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Floristic Diversity between 1960 and 2023, Aboveground Biomass of Vegetation in the Ngamakala Peatland in the Republic of Congo, Congo Basin

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ABSTRACT

There has been very little research done globally on how peatland ecosystems respond to anthropogenic threats. The dynamics of vegetation between 1976 and 2023 as well as its impact on the overall floristic composition and the aerial biomass of groups (herbaceous and woody) were the subject of our study in the Ngamakala peatland. The objective of this study is to characterize the floristic changes that occurred in the Ngamakala peatland from 1976 to 2023, following the environmental changes that occurred and the development of woody vegetation in the Ngamakala peatland on the north-eastern flank. A temporary device of ten plots, four of 8 m² each in the meadow area and 6 plots of 100 m² each in the forest part, was set up. After data collection, they were processed and analyzed and gave very significant results. The flora of the Ngamakala peatland is experiencing a significant change, an increase of 34.76% in its specific richness. These results also show a diversified floristic procession with a Sørensen dissimilarity index of 0.3. The increase in the floristic composition, linked to the state of health of the peatland, influences both the decrease in the frequency and abundance of turficolous species and the variability of biomass stocks. This study made it possible to understand the impact of human activities on land use around the Ngamakala peatland, and also the change in the floristic composition in the Ngamakala vegetation.

Keywords: Wetlands, Peatland, Anthropization, Oligotrophic species, Turficolous species, Congo Basin

INTRODUCTION

The Ngamakala peatland has been under great anthropogenic pressure due to the occupation of land around this wetland for about twenty years, due to the sale of land by local landowners. Peatlands are wetlands characterized by poorly drained soil where organic matter in general and peat in particular accumulates more than it decomposes (Fournier, 2018; Mainneville, 2023). Thanks to their peaty soils, resulting from the slow decomposition of very specific plants, these ecosystems have a great capacity to sequester carbon (Manneville *et al.*, 2006).

Following the last glaciation and during the Holocene, peatlands accumulated about a third of the global terrestrial carbon stock, or 500 gigatonnes, even though they only cover about 4% of the continental surface (Yu, 2012). In this global carbon dynamic, plants display more than 80% of sequestration capacity, of which about 70% is provided by the living plant mass above ground (stems, stumps, branches, bark, seeds and leaves) (Yinon *et al.*, 2018).

Alongside the approximately 167,600 km² of better-known peatlands in the Cuvette Centrale that Congo shares with the Democratic Republic of Congo (Cannon *et al.*, 2021; Crezee *et al.*, 2022), the Ngamakala peatland, the oldest discovered so far, dating back to 24,000 years BP (Elenga *et al.*, 1991), is one of the many riches of the Congo Basin.

The study carried out by Makany (1976) had shown that the Ngamakala peatland did not contain any forest but only scattered groves of *Alstonia*, *Xylopia* and *Grumelia*, all in the middle of a wet meadow dominated by a grass (*Hypogynium spathiflorum* Nees) and forming a sort of peat raft. He had also estimated that the species of the genus *Alstonia* present in this environment could only be *Alstonia bonéi* De Wild, abundant in the forest galleries of the valleys that cut into the foothills of the Batéké plateaus. Today, this peatland shows signs of significant afforestation and a high risk of silting up due to human activities. Several studies have shown that afforestation is one of the most significant changes observed in the flora of peatlands in inhabited regions but also one of the main factors in the loss of biodiversity in wetlands (Pellerin *et al.*, 2003; Warner, 2007; Bart, 2016). Therefore, the question of the consequences of environmental changes on plant growth in the Ngamakala peatland is therefore urgent. It is therefore necessary that more in-depth studies be carried out for the purposes of sustainable management of this ecosystem.

The objective of this study is to characterize the floristic changes that occurred in the Ngamakala peatland from 1976 to 2023, following the environmental changes that occurred and the development of woody vegetation in the Ngamakala peatland on the northeastern flank.

More specifically, we seek to assess the dynamics of peatland vegetation between 1976 and 2023, analyze the impact of changes on the total floristic composition of the ecosystem and estimate the aerial biomass of herbaceous and woody groups present in the study plots.

MATERIALS AND METHODS

Study Area

The Ngamakala peatland is located 37 km north of Brazzaville (Figure 1) between 4º05′ South latitude and 15º25′ East longitude, at an altitude of approximately 508 m (Maley, 2002). It covers a shrinking area of approximately 17,503 ha, a loss of approximately 13 hectares in less than fifty years (Makany, 1976). This peatland is surrounded by hills and remains fed by runoff water in contact with a sandy rocky substrate. The pH of the water biotope is acidic. Phytogeographically, Ngamakala is located in the Guinean-Congolese endemism center (White, 1986; Cusset, 1988; Kami, 1998), Congo/Zambezi transition sector and in the Batéké Plateaux district (Kimpouni et al., 1993). The climate is Bas-Congolese of the Sudano-Guinean type (Aubréville, 1949; Descoings, 1969; Samba-Kimbata, 1978) and in July, precipitation is very low with 1 mm of water, while in November, it rises to 260 mm of water.

Floristic Inventories

Overall, the data were collected in 10 plots, six of which were in forest areas and four in grassland areas, all covering a total area of 616 m² (Figure 1).

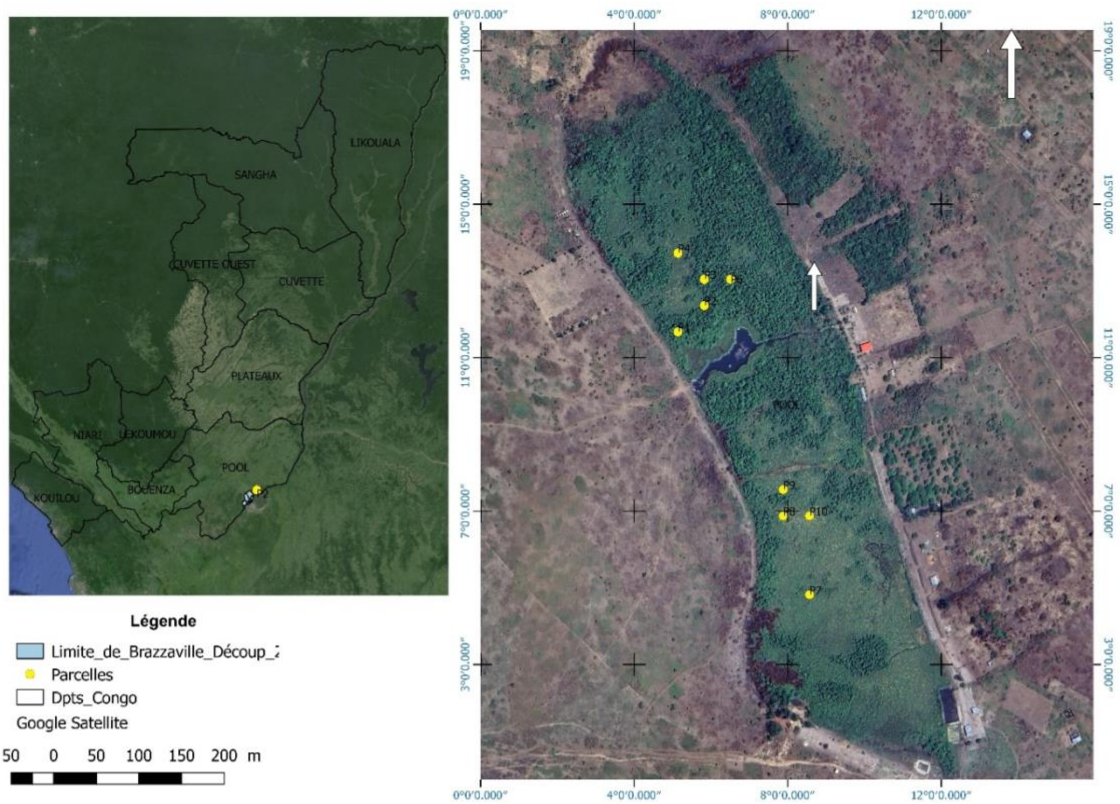

Figure 1: Location of the study area

Inventory in Wooded Area

Sampling was carried out with rectangular surveys (Delassus, 2015), measured using a tape measure and then georeferenced using a GPS. This was followed by a census of all upright woody individuals with a DBH ≥ 5 cm. The area covered is 600 m² divided into 6 small plots numbered P1; P2. P3; P4. P5 and P6, measuring 12.5 m × 8 m, or 100 m² for each of the plots installed in the most accessible places in the wooded area (Figure 2a).

Inventory in Non-Wooded Area (Wet Meadow)

The minimum surface area of 4 m² (2 m × 2 m), necessary to carry out the floristic inventory (Figure 2b) was obtained by applying the principle of the minimum area through the area-species curve method. Then, this minimum surface area obtained was reproduced in four plots PH1; PH2; PH3 and PH4, following a random device. In each of the four plots, all the species recorded were evaluated according to the mixed abundance-dominance coefficient of Braun-Blanquet (1932), then converted into the average coverage percentage (AC) of Bouzillé (2007).

Figure 2a: Photo of the wooded area

Figure 2b: Photo of the grassy area

Assessment of Aerial Biomass

For herbaceous plants

The aerial biomass of herbaceous plants was sampled in three plots of 1 m² each (PL1, PL2, PL3), placed in the center of the floristic inventory plots. The species present were harvested entirely at ground level while avoiding uprooting (Saidou *et al.*, 2010). The wet weight (WW) of each sample taken was measured in the field using a 50 kg precision spring scale (PESOLA). The samples were then labeled and numbered and the GPS coordinates recorded. The samples collected were dried until a constant dry weight (DW) was obtained when weighed. The biomass evaluation was calculated by applying the Valentini equations model (2007) which takes as predictors, the dry weight and the wet weight.

• For the determination of dry matter (DM)

$$\text{MS} = \frac{PSE}{PHE}\ x\ 100 \quad (1)$$

Where:
MS= percentage of dry matter (%)
PSE= dry weight of the sample (g)
PHE= wet weight of the sample in the field (g)

• For herbaceous biomass (BH)

$$\text{B} = \frac{PHT}{MS}\ x\ 100 \quad (2)$$

Where:
PTH = total wet weight in the field
DM (%) = dry matter

• For the average biomass per plot (BM)

$$\text{BM} = \frac{B}{3} \quad (3)$$

With 3, the number of samples collected.

For woody plants

The biomass of woody plants was assessed by the allometric equation of Fayolle *et al.* (2018) (Equation 3) which takes into account three predictors (diameter, wood density, total height of the tree, or the environmental stress factor). The data global wood database for the specific density of each tree species was consulted in order to take the values of the specific biomass (Zane *et al.*, 2006). The density per hectare was also respected; the basal area (Rondeux, 1993) and the scale factor or expansion factor from the size of the plot (IPCC, 2006).

Formula: AGB=0.0673∗ (di∗ ($Dbhi$) 2) ∗$Htotal$ (4)

Where:

- Dbhi: diameter of the tree in centimeters (cm) measured at 1.30 m and for all trees at dbh ≥ 5 cm
- di: specific density of the wood

- Htotal: Total height of the tree.

Data Analysis and Processing

For the analysis of the inventory data, the nomenclature of the species inventoried in 1976 to that of the species that we identified in 2023 were standardized. For this, the AGP IV (2016); Moutsamboté (2012) and Jean's Flowering Plants of Gabon (2016) databases were consulted. The collected data were then entered into the Excel table (V.2016).

Biodiversity Parameters

To better assess the ecosystem state and characterize the diversity of forest stands in our study site, we considered different descriptors, including three diversity indices concomitantly: the Shannon index, the Piélou equitability index and the Sorensen dissimilarity index (Sorensen, 1948; Harrison *et al.*, 1992; Cardoso *et al.*, 2009).

Shannon Index

The Shannon index or Shannon-Wiener index (H') is the most commonly used diversity index. Its formula takes into account the probability of encountering a specific characteristic (here species) in a text studied (the population) and thus makes it possible to express specific diversity, the greater or lesser number of species present in a population.

$$\mathbf{H'} - \sum \boldsymbol{Pi.log2si}$$

Where:

- Pi = Proportional abundance or percentage of abundance of a species present (Pi = ni/N).
- ni = Number of individuals counted for a species present.
- N = Total number of individuals counted; all species combined.
- si = Total or cardinal number of the list of species present.
- If H' = 0, then the index is homogeneous (made up of a single species).
- If H' between 1 and 5, then we will be in the presence of different species.
- H' may also have a tendency to increase when we are in the presence of rare species tends to increase when rare species are present.

Piélou's Evenness Index (1966)

Piélou's evenness index (J), or evenness index (E), also called the evenness index, will allow us to better discuss the Shannon index. Its formula corresponds to the ratio between the Shannon index (H') and the maximum diversity (H_{max}) (Cardoso *et al.*, 2009).

$$\mathbf{E} = \boldsymbol{H'} / \mathbf{Hmax}$$

Ranging from 0 to 1, this index indicates the degree of diversity achieved compared to the maximum possible and better supports comparisons between populations.

When evenness is low (tending towards 0), it expresses a dominance phenomenon; however, when it is high (tending towards 1), a regular distribution of individuals between species is noted, hence the absence of dominance (Kimpouni *et al.*, 2012; Inoussa *et al.*, 2013).

Beta Diversity

Beta diversity (ks or β) is a measure of biodiversity that consists of comparing the dissimilarity or changes in diversity that have occurred between two communities (Harrisson *et al.*, 1992). For this measure, we took into account only the presence or absence of species (Sorensen, 1948; Gower *et al.*, 1986), the objective being to compare the number of taxa that are unique to each of the two inventories (1976 and 2023).

This assessment of the overall floristic difference was done using the Sorensen dissimilarity index (Sorensen, 1948) which varies between 0 and 1.

$$\boldsymbol{Ks\ or\ \beta} = \frac{\mathbf{2\ C}}{\mathbf{S1+S2}}$$

Where:

- S1: total number of species recorded in 1976

- S2: total number of species recorded in 2023
- C: number of species common to both inventories (1976 and 2023).
- If β = 0, there are no species common between the two inventories.
  If β = 1, the same species exist in both communities

RESULTS

Floristic Composition and Specific Richness in the Ngamakala Peatland

The results of the flora inventory carried out in both types of herbaceous and wooded vegetation reveal a significant floristic richness (diversity). In total, 31 different species were inventoried in both the wooded and non-wooded areas of the Ngamakala depression. These 31 species belong to 21 genera and 21 families. This biodiversity is higher in the wooded area with 19 species compared to the herbaceous area which has only 12 plant species. This inventory revealed that the two types of plant formations had species common to both environments. In the wooded area, the most abundant woody species is *Alstonia congensis* Engler followed by *Xylopia rubescens* Oliv.var (?). Apart from these two species, another woody species is present, *Psychotria venosa* (Hiern) Petit. The biodiversity of the flora in the wooded area is high due to the significant biodiversity in the undergrowth with *Lasimorpha senegalensis* Schott. Considering the plant families, Apocynaceae (50.55%) are the most representative, followed by Annonaceae (39.01%) and Rubiaceae (8.79%).

On the herbaceous vegetation side, the inventory of the flora revealed a codominance of three families of plants with 23% each, Cyperaceae with a species *Anosporum pectinatum* (Vahl) Lye., Poaceae of which two species were identified: *Trichanthecium parvifolium* (Lam.) Zuloaga & Morrone and *Ottochloa nodosa* (Kunth) Dandy of Sphagnaceae: *Sphagnum moss* Carl von Linné in the wet meadow zone. Other plant species belonging to other families were inventoried. These are the following species: *Sabicea africana* (P. Beauv.) Hepper (Rubiaceae), *Secamone nontozeana* (H. Huber) Klack (Apocynaceae), *Dupineta brazza* (Cogn.) Veranso-Libalah & G. Kadereit (Melastomataceae), *Lasimorpha senegalensis* Schott (Arecaceae), *Sygonanthus madagascarensis* S.Moore (Eriocaulaceae). *Eulophia odontoglossa* Rchb. f. (Orchidaceae), *Utricularia subulata* (A.G Weberbauer (Lentibulariaceae).

Biodiversity indices, particularly the Shannon index, indicate a disparity between the different plots. It is noted that the highest Shannon and equitability indices are found in Plot 6 (H'=1.90 and E=0.40). On the other hand, in the rest of the plots, these indices are relatively lower (Table 1).

Table 1: Distribution of diversity indices in plots in wooded areas

Plot	Shannon (H)	Pielou (E)
P1	0.94	0.2
P2	0.64	0.13
P3	0.89	0.2
P4	1.08	0.2
P5	1.17	0.23
P6	1.9	0.4

These results show a low regularity of the Pielou index (tending towards 0), which explains a phenomenon of dominance in plots 5, 4, 1, 3 and 2.

Shannon index values range from 0.64 to 1.9, indicating some variation in species diversity among plots. The higher the Shannon index, the greater the species diversity. For example, Plot 6 has the highest Shannon index, suggesting the presence of greater species diversity compared to other plots. For the Pielou index, the values range from 0.13 to 0.4. A value of 0 would indicate an equal distribution of all species present, while a value of 1 would indicate that all species are equally abundant. It is noted here that the Pielou values are within the relatively narrow range, which indicates a certain uniformity in the distribution of species within the different plots.

Our results suggest that plots exhibit variable species diversity, with some having greater diversity than others. However, species evenness appears to be relatively consistent across plots, with a fairly even distribution of species present.

However, in Plot 6, this index is high (1.9), a sign of a regular distribution of individuals between the species, hence the absence of dominance.

The spectrum in Figure 4 illustrates the abundance-dominance as a function of the coverage (it must be the frequency of the species because, after the floristic inventory, the frequency of the species (in %) must be calculated) of the plant species.

Frequency Class of Species in Grassland

Table 2 shows the proportions of individuals with a frequency greater than or equal to 25%. Analysis of these data shows that frequency class IV, whose species presence is >75%, has the largest number of individuals, while class I, whose presence rate is <25%, has not recorded any species.

Table 2: Distribution of herbaceous species by frequency class

Frequency class	Frequency (%)	Number of species
IV	> 75%	7
III	50-75%	2
II	25-50%	4
I	< 25 %	0
Total		**13**

Abundance-Dominance Spectrum in the Herbaceous Zone

The spectrum in Figure 3 illustrates the abundance-dominance as a function of the coverage of plant species according to the Gillet scale (2000). It can be seen that the Cyperaceae, represented by the species *Anosporum pectinatum* (Vahl) Lye; the Poaceae represented by the species *Trichanthecium parvifolium* (Lam.) Zuloaga & Morrone and the Sphagnaceae, represented by the species *Sphagnum moss*, are the most characteristic of the strata in occupation of space with 90% each. Next come species such as *Dupineta brazza* (Cogn.) Veranso-Libalah & G. Kadereit (57%) from the Melastomataceae family and *Sabicea africana* from the Rubiaceae family with 32%.

These results show a codominance of Cyperaceae; Poaceae and Sphagnaceae in the wet meadow zone.

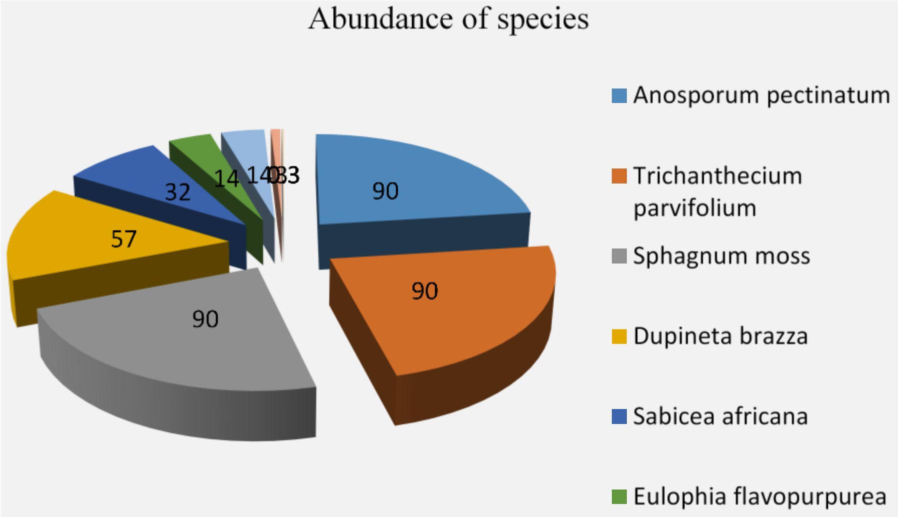

Figure 3: Frequencies in the grassland area

Abundance-Dominance Assessment of Families in the Two Groups

The spectrum in Figure 4 illustrates the distribution of the most representative families in the plant formations studied. This graph shows a codominance of Cyperaceae, Poaceae and Sphagnaceae in the wet meadow zone. In the forest zone, however, Apocynaceae (50.55%) are the most representative, followed by Annonaceae (39.01%) and Rubiaceae (8.79%).

This plant distribution in these different ecosystems can be explained by the fact that Cyperaceae, Poaceae and Sphagnaceae are botanical families adapted to grassland conditions, with species that are well adapted to light and open soils. Their physiological and morphological characteristics make them better adapted to competition in grasslands. In contrast, Apocynaceae, Annonaceae and Rubiaceae have more favorable adaptations to woodland conditions, with species that can thrive better in competition for light and nutrient resources. These families are generally associated with woody or shrubby plants, which thrive in more shaded and humid, but also disturbed, environments.

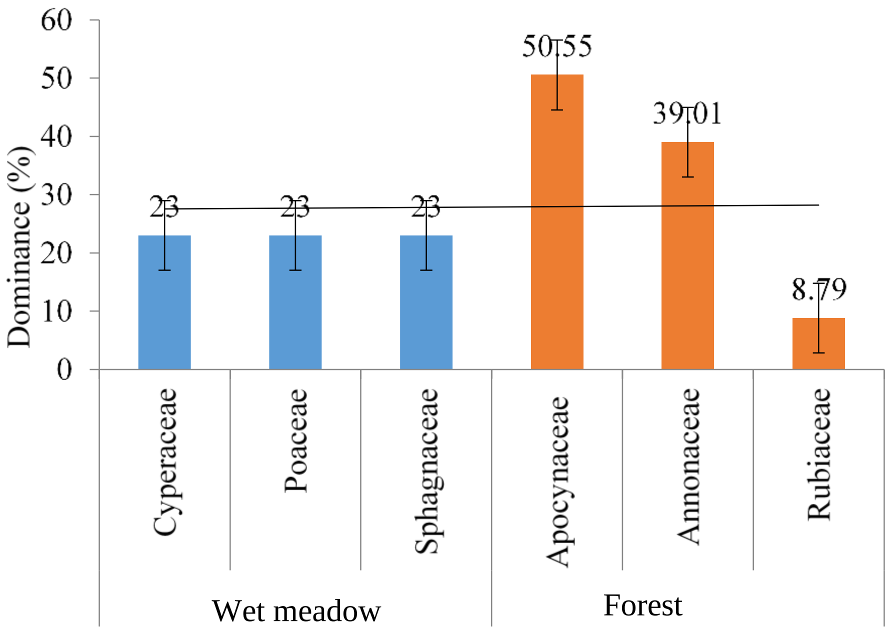

Figure 4: Distribution of the most representative families in the peatland

Table 3 shows the list of species recorded by surface area in the minimum area system. This list shows relative stability from surface S3 (4 m²), characterized by a low presence of new species (with only one species per surface area).

Table 3: List of species by minimum area sampled

Surfaces	Families	Species	Number of species
S1 (1 m²)	Cyperaceae Poaceae Melastomataceae Sphagnaceae	*Anosporum pectinatum* (Vahl) Lye *Trichanthecium parvifolium* (Lam.) Zuloaga & Morrone *Dupineta brazza (Cogn.)* Veranso-Libalah & G. Kadereit *Sphagnum moss* Carl von Linné	4
S2 (2 m²)	Rubiaceae Araceae Apocynaceae	*Sabicea africana* (P. Beauv.) Hepper *Lasimorpha senegalensis* Schott *Secamone nontozeana* (H. Huber) Klack.	3
S3 (4 m²)	Poaceae Eriocaulaceae	*Ottochloa nodosa* (Kunth) Dandy *Sygonanthus madagascarensis*	2
S4 (8 m²)	Eriocaulaceae	*Syngonothus poggeanus*	1
S5 (16 m²)	Lentibulariaceae	*Utricularia subulata*	1
S6 (32 m²)	Orchidaceae	*Eulophia odontoglossa* Rchb. f.	1
	Total		**12**

Figure 5 shows a low representation of species typical of ombrotrophic environments [4 out of 19 species recorded in wooded areas]. We also note a proliferation of species with terrestrial affinity (9 out of 19 species).

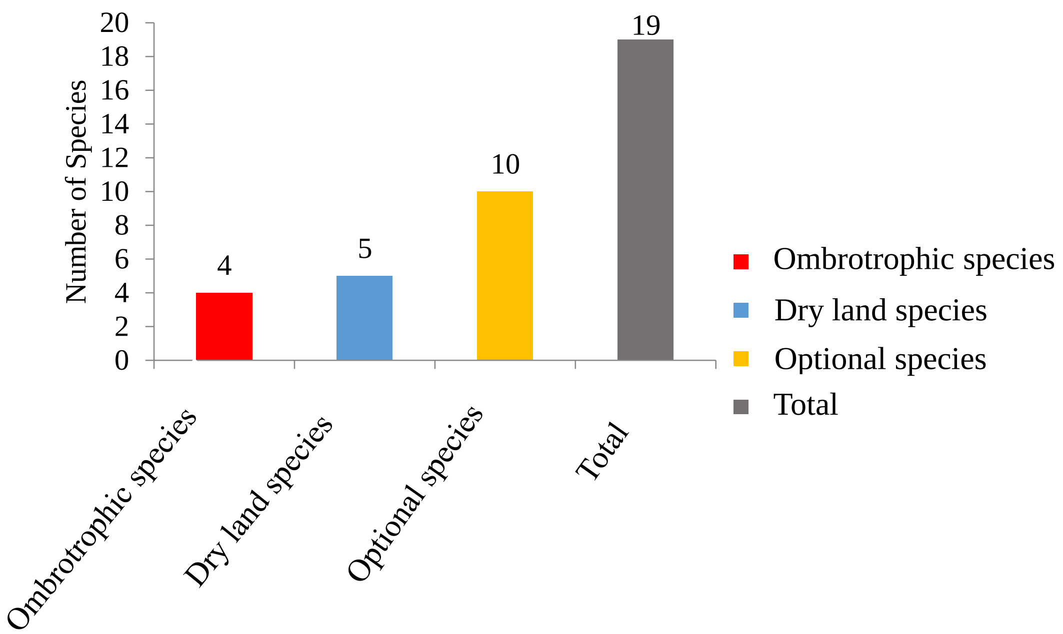

Figure 5: Affinity of species in relation to the environment

Comparison of 1976 Inventory and Current Inventory

The analysis of the two databases shows that only 9 species are common (C) to the two inventories, which means that 14 taxa were found to be unique in the 1976 inventory compared to 22 in the one carried out in 2023 with a dissimilarity coefficient (Ks) of a value of 0.3 for the entire flora of the Ngamakala wetland. Indeed, 31 plant species were recorded in 2023 compared to 23 in 1976. On the other hand, the number of genera was greater than today (i.e. 23 compared to 22). In addition, there was a loss of certain rare species such as *Drosera madagascariensis* and *Indet calanthe*, plants (sphagnum) that like cooler, if not cold, climates (Cratton *et al.*, 2014).

Table 4

Species A (1976)	Species B (2023)	Common species C
Eleocharis fistulosa	*Panicum parvifolium Franch.*	*Eulophia misolimii*
Eleocharis nupeensis	*Eulophia misolimii*	*Syngonothus poggeanus*
Rhynchospora speciosa	*Syngonothus poggeanus*	*Utricularia subulata*
Andopogon huillensis	*Utricularia subulata*	*Sphagnum moss*
Hypogynium spathiflorum	*Lycopodium microphylum*	*Laurembergia repens (welw. Ex Hiem)*
Eulophia milisonii	*Lycopodium serum*	*Alstonia congensis Engler*
Indet calanthe	*Xyris imitatrix*	*Xylopia rubescens Oliv.var.*
Drosera madagascariensis	*Stipularia africana P. Beauv.*	Grumilea venosa = Psychotria venosa
Syngonanthus poggeanus	*Lasimorpha senegalensis Schott*	*Nephrolepis biserrata*
Utricularia subulata	*Sphagnum moss* Carl von Linné	
Lycopodium affine	*Melastomastrum capitatum (Wahl) A.*	
Xyris densa	*Laurembergia repens (welw. Ex Hiem)*	
Sphagnum	*Alchornea cordifolia (Schum. & Thonn.) Müll.Arg.*	
Laurembergia	Cyperus mudicolis	
Alstonia bonei (congensis)	*Dicotis braze*	
Xylopia rubencsens	*Secamone letonzeana*	
Grumilea venosa	*Ottochloa nodosa*	
Phaeoneuron dicellandroides	Panicom parvipholia	
Barteria fistulosa	Sygonanthus madagascarensis	
Zacateza pedicellata	*Mesanhemum radicans*	
Nephrolepis biserrata	*Alstonia congensis Engler*	
Palisota ambigua	*Xylopia rubescens Oliv.var.*	
Cyrtosperma senegalensis	*Xylopia aethiopica (Dunn.) A. Rich.*	
	Psychotria venosa (Hiern) Petit	
	Hallea stipulosa (DC.) Leroy	
	Allophylus africanus P. Beauv.	
	Maprounea membranacea Pax & Hoffm.	
	Calamus deërratus Mann. & Wendl.	
	Secamone letouzeana	
	Nephrolepis biserrata	
	Lasimorpha senegalensis Schott	
	Cycloscorus striatus (Schum.) Ching	
	Dichaetanthera strigosa	
	Panicum brazzavillense Franch.	
	Melastomastrum capitatum (Wahl) A.	
	Stipularia africana P. Beauv.	
	Alchornea cordifolia (Schum. & Thonn.) Müll.Arg.	

Aboveground Biomass in the Herbaceous Stand

The analysis of the data obtained shows a greater spatial variability of the aboveground biomass of non-woody herbaceous vegetation. The aboveground biomass varies from 44.18 tMS/ha to 76.71 tMS/ha. The average aboveground biomass of the vegetation is 55 tMS/ha.

Biomass in the Woody Stand

Assessment of structural parameters and aboveground biomass

The structural parameters of the wooded area were studied, including the density and diameter structure of this stand. The distribution of diameter classes of woody species is very uneven, but does not exceed diameter class III.

The high proportion of young individuals (130 feet), of small diameter (Class 0 = 5-9 cm), and the absence of mature individuals (Class II = 20-29 cm) testify, in the same way, to the strong anthropization of the ecosystems of the Ngamakala peatland.

It varies from class 0 to class II, and the class has a contribution of nearly 71.82% to the total number of individuals, followed by class I with a contribution of 25.41%. In terms of contribution to aboveground biomass, the class contributes 23.74% to the aboveground biomass with a total biomass of 30.17 tMS/ha, class I contributes 49.84% to the aboveground biomass and class II contributes 26.41%.

Furthermore, not all species contribute at the same rate to the aboveground biomass. Only one species, *Alstonia congensis* Engler, contributes 72.89% to the woody aboveground biomass, followed by *Xylopia rubescens* Oliv.var., which has an estimated contribution of 23.77% to the aboveground biomass of the woody species inventoried in the Ngamakala peatland. Compared to the total area covered by this inventory, *Alstonia congensis* Engler has a total aboveground biomass of 92.62 tMS/ha.

At the scale of the inventory plot unit, the results show a large spatial variability between the inventory plots. Three out of six plots have a biomass that does not exceed 20 tc/ha. The average biomass in woody vegetation is 21.17 tc/ha. It thus emerges that the aerial biomass of herbaceous vegetation with 55 tMS/ha, is greater than that of woody biomass.

DISCUSSION

A Floristically More Diverse Peatland

The increase in species richness of approximately 34.76% indicates that significant changes in floristic composition occurred during the 47 years separating the two inventories (A and B). These changes were thus reflected in the beta diversity of the peatland.

The floristic reassessment at the Ngamakala peatland showed that the vegetation has undergone significant changes over the last 50 years. The most obvious effect of afforestation on the diversity of the Ngamakala peatland is generally the decrease in frequency and abundance (see frequency) over time of facultative species of wetland environments with or without peatlands (5 species out of 19), as well as those with terrestrial affinity (4 species out of 19) including *Xylopia aethiopica* (Dunal) A. Rich; *Alchornea cordifolia* (Schumach. & Thonn) ûll.Arg; *Allophylus africanus* Beauv. and *Aphanostylis manii* (Stapf) Pierre.

Furthermore, rising temperatures could explain the fact that some rare species such as *Drosera madagascariensis* and *Indet calanthe*, plants (sphagnum) which like cooler/cold climates and which were easily observed in 1976, are not present today (Makany, 1976; Cratton *et al.*, 2014).

Our observations confirm our first hypothesis and corroborate the results obtained by Pasquet *et al.* (2015) in two peatlands of Montérégie (Small and Large Tea Field), peatlands in which the forest cover increasing from 26 to 51% in the space of 27 years resulted in a significant decrease in the frequency and abundance of turficolous species and a colonization of species of terrestrial affinity, often of exotic origin.

Comparison of Species Richness between 1976 and 2023

The results obtained show that only 9 species are common (C) to the two inventories, which means that 14 taxa were found to be unique to the 1976 inventory compared to 22 in 2023.

The analysis of this graph shows the presence of a dissimilarity coefficient (Ks) with a value of 0.3 for the entire flora of the peatland. This value indicates that significant changes in floristic composition occurred during the 47 years separating the two inventories (A and B). These changes were thus reflected in the beta diversity of the peatland.

Indeed, 31 plant species were recorded in 2023 compared to 23 in 1976. On the other hand, the number of genera was greater than today (i.e. 23 compared to 22). In addition, there was a loss of certain rare species such as *Drosera madagascariensis* and *Indet calanthe*, plants (sphagnum) that like cooler, if not cold, climates (Cratton *et al.*, 2014).

These results corroborate those obtained by Gunnarson *et al.* (2002), Kapfer *et al.* (2011).

Probable Causes of the Observed Floristic Changes

All the data obtained confirm that the peatland is currently undergoing a reforestation phenomenon. Indeed, *Alstonia congensis* Engler and *Xylopia rubenscens* Oliv.var. have increased in frequency and abundance, while several heliophile species typical of open peatlands, such as *Sphagnum moss* (Sphagnaceae) and *Hypogynium spathiflorum* (Poaceae) have greatly decreased. While these phases of tree colonization can sometimes be attributed to warmer and drier climatic periods (Chambers, 1997, Maley, 2002), it appears that the impact of human interventions on the hydrology of the peatland affects the degree of humification of the peat more than the vegetation itself (Mälilä *et al.*, 2008).

This phenomenon of change in the plant composition of peatlands may also be related to agricultural practices, deforestation, mining or other human activities that disrupt the natural ecosystem of the peatland. In addition, global climate change may also contribute to these transformations, leading to changes in precipitation patterns, temperatures and water availability, which can influence the dynamics of peatland vegetation (Maley, 2002; Mälilä *et al.*, 2008).

Consequently, the development of woody plants would be the result of an allogenic disturbance of climatic and anthropogenic origin.

Variation in Aerial Biomass

The variability in time and space of biomass is dependent on various factors such as environmental conditions, plant growth rate and natural or anthropogenic disturbances. The aerial biomass stocks obtained are lower in herbaceous plants (76.71 tMS/ha) than in woody plants (235.42 tMS/ha). These results show that the health of ecosystems is the determining factor (Grinand, & Ntahompagaze, 2015; Kurnianto *et al.*, 2017; Hadi *et al.*, 2018). Indeed, surrounding populations use wood as their main source of energy. In addition, large-diameter woody plants are illegally cut to provide construction timber. The almost exclusive presence of relatively young individuals, with a diameter between 5 and 9 cm, may be due to selective cutting. The abundance of medium-sized individuals seems to confirm the felling of mature individuals.

CONCLUSION

The study of the impact of forest colonization on floristic diversity and above-ground biomass in the Ngamakala peatland highlighted the significant changes that occur when an ecosystem is modified by human intervention. Forest colonization leads to a reduction in turf plants such as sphagnum mosses, leading to a dominance of forest species, which can lead to drying out in cases of this type of ecosystem.

In addition, the assessment of the biomass of woody and herbaceous plants highlights the contribution of each plant formation and each species to biomass production. These aerial biomass stocks are lower in herbaceous plants (76.71 tMS/3 m²) than in woody plants (235.42 tMS/600 m²), probably due to the difference in the areas used but also in the basal area.

In view of the changes observed and the threats that continue to weigh on the Ngamakala peatland, it is essential to involve local communities in the sustainable management of natural resources in order to preserve the floral wealth of the region for future generations.

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COMPETING INTERESTS

The authors declare that there is no conflict of interests regarding the publication of this paper.

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