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Floristic composition and structure of closed and open forests in the Banco National Park, Abidjan, Côte d'Ivoire

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Abstract. *Gnahore E, Douffi KG-C, N'guessan YJ, Amba AJG, Ibrahima D, Kone M, Bakayoko A. 2023. Floristic composition and structure of closed and open forests in the Banco National Park, Abidjan, Côte d'Ivoire. Asian J For 7: 17-26.* Natural ecosystems are pressured to degradation caused by human activities. To develop conservation guidelines for these ecosystems, it was necessary to have enough information on their biodiversity. This study aimed to investigate the species richness, diversity, structure, and composition of vegetation in the Banco National Park (BNP), Abidjan, Côte d'Ivoire, in two forest types, namely closed and open forests. Vegetational data was collected using a sampling plot and itinerant methods. The results showed that 345 and 283 species were recorded in the closed and open forest, respectively, suggesting that the closed forest appears richer than the open forest. Fabaceae, Rubiaceae, and Apocynaceae were the most dominant families in both forest types. Both forest types had a high Shannon-Weaver diversity index and high Pielou equality index. The most important species in the open forest included *Chrysophyllum subnudum* Baker (Sapotaceae), *Allanblackia floribunda* Oliv. (Clusiaceae) and *Funtumia africana* (Benth.) Stapf (Apocynaceae), while in the closed forest were *Strombosia pustulata* Oliv. (Olacaceae), *Turraeanthus africanus* (Welw. ex C.DC.) Pellegr. (Meliaceae), and *Monodora myristica* (Gaertn.) Dunal (Annonaceae). The diametric structure showed the greatest proportion of individuals with low diameter classes, indicating regeneration potential. However, there were great differences in stand structure between the open and the closed forest, especially in high-diameter classes, indicating that the open forest has been pressured by timber cutting. The results of this study can serve as baseline information to develop conservation and rehabilitation strategies in BNP to sustain its biodiversity components.

Keywords: Banco National Park, Côte d'Ivoire, closed forests, conservation, forest structure, open forests

INTRODUCTION

Forest ecosystems provide many ecosystem services necessary for life maintenance, including water supply, carbon sequestration, flood regulation and protection against desertification and soil erosion. In addition, forest vegetation contributes to climate change mitigation and biodiversity conservation (Koubouana et al. 2016). Forests, particularly tropical forests, contain high biological diversity, including at the genetic level (Slik et al. 2015). Nonetheless, many forests in the world are pressured by deforestation and forest degradation, although such pressures are not uniform and vary according to the density of the population, the accessibility from urban areas, the quality of basic infrastructure, and the economic potential of the forest including if it is converted to other land use (e.g., agriculture, plantation). The destruction of forests due to human activities leads to species' disappearance and ecosystem services deterioration (Toko et al. 2012; McDonald et al. 2013). The pressures on forests are expected to increase due to population and economic growth since there would be an increase in the use of forest products (e.g., wood) and forest services (Gnahore et al. 2022).

Situations related to managing the environment and natural resources are major challenges humans face today. In African countries, the trend toward degradation of forest resources due to human activities was worrying. This is due to, among other things, the high dependence of populations on natural resources. West Africa has a significant annual deforestation rate, with an estimated more than 3.94 million hectares of forest lost from 2010 to 2020 (FAO and PNUE 2020). In Côte d'Ivoire, the richest and most diverse forests are now among the most threatened ecosystems on the planet (Achard et al. 2002). The forests in the country are heavily affected by agriculture, which is the main driver of deforestation (Kouakou et al. 2019). This loss of natural forests results in the destruction of some natural habitats and the reduction of forest cover, which reduces biodiversity (Flores et al. 2018). The destruction of Ivorian forests has increased considerably, urging the government to implement conservation strategies by creating national parks and nature reserves. These practices have been recognized worldwide as the most effective strategy for conserving natural resources (Wondie 2015). However, despite creating national parks and nature reserves in Côte d'Ivoire, such conservation areas are infiltrated by populations to fulfill their daily needs. This is the case of the Banco National Park (BNP) under various human pressures (Gnahore et al. 2022).

Most African states have based their conservation strategy on creating and extending protected areas to secure their plant and animal resources better. Nonetheless, two decades after creating some protected areas such as the BNP, conservation is still a major challenge. Today, BNP has become the preferred target of the local population in search of firewood, food, and medicinal plants (Gnahore et al. 2022). In addition to these deplorable conditions for the protection of the BNP, there is the development of human settlements and neighborhoods near the park (Oura 2012). Several authors have reported these human activities as the dominant forms of disturbance of vegetation structure and physiognomy within protected areas (Tankoano et al. 2016). This situation has led to disturbances in the vegetation in the park and in the current state of knowledge, changes in land use, floristic richness and vegetation structure are unknown. Despite the degradation of forest resources and the modification of landscapes in the BNP, the precise and available information on vegetation dynamics and floristic diversity in this protected area was insufficient. Knowledge of forest area, floristic composition and its dynamics provides information essential for establishing and monitoring environmental and economic policies.

Concerning the increasingly strong anthropogenic pressures, an ecological problem today is understanding how tropical plant communities' dynamics are affected by human disturbances. The long-term conservation of biodiversity depends on knowledge of the structure, species richness and ecological characteristics of vegetation (Okende 2021). It is, therefore, more than urgent to assess the remaining forest in protected areas in Côte d'Ivoire to ensure better protection. It was necessary to assess floristic diversity to know the state of plant resources, hence motivating this study. Knowledge of the current vegetation dynamics, floristic composition and structure of BNP is important for sustainable management of the park. The main objective of this study is to contribute to a better knowledge of the flora in BNP by investigating the floristic parameters (i.e., richness, composition and floristic diversity) and structural parameters (i.e., density, diameter class, basal area) of closed and open forests in the park.

MATERIALS AND METHODS

Study area

The Banco National Park (BNP), Côte d'Ivoire was created on 31 October 1953. It covers an area of 3834.34 ha and is located between latitude 5°23' N and longitude 4°03' W. It is located within the city of Abidjan between the communes of Abobo, Adjamé, Attécoubé and Yopougon (Figure 1). The river network is essentially composed of the Banco River. This river is fed by groundwater related to rainwater infiltration under the forest canopy. The city of Abidjan, where the BNP is located, has a sub-equatorial (Atitean climate) with four humid and cool winter seasons. The average annual rainfall recorded by the SODEXAM meteorological station from 2010 to 2021 was 1733 mm. The average temperature was 27.2°C with an amplitude of 4.3°C (Tiébré et al. 2014). The soil of the BNP has the same composition as all the soils of the Abidjan region. The type of soil, wet all year round, was said to be psammohygrophile.

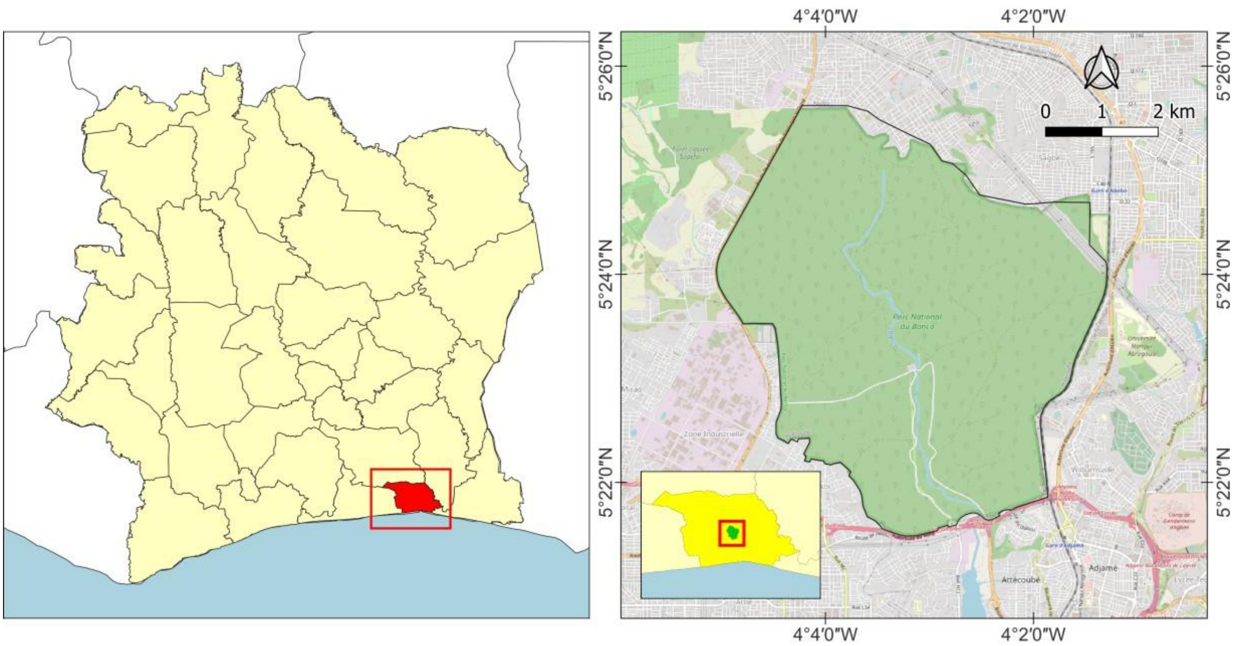

Figure 1. Map of the study area in Banco National Park, Côte d'Ivoire

The vegetation of the BNP consists mainly of dense evergreen humid forest. The dominant trees are *Turraeanthus africanus* (Welw. ex C.DC.) Pellegr (Meliaceae), *Synsepalum afzelii* (Engl.) T.D.Penn. (Sapotaceae), *Berlinia confusa* Hoyle (Fabaceae), *Blighia welwitschii* (Hook.f.) Brenan (Fabaceae), *Coula edulis* Baill. (Olacaceae), *Dacryodes klaineana* (Pierre) H.J.Lam (Burseraceae), *Lophira alata* Banks ex C.F.Gaertn. (Ochnaceae), *Petersianthus macrocarpus* (P.Beauv.) Liben (Lecythidaceae), and *Piptadeniastrum africanum* (Hook.f.) Brenan (Fabaceae). It was specific to an association vegetal, typical of the southeast of the country: the psammohygrophile forest with *T. africanus* and *Heisteria parviflora* Sm. (Olacaceae). In addition, the park is subject to strong anthropogenic pressure on the periphery due to illegal activities such as poaching, harvesting of non-timber forest products, etc.

Vegetation data collection

Inventories were carried out using two sampling methods: plot and itinerant methods. The plot method is a classic method already used by various researchers (e.g., Missa et al. 2018; Tesfay et al. 2019; Misganaw et al. 2021). For this study, we established 130 square plots measuring 25 m x 25 m (625 m²) arranged regularly on each side with the help of stakes. In these squares, all woody species (trees, shrubs, and lianas) were inventoried, taking into account diameters greater than or equal to 10 centimeters at the breast height of the ground. Initially, the floristic inventory concerned all woody species (lianas, shrubs, and trees) with a DBH (diameter at breast height) ≥ 10 cm. The second step was to delimit within these plots a nested plot with a size of 5 m x 5 m (25 m²), called regeneration plots. Here, all plant species (shrubs, lianescents, or herbaceous) encountered were identified without considering their DBH. These circumference measurements were made using a two-meter-long metric ribbon. We used the itinerant method to increase the chances of encountering the maximum number of species (Gnahore et al. 2018; Missa et al. 2018). This second method involved going through each study plot in all directions, noting all newly encountered plant species. All species that had not been documented in the initial surveys were recorded to complete the floristic list of the area.

Samples of unknown species were collected for the preparation of a herbarium. These herbarium samples were identified at the Swiss Center for Scientific Research in Côte d'Ivoire. Two forest types, open and closed forests, were considered to determine differences in structural and floristic parameters (Figure 2). The open forests present a state of deterioration, more or less advanced due to human pressures, while the closed forests are intact and never affected by human pressures.

Data analysis

Species Importance Value Index (SIV) and Family Importance Value (FIV)

The information collected on the field sheets was used to describe diversity, floristic composition, and plant structure. This collected data was entered, classified, and processed using Word (2013 version) and Excel (2013 version).

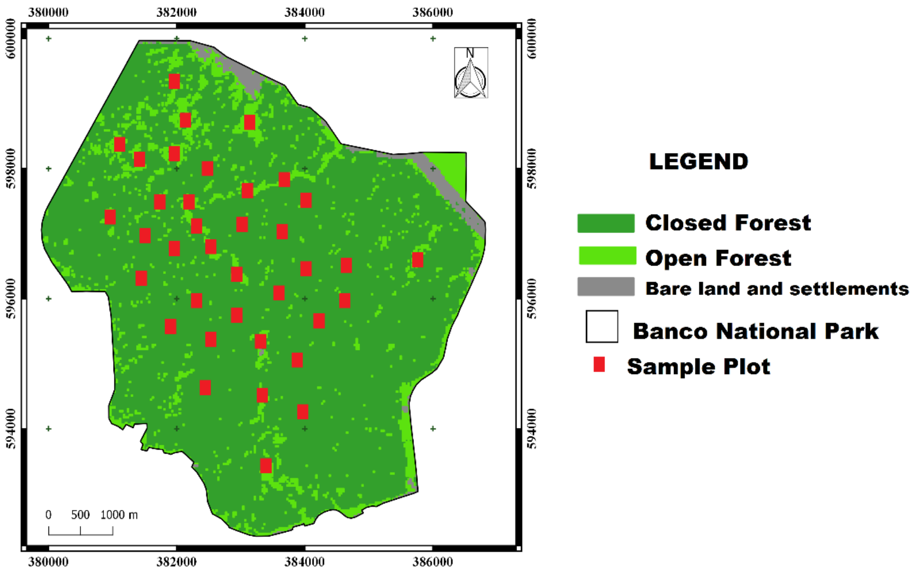

Figure 2. Arrangement of transects and observation plots in Banco National Park, Côte d'Ivoire

Concerning floristic parameters, floristic richness and composition were determined through the frequencies of occurrence in each type of forest. Structural parameters were assessed through stem frequency, density, basal area and species dominance. The importance of species or families in a given plant community was assessed from the Species Importance Value Index (SIV) and the Family Importance Value (FIV). The Importance values ranged from 0 to 300. When the value is zero, there is no dominance. Based on the different parameters, dominant species or families were defined as those with a value ≥ 10 (Missa et al. 2018; Thammanu et al. 2021). Those different parameters have been calculated according to the following formulas:

SIV = Relative density + Relative frequency + Relative dominance

FIV = Relative density + Relative dominance + Relative diversity

Where:

$$\text{Relative Density} = \frac{\text{Number of stems of species}}{\text{Total number of stems}} \times 100$$

$$\text{Relative frequency} = \frac{\text{Frequency of a species}}{\text{Sum of all species}} \times 100$$

$$\text{Relative dominance} = \frac{\text{Total basal area of a species}}{\text{Total basal area o all species}} \times 100$$

$$\text{Relative diversity} = \frac{\text{Number of species in a family}}{\text{Total number of species}}$$

The basal area (BA) of all trees in the sample plots was calculated using the formula:

$$BA = \sum \pi \left(\frac{d}{2}\right)^2$$

Where BA = Basal Area (m² / ha), d = diameter at breast height (cm) and π = Pie (3.142).

Diversity indices

To compare the floristic diversity between the two forest types, the Shannon-Weaver (H') and Pielou equitability (E) indices were used (Pielou 1966) and calculated using the PAST 2.16 software. The indices were calculated from the specific contribution of each species. These indices provide a better understanding of an ecosystem's biological diversity. The Shannon-Weaver Diversity Index (H') quantified the floristic diversity of each area. It is often used to express the diversity of different sites. The following formula calculated it:

$$H' = -\sum_{i=1}^{s} pi \ln pi$$

Where H' is the Shannon-Weaver index, s is the total number of species, pi is the proportion of individuals in the ith species, and ln is the natural logarithm.

From the Shannon-Weaver Diversity Index, the Pielou equitability index (E) was deducted. It provides information on the distribution of numbers of each species. It varies from 0 when a single species strongly dominates to 1 when every species has equal numbers. This index was calculated from the formula below:

$$E = \frac{H'}{\ln S}$$

With S: total number of species (species richness), H' was the Shannon-Weiner index, and ln was the natural logarithm.

Average stocking density of major species

The average density of stems per hectare assessed the average stocking density of the main species of the BNP. The average density is the quotient of the total number of individuals inventoried in the biotope by the total area sampled in the environment in hectares (Hosny et al. 2018). The formula calculated it:

$$N = n/S$$

Where: N the average density, expressed in individuals per hectare; n: the total number of individuals inventoried and S the total area sampled in the environment in hectares.

Diameter classes

Diameter classes are used to characterize the diameter structure of vegetation. The distribution of stems of tree species in different diametric classes evaluated the diameter classes in this study. In this study, the number of stems of all species was assessed by diameter class, which was used to construct histograms. In this study, ten diameter classes were used (Hosny et al. 2018; Misganaw et al. 2021): [10-20 cm], [20-30 cm], [30-40 cm], [40-50 cm], [50-60 cm], [60-70 cm], [70-80 cm], [80-90 cm], [90-100 cm] and [100 cm; + ∞].

Sorensen similarity index (Cs)

The Sorensen similarity index was used to assess the similarity between the two forest types using the formula:

$$Cs = \frac{2S}{Y + Z} \times 100$$

Where: Y = number of species in the area y; Z = number of species in the area z; S = number of common species in both forest types. The index of 0 indicates that both forest types have totally different species and the index of 10 implies that both forest types have exactly similar species

Statistical analysis

For the comparison of the means of the structural and floristic parameters between the two forest types, Student's parametric t-test was used. The two forest types were considered as independent samples. This test was valid only for populations with normal distribution and equal variances (Tiébré et al. 2014). The significance test was performed at $p = 0.05$ (Tesfay et al. 2019; Thammanu et al. 2021). Normality was tested using the Shapiro-Wilk test. When the calculated probability was significant, the Tukey test compares the means two by two and assesses the significant differences between them. The XLSTAT 2014 software was used to carry out these statistical tests.

RESULTS AND DISCUSSION

Species richness and floristic composition

The floristic inventory identified 556 species combined in open and closed forests. A total of 345 plant species belonging to 211 genera and 73 families were identified in the closed forest against 283 species belonging to 229 generas and 80 families in the open forest. In addition, the number of species presents exclusively in the open forest was greater than that encountered in the closed forest. Indeed, 260 species were observed only in the open forest, while 156 species were only in the closed forest. Among these exclusive species, we noted, for example, *Bombax buonopozense* P.Beauv. (Malvaceae), *Capparis tomentosa* Lam. (Capparaceae), *Croton hirtus* L'Hér. (Euphorbiaceae), *Eulophia gracilis* Lindl. (Orchidaceae) and *Majidea fosteri* Sprague Radlk. (Sapindaceae) in the open forest. In the closed forest, we found *Trilepisium madagascariense* DC. (Moraceae), *Clerodendrum polycephalum* Baker (Lamiaceae), *Decorsella paradoxa* A.Chev (Violaceae), *Panda oleasa* Pierre (Pandaceae), and *Phyllocosmus africanus* Hook.f. Klotzsch (Ixonanthaceae). The most significant families in the open forest in decreasing order were Fabaceae (40 species), Apocynaceae (23 species), Rubiaceae (18 species), Annonaceae (15 species), and Euphorbiaceae (15 species). At the specific level, the most commonly encountered species were *Baphia nitida* Lodd (Fabaceae), *Cola heterophylla* (P.Beauv.) Schott & Endl (Malvaceae), *Strombosia pustulata* Oliv. (Olacaceae) and *Dichapetalum pallidum* (Oliv.) Engl. (Dichapetalaceae).

In the closed forest, the most dominant families with at least 10 species were Fabaceae (35 species), Rubiaceae (32 species), Apocynaceae (20 species), Annonaceae (13 species), Sapindaceae (13 species), Malvaceae (12 species), Celastraceae (11 species) and Meliaceae (10 species). The families Fabaceae, Rubiaceae and Apocynaceae alone represented 87 species or 25.21% of all species. The most abundant species were *Albertisia cordifolia* (Mangenot & Miege) Forman (Menispermaceae), *Angylocalyx oligophyllus* (Baker) Baker f. (Fabaceae), *Cola caricifolia* (G.Don) K.Schum (Malvaceae), *C. edulis*, *T. africanus*, *Isolona campanulata* Engl. & Diels (Annonaceae), *Microdesmis keayana* J.Léonard (Pandaceae), *S. pustulata*, *B. welwitschii*, *P. africanum* and *Rhaphiostylis cordifolia* Hutch. & Dalziel (Icacinaceae). The most abundant families of the two forest were Rubiaceae, Fabaceae and Apocynaceae. Student t Test statistical analysis showed a significant difference between the two forest types ($P < 0.0001$). Comparison of the means of species-specific richness in the dominant families reveals a significant difference ($P < 0.05$) between the families Fabaceae and Apocynaceae. However, there was no significant difference ($P = 0.057$) within the Rubiaceae family (Table 1).

Diversity indices of the different forests types

The floristic diversity was estimated using the Shannon-Weaver (H') and Pielou (E) indices. In the open forest, the diversity is categorized as high with the Shannon-Weaver (H') index of 3.36, while the equitability of the Pielou index of 0.84 corresponds to high equitability. On the other hand, in the closed forest, the diversity index was high, with a value of 3.26, while equitability was high, with a value of 0.83.

Species and Families Importance Value Indices

The Importance Value Index reveals that the most important species in the open forest with a value greater than or equal to 10 % in decreasing order were *C. subnudum*, *Allanblackia floribunda* Oliv. (Clusiaceae), *Funtumia africana* (Benth.) Stapf (Apocynaceae), *Elaeis guineensis* Jacq. (Arecaceae), *Pentaclethra macrophylla* Benth. (Fabaceae) and *Bridelia grandis* Pierre ex Hutch. (Phyllanthaceae) (Table 2). The most ecologically important species in closed forests were *S. pustulata*, *T. africanus*, and *Monodora myristica* (Gaertn.) Dunal (Annonaceae), *F. africana*, *Antiaris toxicaria* Loes. *var. africana* Scott-Elliot ex A.Chev (Moraceae), *B. confusa*, *Buchholzia coriacea* Engl. (Capparaceae), *C. edulis* and *L. alata* (Table 2). Similarly, the predominant families in the open forest with important value index greater than 10% in decreasing order were Fabaceae, Apocynaceae, Ebenaceae, Clusiaceae, Arecaceae, Phyllanthaceae, Meliaceae, and Sapotaceae. In the closed forest, the most significant families were Fabaceae, Meliaceae, Apocynaceae, Annonaceae, and Olacaceae (Table 3).

Table 1. Floristic parameters in two different forest types of Banco National Park, Côte d'Ivoire

Floristic parameters		Forest types		Statistical parameters	
		Open forest	Closed forest	T	P
Species	Total	283	345	21.9	< 0.0001*
	Average number	31.39 ± 1.02^b	40.19 ± 0.19^a		
Genera	Total	229	211	17.9	< 0.0001*
	Average number	28.72 ± 0.9^b	38.56 ± 0.17^a		
Families	Total	80	73	5.7	0.018*
	Average number	21.62 ± 0.48^b	25.51 ± 0.09^a		
Fabaceae	Total	35	40	8.511	0.01*
	Average number	11.375 ± 0.46^a	9.3 ± 0.48^b		
Apocynaceae	Total	28	20	8.647	0.01*
	Average number	6.125 ± 0.56^a	4.2 ± 0.29^b		
Rubiaceae	Total	23	32	4.2	0.057
	Average number	2.25 ± 0.66^a	3.7 ± 0.34^a		

Note: Average = (mean ± standard error). *Significant overall means effects, $p < 0.05$. Means with different letters are significantly different based on Student t test

Density, basal area and species representativeness

In the open forest, 19 stems with a diameter at breast height greater than or equal to 10 centimeters over an area of 625 m² corresponding to 304 stems per hectare, were identified. *Millettia zechiana* Harms (Fabaceae) (22.82%) was the most represented species, followed by *F. africana* (18.47%) and *Macaranga beillei* Prain (Euphorbiaceae) with 17.39%. In the closed forest, 496 stems were inventoried per hectare, or 28 stems on an area of 625 m². *F. africana* and *A. floribunda* were the most abundant, representing 59.36% and 25.55%, respectively. These two species alone represented 84.91% of this forest's total number of individuals. The basal area of the closed forest was 36.22 m² per hectare. The species *B. confusa* had the highest basal area and occupied 1.62 m² per hectare, followed by *T. africanus* with 1.07 m² per hectare and *F. africana* with 0.89 m² per hectare. For the open forest, the basal area was 17.33 m² per hectare. *Pycnanthus angolensis* (Welw.) Warb. (Myristicacaeae) occupied 2.02 m² per hectare, followed by *M. zechiana* with 0.13 m² per hectare and *M. beillei* with 0.14 m² per hectare. The three species contributed 22.62% to the total basal area. Despite this variation, the difference between average densities was insignificant (Table 4). The closed forest had an average basal area of 1.791 ± 0.003 m² per hectare and had the highest value for the square plots measuring 25 m x 25 m (625 m²). As for the open forest, the average basal area was 0.36 ± 0.013 m² per hectare. The mean comparison test reveals that the difference in basal areas between the two forest types was statistically significant (Table 4).

Diameter distribution

The diameter class distribution of all woody species of the open forest showed that the classes 10 to 20 cm contained the highest number of stems, with 3308 stems per hectare, followed by the class between 20 and 30 cm, with 761 stems per hectare. For classes between 30 and 40 cm; 40 to 50 cm; 50 to 60 cm, and 60 to 70 cm contained 69, 14, 10, and 5 stems per hectare. The dominance of individuals of small diameters between 10 and 20 cm is clearly noticeable, followed by the class between 20 and 30 cm. In general, a steady decrease in the number of stems was observed when the diameter classes increased. An absence of stems from the class between 70 and 80 centimeters in the whole was noticed. In the closed forest, the class of 10 to 20 cm in diameter had the highest density (3308 stems per hectare) against 896 stems per hectare in the open forest (Figure 3).

Table 2. The Importance Value Index (IVI) of the species in two differents forest types in Banco National Park, Côte d'Ivoire

Species	RDo (%)	RD (%)	RF (%)	IVI (%)
Closed forest				
Strombosia pustulata Oliv.	28.00	4.70	10.15	42.85
Turraeanthus africanus (Welw. ex C.DC.) Pellegr.	13.71	4.93	8.47	27.11
Monodora myristica (Gaertn.) Dunal	5.95	3.04	9.91	18.90
Funtumia africana (Benth.) Stapf	1.81	6.59	10.15	18.55
Antiaris toxicaria Loes. var. *africana* Scott-Elliot ex A.Chev	9.73	2.00	5.81	17.54
Berlinia confusa Hoyle	0.48	5.26	11.19	16.93
Buchholzia coriacea Engl.	1.35	3.78	10.33	15.46
Coula edulis Baill.	1.83	3.04	9.09	13.96
Lophira alata Banks ex C.F.Gaertn.	2.35	3.59	6.81	12.75
Pycnanthus angolensis (Welw.) Warb.	1.83	1.98	5.57	9.38
Vitex grandifolia Gürke	5.79	1.29	2.06	9.14
Allanblackia floribunda Oliv.	6.27	0.78	2.06	9.11
Myrianthus libericus Rendle	1.60	1.15	4.33	7.08
Other species (332)	19.30	57.87	4.07	81.24
Total (%)	100	100	100	300
Open forest				
Chrysophyllum subnudum Baker	27.83	33.33	55.64	116.80
Allanblackia floribunda Oliv.	20.48	5.03	8.57	34.08
Funtumia africana (Benth.) Stapf	0.47	12.58	10.25	23.30
Elaeis guineensis Jacq.	6.03	3.93	9.41	19.37
Pentaclethra macrophylla Benth.	10.03	2.47	4.60	17.05
Bridelia grandis Pierre ex Hutch.	1.47	12.00	0.21	13.68
Diospyros sanza-minika A.Chev.	3.99	0.45	1.88	6.32
Guarea cedrata (A.Chev.) Pellegr.	0.47	5.33	0.41	6.21
Drypetes chevalieri Beille ex Hutch. & Dalziel	3.98	0.45	1.67	6.10
Antiaris toxicaria Loes. var. *africana* Scott-Elliot ex A.Chev	2.06	0.45	3.55	6.06
Coula edulis Baill.	3.67	0.45	1.04	5.16
Microdesmis keayana J.Léonard	0.22	0.65	0.21	1.08
Other species (271)	19.03	22.93	2.56	44.79
Total (%)	100	100	100	300

Note: RDo: Relative dominance, RD: Relative density, RF: Relative frequency, IVI: Importance Value Index

Species that had small diameters between 10-20 cm in the closed forest were *S. pustulata*, *M. keayana*, *B. nitida* and *C. edulis* while *T. africanus*, *Ceiba pentandra* (L.) Gaertn. (Malvaceae) and *P. africanum* were recorded in the largest diameter class. Species such as *M. myristica*, *A. toxicaria* Loes. var. *africana* Scott-Elliot ex A.Chev, *B. confusa* Hoyle had been mainly found in the intermediate class (30 to 60 cm) while *Vitex grandifolia* Gürke (Lamiaceae), *Myrianthus libericus* Rendle (Urticaceae), *Hymenostegia afzelii* (Oliv.) Harms (Fabaceae) et *Omphalocarpum ahia* A.Chev. (Sapotaceae) were recorded in large classes (70 to 90 cm) in diameter. *L. alata*, *B. coriacea* and *A. floribunda* were found in the 90-120 cm diameter class.

Acacia mangium Willd. (Fabaceae), *Senna siamea* (Lam.) H.S.Irwin & Barneby (Fabaceae), *Anthonotha macrophylla* P.Beauv. (Fabaceae) and *B. nitida* were the majority in the smallest diameter class (10 to 20 cm) in the open forest. *Taberneamontana crassa* Benth. (Apocynaceae), *V. grandifolia* and *Gilletiodendron kisantuense* (De Wild.) J.Leonard (Fabaceae) were the species with the largest diameters (90 to 120 cm), while the two largest trees (*C. pentandra*, *P. africanum* and *A. floribunda*) were over 100 cm in diameter. In general, the appearance of the histograms showing the diameter class distribution resembles the reverse J-shape relationship (Figure 3).

Discussion

A total of 556 species were counted across both forest types. The results showed that 345 and 283 species were recorded in the closed and open forest, respectively suggesting that the closed forest appears richer than the open forest. The higher number of species in the closed forest could be explained by the protection and monitoring of this forest by the Ivorian Office Parks and Reserves officers. This result agrees with the findings reported by Soro et al. (2019) in the Taï national park (Côte d'Ivoire). The disturbances could also explain this lower richness in the open forest suffered in this area that would have favored the proliferation of pioneer species (Prévost 1981). Kouakou et al. (2019) have showed through their work that human disturbances are estimated at 95% and that only 5% are of natural origin in the world. Indeed, local communities infiltrated the BNP to collect plants (Gnahore et al. 2022). This situation may cause a reduction in the number of species in the open forest. The low number of species recorded in the open forest is similar to the number of species reported by Yadav et al. (2020) in the Terai region of Nepal.

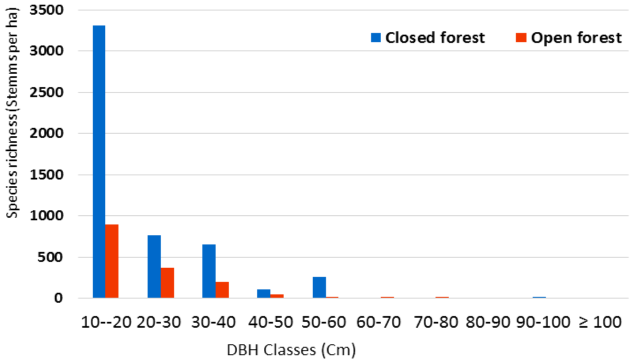

Figure 3. The diameter class distribution of stems in two different forest types of Banco National Park, Côte d'Ivoire

Table 3. The Importance Value Index of Families (VIF) of two different forest types in the Banco National Park, Côte d'Ivoire

Families	RDo (%)	RD (%)	RF (%)	VIF (%)
Closed forest				
Fabaceae	7.48	10.14	23.21	40.83
Meliaceae	22.72	2.89	8.86	34.47
Apocynaceae	10.23	5.79	17.25	33.27
Annonaceae	2.92	3.76	6.73	13.41
Olacaceae	5.05	1.44	4.84	11.33
Lecythidaceae	3.78	1.15	4.93	9.86
Moraceae	4.94	2.02	2.03	8.99
Ochnaceae	2.99	1.44	3.59	8.02
Myristicaceae	4.21	0.57	1.98	6.76
Capparaceae	1.64	0.86	3.78	6.28
Clusiaceae	3.73	1.73	0.78	6.24
Lamiaceae	1.17	1.73	1.84	4.74
Urticaceae	0.66	1.44	1.15	3.25
Other families (60)	28.48	65.04	19.03	112.55
Total (%)	100	100	100	300
Open forest				
Fabaceae	7.45	24.31	17.77	49.53
Apocynaceae	17.38	14.61	4.44	36.43
Ebenaceae	14.18	1.37	4.44	19.99
Clusiaceae	7.61	5.37	2.22	15.2
Arecaceae	10.08	3.93	1.11	15.12
Phyllanthaceae	7.98	2.62	3.33	13.93
Meliaceae	5.44	1.51	5.55	12.5
Sapotaceae	7.11	2.16	3.06	12.33
Olacaceae	3.96	1.5	2.22	7.68
Moraceae	2.04	0.72	3.33	6.09
Putranjivaceae	2.83	0.45	2.22	5.5
Pandaceae	2.2	0.65	1.11	3.96
Other families (68)	11.74	40.8	49.2	101.74
Total (%)	100	100	100	300

Note: RDo: Relative dominance, RD: Relative density, RF: Relative frequency, VIF: Importance Value Index of Families

Table 4. Structural parameters in two different forest types of Banco National Park, Côte d'Ivoire

Structural parameters	Forest type		Statistical parameters	
	Closed forest	Open forest		
Density (stems / ha)	496	432	-	
Average number of density	288 ± 5.093a	146.73 ± 23.053a	t = 2.344	P = 0.099
Basal area (m² / ha)	36.22	17.33	-	-
Average number of basal area	1.791 ± 0.003a	0.36 ± 0.013b	t = 3.305	P < 0.0001*

Note: Average = (mean ± standard error). *Significant overall means effects, p < 0.05. Means with different letters are significantly different based on Student t test. (-) indicates data absent

Fabaceae and Apocynaceae were the dominant families in the studied area. These families are noted as predominant in species in other forest ecological studies. Fabaceae's dominance is also characteristic of old-growth forests. The dominance of the Fabaceae family could be explained by the fact that all the plots studied in the park still retain their forest aspects. This family is also reported as the most diverse at the species level in the Gra-Kahsu natural vegetation in southern Tigray of Ethiopia (Tesfay et al. 2019). The most important families shown by the index of importance in the closed forest were Fabaceae, Rubiaceae, Apocynaceae and Ebenaceae, while those in the open forest were Fabaceae, Rubiaceae and Apocynaceae, suggesting that Fabaceae and the Rubiaceae are the most important families in Banco National Park.

Several studies agree with our observations in Ivorian forests (Tuo et al. 2017). By comparison, the Rubiaceae family found in different forest types had a similar species richness to the study done by Senbeta in the Maji and the Berhane-Kontir forests (Senbeta et al. 2014). The Importance Value Index was used to show the importance of species for good conservation (Tadele et al. 2013; Berhanu et al. 2017) and to understand the ecological significance of the vegetation species in community structure (Premavani et al. 2014). The high proportion at the species level of *S. pustulata*, *F. africana*, *T. africanus* and *M. myristica* in the closed forest indicates a good recovery of stands and this could be explained by the high amount of litter that enriches the soil and the absence of anthropogenic pressures. These results are in line with other studies by Gnahore et al. (2018) in the unburned savannah in the Lamto Scientific Reserve (Côte d'Ivoire) and Zin and Mitlöhner (2020) in the primary and secondary moist evergreen forests in the Tanintharyi Nature Reserve (TNR) Buffer Zone, Myanmar. Similarly, several studies have shown that many of the most prominent species are used for conserving protected areas (Tadele et al. 2013; Berhanu et al. 2017). The species with a lower Importante Value Index may indicate a threat and must be considered in conservation measures (Getie and Getahun 2020).

Based on the number of common species, the Sorensen similarity index was 47.6%. This index, ranging from 0 to 100% and less than 50%, indicates a low similarity between the two forest types. The low percentage of similarity index could be explained by the fact that the two forest types belong to different plant communities, which vary in floristic composition. A similar study was reported by Tesfay et al. (2019) in Gra-Kahsu natural vegetation, southern Tigray of Ethiopia.

The Shannon-Weaver diversity index and the Pielou equitability index were high in both forest types, although the open forest had a slightly higher Shannon-Weaver diversity index. The difference in the value of the Shannon-Weaver index could be explained by the presence of anthropized formations in the open forest due to the impact of human activities (Kouakou et al. 2019). According to Bouko et al. (2007), species diversity is affected by the degree of degradation. The results agree with Naidu and Kumar (2016), which stated that high diversity corresponds to a high species richness. Concerning the Pielou equitability index, the values obtained showed a similarity between the two forest types. This similarity indicates a homogeneous species distribution throughout the forest (Misganaw et al. 2018; Kouakou et al. 2019). The open forest had more heterogeneous environmental conditions because it was near the local communities and consequently highly prone to illegal infiltration (Gnahore et al. 2022). The open forest has been heavily infiltrated for the collection of most species, which has disturbed the canopy through openings that promote the proliferation of new species and increased species diversity. The results obtained in this study corroborate those of Zin and Mitlöhner (2020) in the primary and secondary moist evergreen forests in the Tanintharyi Nature Reserve (TNR) Buffer Zone, Myanmar.

A comparative analysis of the diametric structures of the two forest types indicates a clear difference between them. The diameter class distribution showed a reverted J-shape in both forest types, withstands dominated by individuals of small diameters. This same reverted J-shape has been obtained by Tesfay et al. (2019) in Gra-Kahsu natural vegetation, southern Tigray of Ethiopia, which reflects a decrease in plant individuals as the diameter class increases. In the open forest, there was a complete absence of individuals with a diameter greater than 80 centimeters. This showed that the reconstituted vegetation was still in the juvenile stage. The dominance of small-diameter individuals replacement of the loss of individuals after the anthropization of flora and vegetation (Tra et al. 2021). The absence of individuals with a large diameter in the open forest could be explained by the cutting of woody species by the surrounding communities, which did not occur in the closed forest (Yohannes et al. 2017). The reverted J-shape signifies a regeneration of species individuals after the anthropization of an environment (Goncalves et al. 2018), however young individuals are more vulnerable to anthropogenic disturbance (Bharathi and Devi-Prasad 2017).

On the other hand, a basal area of 17.33 m² per hectare is within the range proposed by Sokpon and Biaou (2002), which characterizes open forests as a basal area between 12 and 25 m² per hectare. The value of the basal area obtained could be explained by the fact that the open forest was in a state of degradation. Similarly, in his study of the Gra-Kahsu natural vegetation in southern Tigray of Ethiopia, Tesfay et al. (2019) found a basal area of up to 35 m² per hectare. The value obtained during this study in the closed forest was higher than that found by Tesfay. The higher value could be explained by the fact that the closed forest is not sufficiently subject to human activities. Also, the results showed that basal area values between 25 and 50 m² per hectare characterize dense humid forests. These results are similar to this study. Differences in basal area values between the two forest types may be due to differences in floristic composition and human activities. Structural parameters are essential for understanding forest ecology (Naidu and Kumar 2016). We also noted a structural variability between the forest types.

In conclusion, anthropogenic pressure and climate change are the leading causes of ecosystem degradation. To guide conservation, it was, therefore, necessary to have a range of information on the current state of biodiversity. The overall objective of this study was to contribute to the characterization of the vegetal biodiversity of Banco National Park (BNP). The study in the park contributed to a better understanding of BNP's floristic composition and plant structure. This study revealed 345 plant species belonging to 211 genera and 73 families in the open forest, while the closed forest possessed 283 species belonging to 229 genera and 80 families. In both forests, the most important families were Rubiaceae, Fabaceae and Apocynaceae. The Shannon-Weaver diversity indices were high in the closed and open forests. The most important species were *C. subnudum*, *T. africanus* and *P. africanum*. The diametric structure showed the greatest proportion of individuals with a low diameter class, representing regeneration potential. However, great differences were observed in the open and the closed forest vegetation structure. These results demonstrate that this forest has great ecological value despite the anthropogenic activities influencing its integrity. The different characteristics of BNP revealed by this study are knowledge necessary to biodiversity management and rehabilitation in all of its components. All these assets militate in favor of the reinforcement of the conservation and rehabilitation strategies of biodiversity in all its components.

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