American Journal of Life Sciences
2024, Vol. 12, No. 4, pp. 65-72
https://doi.org/10.11648/j.ajls.20241204.11

Research Article

Epiphytic Dynamics of the Adaptations to the Changes of Habitats in Taï National Park

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Abstract

Anthropogenic pressures in the eastern zone of the Taï National Park have led to the fragmentation of plant formations. The forests in the eastern part of the park have suffered significant degradation of plant cover and a significant loss of biodiversity. Therefore, this study makes it possible to contribute to monitoring the dynamics of reconstitution of the plant cover based on the ecological characteristics and the distribution of epiphytes present in the Djapadji management sector. Floristic inventories were carried out. In the plots, all trees with a DBH ≥ 5 cm were counted and recorded for the study of the structure of plant formations, all species carrying an epiphyte were recorded and the epiphyte was identified. The analysis of the data presents a flora composed of 26 epiphytes distributed in 18 genera and 9 families, mainly present in mountain forests. The diversity of epiphytic plants is highest in mountain forests, followed by hydromorphic, secondary and gallery forests. Strict epiphytes and Hemiepiphytes are more present in the most preserved habitats, while accidental epiphytes are observed in reconstitution biotopes. The distribution of epiphytic plants allows us to affirm that the formerly anthropized forests of the Djapadji sector present a good dynamic of reconstitution.

Keywords

Epiphyte, Microhabitats, Biodiversity Conservation, Ecological Monitoring

1. Introduction

Epiphytic vascular plants are structurally dependent on other plants without being parasitic to them [1]. These epiphytes constitute one of the most important components of tropical forests [2]. In these humid tropical forests, plants living epiphytically represent almost half of the vascular flora [3]. At the global level, vascular epiphytes constitute 10 pc of plant biodiversity, which represents the highest proportion among vascular plants [4]. Epiphytes occupy a significant

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Received: 10 June 2024; **Accepted:** 29 June 2024; **Published:** 15 July 2024

place in the biological richness of their ecosystems [5]. These vascular epiphytes have major ecological importance in local forest ecosystems. They play an essential role in the nutrient and water cycle, then contribute substantially to the plant biomass of tropical forests [6, 7]. Some epiphytic plants serve as habitat and constitute a food source for insects and birds [8]. They are also used in medicine, agriculture and horticulture [8]. Due to certain particular adaptations, some of them are used as bioindicators of climate change, pollution and in the assessment of ecological impacts [9].

Studies have highlighted striking differences in the diversity patterns of epiphytes compared to terrestrial representatives of some taxa, suggesting that epiphytic and terrestrial plants have different responses to environmental factors [10-13]; Epiphytes are more closely coupled to atmospheric and environmental conditions than terrestrial plants due to their dependencies on woody supports. Epiphytic life constitutes a constraint on access to water and strongly influences the vertical and then horizontal distribution of epiphytes within the forest cover.

One of the anthropogenic factors that influences the presence of an epiphyte in a biotope is deforestation. Their dependence on host trees makes epiphytes particularly vulnerable to deforestation and changes in forest structure generally leading to a loss of epiphyte diversity [14]. Following large-scale logging from Côte d'Ivoire in 1960, many areas of tropical forest were mainly converted to agroforests of cocoa, coffee and annual crops [15]. The scale of this agricultural expansion has led to conflicts between socio-economic interests and the management and conservation of biodiversity.

Tai National Park turns out to be a good example to illustrate this situation. According to the work of Gnagbo [16], this park presents conditions potentially favorable to epiphytes. It constitutes the largest primary tropical forest under strict protection in the entire West African region [17]. Unfortunately, this site has been the subject of numerous intrusions with plantations as well as illegal gold panning [18]. Thanks to military-political crises and insufficient monitoring, land clearing was observed until 2014 in various management sectors including Djapadji. This study is therefore initiated in the Taï National Park to contribute to a better assessment of the impacts of modifications in the park's ecosystems on the distribution of vascular epiphytes. The objective of the study is to characterize the changes in epiphyte populations following the levels of forest reconstitution in the Djapadji management sector.

2. Materials and Methods

2.1. Description of the Study Area

Taï National Park is located in the South-East of Côte d'Ivoire on the edge of the border with Liberia. This park is located between latitudes 5°10' and 6°50' North and longitudes 6°50' and 7°50' West (Figure 1). The eco-climatic conditions which reign throughout the Tai National Park place it in the rain-producing sector of the Guinea-Congolese domain. The park is covered with a sub-hygrophytic rainforest [19]. There are forests on hydromorphic soils. These are swamp forests, riparian forests and periodically flooded forests. In several regions of the park, strong anthropogenic pressures have led to the creation of plantations of annual crops as well as cash crops. After the eviction since 2014 of these populations illegally installed inside the park, the formerly anthropized spaces are gradually converted into fallow land then into secondary forests.

To effectively implement all management programs, the PNT has been subdivided into 5 management sectors which are Djouroutou, Taï, ADK-V6, Soubré and Djapadji. Of all these management sectors, the Djapadji sector subject to this study is one of the most anthropized. There are fallows, secondary forests and hydromorphic forest formations as well as evergreen forests.

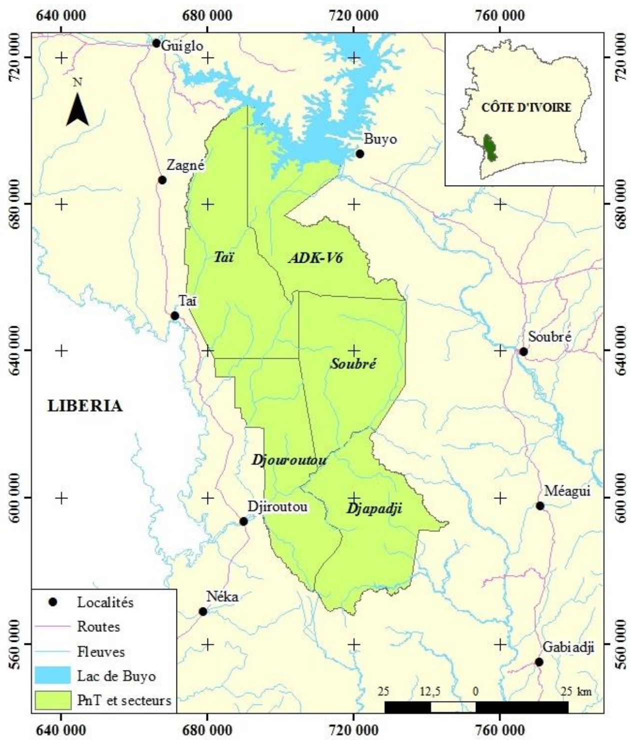

Figure 1. Boundaries of management areas in Taï National Park.

2.2. Data Collection and Analysis

Inventory plots were arranged according to the different plant formations observed in the Djapadji sector. Each plot is a rectangle 20 m wide by 25 m long, or 500 m^2. For each survey, the factors influencing the distribution of epiphytic species were described. This involved the presence of water in the environment, the relief, the structure of the undergrowth, the canopy and the type of plant formation. Conservation levels as well as cultural history were also taken into account. In each inventory plot, each woody plant bearing epiphytes was identified. The epiphytes present on these host species were also identified and then counted.

Surface surveys were supplemented by traveling surveys. This involved covering the entire biotope concerned, noting all the epiphytic and host plants not encountered in the inventory plots. This method is suitable for difficult to access environments or long routes.

Ecological data and biotope structures were also taken into account as part of this study. The distribution of epiphyte host individuals by diameter and height class makes it possible to account for the structure of woody populations [20]. The main morphological and biological types taken into account are classified according to the height of the woody plants [21, 22]. Chamephytes have a height of between 0 and 0.25 m. Nanophanerophytes have a height of between 0.25 and 2 m. As for Microphanerophytes, they are between 2 and 8 m. The Mesophanerophytes follow with heights between 8 and 32 m. Megaphanerophytes are woody plants with a height greater than 32 m.

The floristic diversities of the different epiphytic populations of the inventoried biotopes were evaluated with the diversity index according to Shannon [23]. This index measures the species composition of a population by taking into account the specific richness and relative abundance of each species [24]. It is mainly determined by the dominant species [25]. The mathematical formula for this index is: $H' = -\sum Pi \times \ln Pi$. H' represents the Shannon diversity index, Pi = Ni / Σ N; Pi is the relative frequency of individuals of species i; Ni is the number of individuals of a species i and N is the total number of individuals of all species.

The regularity of the distribution of species within the same biotope was evaluated by the Equitability index according to [26]. Also called the regularity or even distribution index, this index reflects the way in which individuals are distributed across species. It allows you to tell if a space is dominated by any species [27]. Its mathematical expression is as follows: $E = H' / \ln S$. E designates the Pielou equitability index, H' is the Shannon index and S represents the total number of species in the plot or space concerned.

The floristic similarity between the different biotopes was evaluated using the similarity coefficient according to Sorensen [28]. The expression of its formula is: $Cs = {}^{2c}/_{(a+b)} \times 100$. "Cs" is the Similarity Coefficient; "a" the number of species in plot A; and "b" the number of species in plot B; "c" the number of species common to both plots (A and B).

The levels of presence of epiphytes in the inventoried biotopes were also taken into account. The rarefaction index (Ri) made it possible to determine the abundance and rarity of an epiphytic species in its environment. It is calculated from the equation of [29] according to the formula: $Ri = (1 - {}^{ni}/_{N}) \times 100$; Where "ni" represents the number of plots of the species "i" and "N" the total number of plots placed in the environment.

The abundance of epiphytes was assessed using the method of [30]. It is practical for analyzing the structure of small samples with an abundance of less than 100 individuals in a given plot. The horizontal spatial distribution model of species using the method of [30] is applied on the basis of the number of epiphytes recorded on an inventory surface. If sampling is done in "*n*" plots of the same area and "*m*" is the average of individuals inventoried per plot, σ^2 the variance and λ the spatial distribution index, then: $\lambda = \sigma^2/m$.

A direct ordination was carried out to measure the distribution of epiphytic plants according to environmental parameters. Factorial Correspondence Analysis makes it possible to analyze the connection between two qualitative variables [31]. Multiple Correspondence Analysis (MCA), a factorial method of multidimensional descriptive statistics, was used. In principle, the MCA is a particular analysis which allows more than two types of qualitative environmental variables to be taken into account [32, 33]. The distribution of epiphytic species according to environmental parameters was analyzed using MCA with Statistica version 10 software.

3. Results

Floristic inventories within the 4 main biotopes of the Djapadji management sector made it possible to collect 259 individuals of epiphytic plants, distributed between 26 species, 18 genera and 9 families. The greatest epiphytic diversity is observed in mountain forests with 16 species, while only 9 species are observed epiphytically in secondary forests (Tables 1 and 2). The Araceae family was the most represented with 33.46% of the observed epiphytic taxa. Next, the Orchidaceae, Polypodiaceae and Piperaceae have respectively 25.77%, 16% and 15% of the epiphytes in all biotopes. The other families have less than 10% of epiphytic taxa.

Table 1. *Floristic Richness of the Different Studied Biotopes.*

Biotopes	Epiphytic Taxa		
	Species	**Genera**	**Families**
Mountain Forests	16	14	8
Secondary Forests	9	8	8
Hydromorphic Forests	10	9	7
Gallery forests	14	11	5

Table 2. List of Epiphytic Plant Species in the Investigated Area.

№	Taxon	Family	Epiphyte Type	Biological Type
1	*Adientum sp*	Pteridaceae	Accidental	H
2	*Ancistrorhynchus capitatus* (Lindl.) Summerh.	Orchidaceae	Strict	Ch
3	*Angraecum distichum* Lindl.	Orchidaceae	Strict	Ch
4	*Arthropteris palisotii* (Desv.) Alston	Oleandraceae	Hemiepiphyte	rh
5	*Bulbophyllum fuscum* Lindl.	Orchidaceae	Strict	Ch
6	*Bulbophyllum purpurearhachys*	Orchidaceae	Strict	Ch
7	*Calyptrochilum emarginatum* (Afzel. ex Sw.) Schltr.	Orchidaceae	Strict	Ch
8	*Cercestis afzelii* Schott	Araceae	Hemiepiphyte	Lmp
9	*Cercestis dinklagei* Engl.	Araceae	Hemiepiphyte	Lmp
10	*Cercestis ivorensis* A.Chev.	Araceae	Hemiepiphyte	Lmp
11	*Cercestis stigmaticus* N.E.Br.	Araceae	Hemi épiphyte	Lmp
12	*Culcasia barombensis* N.E.Br.	Araceae	Hemiepiphyte	Lmp
13	*Culcasia saxatilis* A.Chev.	Araceae	Hemiepiphyte	Lmp
14	*Culcasia scandens* P.Beauv.	Araceae	Hemiepiphyte	Lmp
15	*Culcasia seretii* De Wild.	Araceae	Hemiepiphyte	Lmp
16	*Elaphoglossum angulatum* (Blume) T.Moore	Dryopteridaceae	Strict	H
17	*Eulophia gracilis* Lindl.	Orchidaceae	Accidental	Ch
18	*Eulophia horsfallii* (Bateman) Summerh.	Orchidaceae	Accidental	Ch
19	*Lomariopsis guineensis* (Underw.) Alston	Lomariopsidaceae	Hemiepiphyte	G
20	*Microsorum punctatum* (L.) Copel.	Polypodiaceae	Strict	H
21	*Nephrolepis biserrata* (Sw.) Desv.	Nephrolepidaceae	Strict / Accidental	H
22	*Philodendron sp*	Araceae	Hemiepiphyte	Lmp
23	*Piper guineense* Schumach. & Thonn.	Piperaceae	Hemiepiphyte	Mp
24	*Platycerium stemaria* (P.Beauv.) Desv.	Polypodiaceae	Strict	H
25	*Rhaphidophora africana* N.E.Br.	Araceae	Strict	Lmp
26	*Vanilla crenulata* Rolfe	Orchidaceae	Hemiepiphyte	Lmp

Note: Mp: Mesophanerophytes; Lmp: Liana microphanerophytes; Ch: Chamaephytes; H: Hemicryptophytes; G: Geophytes; Rh: Rhizoids

Accidental epiphytes, Hemiepiphytes as well as strict epiphytes were observed during data collection. Hemiepiphytes present the highest proportion with 73 pc of plants observed in epiphytic life form. As for strict epiphytes, they represent 19 pc of the species observed. Finally, accidental epiphytes are the least represented and constitute 8 pc of the epiphytes collected. Considering the statuses of the epiphytes collected, *Culcasia dinklagei*, *Culcasia scandens*, *Nephrolepis biserrata* and *Piper guineense* are all of Least Concern and *Microsorum punctatum* is threatened with extinction according to IUCN (2020).

The maximum values of the diversity indices were recorded in the mountain forests, then the minimum values reported in the gallery forests (Table 3). However, these differences in floristic diversity values are not significantly different. As for the equidistributional of epiphytes in the different biotopes, significantly different values are recorded. Hydromorphic forests have the lowest values (0.74 ±0.638) while the highest values (0.89 ±0.42) are recorded in inselberg forests.

The gallery forests and mountain forests have strong similarities in their compositions with a coefficient of 56.3 pc of epiphytes collected. Then, secondary forests and hydromorphic forests show a floristic resemblance to gallery forests. Major floristic dissimilarities were also noted between various biotopes. The lowest values are observed between hydromorphic forests and secondary forests (Table 4).

Table 3. Mean Diversity Indexes for the Surveyed Environments.

Biotopes	Shannon index	Pielou's index
Mountain Forests	2,53 ±0,09[a]	0,89 ±0,42[b]
Secondary Forests	2,38 ±0,07[a]	0,78 ±0,04[a]
Hydromorphic Forests	2,4 ±0,10[a]	0,74 ±0,64[a]
Gallery forests	2,29 ±0,10[a]	0,81 ±0,49[b]

Note: In the same column, means followed by the same letter are not significantly different at the 5% level of the Newman-Keuls test.

Table 4. Similarity between the different biotopes investigated.

	Mountain forests	Secondary forests	Hydromorphic forests	Forest galleries
Mountain forests	100			
Secondary forests	40	100		
Hydromorphic forests	44.4	44.4	100	
Forest galleries	56.3	52.2	56	100

Legend: In bold coefficient of similarities greater than 50 pc

The epiphytes most observed in hydromorphic forests are *Culcasia scandens* and *Piper guineense* with 44 and 38 occurrences respectively. They are followed by *Microsorum punctatum* (16), *Culcasia seretii* (15) and *Cercestis afzelii* (7), with respectively 16, 15 and 7 occurrences collected in hydromorphic forests. In the mountain forests, only *Culcasia saxatillis* and *Nephrolepis biserrata* have occurrences of 7 and 6 individuals. The 14 other epiphytes observed have occurrences of less than 5. The epiphytic flora of the forest galleries is characterized by *Microsorum punctatum* with 23 individuals recorded, followed by *Lomariopsis guieensis*, *Ancistrorhnchus capitatus* and *Cercestis afzelii*. As for secondary forests, collections reported the presence of *Nephrolepis biserrata, Cercestis afzelii* and *Piper guineense.*

Three species present rarefaction index values below 50%. They are the most frequent and most abundantly encountered in the four biotopes studied. In order of importance, they are *Microserum punctatum* (31.25%), *Cercestis afzelii* (37.5%), and *Piper guineense* (48.75%). Six species are considered less abundant, with rarefaction index values between 50% and 80%. These are *Culcasia saxatilis* (56.25%), *Culcasia scandens* (56.25%), *Lomariopsis guineensis* (62.5%), *Nephrolepis biserrata* (68.75%), *Platycerium stemaria* (68.75%) and *Ancistrorhynchus capitatus* (75%). The rarest epiphytes have rarefaction indices greater than 80%. These include *Arthropteris palisotii* (81.25%), *Cercestis dinklagei* (81.25%), *Rhaplidophora africana* (81.75%), *Calyptrochilum emarginatum* (87.5%), *Elaphoglossum angutatum* (93.75%).

The influence of vegetation physiognomy was analyzed through multiple correspondence analysis. The graph in the Figure 2 shows the results relating to the presence data according to the appearance of the undergrowth and the canopy, in the different plant formations inventoried. The analysis of this figure highlights 3 epiphytic groups.

The first group is distinguished in secondary forests. These are habitats with open canopies. Incident radiation from the sun directly reaches the epiphytes. We mainly observe two groups of epiphytes. Accidental epiphytes such as *Asplenium platyneuron*, *Ficus microcarpa*, *Ficus recurvata*, *Phyllanthus amarus* and *Solenangis scandens*. There are also Hemiepiphytes such as *Cercestis dinklagei*, *Nephrolepis biserrata*, *Phymatosorus scolopendria* and *Vanilla crenulata.* Strict epiphytes are absent in these habitats.

The second group is observed in swamp forests. The vegetation is characterized by moderately closed undergrowth and canopies. Accidental epiphytes characteristic of these swamp forests are *Berlinia occidentalis*, *Eulophia horsfallii*, *Ficus polita* and *Oleandra distenta*. The Hemiepiphytes also observed are *Culcasia angolensis*, *Culcasia scandens, Culcasia seretii*, *Epipremnum aureum*, *Microgramma lycopodioides*, *Philodendron sp*., *Piper guineense*. The strict epiphytes present in these habitats are *Epidendrum ciliare* and *Platycerium* *stemaria*.

The third group of epiphytes is observed in mountain forests as well as in gallery forests. These habitats feature closed canopies with open undergrowth. Incident solar radiation does not reach the lower stratum. The accidental epiphytes present in these biotopes are *Arisaema triphyllum* and *Eulophia gracilis*. As for the Hemiepiphytes, they are *Cercestis afzelii*, *Cercestis ivorensis*, *Cercestis stigmaticus*, *Culcasia saxatilis*, *Elaphoglossum angustatum*, *Lomariopsis guineensis* and *Rhaphidophora africana*. Many strict epiphytes are present in these fully covering canopy habitats with open undergrowth. The 12 species observed in strict epiphytic life form are *Ancistrorhynchus capitatus*, *Angraecum distichum*, *Antrophyum boryanum*, *Bulbophyllum fuscum*, *Bulbophyllum fuscum* var. melinostachyum, *Bulbophyllum occultum*, *Bulbophyllum purpureorhachis*, *Calyptrochilum emarginatum*, *Microsorum punctatum*, *Ophioglossum pendulum*, *Polystachya cultriformis* and *Trachoma papuanum*.

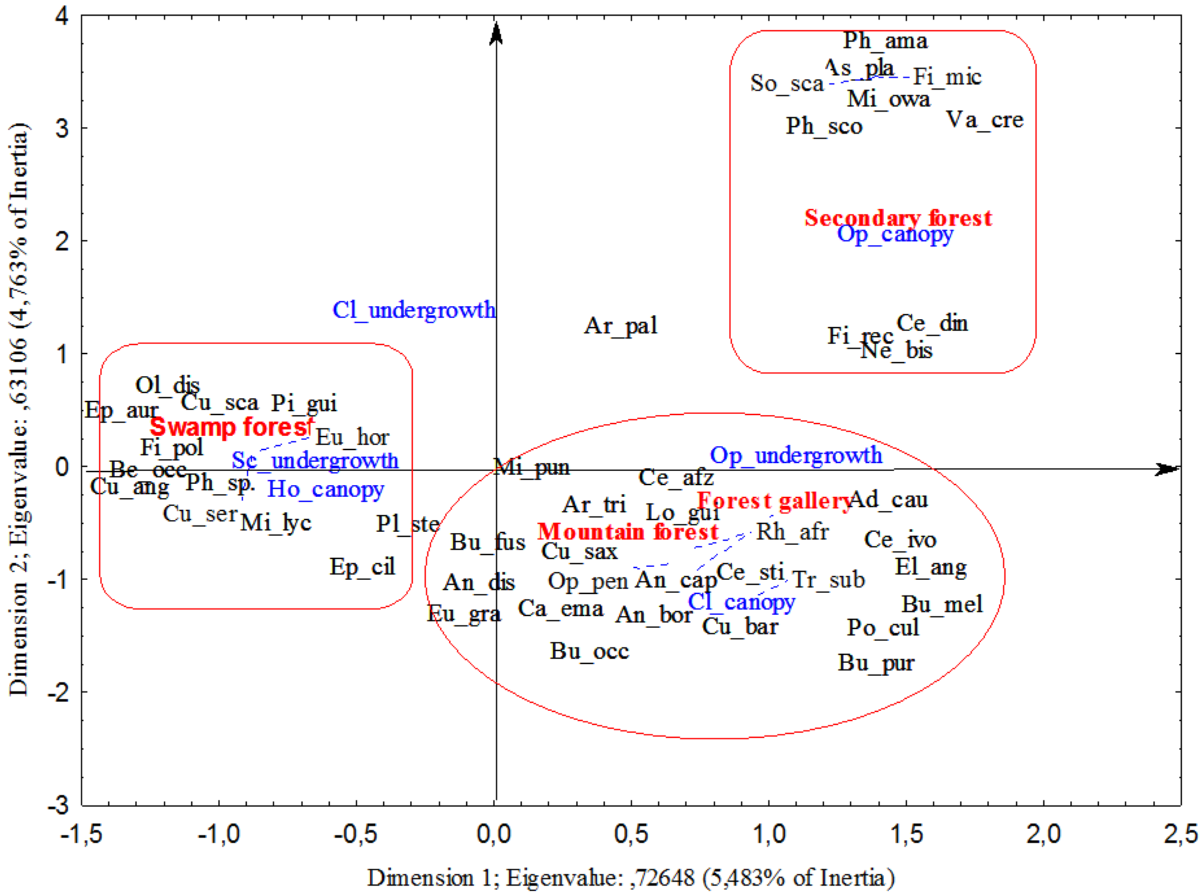

Figure 2. *Multiple Correspondence Analysis (MCA) plot illustrating the distribution and abundance of epiphytic plants according to structural and environmental parameters.*

4. Discussion

The compilation of floristic lists from the various inventories carried out made it possible to obtain a general list of 26 epiphytic species belonging to 10 families. This shows a good presence of epiphytic species in the four biotopes. Secondary forests and mountain forests have low values in terms of specific richness and the highest values are recorded in hydromorphic forests and gallery forests. This difference could be justified by favorable conditions in gallery forests and hydromorphic forests. These biotopes present microclimates favorable to the life of epiphytes. Lianescent microphanerophytes are the most observed in the epiphytic flora of the inventoried sites. This is linked to the fact that these microphanerophytes adapt more easily to life in epiphytic life form. These plants can tolerate harsh environmental conditions more easily [34, 35]. The diversity and floristic richness indices show good trends towards the conservation of the inventoried biotopes. Degraded habitats show strong tendencies towards reconstitution due to favorable environmental conditions.

In terms of occurrences, open-canopy biotopes are the least colonized by epiphytes. Next, come closed-canopy biotopes. Finally, biotopes with a moderately open canopy have the most occurrences of epiphytic flora. The distributions of epiphytes in these biotopes show characteristic relationships with microhabitats. It is the combined effect of dispersal as well as the resilience of certain epiphytic species to the ecological factors of the inventoried habitats [36]. Some epiphytes are specific to microhabitats and others are generalists and colonize the inventoried microhabitats.

Heliophilous epiphytes are observed in secondary forests. These are pioneer epiphytes which colonize the best open ones. They are mainly accidental epiphytes. The dispersal organs of terrestrial plants are generally found on the tops of humus in the internodes of host plants. After germination, these dispersal organs give rise to ephemeral epiphytes such as *Asplenium platyneuron*, *Ficus recurvata* and *Solenangis scandens* observed in secondary forests. The low presence of epiphytes in these biotopes is linked to the poorly covering canopies [37].

Hydromorphic forests and gallery forests are the biotopes richest in epiphytes. This abundance is due to the availability of nutritional resources necessary for epiphytes. The work of Nadkarni [8] shows that there is a positive correlation between the abundance of the original community and epiphyte colonization. The colonization of a biotope by epiphytes is a rapid process when water, humidity and nutrients are present.

5. Conclusion

The study of the current floristic diversity of the four biotopes made it possible to identify 26 epiphytic species distributed between 10 families. The most species-rich families are the Araceae. The most harvested species are *Culcasia saxatilis*, *Cercestis afzelii Piper guineense* and *Microsorum punctatum*. A similarity is observed in the composition of epiphytic species of gallery forests and inselberg forests. Mountain forests have great epiphytic diversity with low occurrences. Hydromorphic forests and gallery forests present average diversity with high occurrences. In secondary forests, qualitative and quantitative diversity is low. Overall, we observed good regeneration of the epiphytic flora of the investigated environments. The recolonization of biotopes degraded by epiphytes is also ensured by heliophiles as well as accidental epiphytes.

Abbreviations

APG	Angiosperm Phylogeny Group
OIPR	Ivorian Office of Parks and Reserves
CA	Correspondence Analysis
MCA	Multiple Correspondence Analysis

Acknowledgments

The authors would like to thank the Islamic Development Bank or funding the research. The authors are also grateful to the OIPR for its technical assistance and facilitation of the research.

Author Contributions

Gnagbo Anthelm: Conceptualization, Data curation, Funding acquisition, Methodology, Project administration, Software, Writing – original draft, Writing – review & editing

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Conflicts of Interest

The authors declare no conflicts of interest.

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