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Table of Contents

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Journal of Ecology and The Natural Environment

Full Length Research Paper

Diversity and composition of the epiphytic flora in an urban agglomeration: The case of city of Douala, Cameroon

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Epiphytes constitute an element of climate regulation in the tropical zone. In Cameroon, the decline in forest area of about 220,000 ha, partly due to urbanization, has been observed. The research aim was to characterize the epiphytic flora of the urban ecosystem of Douala. Four zones represented by nine neighbourhoods were chosen for the surveys. Four transects of a maximum distance of 500 m were scanned on each neighbourhood. Epiphytes were checked by direct visual observation on the host trees. Epiphytes's life forms were determined, and the fixation zone was established using the Johanson method. A total of 72 species of epiphytes were identified, dominated by Polypodiaceae. Casual epiphytes were the most abundant life-form, and true epiphytes were the least, divided into Polypodiaceae, Dryopteridaceae, and Orchidaceae within the genus *Calyptrochillium*. Twenty-two species of host trees were inventoried in the study area. Rutaceae was the most represented family with six species. True epiphytes were abundant in seaside and peripheral areas, while Casual and Hemiepiphytes were in the central sectors. The domestication of epiphytes must be initiated in order to preserve their diversity in urban ecosystem.

Key words: Biodiversity, coastal zone, epiphyte, floristic statement, urbanization.

INTRODUCTION

Epiphytes are plants that attach themselves to and grow on other plants occurring from the forest understorey to the periphery of tree crowns (Benzing, 2020). These organisms face difficulties of obtaining adequate water, as well as mineral nutrients; and thus develop adaptive structures such as pseudo-bulbs or even rosette leaves for the accumulation of water and humus (Bola, 2002). They are the only living plants within a special ecological niche and contribute significantly, sometimes as much as 50%, to the biodiversity of tropical rainforests (Bola, 2002). The diversity of epiphytes is estimate at 28,000 species, representing about 10 to 20% of the diversity of

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vascular plants in the forests in the world, and approximately 30% for neo-tropical forests (Miranda et al., 2020). In tropical vegetation vascular epiphytes make up approximately 25% of vascular plant species and have important roles in maintaining forest ecosystem functions, such as nitrogen fixation, water and nutrient cycles (Nieder et al., 2001; Song et al., 2012; Stanton et al., 2014). They also regulate the biogeochemical cycle of various mineral elements by their retention during the dry season and their progressive dropping during the rainy season as well as their retention by trees (Noumi et al., 2010). They participate in the general improvement of the balance of mineral elements in the forests where they grow. Epiphytes therefore appears in the forest domain as the adaptive response of small-sized non-sciaphilous plants to the very pronounced photic deficit in the undergrowth.

Information on the diversity and abundance of epiphytes is only partially established in tropical regions because of the difficult accessibility due to their location in the canopy (Noumi et al., 2010). Indeed, African tropical forests, especially Biafreena forest, are considered as an important area of biodiversity, very few investigations have been carried out there (Noumi et al., 2010). The main ecological factor that governs the distribution of epiphytes in various ecosystems is the selective accessibility to light (Bola, 2002). This therefore suggests that this plant form would be the congruent response of small plants with high photic demand in the forest environment. However, in disturbed biotopes (substitute forests, fallows, orchards and urban agglomerations), this limiting factor being absent, another mode of ecological development of vascular epiphytes could be observed. Thus, one might think that the composition of the epiphytic flora; its pattern of colonization of trees as well as ecological conditions differ according to the environment (Jiagho et al., 2016). Urbanization is one of the major factors contributing to ecosystem degradation. Its consequences are global warming which includes changes in functioning of ecosystems, in particular due to increase in temperature and greenhouse gases and consequent rise in temperature of the atmosphere (GIEC, 2007). In metropolis of tropical region like Douala, urbanization have an effect on the vegetation and landscape (Nganmo and Priso, 2022). This then can affect the diversity of epiphytes, by the modification of some of their key life factors such as number of host plants or the level of humidity. Some research studies have been carried out on the epiphytic flora of a peri-urban forest (Kimpouni et al., 2017), but no study of epiphytes carried out in an agglomeration has been noted so far. The aim of this study, therefore, was to characterize epiphytic flora of the city of Douala, a metropolis of Central Africa's sub-region.

METHODOLOGY

Douala, the economic capital of Cameroon, is located in the Littoral region between 03° 40' - 04° 11' N and 09° 16' - 09° 52' E. It has six subdivisions of about 150 neighbourhoods (Priso et al., 2011). The landscape is on the whole characterized by its flatness with many swamps which make urbanization difficult. Altitude ranges between 0 in lowlands, to 13 m at the peaks. The climate is coastal equatorial type, with two annual seasons, the dry season did not exceed three months. Average temperatures vary little throughout the year, the maxima are reached in February (27.6°C) and the minima in July (24.8°C). Relative humidity and water vapour pressure are always very high (Din et al., 2002). Precipitation can reach 783 mm in August, 749 mm in July and 649 mm in September. The vegetation is dominated by mangroves in the low hydromorphic areas, and the plateaus offer the presence of degraded littoral forests, thickets or shrubby savannahs.

The study sites were distributed in the centre towards the periphery of the town according to four sectors: (1) Seaside (SS) which included the neighbourhood Bonanjo with administrative buildings bounded on the west by the Wouri river; (2) Industrial sector (IS) which neighbourhoods Espoir and Ndogpassi characterize by food and metallurgical industries; (3) Urban sector (US) included indigenous villages Ndogbong and Ndoghem characterized by popular areas; (4) Peri-urban sector (PU), which neighbourhoods Pk15, Pk16, and Pk17 that constitute urban extension areas characterize by deforestation and high level of construction of buildings (Figure 1).

In the centre of each neighbourhood surveyed, a 4-way crossroads was chosen, and transect with a length of 500 m was measured on each axis. Five plots of 250 m² (or 250 m²) were delimited along these transects using a double tape measure, spaced by a distance of 20 m. For each site, 20 plots were thus delimited, that is, an area of 5000 m² and a total area of 4 ha. Inside each plot, every tree with a minimal diameter of 10 cm was examined. The presence or absence of epiphytes was noted for each tree prospected, and the species were identified on site, using an identification key of reference manuals such as "Flore du Cameroun" and "Arbres des forêts denses d'Afrique Centrale" (Vivien and Faure, 2011). Unidentified specimens were taken to the Laboratory of Plant Biology of the University of Douala, or at the National Herbarium of Cameroon, for detailed analysis and taxonomic identification. The epiphytes life-forms were determined according to Addo-Fordjour et al. (2009):

(1) True or strict epiphytes are species that normally spend their entire lifespan as epiphytes;
(2) Hemi-epiphytes are species without contact with the ground at the beginning of their life but which they establish later (primary hemi-epiphyte) or which break contact with the ground at the end of their life (secondary hemi-epiphyte);
(3) Casual epiphytes, which are normally terrestrial plants but which can grow on trees.

For the determination of the distribution of epiphytes on the host plant, each phorophyte was divided into four zones according to the Johansson method (Wang et al., 2016) (Figure 2), Trunk Zone (TZ), Inner Crown Zone (ICZ), Middle Crown Zone (MCZ), and Outer Crown Zone (OCZ). The TZ refers to the host trunk areas below the first branch; the ICZ covers the area from the first branch to the second branch; the MCZ covers the area from the second branch to the third branch; and the OCZ refers to the remaining areas above the third branch.

RESULTS

Diversity of vascular epiphytes

An inventory of epiphytic flora showed 72 species

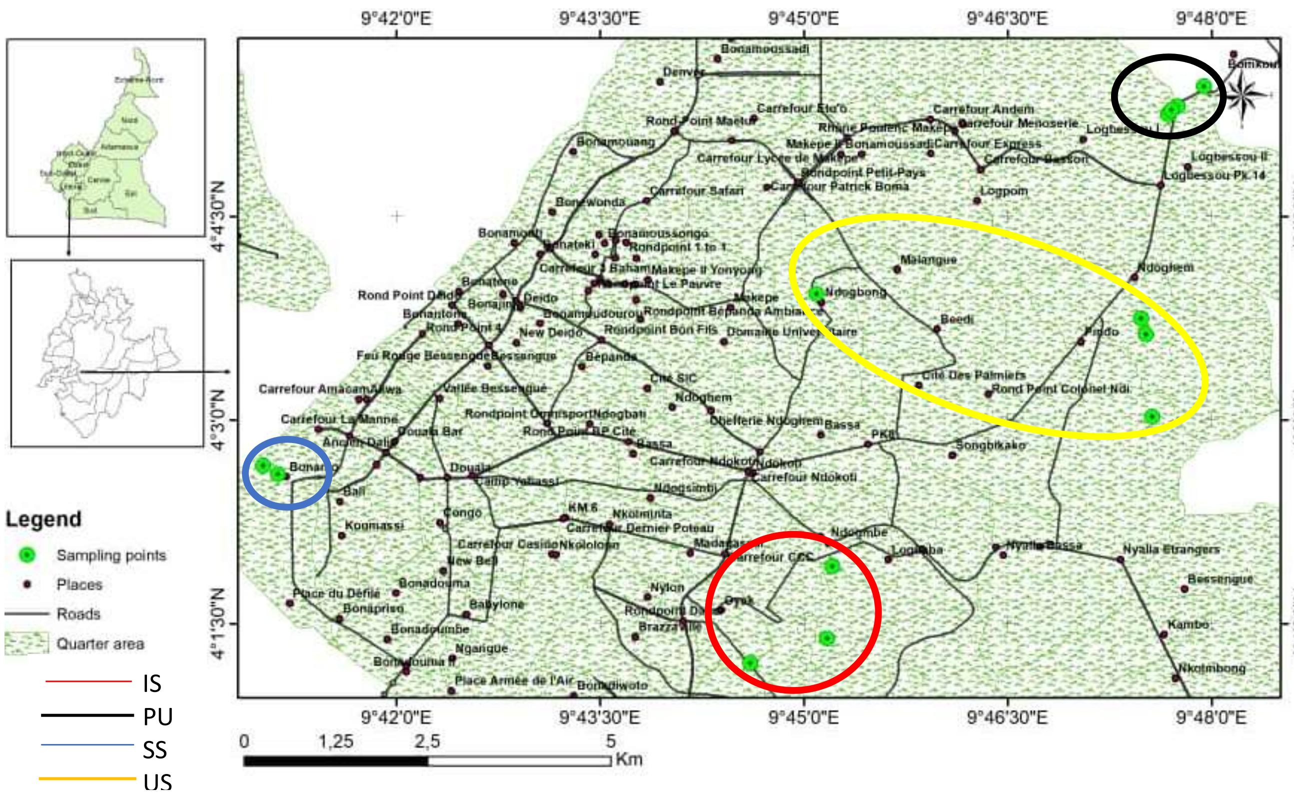

Figure 1. Map of the studied zone.
Source: Author

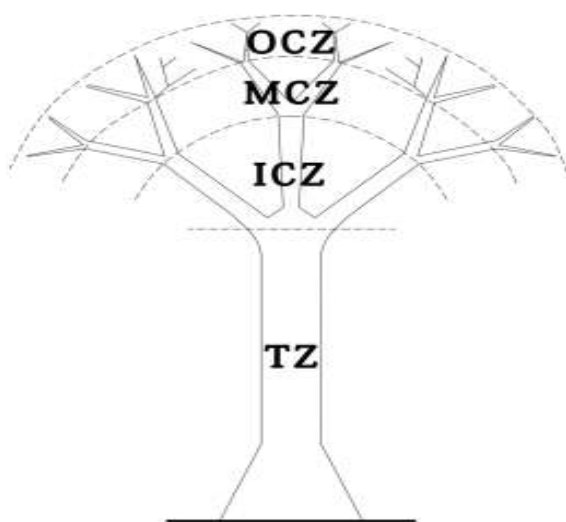

Figure 2. Diagram of the vertical zones of host tree where epiphyte is distribution. TZ: Trunk zone; ICZ: inner canopy zone; MCZ: Medium canopy zone; OCZ: Over canopy zone.
Source: Addo-Fordjour et al. (2009)

belonging to 57 genera grouped into 32 families. The families with the highest number of species were Polypodiaceae (6 species), Asteraceae (5 species) and Cucurbitaceae (5 species). The life-forms were divided into 08 species (11.11%) of True epiphytes, 16 species (22.22%) of Hemi-epiphytes, and 48 species (66.67 %) of Casual epiphytes. True epiphytes belonged to two groups, Pteridophytes (7 species) and Angiosperms with the Orchidaceae (1 species). The specific richness of life-forms in the studied sectors revealed a higher number of True epiphytes in US (6 species) and SS (5 species), Hemi-epiphytes were more abundant in PU (10 species) and US (9 species), while Casual epiphytes showed higher specific richness in PU (30 species) and IS (28 species) (Table 1).

Diversity of host trees

The inventory of phorophytes revealed 347 individuals belonging to 22 species, 17 genera and 13 families. Anacardiaceae were most represented with four species, followed by Rutaceae (3 species), Arecaceae (2 species) and Combretaceae (2 species). Apocynaceae and Burseraceae were the paucispecific families with only one species, respectively *Voacanga africana* and *Dacryodes edulis*. *Elaeis guineensis,* was phorophyte with most epiphyte species (55), followed by *Cocos nucifera* and *Mangifera indica* (27 species each). *Albizia adianthifolia* and *Citrus maxima* recorded the lower number of species (Figure 3). The presence of epiphytes in considerable abundance on *E. guineensis* and *C. nucifera* shows the importance of palm trees as host plants for the epiphytes.

Spatial pattern of vascular epiphytes

A total of 804 individuals of epiphytes was recorded in the studied area, the US showed the higher number (323 individuals), followed by SS (203 individuals), IS (179 individuals) and PUS (99 individuals. This epiphytic abundance was compared to the total number of trees of each sector in Figure 4. It reveals the absence of a real gradient between the number of trees and number of epiphytes. The breakdown occurs in IS which has a greater number of trees than AS, but a few numbers of epiphytes compare to the relative tree abundance.

Figure 5 shows the composition in life-forms of studied sectors. In SS, True epiphytes were the dominate life-form (75.37%), followed by Casual (16.26%), and Hemi-epiphytes (8.37%); in IS, there was a similar proportion of Casual (50.84%) and True (49.16%); PUS recorded a proportion of True epiphytes of 50.51%, Casual (28.28%) and Hemi at 21.21%; in US, we recorded a proportion of 49.85% of Casual epiphytes, followed by True (38.08%), and Hemi epiphytes (12.07%). It seems the dominance of True epiphytes is in the peripheral sectors of the town.

The distribution of true epiphytes among the studied sectors (Table 1) revealed that *Micrograma* species and *Platycerium stemaria* were recorded in all the sectors, and were thus qualified as ubiquitous. *Nephrolepis biserrata* and *Pyrrosia* species were recorded in three sectors and were qualified as escorts; *Syngonium podophyllum* was encountered in IS and US, while *Asplenium nidus*, *Calyptrochilium* species and *Pyrrosia mechowii* have only been reported respectively in one sector. They were qualified as characteristic of the Urban sector for *A. nidus*, and of Sea side for both others.

Distribution of epiphytes life-forms among host trees

The analysis of the fixation zone of epiphytes life-forms from trunk to the tree top showed an ascending gradient (from the trunk to the top) for True epiphytes, and a decreasing gradient (for top to the trunk) for Casual. Upper canopy was colonized by True epiphytes with four species (80%), and Hemi epiphytes (1 species). Middle canopy recorded three life-forms, dominated by True epiphytes (5 species), followed by Hemi (2 species), and Casual epiphytes with one species. The inner canopy was also dominated by True epiphytes (7 species), but this time followed by Casual (4 species), and Hemi epiphytes (1 species). Trunk was dominated by Casual epiphytes (48 species), Hemi (16 species), and True epiphytes (8 species) (Figure 6).

DISCUSSION

A total of 72 species of epiphytes was found as a result of the study. This is more than the 28 species found in an urban forest in Brazzaville (Gabon), 29 species in a semi-deciduous forest in Ghana, and 61 species found in the oriental sector of Lac Kivu in DRC (Buhendwa et al., 2014; Kimpouni et al., 2017). Results showed some phanerophytes as epiphytes (*Alchornea cordifolia*, *Cecropia peltata*, *Ceiba pentandra*, *Elaeis guineensis*, *Mangifera indica*, *Psidium guajava*, *Rauvolfia vomitoria*, *Vernonia amygdalina*, *Voacanga africana*) with few occurrences. The diaspores of these terrestrial species were likely transported in the substrate on the other plant species by animals, gravity, or wind (Chapman et al., 1999).

True epiphytes represented 10% of vascular epiphytes encountered in the study area, and were thus the rarest life-form. Casual epiphytes were commonest life-form with 63.86%. Similar results were also found in Côte d'Ivoire and Ghana (Addo-Fordjour et al., 2009; Gnagbo et al., 2016). Nevertheless, Mucunguzi (2007) in DRC, and Kimpouni et al. (2017) in Congo found True epiphytes as the commonest life-form, whereas True epiphytes were the rarest life-form in this study. About True epiphytes, seven species belonged to Pteridophytes, and one from the Angiosperms, that is, Orchidaceae family. This is unlike Noumi et al. (2010) in the National Park of Korup, who found 102 Orchidaceae

Table 1. Epiphyte's diversity of studied sectors.

Family	Species	Life-forms	Sectors			
			IS	PU	SS	US
Acanthaceae	*Asystasia gangetica* (L.) T Anderson	Casual	+	+	+	+
	Thumbergia grandiflora Roxb.	Hemi				+
Amanrathaceae	*Cyathula prostrata* (L.) Blume	Casual			+	+
Anarcadiaceae	*Spondias mombin* L.	Casual				+
	Mangifera indica L.	Casual				+
	Pistacia vera L.	Hemi		+		
Apocynaceae	*Rauvolfia vomitoria* Afzel.	Casual				+
	Voacanga africana (Stapf.) Pichon	Casual	+			+
Araceae	*Anchomones difformis* (Blume) Engl.	Casual				+
	Cercestis sp Schott	Hemi		+		
	Epipremnum pinnatum Schott	Hemi				+
	Syngonium podophyllum Schott	Hemi	+	+		+
Arecaceae	*Elaeis guineensis* Jacq.	Casual	+	+	+	+
Asteraceae	*Ageratum conyzoides* L.	Casual	+			
	Chromoelaena odorata (L.) R.King&H.Robyns.	Casual		+		
	Emilia coccinea G. Don	Casual	+			
	Vernonia amygdalina (Delile) Sch.Bip.	Casual	+			
	Vernonia cinerea (Delile) Sch.Bip.	Casual	+			
Bombaceae	*Ceiba pentandra* (L.) Gaertn.	Casual	+			+
Capparaceae	*Cleome ciliata* Schum. & Thonn.	Casual	+			
Commelinaceae	*Commelina benghalensis* L.	Casual	+	+	+	+
Convolvulaceae	*Ipomoea batatas* L.	Casual			+	
	*Ipomoea involucrata*L.	Casual	+			+
Costaceae	*Costus afer* Ker Gawl.	Casual		+		+
Curcubitaceae	*Coccinia barteri* (Hook.f.) Keay.	Hemi		+		
	Cucumis melo L.	Hemi				+
	Lagenaria sp Ser.	Hemi		+		+
	Momordica charantia L.	Hemi		+		
	Momordica foetida Schum.	Hemi		+		+
Cyperaceae	*Cyperus alternatifolius* L.	Casual	+			+
	Cyperus amarus L.	Casual				+
	Cyperus esculentus L.	Casual	+			
	Cyperus iria L.	Casual		+		
Dioscoreaceae	*Dioscorea* sp L.	Hemi		+	+	
Dryopteridaceae	*Nephrolepis biserrata* (Sw.) Schott	True	+	+		+
Euphorbiaceae	*Alchornea cordifolia* (Schumach. & Thonn.) Mull. Arg.	Casual	+			
	Euphorbia hirta L.	Casual	+			

Table 1. Contd.

	Euphorbia hyssopifolia L.	Casual				+
	Desmodium sp. Desv.	Casual	+			+
Fabaceae	*Pueraria phaseoloides* (Roxb.) Benth	Hemi	+			+
	Trifolium sp L.	Casual				+
Lamiaceae	*Solenostemon monostachyus* (P. Beauv.) Briq.	Casual	+		+	
Maranthaceae	*Haumania danckelmaniana* (J.Braun & K. Schum.) Milne-Redh.	Hemi		+		+
Melastomataceae	*Dissotis rotondifolia* (Sm.) Triana	Casual			+	+
	Dissotis sp Benth.	Casual		+		
	Mimosa invisa Mart. Ex Colla	Casual	+			
Mimosaceae	*Mimosa oleifera* Lam.	Casual				+
	Mimosa pudica L.	Casual	+			+
	Ficus kamerunensis Warb. Ex Mild br. & Burret	Hemi		+	+	
Moraceae	*Ficus mucoso* Welw. Ex Ficalcho	Hemi			+	
	Ficus sp L.	Hemi			+	+
Myrtaceae	*Psidium guajava* L.	Casual	+			
Orchidaceae	*Calyptrochilium* spp. (Rchb.f.) Summerh.	True			+	
Oxalidaceae	*Oxalis barrelieri* L.	Casual	+	+		+
Passifloraceae	*Passiflora foetida* L.	Casual		+		+
	Passiflora sp L.	Casual		+		
Phyllanthaceae	*Phyllanthus amarus* Schumach. Et Thonn.	Casual	+	+	+	+
	Phyllanthus urinaria Schumach. Et Thonn.	Casual	+			
	Acroceras zizanioides (Kunth) Dandy	Casual	+	+		+
	Axonopus compressus (Sw) P. Beauv.	Casual				+
Poaceae	*Eulesine indica* (L.)Caerten.	Casual	+			+
	Panicum maximum Jacq.	Casual	+			
	Asplenium nidus L.	True				+
	Micrograma sp L.	True	+	+	+	+
Polypodiaceae	*Microsorium punctatum* (L.) Copel.	True				+
	Platycerium stemaria (P.Beauv.) Desv.	True	+	+	+	+
	Pyrrosia mechowii (Brause & Hieron. ex Hieron.) Alston	True			+	
	Pyrrosia sp Mirb.	True	+		+	+
Rubiaceae	*Ixora coccinea* L.	Casual	+			
	Cecropia sp Loefl.	Casual		+		
Urticaceae	*Laportea astuans* (L.) Chew	Casual		+		
	Urera sp Benth.	Casual		+		

IS: Industrial sector; PU: peri-urban; SS: sea side; US: urban sector.
Source: Author

species. This agreed with Addo-Fourdjour et al. (2009) who considered that Orchidaceae had a preference for habitats with lower levels of human interferences, like secondary forests than cultivated forests or urban forests.

The low diversity of True epiphytes in the studied area can be explained by the high level of urbanization and anthropogenic activities, which affect epiphytes' key life factors such as number and architecture of phorophytes,

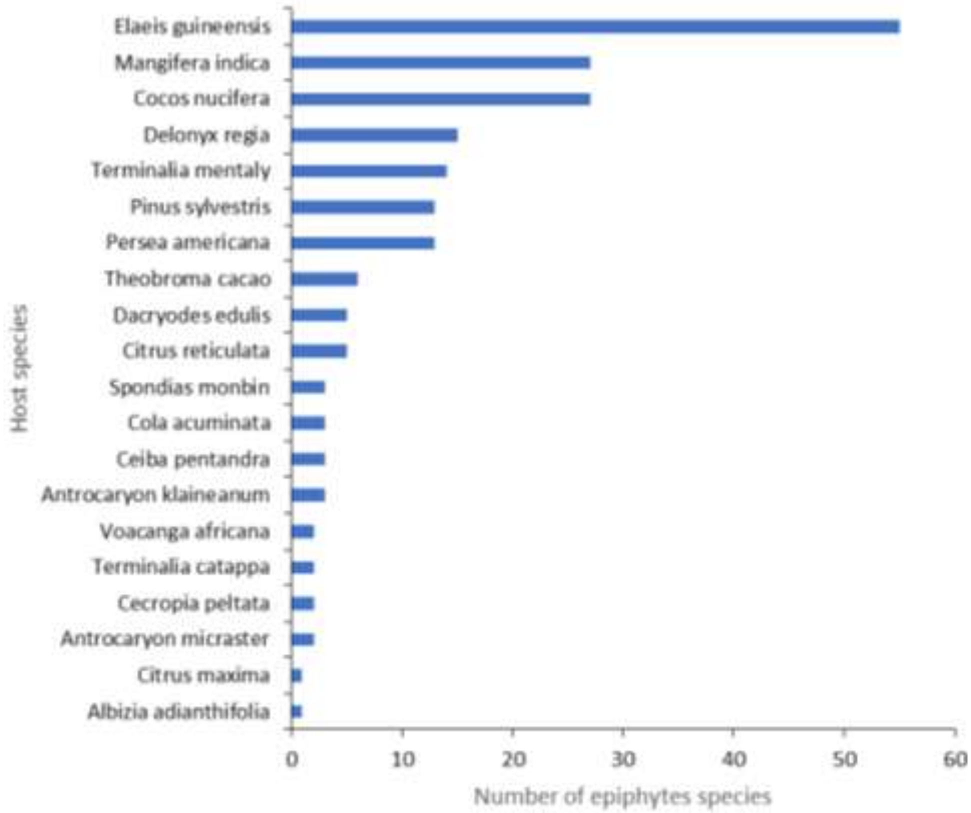

Figure 3. Epiphytes diversity of host species.
Source: Author

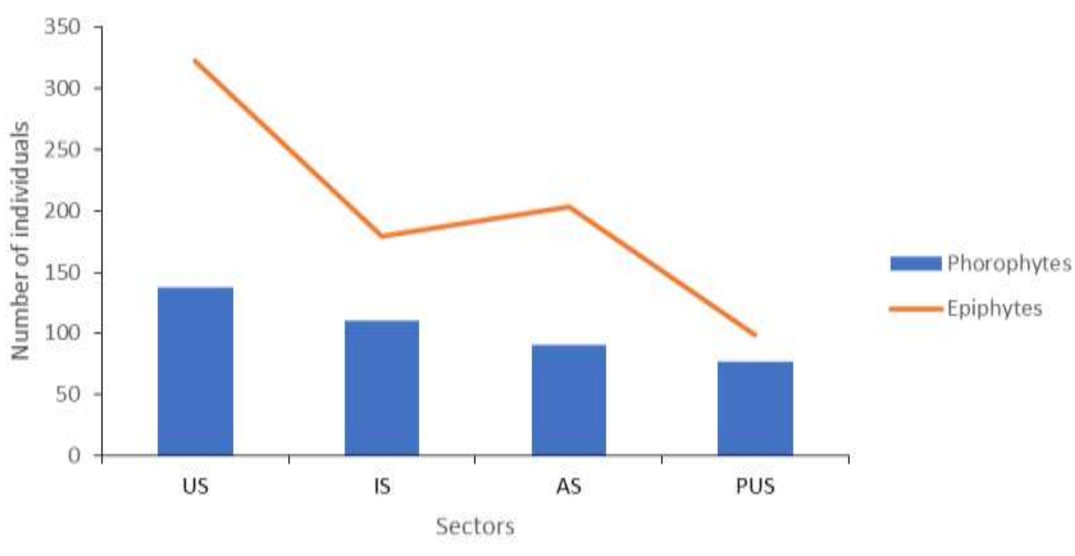

Figure 4. Abundance of phorophytes and epiphytes in the studied sectors.
Source: Author

luminosity, level of humidity, and trunk diameter of phorophytes (Sonké et al., 2001; Kimpouni et al., 2014).

A decreasing gradient of number of epiphytes species from trunk to the upper canopy was found in this study. This is consistent with the findings of other studies (Wang et al., 2016; Noumi et al., 2010) that suggested that this

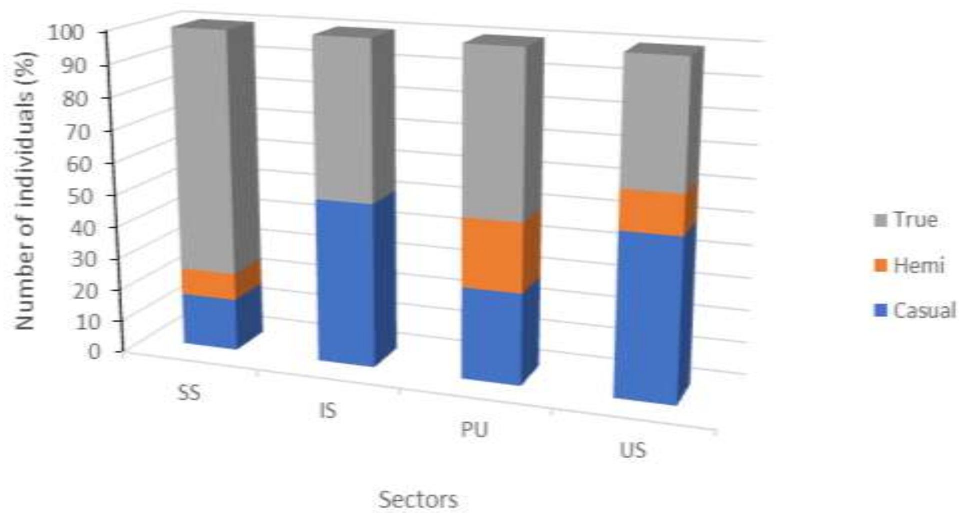

Figure 5. Abundance of epiphytes life-forms in the studied sectors.
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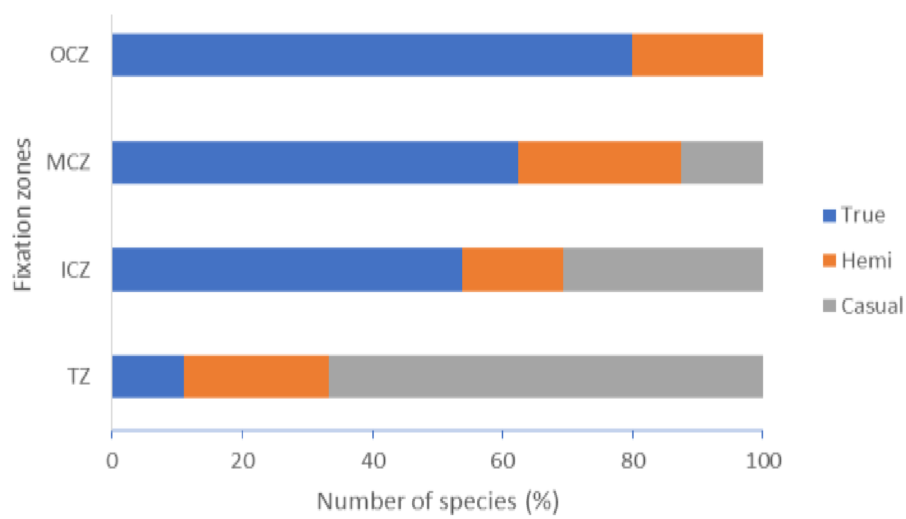

Figure 6. Proportion of epiphytic life-forms on the fixation zones of host trees.
Source: Author

may be explained, partially, by a vertical gradient of humidity, organic matter and light intensity. It could also reveal a level of specialization: canopy for true epiphytes, and trunk for the other life-forms. Addo-Fordjour et al. (2009) presented evidence in Ghanaian forests of another gradient in which middle trunk was the most occupied zone, followed by lower trunk and upper trunk.

Results of the present research showed that urban sector has the higher epiphyte richness, and the higher number of true epiphytes. However, the peri-urban sector recorded the lowest number of true epiphytes due to the expansion of the town, and urbanization. The common occurrence of casual epiphytes can be explained by the presence of palm trees whose foliar forks serve as substrate and diaspore receptors. Indeed, in the African semi-deciduous forests, hosts trees that have cracked bark on the trunk harbour more epiphytes than those with a less cracked bark (Zapfack, 1993).

The number of individuals of strict epiphytes was more abundant in peripheral areas of the city, and less in the central areas. The central zones would, therefore, be less favourable to the development of strict epiphytes. This is certainly due to the high level of industrial and anthropogenic activities that take place there. Indeed, epiphytes are even used as indicators of the conservation status of forest ecosystems, and are sensitive to anthropogenic activities (Gnagbo et al., 2016). The status of epiphytes would also help to identify areas of the city with higher humidity. Indeed, epiphytes are indicators of the humidity of the environment. It can therefore be said that the peripheral areas of the city of Douala are the wettest, and could constitute a site for the conservation of epiphytes.

Calyptrochilium spp., the only Orchidaceae species was found in the administrative sector. It was far from the industrial and urban sectors which provide many sources of pollution. Orchidaceae epiphytes are commonly inventoried in the montane forests and/or in the ecosystem without anthropic intervention such as protected areas, or primary forests (Noumi et al., 2010; Stevart and Sonké, 2002). The presence of *Calyptrochilium* spp. in the urban ecosystem implies an adaptation to survive in this environment. Thus, it is important to domesticate this species for its better conservation.

Conclusion

This study demonstrates that epiphytes are present in the urban ecosystem of Douala, and may persist in fairly stable representative numbers unless increased industrial activities and urbanization makes the urban centers less amenable for the epiphytes. Inventories made revealed 72 species of epiphytes. Casual epiphytes were the most abundant life-form. Pteridophytes were the major constituents of True epiphytes, *Calyptrochilium* spp. was the only Orchidaceae recorded in the study area. True epiphytes showed an ascending gradient of fixation, from trunk to crown, while Hemi and Casual epiphytes had a decreasing gradient of fixation, from crown to trunk. True epiphytes were rare in the industrial sector and urban sector where pollution was higher. Phorophytes were diversified, and the palm *E. guineensis* was the most colonised mainly with Casual epiphytes. Additional assessment of epiphytes should be made for their conservation in this ecosystem.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests

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Full Length Research Paper

Effect of IAA on spore germination and gametophyte development in *Ceratopteris thalictroides* (l.) brongn. from Sitamata Wild Life Sanctuary, Rajasthan

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The effect of different concentrations of Indole acetic acid (IAA) on spore germination and gametophyte development of *Ceratopteris thalictroides*, a leptosporangiate fern of the family Pteridaceae found at the marshy places near Sitamata sanctuary in Rajasthan, was observed. The highest spore germination percentage was recorded in the 2 to 6 ppm concentration range of IAA, with minimum in the 10 ppm concentration. The number of cells in the protonemal filament and percentages of 2-D growth, spatulate and cordate gametophyte were highest in the 1 ppm concentration of IAA, followed by the control. Maximum percentages of archegonia and antheridia development were also recorded in 1 ppm IAA and control treatments, with percentages gradually declining from 2 to 10 ppm treatments. However, the maximum percentage of sporophyte development was recorded in 4 and 6 ppm IAA treatments.

Key words: IAA, ppm, 2-D growth, leptosporangiate ferns, sporophytes.

INTRODUCTION

Pteridophytes, known as shade and moisture loving plant, form a sizeable component of the vegetation of Rajasthan. This group is represented by 21 genera and 39 species (Gena, 1998). Bir and Goyal (1982) were the first to provide comprehensive records of the pteridophytic flora of Mt. Abu, listing 22 species of ferns. Sitamata forest, located in Chittorgarh and Pratapgarh district in the southern part of Rajasthan, comprises 422.95 sq. km and is known to be one of the richest localities of pteridophytes in the state. Behera et al. (2022) reported that *Ceretopteris thalictroides* is consumed as a leafy vegetable and used medicinally, with an antibacterial activity against Streptococcus mutans and Shigella flexneri. However, the taxa in this area are likely facing extinction due to natural and manmade factors (Yadav, 2008). This necessitates the formulation of conservational strategies for this rapidly depleting group of plantsIn light of this present work, the effect of different concentrations of Indole-3-Acetic Acid (IAA) from 1 to 10 Parts Per Million (ppm) in an even mode after 1 ppm treatment on spore germination and gametophytic development, starting from 2-dimensional (2-D) growth, spatulate growth, cordate gametophyte and gametophyte with germinal organs of Cheilanthes thalictroide has been studied. Previous studies have investigated the effect of growth hormones on sporegermination and gametophyte

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development in ferns (Hurel-Py, 1943; Miller, 1961; Hickok and Kiriluk, 1984). An extensive review of the gametophytic generation and experimental studies has been provided by Bir (1987). Sharma and Vangani (1988) investigated the effect of Gibberellin (GA3) on spore germination, gametophyte development and sex expression in Cheilanthes farinosa Forssk. They reported that small linear gametophytes were protandrous and did not produce archegonia at any stage of development. Large bilobed gametophytes has distinct median ridge and were protogynous. According to them, there was a male to hermaphrodite sequence in prothallial development and the antheridial system was not evident. Gupta and Bhambi (1991) have investigated that cytokinins are better than other hormones for the induction and promotion of spore germination, leading to the faster rate of gametophyte and sporophyte development in *Adiantum capillus-veneris* L. Vidhya et al. (2000) tested 2, 4-D and GA_3 for their effects on spore germination and gametophyte development in three ferns viz., *Ceratopteris thallictroides* L., *Pityrogramma calomelanos* (L.) Link and *Pteris vittata* L. They observed that effect of 2, 4-D on gametophyte development in *Ceratopteris* and *Pityrogramma* were more pronounced than in *Pteris*. Higher concentration of 2, 4-D was found to be detrimental to the gametophyte development. Higher concentrations of GA_3 stimulated early germination of spores of *Pteris*; delay in *Pityrogramma* and without any significant effect in *Ceratopteris.* Low concentration of GA_3 stimulated early appearance of antheridia in *Ceratopteris* and *Pityrogramma* and reduction of number of archegonia were observed in *Ceratopteris* Purohit and Bohra (2007) described gametophyte development and impact of various plant growth regulators (GA_3, IAA and morphactin) on sex expression and sporophyte formation in *Equisetum* L., *Cheilanthes*; Sw. and *Hypodematium*; Kunze which were collected from different localities in the Aravalli hills, Rajasthan.

MATERIALS AND METHODS

For germination experiments, spores of *C. thalictroides* found in marshy place along the road side punga pond (route to jhakham dam) of Sitamata sanctuary from Pratapgarh district were collected in the months of August-September. Spores were surface sterilized by 2% sodium hypochlorite solution and then kept on Knop's nutrient medium (Half strength) in petri-plates. For control set of experiments, one set of petri-plates containing 100 spores on nutrient medium (without growth regulators) was treated as control. Similarly, IAA treatment of vary concentration was given to another set of petri-plates containing 100 spores of selected taxa. Total seven sets of petri plates (including one set as a control) containing spores were taken for study. The culture medium used for these experiments consisted of Knop's major elements and Nitsch's trace elements (1 ppm). The composition of Knop's medium was as follows: KNO_3: 100 mg; $MgSO_4$: 100 mg; $Ca(NO_3)_2$: 400 mg; K_2HPO_4: 100 mg; Distilled water to make dilution of 1000 ml. Composition of Nitsch's medium was as follows: H_2SO_4: 0.5 ml; MnSO4: 3.0 ml; ZnSO4: 7H2O: 500.0 mg; H3BO3: 25.0 mg; CuSO4, $5H_2O$: 25.0 mg; $NaMoO_4$, $2H_2O$: 25.0 mg; $CoCl_2$: 25.0 mg; Distilled water: 1000.0 ml.

Illumination was provided by two 40 watt fluorescent tubes kept at a distance of 60 cm. Spores were allowed to germinate in a culture chamber maintained at 25 ± 2°C. For each treatment, spores were sown in two sets of petri-dishes (7.5 cm. diameter) thus total 14 petri dishes were used each pair is used for different concentration in ppm (1, 2, 4, 6, 8, and 10 ppm as well as control) of IAA. The data are based on counts of 100 spores from each petri-dish.

A control set was invariably included in all the experiments.

Treatment of IAA

For treatment of IAA on spore germination after 48 h of dark inhibition were made to germinate on liquid Knop's medium (half strength) supplemented with Nitsche's trace elements in 7.5 cm petri-dishes. White light was obtained by two fluorescent tubes fixed 60 cm above the petri-dishes. Different sets of petri dishes were supplied with different concentrations of IAA. Stock solutions of required concentration of the plant hormone were prepared to investigate the effect of IAA, and the desired concentrations for the experiment were incorporated in the culture medium and kept in petri-dishes before sprinkling spores on the surface of the medium. Stock solution of IAA was prepared by dissolving the required quantity of the chemical in 2 ml. of ethanol, the required volume of distilled water being added afterwards. Further concentrations were made by diluting this stock solution. Entire experimental work was carried out under aseptic conditions including the use of sterilized glassware in a thermostatically controlled culture chamber in the laboratory. The temperature during the course of these experiments was maintained at 25± 2°C. Microscopic observations were made on an Olympus HSA microscope. Most of the photomicrographic work was done from the temporary preparations using photomicrographic attachment on Olympus trinocular microscope.

RESULTS

To determine the effect of IAA, spores of *C. thalictroides* were treated with different concentrations of IAA ranging from 1 to 10 ppm. The data presented in Table 1 indicate that spores of selected taxa require different period for spore germination. The spores started to germinate after 9 days under control where only 55% of spores were able to germinate while rest undergone dormant and later disintegrate.10 ppm concentration of IAA has been recorded to induce earliest (within 7 days) with minimum spore germination (25%) as compared to other treating concentrations of IAA and control treatment (Table 1). An increase in percent spore germination was observed under 1ppm (60.00%) to 6ppm (66%) concentration as compared to control (55%) treatment. Amongst different concentrations of IAA, maximum spore germination (66.6%) was observed in 2-6 ppm. However, a decrease in percentage spore germination after 6 ppm IAA concentration has been observed. Data represented in Table 2 indicates that number of cells in protonemal filament is found to be varying in different concentrations of IAA at different time periods. 2-D gametophyte percentage was found maximum (80%) after 12 days of

Table 1. Effect of different concentrations of IAA on spore germination of *Ceratopteris thalictroides* from Sitamata wild life sanctuary, Rajasthan.

Serial number	Name of plant	*Ceratopteris thalictroides*	
	Concentration of IAA (ppm)	Days after sowing	% Spore germination
1.	Control	9	55
2.	1	8	60
3.	2	8	66
4	4	9	66
5.	6	9	66
6.	8	10	40
7.	10	7	25

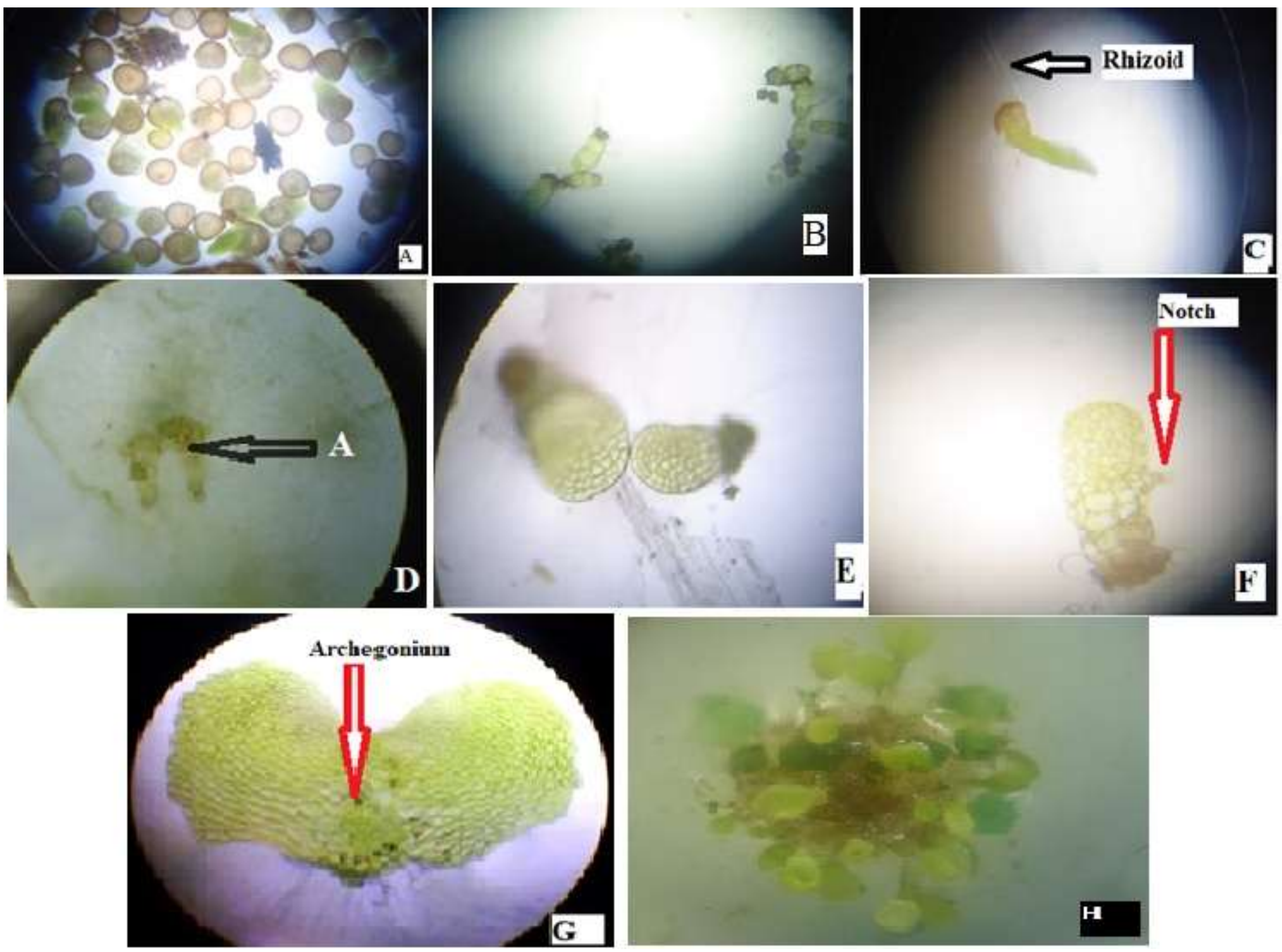

Figure 1. Spore germination and different stages of gametophyte development in *Ceretopteris thalictroides*, Sitamata forest (A-H). A. Initiation of Spore germination in 4 ppm concentration of IAA (after 9 days of sowing); B-C. Protonema formation with rhizoids in 8 and 2 ppm of IAA respectively; D. Spatulate gametophyte with "Antheridia (A)" in control (after 14 days of sowing); E. Spatulate gametophyte in 6 ppm of IAA (after 17 days of sowing); F. Cordate gametophyte showing notch in 6 ppm IAA (after 21 days of sowing); G. Mature prothallus showing Archegonia in 2 ppm IAA (after 32 days of sowing); H. Clusters of Sporophyte in 8 ppm concentration of IAA (after 38 days of sowing).

sowing in 1ppm of IAA while minimum (23%) after 19 days of sowing in 10 ppm and percentage growth of others were lies in between these two. Similarly, the highest percentage growth of spatulate gametophyte

Table 2. Effect of different concentrations of IAA on gametophyte development in *Ceratopteris thalictroides.*

Serial number	IAA Conc. (ppm)	Protonemal filament		Initiation of 2-D growth		Spatulate gametophyte		Cordate gametophytes		Development of sex organs				% of gametophyte with sporophyte	
		Days after sowing	No. of cells sowing	Days after sowing	% of 2-D gametophyte	Days after sowing	% of spatulate gametophyte	Days after sowing	% of cordate gametophyte	Days after sowing	Gametophyte with Antheridia%	Days after sowing	Gametophyte with Archegonia %	Days after sowing	Gametophyte with sporophyte %
1	Control	10	3	12	40	14	64	18	63	27	66	35	45	43	72
2	1 ppm	10	7	12	80	13	67	17	71	27	52	30	61	35	70
3	2 ppm	10	7	11	45	13	56	18	54	26	35	32	42	36	65
4	4 ppm	11	3	12	44	15	60	19	50	26	43	32	43	38	80
5	6 ppm	10	5	12	64	17	52	21	53	25	42	31	28	36	80
6	8 ppm	12	6	13	36	18	36	20	20	23	37	28	24	38	50
7	10 ppm	9	6	19	21	18	23	17	16	53	28	46	15	60	42

(67%) and cordate gametophyte (71%) are observed in 1 ppm of IAA treatment after 13 and 17 days of sowing respectively (Figure 1, D and E). Sex organs were developed after a month of spore inoculation. However, the further growth of these gametophytic portions underwent decline from 6 to 10 ppm (Table 2). The gametophytes were found protandrous under control and hormonal treatment. Antheridial formation took place in spatulate gametophyte (Figure 1D). Sex organs begin to develop after 20 days of sowing. Antheridial formation takes place earlier then archegonia and it is found that treatment of IAA usually has not promontory effect for the development of antheridia in compare to control (66%) except 1 ppm (55%). However, 1 ppm of IAA causes earlier promoter effect for the development of archegonia (61%) in compare to control (45%) and other concentrations of IAA. Similarly, Yadav and Uniyal (2021) studied in vitro spore germination and gametophyte development of *Drynaria mollis* Beddome, and *Pteris aspericaulis* wall and noticed early development of antheridia after 90 days of sowing and later archegonial formation began after 100 days of sowing in both the treated species. Delayed formation of sex organs and the least number of antheridia and archegonia are recorded in 10 ppm. Sporophytes were observed after 45 days in control while in treated plates they appeared earlier between 35-38 days of sowing. Maximum percentage of sporophytes (80%) was calculated in 4 ppm and 6 ppm hormonal treatment (Figure 1). The least percentage observed in 10 ppm after 2 months of sowing.

DISCUSSION

The effect of growth regulators on spore germination under different concentration of IAA indicate that the spores of *C. thalictroides* start to germinate earlier in different concentrations of treated hormone except 8 ppm where it causes little delayed to germinate. In control the germination was recorded on 9th days of sowing. Raghavan (1971b) reported that the longer period of exposure of white light for the induction of spore germination may be due to longer hydration period. Under 10 ppm of IAA treatment the spores of *C. thalictroides* germinate earlier while percent spore germination decreases gradually from the concentration of 1to 8 ppm. Thus, the spore germination is not much affected under PGRs in the selected fern taxa of Sitamata forest as reported by Sharma et al. (1996) in some common ferns of Rajasthan. Roshni and Hegde (2020) suggested that the spore germination of *Pityrogramma calomelanos* L. needed knops medium for in vitro culture and follow vittaria-type of spore germination pattern. Prothallus development is of Ceretopteris-type. In general, germination and protonemal development take one to two weeks under optimum conditions and mature gametophytes are formed after 6-8 weeks (Table 2). Similar observations were made by

Praptosuwiryo (2017) who reported that the germination of spores in *Platycerium wande* Racib takes place between 7-14 days on natural media. However, in *C. thalictroides*, fertilization can take place only in two weeks after germination (Stein, 1971). The whole life cycle can be completed in vitro in 3-4 months in *C. thalictroides* and *C. pteridiodes* (Loyal and Chopra, 1977). The gametophytic development of *Christella hispidula* (Deene) Holttum has been described and illustrated by Bejoy et al. (1994).

Sex organs were developed after a month of spore inoculation. The gametophytes were found protandrous under control and hormonal treatment. Maximum percentage of gametophytes with sporophytes in *C. thalictroides* (Table 1) was observed in 4 and 6 ppm concentration of IAA in comparison to the control. A decrease in percentage development of sporophytes in selected taxa is observed under higher concentration of IAA. 1ppm concentration of IAA has been found effective in antheridial development however; Ohishi et al. (2021) suggested that GA_4 stimulates both protonemal elongation and antheridium formation in *Lygodium japonicum* Thunb. On the other hand, IAA promoted protonema elongation but causes reduced antheridium formation. Overall it may be concluded that formation of spatulate gametophytes and antheridial development in this taxa are not favoured by hormone, especially at higher concentration of IAA, while archegonial development is enhanced by the minimum concentration of treated hormone as compare to control in the selected fern taxa.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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Full Length Research Paper

Effects of land use on floristic composition and diversity of woody vegetation in the commune of Enampore, Senegal

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The diversity of woody vegetation is threatened by intensified land use and soil chemistry. However, the effects of land use and soil chemistry on woody vegetation are not well known. The objective of this study was to determine the influence of land use classes (upland, uncultivated lowland, cultivated lowland, and tans) on the diversity and structure of woody vegetation in the commune of Enampore. To do this, an inventory was conducted in two sites (Essyl and Selecky). A total of 80 plots for vegetation surveys were conducted, 10 in each land use (The plots were circular in size, ranging from 15 to 100 m in radius depending on the land use class. In each plot, the chemical properties (pH and salinity) of the soil, diversity, density, abundance, regeneration, and growth parameters (height and diameter) of the woody plants were determined. Soil chemical properties varied significantly ($p<0.05$) according to land use. Uncultivated lowlands and tans had lower pH (pH≤4.62) and higher electrical conductivities (EC≥580µs/cm). A total of 33 species belonging to 31 genera from 17 families were recorded across all land use types. The most represented families were *Fabaceae*, *Apocynaceae*, and *Combretaceae*. Land use significantly ($p<0.05$) influenced woody diversity, abundance, and density. The uplands had more diversity than the other land use types. Salinity had a strong influence on the vegetation located in the tans and uncultivated lowlands. Vertical and horizontal structures had an "L" shape typical of a stand dominated by young trees. The diversity and density of woody plants in the commune of Enampore are influenced by land use and soil chemical properties.

Keywords: Land use, pH, Salinity, Woody vegetation, Diversity, Structure.

INTRODUCTION

Human use of vegetation has a long tradition in semi-arid West Africa, and local people highly value the goods and

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services provided by woody plants in the Sudano-Sahelian region of Senegal. Forests and woodlands surrounding rural habitats provide vast natural resources such as firewood and timber, food, medicine, and fiber (Shackleton and Gumbo, 2010). Local people regard woody plants as a key resource that provides many functions and use them intensively (Ganaba and Guinko, 1995). Woody vegetation is a key component of the savannah ecosystem and an indicator of ecosystem condition and health (Lawesson, 1990; Tappan et al., 2004). Trees play an important role in the functioning of savannah ecosystems (Sankaran et al., 2008) maintaining soil chemistry and nutrient cycling (Schlesinger and Gramenopoulos, 1996; Reid et al., 1999). They also provide habitat for wildlife and a range of ecosystem services that directly support livelihoods. Woody plants are also coppiced for fodder (Le Houérou, 2002) and therefore play an important role in the pastoral economy. In Lower Casamance, woody plants play an extremely important role in the life of rural populations (Rabiou et al., 2014). They help to mitigate extreme climatic events. Several woody species of ecological, socio-economic, and cultural interest are deliberately conserved in the crop fields (Sambou et al., 2017).

Despite its importance, woody vegetation is under strong pressure causing its degradation. In Senegal, the degradation of woody vegetation is very advanced in the agroecological zones. Woody species are subject to degradation caused by several natural, climatic, and anthropogenic factors (Samaké et al., 2011; Diatta et al., 2016). Climatic factors have contributed to the disappearance of certain woody species locally. Among the most cited causes of vegetation regression in Senegal are overexploitation of resources, land use change, bushfires, climate change, deterioration of soil properties (salinization and pH), and erosion (Brandt et al., 2014; Sambou et al., 2016). Similarly, salinization and acidification of soils create imbalances in the ecosystem and would cause significant damage to wildlife, pastures, habitats, and vegetation cover (Mbow et al., 2000). The problem of salinity has been present for a long time in the uncultivated lowlands, especially in Lower Casamance (Sadio, 1991). However, knowledge of the spatial distribution of woody vegetation diversity and density across landscape classes is still limited (Foley et al., 2005). In particular, more information is needed on woody vegetation diversity and distribution in agricultural areas compared to other parts of the landscape (Augusseau et al., 2006; Raebild et al., 2007). This research aimed to study the spatial distribution of woody species and its determining factors according to land use types in the commune of Enampore in Lower Casamance.

MATERIALS AND METHODS

Study area

The study was conducted in the localities of Selecky (12° 31'37'' N, 16° 27'56'' W and Essyl (12° 31'10'' N, 16° 25'34'' W) located in the Lower Casamance region of Ziguinchor, Senegal (Figure 1). The climate is characterized by the coastal South Sudanese type (Sagna, 2005) and is dominated by two seasons: a dry season from November to May and a rainy season from June to October, during which agricultural activities are conducted. The average annual temperature is 27°C with a maximum (of 35°C) in April and a minimum (of 15°C) in December (Sagna, 2005). The study area is characterized by vegetation dominated by the species *Elaeis guineensis, Borassus akeassii, Ceiba pentandra, Parkia biglobosa, Adansonia digitata, Khaya senegalensis, Anacardium occidentale, Mangifera indica*, etc. The mangrove ecosystem is still colonized by two tree species (*Avicennia germinans* and *Rhizophora mangle*) (PDC, 2021).

Sampling and data collection

Google Earth imagery was combined with a visual interpretation of Landsat imagery for exploratory assessment before fieldwork. Classification of satellite imagery was based on the landscape classes (Sambou et al., 2016; Dewan et al., 2012; Cui et al., 2013; Dieng et al., 2014). Four land use classes (upland, uncultivated lowland, cultivated lowland, and Tans) were identified. After the selection of sites (Selecky and Essyl) and land use classes, a prospective visit was organized to validate the classification, mapping, and delineation of the land use classes using GPS. Based on the classification of land use classes, stratified sampling was carried out. Within each land use, 10 plots were randomly selected by choosing geographic coordinates (Figure 2). A total of 80 plots, 40 in each site, were selected. To obtain an approximately similar number of trees in each plot, circular plots of varying size were adopted according to land-use types, that is, 15 m radius for upland and tans and 100 m radius for uncultivated lowland and cultivated lowland. In each plot, all woody species were identified and counted, and diameter and height were measured. All individuals with a diameter greater than 5 cm were measured at 1.30 m using a tree caliper. In addition, all individuals with a diameter of less than 5 cm were counted systematically. The total height of each individual was measured with a Blum leiss. In each plot, a 500 g sample of soil was taken with an auger from several randomly selected locations. Soil samples were taken from the 0-30 cm horizon. Composite samples were made by mixing different samples for sites that appeared heterogeneous. Soil samples were taken to the Laboratory of Agroforestry and Ecology (LAFE) at the Assane Seck University in Ziguinchor to determine pH and electrical conductivity (EC).

Data processing and analysis

At the end of data collection, other parameters of the woody vegetation such as density, diversity, and structure were calculated. The density is the number of individuals per unit area. It is expressed in a number of individuals/ha. The observed or real density (D) is obtained by the following formula:

$$D = \frac{N}{S}$$

D: density (number of individuals per hectare); N: total number of individuals; S: area (ha).

To assess the floristic composition and diversity of woody vegetation by land use class, Menhinick's richness, Shannon's diversity indices, Pielou's evenness, and Jaccard's dissimilarity were determined. The Menhinick (DMn) richness index (Rh, 1977) was determined from the formula:

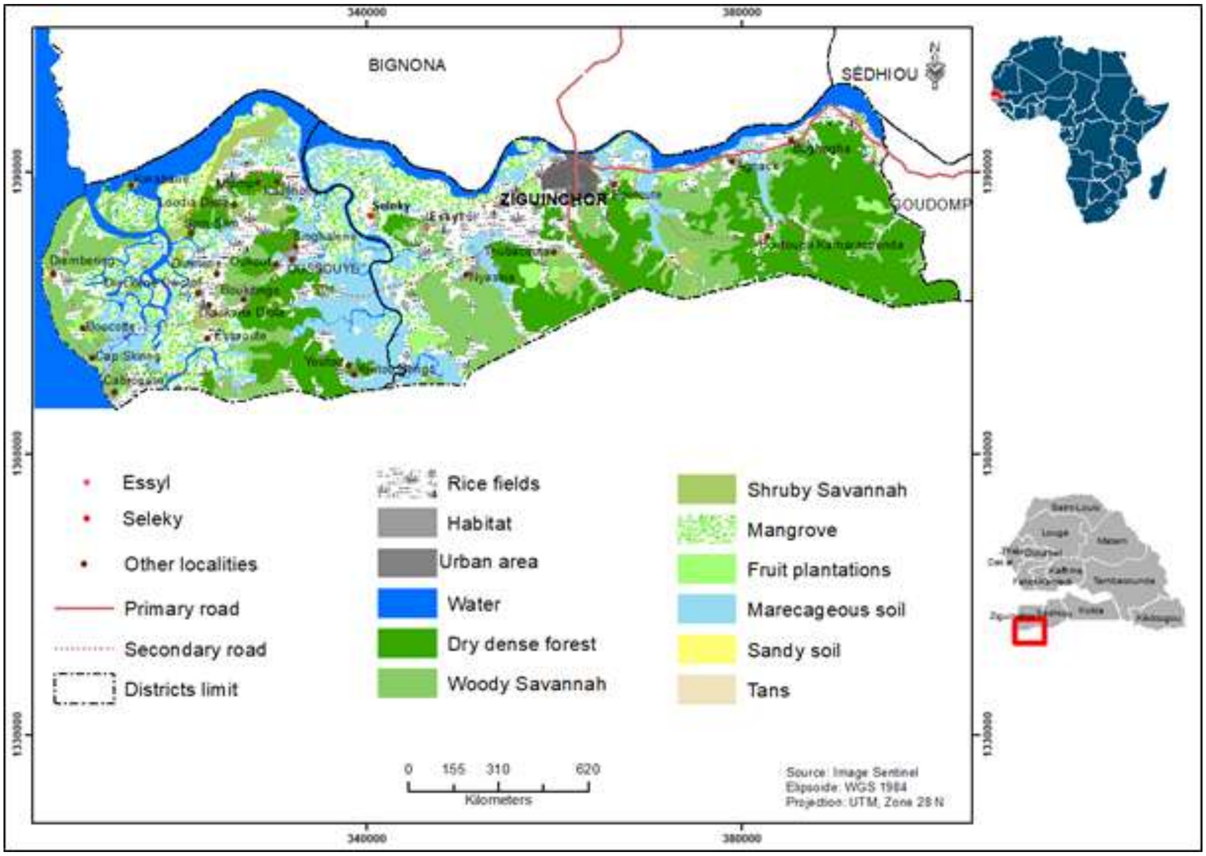


Figure 1. location of the study sites.
Source: Authors

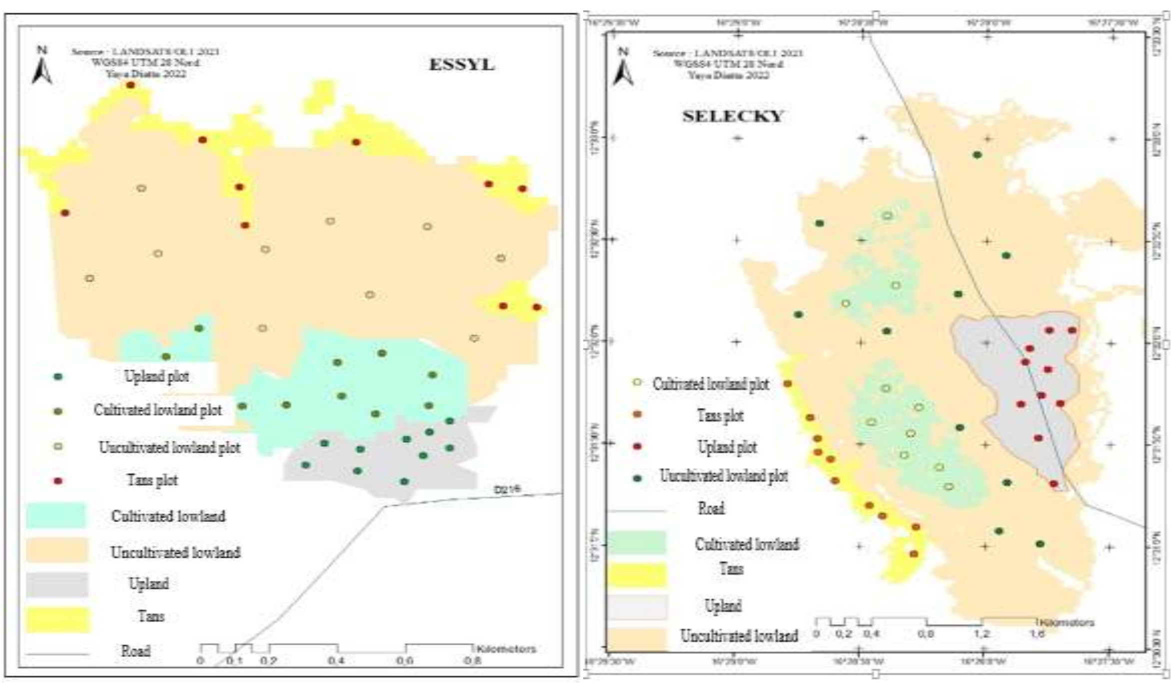


Figure 2. Location of inventory plots by occupancy type at both sites.
Source: Authors

Table 1. Variation in soil pH and EC according to land use classes in the two sites.

Site	Land use classes	pH	EC (µs/cm)
Selecky	Uncultivated lowland	4.25±0.33[c]	1497±1195[b]
	Upland	5.3±0.43[a]	62±19.23[c]
	Tans	4.25±0.07[c]	5280±707.1[a]
	Cultivated lowland	4.66±0.36[b]	292±248.89[c]
	Probability	0.00028	9,71E-08
Essyl	Uncultivated lowland	4.62±0.7[bc]	580±1030.11[b]
	Upland	5.48±0.71[a]	62.22±52.14[b]
	Tans	4.48±0.48[c]	6479.75±709.25[a]
	Cultivated lowland	5.27±0.75[ab]	416±846.89[b]
	Probability	0.011	2.00E-16

Values in the same column with the same letters are not statistically different (Fisher LSD test, 5% threshold).
Source: Authors

$$DMn = \frac{S}{\sqrt{N}}$$

DMn: Menhinick richness index; S: species richness, which is the total number of species in the stand considered in a given ecosystem (Erard, 2003); N: total abundance.

The Shannon index is a diversity index that measures the species composition of a stand by taking into account the species richness and equitability of the species (Felfili et al., 2004). The Shannon index (H') is calculated from the formula:

$$H' = -\Sigma pi lnpi$$

H': Shannon index; pi: relative abundance.
Piélou's evenness (Pielou, 1966) also known as Shannon's equitability translates the way individuals are distributed across species and allows us to say if space is dominated by any species (Adjakpa et al., 2013). Pielou's evenness (J') was calculated from the formula:

$$J' = {H'}/{lnS}$$

H': Shannon index; S: species richness
To determine the difference in species composition between land use classes, Jaccard's dissimilarity, clustering, and principal component analysis (PCA) were performed. Jaccard's dissimilarity (Colwell and Coddington, 1994) or Jaccard's ecological distance (J) was calculated from the equation:

$$J = 1 - \frac{\Sigma mini\,(ai, bi)}{\Sigma \max\,(ai, bi)}$$

With *ai*: the abundance of species i in site A and *bi*: the abundance of species i in site B.

The data in the form of community and environment matrices were analyzed with BiodiversityR (3.5.0) to compare floristic diversity and composition between land use classes. The difference between land use classes was tested by analysis of variance (ANOVA) followed by Fisher's multiple comparison test at the 0.05 threshold. Data on growth parameters were grouped into diameter and height classes to characterize the horizontal and vertical structure of the woody vegetation. Frequencies for each diameter and height class were plotted for the woody species. Similarly, the diameter and height structure was plotted against land use classes.

To examine the parameters influencing woody species diversity, regression analyses were used to identify explanatory variables for species distribution, using the following model:

Y= Land use+CE+pH

Where Y is the response variable (Menhinick index, abundance, density, and Shannon index).

RESULTS

Soil characteristics

The analysis of pH and electrical conductivity (EC) according to land use classes showed significant differences (P<0.05) in the two sites (Table 1). The soil pH in both sites varied between 4.25 and 5.48 and was significantly different between land use classes (P<0.05). Indeed, the highest pH was obtained in upland (5.3±0.43 and 5.48±0.71 respectively in Selecky and Essyl) and cultivated lowland (4.66±0.36 and 5.27±0.75). These two land use classes were also characterized by low salinity. EC varied between 62 and 6479.75 µs/cm in the study area. Thus, the tans recorded the highest EC (5280±707 and 6479.75±709.25µs/cm) followed by uncultivated lowland (1497±1195 and 580±1030.11µs/cm) and cultivated lowland (292±248.89 and 416±846.89µs/cm). The lowest EC were recorded in upland with 62±19.23 and 62.22±52.14µs/cm respectively in Selecky and Essyl.

Floristic composition and diversity

The inventory recorded 33 tree species, belonging to 17 families. A total of 31, 9, 8, and 4 tree species were recorded in the upland, cultivated lowland, uncultivated lowland, and tans respectively. Fabaceae, Apocynaceae, Combretaceae, and Moraceae were families mostly taxonomic diversified. *Faidherbia albida* was found in all land use classes. However, some species such as

Lannea acida, Mangifera indica, Uvaria chamae, Holarrhena floribunda, Landolphia heudelotii, Saba senegalensis, Voacanga africana, Alchornea cordifolia, Cassia sieberiana, Dialium guineense, Ficus sycomorus Ficus sur, Ficus vogelii, Morinda citrifolia, Fagara zanthoxyloides, Allophilus africanus, Cola cordifolia, and *Gmelina arborea* were only found at upland. For the Tans, species such as *Conocarpus erectus* and *Rhizophora racemose* were characteristics (Table 2). The floristic composition varied according to the land use classes for both sites. 22 and 18 species belonging to 22 and 17 genera, and 13 and 12 families were recorded at the uplands of Essyl and Selecky respectively. The land use classes have significantly influenced most of the studied parameters in the two sites. The analysis of variance on diversity, abundance, and density parameters showed a significant difference ($P<0.05$) between land use classes. The richness index did not vary significantly ($P>0.05$) between land use classes. Comparing the species diversity in land use classes, uplands were more diversified than cultivated and uncultivated lowlands and tans. Abundance and density varied significantly between land use classes. The uplands were the only category that differed significantly from the other land use classes, having higher abundance and density (Table 3).

Difference in species composition

Analysis of dissimilarity between land use classes at both sites showed ecological distance greater than 58% (Table 4). The largest ecological distances were noted between tans and other land use classes. Clustering and principal component analysis showed different groups between land use classes (Figures 3 and 4). For Selecky, the analysis revealed two distinct groups. The first group (upland) was characterized by *Lannea acida, Uvaria chamae, Saba senegalensis, Dialium guineense, Ficus sycomorus, Ficus sur, Ficus vogelii, Fagara zanthoxyloides, Allophilus africanus, Ceiba pentandra, Elaeis guineensis, Borassus akeassii,* and *Adansonia digitata*. The second group (cultivated and uncultivated lowlands) was characterized by the presence of specific species such as *Faidherbia albida, Azadirachta indica*, and *Neocarya macrophylla*. For Essyl, the analysis based on land use discriminated three groups (upland, tans, and cultivated and uncultivated lowlands) according to their influence on floristic composition, abundance, and diversity. Characteristic species for upland were *Mangifera indica, Uvaria chamae, Holarrhena floribunda, Landolphia heudelotii, Saba senegalensis, Alchornea cordifolia, Cassia sieberiana, Dialium guineense, Ficus sur, Morinda citrifolia, Cola cordifolia, Gmelina arborea, Terminalia macrophylla, Anonychium africanum, Combretum micranthum, Faidherbia albida, Ceiba pentandra, Piliostigma thonningii, Borassus akeassii, Elaeis guineensis,* and *Parkia biglobosa*. Tans were characterized by *Conocarpus erectus and Rhizophora racemosa*, whereas *Neocarya macrophylla, Azadirachta indica, Adansonia digitata,* and *Acacia nilotica* were characteristic species for both cultivated and uncultivated lowlands. Based on soil chemical properties, tans, and uncultivated lowlands were associated with high salinity characterized by high electrical conductivity (EC) values, whereas higher soil pH was a characteristic value for upland. The analysis showed an opposition between pH and Electrical Conductivity (EC) in both sites.

Structure of woody vegetation

Diameter structure

The analysis showed that individuals with a diameter between 5 and 50 cm represented 30 and 40% of individuals in Essyl and Selecky respectively (Figure 5). The proportions of individuals with a diameter between 5 and 50 cm were 0, 24, 33.33, and 29.66% in tans, cultivated and uncultivated lowland, and upland respectively at Selecky, whereas 100, 31.25, 31.67, and 33% at Essyl. Individuals with a diameter greater than 50 cm were poorly represented in both sites. However, the stand of individuals was not balanced in sites and land use classes with an "L" structure characteristic of a young and stable stand. The pattern of the L-shaped distribution at Essyl in the cultivated lowland and upland revealed some stability in the stand.

Height structure

The analysis showed that individuals with a height between 2 and 8 m were represented by 17 and 23%of individuals located at Selecky and Essyl respectively. In Selecky, individuals with a height between 4 and 14 m constituted 29.47 and 27.21% in the uncultivated and cultivated lowland respectively. On the other hand, individuals with a height between 10 and 12 m were represented by 24% in upland. In Essyl, the proportion of individuals with a height between 2 and 8m was 28, 24, 12.5, and 35% of the individuals in upland, uncultivated, and cultivated lowland and tans respectively. At Selecky, individuals with a height between 10 and 12m were represented by 24% of individuals in the upland. Generally, individuals with a height greater than 20 m were weakly found at Essyl and Selecky. The height structure was globally balanced in both sites (Figure 6).

Influence of environmental factors (pH, EC, and land use classes) on woody vegetation parameters.

Multiple regression analyses showed significant effects of

Table 2. Species occurrence according to land use classes and sites.

Families	Genera	Species	Land use classes			
			Upland	Cultivated lowlands	Uncultivated lowland	Tans
Anacardiaceae	Lannea	*Lannea acida*	+			
	Mangifera	*Mangifera indica*	+			
Annonaceae	Uvaria	*Uvaria chamae*	+			
Apocynaceae	Holarrhena	*Holarrhena floribunda*	+			
	Landolphia	*Landolphia heudelotii*	+			
	Saba	*Saba senegalensis*	+			
	Voicanga	*Voacanga africana*	+			
Arecacea	Borassus	*Borassus akaessii*	+	+	+	
	Elaeis	*Elaeis guineensis*	+	+	+	
Chrysobalanaceae	Neocarya	*Neocarya macrophylla*	+		+	+
Combretaceae	Combretum	*Combretum micranthum*	+			
	Conocarpus	*Conocarpus erectus*				+
	Terminalia	*Terminalia macroptera*	+	+		
Euphorbiaceae	*Alchornea*	*Alchornea cordifolia*	+			
Fabaceae	Acacia	*Acacia nilotica*	+		+	
	Cassia	*Cassia sieberiana*	+			
	Dialium	*Dialium guineense*	+			
	Faidherbia	*Faidherbia albida*	+	+	+	+
	Parkia	*Parkia biglobosa*	+	+	+	
	Piliostigma	*Piliostigma thonningii*	+	+	+	
	Anonychium	*Anonychium africanum*	+			
Malvaceae	Adansonia	*Adansonia digitata*	+	+		
	Ceiba	*Ceiba pentandra*	+	+		
Meliaceae	Azadirachta	*Azadirachta indica*	+	+	+	
Moraceae	Ficus	*Ficus sycomorus*	+			
		Ficus sur	+			
		Ficus vogelii	+			
Rhizophoraceae	Rhizophora	*Rhizophora racemosa*				+
Rubiaceae	Morinda	*Morinda citrifolia*	+			
Rutaceae	Fagara	*Fagara zanthoxyloides*	+			
Sapindaceae	Allophilus	*Allophilus africanus*	+			
Sterculiaceae	Cola	*Cola cordifolia*	+			
Verbenaceae	Gmelina	*Gmelina arborea*	+			

Source: Authors

Table 3. Test of differences for vegetation structure and diversity for land cover types at both sites, with mean values for each variable within each land cover type.

Site	Land use classes	Abundance	Menhinick Index	Shannon	Density
Essyl	Uncultivated lowland	18±16.01[b]	0.79±0.25[a]	0.68±0.27[b]	0.001±000[b]
	Upland	54±24.62[a]	0.87±0.39[a]	1.05±0.46[a]	0.07±0.03[a]
	Tans	7,5±8.07[b]	0.60±0.27[a]	0.05±0.12[c]	0.011±0.01[b]
	Cultivated lowland	16±16.12[b]	0.86±0.39[a]	0.69±0.39[b]	0.001±0.00[b]
	Probability	3.43E-05	0.44	0.00013	1.17E-09
Selecky	Uncultivated lowland	4±3.4[b]	0.93±0.56[a]	0.35±0.4[a]	0.0001±0.00[b]
	Upland	24.4±23.6[a]	0.83±023[a]	0.73±0.25[a]	0.0346±0.03[a]
	Cultivated lowland	4.9±4.4[b]	0.88±0.34[a]	0.37±0.45[a]	0.0002±0.00[b]
	Probability	0.038	0,89	0.098	0.0093

Values in the same column with the same letters are not statistically different (Fisher LSD test, 5% threshold).
Source: Authors

Table 4. Dissimilarity matrix between land use classes in the two sites.

Site	Land use classes	Uncultivated lowlands	Upland	Tans
Essyl	Upland	0.883914		
	Tans	0.925287	0.993007	
	Cultivated lowlands	0.582160	0.834739	0.985149
Selecky	Upland	0.969432		
	Cultivated lowlands	0.920000	0.929461	

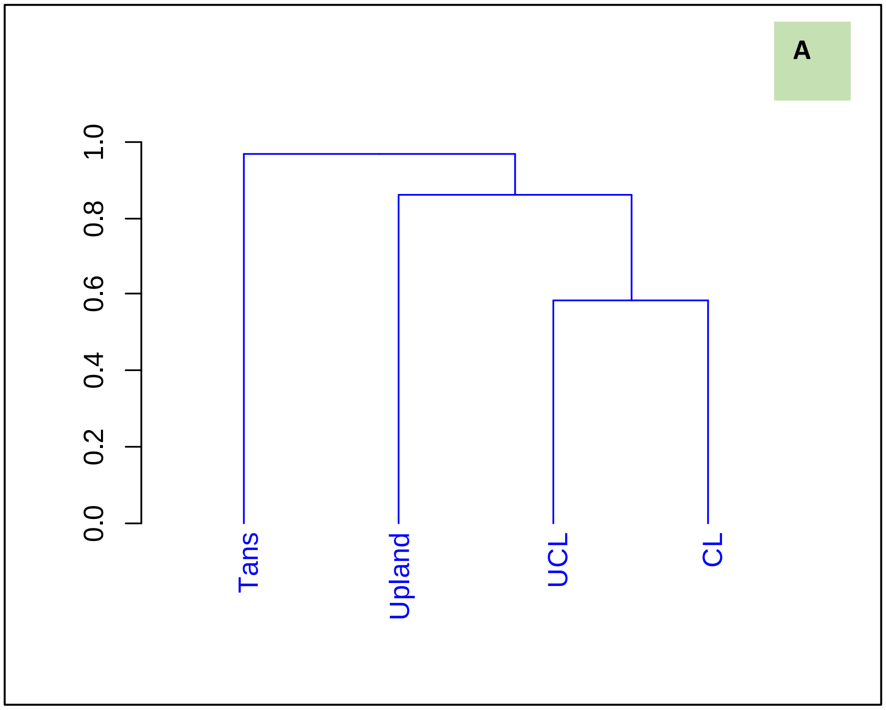
Source: Authors

land use classes on woody vegetation parameters (Table 5). Land use class influenced density, Shannon index, and abundance. At Essyl, all of these parameters were significantly greater at the plateau level ($P<0.05$). The same observation was noted at Selecky. Soil salinity expressed as EC and pH influenced Menhinick and Shannon index at Essyl, abundance, and density at Selecky. The negative slope indicates that vegetation parameters decrease with increasing salinity. Finally, soil pH positively influences species density and abundance at both sites.

DISCUSSION

Floristic composition and diversity of woody species

In all the study sites, 33 woody species were encountered. These species belong to 31 genera of 17 botanical families. The most represented families are Fabaceae, Apocynaceae, and Combretaceae. These results corroborate those of (Coly et al., 2005) who obtained 35 species in the fields of the Nema watershed, in Niombato in the Saloum. However, the area is moderately rich in species. Plant species are more represented in the upland and less in the uncultivated lowlands, cultivated lowlands, and tans. Thus, the dominance of species in the uplands may be because in this area the species are predominantly conserved. However, their low presence in the cultivated lowland and the uncultivated lowland would be due, on the one hand, to the fact that these areas are relatively dedicated to rice cultivation and producers tend to eliminate certain species to the detriment of others, and, on the other hand, to the significant presence of salt in these areas. This trend is general in the Sudano-Sahelian zone, where uncultivated lowlands have been intensively farmed in recent decades because of their fertile soils and hydromorphic character (Souberou et al., 2017, 2018; Talla et al., 2020). The exploitation of uncultivated lowlands is one of the adaptation strategies of farmers to climate change. This explains the low wealth in this area. The results obtained on the distribution of classes according to their frequency and specific contribution are in line with those observed by (Arshad, 2003) for the distribution of vegetation according to edaphic factors in the Cholistan desert (Pakistan). The diversity indices (Shannon and Menhinick) confirm the low richness in this area and according to the land use classes. These indices are more important in the upland. However, they are lower in the cultivated lowlands, the uncultivated lowlands, and especially in the tans. These low indices noted in the uncultivated lowlands and the tans would be due to the negative effect of salt on woody vegetation.



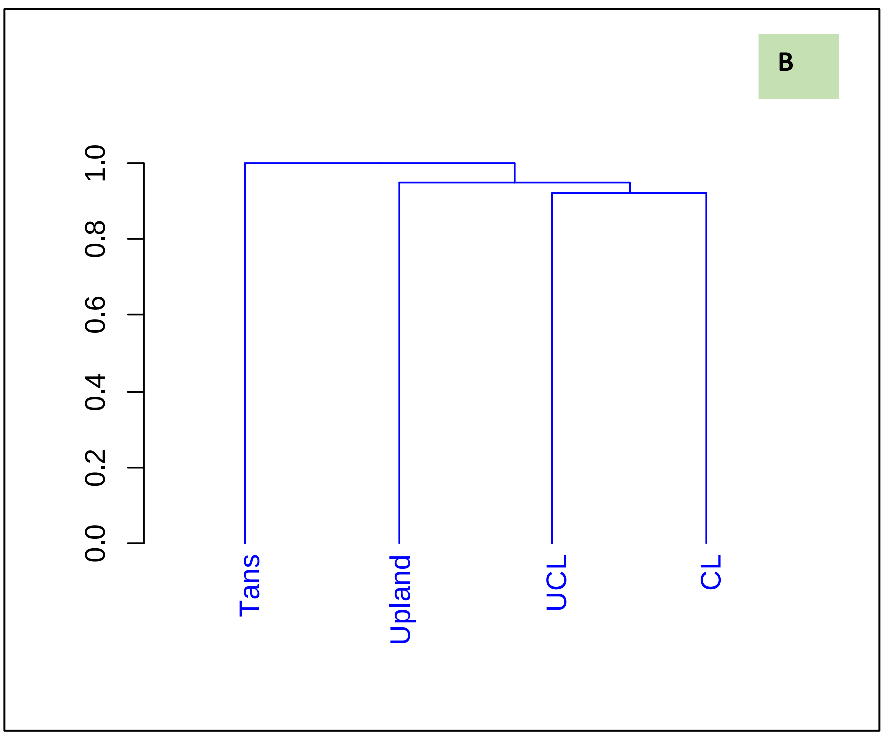
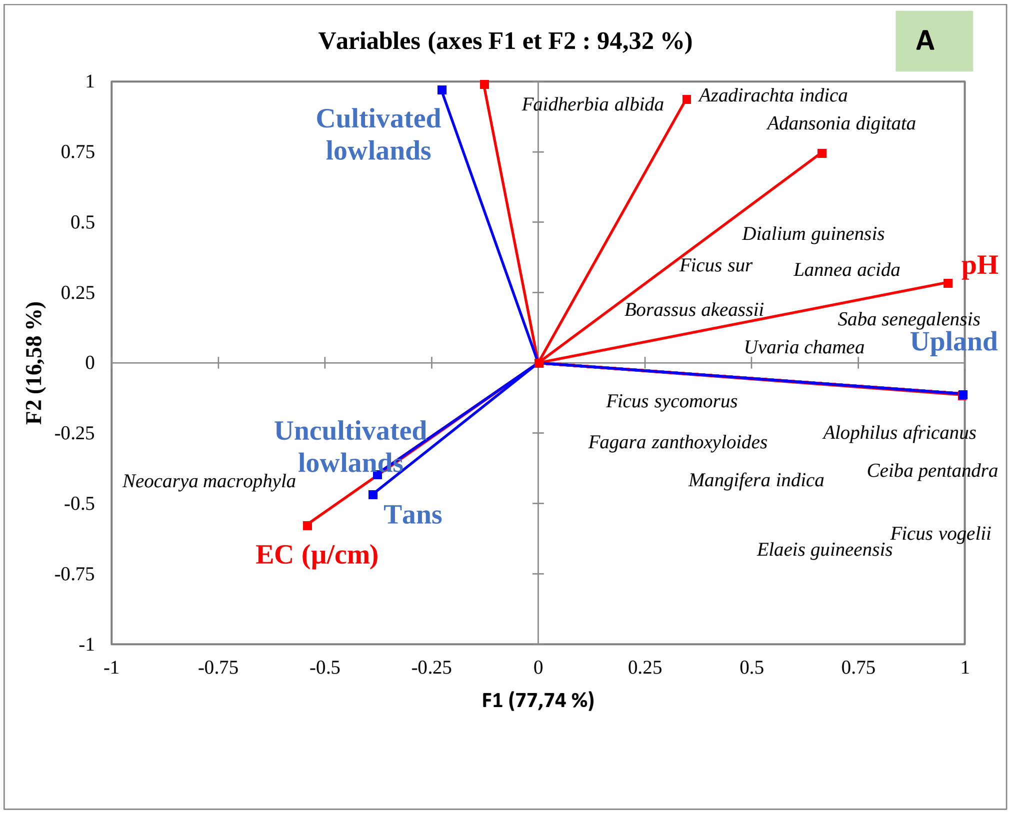


Figure 3. Cluster dendrogram of land use classes in Essyl (A) and Selecky (B). UCL, Uncultivated lowlands; CL, Cultivated lowlands.
Source: Authors

These results are in line with the work of (Amar et al., 2022) who noted a repressive effect of salinity on floristic diversity. These authors noted the lowest numbers of species in the most saline areas. Thus a dissimilarity of floristic diversity according to the salinity gradient was also reported by these authors.



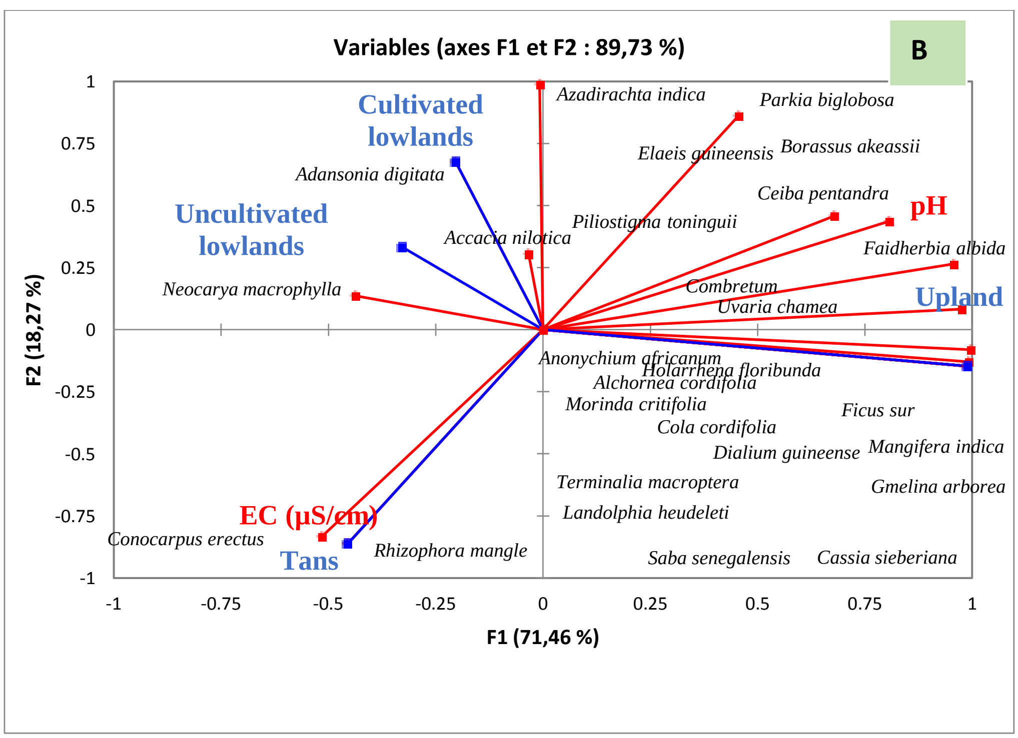


Figure 4. Relationship between vegetation parameters, land use classes, and soil chemical properties in Selecky (A) and Essyl (B).
Source: Authors

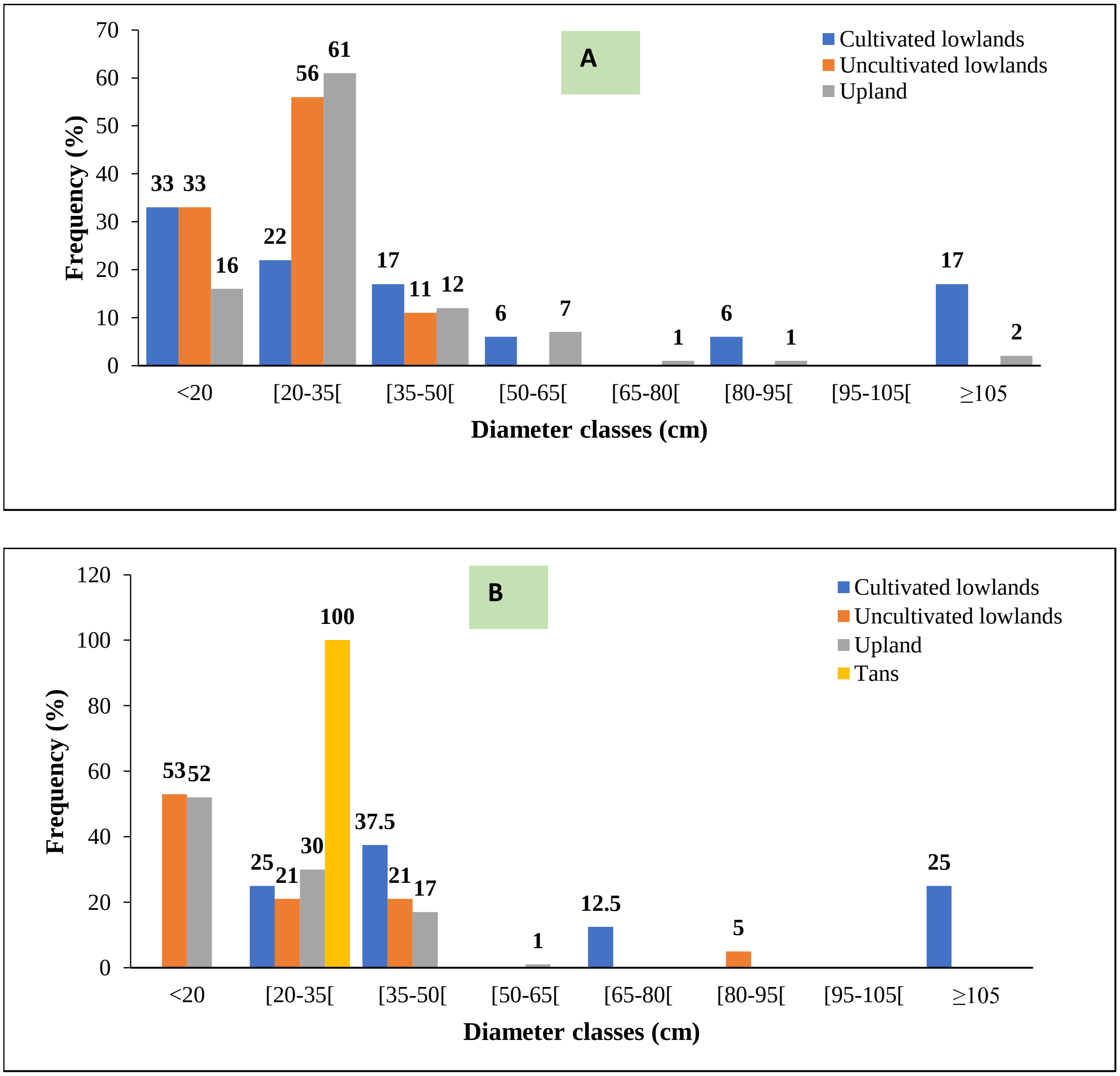


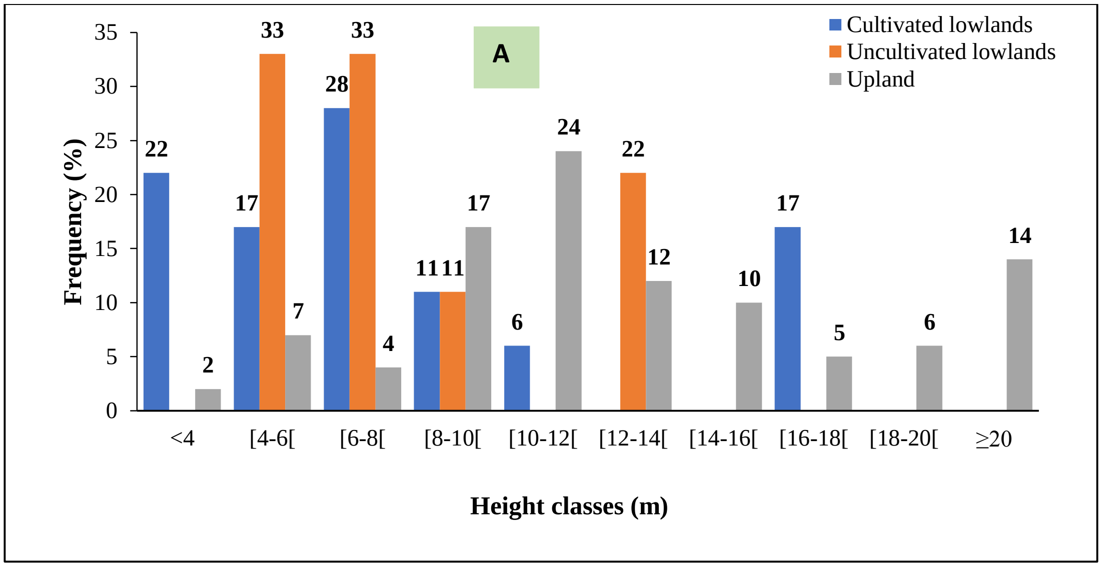
Figure 5. Distribution of individuals of the woody stand of the different land use by diameter classes in Selecky (A) and Essyl (B).
Source: Authors

Effect of soil physical characteristics on woody species composition

For the soil parameters (pH and Salinity), the analyses showed that the tans recorded the highest salinity values and the most acidic pH. These parameters negatively influenced the specific diversity of the stand. The latter shows a strong relationship between woody vegetation and soil parameters. The work of (Jafari et al., 2004) on vegetation-soil relationships in the Hoz-e-Soltan region (Iran) revealed the existence of a specific relationship between soil characteristics and vegetation distribution. In our study, we targeted salinity and pH as variables. This has been adopted by several authors to see the relationships between soil characteristics and halophytic vegetation (Caballero et al., 1994; AHMAD, 1995; Thiam et al., 2015). These authors found that the distribution of vegetation in a given area is a function of soil salinity. Abu-Ziada (1980) was able to demonstrate a strong relationship between vegetation distribution with salinity and moisture in the soil.

Effect of land use types on woody species structure

In terms of stand structure, the analyses showed that this area is characterized by small individuals with heights between 2 and 8 meters and diameters ranging from 5 to



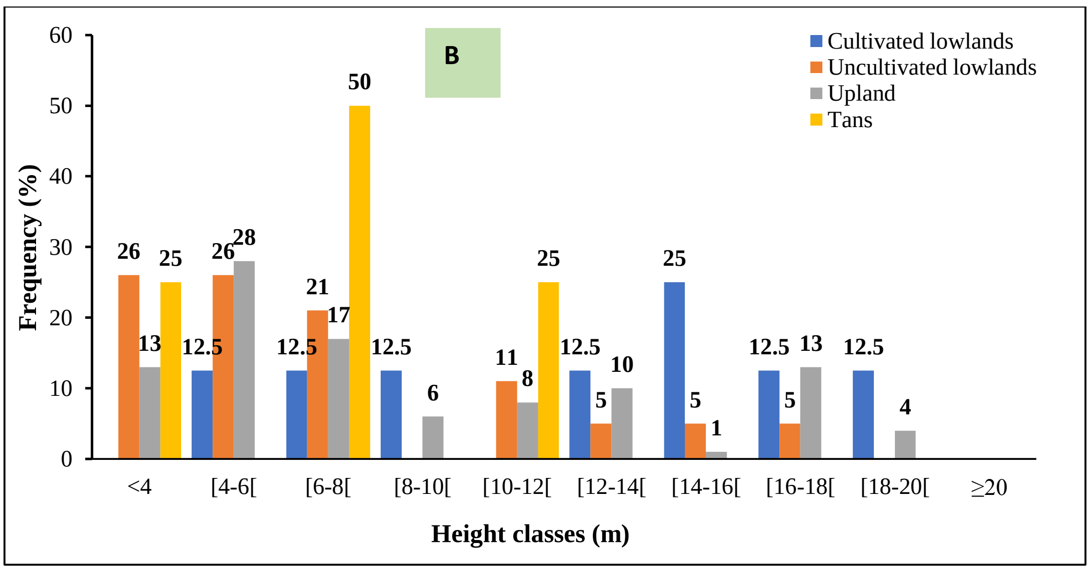


Figure 6. Distribution of individuals of the woody stand of the different land use classes by height classes in Selecky (A) and Essyl (B).
Source: Authors

Table 5. Regression analysis of the influence of landscape classes of soil pH and EC on vegetation composition, structure, and distribution.

Site	Variable	Explanatory variable	Estimate	T-value	Pr(>[t])	R2
Essyl	Abundance	Upland	31.68	3.278	0,00265**	57.56
		pH	2.67	0.569	0,57	57.56
		EC	-0.0044	-1.020	0,315	57.56
	Density	Upland	7.50E-02	7.022	8,36e-8***	77.1
		pH	1.35^{e}-03	0.261	0,796	77.1
		EC	4.180^{e}-07	0.088	0,931	77.1
	Menhinick Index	Tans	-1.598e-01	-0.292	0.77277	52.1
		pH	-1.284e-01	-1.374	0.18068	52.1
		EC	-9.253e-06	-0.106	0.91608	52.1

Table 5. Contd.

Selecky	Shannon	Tans	-5.89^{e}-01	-1.053	0,301	52.32
		Upland	4.51^{e-01}	2.311	0,028*	52.32
		pH	-1.584^{e}-01	-1.686	0,1032	52.32
		EC	-1.151^{e}-05	-0.132	0,89	52.32
	Abundance	Upland	15.73	3.201	0.00323**	49.71
		pH	-4.528	-1.262	0.216	49.71
		EC	-0.00077	-0.454	0.652	49.71
	Density	Upland	2.41E-02	3.804	0.000652***	58.91
		pH	-5.249^{e}-03	-1.136	0.264	58.91
		EC	-6.531^{e}-07	-0.298	0.7675	58.91

Source: Authors

50 cm. Individuals with diameters greater than 50 cm are poorly represented at both sites and across all land use types. These results are not in phase with the work of (Coly et al., 2020) who found a predominance of individuals with a diameter between 5 and 25 cm. However, the stand of individuals is not balanced across sites and occupancy types with an "L" structure characteristic of a young and stable stand. These results are similar to those of (Kebenzikato et al., 2014)in an *Adansonia digitata* park in Togo and (Ali et al., 2017) in the *Diospyros mespiliformis* park in central Niger.

Conclusion

The study of the diversity and structure of woody species in the commune of Enampore contributed to the understanding of their distribution according to land use types. The results show that the study area had an important taxonomic diversity. However, the study area was characterized by low diversity. Land use influenced the floristic composition, diversity, distribution, and structure of woody vegetation. Uplands, with their high pH and electroconductivity (EC), had the highest species diversity. In contrast, high salinity in the tans, uncultivated and cultivated lowlands had negative effects on tree diversity and density. In these different areas, few tree species are retained by producers. These areas are generally used for rice cultivation. Any reduction in forest area is likely to reduce tree diversity. Trees can act to cope with salinization. Thus, farmers should conserve and restore soil fertility through the use of trees, but also through the use of available organic amendments.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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