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Influence of Spatial Distribution on the Regeneration of *Piptadeniastrum africanum* and *Ocotea usambaernsis* in Kalikuku, Lubero, North Kivu, Democratic Republic of Congo

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Abstract

The aim of our study is to highlight the spatial structure of the trees and to determine its influence on the natural regeneration of the Kalikuku dense forest, with a view of its optimal conservation and enhancement. Data collection was done by measuring diameter at breast height along 10 plots of 0.5 ha in size. In analyzing these data, the Dajoz test was used to determine the horizontal spatial distribution pattern of the two most abundant tree species in the forest (*Piptadeniastrum africanum* and *Ocotea usambarensis*). The χ^2 test was used to compare the frequency distribution of diameter classes for the two species tested. To estimate the difference between the number of seedlings in aggregate versus non-aggregate areas, the Wilcoxon signed-rank test was used. In addition, the equability index was used to test the preponderance of proportions between diameter classes. Finally, the natural regeneration index was evaluated.

Keywords

Spatial Distribution, Natural Regeneration, Seedlings, Diameter Class

1. Introduction

In a forest, the spatial structure of the trees depends on their density and horizontal distribution, which can be random, aggregated or uniform [1] [2]. Natural regeneration is achieved by vegetative propagation through offshoots from existing stumps and by germination of seeds from mature trees [3].

[4] shows that spatial structure and natural regeneration of trees are intimately linked and play an important role in forest dynamics. In addition, human disturbances affect the spatial structure and natural regeneration of trees.

Regeneration is therefore the basis of the dynamic and demographic balance of plant populations, ensuring the renewal of individuals and the sustainability of species [5].

These are the uncontrolled removal of forest resources, extensive agriculture and forest fires that [6] and [7] consider being the most harmful given the frequency and extent that they affect in a short period of period.

The present study focuses on the dense forest of Kalikuku Reserve, which has enjoyed "protected area" (Nature Reserve) status since 1952 [8].

As this forest is surrounded by the villages of Vwandanze, Kimbulu and the agglomeration of Lubero, the local populations cannot help but illegally harvest the various forest resources they need. Its conservation is thus compromised. In development and sustainable management of natural forest ecosystems and the Kalikuku dense forest in particular, this study is therefore necessary.

The central hypothesis to be tested in this research is that the spatial distribution pattern of the trees influences the natural regeneration of Kalikuku dense forest.

The aim of this study is multiple. The main purpose is to determine the density of trees in the Kalikuku dense forest, to analyze their horizontal spatial distribution, to show the effect of the spatial pattern found on the number of seedlings and to evaluate the state of natural regeneration of the main tree species, in this case the first two most abundant tree species in this forest.

2. Methods

2.1. Study Site

Geographically, the Kalikuku Forest Reserve is located 7 km from the chief town of Lubero Territory, Baswagha Chiefdom, Lubero Territory, North Kivu Province in the Democratic Republic of Congo. It extends to the West on the Butembo - Goma road, in the Luongo Grouping with an updated surface area of 89 ha, Diversity Components: Richness = 4 Evenness = 0.21 (**Figure 1** [9] [10] [11]).

Like Lubero and its surroundings, this reserve is between 29˚30' Longitude East, 00˚30' Latitude South, with an altitude varying between 1830 m and 2000 m, thus forming part of the highlands of Lubero territory [12].

The dense forest of Kalikuku enjoys a tropical climate of Af type [13]. It covers an area of approximately 89 ha spread over a hilly terrain whose highest peak reaches 2000 m. The soils of the Beni-Lubero region are derived from the bedrock that is mostly clayey. It appears from this work that the soils of the highlands

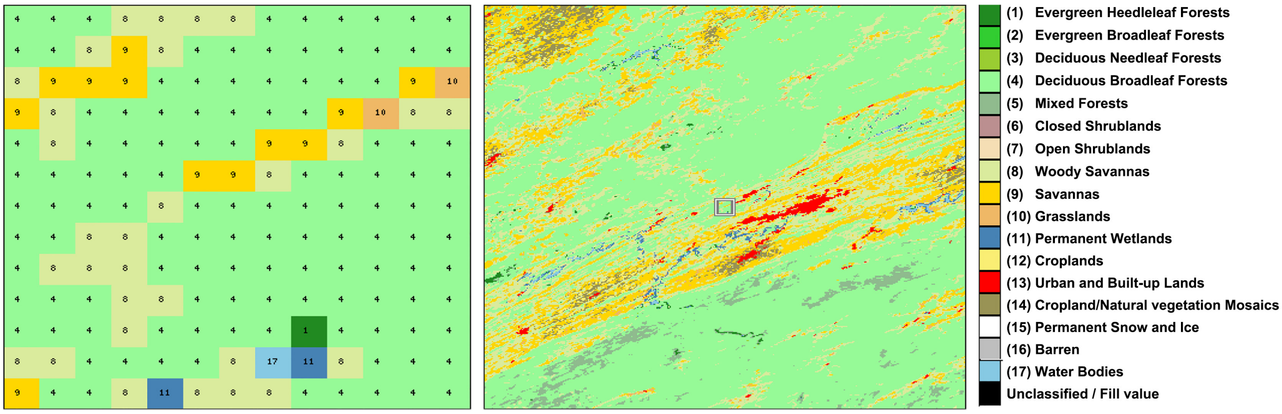

Figure 1. Kalikuku forest reserve.

in the extreme of North Kivu are essentially clayey and weakly ferritic, crystalline terrains of the Lower Cambrian [14].

These different streams are: Kalikuku, Lusimi, Makanga, Kyamasamba, Kihuko, Mupa, and Vwandanzi stream. The average annual rainfall is 1750 mm [15].

2.2. Sampling Method

To establish the list of tree species and their density in Kalikuku dense forest, data collection was carried out by measuring diameter at breast height (dhp). However, only data with dhp ≥ 10 cm [16] were kept for further analysis under [17]. These measurements were made along 10 plots spread over a 2000 m long layon through the forest in agreement with [18]. The width of a plot is 20 m while the length was 250 m. For each plot, counts of seedlings (dhp < 10 cm) of each of the more abundant tree species were also made in aggregate (A) and non-aggregate (B) areas. Next, we counted the number of tree seedlings in all plots for the respective species.

Thus, the seedling count was conducted in these two plots to have paired or matched samples. The identification of tree species was based on the nomenclature of [19].

2.3. Data Analysis Method

In terms of the horizontal spatial distribution of trees, [1] [2] distinguish three horizontal spatial models: the random horizontal spatial model when, given the location of an individual, the probability that another individual will be found in its vicinity is unaffected; the aggregated horizontal spatial model when this probability is increased; and the uniform horizontal spatial model when this probability is reduced. In this study, the horizontal spatial distribution model of the trees was tested and confirmed by the method of [20] (Da) adapted to small samples. This test was applied based on the number of trees counted on an equal inventory area for all 10 plots (10 = pn). Further analysis was given by the values of $\lambda = 2\ \sigma/\text{m}$; 2 σ being the variance and m the arithmetic mean. With a uniform distribution, $\lambda < 1$; in a random distribution $\lambda \approx 1$; and in an aggregated distribution, $\lambda > 1$.

The value of λ varies, for a probability rate, between confidence limits that are a function of the number of samples *np*. The deviation from unity of λ is significant for $\alpha = 0.05$ where Da > β (in this case, Da = $\lambda - 1$ and $\beta = 2\sqrt{(2 \times np) \times (np-1) - 1} = 0.9$).

The effect of aggregates on the number of seedlings was determined using the Wilcoxon signed-rank test (W) [21]. This test is most appropriate for comparing paired or paired numbers in this case, the numbers of tree seedlings counted in aggregate and non-aggregate areas of the same transect.

Regeneration status was determined by analyzing the diametric distribution of individual trees into diameter classes according to the [16] rule. To test this state, the equitability index (R) and the χ^2 test were applied [21] [22] [23]. The value of R is given by the formula below [Equation (1)]:

$$R = H/H_{\max} \tag{1}$$

where H corresponds to the Shannon-Weaver diversity index (observed diversity)

$H_{\max}$ corresponds to the theoretical maximum diversity calculated assuming frequency of biological traits.

Finally, the value of the natural regeneration index (Rn) was determined by the ratio of the proportion of seedlings (dhp < 10 cm) to other three individuals (dhp ≥ 10 cm). According to [24], if the value of this index is less than unity, the population is in deficit; if it is greater than or equal to unity; the population is balanced, *i.e.*, in terms of the distribution of tree individuals in diameter classes, the numbers continue to decrease as one moves from the lower to the higher diameter class.

3. Results

Figure 2 illustrates the evolution of NDVI, EVI and LST of day and night in Kalikuku reserve from 2000 to 2021 dominated by a woody savanna.

3.1. Analysis of Tree Species Density in Kalikuku Dense Forest

In Kalikuku Dense Forest, 2169 individual trees of 30 species were identified. **Table 1** and **Figure 3** present the list and density of these identified species. The average density of trees in Kalikuku dense forest is 541 feet/ha. The two most represented species are *Piptadeniastrum africanum* and *Ocotea usambarensis*, whose relative abundance is 20.3% and 17% respectively, with a density of 439 and 311 trees/ha, respectively.

3.2. Analysis of the Horizontal Spatial Distribution Pattern of Trees

Table 2 shows the number of individual trees for each of the three most abundant species on the same 0.5 ha inventory area in the 10 plots surveyed. It also

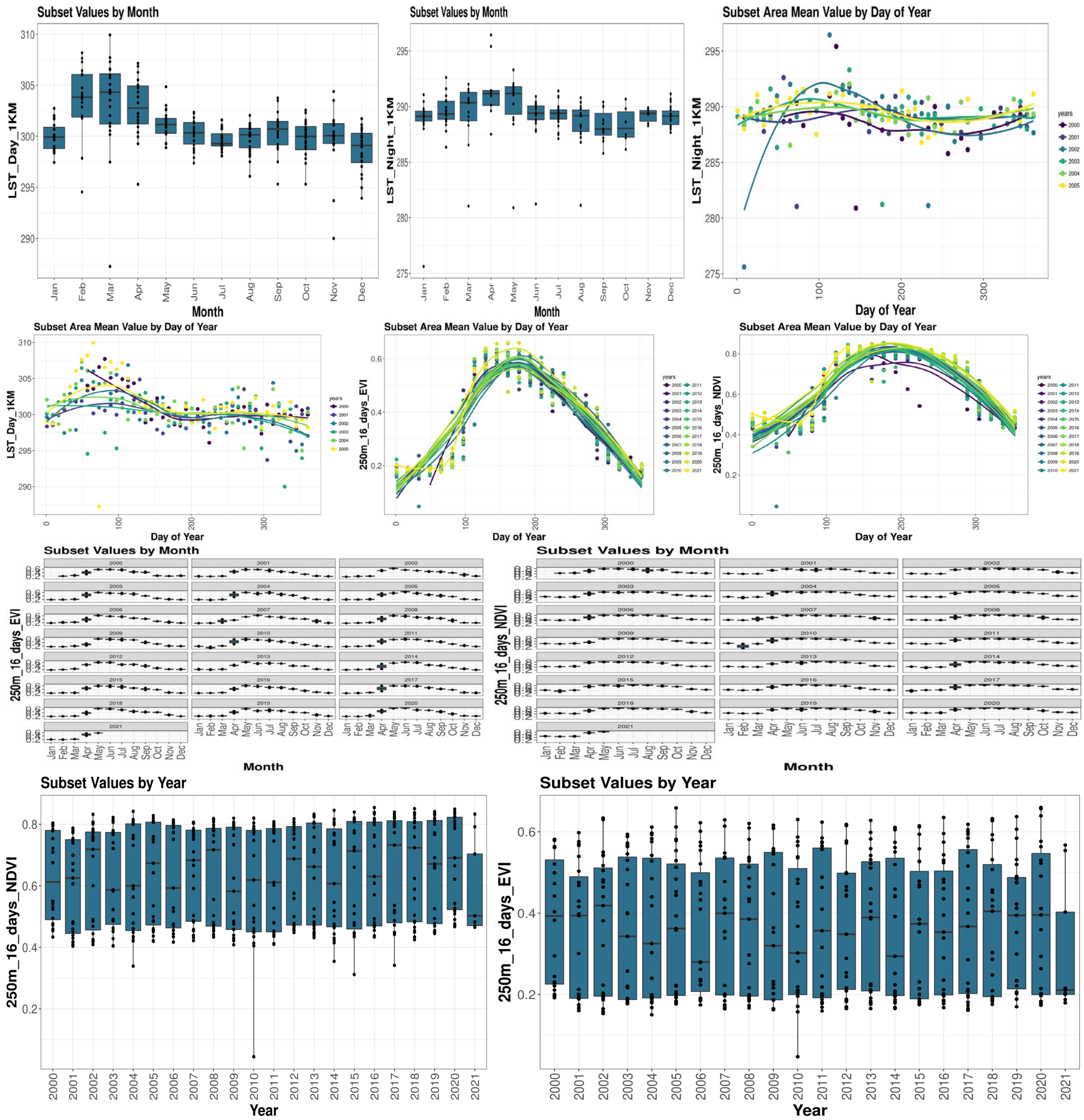

Figure 2. Evolution of NDVI, EVI and LST in Kalikuku (source: [9] [10] [11]).

Table 1. List of tree species identified and their density in Kalikuku dense forest. N: number of trees per species; Da: density (number of trees/ha).

Species	N	%	Da
Albizia gummifera	68.0	3.1	14
Anthochleista grandifolia	6.0	0.3	2
Beilshimedia oblogifolia	6.0	0.3	2
Bersama abyssinica	5.0	0.2	1
Bosquiea phoberi	13.0	0.6	3

Continued

Bridelia micrantha	8.0	0.4	2
Carapa procera	236.0	10.9	59
Cathas edulis	125.0	5.8	31
Cyanthea manii	111.0	5.1	28
Dialium corbisieri	212.0	9.8	53
Ficalhoa laurifolia	66.0	3.1	17
Grewia milbraedii	42.0	1.9	11
Hallea robrostipulata	12.0	0.6	3
Ilex mitis	23.0	1.1	6
Maythenus acuminatus	32.0	1.5	8
Musanga cecropioides	11.0	0.5	3
Myrianthus holstii	12.0	0.6	3
Ocotea usambarensis	381.0	17.6	95
Paramacrolobium coerulum	36.0	1.7	9
Parinaria holstii	56.0	2.6	14
Pentadesma lebrunii	68.0	3.1	17
Piptadenia africanum	439.0	20.3	110
Polyscias fulva	65.0	3.0	16
Rapanea melonophloeria	45.0	2.1	11
Sapium ellipticum	21.0	1.0	5
Syzygium guinense	11.0	0.5	3
Tabernaemontana	6.0	0.3	2
Trema guineensis	2.0	0.1	1
Vepris stolgii	12.0	0.6	3
Xymalos monospora	32.0	1.5	8
Total	**2163.0**	**100.0**	**541**

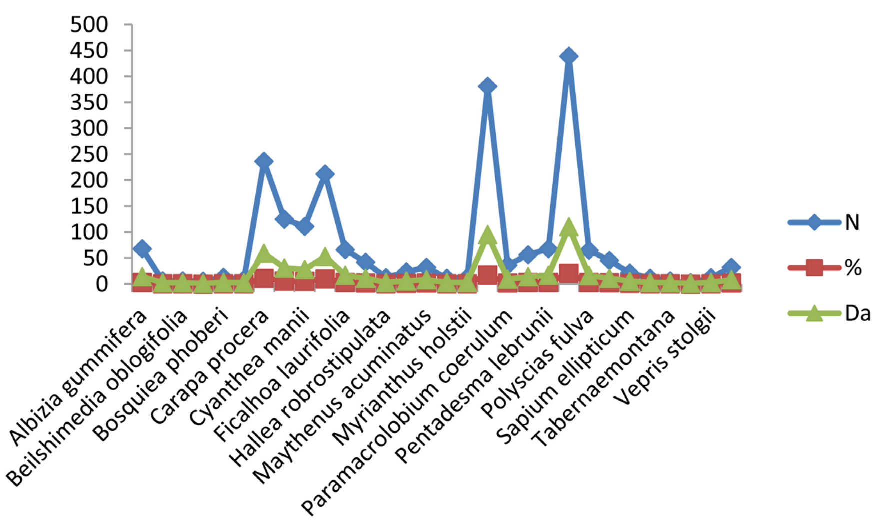

Figure 3. List of tree species identified and their density in Kalikuku dense forest.

shows the test of the horizontal spatial distribution model according to [25] (Da). Individuals of the main tree species in Kalikuku dense forest are spatially distributed according to the aggregated model. Indeed, $\lambda > 1$ for all three species tested. For $\alpha = 0.05$, this deviation from unity is significant given that Da values are well above β, *i.e.* Da > 0.9 (**Table 2** and **Figure 4**).

3.3. Comparison of Seedling Numbers in Aggregate and Non-Aggregate Areas

Table 3 and **Figure 5** present the number of seedlings counted in aggregate and non-aggregate areas for the three most abundant tree species in Kalikuku dense forest (*Piptadeniastrum africana* and *Ocotea usambarensis*). Seedlings are more abundant in aggregate areas than in non-aggregate areas. This difference is confirmed by the Wilcoxon signed-rank test (*W*) which shows that for both species tested, the value of *W* is less than the value of *W*0.05 = 17. Thus, there is a significant difference between the number of seedlings in aggregate and non-aggregate areas. The influence of spatial structure on the natural regeneration of Kalikuku dense forest is therefore confirmed.

Table 2. Number of individuals for the three most abundant two species in Kalikuku Forest. χ^1 to χ^{10}: number of individuals; λ: ratio of variance to arithmetic mean; Da: test for horizontal spatial distribution model.

Species/Plot	χ^1	χ^2	χ^3	χ^4	χ^5	χ^6	χ^7	χ^8	χ^9	χ^{10}	λ	Da
Piptadeniastrum africanum	58	15	65	48	6	24	43	85	11	84	9.9	8.9
Ocotea usambarensis	25	55	29	41	39	47	14	35	29	67	8.1	7.1

Table 3. Number of seedlings in aggregate (A) and non-aggregate (B) areas.

Piptadeniastrum africanum		***Ocotea usambarensis***	
A1	B1	A2	B2
53	29	26	15
21	13	14	6
34	2	35	18
21	3	34	13
43	14	11	15
16	5	38	11
34	2	6	6
53	15	23	9
19	8	38	21
39	15	31	11
296	143	186	195
***W* = 8.2**		***W* = 7.5**	

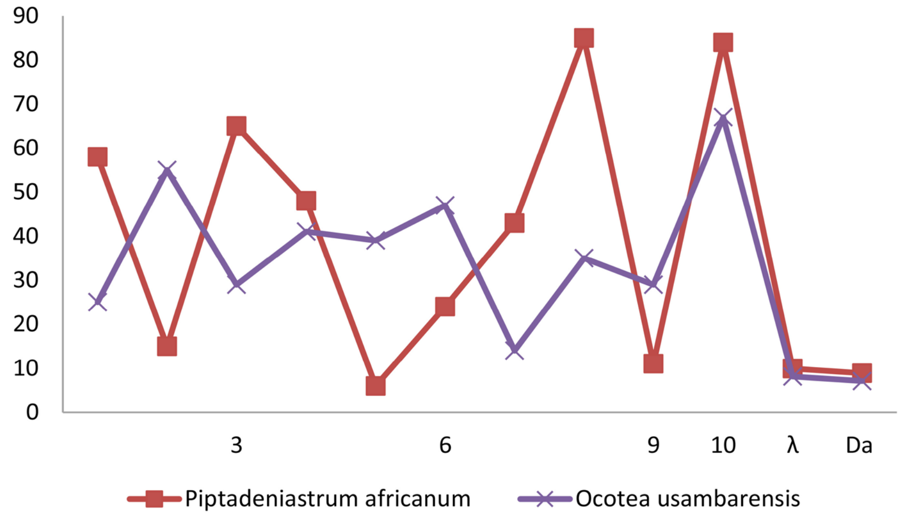

Figure 4. Number of individuals for the three most abundant two species in Kalikuku forest.

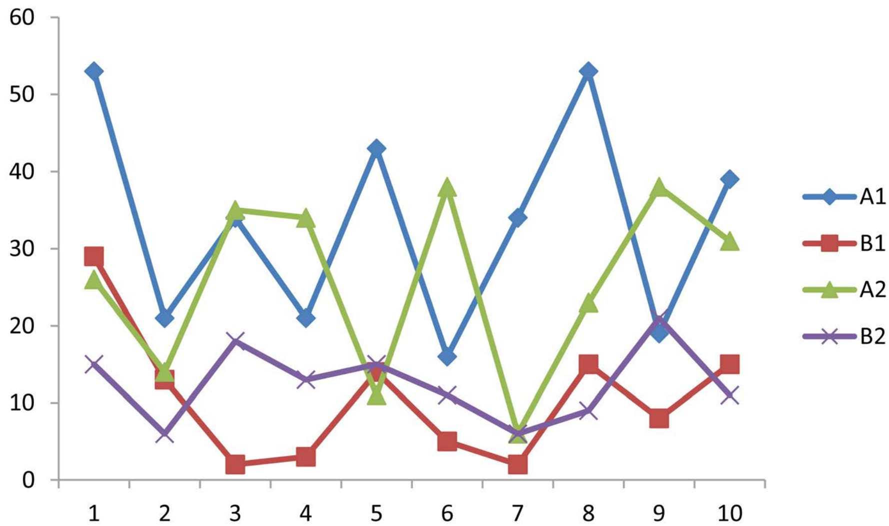

Figure 5. Seedlings in aggregate (A) and non-aggregate (B) areas.

3.4. Analysis of Natural Regeneration in Kalikuku Dense Forest

The values of the equitability index confirm that for both species, the seedling class (dhp < 10 cm) contains more individuals than the other diameter classes. Indeed, this index is equivalent to $R = 0.14$ for *Piptadeniastrum africana* and $R = 0.12$ for *Ocotea usambarensis*. Thus, the diameter class does not share equally the proportions of tree individuals because these values of the equitability index are close to zero. Furthermore, comparative analysis of the distribution of the proportions of the frequencies of the different diameter classes for the two tree species indicates that there is no significant difference as $\chi^2 = 3.1$ ($p > 0.05$). Furthermore, the values of the natural regeneration index reflect the state of equilibrium of the Kalikuku dense forest as they are greater than unity for all the species analyzed. Indeed, for *Piptadeniastrum africana*, Rn = 2.6 and for *Ocotea usambarensis*, Rn = 1.1 (**Table 4** and **Figure 6**).

Table 4. Regeneration index values for the two most abundant two species in Kalikuku dense forest. Np: number of seedlings (dhp < 10 cm); Na: number of mature trees (dhp ≥ 10 cm); Rn: natural regeneration index.

Species	Np	Na	Rn
Piptadeniastrum africanum	319	120	2.6
Ocotea usambarensis	199	182	1.1

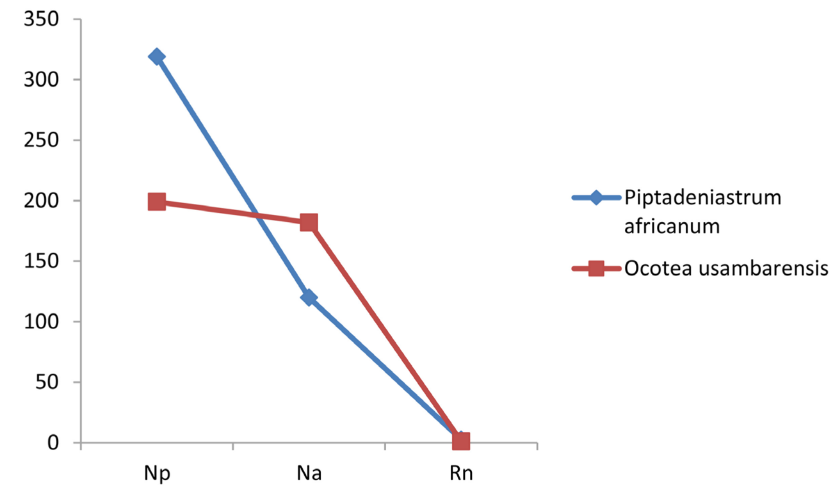

Figure 6. Regeneration index values for the two most abundant two species in Kalikuku dense forest.

4. Discussion

In the Kalikuku dense forest, the analysis of tree density confirms the observations of [26] on the preponderance of *Piptadeniastrum*, *Carapa and Ocotea* species in Afromontane forests. Furthermore, the density recorded (541 plants/ha) is lower than the average of 600 plants/ha observed in other dense forests of the Guineo-Congolese domain, notably by Lebrun [19]. This indicates that the Kalikuku forest is at a less advanced stage of evolution than those described by [27] [28].

In fact, the younger the dense forest, the more it presents numerous shrubs that are not widely spaced, which is the opposite for an old stand with large, widely spaced trees. This density obtained remains, however, in the same order of magnitude generally obtained in tropical Africa where the density of trees in the various inventories varies between 368 and 645 feet/ha [29].

The distribution of trees in diameter classes follows a regularly decreasing trend, with a maximum in the first diameter classes. A similar conclusion was reached in the Dja Faunal Reserve in Cameroon by [29]. In nature, such a diametric distribution reflects a state of equilibrium [30], which is itself synonymous with good natural regeneration [5]. This shows that, thanks to the growth of numerous seedlings and via their recruitment into the higher diameter classes [31], the Kalikuku forest will be maintained.

The analysis of the horizontal spatial distribution by the test [20] shows that the individuals of the trees in Kalikuku dense forest are distributed in an aggregated way. This aggregated spatial structure in turn influences the state of natural regeneration in this forest. The state of balanced regeneration is confirmed by Rn values that are all above unity [24]. Ecologically, the observed aggregation of trees can be explained either by the variation or heterogeneity of environmental characteristics, or by the genetic characteristics and behavior of living beings of the same species that often tend to group together [1] [2] [25]. In Kalikuku, the aggregated pattern of spatial distribution of trees is explained by variation in soil characteristics. The soil is silty in structure on the hilltops, whereas it is relatively deep and fine on the slopes and towards the lowlands.

In addition, the spatial structure determines the local environment around each tree (in particular the number of neighbors) and thus its growth conditions. This local environment modifies the expression of natural processes such as growth, mortality and regeneration of the stand; this can lead to a local monospecific composition [32]. This trend is confirmed for the Kalikuku dense forest in which all the two most abundant tree species are of different genera.

These authors point out that density is a particularly important concept in forest management because it provides information on the degree of occupation of space by the stand. In the case of the Kalikuku dense forest, the fact that there is a balance in natural regeneration means that it is not necessary to introduce other species for restocking. Furthermore, the density of 541 trees/ha is within the range known in tropical Africa [29]. However, this density of trees observed in the Kalikuku dense forest shows that there is intense competition between these trees for resources.

The behavior of the juvenile stage of the Kalikuku rainforest provides more information about the future of this ecosystem. Indeed, the regeneration of a tree species is subject to the density and spatial distribution of individuals [33]. Thus, the preponderant proportion of seedlings found in the Kalikuku dense forest is a sign of a balanced regeneration. This conclusion corroborates the observations of [34]-[40].

5. Conclusion

We note that the aggregated horizontal spatial structure of the trees in the Kalikuku dense forest favors natural regeneration in a balanced state despite the many factors of disturbance of anthropic origin that are exerted on this ecosystem. The present analysis constitutes an important argument in favor of taking integral protection measures to maintain the good natural regeneration of this forest. It is therefore not possible to introduce species by reforestation in the Kalikuku dense forest. These protection measures would focus on maintaining the integrity of the forest, in particular by preserving it from any action that could disturb the spatial structure of the trees, such as logging and clearing.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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