011) among which wild fruiting plants are the most targeted. Undeniably, because of their importance for human well-being, these wild plant species are facing increasing harvesting pressures (Haarmeyer *et al.* 2013) and this combined with climatic variability and land cover change constitutes a threat not only for their survival but also for the goods and services provision for human well-being (MEA 2005). There is then a need to understand and document effects of such threats on their populations. Moreover, assessing their current status and factors affecting their survival is an important step towards their conservation in this context of global change (Lindenmayer & Fischer 2006; Mensah *et al.* 2014).

The black plum or African oak (*Vitex doniana* Sweet) is one of these important multipurpose plant species in many parts of Africa for which sustainable management actions are required (Achigan-Dako *et al.* 2011; Mapongmetsem *et al.* 2012; Maundu *et al.* 2009). Apart of its probable role in soil fertility improvement by litter production (Mapongmetsem 2005), the species is used for several purposes. For instance, the blackish pulp of the ripened fruits is edible and used in the preparation of some drinks. The young leaves are used as leafy vegetables in sauces preparation. The leaves are also used as fodder for livestock. The wood is suitable for construction and fire (Arbonnier 2002; Louppe *et al.* 2008). The mature leaves, the bark and the roots have phytotherapeutic properties and are used to heal several diseases (Kilani 2006; Iwekue *et al.* 2006; Padmalatha *et al.* 2009). In Benin, *V. doniana* is one of the ten most important NTFPs species valued by local people and for which sustainable use and conservation strategies are required (Achigan-Dako *et al.* 2011, 2014; Assogbadjo *et al.* 2012; N'Danikou *et al.* 2011). It is known as a particular agroforestry tree with high socio-economic value (Achigan-Dako *et al.* 2011; Dadjo *et al.* 2012; Oumorou *et al.* 2010).

Some studies have proved its pharmacological importance (Iwekue *et al.* 2006; Kilani 2006; Padmalatha *et al.* 2009), its importance in food proceeding (Agbede & Ibitoye 2007; Okigbo 2003), its ethnobotanical values (Dadjo *et al.* 2012), and its domestication status and germinative abilities (Achigan-Dako *et al.* 2011, 2014; Mapongmetsem *et al.* 2012; N'Danikou *et al.* 2014; Sanoussi *et al.* 2012). However, only few data are available on the ecology and population structure of the species at local scale (Oumorou *et al.* 2010). The knowledge of the ecology and structure of the species population could then foster domestication and conservation strategies in the context of global change.

Even though several studies have proved impacts of respectively climatic variability and land cover on the population structure of many useful plants species, only few of them have focused on widely distributed species (Ouédraogo *et al.* 2013) like *V. doniana*. With its high plasticity in habitat selection (Arbonnier 2002; Louppe *et al.* 2008), *V. doniana* may have developed adaptive responses to its local climatic environment (Anyomi *et al.* 2012; Mensah *et al.* 2014). Moreover, following insights from previous studies which showed impacts of climatic variability and human disturbances on structural parameters of some plant species (Fandohan *et al.* 2011; Glèlè Kakaï *et al.* 2011; Mensah *et al.* 2014; Nacoulma *et al.* 2011; Ouedraogo *et al.* 2013), it is expected that *V. doniana* occurs in specific ecological conditions with specific structure according to climatic zones and local environment patterns (land cover and distance to river). Indeed, Huston Dynamic Equilibrium Model (Huston 1979) predicts effects of interactions between resource factors and disturbances on tree species and growth. In addition, the fact that the global change does not occur in homogenous way in regions (Walther *et al.* 2002) leads to hypothesize that *V. doniana* may show heterogeneity in its

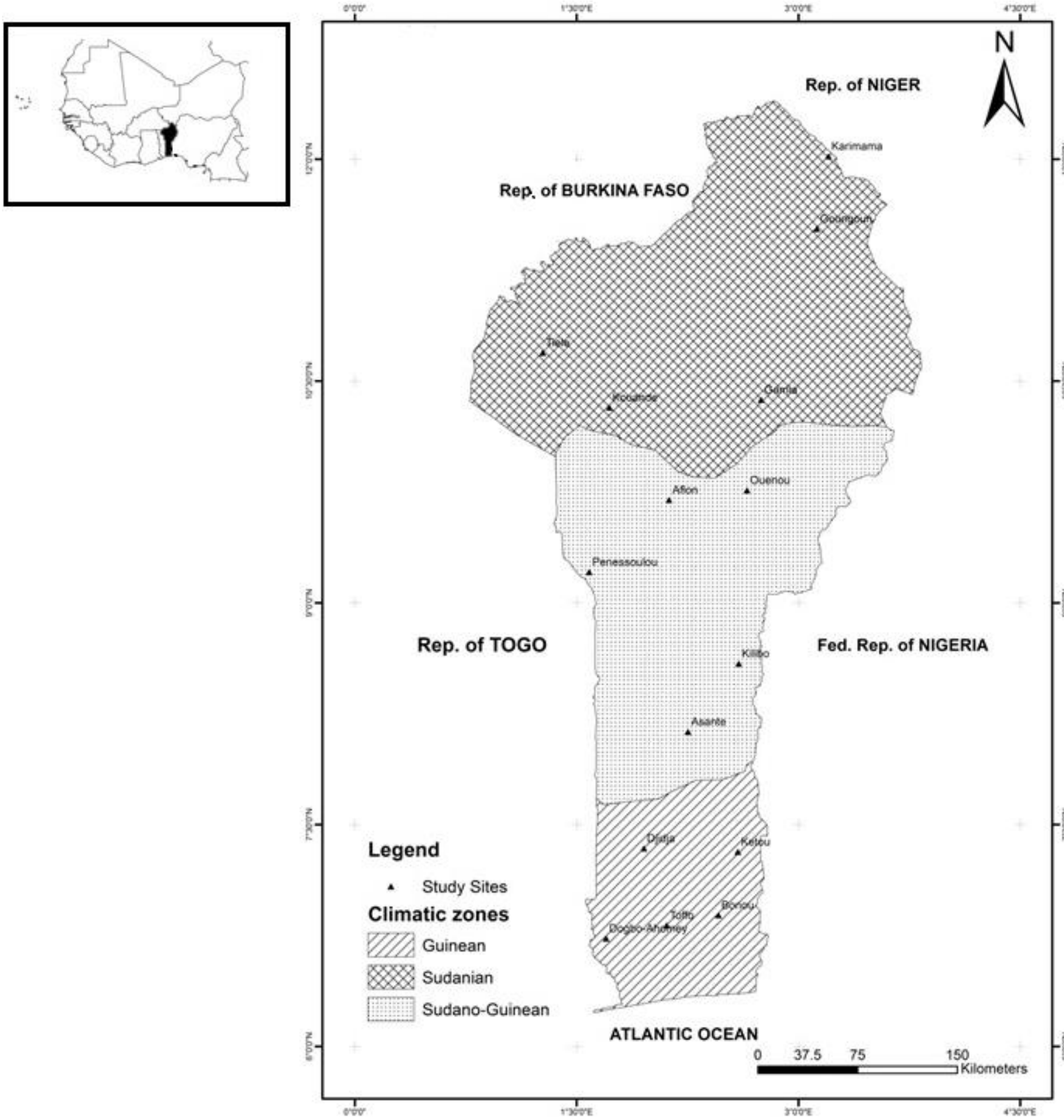

Fig. 1. Location of study sites.

ecological dynamics across the country based on the environmental differences especially climatic zones, land cover and distance to the closest river.

Material and methods

Target species

Vitex doniana Sweet (black plum or African oak) of the Lamiaceae family (formerly Verbenaceae) is a multipurpose agroforestry tree species occurring in various habitats from forests to savannahs, often in wet localities and along rivers. It occurs in regions with a mean annual rainfall between 750–2000 mm and a temperature ranging from 10 to 30 °C. It is a deciduous small to medium sized tree species up to 25 m, bole branchless for up to 11 m with a diameter which can reach 160 cm. It presents opposite and digitately compound leaves; its flowers are bisexual and zygomorphic and the fruits obovoid to oblong-ellipsoid drupes (2–3 cm long), purplish black and fleshy (Arbonnier 2002; Louppe *et al.* 2008).

Study area

The study was carried out in Benin republic (114,763 km^2, between 6°10′ and 12°50′N and 1° and 3°40′E, Fig. 1) in West Africa. The country's climatic profile shows three climatic zones: the Guinean zone, between 6°25′ and 7°30′N; the Sudano-Guinean zone, from 7°30′ to 9°45′N and the Sudanian zone,

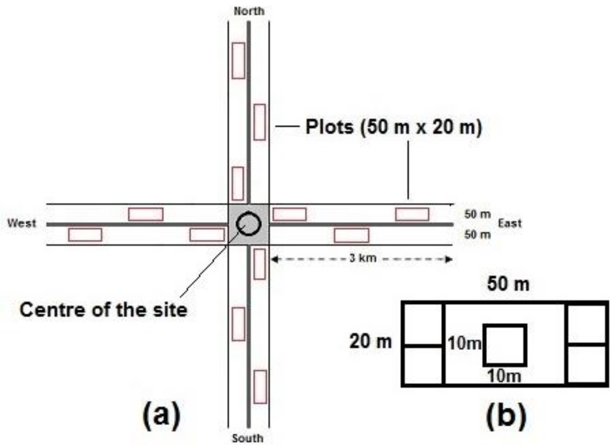

Fig. 2. Research design for ecology and structural parameters assessment on *V. doniana*: (a) Orientation of transects, (b) Plot design with disposition of subplots.

between 9°45′ to 12°25′ N (Adomou *et al.* 2006). The Guinean zone is characterised by a subequatorial climate with four seasons (two rainy and two dry). The rainfall of about 1200 mm per year is bimodal mostly from March to July and September to November. The temperature varies between 25 and 29 °C, and the relative humidity is between 69 and 97%. The Sudanian zone has a tropical dry climate with two equal length seasons (rainy and dry). The mean annual rainfall in this zone is often less than 1000 mm and occurs mainly from May to September; the relative humidity varies from 18 to 99% and temperature from 24 to 31 °C. The Sudano-Guinean is a transitional zone with two rainy seasons merging in a unimodal regime. The annual rainfall varies between 900 and 1110 mm, the temperature is between 25 and 29 °C and relative humidity from 31 to 98% (Assogbadjo *et al.* 2012; Gnanglè *et al.* 2011).

The country presents different land cover types which can be grouped in four major units (Orekan 2007): natural formations, anthropogenic formations, agglomerations and water and bare terrain (water surfaces, rocky surfaces, and sandy beaches). The predominant units are natural formations and anthropogenic formations. The natural formations covering more than half of the country include: tree and shrub savannahs (50.35% of the country area), open forests and woodlands (13.12%), riparian forests (2.49%), swampy forests (1.66%) and dense forests (0.62%); while the anthropogenic formations are composed of mosaics of croplands and fallows (28.31%) and plantations (2.11%).

The hydrographic network of the country is structured in four major sets which are parts of sub-regional river-catchments (Niger, Volta, Mono Couffo and Ouémé Yewa). It is a very dense hydrographic network covering the whole country and composed of seven permanent rivers (Ouémé, Mono, Couffo, Pendjari, Mékrou, Alibori and Sota) and several seasonal and temporary rivers (Le Barbé *et al.* 1993).

Research design and data collection

Five villages were randomly selected in each climatic zone for data collection. In each of the villages selected, a point was chosen as the centre of the site and from this point, four transects of 3 km each were set (Fig. 2a) in the four directions (North, South, East and West). A Global Positioning System (GPS) and a compass were used for the transect orientation and a measuring tape for distance measuring. Investigations were done within a band of 100 m of width along each transect. Within each band, plots of 50 × 20 m were laid around each encountered individuals of *V. doniana* with diameter at breast height of at least 5 cm (dbh ≥ 5 cm). Five sub-plots (10 × 10 m^2) were set in each plot to study the regeneration of the species (Fig. 2b). In total, 226 plots were laid along sixty 3-km long transects.

Within each 50 × 20 m^2 plot, the dbh of adult individuals (dbh ≥ 5 cm) of all woody species and the total height of adult individuals (dbh ≥ 5 cm) of *V. doniana* were recorded, respectively, with a diameter tape and a clinometer. In each 10 × 10 m^2 sub-plot, the regeneration of the species (dbh < 5 cm) was assessed by counting the number of individuals. For each plot, land cover type was recorded in field. Soil samples were collected in about 55 randomly selected plots for determination of some key physico-chemical parameters (granulometry, total nitrogen, organic carbon and pH). Moreover, the GPS coordinates of the plots (at the centre of each plot) were projected respectively on a land cover map, soil map and hydrographic map of Benin in QGIS 1.8.0 (QGIS Development Team 2013) in order to update the land cover type and soil information and determine the plot distance to the closest river.

Finally, five land cover types were observed and considered: riparian forests (RF), open forests and woodlands (OFW), tree and shrub savannahs (TSS), mosaics of croplands and fallows (MCF) and plantations (Plt). According to the distance to the closest river, four classes of distance were considered: class1 (<500 m), class2 (500–1000 m), class3 (1000–1500 m) and class4 (>1500 m).

Table 1. Negative binomial regression estimates for frequency and abundance of *V. doniana*. Land cover types: MCF = mosaics of croplands and fallows, OFW = open forests and woodlands, Plt = plantation, RF = riparian forests, TSS = tree and shrub savannahs; Classes of distance to the closest river: class1= <500 m; class2 = 500–1000 m; class3 = 1000–1500 m; class4 = >1500 m.

	Number of contacts per transect		Abundance per contact	
Factors	Estimates	*P*	Estimates	*P*
Climatic zones (Ref= Guinean)				
Sudanian	−0.336	0.317	0.251	0.384
Sudano-Guinean	−0.262	0.433	0.522	0.062
Land cover types (Ref=MCF)				
OFW	−2.766	0.000	−2.238	0.000
Plt	−2.883	0.000	−2.238	0.000
RF	−2.565	0.000	−2.015	0.000
TSS	−0.956	0.001	−0.679	0.002
Classes of distance (Ref=class1)				
class2	−1.352	0.000	−1.136	0.000
class3	−1.872	0.000	−1.686	0.000
class4	−1.785	0.000	−2.197	0.000

Data analysis

Apart from diameter structures analysis, all analyses were performed in R 3.1.0 software (R Core Team 2014) with specific packages. Effects of studied factors or their interactions were declared statistically significant when *P* value is less than 0.05.

Ecological preferences of Vitex doniana

Numbers of contacts with adult individuals (dbh ≥ 5 cm) of the species (i.e. absolute frequencies of observations of the species) along transects and number of adult individuals per contact (abundance of the species) were used to assess its ecological preferences according to the local environmental patterns (climatic zones, land cover types and distance to the closest river) and their interactions. Generalized linear models (GLM) were used because normality and homogeneity of variance assumptions were not fulfilled by the data (Glèlè Kakaï *et al.* 2006). The negative binomial model was preferred because it fitted well the data than Poisson and QuasiPoisson models. MASS package (Venables & Ripley 2002) was used for the analysis.

Assessing the floristic composition of the woody plant community in which V. doniana *occurs*

In order to assess the woody floristic assemblages within which *V. doniana* occurs, a non-metric multidimensional scaling (NMDS) with metaDMS procedure was performed on an abundance matrix (226 plots and 65 woody plant species except *V. doniana*) from which a dissimilarity matrix based on Bray-Curtis index was derived. A Permutational Multivariate Analysis of Variance Using Distance Matrices was also performed to test the difference in floristic composition of climatic zones, land cover types and distance to the closest river classes. Moreover, in order to emphases precedent results, pairwise Jaccard's similarity index (Chao *et al.* 2005) was calculated considering the above mentioned environmental patterns. Vegan package (Oksanen *et al.* 2013) was used for NMDS and permutational multivariate analysis of variance using distance matrices and diversity indices calculation, while fossil package (Vavrek 2011) was used for Jaccard's similarity index calculation.

Structural parameters of V. doniana *population*

Mean and standard deviation of mean diameter (Dg, cm), basal area (Ba, m^2 ha^{-1}), contribution of *V. doniana* to the basal area of the stand (Cs, %), mean height of Lorey (HL, m), density of adult individuals (N, stems ha^{-1}) and density of regeneration (Nreg, plants ha^{-1}) were calculated per plot. Two-way analysis of variance was used to test for mean differences (Dg, Ba, Cs and HL) regarding land cover types by climatic zone on one hand, and classes of distance by climatic zone on the other hand. Data were log-transformed (log(x)) to fulfil

Table 2. Soil parameters under *V. doniana* according to climatic zones. Values are mean±1SD. *P* values are from one-way ANOVA on transformed data in some cases (square root transformation for OC, TN, C and Fsand; and log (x+1) for CSilt and FSilt. On lines, numbers followed by the same letters are not statistically different at 0.05. OC = organic carbon; TN = total nitrogen; CSilt = coarse silt; FSilt = fine silt; C = clay; Fsand = fine sand; Csand = coarse sand.

	Guinean	Sudano-Guinean	Sudanian	*P*
pH	4.96^{a} ±0.5	5.10^{a} ±0.56	5.53^{b}±0.52	0.006
OC (%)	0.85^{a} ±0.5	1.49^{b} ±0.91	1.41^{b}±0.96	0.025
TN (%)	0.08±0.03	0.10±0.04	0.10±0.03	0.298
CSilt (%)	6.77^{a} ±5.87	$9.92^{a,b}$±7.12	14.09^{b}±9.08	0.007
FSilt (%)	7.22±6.68	10.71±7.39	9.27±6.26	0.160
C (%)	13.55±8.41	11.39±5.91	9.98±4.04	0.324
Fsand (%)	30.94±9.62	26.00±8.20	32.53±9.74	0.091
Csand (%)	40.89±18.19	41.15±20.03	33.22±11.88	0.323

the assumption of normality. In case of significant effect, Tukey's post hoc test was used for pair-wise comparison. Negative binomial models were used with MASS package (Venables & Ripley 2002) for the density data (adults and regeneration).

Within each climatic zone, stem diameter structures were established and adjusted to the 3-parameters Weibull theoretical distribution (Johnson & Kotz 1970) for each land cover type and class of distance to the closest river. Since only adult individuals with dbh ≥ 5cm were considered in the study, a threshold of 5 cm was used to estimate the two other parameters of the Weibull distribution (scale and shape) with Minitab 17 (Minitab Inc. 2010). A log-linear analysis was performed in SAS 9.1 (SAS Inc. 2003) to test the adequacy of adjustments.

Results

Ecology of Vitex doniana

Ecological preference

Vitex doniana seems to not have preference to a particular climatic zone because climatic zone did neither affect absolute frequencies of contacts with the species along transect nor its abundance (number of adult individuals per contact). It was rather land cover and distance to the closest river that showed significant effect on absolute frequencies of contacts and abundance of the species (Table 1). Moreover, significant interaction effects of climatic zone and respectively land cover and distance to the closest river were observed on the absolute frequencies of contacts with *V. doniana* along transects and its abundance. Globally, whatever the climatic zone, *V. doniana* was more observed and abundant in mosaics of croplands and fallow with in average about 4 contacts per transect in the Guinean zone, 2 in the Sudanian zone and 1 in the Sudano-Guinean zone (Fig. 3a,b); and in areas at less than 500 m to a river with in average about 2 observations in the Guinean and Sudanian zones and 3 in the Sudano-guinean zone (Fig. 4a,b). Although findings showed that the species occurs in variety of habitats, in the Sudano-Guinean zone, the species was not observed beyond 1000 m to a river.

V. doniana was observed on a variety of soils with the highest relative frequencies of observations on ferrallitic soil (30.53%), mainly in the Guinean climatic zone and on lixisols with concretions (28.3%). Soils under the species were acid (pH < 6) and the acidity was more pronounced in the Guinean and Sudano-Guinean zones (Table 2). In the Sudano-Guinean and Sudanian zones, soils under *V. doniana* had higher proportions of organic carbon and coarse silt than in the Guinean zone ($P < 0.05$, Table 2).

Floristic composition of woody plant community around *Vitex doniana*

The non-metric multidimensional scaling (NMDS) gave a very good ordination of the 226 plots with a stress of 0.061 and a R^2 value of 0.996. Even though the results did not show clear discrimination of the plots according to climatic zones (Fig. 5a), land cover types (Fig. 5b) and distance to the closest river (Fig. 5c), a closer look at Fig. 5a reveals a discrimination of the plots along the NMDS1. Along this axis, plots of the Sudanian zone are at the left side, while Guinean plots are at the right side with the Sudano-Guinean's in between them. This was

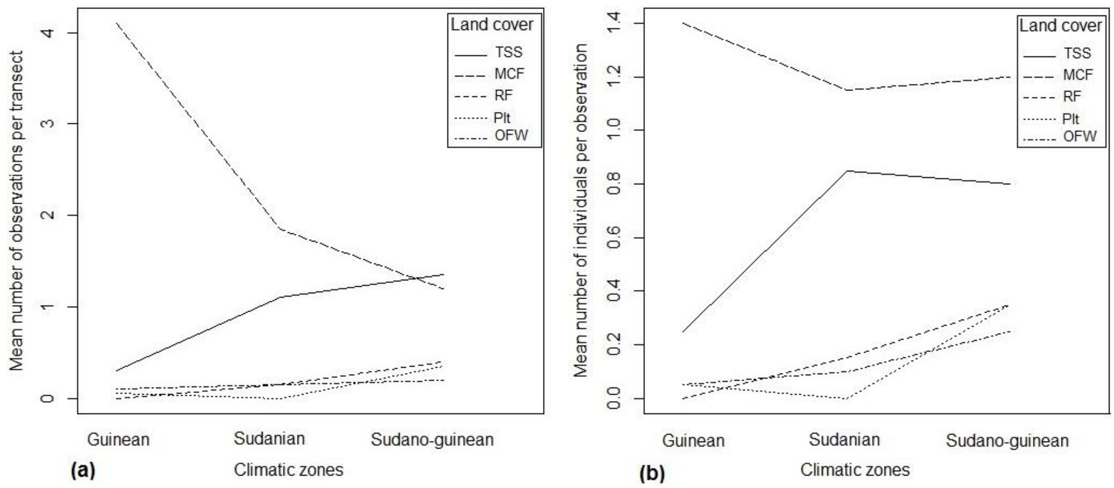

Fig. 3. Interaction plot of climatic zone and land cover type on the ecological preferences of *Vitex doniana:* (a) Mean number of observations (contacts with adult individuals of *V. doniana*) per transect, (b) Mean number of individuals (abundance of *V. doniana*) per observation. TSS = tree and shrub savannahs, MCF: mosaics of croplands and fallows, RF: riparian forests, Plt: plantation, OFW: open forests and woodlands.

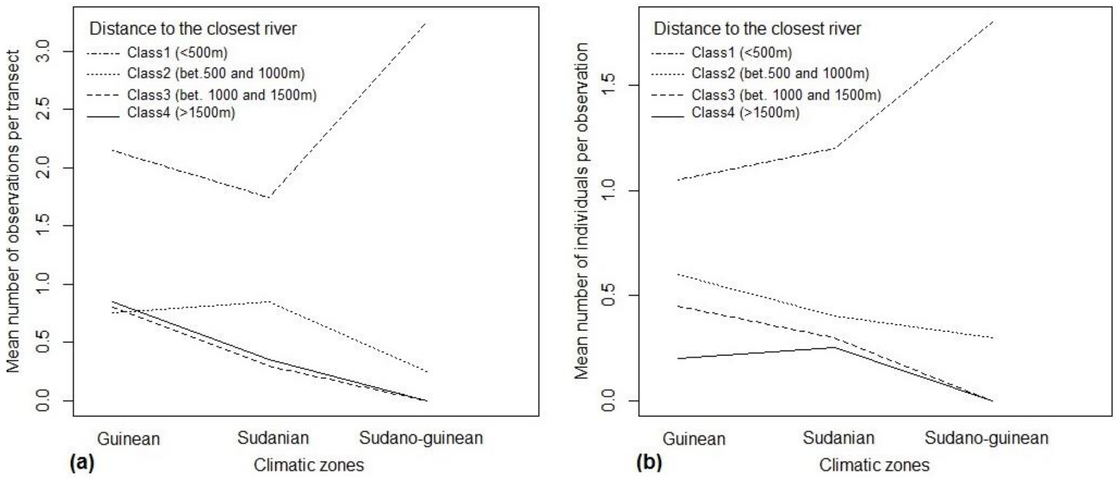

Fig. 4. Interaction plot of climatic zone and distance to the closest river on the ecological preferences of *Vitex doniana:* (a) Mean number of observations (contacts with adult individuals of *V. doniana*) per transect, (b) Mean number of individuals (abundance of *V. doniana*) per observation.

confirmed by the permutation multivariate analyses of variance using distances matrices whose results showed a significant difference ($P < 0.05$) in the woody floristic composition of the plots according to climatic zones, land cover types and classes of distance to the closest river.

These results were emphasised by the pairwise Jaccard's index showing that *V. doniana* occurred globally in different woody floristic communities when considering either climatic zones, or land cover types or classes of distance to the closest river in climatic zones (Tables S1–3). It was only in the Sudanian and Sudano-guinean zones that some similarities (Jaccard > 0.5) were observed for the woody plant communities around *V. doniana* regarding land cover types (Table S2). When considering the distance to the closest river, class1 (<500 m) and class2 (500–1000 m) in the Guinean zone showed also similar woody communities around *V. doniana* (Table S3).

Population structure of V. doniana

Structural parameters of *V. doniana*

Table 3 and Table S4 summarized structural parameters of *V. doniana* according to the considered environmental factors. In general, there

Table 3. Structural parameters of *V. doniana* (dbh ≥ 5 cm) according to climatic zones and land cover types. Values are mean ± 1 SD. *P* values computed from log-transformed data (y = log(x)) for Dg, Ba and HL for the comparison of the 3 climatic zones (last column) and land cover types (lines). On lines, values followed by the same letters are not statistically different at $P < 0.05$.

Land cover	Guinean	Sudano-Guinean	Sudanian	*P*
		Density (N, stems ha^{-1})		
MCF	16.71±11.45	16.67±9.63	17.30±10.71	0.945
OFW	-	17.50±9.57	10.00±0.00	0.072
Plt	-	15.71±11.34	-	-
RF	-	12.50±7.07	10.00±0.00	0.427
TSS	11.67±4.08	19.26±12.69	18.64±11.25	0.744
P	0.25	0.40	0.13	
		Density of regeneration (Nreg, plants ha^{-1})		
MCF	5.41±6.95	4.17±6.07	3.62±6.75	0.549
OFW	-	9.50±11.24	0.00	-
Plt	-	2.29±5.22	-	-
RF	-	4.00±7.41^{a}	15.33±21.57^{b}	0.000
TSS	7.67±7.94	8.44±8.10	5.09±5.75	0.157
P	0.20	0.377	0.08	
		Mean diameter (Dg, cm)		
MCF	22.04±10.96^{a}	25.67±19.04^{a}	46.11±23.83^{b}	0.000
OFW	-	26.81±23.53	32.83±16.33	0.178
Plt	-	7.44±2.46	-	-
RF	-	41.54±29.53	39.00±39.36	0.881
TSS	18.80±16.33	18.73±14.68	25.24±14.34	0.169
P	0.004	0.003	0.007	
		Basal area (Ba, m^{2} ha^{-1})		
MCF	0.68±0.62^{a}	1.36±2.28^{a}	3.35±3.07^{b}	0.000
OFW	-	1.11±1.22	1.00±0.92	0.225
Plt	-	0.11±0.18	-	-
RF	-	2.04±2.10	2.00±3.03	0.791
TSS	0.49±0.8	0.98±2.05	0.96±0.92	0.149
P	0.009	0.009	0.010	
		Contribution to stand basal area (Cs, %)		
MCF	41.08±29.35^{a}	28.69±24.66^{b}	47.20±30.18^{a}	0.052
OFW	-	18.22±3.83	20.24±8.76	0.087
Plt	-	6.56 ±3.45	-	-
RF	-	26.83±23.89	20.56±25.97	0.713
TSS	41.22±26.80^{a}	20.67±17.98^{b}	17.46±13.03^{b}	0.015
P	0.09	0.131	0.000	
		Mean height of Lorey (HL, m)		
MCF	7.09±3.10	8.41±5.07	8.31±3.14	0.207
OFW	-	10.94±7.26^{a}	12.69±2.44^{b}	0.028
Plt	-	4.73±1.31	-	-
RF	-	13.00±7.25	8.26±3.38	0.684
TSS	6.56±5.97	6.57±4.56	7.23±3.39	0.508
P	0.01	0.08	0.13	

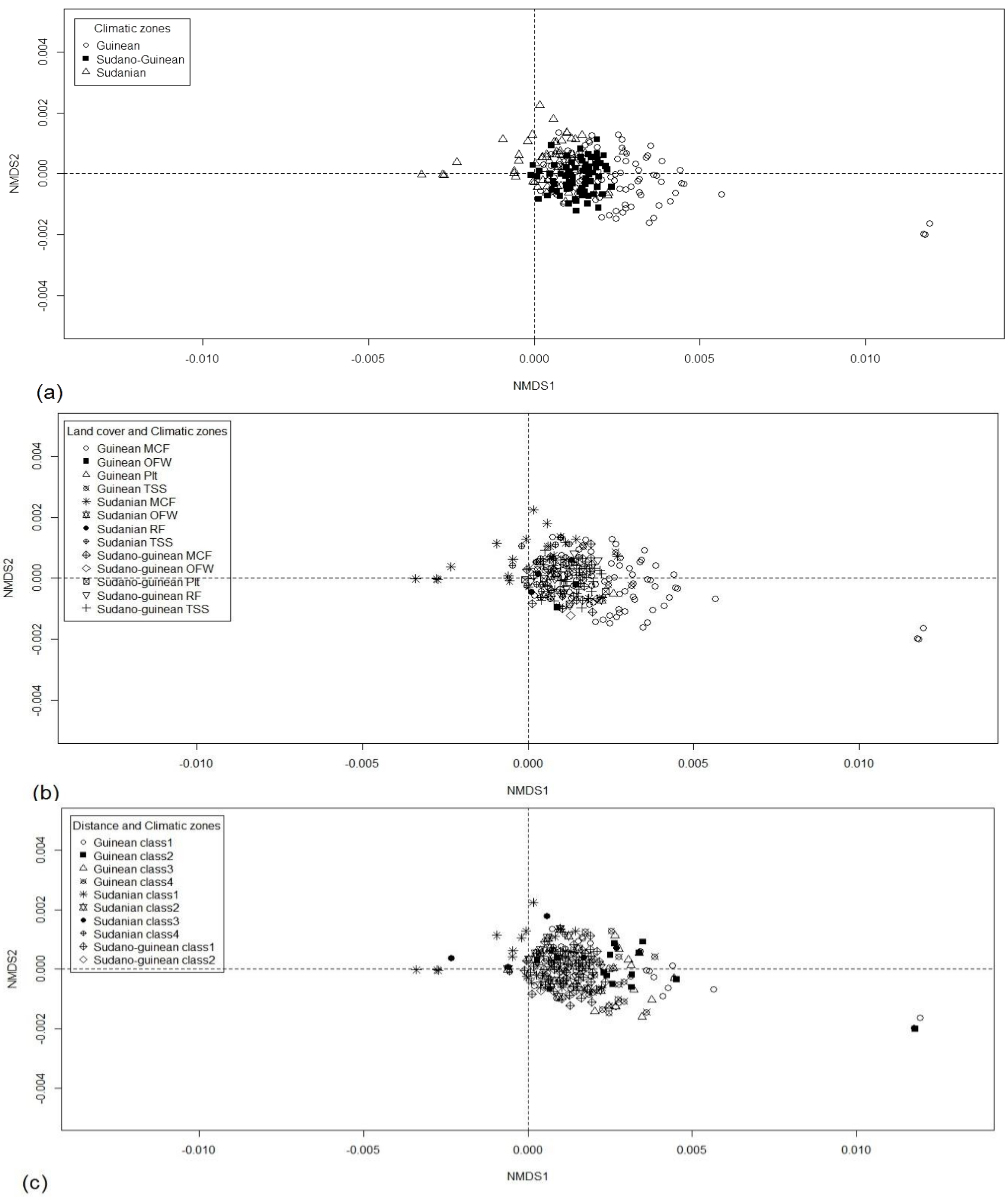

Fig. 5. Projection of the 226 plots (50 × 20 m^2) in the NMDS1 and NMDS2 axes system (a) According to climatic zones, (b) According to land cover types and climatic zones, (c) According to classes of distance to the closest river and climatic zones. MCF= Mosaics of croplands and fallows; OFW = Open forests and woodlands; Plt = Plantation; RF = Riparian forests; TSS = Tree and shrub savannahs. class1= <500 m; class2 = 500–1000 m; class3 = 1000–1500 m; class4 = >1500 m.

were no significant effects of studied factors on densities (adults and regeneration) of the species. Globally, densities of adult individuals and regeneration of the species were below, respectively, 20 stems ha^{-1} and 10 plants ha^{-1}. Significant interaction effects of climatic zone and land cover were observed on mean diameter (Dg), basal area (Ba), contribution of *V. doniana* to stands' basal area (Cs) and mean height of Lorey (HL). Meanwhile, only contribution of the target species to stands basal area was under the effect of interaction of climatic zone and distance to the closest river.

Effects of land cover and climatic zones

Within each of the three climatic zones, mean diameter (Dg) and basal area (Ba) varied significantly between land cover types with the highest values in mosaics of croplands and fallows in the Guinean and Sudanian zones, and in riparian forest in the Sudano-guinean zone (Table 3).

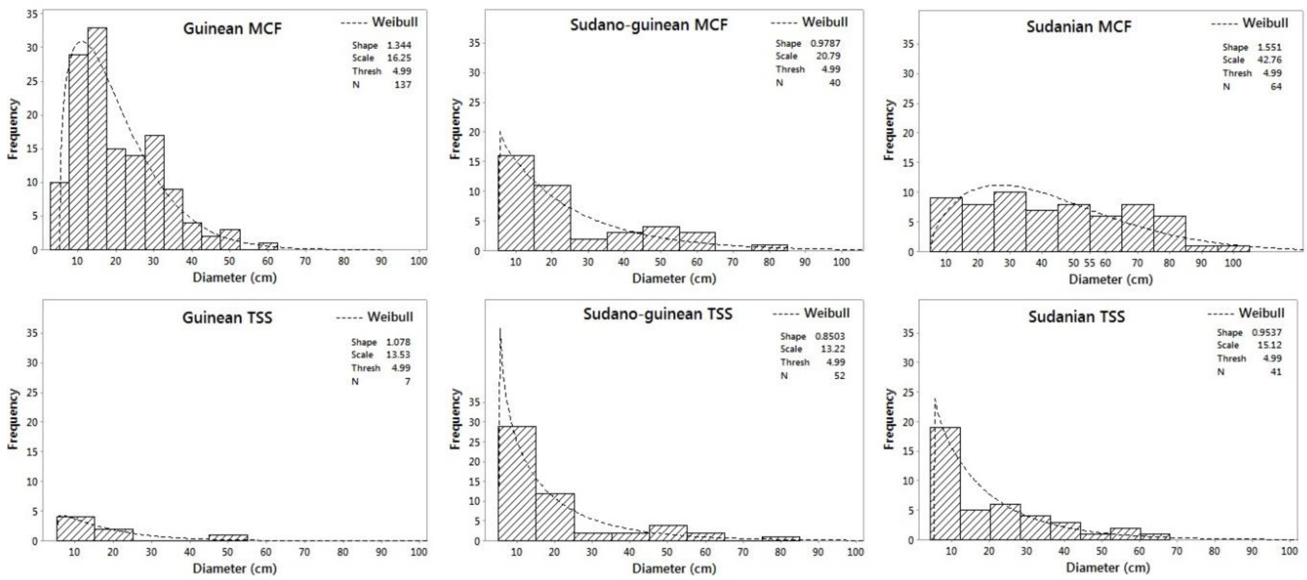

Fig. 6. Diameter structures of *V. doniana* according to climatic zones and land cover types (Only land cover types present in all climatic zones have been considered). MCF = Mosaics of croplands and fallows; TSS = Tree and shrub savannahs.

Meanwhile, contribution of *V. doniana* to stands basal area (Cs) and mean height of Lorey (HL) varied between land cover types only in, respectively, the Sudanian and Guinean zones with the highest values (47.20±30.18% for CS and 7.09±3.10 m for HL) in mosaics of croplands and fallows (MCF).

When considering land cover types between climatic zones, mean diameter and basal area varied significantly only for mosaics of croplands and fallows with highest values in the Sudanian zone (46.11±23.83 cm and 3.35±3.07 m^2 ha^{-1}, respectively). While the highest contribution of the species to stands basal area (Cs) was observed in the Guinean tree and shrubs savannahs (41.22±26.80%), the highest mean height of Lorey was recorded in the Sudanian open forests and woodlands (12.96±2.44 m).

Effects of distance to the closest river and climatic zone

Within climatic zones, only contribution to stands basal area varied significantly in the Guinean zone with the highest value (61.46±29.12%) in class3 (1000–1500 m) (Table S4). Between climatic zones, regarding mean diameter and basal area, there was significant difference for all distance classes except for class2 (500–1000 m) and the highest values were recorded in the Sudanian zone. Moreover, only class2 showed significant difference of the species contribution to basal area and the Guinean zone had the highest values (51.90± 31.99%).

Diameter structure

Globally, *V. doniana* exhibited left dissymmetric diameter structures (1 < shape < 3.6) in the Guinean and Sudanian zones according to land cover type (Fig. 6) and distance to the closest river (Fig. 7) while in the Sudano-guinean zone, the diameter structures had reversed-J shape (shape <1). All these diameter structures revealed predominance of relatively young individuals (dbh ≤ 20 cm) with some particularities.

Regarding land cover types, for instance, in stands of the Guinean mosaics of croplands and fallows (MCF), the 10–20 cm dbh class was the most represented with more than 30 individuals whereas the other dbh classes had less than 20 individuals each. The trend was similar for Sudano-guinean MCF but with low frequency of individuals. Meanwhile, stands of the Sudanian MCF exhibited a particular stem distribution with relatively balanced frequencies (about 10 individuals) for each of the dbh classes except for the last two classes. Stands of the TSS presented almost the same trend in the three climatic zones with predominance of individuals of 5–15 cm dbh class (Fig. 6).

According to distance to the closest river, left dissymmetric (1 < shape < 3.6) diameter distributions were observed for the Guinean and Sudanian

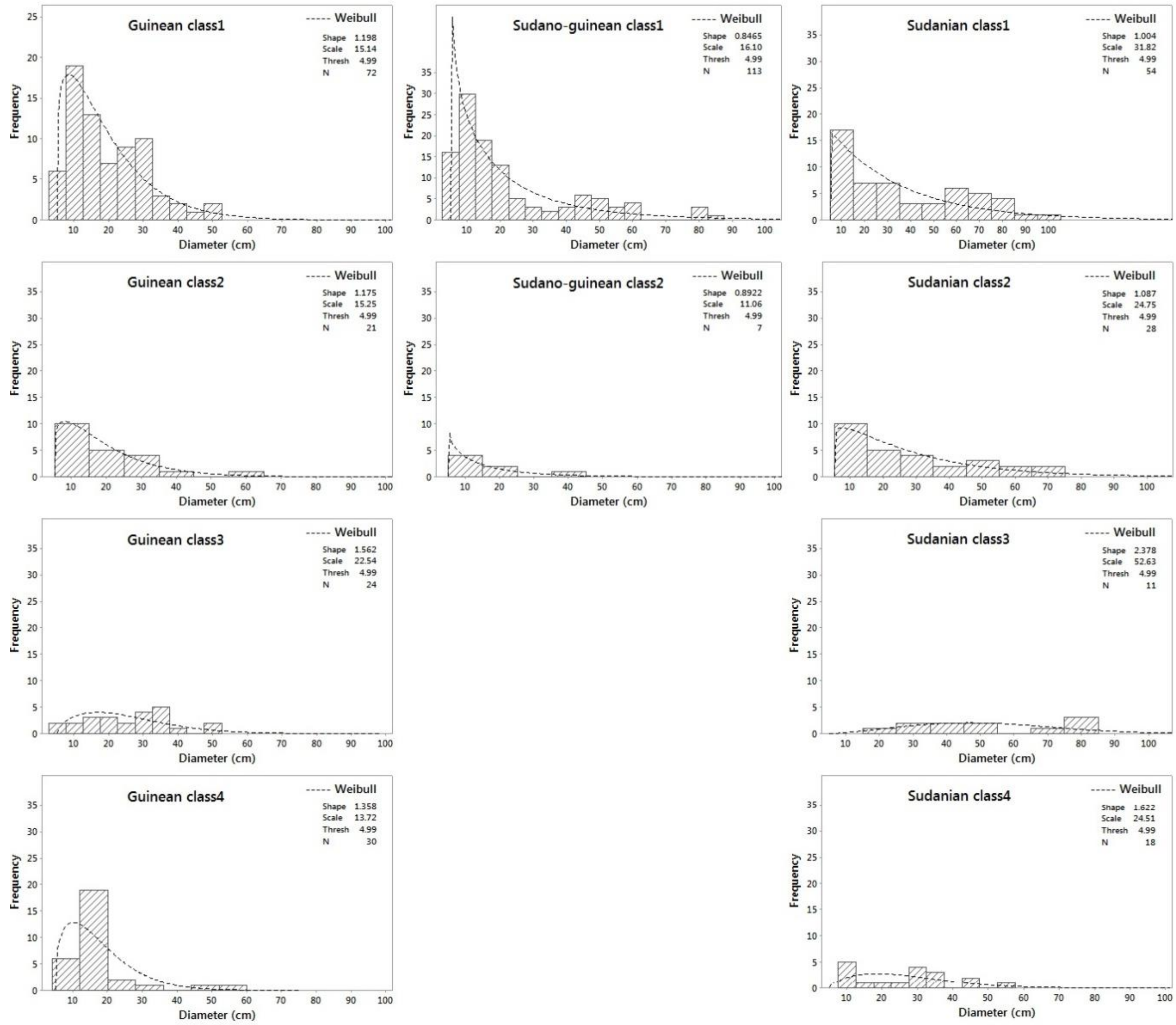

Fig. 7. Diameter structures of *V. doniana* according to climatic zone and classes of distance to the closest river. class1= <500 m; class2 = 500–1000 m; class3 = 1000–1500 m; class4 = >1500 m.

zones for all distance classes while J-reversed distribution (shape < 1) was exhibited in the Sudano-guinean zone. There was then predominance of young individuals (5 < dbh < 30) in almost all the cases. The frequencies were globally higher in class1 (distance < 500 m) than in the other classes for all climatic zones (Fig. 7).

Discussion

Impacts of climatic variability, land cover changes and proximity of river on the ecology and population's patterns of *Vitex doniana* were assessed in Benin in order to provide relevant information for its sustainable management and conservation in the context of global change. The study reveals somehow particular patterns of the species according to the considered factors.

Ecological preferences and woody communities around Vitex doniana

Our investigations showed that *V. doniana* is present in all climatic zones of Benin and, climatic variability does not have influence on the frequency of observation (number of contacts) and abundance of the species (number of individuals per observation) along transects. This may suggest that the species does not have preference to a particular climatic zone. Although average frequencies of observations and abundance of the species are low, whatever the climatic zone, the species is more frequent and abundant in mosaics of croplands and fallows on one hand and in areas relatively close to river on the second hand (Figs. 3,4). Also, the Sudano-guinean zone shows a particularity regarding proximity of river. In tis zone, the species was not observed after 1000 m to the closest river. This may indicate that in this climatic zone, water availability mainly the proximity of river seems to the local environment. Although the difference is not as straighter because NMDS does not show clear discrimination of the plots (Fig. 5), there is evidence from pairwise Jaccard indices calculation which shows that the woody plant communities around *V. doniana* do not share lot of common species (Jaccard < 0.5) regarding the considered environmental parameters. This suggests that although *V. doniana* colonizes varieties of habitats, it is not followed by the same floristic cortege within which competition for resources may be fatal for its survival (Huston 1979). Also, because local environmental stress is not uniform through the country, being followed by the same species in all conditions may negatively impact its fitness.

Structural parameters

This study shows that the structural parameters mainly the mean diameter (Dg) and the basal area (Ba) of *V. doniana* are under the influence of studied factors and their interactions. Combined effects of climatic zone and land cover type appeared the most important trend on the major structural parameters of the species in Benin. In the extremes climatic zones (Guinean and Sudanian), the species performs well in mosaics of croplands and fallows. This might be explained by the absence of relevant competitors for resources (light and water). For instance, *V. doniana* is the msin species preserved by local people during land clearing for agriculture in the Guinean zone, while in the Sudanian zone, after *Vitellaria paradoxa* C.F. Gaertn. and *Parkia biglobosa* (Jacq.) R.Br. Ex Benth, *V. doniana* has great values for local people (personal field observations).

In general, densities of either adult individuals (dbh ≥ 5 cm) or of regeneration (dbh < 5 cm) of the species are low and this may lead to a decline of its populations because such populations with low densities are exposed to extinction under human use pressures and other disturbance factors (Cunningham & Mbenkum 1993). Oumorou *et al.* (2010) have already mentioned low density values be an important factor for the ecology of the species. In general, our findings support the flexibility of the species regarding its habitat choice (Arbonnier 2002; Louppe *et al.* 2008). In the same order, our findings followed the trend of decreasing abundance and frequency at greater distance to river along gallery forest-savannah gradient (Azihou *et al.* 2013).

The study revealed that the *V. doniana* occurs in different woody plant communities when considering for densities on the species in the district of Banikoara in the northern part of Benin. In fact, according to our research design, we were expecting higher values of densities since plots were set along transects around found adult individual of the species.

Diameter structures

In general, the trend observed in the species' diameter structures suggests a predominance of young individuals (Husch *et al.* 2003). These observations can mean that the population of *V. doniana* is not at risk of extinction to date, but when we consider the low density observed for the species regeneration, we can assume that if sustainable measures are not undertaking to favour and preserve the regeneration of the species, its survival may be affected by a rapid decline of the population. In fact, frequencies of big individuals are low in all cases and this can be explained by the selective exploitation of the species elsewhere by local people. Indeed, it is reported that its wood can be used for several building purposes and for carving (Arbonnier *et al.* 2002; Dadjo *et al.* 2012; Louppe *et al.* 2008). Also, during personal field observations, we have noticed that there are often holes in the big trunks and this exposes individuals to death.

Conclusions

To sum up, this study enables us to highlight the impacts of climatic variability, land cover and proximity of river on the ecology and population's structure of *Vitex doniana* in Benin. From the findings, it is assumed that although *V. doniana* does not have a preference to a particular climatic zone, it is more observed and abundant in mosaics of croplands and fallows and in areas close to rivers. Also, woody plant communities around the species vary regarding climatic zone, land cover type and distance to the closest river. *V. doniana* exhibits high values of mean diameter and basal area in

MCF in the Guinean and Sudanian zones while in the Sudano-guinean zone, the highest values of the same structural parameters are noted in the riparian forest. In addition, although the considered factors do not affect the adult and regeneration densities of the species, low density of adults and regeneration were recorded suggesting that the species is exposed to unpredictable decline. Finally, diameter structures of the species are quite similar in all cases with predominance of young individuals revealing that the regeneration of the species can be assured. But, this should not be an end in itself because sustainable management practises are always required to face unpredictable hazards.

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Supporting Information

Additional Supporting information may be found in the online version of this article.

Table S1. Pairwise Jaccard's similarity index according to climatic zones.

Table S2. Pairwise Jaccard's similarity index according to climatic zones and land cover types.

Table S3. Pairwise Jaccard's similarity index according to climatic zones and distance to the closest river.

Table S4. Structural parameters of *V. doniana* (dbh $\geq$ 5 cm) according to climatic zones and distance to the closest river.