

Efficiency of conservation areas to protect orchid species in Benin, West Africa

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Highlights

- Three epiphytic orchid species were recorded and all in gallery forest of unprotected areas
- Sixty seven per cent of the orchid species were only recorded in unprotected areas.
- Conservation status of studied zones had a significant effect on orchid density.
- Woodland orchid species were well represented in the protected area.
- A conservation gap can be assumed to exist for most epiphytic orchids recorded in the gallery forests of unprotected areas.

Abstract:

The effectiveness of protected areas to guarantee future conservation of several plant species remains questionable. This study was carried out in the Biosphere Reserve of Pendjari (BRP) and surrounding unprotected areas to assess the efficiency of the reserve to conserve orchids. A total of 90 plots (52 in protected areas; 38 in unprotected areas) were sampled. The recorded data include: orchid species, number of individuals per species, the height and diameter at breast height of host trees. Diversity indices were used to assess the orchid diversity in the protected and unprotected areas. Preferred habitat conditions of orchid species were investigated using Constrained Correspondence Analysis. An independent t-test and two-way analysis of variance were performed to assess an existing combined effect of vegetation type and the conservation status on the density of orchid species. The Importance Value Index (IVI) was used to measure how dominant an orchid species is in a given zone according to the conservation status of the zone. Only three epiphytic orchids (*Calypstrochilum christyanum*, *Cyrtorchis arcuata* and *Plectrelminthus caudatus*) were recorded and all in gallery forest of unprotected areas. Indeed, 67% and 58% of the orchid species were only recorded in unprotected areas and in gallery forest, respectively. There was no significant difference between the density of all recorded orchids in protected and unprotected areas. The conservation status of the studied zone had a significant effect on the densities of *Nervilia kotschy* and *Eulophia guineensis* ($p < 0.0001$). The highest IVI of *N. kotschy* was observed in the protected area and of *E. guineensis* was in the unprotected area.

This first effort to compile a reference list of the orchid species of the BRP showed that some orchid species were well represented within the protected area, but all of the epiphytic orchids were recorded from unprotected areas. A representative gap can be assumed to exist for most epiphytic orchids only recorded in the gallery forests of unprotected areas. Our results

highlighted the need to redefine protective management strategies for orchid species in the BRP.

Key words: Orchid conservation; habitat conditions; Biosphere Reserve of Pendjari.

1. Introduction

The role of protected areas in the prevention of extinction of species has been much debated (Bruner et al., 2001). Several studies focused on the effectiveness of the protected areas to ensure the representativeness and persistence of biodiversity components (Defries et al., 2005; Wittemyer et al., 2008; Houéhanou et al., 2011, 2012, 2013). Some of the studies (Djossa et al., 2008; Gouwakinnou et al., 2009; Schumann et al., 2010; Fandohan et al., 2011) have emphasized the positive effect of protected areas to conserve some valuable species. However, a review of conservation goals for different protected areas (Myer et al., 2000; François et al., 2015, Diniz and Brito, 2015) indicated a clear difference between expectations of conservation and the effectiveness in species conservation. In addition, a gap of some priority areas for orchid protection still needs to be filled by the existing protected areas network (Wan et al., 2014). Furthermore, the number of species threatened with extinction far exceeds the projections of scientists (Myers et al., 2000). This is the case of orchid species (CITES, 2017).

Orchids are distributed throughout the world from tropical to high alpine areas (Delforge, 2001). The Orchid family is with the Asteraceae the two largest families (Doyle and Luckow 2003).

From the demographic explosion, correspondingly strong land modification was observed in West Africa (Wittig et al., 2007; Wittemyer et al. 2008). Habitat alteration, including total

loss, modification, and fragmentation was by far the main threat to most orchids in the tropics (Dressier 1981b). As a result, significant modification of light intensity, humidity, and other microclimatic factors affecting the survival of the epiphytic orchids, were observed. Many orchid species in West Africa are now considered to be at risk of extinction as a result of selective logging of valuable timber species and clear-felling for agricultural development (IUCN/SSC Orchid Specialist Group, 1996; Pillon et al., 2007; Pant, 2013). Wild orchids have been overharvested at large scale to supply the medicinal, edible, and horticultural trades (Ghorbani et al., 2014; Hinsley et al., 2015; Kasulo et al., 2009; Liu et al., 2014; Pant, 2013; Vermeulen et al., 2014). Reliable statistics on the extent of the trade in orchids in West Africa are scarce. However, several representatives of the orchid family are under threat of extinction due to indiscriminate collection (Cribb et al., 2005; Dunkan et al., 2005). In West Africa, extraction of wild orchids for trade affects mostly those few orchid taxa that either produce very showy flowers or provide certain edible products (IUCN/SSC Orchid Specialist Group, 1996). As a result of these multiple threats, orchids feature prominently in the Red Data Book prepared by International Union for Conservation of Nature (IUCN) (Pant, 2013). The entire family is now included in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 2017). However, in West Africa, large populations of orchids are still assumed to be present in their natural habitats in protected areas. It is therefore paramount to assess how effective the protected areas are in conserving the orchids in West Africa.

The Biosphere Reserve of Pendjari (BRP) is part of a well-managed protected area network in West Africa. It conserves 28% of the total flora of Benin Republic (Assédé et al., 2012). Previous studies have highlighted the importance of this reserve in plant conservation (Gouwakinnou et al., 2009; Fandohan et al., 2011; Houéhanou et al., 2011; Houéhanou et al., 2013). Although the BRP is assumed to be the best way to conserve biodiversity of this area,

its effectiveness in future conservation of several plant species is not always guaranteed (Houéhanou et al., 2013). Substantial representative gaps remain in its coverage of some plant taxa. Terrestrial orchids are known to colonize both savanna and forest areas (Delforge, 2001), while epiphytic orchids need appropriate host plants on which to grow.

In the Sudanian zone of Benin Republic, the two major networks of protected areas are focused on large mammal conservation. The targeted zones to create the conservation areas are then savanna ecosystems (the main habitat of those animals), covering up to 80% of the total protected areas. Based on the ecology of orchids, one might expect a gap of representation in the network of the protected areas in the study area. In Benin Republic, very few scientific studies have focused on orchid species (Akoegninou et al., 2006).

The purpose of this paper is to assess the suitability of existing conservation areas to conserve orchid taxa in West Africa. This study therefore compares protected and unprotected areas to test the assumption that the protected areas will have a higher conservation status of the orchid taxa than the unprotected areas. Specifically, we addressed two research questions: (1) What are the habitat requirements of orchid species occurring within the area? (2) How are orchid populations affected by the conservation status of the land, i.e. in protected versus unprotected habitats?

2. Materials and methods

2.1. Study area

This research was conducted in the Biosphere Reserve of Pendjari (BRP), located in the Sudanian zone of Benin Republic (West Africa) and in its surrounding areas (Fig. 1). The BRP covers about 4666.4 km². It is composed of the National Park of Pendjari or core zone (2,660.4 km²) representing the protected area in this study, and the hunting zones (Pendjari: 1,750 km² and Konkombri: 251 km²). In the protected area, anthropogenic activities are

strictly prohibited. The surrounding areas representing unprotected areas in this study are dominated by farmlands, fallows (disturbed savannas), and gallery forests. The vegetation types in the unprotected areas were all subjected to selective cutting of valuable tree species for timber and poles, livestock grazing and harvesting of non-timber forest products. Gallery forest occurs along the Pendjari river both inside and outside the reserve. The dominant vegetation type in the protected area is savanna (wooded grassland), intermingled with patches of woodland and grassland. The climate is tropical with a five-month dry period (November–March). The mean annual rainfall is 1,000 mm with 60% rain between July and September (Delvingt et al., 1989). Temperature varies between 21°C during the night, and up to 40°C during the day (CENAGREF, 2016). Ferruginous, indurate and swampy tropical soils occur in many areas of the protected and unprotected areas. The BRP is surrounded by 20 villages with subsistence agriculture as the main activity followed by livestock breeding and natural resources harvesting. Logging and clearing of land for agriculture remain the main sources of income for the local population. Cultivated crops include rice, yams, maize, sorghum, millet, and cotton; the latter being a cash crop and requires intense use of pesticides (Delvingt et al., 1989).

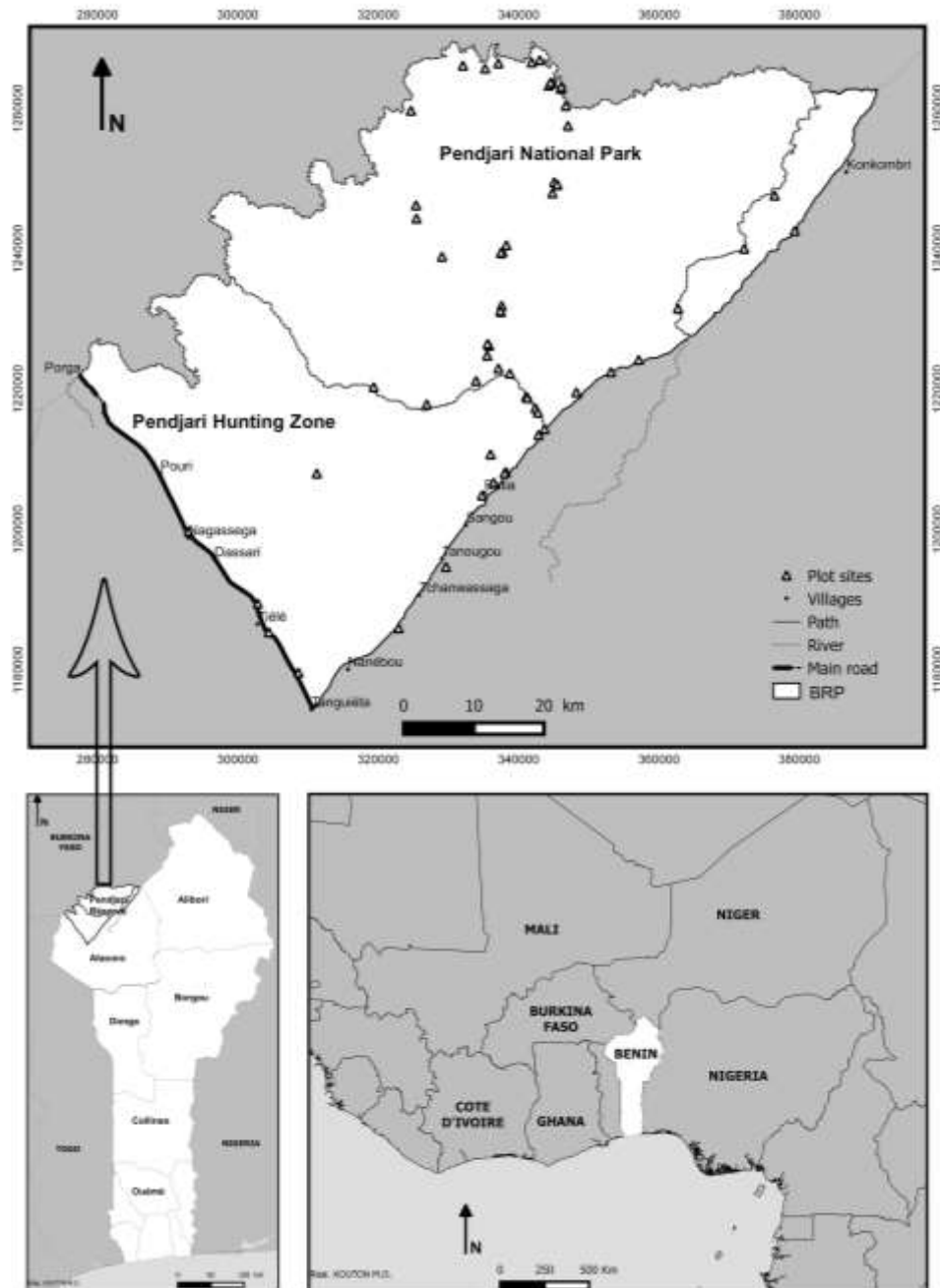


Fig. 1. Location of the study area with the plot sites.

2.2. Data collection

Data were collected between December 2014 and August 2015, i.e. covering the two main seasons of the region: dry and rainy seasons. The vegetation map of the reserve (König, 2005)

was used to identify the three main vegetation types (savannas, woodlands and gallery forests). Both protected and unprotected areas were included in the study. In each vegetation type, points were randomly selected to serve as the starting point of a transect. In total, 65 transects of at least 3 km long in each vegetation type were surveyed for the presence of orchid species.

Three-person teams were used to intensively survey the trees and the vegetation on the ground for the presence of epiphytic and terrestrial orchids. One team member monitored the compass bearing of the transect, and the other two members scanned the vegetation for orchids. The presence of orchid species was confirmed by two team members. This method was adapted from Bergstrom and Carter (2008) and Yulia et al. (2011).

Sample plots (Fig 1) were selected along the transects, based on the presence of orchid species. Rectangular plots (10 m × 50 m) were sampled in gallery forests (due to the linear shape of the gallery forests) and Square plots (30 m × 30 m) in savannas, woodlands and fallows. At least 25 plots were sampled per vegetation type, and 90 plots in total (Table 1; with 52 plots in protected areas and 38 in unprotected areas).

Table 1. Distribution of the sampled plots in protected and unprotected areas.

Ecosystems	Protected area	Unprotected areas	Total
Tree and shrub savannas	20	8	28
Woodlands	16	15	31
Gallery forests	16	15	31
Total	52	38	90

The species and number of individuals of all orchid species (terrestrial and epiphytic) and the identity of host trees of epiphytic orchids were recorded within each plot. The dominant plant species of tree and shrub layers were recorded. Simultaneously, field data on environmental variables were collected. These included the vegetation type, vegetation cover, soil texture, and the presence of rocks or stones. Signs of human disturbance, including agriculture, grazing, tree cutting and pruning, were also collected within the plots of unprotected areas. Herbarium specimens of all recorded orchid species were prepared and confirmed with the National flora (Akoègninou et al., 2006) and at the National Herbarium of Benin Republic.

2.3. Data analyses

2.3.1. Orchid diversity and habitat requirements

Diversity indices were used to assess the orchid diversity in the two zones (protected and unprotected areas). The taxonomic diversity considers the number of species, genera, and families. The Shannon-Weaver index (H'), the most important diversity index (Magurran, 2004), was calculated with the following formula:

$$H' = - \sum_i^n p_i \log_2 p_i$$

where, $p_i = n_i / N$ and n_i = Number of individuals of an orchid species. N = Total number of individuals of all orchid species. H' is low (if between 0 and 2.5); moderate (if between 2.6 and 3.9); or high (if between 4 and 5].

The Shannon measure of evenness (J') was calculated using the following formula.

$$J' = \frac{H'}{H_{\max}}$$

where H_{\max} is computed as $H_{\max} = \log_2(SR)$; SR representing the species richness.

The Shannon measure of evenness (J') has a theoretical minimum value of zero when all orchids belong to the same species, and the index value increases to 1 when the number of species increases.

Preferred habitat conditions of orchid species were investigated using Constrained Correspondence Analysis (CCA). The aim of CCA was to display the plots of protected and unprotected areas as groups in ordination space, based on habitat characteristics. The environmental variables tested were tree cover, herb cover, topography, altitude and soil texture. A weighted method was used and environmental data are reweighted at each permutation step using permuted weights. All qualitative environmental variables were coded. The CCA model and the significance of the fitted environmental variables were evaluated by the Monte Carlo permutation test with 499 permutations. Monte-Carlo permutation tests were also used to test the significance of the ordination axes (499 permutations under reduced model). A P-value of ≤ 0.05 for the first ordination axis was accepted as an indicator for a significant relationship between the items. Data were computed using the Vegan package of R software, version R-3.2.4.

2.3.2. Effect of conservation status of sites on orchids

The independent Student t-test was first performed to examine whether the conservation status of a study area influenced the density of the overall orchid species. The mean density of all orchid individuals was compared statistically between the protected and unprotected areas. Data were log-transformed in order to normalize the distribution.

Two-way Analysis of Variance (Two-way ANOVA) was then performed to assess an existing combined effect of vegetation type (woodland, savanna and gallery forest) and the conservation status of the two zones (protected and unprotected) on the density of orchid

species. Zones and vegetation types were used as categorical independent variables. The continuous dependant variable was the density of orchids. The density of orchids was therefore determined for each studied zone and vegetation type. Two-way ANOVA was also computed on the two most common orchid species (*Nervilia kotschy* (Rchb.f.) Schltr. and *Eulophia guineensis* Lindl.) to assess the importance of the protected area in their conservation. The average density per plot of orchids was log-transformed in order to normalize the distribution. Data were tested to check the homogeneity of variance with Levene's test. Two-way ANOVA and Tukey's post-hoc tests were used in the case of homoscedasticity. In the absence of homoscedasticity, samples were compared using the Kruskal-Wallis and Tukey's post-hoc tests (Scherrer, 2007).

In addition, the importance value index (IVI) was used to measure how dominant an orchid species is in a given zone according to the conservation status (protected and unprotected) of the area (Houéhanou et al., 2012). The calculation of IVI for orchid species was based on Relative Density (RD) and Relative Frequency (RF).

$$IVI = RD + RF$$

$$RD = \frac{\text{Number of individual of a species}}{\text{Number of individual of all species}} \times 100$$

$$RF = \frac{\text{Number of occurrence of a species}}{\text{Number of occurrence of all species}} \times 100$$

A species with high IVI value is considered to be well represented and thus, ecologically healthy in the given zone. The significance level of all analyses was set at 0.05. Data were computed using the Stats package of R software, version R-3.2.4.

3. Results

3.1. Orchid diversity in protected versus unprotected areas

A total of 12 orchid species distributed over 7 genera were recorded in the studied areas (Table 2). Three epiphytic orchid species, i.e. *Calypstrochilum christyanum* (Rchb.f.), *Cyrtorchis arcuata* (Lindl.) Schltr. and *Plectrelminthus caudatus* (Lindl.) Summerh., were recorded on eight host trees (*Pentadesma butyracea* Sabine, *Breonadia salicina* (Vahl) Hepper & J.R.I.Wood, *Syzygium guineense* (Willd.) DC., *Berlinia grandiflora* (Vahl) Hutch. & Dalziel, *Diospyros mespiliformis* Hochst. ex A.DC., *Isoberlinia tomentosa* (Harms) Craib & Stapf, *Tamarindus indica* L. and *Ficus* spp.) in the gallery forest of the unprotected area. The two most diversified genera were *Eulophia* and *Habenaria*. *Nervilia kotschy* (Rchb.f.) Schltr. and *Eulophia guineensis* Lindl. were the most common and abundant terrestrial orchid species respectively in the protected and unprotected areas (Table 2). *C. christyanum* (Fig. 2A,B) was the most common epiphytic orchid with a high occurrence on *S. guineense* (35.4 %), *B. salicina* (24.6%) and *B. grandiflora* (17%). The rarest orchid species recorded with less than three individuals each, were the terrestrial *Platycoryne paludosa* (Lindl.) (Fig. 2C) Rolfe and epiphytic *Plectrelminthus caudatus* (Fig. 2D). Gallery forests contained the most important proportion of recorded orchid species (58%). The majority of the orchid species (67%) were only recorded in unprotected areas.



Fig. 2. Orchid species in the Biosphere Reserve of Pendjari: the most common orchid, *Calypstrochilum christyanum* individual (A) and flower (B); the rarest terrestrial orchid, *Platycoryne paludosa* (C); the rarest epiphyte orchid *Plectrelminthus caudatus* (D).

Table 2. Distribution of the orchid species in protected and unprotected areas.

RA= Relative abundance of orchid species.

		Protected area						Unprotected area					
		Number of individuals				RA (%)	Number of individuals				RA (%)		
Species	Type of orchid	Woodland	Savanna	Gallery	Total		Woodland	Savanna	Gallery	Total			
<i>Calypstrochilum christyanum</i> (Rchb.f.) Summerh.	Epiphytic	0	0	0	0	0.00	0	328	284	612	13.18		
<i>Cyrtorchis arcuata</i> (Lindl.) Schltr.	Epiphytic	0	0	0	0	0.00	0	26	0	26	0.56		
<i>Eulophia</i> spp	Terrestrial	0	33	21	54	1.14	0	0	21	21	0.45		
<i>Eulophia guineensis</i> Lindl.	Terrestrial	9	27	139	175	3.69	0	0	2183	2183	47.02		
<i>Eulophia horsfallii</i> (Bateman) Summerh.	Terrestrial	0	0	0	0	0.00	0	0	116	116	2.50		
<i>Habenaria cirrhata</i> (Lindl.) Rchb. f.	Terrestrial	0	0	41	41	0.87	0	0	22	22	0.47		
<i>Habenaria filicornis</i> Lindl.	Terrestrial	0	0	0	0	0.00	0	79	0	79	1.70		
<i>Habenaria schimperiana</i> Hochst. ex A.Rich.	Terrestrial	0	0	0	0	0.00	0	171	0	171	3.68		
<i>Nervilia bicarinata</i> (Blume) Schltr.	Terrestrial	0	0	0	0	0.00	0	0	942	942	20.29		
<i>Nervilia kotschy</i> (Rchb.f.) Schltr.	Terrestrial	1847	2269	352	4468	94.30	0	0	417	417	8.98		
<i>Platycoryne paludosa</i> (Lindl.) Rolfe	Terrestrial	0	0	0	0	0.00	0	53	0	53	1.14		
<i>Plectrelminthus caudatus</i> (Lindl.) Summerh.	Epiphytic	0	0	0	0	0.00	0	0	1	1	0.02		
Total		1856	2329	553	4738	100.00	0	657	3986	4643	100.00		

The taxonomic diversity (SR) was moderate in unprotected areas and low in protected areas (Table 3). The Shannon-Weaver diversity index (H') was low in both the protected and in unprotected areas, but close to zero in the protected areas. The Evenness index of Shannon (J') was low in protected areas but relatively high in unprotected areas (Table 3).

Table 3. Diversity indices of protected and unprotected areas.

Index	Protected areas	Unprotected areas
Species Richness: SR	4	12
Shannon-Weaver diversity: H'	0.3	2.3
Shannon evenness: J'	0.1	0.6

3.2. Orchid distribution and habitat condition requirements

The CCA explained 26.8% of the total variation (6.8). Table 4 showed the correlation of environmental variables with the first two canonical axes. The major floristic groups correlated with the tree cover gradient (axis 1). Topography, tree cover, herb cover and soil texture correlated best with the first axis (CCA1) whereas altitude correlates with the second axis (CCA2). The environmental variables are projected in the first two axes as well as the discriminated habitat groups (Fig. 3). The pattern of these variables confirmed effectively that the first axis showed a decreasing tree cover gradient.

Table 4. Correlation of environmental variables with ordination axes of CCA. Only values $> |0.5|$ contribute substantially to the axis.

Variables	CCA1	CCA2
Soil texture	0.5284	-0.0464
Topography	0.7751	-0.5304
Altitude	-0.6688	-0.7227
Herb cover	0.7463	0.0992
Tree cover	-0.7472	-0.1027

A differentiation appeared between groups of gallery forests of protected and unprotected areas (G1), woodland of protected areas (G2) and grassland of unprotected areas (G3) (Fig. 3). The two subgroups on the top and bottom of G1 (Fig. 3) were respectively dominated by the genus *Eulophia* and the epiphytic orchid *C. christyanum* on respectively relatively low (mean of 220 m) and high altitudes (mean of 363 m). Both subgroups were characterized by a high cover of the woody layer (mean of 85%), a low cover of the herb layer (mean of 15%), clayey soil with presence of rocks and boulders, and a steep slope. The dominant tree species were *S. guineense* and *B. salicina*. The third subgroup of G1 dominated by *Nervilia bicarinata* and *E. guineensis* was a mixed stand of terrestrial and epiphytic orchids, recorded on clay-sandy soil at relatively low altitude (mean of 267 m) and moderate slope in unprotected areas. In this subgroup (G1), the vegetation was tree and shrub savanna dominated by *Khaya senegalensis*. The tree layer covered 45%-50% and the herb layer 25%-30%. The second group G2, constituted by *N. kotschyi*, is a mixed stand of woodland and gallery forest of the protected and unprotected areas on clayey soil, relatively low altitude (mean of 246 m), and slope. The average cover of the tree and herb layers was respectively 70% and 30%. The dominant tree species was *Anogeissus leiocarpa* (DC.) Guill. & Perr. The Group G3, was

clearly differentiated from the other groups, being represented by plots from unprotected areas and dominated by *H. schimperiana*, *H. filicornis* and *P. paludosa*. This group was associated with the plains at 245 m, silty soil, and characterized by a high cover of the herbaceous layer (95%) dominated by *Cyperus* spp and *Andropogon* spp and a relative absence of the tree layer.

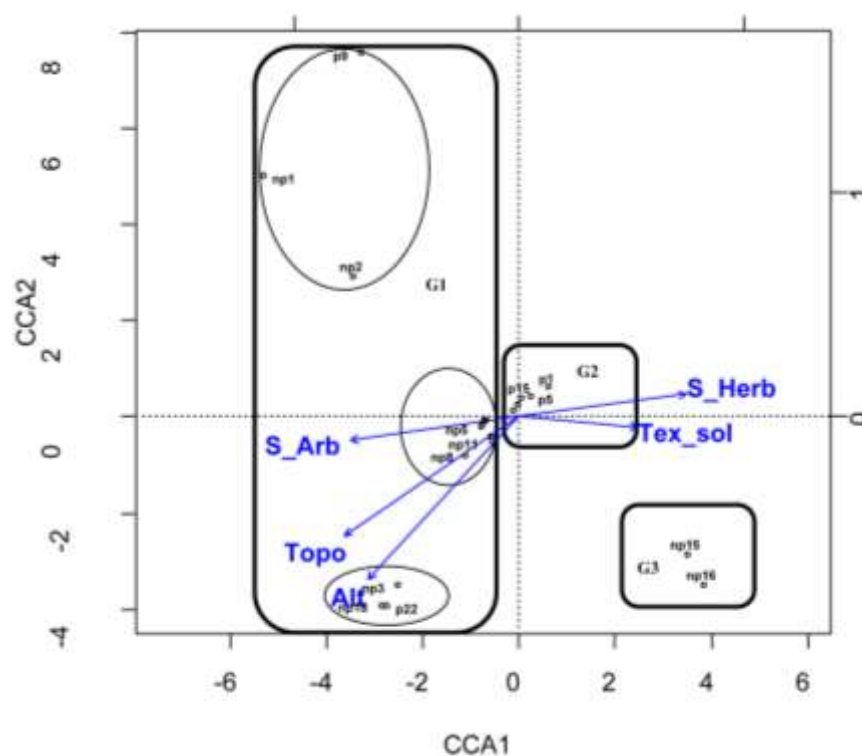


Fig. 3. Canonical Correspondence Analysis (CCA) diagram representing the first two axes that explained 72.8% (CCA1: 39.2% and CCA 2: 33.6%) of all variance explained by the CCA. Empty circle designate the plots scores in each discriminated habitat group (np: unprotected area; p: protected area) by orchid species composition; G1: gallery forest plots (dominated by those of unprotected areas), G2: protected woodland and tree savanna plots, G3: unprotected grassland plots. Environmental variables are represented by blue vectors (Alt: Altitude, Topo: Topography, Tex_sol: Soil texture, S_Arb: Tree cover, S_Herb: Herb cover) that determine additional arrowed axes in the diagram.

3.3. Influence of conservation status and vegetation types on orchid density

Results from the Student t-test ($p = 0.3$) and that from the two-way ANOVA inside zones ($p = 0.2$) did not show any significant difference between the density of all recorded orchids in protected and unprotected areas. However, there was a significant difference in the orchid density when considering the vegetation types ($p = 0.004$) as well as the interaction between zones and vegetation types. Based on Tukey's post-hoc tests, the gallery forests presented a higher orchid density than woodlands ($p = 0.03$). The protected area presented the highest density of *N. kotschyi*, and significantly more than in the unprotected areas ($p < 0.0001$), but the vegetation type, and the interaction between zones and vegetation type, had no effect. Only vegetation type effect was significant on *E. guineensis* density ($p < 0.0001$). The result from Tukey's post-hoc test showed significant differences between gallery forest and woodland ($p < 0.0001$), and between gallery forest and savanna ($p < 0.0001$). *E. guineensis* was more abundant in gallery forest than in woodland and savanna ($p = 0.03$).

3.4 Conservation status of orchid species based on IVI

The IVI of the recorded orchid species varied between the protected and unprotected areas (Table 5). *Nervilia kotschyi* had the highest IVI (169.3) in the protected areas. In unprotected areas, the species with the highest IVI values were *Eulophia guineensis* and *Calypstrochilum christyanum* (respectively 69.52 and 45.68).

Table 5. Importance Value Index (IVI) of orchid species within the studied zones

Species	Protected areas			Unprotected areas		
	RD	RF	IVI	RD	RF	IVI
<i>Calypstrochilum christyanum</i>	0	0	0	13.18	32.50	45.68
<i>Cyrtorchis arcuata</i>	0	0	0	0.56	2.50	3.06
<i>Eulophia spp</i>	1.14	4.20	5.34	0.45	2.50	2.95
<i>Eulophia guineensis</i>	3.69	16.60	20.29	47.02	22.50	69.52
<i>Eulophia horsfallii</i>	0	0	0	2.50	5.00	7.50
<i>Habenaria filicornis</i>	0	0	0	1.70	2.50	4.20
<i>Habenaria schimperiana</i>	0	0	0	3.68	2.50	6.18
<i>Habenaria cirrhata</i>	0.86	4.20	5.06	0.47	7.50	7.97
<i>Nervilia bicarinata</i>	0	0	0	20.29	5.00	25.29
<i>Nervilia kotschy</i>	94.30	75.00	169.30	8.98	12.50	21.48
<i>Platycoryne paludosa</i>	0	0	0	1.14	2.50	3.64
<i>Plectrelminthus caudatus</i>	0	0	0	0.02	2.50	2.52

4. Discussion

4.1. Orchid diversity and habitat characteristics

The Biosphere Reserve of Pendjari (BRP) is known to be a corner stone for strategic conservation of plant species in the Sudanian zone, with 35.6% of all species and 33.3% of all genera listed for Benin (Akoégninou et al. 2006). However, only 23% of recorded orchid species was found in the core zone of the reserve with no epiphytic species. It has been assumed that the protection status of an area would normally conserve more animal and plant species (Dudley and Bean, 2012). This assumption may be true only when the vegetation

structure is suitable to the ecology required by the species. For example, gallery forests had the highest orchid density and a great diversity of terrestrial orchids in the protected area of the BRP (a mosaic of savannas and woodlands) compared to unprotected areas (Table 3). Several factors influence the distribution pattern of orchid species. Epiphytic orchid diversity increases along moisture and latitudinal gradients (Gentry and Dodson, 1987; Phillips et al. 2011). At larger scale, orchid richness is highest in the high rainfall zones with closed vegetation cover. In addition, closed formations with high tree density were found to be providing ideal development conditions for epiphytic orchids. Therefore, with the low rainfall (an average of 1,000 mm per year) and long dry season (five month dry period) observed in the BRP compared to the national scale (up to 1,400 mm per year), several orchid species may experience less drought stress in gallery forests. However, the conditions required by some terrestrial orchids are an open area with thin ground litter. The vegetation found across both protected and unprotected areas and the difference in orchid species might also be a consequence of different land uses. The vegetation in unprotected areas was more disturbed by anthropogenic activities, especially logging and farming system. In the protected areas there was no human activity. But, if gallery forests of unprotected areas still conserve more orchids than gallery forests in protected areas, it is probably because some specific ecological conditions were also required by orchids even if the vegetation was not disturbed.

The small size of orchid seeds and the fact that they lack endosperm make these plants dependent on mycorrhizal symbioses to provide energy and nutrients during their early development stages (Otero and Flanagan, 2006; Barthlott et al., 2014). Mycorrhizal specificity and habitat specialization (Gravendeel et al., 2004; Otero and Flanagan, 2006) have both been implicated in the diversification of the orchid family. The diversity of mycorrhiza was demonstrated as a factor to influence seed germination and greater growth for all orchid species (Phillips et al., 2011; McCormick et al., 2016). However, the real benefit conferred by

mycorrhizal associations to plants may also depend on soil conditions, especially fertility. Therefore, identifying the mycorrhiza associated with the recorded terrestrial orchids and their role in orchid distribution in protected vs unprotected zone of the BRP should be the next goal in the study of the ecology of orchids.

The habitat conditions required by the orchid species were shown in the CCA (Fig. 3). There is a differentiation between habitats of protected and unprotected areas in terms of tree cover, altitude, soil type and topography that influence the pattern of orchid distribution in both zones, and the importance of woodland in the protected area. Therefore, orchids associated with woodland, the dominant vegetation type in the protected area, characterized by an average tree cover, were assumed more conserved in the protected area as confirmed by the conservation status of *N. kotschyi*. However, a gap of conservation can be assumed to exist for most of the epiphytic orchids confined to the gallery forests of unprotected areas.

Setyawan (2000) highlighted the importance of the height of the host trees in the distribution, diversity and density of epiphytic plants. Even though data were not collected and tested with reference to this assumption, it was observed during this study that the taller host tree species were the most colonized by *C. christyanum* in gallery forest. Similarly, Yulia and Budiharta (2011) also showed that the characteristics of the host tree (height and bark type) impact on the establishment and development of epiphytic orchids. However, several other environmental factors not quantified by this study have been highlighted as determinants of orchid distribution. Indeed, the constraint axis of the CCA explained only 26.8% of the total variance between plots. The micro-climatic factors (sunshine intensity, humidity and air temperature) and the potential for soil resources (moisture and soil pH) have also been reported to influence the orchid distribution (McCormick et al., 2012). Furthermore the difference in host tree composition and pollination strategy (Jersàková et al., 2006) are key

aspects to examine in the future because this may help explain the observed distribution patterns of orchid species.

4.2. Conservation status and orchid density

Although there was low species richness in protected areas compared to unprotected areas, the absence of conservation effect on orchid density (when all species are considered), was observed mainly because the species recorded in the protected area were characterized by a high density. Thus, this effect became significant when considering the orchid species separately. *N. kotschyi* seems more common in protected than in unprotected areas, probably because of its habitat preference. As a terrestrial orchid, the species grew more in woodland (Akoegninou et al., 2006), the dominant vegetation type of the protected area. The habitat suitability, a factor that determines where a species is found, can explain the affinity of some recorded orchids to particular tree species associated with a specific community of gallery forest occurring within unprotected areas. *E. guineensis* is an example of this with the highest density and IVI in unprotected areas. *E. guineensis* was always recorded under shade in dense vegetation of gallery forest with a steep slope (Akoegninou et al., 2006). This species could be assumed to be ecologically suited to specific gallery forest communities of unprotected areas. The gallery forest community in unprotected areas would also be one of the suitable habitats for *Calypstrochilum christyanum* and *Plectrelminthus caudatus* where these orchids were the most abundant. Hence, the prevalence of specific trees (e.g., *Berlinia grandiflora*, *Breonadia salicina*, *Pentadesma butyracea*) and high tree cover in the gallery forests of unprotected areas should be one of the factors explaining both *E. guineensis* abundance and the occurrence of three epiphytic orchid species in unprotected areas. Therefore, the establishment of *C. christyanum*, the most common epiphytic orchid, should not be affected

by human activities. Even if recorded under closed canopy, *C. christyanum* can establish on a host tree under severe pruning. In addition, one of the factors which determined the epiphytic orchid establishment may be the presence of rock slabs or sandstone boulders. Indeed, contrary to the situation in the protected area, the edaphic support of more than 90% of investigated gallery forests in unprotected areas, was represented by the rock slabs and large deposits of sandstone boulders of varying size. A high density of epiphytic orchids, in particular *C. christyanum*, was observed. However, these assumptions need to be tested in future studies. The environmental conditions required at finer scale for epiphytic orchids in gallery forests in unprotected areas need to be ascertained. Are those specific site conditions requirements provided by tree species only present in gallery forest in unprotected areas, or by specific physical habitats provided by rock slabs and/or sandstone boulders, or both?

5. Conclusion and suggestions for management

The Biosphere Reserve of Pendjari was found to be a habitat for orchid species of the Benin Republic. Three epiphytic orchid species were recorded from eight host tree species. The two most diverse orchid genera were *Eulophia* and *Habenaria*. Some orchid species (*N. kotschyi*) were well represented within the protected area, while all the recorded epiphytic orchids and *E. guineensis* (67% of all species recorded in the study) were only recorded in unprotected areas. Gallery forests had a higher orchid density than woodlands. The most common orchid species in unprotected areas were *C. christyanum* (epiphyte) and *E. guineensis* (terrestrial), while in protected area it was *N. kotschyi* (terrestrial).

Based on our extensive findings, we propose a new approach for the joint protection and management of orchid species. A special management plan should be developed for gallery forest in unprotected areas. Control measures should be reinforced in those areas left to the

local population for their livelihoods, especially in the gallery forests, to facilitate the sustainable management of orchid populations. The current deforestation and anthropogenic activities observed in unprotected areas should be mitigated to maintain the habitats of the orchids.

Finally, our study did not consider the influence of several factors, such as soil nutrients, humidity and light conditions, and host tree identity and characteristics that could explain more of the high occurrence of orchids, both epiphytic and terrestrial, in unprotected areas. In future, factors such as these should be included in the analyses to refine our understanding of the effects of distribution patterns and conservation status on the orchid species. In so doing, we will further improve conservation strategies that aim to protect these orchid species. Despite this limitation, our results highlighted the need to redefine protective and management strategies for orchid species in the Biosphere Reserve of Pendjari.

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