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Kinshasa Province (Democratic Republic of Congo): Typology of Peri-Urban Ecosystems Providing Edible Insects

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Abstract: Tropical peri-urban ecosystems are essential for the urban population's well-being through the goods and services they provide. Unfortunately, these ecosystems are subjected to anthropogenic pressures for various reasons. This study aims to assess the diversity and structure of the peri-urban ecosystems that provide the most edible insects in Kinshasa. A total of 360 people were interviewed to identify the two insect species most frequently consumed. The tree inventory was carried out in 50 plots (2500 m^2 each), of which 25 were in *Acacia* plantations, 10 were planted *Milletia* forests, and 15 were natural *Millettia* forests. The diameters of each tree, dbh $\geq$ 10 cm, were measured. Principal component analysis (PCA) was used to distinguish the forest communities. Diversity indices were used to assess floristic variability and structural parameters were used to characterize forest stands. Two insects were identified as being the most commonly consumed in Kinshasa: *Gonimbrasia jamesoni* (28%) and *Cirina forda* (27%), found the in *Acacia* plantation, and in the planted *Milletia* forests and natural *Milletti* forest, respectively. The results indicate floristic (higher in the *Acacia* plantation) and structural variability between stands. The structure of the stands indicates good news for all forests, except the planted forest. The high frequency/dominance of *A. auriculiformis* and *M. laurentii* in the peri-urban ecosystems of Kinshasa would therefore be optimal conditions (under natural conditions) for good production of these two caterpillar species.

Keywords: *Acacia auriculiformis*; *Millettia laurentii*; diversity and structure; peri-urban ecosystem; Kinshasa province; edible insects

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1. Introduction

Natural peri-urban ecosystems in the tropics contribute to the well-being of urban populations through the goods and services they provide. Unfortunately, in recent decades, these ecosystems have been subjected to anthropogenic pressures for a variety of reasons, thereby considerably altering their structure and jeopardizing their sustainability [1].

For instance, in 2000, the total area of degraded forests and woodlands in 77 tropical countries was estimated at around 800 million hectares (40%), including 500 million hectares (25%) of primary and secondary forests [2]. In Africa, the annual deforestation rate is 50% [3]. This situation has been exacerbated by the widespread adoption of unsustainable development models, which have led to substantial and irreversible losses of biological diversity. Around 60% of ecosystem services identified in the 2005 Millennium Ecosystem Assessment have been degraded or used unsustainably [4,5].

In humid tropical Africa, peri-urban forest ecosystems represent diverse and structured habitats. They display spatial floristic heterogeneity, which is expressed to a large extent by continuous changes in floristic composition and/or species stand structure at local and regional scales [6]. Within this floristic and structural heterogeneity, certain preferential arrangements are easily distinguishable, for example, clusters of specific biological types, clusters of trees in certain topographic or physiographic positions, and even clusters of species due to particular biotopes [6]. Several studies have attempted to explain the causes of this plant diversity, by taking into account factors such as climate, soil, and species temperament [7]. Other research carried out in the tropics has highlighted the influence of soil properties on the spatial distribution of species [8]. Today, sensitive natural peri-urban ecosystems such as forest patches, which are essential for influencing climate change as carbon sinks, require knowledge of their characteristics for their sustainable management.

In particular, wooded green spaces are valuable for their multiple ecosystem services, which include regulating water flows and urban climates, reducing noise levels, and providing nutritional services [9–13].

Although studies on shrubs and trees in urbanized areas are beginning to emerge in developing countries, the literature generally highlights the need for greater knowledge about wooded green spaces [10,14,15], particularly on aspects relating to their improved management [16]. However, wooded green spaces are present in both peri-urban and urban areas, depending on the ecological context of the region and the history of the urban planning process [12], which is the case in Kinshasa, the capital of the Democratic Republic of Congo (DRC).

In the specific case of the province of Kinshasa, the ecosystems are subjected to the same disturbances that have led to their extinction. These ecosystems are used as storage reservoirs for basic vital needs while serving as drains for solid and biological waste. They are therefore more likely to be exploited and misused. This situation is exacerbated by rapid urbanization [17]. Thus, land use and land cover change in African cities are reducing the cover of green spaces [17–19].

The phytosociological approach, based on the analysis of floristic or structural data, or a combination of the two, would make it possible to identify several types of factors explaining the heterogeneity of tropical rainforests. However, certain ecological factors (mode of dissemination, ecological barrier, type of substrate, microclimate, etc.) are considered to have a major influence on the structure and composition of stands at different scales [7,8].

The general objective of this study is to contribute to the sustainable management of urban biodiversity in Kinshasa in the context of strong urbanization.

Specifically, the aim is to (i) identify the two (2) species of insects most commonly consumed in Kinshasa; (ii) assess the diversity and structure of plant formations providing the insects most commonly consumed in Kinshasa; (iii) establish correlations between the dendrometric parameters studied.

2. Material and Methods

2.1. Presentation of the Study Framework

The Kinshasa Province covers an area of 9965 km^2 [18]. It extends along the southern bank of the "Pool Malebo" and constitutes a huge crescent covering a flat, low-lying area with an average altitude of about 300 m. Located between 4° and 5° south latitude and between 15° and 16°32′ east longitude, the Kinshasa Province is bordered to the east by the provinces of Mai-Ndombe, Kwilu, and Kwango, to the west and north by the Congo River, forming the natural border with the Republic of Congo, and to the south by the province of Kongo Central (Figure 1).

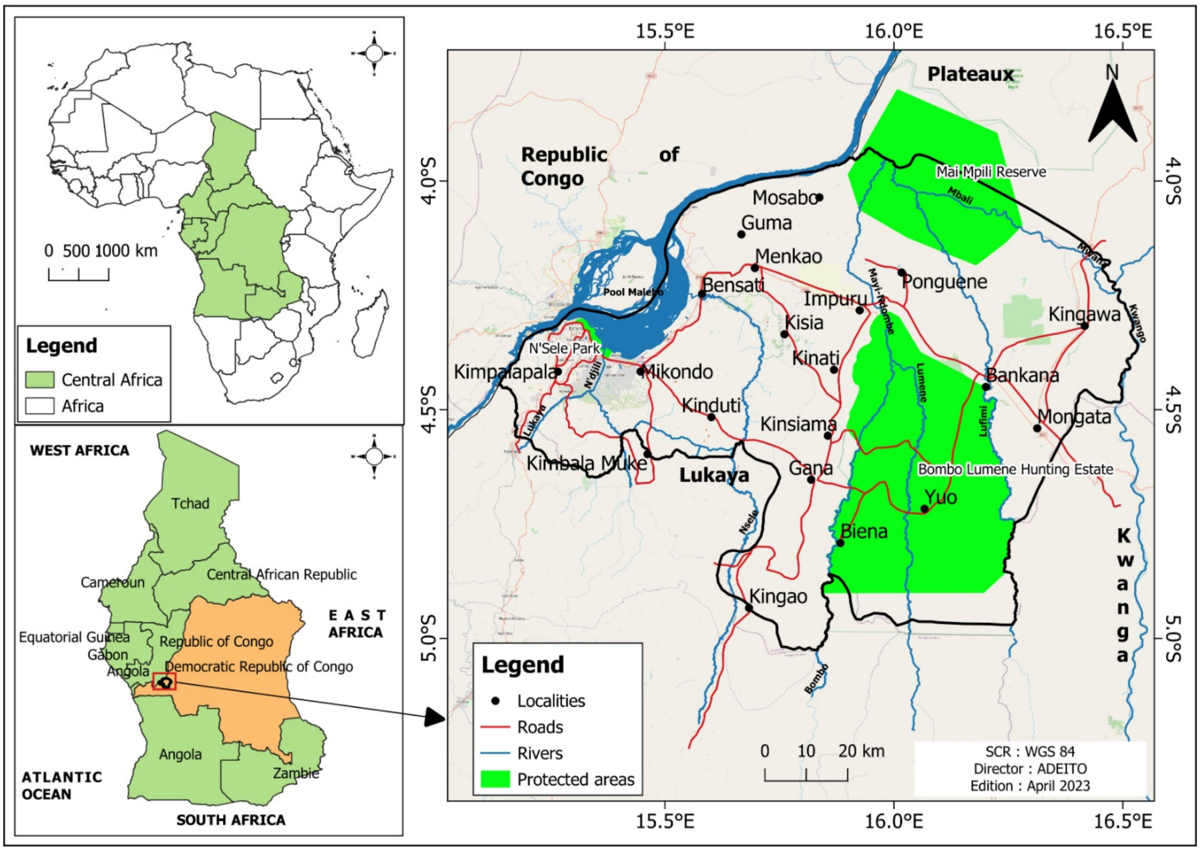

Figure 1. Location of the Kinshasa Province in the DRC (with the 4 surveyed communes and the 3 tree inventory sites) and the situation in Central Africa and Africa.

The population has grown strongly and continuously since its inception. This population growth should be seen in the global context of unprecedented urban population growth [19].

The climate is tropical, hot, and humid. The average annual temperature is 25 °C and the average annual rainfall is 1400 mm, with an average of 112 rainy days per year, peaking in April with 18 rainy days [20].

The vegetation, which in the past consisted of gallery forests in the wet valleys of the Guineo-Congolese ombrophile-type and grassy formations, is characterized by pre-forest fallows that have been severely degraded and intensively exploited in the form of forest rejects of various ages. In addition, a small group of typically ruderal vegetation can be found along a strip of railway track a few meters wide [21].

2.2. Site Sampling and Data Collection

Concerning ethnobotanical and ethnoentomological surveys, the first stage of the work consisted of identifying four communes (Mont Ngafula, Kasa-Vubu, Masina, and Maluku) based on the culture of the local populations with regard to the consumption of insects, the geographical position, accessibility, and frequency of supply of edible insects.

Based on this choice, the second stage of the work was devoted to pre-surveys carried out on a sample of four well-targeted respondents (non-timber forest products (NTFPs) depot manager, head of household, restaurant manager, and head of the environment department) per commune, i.e., 16 respondents aged 45 or over, with at least 25 years of service/residence in the commune.

The third stage of the work involved surveys of a sample of 360 people, using a pre-established questionnaire. These included 30 heads of household, 30 restaurant managers, and 30 edible insect sellers per commune. The respondents identified were 45 years of age or older and had been in the profession for at least 10 years and lived in the area for at least

20 years. The information sought is notably the names (vernacular or scientific/glossary of insects) of the most commonly consumed insects, their periods of appearance, their places of origin (province/city), their types of habitats (plant formations), etc.

The inventories (floristic, ecological, and forestry) were carried out simultaneously in the *Acacia* plantations, *Millettia* plantations, and *Millettia* natural forest on 50 plots of 50 m × 50 m, i.e., 2500 m^2. These include 25 plots in the *Acacia* plantation, 10 plots in the *Millettia* planted forest, and 15 plots in the *Millettia* natural forest. These different numbers of plots inventoried per formation result from the sampling rate.

In each area, the circumference of all tree stems with Diameter at Breast Height (dbh) $\geq$ 10 cm was measured using a tape measure. Species were identified based on the edge (color, smell), the characteristics of the bark, the leaves, and possibly the flowers and fruits of the trees surveyed.

For the *Millettia* formations, following a large difference in dbh between the individuals and the search for a source plant, the location of the plots was chosen based on the criterion of locating in the center of each plot a sufficiently fruiting *M. laurentii* plant isolated at a minimum distance of 75 m from the others, at dbh $\geq$ 90 cm. An herbarium was made and systematically contained more or less two specimens per species. Botanical determination was carried out at the Laboratory of Ecology and Forest Management (LECAFOR) and the Herbarium of the University of Kisangani (UNIKIS) for problem species. The Flora (Volume I to V) of [22], the criteria described by [23], and the general characteristics of the architecture were used for the determination. For the *Millettia* formations, following a high difference in dbh between the individuals and the search for a mother plant, the location of the plots was chosen based on the criterion of locating in the center of each plot a sufficiently fruiting *M. laurentii* plant isolated at a minimum distance of 75 m from the others, at dbh $\geq$ 90 cm (Figure 2). The heterogeneity of the *Acacia* plantation was the only criterion for location plots.

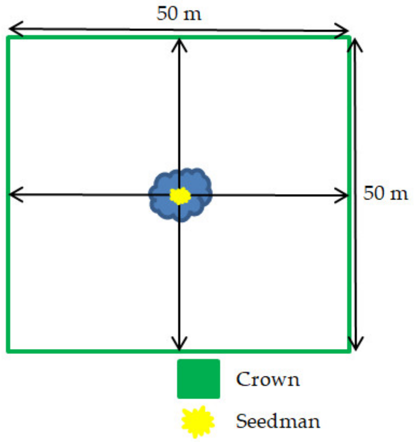

Figure 2. Experimental setup for collecting inventory data.

Data Analysis

The survey data were entered into the Excel spreadsheet and then processed with the R software, which made it possible to discriminate between the two insect species most consumed in Kinshasa, their periods of appearance, their places of origin or supply, their habitat types, and other related information [24]. Principal component analysis (PCA) on an abundance table crossing “plots × species” of floristic data was carried out to determine the main structuring axes and thus provide a good approximation of the response of species to an environmental factor [25]. To determine the dominant species for each formation, the Importance Value Index (*IVI*) was calculated. This index represents for each species I the sum of its relative density (DR), its relative dominance (DoR), and its relative frequency (FR).

This index varies between 0 and 300; it allows species to be ranked in order of ecological importance [26]. This index was evaluated using the formula below.

$$IVI_{(i)} = \mathrm{DR}_{(\mathrm{i})} + \mathrm{DoR}_{(\mathrm{i})} + \mathrm{FR}_{(\mathrm{i})}$$

The diversity index (H') of [27] was calculated for each forest stand to assess the heterogeneity and diversity of a biotope using the following formula:

$$H' = -\sum\left(\frac{ni}{N}\right) \times \ln\left(\frac{ni}{N}\right)$$

where ni is the number of individuals of a species i and N is the total number of individuals of all species in the biotope.

To measure the species diversity, the [28] index was used. This index was calculated by the following formula:

$$D = 1 - \left(\frac{\sum n_i(n_i - 1)}{N(N-1)}\right)$$

where ni is the frequency of species I, N is the sum of the frequencies of all species in the sample, and D is the Simpson's index.

Fisher's alpha diversity index (α) has been calculated to compare the diversity of different forest stands in an ecosystem. This index has the advantage of being insensitive to the sampling method and only requires knowledge of the total number of individuals and species in a forest community [29]. It was calculated from the following relationship:

$$S = \alpha \ln(1 + \frac{N}{\alpha})$$

where α represents Fisher's alpha diversity, N is the number of individuals, and S is the number of species.

To better discuss the Shannon index, it is often accompanied by the Piélou index (J) or the equitability index (E) [30]. Its formula corresponds to the ratio between H' and $Hmax$. This index, therefore, varies between 0 and 1.

$$E = \frac{H\prime}{Hmax}$$

These indices are the most widely used for the study of tropical vegetation diversity [31].

The basal area (G) was calculated for each individual [32] by plot and then by forest formation according to the following formula:

$$G = \frac{\pi}{4} D^2$$

where G is the basal area and D is the diameter at 1.30 m above ground level.

For some structural parameters (density, basal area, biomass, etc.), the box plot (x) or whisker box was used. This box shows the first and third quartiles as well as the median, which is shown as a line inside the box; the whiskers show the minimum and maximum values. If there are outliers or 'outliers', these will be shown above the maximum.

Above-ground biomass (AGB) was determined from an allometric equation applicable to plant species in Congo Basin forests [33]. The equation considered in the present study uses two sets of input data, the dbh and wood density.

$$\mathrm{AGB}_{\mathrm{est}} = \mathrm{esp}\ [0.046 + 1.156 \times \log(\mathrm{WSG}) + 1.123 \times \log(\mathrm{D}) + 0.436 \times (\log(\mathrm{D}))^2 - 0.045 \times (\log(\mathrm{D}))^3]$$

The international database (Dryad) provides species-specific wood densities by geographical area [34]. However, there is a lack of information on the wood density of many African species. Genus-wide wood density can be estimated from the average wood density of the species of the component species [35]. Thus, the wood density of the species was averaged at the level of each genus. For genera without densities in the database, the average value of all genera for the site was assigned.

In general, the density (φ) of wood is predicted from the species (CTFS Wood Density; http://www.fao.org/docrep/w4095e/w4095e0c.htm, accessed on 21 December 2022). If the surveyed trees are not identified or if the surveyed species does not have a known density, a strategy for replacing missing values is needed. Usually, this strategy is either taxonomic (use of incomplete taxonomic information: genus, family, etc.) or local (wood densities of nearby trees).

To test the differences in biomass between the data of the studied forest stands, one-way analyses of variance were used. The difference is significant between the data if the *p*-value is less than 0.05. For the parameter that was tested, the *p*-value was given.

It should also be noted that ecological survey data related to abiotic, biotic, and edaphic factors were combined to observe certain interactions and their impacts on the functioning of the ecosystems under study.

3. Results

3.1. Entomophagic Assessment in Kinshasa

In the Kinshasa Province, survey data revealed the most consumed and traded insect species. Mainly nine (9) species of insects from peri-urban ecosystems are the most traded. These are *Gonimbrasia jamesoni* (Druce), *Cirina forda* (Westwood), *Brachytrupes membranaceus* (Drury), *Macrotermes bellicosus* (Smeathman), *Cymothoe caenis* (Drury), *Imbrasia obscura* (Butler), *Bunaea alcinoe* (Stoll), *Tettigonia viridissima* (Linnaeus), and *Rhynchophorus ferrugineus* (Olivier). Of the species traded, two are the most commonly consumed, namely *G. jamesoni* (28%) and *Cirina forda* (27%) (Figure 3).

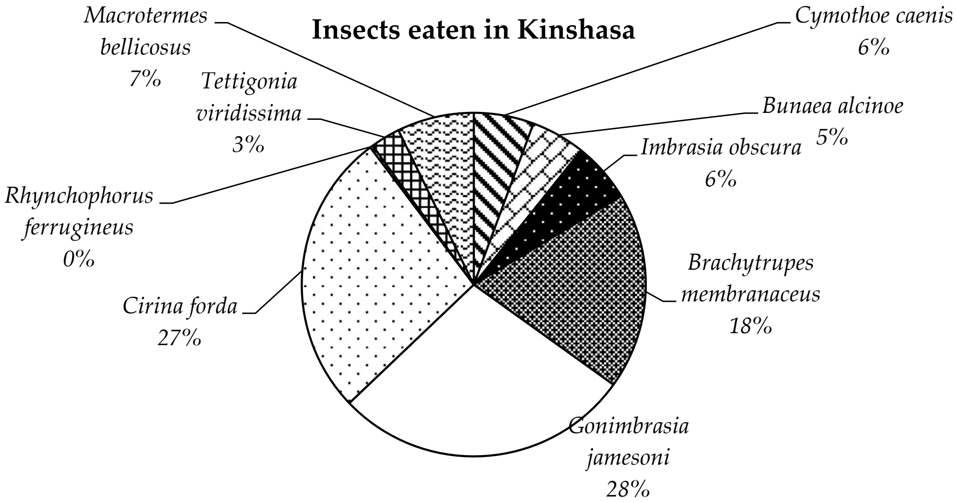

Figure 3. Species of insects consumed and traded in the Kinshasa Province.

The most consumed insects come from five peripheral localities of the Kinshasa Province. The province of Grand Bandundu is the main supply point (37%), followed by Grand Bas-Congo (21%) then Grand Equateur (19%), Tshopo province (13%), 8% exclusively in the outskirts of Kinshasa, and 2% from undetermined areas (Figure 4a). The plant formations that provide edible insects are *Acacia* plantation (55%), *Millettia* planted forest (29%), and *Millettia* natural forest (16%) (Figure 4b). These plant formations are dominated, respectively, by *A. auriculiformis* and *M. laurentii.*

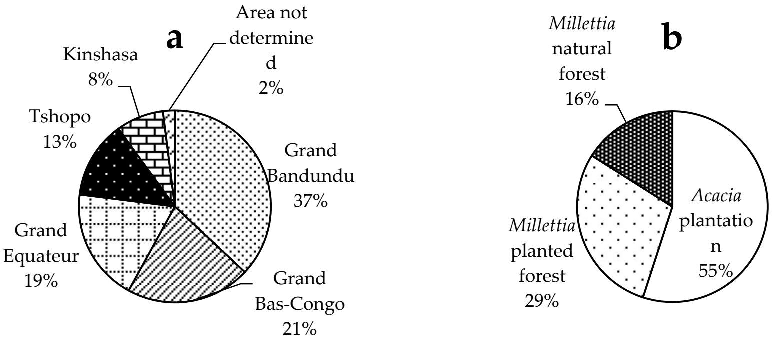

Figure 4. Origin of the 2 most consumed insect species in DRC (**a**) and their plant formation providers in Kinshasa (**b**).

3.2. Structure of Forest Stands

3.2.1. Typology of Identified Forest Stands

Following PCA, three forests stand out. These are the *Acacia* plantation, *Millettia* planted forest, and *Millettia* natural forest (Figure 5).

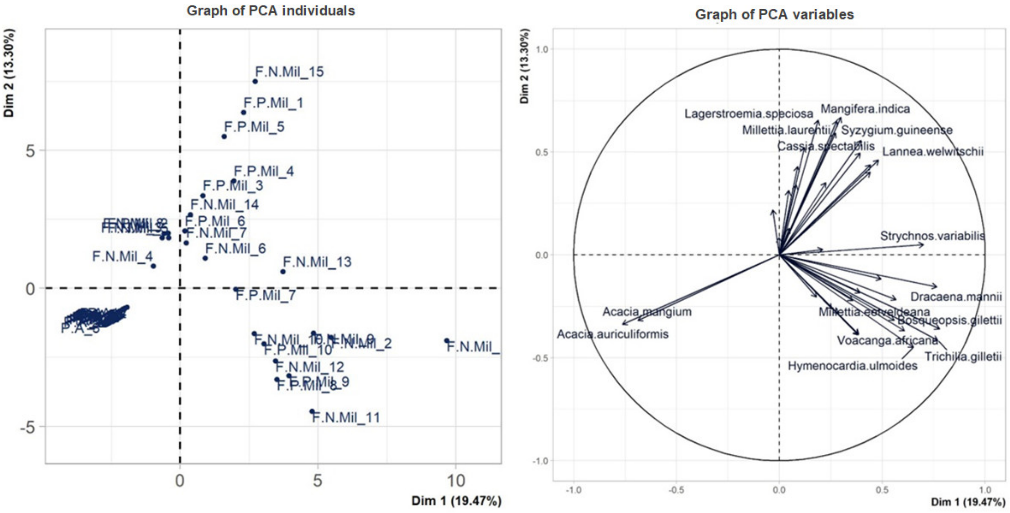

Figure 5. PCA ordination of the studied forest formations (individuals and variables). Legend. P.A: *Acacia* Plantation, F.P.Mil: *Millettia* Planted Forest, and F.N.Mil: *Millettia* Natural Forest.

The stand of *Acacia* plantations (class 1) is characterized by:

- high values for the variables *A. auriculiformis* and *A. mangium* (from the most extreme to the least extreme);
- low values for variables such as *M. laurentii*, *Oncoba welwitschii*, *Lannea welwitschii*, *Cassia spectabilis*, *Dracaena mannii*, *Markhamia tomentosa*, *Strychnos variabilis*, *Voacanga africana*, *M. eetveldeana,* and *Bosqueopsis gilettii* (from the most extreme to least extreme).

The stand of *Millettia* plantation (class 2) is characterized by:

- high values for variables such as *M. laurentii*, *C. spectabilis*, *O. welwitschii*, *Vitex welwitschii*, *Mangifera indica*, *V. congolensis*, *L. welwitschii*, *Persea americana*, *Lagerstroemia speciosa*, and *Delonix regia* (from the most extreme to the least extreme).
- low values for the variables *A. auriculiformis* and *A. mangium* (from the most extreme to least extreme).

The natural forest stands with *Millettia* (class 3) are characterized by:

- high values for variables such as *V. africana*, *Bosqueopsis gilettii*, *Trichilia gilletii*, *M. eetveldeana*, *Hymenocardia ulmoides*, *Dracaena mannii*, *Psydrax palma*, *M. drastica*, *Macaranga monandra*, and *Gaertnera paniculata* (from the most extreme to least extreme).

- low values for the variables *A. auriculiformis* and *A. mangium* (from the most extreme to least extreme).

The hierarchical tree can be drawn on the factor map with the individuals colored according to their people. Figure 6 shows the greater floristic similarity of group 2 (*Acacia* plantation) and group 3 (*Millettia* plantation) than group 1 (natural forest).

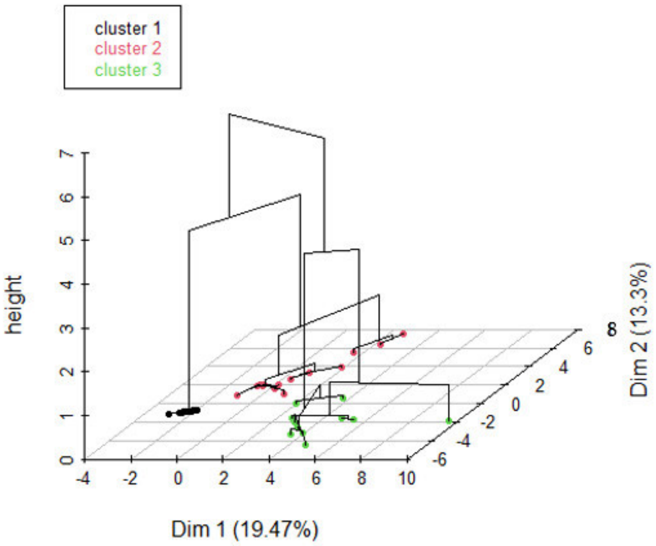

Figure 6. Hierarchical tree on the factorial plan according to the floristic compositions per plot.

3.2.2. Floristic Report

A total of 4320 individuals were inventoried, of which 2906 were in the *Acacia* plantation, 508 in the *Millettia* planted forest, and 906 in the *Millettia* natural forest. These were distributed, respectively, in 2, 37, and 31 species, according to the previous order of forest formations under study. The most important species according to the IVI are *A. auriculiformis* (188.30), *M. laurentii* (93.04), and *M. laurentii* (92.96) in *Acacia* plantations, *Millettia* plantations, and natural *Millettia* forests, respectively (Table 1).

Table 1. The five best-represented species in the different forest formations under study.

		P.A		
Species Name	AbRel (N/ha)	DoRel (m^2/ha)	FR (%)	IVI
Acacia auriculiformis	73.63	64.66	50	188.30
Acacia mangium	26.37	35.34	50	111.70
		F.P.Mil		
Millettia laurentii	35.43	48.09	9.52	93.04
Oncoba welwitschii	12.80	3.50	8.57	24.86
Dracaena mannii	6.50	12.79	4.76	24.05
Millettia eetveldeana	5.71	4.87	3.81	14.38
Anthocleista schweinfurthii	6.50	1.38	5.71	13.59
		F.N.Mil		
Millettia laurentii	41.50	41.97	9.49	92.96
Dracaena mannii	9.60	13.98	6.33	29.91
Oncoba welwitschii	7.06	2.44	7.59	17.10
Trichilia gilletii	3.86	6.24	5.06	15.16
Millettia drastica	4.64	6.18	3.80	14.61

Legend. AbRel = Relative Abundance, DoRel = Relative Dominance, FR = Relative Frequency, IVI = Significant Value Index, P.A: *Acacia* Plantation, F.N.Mil: Natural Forest at *Millettia*, F.P.Mil: Planted Forest in *Millettia*.

The most representative family in terms of species is Fabaceae, at 100%, 42%, and 51% in the *Acacia* plantation, *Millettia* planted forest, and *Millettia* natural forest, respectively (Figure 7).

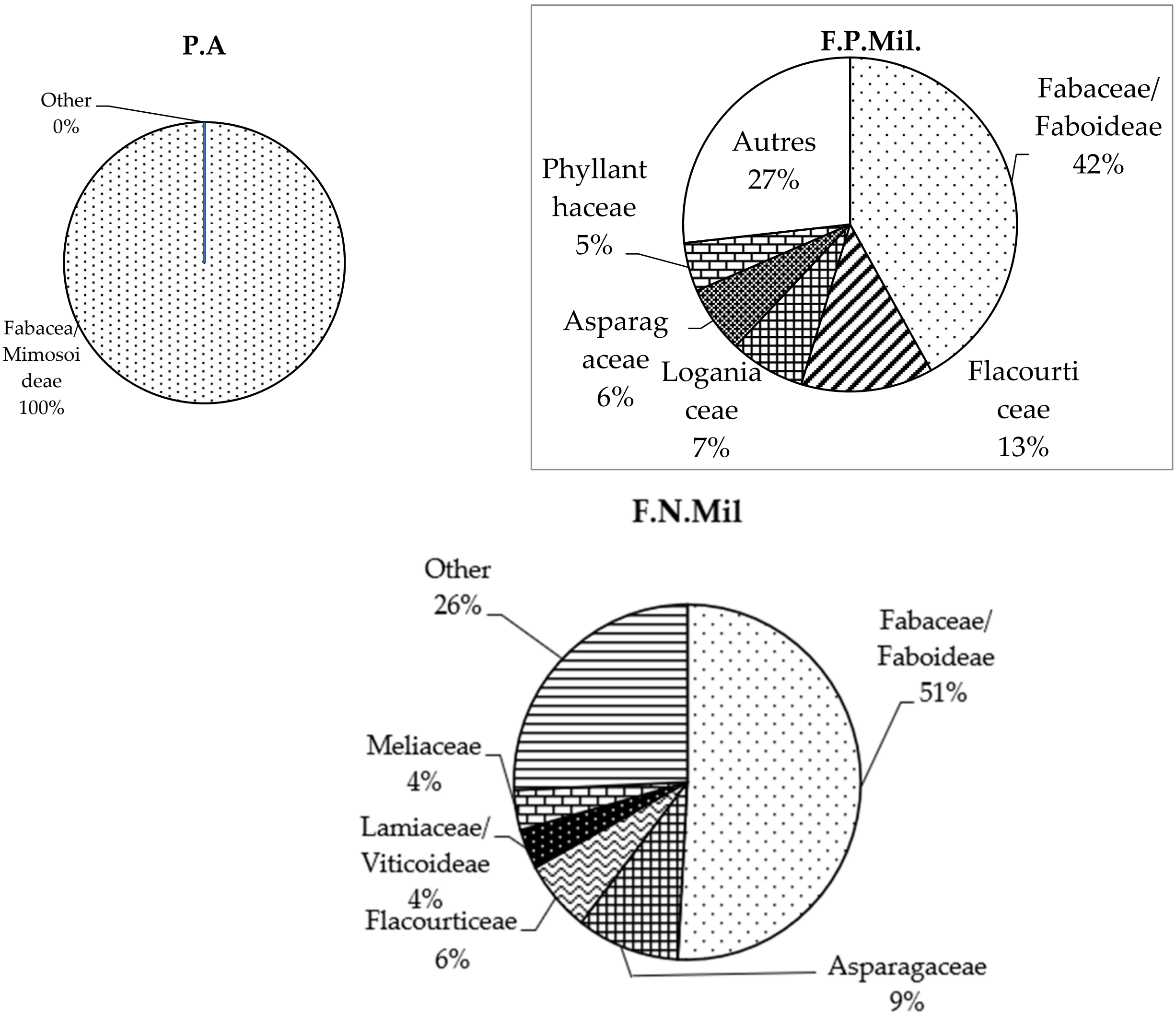

Figure 7. The five families best represented in the forest stands studied. Legend. P.A: *Acacia* Plantation, F.P.Mil: *Millettia* Planted Forest, and F.N.Mil: *Millettia* Natural Forest.

The indices calculated for each of the formations studied show, spatially speaking, a high specific diversity, except for the *Acacia* plantations (Table 2). The highest diversity is observed in the *Millettia* planted forest (0.76) and the lowest in the *Acacia* plantations (0.37). *Millettia* forests (planted and natural) have relatively similar diversity indices.

Table 2. Diversity indices were calculated for each forestry training course under study.

F.F	Ha	N.Ind.	N.S	N.Genera	N.Family	H'	D	S	Eq
P.A	6.25	2905	2.0	1.0	1.0	0.54	0.37	0.35	0.79
F.P.Mil	6.0	507	31.0	31.0	20.0	1.82	0.76	4.27	0.78
F.N.Mil	2.5	905	37.0	39.0	23.0	1.72	0.69	4.04	0.74

Legend. F.F: Forest Training; Ha: Hectare; N. Ind: Number of individuals; N.S: Number of species; H': Shannon's diversity index; D: Simpson's diversity index; S: Fisher's alpha diversity index (α); Eq: Equitability Index; P.A: *Acacia* Plantation, F.P.Mil: *Millettia* Planted Forest, and F.N.Mil: *Millettia* Natural Forest.

3.2.3. Structural Characteristics of Forest Stands Identified

a. Density and basal area

The average densities and land areas obtained within the forest stands were 116 trees/ha, 203 trees/ha, and 242 trees/ha and 10.68 m^2/ha, 22.00 m^2/ha, and 22.36 m^2/ha, respectively, in the *Acacia* plantation, *Millettia* plantations, and *Millettia* natural forests. The difference in density and basal area was not significant between the forest stands identified (W = 0.90358, *p*-value = 0.3955 for density and W = 0.91981, *p*-value = 0.504 for basal area). In addition, the dispersion of density and basal area values for each stand studied shows high variability in density and the basal area within plots of the same stand and from one stand to another in the study area (Figure 8a,b).

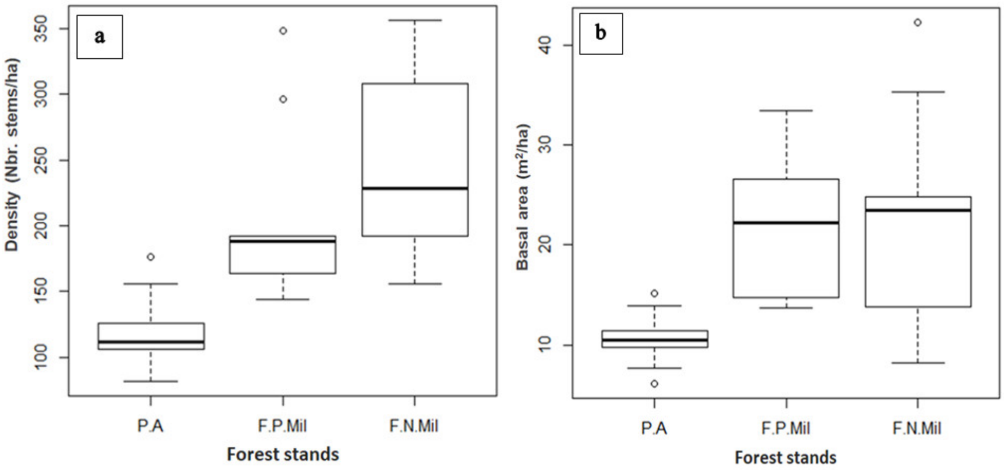

Figure 8. Density dispersion: (**a**) and basal area dispersion (**b**) of the forest stands studied. Legend. P.A: *Acacia*'s Plantation, F.P.Mil: *Millettia*'s Planted, F.N.Mil: *Millettia*'s Natural Forest.

b. Diametric structure

Taking into account the variation in the density of individuals in relation to the diameter classes in the forest formations studied, this density of individuals decreases as the number of diameter classes increases, with a shift observed in classes two and four in *Millettia*'s natural forest and *Millettia*'s planted forest, respectively (Figure 9).

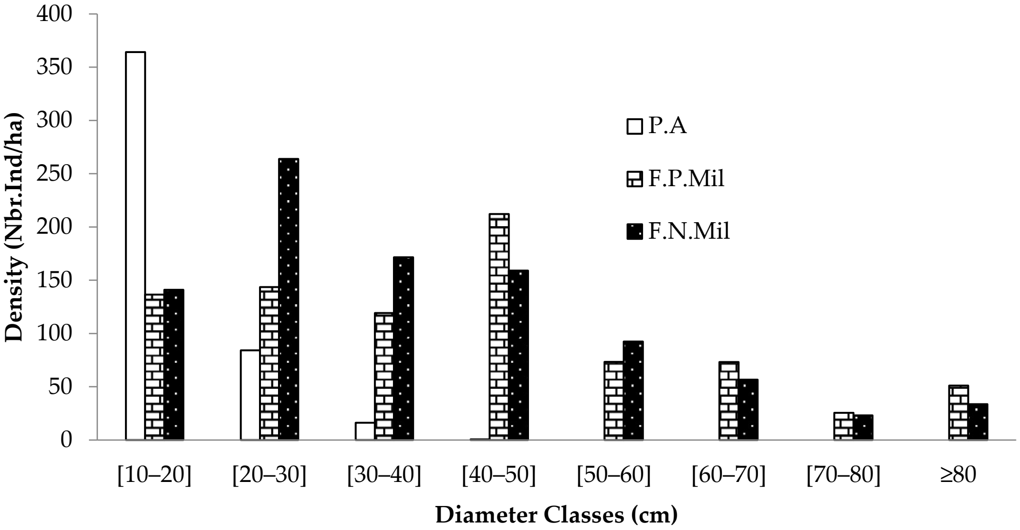

Figure 9. Distribution of tree stem density by diameter class in the studied forest stands. Legend. P.A: *Acacia* Plantation, F.P.Mil: *Millettia* Planted forest, F.N.Mil: *Millettia* Natural Forest.

c. Biomass estimation

The estimated above-ground biomass varies from stand to stand. The estimated average is 110.99 ± 13.55 t/ha in the *Acacia* plantation, 156.85 ± 37.19 t/ha in the planted *Millettia* forest, and 208.46 ± 43.03 t/ha in the natural *Millettia* forest. The statistical analysis shows a non-significant difference between the values of the different stands identified (W = 0.87792, *p*-value = 0.2597).

However, in each stand identified, some biomass values seem to deviate from the average. This shows the variability of biomass within the same forest stand and between the different stands studied in these peri-urban areas (Figure 10).

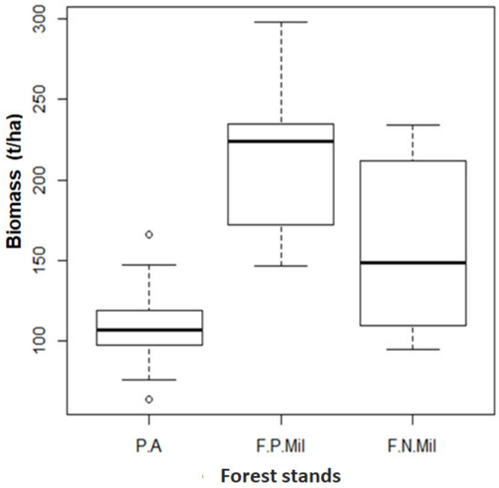

Figure 10. Dispersion of above-ground biomass in the studied forest stands. Legend. P.A: *Acacia* Plantation; F.P.Mil: *Millettia* Forest planted; F.N.Mil: *Millettia* Natural Forest.

✓ Biomass distribution in the different plant strata of forest formations

The distribution of above-ground biomass in the different diameter classes shows a variation. In the three forest formations studied, biomass decreases with increasing diameter, except in *Millettia* forests, where classes 1, 2, and 3 do not respect this principle (Figure 11).

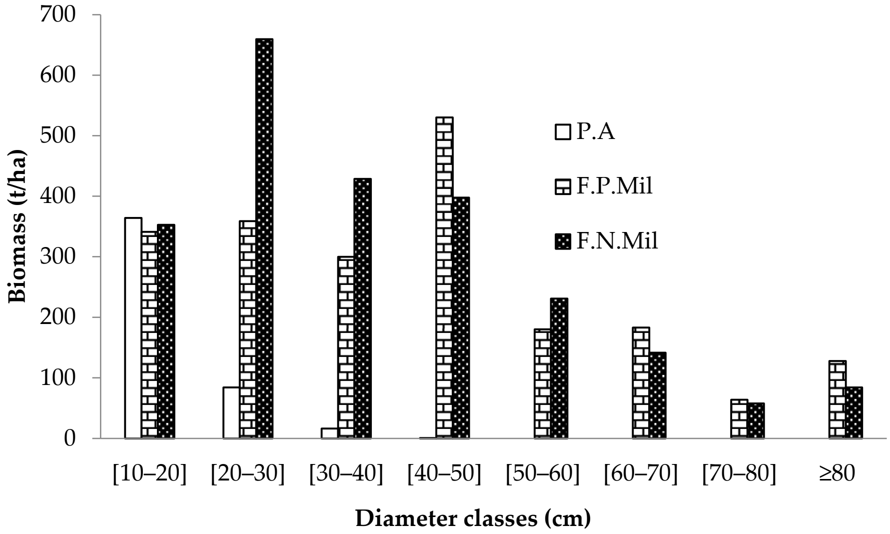

Figure 11. Biomass variation by diameter classes in the studied forest stands. Legend. P.A: *Acacia* Plantation, F.P.Mil: *Millettia* Forest planted, F.N.Mil: *Millettia* Natural Forest.

The distribution of biomass in the different plant strata shows a dominance of small-diameter stems (Figure 12).

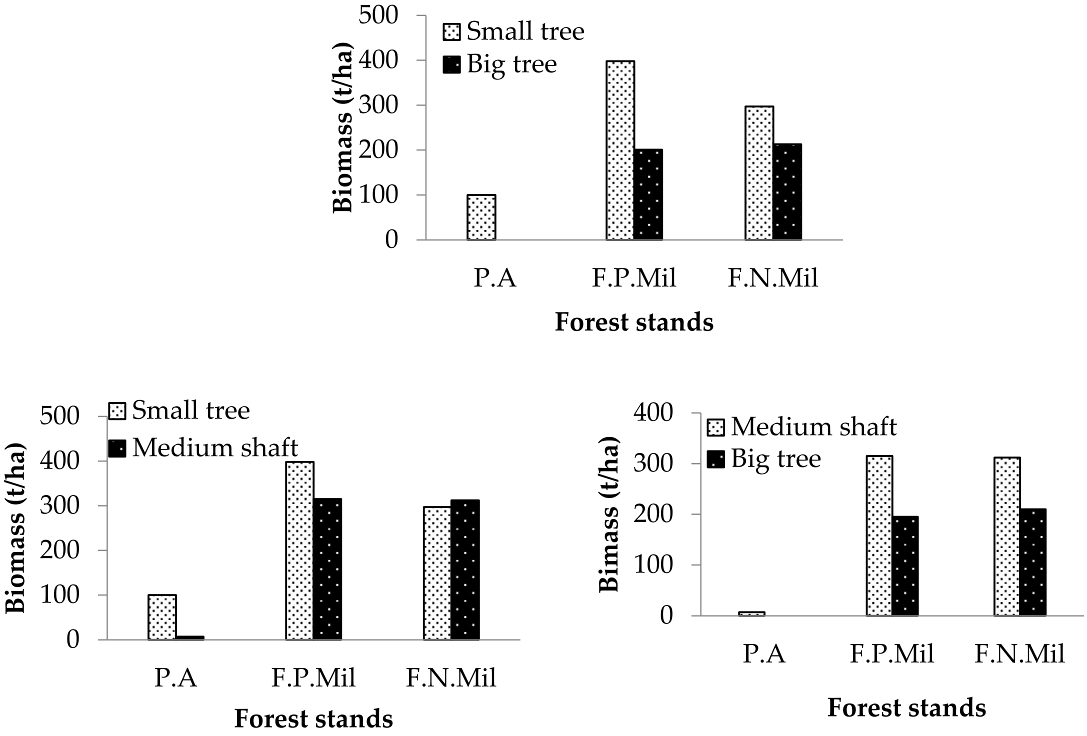

Figure 12. Biomass distribution in the strata of the studied forest stands. Legend. P.A: *Acacia* Plantation, F.P.Mil: *Millettia* Planted Forest and F.N.Mil: *Millettia* Natural Forest.

3.3. Correlation Studies

By taking into consideration the basal area, above-ground biomass, species richness, and density of forest stands, various correlations are identified. The correlation varies according to the pair of parameters considered. The correlation between basal area and species richness is positive and significant in natural *Millettia* forests (r^2 = 0.421 and p = 0.008). In contrast, there was no correlation in the *Acacia* plantations (Figure 13).

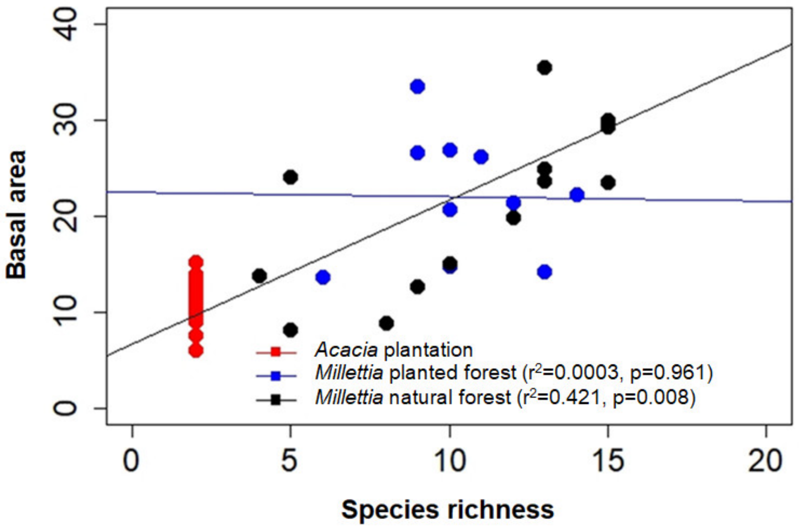

Figure 13. Correlation between basal area and species richness of the studied forest stands.

The correlation between biomass and species richness was positive but not significant in natural *Millettia* forests (r^2 = 0.071 and p = 0.0339) and no correlation was found in *Acacia* plantations (Figure 14).

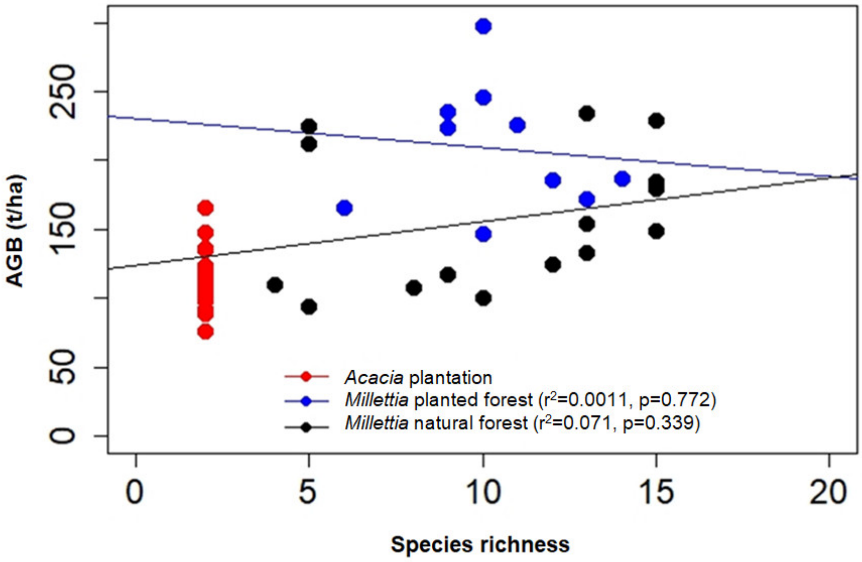

Figure 14. Correlation between biomass and species richness of forest stands studied.

Furthermore, the correlation between biomass and density was positive and significant in *Acacia* plantations (r^2 = 0.927 and $p < 0.05$) and in *Millettia* plantations (r^2 = 0.721 and p = 0.002) (Figure 15).

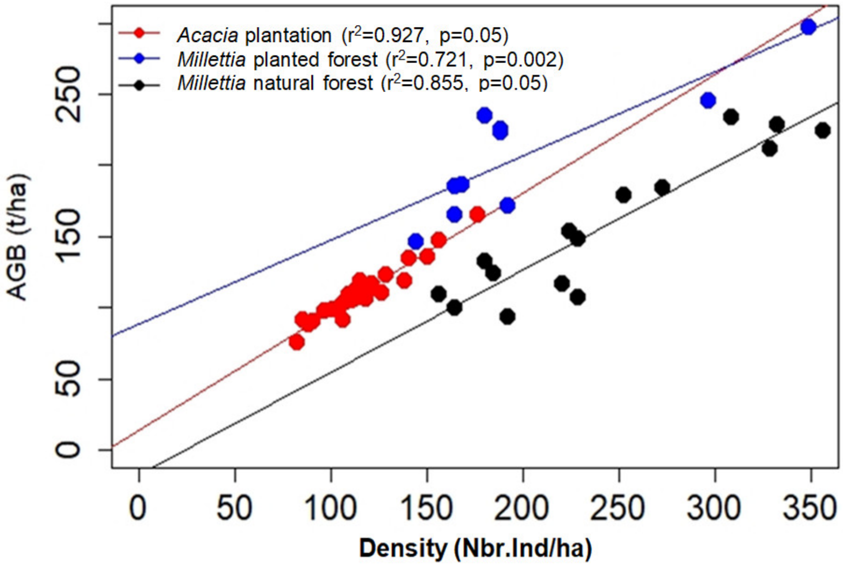

Figure 15. Correlation between biomass and density of studied forest stands.

Finally, the correlation between biomass and basal area was positive and significant in *Acacia* plantations (r^2 = 0.809 and $p < 0.05$) and positive and low in *Millettia* plantations (r^2 = 0.526 and p = 0.018) (Figure 16).

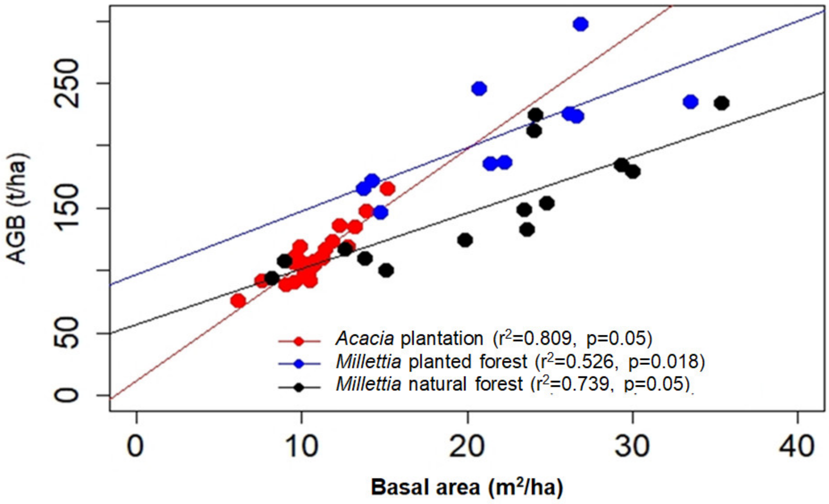

Figure 16. Correlation between biomass and basal area of studied forest stands.

4. Discussions

4.1. Supply of Consumed Insects to the Province of Kinshasa and Hyper-Entomophagy in Kinshasa

This study has confirmed that a large number of insect species are edible in Kinshasa. Studies [36–38] have cited numerous species of Termitidae (Isoptera), caterpillars of the Lepidoptera families (mainly Attacidae and Notodontidae), and other families belonging to the orders of insects consumed in DRC. For these authors, several species are consumed in both rural and urban areas. This is consistent with the results obtained, which share a similar geographical area and similar environmental conditions.

The Province of Kinshasa, the country's main city, is supplied with food and other forest products (wood and non-wood) by its peri-urban areas. As a result, the availability of edible insects is more or less assured throughout the year (at least 10 months/year), although in the respective provinces, the biomass and availability of insects can vary significantly due to different climatic conditions [38]. According [37], to supply the Province of Kinshasa, more than 95% of insect sellers in Kinshasa obtain their supplies mainly from other stakeholders (wholesalers from the outlying provinces or producers in peri-urban areas) due to different climatic conditions and plant species diversity. These results are in line with those of [37,38], who also specify the commercial circuit in relation to this sector. For this author, the Province of Kinshasa obtains a large proportion of its edible insects from the provinces and a small proportion from the outskirts of Kinshasa.

4.2. Floristic and Structural Variability in Forest Stands

The present study shows a high specific and family diversity in the natural *Millettia* stand compared to the *Acacia* and *Millettia* plantations. Many researchers have found higher values in terms of species and families, respectively, in the forest stands of Isangi [13], in the mainland forest of Mbiye Island in DR Congo [39], and in the Odzana National Park of Brazzaville in Congo [40].

These differ in the results obtained. This difference in results would be due to the difference in surface areas considered during the inventories, to the geographical position of each study area (in relation to a conurbation), but also to the degrees and forms of anthropogenic pressure exerted on the different stands compared. This confirms findings made by [31] in the open forests in Togo (West Africa), showing that these types of stands are subject to strong anthropization and deserve special attention.

The IVI of the present study shows a dominance of *A. auriculiformis* in the *Acacia* plantation and *M. laurentii* in the *Millettia* stands, inducing a family dominance of Fabaceae for all the formations under study. The abundance/dominance and frequency of *A. auriculiformis* and *M. laurentii* would be a key prerequisite for the production of *Gonimbrasia jamesoni* and *Cirina forda*, respectively, in the plant formations under study. This condition would therefore require the establishment of plantations dominated by *A. auriculiformis* and *M. laurentii* in order to maximize the production of these caterpillar species in the area. In addition, this uniformity of the dominant family in all the formations would be due to the dominance of two species (*A. auriculiformis* and *M. laurentii*, sometimes by human choice), both belonging to the Fabaceae family. In DRC, in the forest of Isangi territory, ref. [13] found a dominance of Fabaceae over Meliaceae, Malvaceae, and Euphorbiaceae. In Ivory Coast, Nusbaumer showed that the dominant family in their study was Fabaceae. On the other hand, in the ecosystems of the city of Lubumbashi (RDC), the data from forest inventories carried out in the two ecosystems made it possible to identify 931 individuals, including 610 in clear forest and 321 in wooded savannah, divided into 55 species belonging to 23 families [41]. Generally, the species diversity of a forest formation varies with the area and type of stand considered. On a local scale and in monodominant forests, this diversity is lower than on a large scale and in heterogeneous or mixed forests. Forests that are richer at the specific level are also richer at the family level [42]. Nevertheless, within the same forest stand, ecological factors (edaphic, anthropogenic, and certain natural barriers) often induce variability in the floristic composition. This is regularly noticeable along a transect crossing, often contrasting edaphic environments.

For this study, the highest diversity was observed in the forest planted with *Millettia* and the lowest in the *Acacia* plantation. This would be due to the fact that in the *Acacia* plantation, there is only one stratum (absence of undergrowth), but also to the criterion of the choice of individuals to be planted (anthropogenic force/plantation), hence the dominance of *A. auriculiformis*. The high diversity in the planted forest would be due to a highly diversified collection at the time of planting. Climate disturbance, windthrow, and anthropic pressure in this formation would also be at the basis of this floristic richness induced by the differentiation of the forest stands in the study. This result is supported by that of [43], suggesting that this diversity is due to the ecological spectra.

According to ref. [42], the densities of trees of at least 10 cm dbh vary between 300 and 800 trees/ha in tropical forests. For the present study, the average density in different stands is lower than the average and below those observed in the Guinean–Congolese area [37]. The density averages obtained in plots of the same forest formation also vary. This shows the variability of the density within the same formation and between the different formations under study. This variation in density and basal area between plots of the same formation and between plots of different formations would be mainly due to anthropogenic pressures (cutting of wood, etc.), thus causing heterogeneity in the number of tree stands and their basal areas, a reality similar to the settlements of Isangi [13] and of Kisangani in DRC [44] and of Atakpamé in Togo [45].

The basal area average of individuals with dbh $\geq$ 10 cm in the natural *Millettia* forest is slightly higher than that of the planted *Millettia* forest and twice that of the *Acacia* plantation. This strong difference to the *Acacia* plantation would be due to the presence only of *A. auriculiformis* and *A. magium*, characterized by the absence of large trees of dbh $\geq$ 40 cm. The basal area of tree strata (dbh $\geq$ 10–30 cm) in tropical forests is between 27 and 32 m^2/ha [40,43,44]. It generally increases from lower strata to superior strata. In the different formations studied, except for the *Acacia* plantation, the basal area of trees with a dbh between 10 and 30 cm is relatively the same proportion as that of trees above 30 cm. This shows that the *Millettia* stands studied would recover well if they were not disturbed by certain human activities (encroachment of seedlings, grazing by ruminants, cutting of bald wood or lumber).

The diametric structure in our stands shows that small-diameter individuals are much more numerous overall for all stands. These distributions are generally in the shape of an "inverted J", which is common in natural tropical forests [13], except for the forest planted with *Millettia,* where the distribution of individuals is bell-shaped. The abundance of medium-diameter stems (class 4) for the *Millettia* forest could be explained by the presence of a more favorable ecological gradient for this stand.

4.3. Basal Area-Specific Richness, Biomass-Specific Richness, Biomass Density, Biomass and Basal Area

Overall, the correlation between all parameters studied is positive in the natural forest and zero in the *Acacia* plantation. This could be justified by the age difference between the stands under study (*Acacia* plantation, *Millettia* forest planted, and *Millettia* natural forest) and the influence of man on the establishment of the latter, but also by the proximity of these stands to dwellings and the lake of respect for nature conservation standards and principles, which do not favor their perfect evolution.

This result corroborates that of Mavunda, who found a positive correlation between biomass and species richness, biomass and density, and biomass and basal area in Isangi forest stands. Similar to the findings of [46], aboveground tree biomass is correlated with basal area, but also root mean square diameter. This similarity between the results of the present study and those of Torti and Fousséni is due to the similarity of the parameters that were taken into account to establish the correlations. On the other hand, as shown by Mavunda, the aboveground biomass of trees was strongly correlated with large-diameter trees (DBH > 60 cm). Similarly, Lewis found that the relationship between tree dbh quantiles and floristic groups clearly shows that large trees are highly significantly correlated with floristic axes. The largest trees were strongly correlated with NSCA 2 (Non-symmetric Correspondence Analysis), indicating a high number of largest-diameter trees in *J. seretii*-dominated forests in the dominant stands of the Kisangani region. This contradiction between the results of the present study and those of [47,48] would be due to the stage of evolution of the forest formations in relation to the results (evolving versus mature forest or climax), but also to the choice of location of the plots (a reference to the feet of trees versus random location) and the position of these forest formations in relation to agglomerations (peri-urban versus forest or rural zone).

In the formations studied, in particular the planted *Millettia* forest and the natural *Millettia* forest, the biomass has relatively similar values, at 156.85 t/ha and 208.46 t/ha, respectively. The biomass of the *Acacia* plantation, 110.99 t/ha, contrasts with that of the *Millettia* formations, indicating strong human action in this stand. Apart from *Acacia* plantations, these values are within the range of estimates from studies by [43] in a tropical rainforest in Cameroon, which reported biomasses ranging from 126 to 250 t/ha, and significantly lower than the values found by [13] in the Isangi forest in the DRC. This significant difference is due to the allometric equations used in these studies but also to the proximity to the distances separating these formations from the agglomerations (favoring anthropogenic pressure on the forests). Indeed, the study by [41,42] uses the local equation integrating diameter, height, and specific gravity with a diameter distribution between 1 and 71 cm, which could underestimate large trees. In the present study, the equation used does not include height, which could also create overestimates.

5. Conclusions

This study, which focuses on "Peri-urban ecosystems in the province of Kinshasa (DR Congo): diversity and structure of plant formations", aims to assess the diversity and structure of plant formations in the peri-urban ecosystems in the Province of Kinshasa. This evaluation was preceded by a preliminary study of the preference for edible insects among the population of Kinshasa. Thus, the most commonly consumed species are *Gonimbrasia jamesoni* and *Cirina forda*. These insects come from the greater Bandundu, the greater Bas-Congo, greater Equateur (19%), and Tshopo province (13%), with 8% originating exclusively in the outskirts of Kinshasa and 2% from undetermined areas.

Three forest stands were identified: *Acacia* plantation, *Millettia* planted forest, and natural *Millettia* forest. Floristically, the most important species according to the IVI are *A. auriculiformis* in the *Acacia* plantations and *M. laurentii* in the *Millettia* planted forest and the natural *Millettia* forest. The highest diversity is observed in the *Millettia* planted forest. The highest average density and basal area are observed in the *Millettia* natural forest stand. The diameter structures show overall good forest recovery in all of the stands. The average above-ground biomass is higher in the natural *Millettia* forest. The correlation between the parameters is positive and higher in the *Millettia* natural forest for most of the cases of the correlations established in each stand studied.

The results show that the *Acacia* plantation has a strong potential for high production of *G. jamesoni*, depending on the availability of food (leaves of *A. auriculiformis*).

The high frequency/dominance of *A. auriculiformis* and *M. laurentii* in the peri-urban ecosystems of Kinshasa would therefore provide optimal conditions (under natural conditions) for good production of these two caterpillars' species, which are the most widely consumed.

The results of this study will enable managers and planners to achieve rational and sustainable management of the various urban ecosystems.

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