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RESEARCH ARTICLE

INFLUENCES OF SPATIAL AND ENVIRONMENTAL FACTORS IN THE STRUCTURING OF ORCHIDACEAE COMMUNITIES IN THE EASTERN SECTORS OF TAÏ NATIONAL PARK

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ABSTRACT

The influences of environmental factors on the spatial distribution of epiphytic Orchidaceae groups were addressed through this study conducted in the Taï National Park. It made it possible to monitor the composition of populations of epiphytic Orchidaceae in the different biotopes of the park. The objective was to monitor changes in the composition of epiphytic Orchidaceae following local environmental variations. Floristic inventories were carried out in the ADK-V6, Djapadji and Soubré management sectors. Each inventory plot is a rectangle of 500 m². For data collection, each epiphytic Orchidaceae individual identified and counted. Across all collections, 18 species of Orchidaceae were observed epiphytically in the different biotopes. These are swamp forests, mountain forests, gallery forests, secondary forests and dense forests. The greatest number of epiphytic Orchidaceae is observed in mountain forests, followed by gallery forests. The most abundant taxa are *Ancistrorhynchus capitatus*, *Bulbophyllum purpureorhachys* and *Calyptrochilum christyanum*. Concerning the frequencies of appearance during the different botanical surveys, *Ancistrorhynchus capitatus*, *Eulophia horsfallii*, *Eulophia gracilis*, *Epidendrum ciliare*, *Calyptrochilum emarginatum*, *Bulbophyllum fuscum* and *Angraecum distichum* have the highest frequencies of occurrence. Epiphytic Orchidaceae communities are organized according to the importance of the undergrowth, the canopy and then atmospheric humidity. The phytosociological organization of epiphytic Orchidaceae in Taï National Park is therefore influenced by the presence of water, humidity and nutrients.

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INTRODUCTION

African tropical forests contain significant and varied biodiversity. Several studies have highlighted the importance of this biological diversity and especially that of the flora of the forests of Upper Guinea (Kouamé *et al*., 2021 ; MISSA *et al*., 2023 ; Ouattara *et al*., 2023). These forests also have an important place in climate regulation (Adji *et al*., 2022).

The floral components of these forest ecosystems occupy an important place in local biodiversity (Gentry, 2008). Tropical forests are subject to anthropogenic pressures which lead to surface loss (Gnagbo, 2009). Faced with the exhaustion of forest resources, the creation of protected areas is recognized as a fundamental tool for achieving conservation and then sustainable management of the environment and floral resources (Brou, 2009).

In Côte d'Ivoire, efforts in this direction have resulted in the establishment of a vast network of protected areas made up of eight national parks and six nature reserves. These protected areas, although covering only 6.5% of the national territory, or 2.1 million hectares, contain most of the country's biological diversity. In addition, together with classified forests, they constitute the majority of Ivorian natural plant cover (Lauginie, 2007). Anthropogenic pressures on natural ecosystems lead to an erosion of local biodiversity. The most impacted plant species serve, through their presence or absence, as indicators of the conservation of natural habitats. This is the case of epiphytic Orchidaceae, which are indicators of habitat quality (Ai *et al*., 2023 ; Liu *et al*., 2023). Epiphytic Orchidaceae are therefore made up of a set of taxa allowing the quality of natural habitats to be assessed. Like the protected areas of Côte d'Ivoire, the Taï National Park also suffers from numerous anthropogenic pressures which alter the quality of its animal and plant biodiversity, as well as natural habitats (Adou Yao et N'guessan, 2005). The eco-climatic conditions which reign throughout the PNT, place it in the rain sector of the Guinea-Congolese domain, characterized by dense evergreen humid forest or rain forest, more particularly sub -hygrophilous forest (Mangenot, 1956). This study therefore aims to monitor the reconstitution of populations of epiphytic Orchidaceae in the different biotopes of the park. It will be a question of monitoring the population dynamics of epiphytic Orchidaceae from areas heavily impacted by anthropogenic activities to primary forests. The objective is to monitor changes in the composition of epiphytic Orchidaceae following local environmental variations.

MATERIAL AND METHODS

Study site: Taï National Park is located in the southwest of Côte d'Ivoire, not far from the Liberian border, between latitudes 5° 10' and 6° 40' North and between 6° 80' and 7° 50 ' west longitude (Figure 1). This park, which covers an area of 536,016 hectares, is limited to the southwest by the Haute Dodo Classified Forest, to the southeast by the Rapide- Grah Classified Forest.

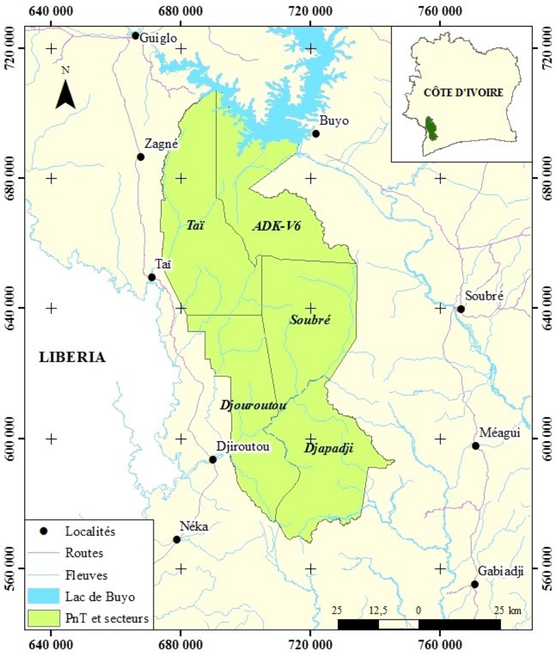

Figure 1. Location of Taï National Park

Floristic inventory: The management sectors which contain the most varied biotopes were selected for this study. These are the ADK-V6, Djapadji and Soubré sectors. These sectors have the particularity of being strongly impacted by anthropogenic activities. There we find the ex-ZOC (Controlled Occupation Zone) made up of old plantations and fallow land currently being reforested. In the ADK-V6 sector, the islands of the Soubré dam, secondary forests, dense forests and gallery forests were inventoried. In the Djapadji sector, swamp forests, dense forests, secondary forests, gallery forests and mountain forests were inventoried. In the Soubré sector, ex-ZOCs and secondary forests were visited. In each part of the same biotope, 10 inventory plots were placed. Throughout the park, 100 inventory plots were placed. The choice of an inventory block is guided by the presence of epiphytic plant species. Each inventory plot has an area of 500 m², i.e. 20 meters wide by 25 meters long. Inside each plot, each woody individual carrying an epiphytic Orchidaceae was listed, the epiphytic Orchidaceae identified and counted. During data collection, only Orchidaceae directly rooted on woody supports were inventoried. These surface surveys were supplemented with traveling surveys with a view to listing epiphytic Orchidaceae not observed during data collection.

Data analysis: The specific richness of the investigated sites was established. It consisted of counting all the epiphytic Orchidaceae recorded without taking into account their abundance. The specific richness of epiphytic Orchidaceae present on the study site was established from the lists of species observed on each plot. Diversity indices express the quality of a habitat according to the number of plant species and the number of individuals per species. The index according to Shannon (1948) expresses the relative importance of the number of abundant species in a given environment. Thus, the higher the proportion of rare species and the reduced proportion of abundant species, the greater the diversity index. This index is minimum when all individuals belong to the same species, it is maximum when each individual represents a distinct species. The expression for the Shannon index is:

With *pi* being the relative frequency of individuals of species *i*. The frequencies of appearance of each Orchidaceae were calculated according to the inventoried biotopes. The specific frequency of a species is the number of plots in which this species is present across all inventories. Its relative frequency is the ratio of its specific frequency to the total of specific frequencies. The expression of floristic diversity was supplemented by the fairness index according to Pielou (1966). The equitability index makes it possible to assess imbalances in the spatial distribution of species. It expresses the regularity or equitable distribution of individuals within species. In this formula, *H* denotes the Shannon index and *S* the species richness.When E is low, the majority of individuals concentrate in a reduced number of species. For high E, individuals are evenly distributed within the species present. For a given medium, when H and E are low, the medium is non-homogeneous. On the other hand, H and E are high when the medium is isotropic. Floristic similarity, that is to say the degree of resemblance between the flora of two different inventoried sites, was evaluated. To do this, the similarity index according to Sorensen (1948) was used. This index allows objects to be compared on the basis of the presence-absence of species. It varies from "zero" when there is no common species between two communities to the value "one" when the two communities are perfectly identical. For two plots a and b, the expression of the formula is as follows:

With *Cs* the Similarity Coefficient; "*a*" the number of species on list A; "*b*" the number of species in list B and "*c*" the number of species common to both lists A and B. The distributions of epiphytic Orchidaceae were compared on the basis of environmental factors in order to establish the phytosociological parameters that guide their presence. Canonical Correspondence Analysis (CCA) was useful for highlighting the environmental variables that could influence the presence of epiphytic Orchidaceae in different biotopes (Ter braak, 1985; Lebreton *et al*., 1988). As part of this study, Canonical Correspondence Analysis was used to group the plots on the basis of the presence and abundance of Orchidaceae according to environmental variables such as the management sector, plant formation, shape of the undergrowth and canopy. The management sectors concerned are Soubré, ADK-V6 and Djapadji. The plant formations observed are mountain forests, dense forests, swamp forests, secondary forests and gallery forests. The undergrowth and canopies of these different plant formations have been described as closed, semi-open or open.

RESULTS

On all the sites visited in the ADK-V6 management sector, epiphytic Orchidaceae were observed in dense forests as well as in gallery forests. In the Djapadji management sector, inventories of epiphytic Orchidaceae were carried out in mountain forests, swamp forests, secondary forests and gallery forests. Visits to all sites in the Soubré management sector did not allow the observation of epiphytic Orchidaceae. Of all the collections, 71 occurrences of epiphytic Orchidaceae were recorded in the Djapadji sector, compared to 30 occurrences in the ADK-V6 sector and zero in the Soubré sector. Across all collections, there are 101 occurrences of epiphytic Orchidaceae distributed between 18 species and 10 genera. The most represented genus is *Bulbophyllum* with 6 species followed by the genera *Calyptrochilum*, *Eulophia* and *Vanilla* with 2 species each. The most observed species are *Ancistrorhynchus capitatus*, *Bulbophyllum purpureorhachys* and *Calyptrochilum christyanum* with 24, 17 and 12 occurrences respectively. The other epiphytic Orchidaceae have occurrences of less than 7. The Shannon diversity and fairness index values are compiled in Table 1. The Shannon diversity index values vary between 0.64 and 1.68 depending on the biotopes of the AKD-V6 sector, then are included between 0.80 and 2.30 in the Djapadji sector. All equitability values recorded are greater than 0.65 on all the sites inventoried. The degree of floristic similarity between the epiphytic Orchidaceae observed in the ADK-V6 and Djapadji biotopes is 20%.

We observe small variations in the diversity indices according to Shannon between the different biotopes inventoried (Table 2). The maximum value of diversity in epiphytic Orchidaceae flora is observed in mountain forests (1.86) and the minimum value (0.64) in secondary forests. Of all the five biotopes studied, swamp forests and dense forests have significantly close values in terms of floristic diversity. The values of Pielou's fairness indices are between 0.79 and 0.95. The biotopes with the most similar composition of epiphytic Orchidaceae are gallery forests and mountain forests. These biotopes have a similar epiphytic Orchidaceae population composition in a proportion of 62.50% according to the Sorensen index. The other biotopes have lower similarity coefficients (Table 3). The other pairwise comparisons present similarities or none in their compositions in epiphytic Orchidaceae. The frequencies of appearance of epiphytic Orchidaceae were evaluated in the different biotopes across all collections. In mountain forests, floristic inventories made it possible to collect 10 epiphytic Orchidaceae. *Ancistrorhynchus capitatus* is the species with the highest occurrence frequency with an appearance frequency of 31.81%. She is followed by *Eulophia horsfallii*, *Eulophia gracilis*, *Epidendrum ciliare*, *Calyptrochilum emarginatum*, *Bulbophyllum fuscum* and *Angraecum distichum* which each have a spawn rate of 9.09%. They are followed by *Trachoma subluteum*, *Bulbophyllum purpureorhachis* and *Bulbophyllum occultum* are the least observed epiphytic Orchidaceae in mountain forests with 4.55% of the frequency of appearances. In the forest galleries, 9 taxa were inventoried. The most observed are *Ancistrorhynchus capitatus*, *Bulbophyllum purpureorhachys* and *Calyptrochilum christyanum* with respective values of 30.35%, 28.57% and 21.42%. The other Orchidaceae were poorly observed. These are *Bulbophyllum longiflorum* and *Bulbophyllum fuscum* with frequencies of occurrence of 8.92%, and 3.57. Other epiphytic Orchidaceae such as *Polystachya cultriformis*, *Bulbophyllum fuscum* var. melinostachyum, *Calyptrochilum emarginatum* and *Trachoma subluteum* each have a frequency of occurrence of 1.78%.

In dense forests, the collections highlighted the presence of 5 taxa. *Polystachya cultriformis* is the most observed epiphytic Orchidaceae with a frequency of appearance of 30.76%. *Bulbophyllum* follows *occultum* and *vanilla planifolia* which each have a frequency of appearance of 23.07%. Next, *Bulbophyllum elliottii* with a frequency of appearance of 15.38% is one of the least observed Orchidaceae. Finally, *Bulbophyllum longiflorum* has the lowest frequency of occurrence with a value of 7.69%. Alone *Eulophia horsfallii*, *Epidendrum ciliare* and *Bulbophyllum fuscum* have been identified in swamp forests. These species have respective occurrence frequencies of 57.14%, 28.57% and 14.28%. As for secondary forests, *Vanilla crenulata* and *Solenangis scandens* are observed with respective occurrence frequencies of 66.66% and 33.33%. The canonical correspondence analysis of the raw matrix consisting of 40 sampling plots, 18 species and 65 occurrences made it possible to understand the influences of environmental factors on the dispersal of epiphytic Orchidaceae. The factorial map (Figure 2, Table 4) makes it possible to discriminate 3 plant communities in the factorial plan of axes 1 and 2. Community 1 is made up of *Solenangis scandens* and *Vanilla crenulata.* These two Orchidaceae are characteristic of secondary forests. These forests are characterized by strong sunlight in their habitat. We observe vegetation with an open canopy with a closed undergrowth dominated by an abundant low stratum. The second plant community that stands out is composed of *Bulbophyllum occultum*, *Bulbophyllum elliottii*, *Bulbophyllum longiflorum*, *Calyptrochilum christyanum*, *Polystachya cultriformis* and *vanilla planifolia*. These are Orchidaceae which are characteristic of the dense forests and gallery forests present in the ADK-V6 management sector. These biotopes have a moderately open undergrowth with a moderately closed canopy. These biotopes have intermediate levels of sunlight. The third community of epiphytic Orchidaceae is observed in the Djapadji management sector.

Table 1. Floristic wealth and diversity of the inventoried sites

	AKD-V6		Djapadji			
Biotopes	Dense forest	Forest gallery	Mountain forest	Swamp forest	Secondary forest	Forest gallery
Species	5	2	10	3	2	7
People	13	17	22	7	3	39
Shannon	1.68	0.64	2.30	1.10	0.80	1.33
Fairness	0.70	0.94	0.89	0.67	0.67	0.65

Table 2. Average values of the diversity and structure indices of the inventoried environments

Habitats	Swamp Forest	Mountain Forest	Forest Gallery	Secondary Forest	Dense Forest	Test statistics
Shannon Index	14.7 ± 0.22^{a}	1.86 ± 0.25^{b}	1.64 ± 0.20^{ab}	0.64 ± 0.18^{c}	1.52 ± 0.24^{a}	F=7.32, p<0.001
Pielou Evenness	0.91 ± 0.06^{b}	0.89 ± 0.05^{b}	0.79 ± 0.08^{a}	$0.92\pm0{,}04^{b}$	0.95 ± 0.03^{b}	F = 6.86, P<0.001

Table 3. Floristic similarities between the different inventoried biotopes *In bold: similarity coefficient greater than 50%.*

	Swamp forest	Mountain forest	Forest gallery	Secondary forest	Dense forest
Swamp forest	100				
Mountain forest	37.50	100			
Forest gallery	12.50	62.50	100		
Secondary forest	0	0	0	100	
Dense forest	20	0	25	0	100

Table 4. Cumulative percentages of explained variance and ACC inertia value

Axes	1	2	3	4	Total inertia
Eigenvalues	1,000	0.916	0.756	0.677	9,653
Species-environment correlations	1,000	0.971	0.953	0.949	
Cumulative percentage variance					
of species data	10.4	19.8	27.7	34.7	
of species-environment relationship	20.5	39.3	54.8	68.6	
Sum of all eigenvalues					9,653
Sum of all canonical eigenvalues					4,879

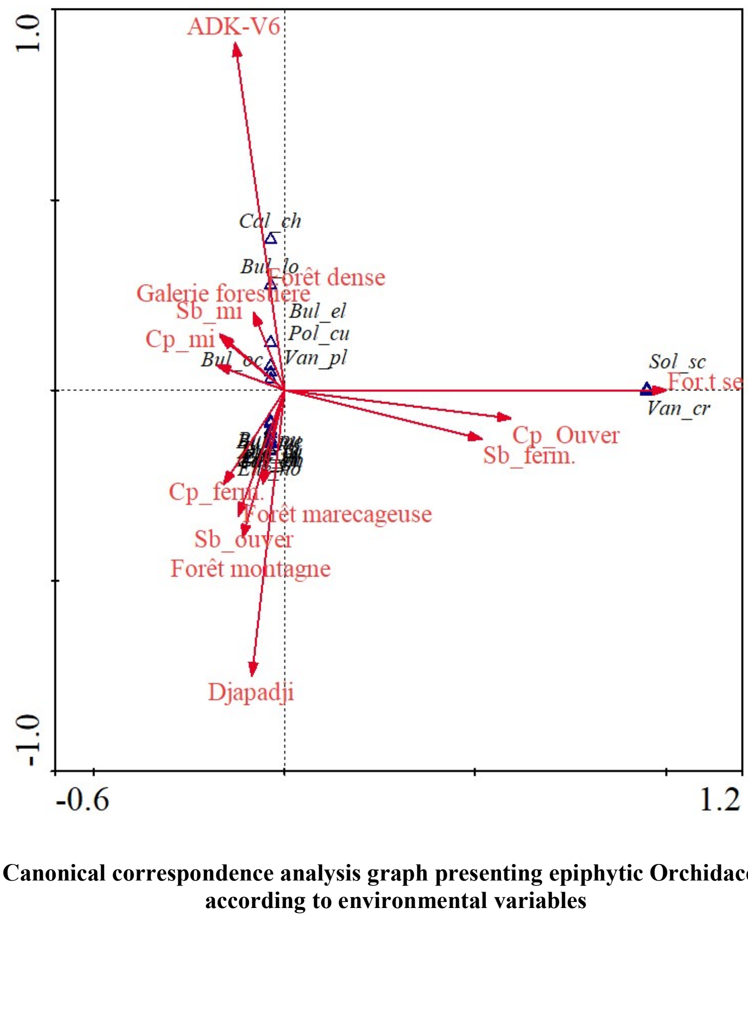

Figure 2. Canonical correspondence analysis graph presenting epiphytic Orchidaceae groupings according to environmental variables

These are Orchidaceae present in swamp forests and mountain forests. These are habitats with open undergrowth with a closed and completely covering canopy in places. The taxa characteristic of these biotopes are *Ancistrorhynchus capitatus*, *Angraecum distichum*, *Bulbophyllum fuscum*, *Bulbophyllum fuscum* var. melinostachyum, *Bulbophyllum purpureorhachys*, *Calyptrochilum emarginatum*, *Epidendrum ciliare*, *Eulophia gracilis*, *Eulophia horsfallii* and *Trachoma subluteum*.

DISCUSSION

The compilation of floristic lists from the inventories made it possible to list 18 epiphytic Orchidaceae belonging to 10 genera. Epiphytic Orchidaceae are therefore present in the Taï National Park. However, strong variations in richness and diversity are observed depending on the different biotopes inventoried. Levels of similarity also vary between biotopes in their epiphytic Orchidaceae compositions. This could be justified by the fact that these epiphytic Orchidaceae are strongly linked to particular habitats. For Kirillova et Kirillov (2022), Orchidaceae are sensitive to environmental changes and are the first species to disappear from phytocenoses. The richest and most diverse biotopes in epiphytic Orchidaceae are dense forests, gallery forests and mountain forests. However, mountain forests and gallery forests have the closest compositions of epiphytic Orchidaceae. These habitats have vegetation cover with large trees and significant atmospheric humidity. According to the study of Tahinarivony (2023), in Marojejy National Park, the dense humid evergreen forests of low altitudes as well as the mountain forests are habitats conducive to the maintenance of Orchidaceae. These differences observed in the quantitative distributions of epiphytic Orchidaceae could also be justified by favorable ecological conditions (Gnagbo *et al*., 2015). Indeed, these biotopes present microclimates favorable to the life of epiphytes. A closed canopy which retains humidity and hygrometry levels high enough for a better presence of epiphytes.

Epiphytic Orchidaceae were not observed in the Soubré Sector as well as in many formerly anthropized areas of the Taï National Park. The habitats of the Soubré sector are made up of forests formerly occupied by crops, former illegal gold mining sites and sites affected by pollution linked to anthropogenic activities (Diarrassouba *et al*., 2020). These are former controlled occupation zones cleared since 2014. Only a small presence of epiphytic Orchidaceae is reported in secondary forests. All these factors combine to confirm that the distribution of epiphytic Orchidaceae is negatively impacted by anthropogenic activities. The study of Hietz (2005) in Mexico also reports that epiphyte diversity in disturbed habitats of anthropogenic origin decreases sharply compared to that of primary forests. For Coxson *et al*. (2013), epiphytes are species whose presence is strongly linked to environmental factors. *Solenangis scandens* and *Vanilla crenulata* are observed in secondary forests. This biotope is characterized by strong sunlight with vegetation with an open canopy, closed undergrowth dominated by an abundant low stratum. It is therefore a question of the resilience of these two epiphytic Orchidaceae in the face of deteriorating ecological conditions. We also observe a gradient in the levels of resilience of epiphytic Orchidaceae in Taï National Park. With intermediate levels of sunshine, we observe the presence of a community composed of *Bulbophyllum occultum*, *Bulbophyllum elliottii*, *Bulbophyllum longiflorum*, *Calyptrochilum christyanum*, *Polystachya cultriformis* and *vanilla planifolia*. According to the study of Lüscher *et al*. (2023), plant adaptation strategies are linked to stress intensity. The presence of the plant is dependent on its tolerance to dehydration. The presence of these epiphytic Orchidaceae in ecologically rigorous biotopes is a functional compromise between growth and resilience to water stress and then to sunlight. Human disturbance, despite reducing epiphyte population sizes, serves as a catalyst to promote change and perhaps an increase in epiphyte diversity across habitat diversity (Nkongmeneck *et al*., 2002). The other epiphytic Orchidaceae present at the study site are observed in biotopes with a completely closed canopy and a high humidity level. This proportion of epiphytes to colonize wetlands is corroborated by various scientific works. Nadkarni (2000) shows that the colonization of a biotope by epiphytes is a rapid process when there is the presence of water, humidity and nutrients. For Porembski (2011), the nature of microhabitats influences the presence of epiphytic species.

CONCLUSION

A total of 18 species of epiphytic Orchidaceae were observed in the different biotopes covered during this study. These are swamp forests, mountain forests, gallery forests, secondary forests and dense forests. In all these biotopes, the presence of epiphytic Orchidaceae is reported. However, the greatest number of epiphytic Orchidaceae species is observed in mountain forests, followed by gallery forests. The most abundant taxa are *Ancistrorhynchus capitatus*, *Bulbophyllum purpureorhachys* and *Calyptrochilum christyanum.* Concerning the frequencies of appearance during the different botanical surveys, *Ancistrorhynchus capitatus* is the most regularly observed with a frequency of appearance of 31.81%. She is followed by *Eulophia horsfallii*, *Eulophia gracilis*, *Epidendrum ciliare*, *Calyptrochilum emarginatum*, *Bulbophyllum fuscum* and *Angraecum distichum* which each have a spawn rate of 9.09%. They are followed by *Trachoma subluteum*, *Bulbophyllum purpureorhachis* and *Bulbophyllum occultum* are the least observed epiphytic Orchidaceae in mountain forests with 4.55% of the frequency of appearances. In secondary forests, we find an epiphytic community composed of *Solenangis scandens* and *Vanilla crenulata*. These are open canopy forests with a closed undergrowth dominated by an abundant lower layer. In the dense forests and gallery forests of the ADK-V6 management sector, we also observe an epiphytic community. These biotopes have a moderately open undergrowth with a moderately closed canopy. These biotopes have intermediate levels of sunlight. This plant community is composed of *Bulbophyllum occultum*, *Bulbophyllum elliottii*, *Bulbophyllum longiflorum*, *Calyptrochilum christyanum*, *Polystachya cultriformis* and *vanilla planifolia*. The third community of epiphytic Orchidaceae is observed in the Djapadji management sector. These are Orchidaceae present in swamp forests and mountain forests. These habitats have an open undergrowth with a closed and completely covering canopy in places.

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