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CONSERVATION STATE OF THE NATIONAL ZOO FOREST OF ABIDJAN (COTE D'IVOIRE)

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ABSTRACT

This study aimed to assess the degradation of the National Zoo of Abidjan. To achieve this, we employed two field methods: surface survey and linear survey. The surface survey involved counting all plant species within each plot, focusing on those with circumferences greater than or equal to 7.85 cm at breast height. A 100-meter-long rope was stretched horizontally just above the ground for the linear survey. Using this technique, 100 measurements were taken at regular one-meter intervals. At each contact point, we recorded the species and the distance at which each individual was encountered along the survey line. The results indicated that the forest possesses a good regeneration capacity. Analysis of the structural profiles revealed numerous openings, and it was found that the most dominant species include lianas (such as *Acacia kamerunensis*, *Adenia cissampeloides*, and Harms) and nanophanerophytes. Additionally, the observations showed that this area is a remnant of degraded semi-deciduous forests. Based on these findings, developing strategies to protect this forest and provide valuable goods and services to Abidjan is essential.

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1 Introduction

Côte d'Ivoire is home to 3,853 species of flora, which are threatened with extinction due to illegal activities such as agricultural clearing and forest over-exploitation (Aké-Assi 2002; FAO/PNUD 1981). Most of this flora is now found only in protected areas like national parks, classified forests, and nature reserves (Dao 1999). However, local populations increasingly encroach on these protected areas in their search for arable land and various plant species with different benefits, resulting in a continuous reduction of these areas. The government has implemented several measures to combat the decline of protected land and enhance the conservation potential of these biodiversity reservoirs. These include establishing a forest police force and creating animal parks. The National Zoo of Abidjan is one such park and plays a crucial role for the country, particularly for the city of Abidjan. It houses various animals, including lions, elephants, chimpanzees, and crocodiles (N'guessan et al. 2021). Additionally, the zoo is significant for wildlife education and conservation awareness, serving as a recreational site, an educational center, and a community meeting place. Nevertheless, the National Zoo of Abidjan and its remaining forest are under pressure from rapid urbanization in the city. Recently, the forest has faced increasing degradation (Cisse 2024). The loss of this forest could have significant consequences for wildlife, as some plants provide food for animals in captivity. Therefore, finding ways to preserve this forest is essential. Given its importance, studying the vegetation structure is necessary. This study aims to assess the degradation of this forest remnant and contribute to improving its management.

2 Material and methods

The study was conducted at the National Zoo of Abidjan, situated in the heart of Abidjan, Côte d'ivoire, at the intersection of the Deux Plateaux and Abobo Dokui neighborhoods, near the Abidjan Military Hospital (HMA) (Figure 1). The zoo spans approximately 20 hectares, with four hectares currently in operation. It is home to around 270 animals representing 48 species. The animals are divided into four sections: carnivores, duikers, crocodiles, and primates.

2.1 Methods

This study employed two field methods: surface survey and linear survey. The surface survey was conducted in three randomly

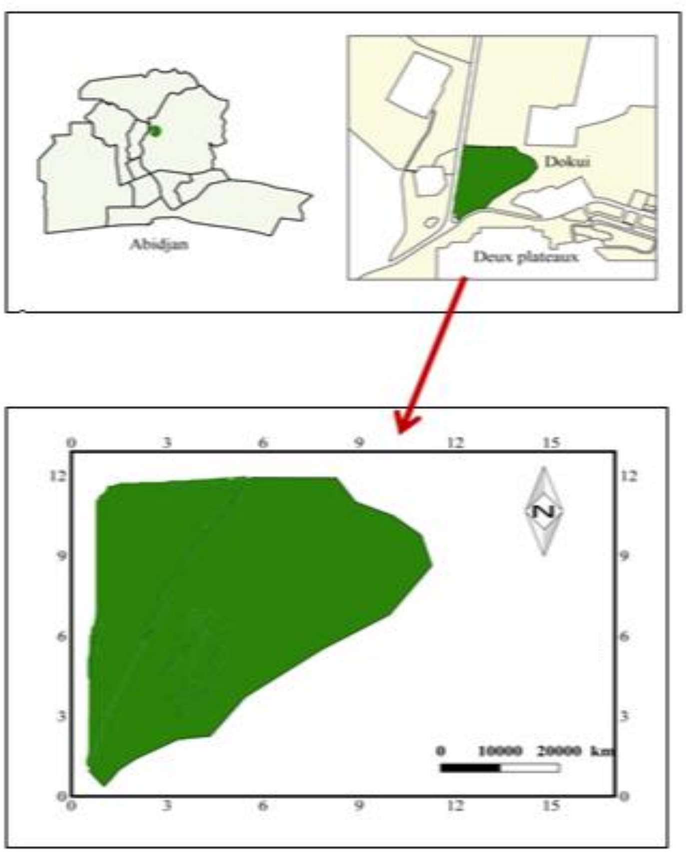

Figure 1 Location of the Forest of the National Zoo of Abidjan

selected plots within the National Zoo of Abidjan forest. In each plot, 100 m² areas (10 m x 10 m) were established along a 100 m line (Figure 3). All tree species with circumferences greater than or equal to 7.85 cm at breast height were inventoried within each plot. A 100-meter-long cord was stretched horizontally just above the ground for the linear survey. This setup allowed for 100 measurements to be taken at regular one-meter intervals. For each contact, the species and the distance from the starting point of the survey line were recorded. Additionally, each vegetation contact's minimum and maximum heights were measured using a vertically erected 4 m marker. Heights above 4 m were estimated following the method outlined by Gautier et al. (1994). A sample was taken for analysis for each contact. A total of three linear surveys were conducted in this study. The study area was divided into three zones: A, B, and C. Each survey zone was designated as Zone A, B, and C. This method enabled us to obtain the various surveys' structural profiles and vegetation cover. It has been previously used in studies by Chatelain (1996), Kouamé et al. (1998), and Bakayoko et al. (2001, 2004) in Côte d'Ivoire.

2.2 Structural data analysis

2.2.1 Diameter classes

The distribution of individuals by diameter class is commonly called "total structure" by foresters (Bouko et al. 2007). This concept provides insight into the demographic structure of wooded areas by using histograms that display the distribution of individuals across various diameter classes. To achieve this, we counted the number of individuals in each plot and then categorized them into different diameter classes. This classification enabled us to create distribution curves for the individuals.

2.2.2 Vegetation structure

We constructed structural profiles to understand how individuals are spatially distributed along the transect. This involves creating a graphical representation of all contacts recorded along the survey line. The x-axis represents the distance along the transect where these contacts were noted, while the y-axis indicates the height of the contacts. This method is useful for describing the horizontal structure of vegetation and how species are distributed along linear surveys. The survey's structural profiles highlighted abundant or characteristic species distribution within each survey (Chatelain 1996). These profiles allow us to assess the height of the vegetation in the surveys and evaluate their state of degradation (Kouamé 1998).

2.2.3 Vegetation cover

Vegetation cover refers to the area occupied by individuals of a species. According to Chatelain (1996), this is determined by projecting the crown width vertically onto the ground. In the current study, species cover is estimated as the percentage of contact points between the species and a vertically positioned milestone. Cover can be analyzed at two levels. At the species level, it is expressed by the frequency with which the species is encountered during the survey. From the perspective of vertical vegetation distribution, cover indicates the distribution of all species combined across defined height intervals, expressed as the percentage of contacts within those intervals. A cover histogram was created for each survey, and the cover was calculated using the formula developed by Menzies (2000).

$$\text{Cover (C)} = \frac{A}{B} \times 100$$

A : Number of points on the transect line on which a species is present.

B : Total number of measurement points on the transect.

In this study, cover measurement focused on noting the presence or absence of contact within specific height intervals at each point. The height intervals used were defined by Richards (1952), Kahn (1982), and Bongers et al. (1988). For each survey, we constructed a cover histogram. Following the approach of Chatelain (1996), Emberger et al. (1968), and Kouamé (1998), we categorized the height intervals as follows: 0 < height ≤ 4 m (lower tree stratum), 4 < height ≤ 16 m (upper tree stratum), 16 < height ≤ 32 m (emergent stratum), and height > 32 m (upper emergent stratum).

2.2.4 Number and width of gaps

To assess the state of vegetation degradation, we evaluated the width and number of gaps in the canopy (Kouamé 1998). The number of gaps is useful for determining the degree of openness at different height thresholds and understanding the dynamics and heterogeneity of the vegetation. According to Bakayoko (2005), the width and the number of gaps provide insights into the extent of openings observed in various surveys. Given the low canopy height in our plots, with a maximum vegetation height rarely exceeding 20 meters, we standardized our assessment by using 10 meters across all plots to ensure non-zero cover values (Bakayoko 2005). We could count the gaps by constructing a curve indicating maximum heights.

2.2.5 Vegetation State Assessment

According to Chatelain (1996), an analysis of the cover (Figure 2) by height class identified three types: A, B, and G. Each type corresponds to a specific plant formation. Type A represents less degraded environments, while Types B and G characterize degraded semi-deciduous forests, as outlined below.

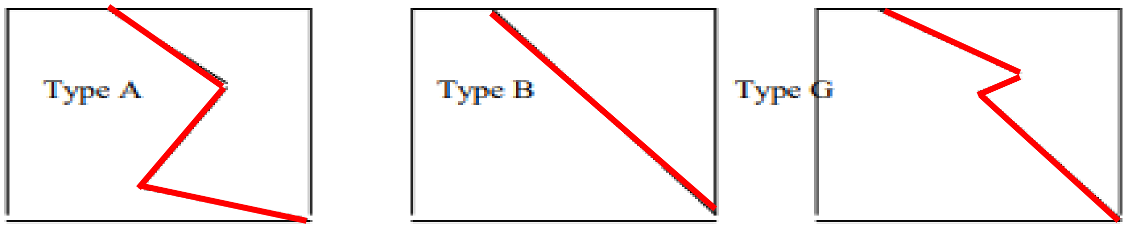

Figure 2 Vegetation condition based on cover type

2.3 Principal Component Analysis

Principal Component Analysis (PCA) is a method used to represent data in a reduced space, making it easier to analyze complex datasets. This technique is particularly common in ecology, where it helps to evaluate species distributions across multiple sites. The primary objective of PCA is to identify and highlight the main trends in the variability of these distributions. By reducing the data to lower dimensions, typically two-dimensional representations, PCA simplifies analysis and interpretation. This process allows researchers to determine which variables significantly contribute to forming the first two principal axes. Moreover, it facilitates the extraction of coordinates for the observations, particularly focusing on the variables that strongly influence those axes.

3 Results

3.1 Diameter class

The histogram illustrating the distribution of trees by diameter class reveals an inverted 'J' shape across the three studied plots (Figure 3). As the diameter increases, the number of individual trees decreases. In all three plots, the diameter class of 0-5 cm contains the highest number of individuals, representing the most abundant group of regenerating trees.

3.2 Cover and Structural profile

Figure 4 illustrates the cover and structural profiles of the three plots. The vegetation cover rate decreases progressively in a staircase manner, reaching the upper stratum at 32 meters across

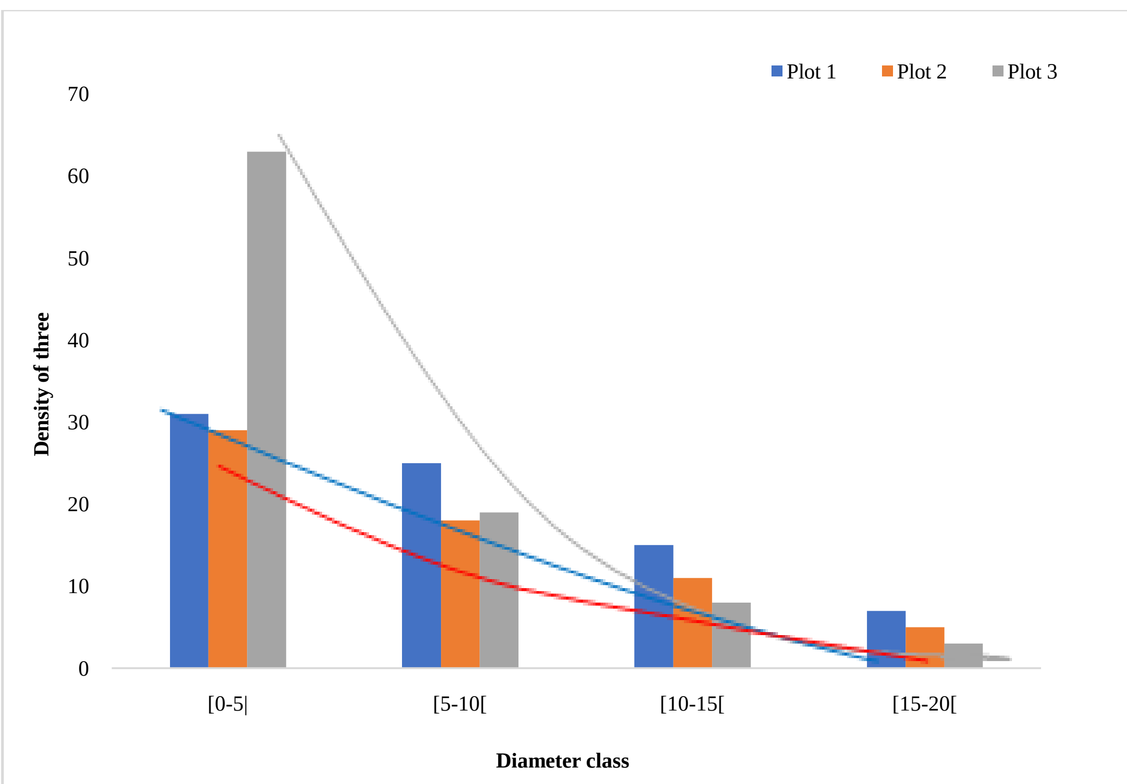

Figure 3 Distribution of stems by diameter class

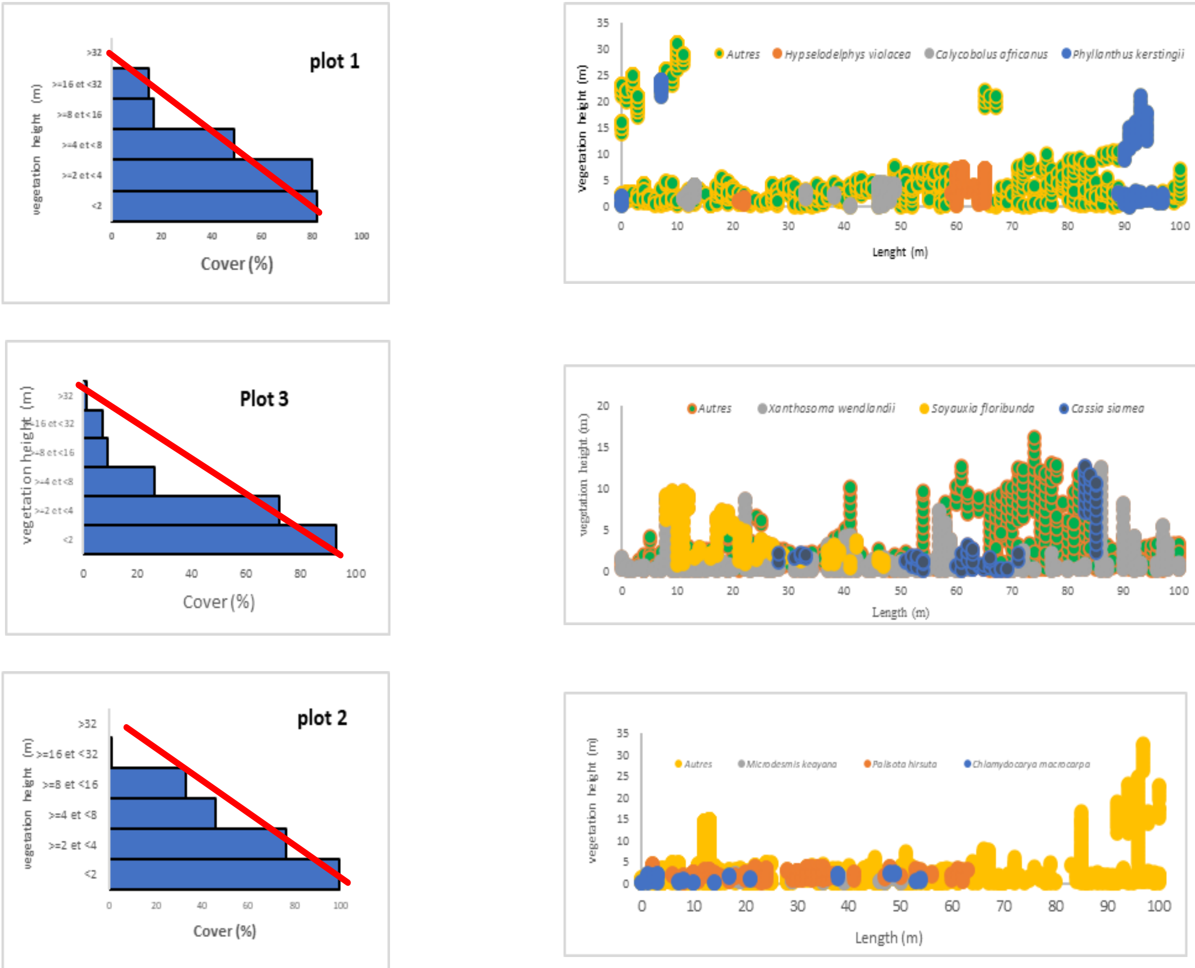

Figure 4 Cover and structural profiles of the vegetation in the three plots

all three zones. In zones A and C, recovery falls below 20% in the 16 to 32 m and 8 to 16 m strata. In contrast, zone B shows cover below 20% in the 8 to 16 m stratum but exceeds 30% in the 16 to 32 m stratum. In zones A and B, cover surpasses 40% in the 4 to 8 m stratum, whereas it remains below 40% in zone C. Overall, the spatial distribution of characteristic species varies significantly from one survey to another. Additionally, many openings and dense undergrowth are present. Regarding plot 1, the vegetation appears generally shorter and more heterogeneous, characterized by numerous openings. The structural profile of this plot is predominantly composed of species such as *Calycobolus africanus*, *Hypselodelphys violacea*, and *Phyllanthus kerstingii*. Species like *Xanthosoma wendlandii*, *Soyauxia floribunda*, and *Cassia siamea* primarily dominate plot 2. In Plot 3, the dominant species include *Chlamydocarya macrocarpa*, *Palisota hirsuta*, and *Microdesmis keayana*. Among these dominant species, *C. africanus*, *H. violacea*, and *C. macrocarpa* are categorized as lianas. *P. kerstingii*, *X. wendlandii*, and *P. hirsuta* are classified as nanophanerophytes, while *Cassia siamea* and *Microdesmis keayana* are considered microphanerophytes. Notably, *Soyauxia floribunda* is the only mesophanerophyte species observed among the recorded species.

3.3 Influence of structural parameters and canopy openness on the plots

We conducted a Principal Component Analysis (PCA) on the structural data. Figure 5 illustrates that the first two axes of the PCA account for 29.61% of the total variability. Specifically, Axis 1 explains 70.39% of this variability, with key contributing variables being the strata at depths of ≥ 16 m and < 32 m and those > 2 m. For Axis 2, the contributing variables include strata ≥ 32 m, those in the range of ≥ 2 and < 4 m, ≥ 8 and < 16 m, the width of gaps at 10 m, and the number of gaps at the height of 10 m. These variables explain 29.61% of the variability associated with this axis. Aside from the overlaps and structural profiles of plots 1 and 3, only the overlap and profile of plot 2 show a correlation with the number and width of gaps.

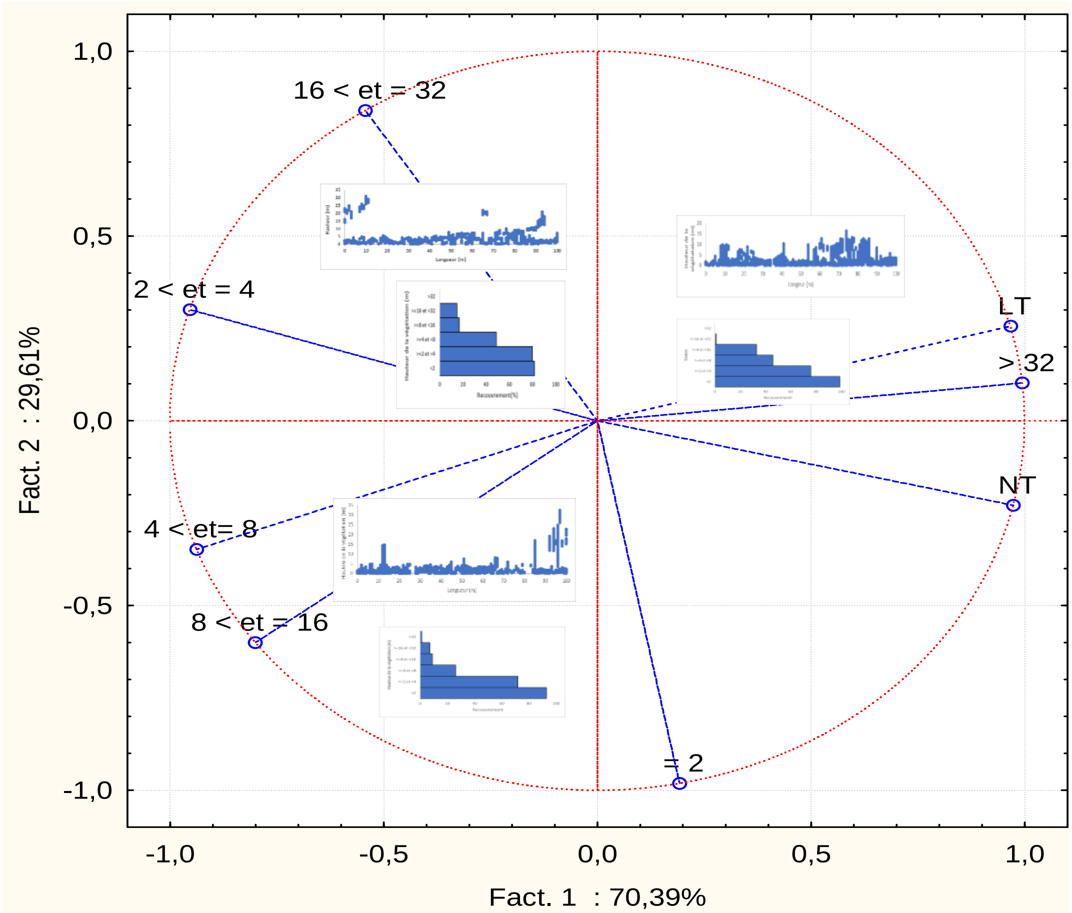

Figure 5 Principal Component Analysis of structural parameters and canopy openness for the surveys in the three plots

4 Discussion

In the forest of the National Zoo of Abidjan, the horizontal structure of the vegetation displays an inverted 'J' shape histogram for each plot. This indicates a strong representation of individuals with a diameter of 5 cm or more (Missa et al. 2023). Such a pattern suggests that in a stable natural environment, the number of individuals in a stand decreases regularly as one moves from smaller-diameter trees to larger ones. Senterre and Nguema (2001) demonstrated that this trend reflects a strong capacity for forest regeneration. Similarly, Adou-Yao et al. (2007) observed this pattern in Taï National Park, noting that the youngest and smallest-diameter trees are the most numerous among all species. This is characteristic of forests with good regeneration capacity (Nusbaumer et al. 2005). Structural profiles indicate a dominance of lianas and nanophanerophytes throughout the forest. These findings contrast with those of Bakayoko (2005), who reported a dominance of megaphanerophytes and mesophanerophytes. This discrepancy may be attributed to the different states of degradation of the study sites. The structural profiles also reveal a noticeable presence of numerous gaps, which aligns with the observations made by Kouamé (1998) regarding semi-deciduous humid dense forests. Kouamé et al. (1998) indicated that the numerous openings indicate anthropogenic activities by local communities. The percentage of cover in the lower strata is prevalent throughout the forest. Bamba (2004) and Bakayoko (2005) made similar observations in the large fragments of Banco National Park, stating that high percentages in the lower strata are indicators of degradation in these areas. These elevated percentages of cover at lower strata may stem from an abundance of understory species and the absence of individuals taller than 32 meters in the peripheral zone of the National Zoo Forest. Soro (2020) made similar observations, suggesting that the lack of large individuals may be due to delayed growth caused by anthropogenic actions affecting certain emergent species in these regions.

The examination of the forest covers indicates a similarity with Type B, as Chatelain (1996) described, which characterizes degraded semi-deciduous forests. This degradation of habitat structure may be attributed to human exploitation, which significantly impacts the forest's integrity (Missa et al. 2019). Such degradation is largely due to extensive incursions by farming communities into this forest area for harvesting and woodcutting (Gnahore 2021). The PCA analysis enabled us to categorize the three plots based on their level of degradation. Notably, Plot 2 is the most affected by human activities. The classification of vegetation degradation was based on canopy openness measured at 10 meters and other structural parameters, which served as a reference for evaluating the effects of degradation on various structural and floristic factors. Specifically, by counting the gaps intersected by a line drawn at a height of 10 meters and measuring their total width, we found that the vegetation in Plots 1 and 3 is the densest, while Plot 2 exhibits the most open vegetation.

Conclusion

The analysis of the degradation state of the forest at the National Zoo of Abidjan indicates a good representation of trees with a diameter of 5 cm or more, which is a sign of healthy regeneration capacity. However, the classified forest in this area is significantly degraded. The presence of numerous gaps in the structural profiles can be attributed to local communities' anthropogenic activities. The loss of this forest would lead to immeasurable damage to the region's biodiversity and microclimate. To protect it, it is essential to develop conservation policies to preserve floral biodiversity for the survival of all the ecosystems within the study area.

Conflict of interest

The authors declare no conflicts of interest

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