A 17 Year Successional Enrichment Plantation of Tree Recruitment and Restoration in an African Tropical Forest

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Research Article

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Abstract

Key message: The Enrichment Plantation of Akure Forest Reserve is one of the forests currently experiencing a 17-year-long post-disturbance following deforestation and fragmentation in Nigeria.

Context: To better understand the contribution of enrichment planting on forest regeneration and restoration, when the Enrichment Plantation after 17 years of post-disturbance was examined.

Aims: We studied the recruitment drive of aboveground and undergrowth stands of an Enrichment Plantation in the tropical forest reserve. We assess the trees diversity, species compositions, species richness, and growth forms of the vegetations.

Methods: A total of 3(50m x50m) plots were sampled. A total of 47 aboveground tree species and 45 undergrowth stands from Enrichment Plantation were identified. A statistical analysis were used to quantified the data obtained from this results

Results: The result shows an increase in the diversity and an even distribution of the species of the aboveground forest trees, compared to the undergrowth stands. Conversely, the aboveground forest trees have lower species richness as compared to the level of undergrowth stands. The sapling density was significantly higher than the aboveground tree of the. It was also observed that the aboveground forest trees and undergrowth stands are somewhat similar in species compositions, which implies that sapling recruitment is a key determinant of the tree species composition of the forest.

Conclusion: It is then concluded that the method adopted for restoration encouraged species diversity in this successional forest among the aboveground trees species and undergrowth.

Keywords: aboveground tree, successional forest, disturbed forest, forest regeneration, sapling recruitment, post-disturbance.

Introduction

Forest diversity is a significant role player in the heart of every ecosystem, with various degrees of unmanaged challenges facing flora and fauna ecosystem integrity. These challenges include growing global demand of ecosystem services like food, timber, fuel, water, charcoal, and firewood (Hoffmann and Baumung 2013). Such challenges are however a global struggle against forest disturbance or degradation which may be alleviated via forest recruitment and restoration. Forest disturbance is tentatively associated with the removal of vegetation cover of an ecosystem leading to a change in ecological imbalance. Technically, many countries have developed management that is acceptable in managing forest restoration of degraded or disturbed forest. This management comes via various methods which can either be endemic to a particular geographical location (temperate or tropical), or suitable to the general locality. Among this forest management, Julia Raquel (2013) mentioned a good number of research studies that have tested methods (Gardner et al. 2009; Brancalion et al 2013; Melo et al 2013; Bertacchi et al. 2015; Montagnini et al. 1997), of forest management via enrichment plantation. Other research carried out tested endangered seed enrichment plantations in the tropical forest of Tan Phu, Vietnam (Millet, et al. 2013). The natural regeneration of trees was widely used in Zinder and Maradi, Niger. Reji et al. (2009) reported varied remarkable data benefiting and transforming the region.

This forest reserve is a popular forest surrounded by two distinct communities previously known to have provided various flora and fauna biodiversity. For various reasons and for a long period of time, the reserve had faced human disturbance resulting in exploitation of its flora and fauna with no adequate regeneration strategies for restoration. As part of strategies to conserve the animal and plant biodiversity of this forest, in 1948 (see details in Ola-Adam. 1978), a Strict Nature Reserve (SNR), as a natural high forest, was first demarcated from the forest reserve with the aims of protecting and conserving the indigenous species from human exploitation. In furtherance to conserving the biodiversity of this ecosystem, this forest reserve was further subjected to three monitory reserves. The first reserve, Strict Nature Reserve, earlier mentioned, covered the 32 hectares of natural high forest called Strict Nature Reserve (Queen plot), the buffer zone with 15 hectares. More recently, in 2004, a regeneration method called Enrichment Plantation (Figure 1) was adopted to cover an additional 5 hectares of the forest reserve where removal of selected aboveground trees had occurred. Regenerating trees were manually planted to replace what was removed from the ecosystem. A recent accompanying paper by Omomoh et al. (2019), was used in comparing the current status of this study of a related undisturbed tropical forest as the only existing adjacent natural forest where an unperturbed species composition still exists.

Therefore, the objective of this study was to quantify the recruitment and restoration pattern of trees and undergrowth of a 17-year long post-disturbance tropical forest. We assessed the species composition and growth form of both aboveground tree species and undergrowth. Finally, we evaluated whether species richness follows succession.

Materials and Methods

Study area

The Enrichment Plantation is a remnant portion of the Akure Forest Reserve which was designated for indigenous trees species regeneration and restoration. The regeneration method adopted for the Enrichment Plantation was carried out in2004 (Figure 1) under the auspices of the Federal Government of Nigeria as a forest assisted-project with the objective of recuperating the forest with regenerating trees. Since then the forest had been under intensive care and protection of the Forestry Research Institute of Nigeria. The seedling ages at the time of planting were not known, but due to its 17 years of post-disturbance of enrichment plantation, this forest can be categorized as an older successional forest type (Perera 2005) or late-successional forest. In this context, we observed that this typical tropical older or late-successional forest is devoid of mid- and early-successional driven trees such as *Trema orientalis* (L.) Blume,*Manihot glaziovii* Müll. Arg., *Alchornea laxiflora* (Benth.) Pax & K. Hoffm etc. The transitional dynamics of early- and mid-successional forest to late-successional forest most times brings about the natural removal of trees of mid-successional species in the late-successional forest. To be more specific in this context, regenerating trees or young trees are referred to as sapling, herbaceous as forbs, climber as a vine, and plants of early-disturbance as pioneer plants, e. g. agricultural weeds.

The study area (Figure 2) is located in Akure Forest Reserve, Nigeria at $N07^{0}.2645^{1}$, and $E005^{0}.03675^{1}$. Akure Forest Reserve is one of the tropical forests in world with a history of deforestation and fragmentation (Adekunle et al. 2013). Before the Enrichment Plantation project, aremnant portion of the Akure Forest Reserve that was known to have undergone a series of anthropogenic activities such as timber logging and exploitation in the hands of illegal fellers was in 2004 projected out for enrichment planting.However, this remnant and fragmented part was located at the adjacent area of the Strict Nature Reserve. The purpose of the enrichment planting was for forest restoration and regeneration. Recent studies described the forest climatic condition of this study (Omomoh 2018, Omomoh et al. 2019, and Omomoh et al. 2020) in detail.

Sampling and Identification techniques

The laying of the plots was carried out using the systematic line transects method as shown in Figure 3. A 50m transect was centrally located in the forest where three sampling plots of 50 m x 50 m were laid in alternate sides with the aids of the prismatic compass and ranging poles for positioning.

To establish the species composition of the aboveground vegetation, trees, and shrubs, the floristic composition of each study plot was enumerated. The saplings girth >0.8m of woody species at the height ranging from 1-2m were measured with diameter tape. Other non-woody species such as forbs and vines encountered were also counted. Identification of the species and their nomenclatures followed the flora of tropical West Africa (Hutchinson et al 1963) and Tree of Nigeria (Keay 1989), while the leguminous members (Fabaceae) followed the order of new families of the legume phylogeny working group (LPWG) of Azani et al. (2017). Samples of plant species with difficult identification were collected, pressed, and taken to Federal University of Technology, Akure (FUTA) herbarium for proper identification.

Forest Structure

The forest structure was evaluated using the forest parameters and indices. The basal area, relative density, relative dominance, Importance Value (IVI), and family Importance Value (FIV) were determined using the following formula:

(i) Basal area (BA):

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

Where BA = Basal area (m^2), D = Diameter at breast height (cm), and n = pie (3.142). The total BA for each plot was obtained by adding all trees BA in the plot.

(ii) Relative density (%). Brashears et al. (2004):

$$RD = \frac{n_i}{N} \times 100$$

Where RD is the relative density of the species, $n_i$is the number of individuals of species *i,* and N is the total number of all individual trees.

(iii) Species relative dominance (%). Curtis and McIntosh (1950):

$$RD_O = \frac{\sum Ba_i \times 100}{\sum Ba_n}$$

Where: Ba_i = basal area of individual tree belonging to species *i,* and Ba_n = stand basal area.

(iv) Family Importance Value (FIV):

$$FVI = \frac{(\text{Relative Density} + \text{Relative Dominance})}{2}$$

(v). Importance Value Index (IVI). Brashearset al. (2004):

$$IVI = \frac{(\text{Relative Density } x \text{ Relative Dominance})}{2}$$

Plant Species Diversity

Diversity indices such as Shannon-Wiener diversity index (Shannon, 1948) and the Species evenness (Pielou, 1969) were used.

(i) Shannon-Wiener diversity index:

$$H' = -\sum_{i=1}^{S} p_i \ln(p_i)$$

Where H' = Shannon diversity index, S = the total number of species in the community, p_i= proportion S (species in the family) made up of the *i*th species, and ln = natural logarithm.

(ii) The Species evenness (E), using Pielou (1969):

$$E_H = \frac{H'}{H_{Max}} = \frac{\sum_{i=1}^{S} P_i \ln(P_i)}{\ln(S)}$$

These equations still follow the calculation of the Shannon and Wiener function above.

Data analyses

The analysis of variance (One-way ANOVA) was applied to determine the significant differences between the variances, using IBM SPSS Version 23. The diversity indices were quantified using 1000 bootstrap replicates in the PAST software 3.0 to observe the forest structure of this study. The Principal Component Analysis (PCA) ordination and multivariate clustering graph were also employed to explain the variations of the two physiognomies of the forest.

Results

Species composition structure

There were sixty-five (65) plant species distributed across forty-nine (49) genera, and twenty-eight (28) families within the entire vegetation of the study area (Table 1).

Trees diversity of the aboveground vegetation

Forty seven forest trees were identified from all three plots of the aboveground study area (Table 2). In the study area (Figure 4), Sterculiaceae, Moraceae, Fabaceae (Caesalpinioideae &Detarioideae), Anacardiaceae, Euphorbiaceae and Ebenaceae, with dominances of 15%, 11%, 10%, 9%and 6% (Anacardiaceae & Euphorbiaceae) respectively, are the known dominant families in the forest, with species members falling between the ranges of 6 to 5 different species. The Sterculiaceae family recorded the highest number of members (6) with the following species: *Cola gigantea* var. *glabrescens* Brenan &Keay., *Mansonia altissima* (A. Chev.) A. Chev. var. altissima, *Pterygota macrocarpa* K. Schum., *Sterculia rhinopetala* K. Schum., *Sterculia tragacantha* Lindl, and *Triplochiton scleroxylon* K. Schum. The Moraceae family has the following 5 member species: *Antiaris toxicaria* var. *africana* Scott-Elliot ex A. Chev., *Ficus exasperata* Vahl., *Milicia excelsa* (Welw.) C.C. Berg., *Myrianthu sarboreus* P. Beauv., and *Trilepisium madagascariense* DC. Syn *Bosqueia angolensis* Ficalho., followed by Fabaceae contributing 5 species members viz. *Albizia adianthifolia* (Schum.) W. F. Wight., *Albizia zygia* (DC.) J. F. Macbr. *Anthonotha macrophylla* P. Beauv., *Anthonotha obanensis* (Bak.f.) J. Léonard., and *Piptadeniastrum africanum* (Hook. f.) Brenan., while the families, Annonaceae and Euphorbiaceae with 4 species members. The only family with intermediate dominant members is Ebenaceae. Other families were found in low dominant members ranging between one to two species (Table 2).

The total basal area of the aboveground species per hectare is 109.51. In the Ebenaceae family, the genus *Diospyros* contributed the highest number of three species *viz*. *Diospyros barteri* Hiern, *Diospyros dendo* Welw. ex Hiern., and *Diospyros monbuttensis* Gürke, with a total basal area of 1.25m^{2}ha-^{1} and relative density of 4 individualsha-^{1}. The most dominant tree species, *Picralima nitida* (Stapf) Th. & H. Dur, contributed a total basal area of 6.525m^{2}ha-^{1} all together with a relative density of 7.95 of individuals.ha-^{1}. The least dominant tree species encountered were 28 with a relative density of one (1) individualha-^{1} (Table 3).

Quantitative details of other dominant trees were recorded among the much more mature trees measured. The species with higher relative densities were *Pterygota macrocarpa* K. Schum., *Buchholzia coriacea* Engl., *Celtis zenkeri* Engl., *Sterculia rhinopetala* K. Schum., and *Trilepisium madagascariense* DC (Table 2). The diameter class was extremely high, with only in 11-20 dbh among all the diameter class distributions recorded (Figure. 5). The two most dominant tree species in this diameter class distribution were *Buchholzia coriacea* Engl., and *Picralima nitida* (Stapf) Th. & H. Dur. The diameter class decreased from 91-100 cm to 51-60 cm but was extremely low at 0-10 cm. The analysis of variance for sapling density was varied and significantly higher than the aboveground tree of the forest (one way ANOVA: P <. 0.05 and P= 0.000). The mean ± standard deviation of 2.41±1.55 tree species was extremely low to what was obtained (17.55±8.06) of tree sapling in the forest structure. From Table 4, the Shannon-Wiener index (H'), Simpson's index (CD), and Evenness index (e) for the tree species were obtained as 3.59, 0.05, and 0.80, respectively.

The recruitment status of forest undergrowth

Forty-five (45) forest undergrowth species were identified in the forest floor of this study, consisting of 6 vines, 3 forbs, and 36 tree saplings (Table 1). One of the most notable differences in this forest undergrowth is the rate of occurrence at which the life forms recruit and regenerate in the forest floor (Figure 6). Our results show that the sudden increase in recruitment level of tree saplings can be linked to natural disappearance or removal of early- and mid-successional species to later stages in succession. Our records show a remarkable impact on the regeneration of life forms owing to a wide increase in sapling occurrence (Figure 6). Of the different life forms observed in the forest undergrowth, tree saplings show the highest percentage of regeneration (54%), followed by vines, 26%, mature trees 14%, and forbs 7%. The result from Table 3 shows the species diversity of forbs and vines in this forest to be extremely low and invariably consists of what flora of West tropical Africa described as forest forbs and vines, namely; *Anchomanes difformis*, *Cyrtosperma senegalense*, *Geophila,* and *Culcasia scandens*. According to the tree sapling record, the undergrowth stand of the total families' dominance was estimated to 97 families (Figure 4). Sterculiaceaeis the most dominant family, with 18% families' dominance contributing a total of 22.9% of its individual members (8) to the recruitment status viz. *Cola acuminata*, *Cola gigantea*, *Cola hispida*, *Mansonia altissima*, *Pterygota macrocarpa*, *Sterculia rhinopetala*, *Sterculia tragacantha,* and *Triplochiton scleroxylon*. Other families with intermediate family dominance were Ebenaceae and Moraceae, with 11.4 % of total individual members (4). On the contrary, relatively low percentage dominant families were recorded in the remaining families i.e. 3(5.7%); Annonaceae and *Ulmaceae*, 2(5.7); *Apocynaceae* and *Sapotaceae*, 1(2.9%); *Bombacaceae*, *Boraginaceae*, *Burseraceae*, *Combretaceae*, *Detariodeae*, *Euphorbiaceae*, *Meliaceae*, *Rutaceae*, and *Sapindaceae*. The population structure of undergrowth reveals the density of individuals ha^{-1} (Table 3) of 11 dominant tree saplings found among the undergrowth was different from what was accounted for in the forest tree viz. *Funtumia elastica* (28), *Anthonotha macrophylla* (16), *Diospyros dendo* (14), *Ricinodendron heudelotii* (18), *Entandrophragma utile* (18), *Trilepisium madagascariense* (28), *Lecaniodiscus cupanioides* (14), *Cola gigantea* (16), *Mansonia altissima* (17), *Sterculia tragacantha* (24), *Celtis zenkeri* (28).

The one-way cluster analysis shows plants relationships among the different plant types as it is seen in Figure 7. This clustering is relatively smaller in some species associations, like in the cases of the *Celtis zenkeri* and *Trilepisium madagascariense*, *Ceiba pentandra* and *Monodora myristica*, *Anchomanes difformis* and *Piper guineense, Celtis mildbraedii* and *Cola acuminata, Chrysophyllum albidum* and *Lannea welwitschii, Diospyros monbuttensis* and *Ficus exasperata, Cola hispida, Rhaphidophora africana* and *Ricinodendron heudelotii.* The large clustering were observed among the following plant types: *Bridelia micrantha, Albizia zygia, Anthonotha obanensis, Croton penduliflorus, Entandrophragma angolense, Glyphaea brevis, Lecaniodiscus cupanioides, Myrianthus arboreus, Pachystela brevipes, Picralima nitida, Pterygota macrocarpa, Sterculia rhinopetala,* and *Terminalia ivorensis.* Several other smaller clusters were found in secondary clusters and sub-clusters consisting of some other closely associated plant species. Results of the PCA show there was a large variation of plant species at the aboveground level as compared with the undergrowth (Figure 8). *Pterygota macrocarpa, Picralima nitida,* and *Culcasia scandens* were the outliers of the 95% eclipse.

Discussion

The growing number of plants and tree species of aboveground trees and undergrowth stands in a 17 year long enrichment plantation establishment of a tropical forest has revealed a significant difference in species recruitment and aboveground trees of the successional forest. Our findings show that the tropical forest is the most diverse forest known to have the family Sterculiaceae members as major dominant in tree diversity (Omomoh et al. 2019, Adekunle et al. 2013, Onyekwelu et al. 2008) which substantiate what Cronquist (1981) said about Sterculiaceae mainly found in tropical and subtropical regions. Sterculiaceae had higher members of tree species diversity. However, our study confirmed the comparable results of Sharkar and Devi (2014) in a semi-tropical forest where Moraceae, Meliaceae, Apocynaceae, Euphorbiaceae, Ebenaceae, and Fabaceae were found to be the major family species drivers in the restoration status of a tropical semi-evergreen forest of Assam, Northeast India.

This study further demonstrated the seedling diversity of non-woody species of undergrowth identified at the soil surface level in which Araceae, a forest non-woody family, were identified as the second highest dominant species, e.g.: *Anchomanes difformis, Culcasia scandens, Cyrtosperma senegalense, and Rhaphidophora africana.* The impact of the dominant species, with the exception of *Anchomanes difformis,*on the annual undergrowth is the natural regenerative ability to establish as a long-lived understorey in a tropical humid rainforest. In general, when pioneer species of early-successional forest (Omomoh et al. 2020) decrease, i.e. the agricultural weeds give ways to forest tree seedlings/saplings, hence an indication of the forest transitioning to a stable forest. It is clear from our studies that the dense natural regeneration of saplings increases in association with abundant light availability, an important factor precluding regeneration (Covey et al. 2015; De Lombaerde et al. 2020) before the removal of overstorey trees. The *Geophila obvallata* (Table 3),a forest non-woody creeping prostrate herb usually found in the stable forest floor and often around the base of tropical forest trees, confirms the forest becoming species-rich in plant diversity. This can be categorized as a late-successional forest based on the associated forest attribute described in Perera (2005).The enrichment plantation shows us that the agricultural weeds associated with and peculiar to young successional forest and forest plantation (Omomoh et al. 2020) are nearly absent in this forest type. This study is in support of Perera's (2005) finding that the common herbaceous density decreases after 15 years in the older successive forest and natural high forest with very low seed densities. The total basal area of the aboveground tree species in this study area is 109.51, which was significantly lower than what was obtained in Strict Nature Reserve, Akure (Omomoh et al. 2019). The differences can be seen in the disparity between the tree's diameter class categories. The small diameter tree species pre-dominate the successional forest. The individual basal area per hectare falls between the range of the 11-30 cm diameter class which, nevertheless, was quite similar to what was reported in the older natural high forest (Omomoh et al. 2019 and Adekunle et al. 2013). Interestingly, this is in agreement with Sokpon & Biaou's (2012) description where diameter classes with continuous recruitment and expanding population are categorized as stable or expanding species. Similarly, Pugu Forest Reserves (Rocky & Mligo 2012) reported a diameter size class, 11 to 15 cm (Figure 4) in Tanzania. Moreso, in Assam, northeast India, (Sarkar & Devi. 2014), the diameter class in the tropical forest of Hollongapar Gibbon Wildlife Sanctuary falls within the smaller diameter class.

Mamo et al (2012)'s report also shows us the highest diameter percentage distribution among the smaller DBH class of 2-10 cm in Wondo Genet Afromontane forest. Likewise, in Ethiopia, the older successional forest was reported to have more individual trees ranging in average from 5 to 20 diameter classes. However, looking at the result of this study (Figure 5), the floristic composition and forest structure of this forest were consistent except for where there were fewer or no older trees to compete with. The trees with the highest Importance Value Index (IVI) value, *Trilepisium madagascariense* (29.84), have 4 individual plants ha^{-1}, followed by *Pterygota macrocarpa*(19.41), with 6 individual plants ha^{-1}. These two tree species are highly economic due to the high-density properties in Africa, and for that, they are mostly found in the multi-species rich ecosystem. Despite forest disturbance of the trees composition in the study area, the result obtained from the Importance Value Index of selected trees species such as *Mansonia altissima, Celtis zenkeri,* and *Triplochiton scleroxylon,* are still of little variance to what was obtained from other studies (Omomoh et al. 2019, Onyekwelu et al. 2008). The exceptions to this were *Rothmannia whitfieldii*, *Cola gigantea* and *Pterygota macrocarpa,* with higher Importance Value Index in this study area (Table 2).

Apparently, others with a relatively higher number of individual plants ha^{-1} across the different dominant species were observed to have low IVI values. This can be attributed to the extremely low cumulative DBH. The ability of a tree to increase in population size and increase in girth within a space of time depends on the objective of forest management. Poor or lack of management was recognized as a factor in an older Forest Plantation in Nigeria where the issue of thinning since establishment was causing retarded growth to the many species of ground flora (Onyekwelu et al. 2010). Other factors are environmental stress and anthropogenic disturbance at the young stages of any species (Sarkar & Devi 2014).

Several dominant tree species which were highly valued as timber trees in natural tropical forests (Omomoh et al. 2019) are apparently the natural history (Brudvig et al. 2017) of enrichment plantation during pre-disturbance. Our studies revealed that the timber trees were under-represented and somewhat well represented among the saplings (Nuñez et al. 2019). This may have supported the efforts of enrichment plantation in this forest to restore tree diversity (Bertacchi et al. 2015). The low number of aboveground trees per hectare has created a light opening. Its incursion may have contributed more to the increase in seedling regeneration and sapling recruitment (Webb &Sah 2003) than any other life form. The tree recruitment of an ecosystem depends greatly on the population structure and level of disturbance (Sarkar & Devi 2014). An ecosystem with a mild disturbance would regenerate easily at a shorter period of time than seriously disturbed vegetation (Ganlin et al. 2006). The result shows that aboveground forest trees are somewhat diverse and more even than undergrowth species except in the species richness, where forest undergrowth was higher than the aboveground forest trees. This diversity index (H^1) shows little dissimilarity between the aboveground forest trees and undergrowth. Diversity indices of a typical tropical forest are generally range from 1.5 to 3.5 and it is also exceptionally rare to exceed normal range but rarely exceed 4.5 (Kent & Coker 1992). In this study, the undergrowth Shannon-Wiener diversity index value (3.37) falls within the normal range. On the other hand, aboveground trees diversity (H^1) is higher and exceeds the normal range reported by Kent & Coker (1992). This result is not in any way at variance with what was published on Queen's, Oluwa and Elephant forest by Onyekwulu et al. (2008). It is even in more consonance with other studies in Indian forests (Sarkar & Devi 2014; Parthasarathy et al. 1992; Visalakshi 1995) where the diversity index ranged from 0.83 to 4.1. There are species consistence in species evenness index values of aboveground forest (0.8) and undergrowth (0.6). This was reported in Ganlin et al. (2006), & Palmer et al. (2000), where species richness was higher in a low disturbance. However, there is no significant difference in the relative density between the forest trees and saplings (P= 0.341). This confirmed that the aboveground trees and saplings are dissimilar in species abundance, which apparently means that sapling density is surviving the tree species composition of the forest.

Recommendation

A collaborative effort on ecosystem restoration and sustainable forest management can intensify the biodiversity integrity of disturbed forests for the next decade to come (Bernier et al. 2017, Chazdon et al. 2009). We recommend that a successional forest would need a collaborative forest management campaign to reduce and stop anthropogenic disturbance such as nomad colony, herdsmen, and cattle rearers from infringing and settling into susceptible forests. These are the current and prevailing factors affecting African forests.

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Author contributions Contributions of all the co-authors. BE conceived the ideas, designed methodology, identified all the plants to species and family level and collected the data analyzed the data and wrote the manuscript and LB proofread the manuscript and added significant keyword to the write up. GA and VAJ supervised the study and also assisted in the statistical analysis. All authors contributed to the final draft and gave final approval for publication.

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Data Availability Nil

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Table 1: Summary of plant species diversity in the study areas

No	Scientific names	A	B
1	*Albizia adianthifolia* (Schum.) W. F. Wight	X	-
2	*Albizia zygia* (DC.) J. F. Macbr.	X	-
3	*Anchomanes difformis* var. *difformis* Hepper	-	X
4	*Annickia chlorantha* (Oliv.) Setten & Maa Syn *Enantia chlorantha* Oliv	X	X
5	*Anthonotha macrophylla* P. Beauv.	X	X
6	*Anthonotha obanensis* (Bak. f.) J. Léonard	X	-
7	*Antiaris toxicaria* var. *africana* Scott-Elliot ex A. Chev.	X	-
8	*Antidesma laciniatum* Müll. Arg. var. Laciniatum	X	-

9	*Bridelia micrantha* (Hochst.) Baill.	X	-
10	*Buchholzia coriacea* Engl.	X	-
11	*Canarium schweinfurthii* Engl.	X	X
12	*Ceiba pentandra* (Linn.) Gaertn.	X	X
13	*Celtis mildbraedii* Engl.	X	X
14	*Celtis philippensis* Blanco syn *Celtis brownii* Rendle	X	X
15	*Celtis zenkeri* Engl.	X	X
16	*Chrysophyllum albidum* G. Don	-	X
17	*Chrysophyllum perpulchrum* Mildbr. ex Hutch. & Dalz.	-	X
18	*Cola acuminata* (P. Beauv.) Schott & Endl.	-	X
19	*Cola gigantea* var. *glabrescens* Brenan & Keay	X	X
20	*Cola hispida* Brenan & Keay	-	X
21	*Cola millenii* K. Schum.	X	-
22	*Cordia millenii* Bak.	X	X
23	*Croton penduliflorus* Hutch.	X	-
24	*Culcasia scandens* P. Beauv.	-	X
25	Cyrtosperma senegalense (Schott) Engl.	-	X
26	*Diospyros barteri* Hiern	X	-
27	*Diospyros dendo* Welw. ex Hiern	X	X
28	Diospyros mespiliformis Hochst. ex A. DC.	-	X
29	*Diospyros monbuttensis* Gürke	X	X
30	*Diospyros suaveolens* Gürke	-	X
31	*Entandrophragma angolense* (Welw.) C. DC.	X	-
32	*Entandrophragma utile* (Dawe & Sprague) Sprague	X	X
33	*Ficus exasperata* Vahl	X	X
34	*Funtumia elastica* (Preuss) Stapf	X	X
35	Geophila obvallata (Schumach.) F. Didr.	-	X
36	*Glyphaea brevis* (Spreng.) Monachino	X	-
37	*Hexalobus crispiflorus* A. Rich.	X	X
38	*Irvingia wombolu* Vermoesen	X	-
39	*Khaya grandifoliola* C. DC.	-	X
40	*Lannea welwitschii* (Hiern) Engl.	X	-
41	*Lecaniodiscus cupanioides* Planch. ex Benth.	-	X

42	*Mansonia altissima* (A. Chev.) A. Chev. var. altissima	X	X
43	*Milicia excelsa* (Welw.) C.C. Berg	X	X
44	*Monodora myristica* (Gaertn.) Dunal	X	X
45	*Monodora tenuifolia* Benth.	X	-
46	*Myrianthus arboreus* P. Beauv.	X	X
47	*Napoleona imperialis* P. Beauv.	X	-
48	*Pachystela brevipes*. P. syn *Synsepalum brevipes* (Baker) T. D. Pennington	X	-
49	*Picralima nitida* (Stapf) Th. & H. Dur.	X	X
50	*Piper capense* Linn. F	-	X
51	*Piper guineense* Schum. & Thonn.	-	X
52	*Piptadeniastrum africanum* (Hook. f.) Brenan	X	-
53	*Pterygota macrocarpa* K. Schum.	X	X
54	*Pyrenacantha staudtii* (Engl.) Engl.	-	X
55	*Rhaphidophora africana* N. E. Br	-	X
56	*Ricinodendron heudelotii* (Baill.) Pierre ex Pax	X	X
57	*Rothmannia whitfieldii* (Lindl.) Dandy	X	-
58	*Sterculia rhinopetala* K. Schum.	X	X
59	*Sterculia tragacantha* Lindl.	X	X
60	*Symphonia globulifera* Linn. f.	X	-
61	*Terminalia ivorensis* A. Chev.	-	X
62	*Tetracera potatoria* Afzel. ex G. Don	-	X
63	*Trilepisium madagascariense* DC. syn *Bosqueia angolensis* Ficalho	X	X
64	*Triplochiton scleroxylon* K. Schum.	X	X
65	*Zanthoxylum rubescens* Planch. ex Hook. f.	X	X
	Total No. of plant species	**47**	**45**

A= Aboveground tree, B= Undergrowth plant species, X= Species present, - = Species absent

Table 2: Tree species diversity, relative frequency, volume and diversity index of the Enrichment Forest Plantation

Family	**Scientific Name**	**Ha^{-1}**	**Baha^{-1}**	**RD**	**RD$_0$**	**IVI**	**FVI**
Guttiferae	*Symphonia globulifera* Linn. f.	1	2.87	1.14	2.62	1.49	1.8
Irvingiaceae	*Irvingia wombolu* Vermoesen	1	0.58	1.14	0.53	0.30	0.83
Anacardiaceae	*Lannea welwitschii* (Hiern) Engl.	1	2.61	1.14	2.39	1.36	1.76
	Annickia chlorantha (Oliv.) Setten & Maa syn *enantia chlorantha* Oliv	1	0.17	1.14	0.15	0.09	0.65

Annonaceae	*Hexalobus crispiflorus* A. Rich.	1	0.31	1.14	0.28	0.16	0.71
	Monodora myristica (Gaertn.) Dunal	1	1.44	1.14	1.32	0.75	1.23
	Monodora tenuifolia Benth.	1	0.13	1.14	0.12	0.07	0.63
Apocynaceae	*Funtumia elastica* (Preuss) Stapf	3	2.04	3.41	1.86	3.17	2.63
	Picralima nitida (Stapf) Th. & H. Dur.	7	1.59	7.95	1.45	5.77	4.70
Bombacaceae	*Ceiba pentandra* (Linn.) Gaertn.	1	0.27	1.14	0.25	0.14	0.69
Boraginaceae	*Cordia millenii* Bak.	1	6.77	1.14	6.18	3.51	3.66
Burseraceae	*Canarium schweinfurthii* Engl.	2	0.85	2.27	0.78	0.89	1.53
Caesalpinioideae	*Albizia adianthifolia* (Schum.) W. F. Wight	2	1.98	2.27	1.80	2.05	2.04
	Albizia zygia (DC.) J. F. Macbr.	1	0.84	1.14	0.77	0.44	0.95
	Piptadeniastrum africanum (Hook. f.) Brenan	1	0.24	1.14	0.22	0.13	0.68
Capparidaceae	*Buchholzia coriacea* Engl.	5	0.66	5.68	0.61	1.72	3.14
Detarioideae	*Anthonotha macrophylla* P. Beauv.	2	0.72	2.27	0.65	0.74	1.46
	Anthonotha obanensis (Bak. f.) J. Léonard	1	0.18	1.14	0.16	0.09	0.65
Ebenaceae	*Diospyros barteri* Hiern	2	0.28	2.27	0.26	0.29	1.27
	Diospyros dendo Welw. ex Hiern	1	0.71	1.14	0.65	0.37	0.89
	Diospyros monbuttensis Gürke	1	0.26	1.14	0.24	0.14	0.69
Euphorbiaceae	*Antidesma laciniatum* Müll. Arg. var. laciniatum	2	0.82	2.27	0.75	0.85	1.51
	Bridelia micrantha (Hochst.) Baill.	1	0.65	1.14	0.60	0.34	0.87
	Croton penduliflorus Hutch.	1	2.58	1.14	2.36	1.34	1.75
	Ricinodendron heudelotii (Baill.) Pierre ex Pax	1	12.0	1.14	10.9	6.23	6.05
Lecythidaceae	*Napoleona imperialis* P. Beauv.	1	0.14	1.14	0.12	0.07	0.63
Meliaceae	*Entandrophragma angolense* (Welw.) C. DC.	1	6.73	1.14	6.15	3.49	3.64
	Entandrophragma utile (Dawe & Sprague) Sprague	2	1.34	2.27	1.23	1.39	1.75
Moraceae	*Antiaris toxicaria* var. *africana* Scott-Elliot ex A. Chev.	2	1.78	2.27	1.62	1.84	1.95
	Ficus exasperata Vahl	1	1.90	1.14	1.74	0.99	1.44
	Milicia excelsa (Welw.) C.C. Berg	1	0.36	1.14	0.33	0.19	0.73
	Myrianthus arboreus P. Beauv.	2	0.45	2.27	0.41	0.46	1.34
	Trilepisium madagascariense DC. syn *Bosqueia angolensis* Ficalho	4	14.4	4.55	13.1	29.8	8.84
Rubiaceae	*Rothmannia whitfieldii* (Lindl.) Dandy	1	0.14	1.14	0.13	0.07	0.63
Rutaceae	*Zanthoxylum rubescens* Planch. ex Hook. f.	1	1.94	1.14	1.77	1.01	1.45
Sapotaceae	*Chrysophyllum albidum* G. Don	1	2.74	1.14	2.50	1.42	1.82
	Pachystela brevipes. P. syn *Synsepalum brevipes* (Baker) T. D. Pennington	1	0.80	1.14	0.73	0.41	0.93

Sterculiaceae	*Cola gigantea* A. Chev. var. *Gigantea*	3	8.81	3.41	8.04	13.7	5.73
	Cola millenii K. Schum.	2	0.60	2.27	0.55	0.63	1.41
	Mansonia altissima (A. Chev.) A. Chev. var. *altissima*	3	2.57	3.41	2.35	4.00	2.88
	Pterygota macrocarpa K. Schum.	6	6.23	6.82	5.69	19.4	6.26
	Sterculia rhinopetala K. Schum.	4	4.41	4.55	4.03	9.15	4.29
	Sterculia tragacantha Lindl.	2	4.21	2.27	3.85	4.37	3.06
	Triplochiton scleroxylon K. Schum.	2	4.82	2.27	4.40	5.00	3.34
Tiliaceae	*Glyphaea brevis* (Spreng.) Monachino	1	0.25	1.14	0.22	0.13	0.68
Ulmaceae	*Celtis philippensis* Blanco syn *Celtis brownii* Rendle	1	0.40	1.14	0.36	0.21	0.75
	Celtis zenkeri Engl.	4	2.94	4.55	2.68	6.09	3.61
		88					

Table 3: Summary of floristic Composition of undergrowths Enrichment Plantation

Family	**Name**	**Life form**	**Ha^{-1}**	**RD**
Annonaceae	*Annickia chlorantha* (Oliv.) Setten & Maa Syn *Enantia chlorantha* Oliv	Sapling	3	0.540
	Hexalobus crispiflorus A. Rich.	Sapling	5	0.899
	Monodora myristica (Gaertn.) Dunal	Sapling	7	1.259
Apocynaceae	*Funtumia elastica* (Preuss) Stapf	Sapling	28	5.036
	Picralima nitida (Stapf) Th. & H. Dur.	Sapling	11	1.978
Araceae	*Anchomanes difformis* var. *difformis* Hepper	Herb	9	1.619
	Culcasia scandens P. Beauv.	Climber	104	18.71
	Cyrtosperma senegalense (Schott) Engl.	Herb	18	3.237
	Rhaphidophora africana N. E. Br	Climber	11	1.978
Bombacaceae	*Ceiba pentandra* (Linn.) Gaertn.	Sapling	7	1.259
Boraginaceae	*Cordia millenii* Bak.	Sapling	1	0.18
Burseraceae	*Canarium schweinfurthii* Engl.	Sapling	4	0.719
Combretaceae	*Terminalia ivorensis* A. Chev.	Sapling	2	0.36
Deteriodeae	*Anthonotha macrophylla* P. Beauv.	Sapling	16	2.878
Dilleniaceae	*Tetracera potatoria* Afzel. ex G. Don	Climber	13	2.338
Ebenaceae	*Diospyros dendo* Welw. ex Hiern	Sapling	14	2.518
	Diospyros mespiliformis Hochst. ex A. DC.	Sapling	1	0.18
	Diospyros monbuttensis Gürke	Sapling	2	0.36
	Diospyros suaveolens Gürke	Sapling	7	1.259
Euphorbiaceae	*Ricinodendron heudelotii* (Baill.) Pierre ex Pax	Sapling	18	3.237
Icacinaceae	*Pyrenacantha staudtii* (Engl.) Engl.	Climber	11	1.978
Meliaceae	*Entandrophragma utile* (Dawe & Sprague) Sprague	Sapling	18	3.237

	Khaya grandifoliola C. DC.	Sapling	3	0.54
Moraceae	*Ficus exasperata* Vahl	Sapling	2	0.36
	Milicia excelsa (Welw.) C.C. Berg	Sapling	10	1.799
	Myrianthus arboreus P. Beauv.	Sapling	13	2.338
	Trilepisium madagascariense DC.	Sapling	28	5.036
Piperaceae	*Piper capense* Linn. F	Climber	9	1.619
	Piper guineense Schum. & Thonn.	Climber	23	4.137
Rubiaceae	Geophila obvallata (Schumach.) F. Didr.	Herb	17	3.058
Rutaceae	*Zanthoxylum rubescens* Planch. ex Hook. f.	Sapling	4	0.719
Sapindaceae	*Lecaniodiscus cupanioides* Planch. ex Benth.	Sapling	14	2.518
Sapotaceae	*Chrysophyllum albidum* G. Don	Sapling	3	0.54
	Chrysophyllum perpulchrum Mildbr. ex Hutch. & Dalz.	Sapling	8	1.439
Sterculiaceae	*Cola acuminata* (P. Beauv.) Schott & Endl.	Sapling	4	0.719
	Cola gigantea var. *glabrescens* Brenan & Keay	Sapling	16	2.878
	Cola hispida Brenan & Keay	Sapling	11	1.978
	Mansonia altissima (A. Chev.) A. Chev. var. altissima	Sapling	17	3.058
	Pterygota macrocarpa K. Schum.	Sapling	5	0.899
	Sterculia rhinopetala K. Schum.	Sapling	7	1.259
	Sterculia tragacantha Lindl.	Sapling	24	4.317
	Triplochiton scleroxylon K. Schum.	Sapling	7	1.259
Ulmaceae	*Celtis mildbraedii* Engl.	Sapling	4	0.719
	Celtis philippensis Blanco	Sapling	9	1.619
	Celtis zenkeri Engl.	Sapling	28	5.036
			576	

Table 4: Summary of the results of various diversity indices conducted

Forest Structure	Aboveground	Undergrowth
Taxa_S	47	45
Individuals	88	576
Dominance_D	0.03306	0.05533
Simpson_1-D	0.9669	0.9447
Shannon_H	3.634	3.374
Evenness_e^H/S	0.8058	0.6485
Species richness_M	19.6	90.5
Margalef	10.27	6.922

Fisher_alpha	41.01	11.42

Figure 1: The Enrichment Plantation showing the study area

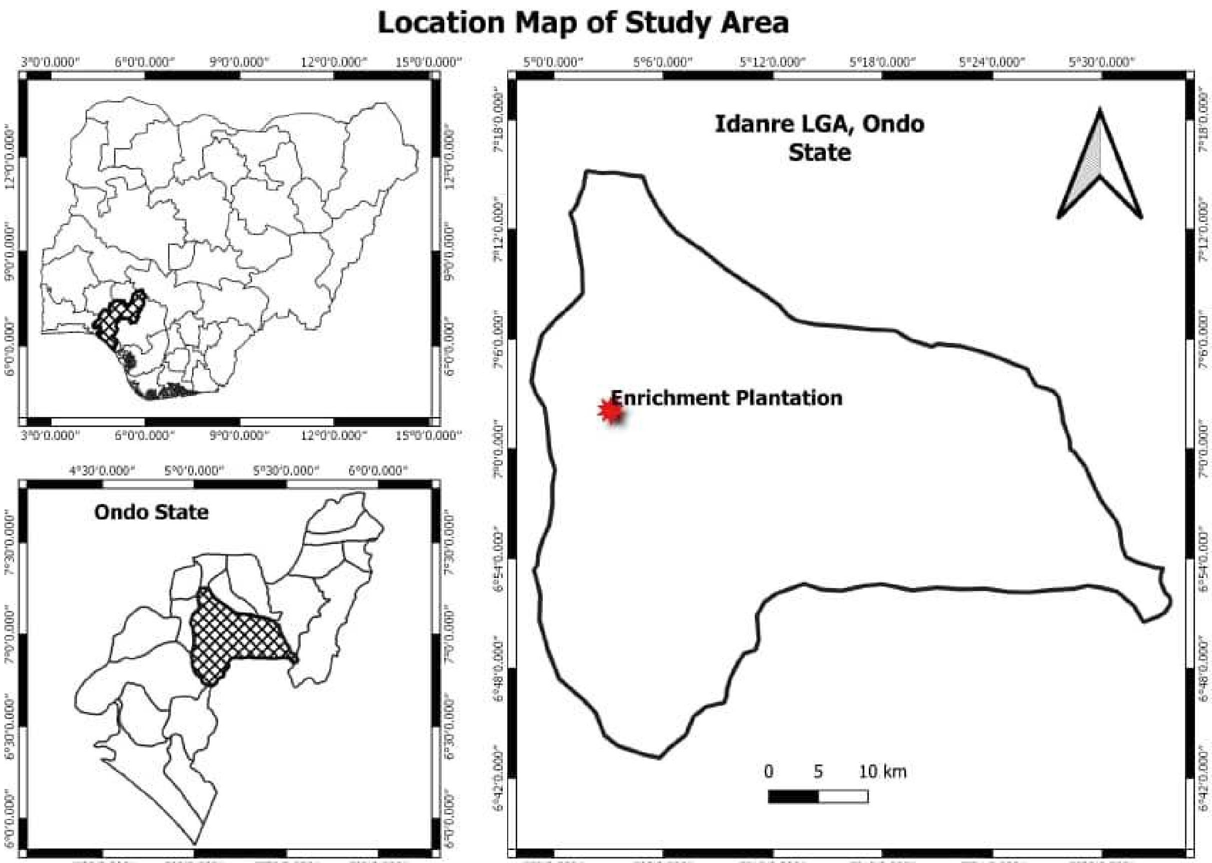

Figure 2: Map of the study area

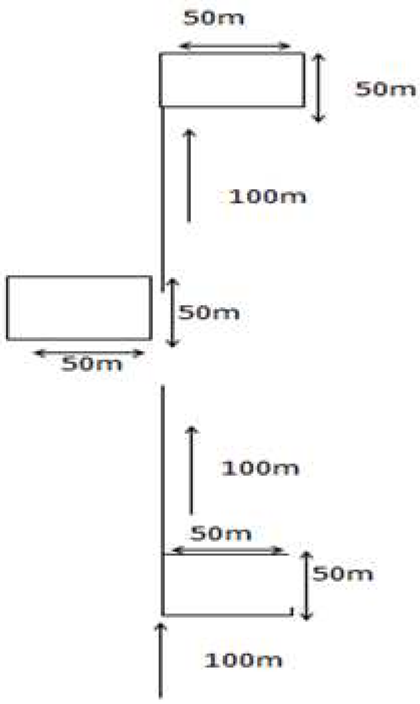

Figure 3: Systematic line transects sampling technique for the study area

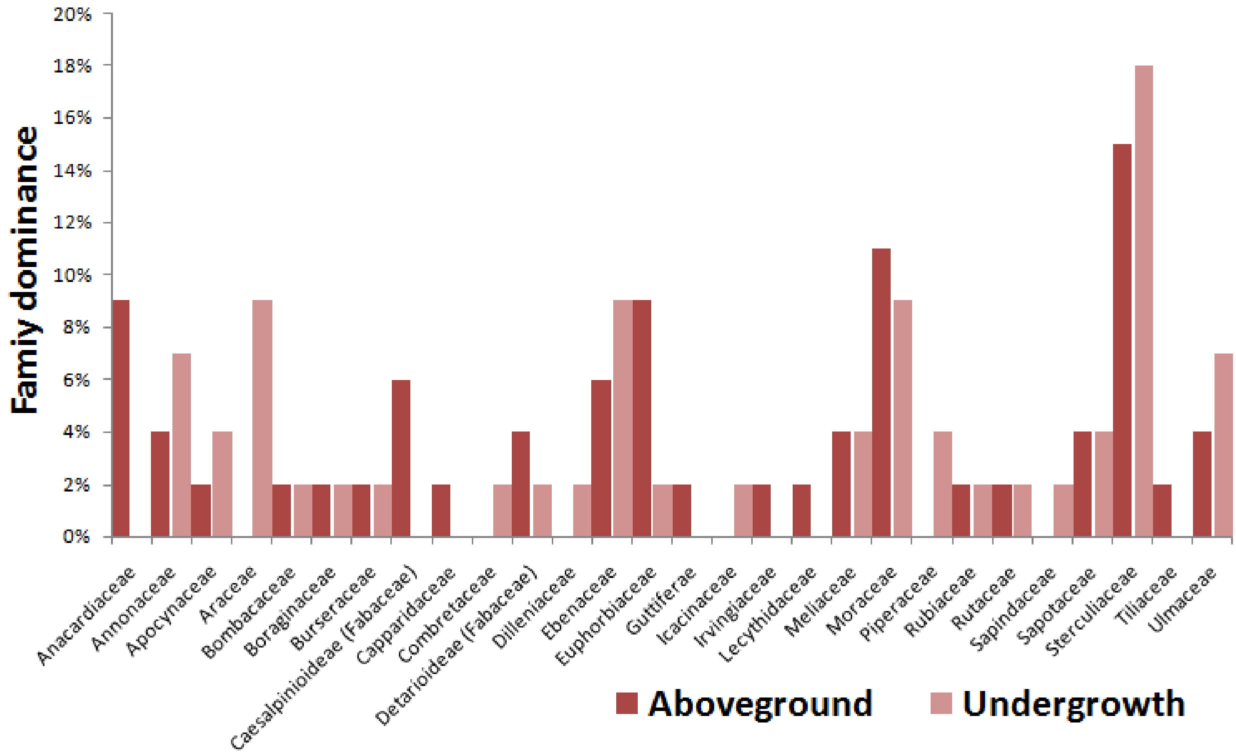

Figure 4: The family composition in the study areas consisting of total number of tree families.

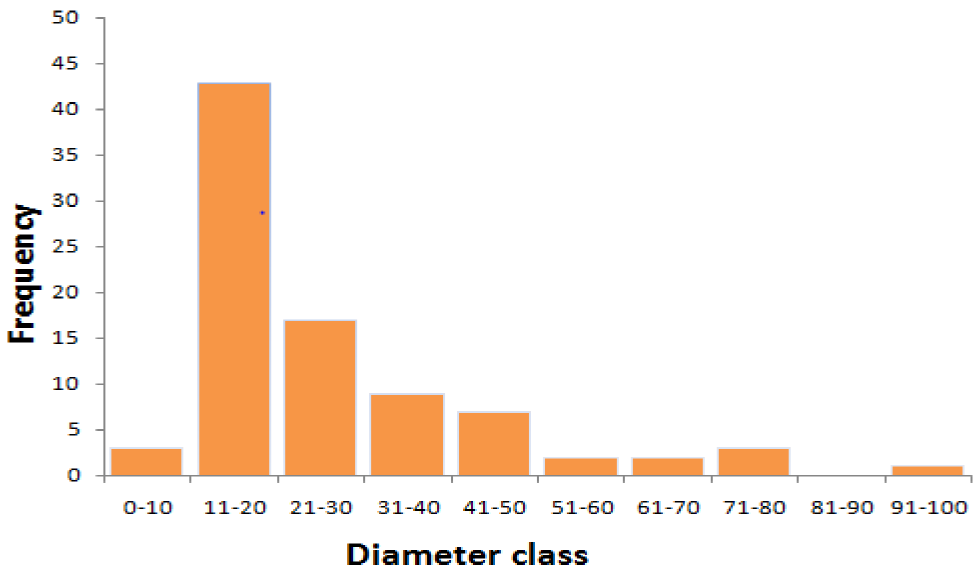

Figure 5: Diameter class showing diameter distribution among the aboveground tree species in the study area

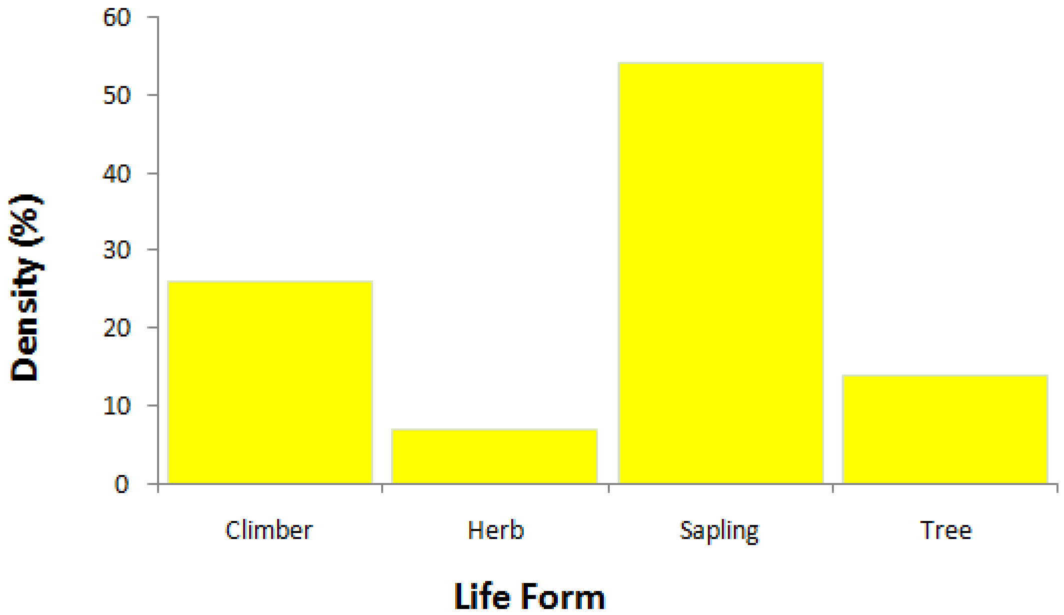

Figure 6: The different life forms of the Enrichment Plantation

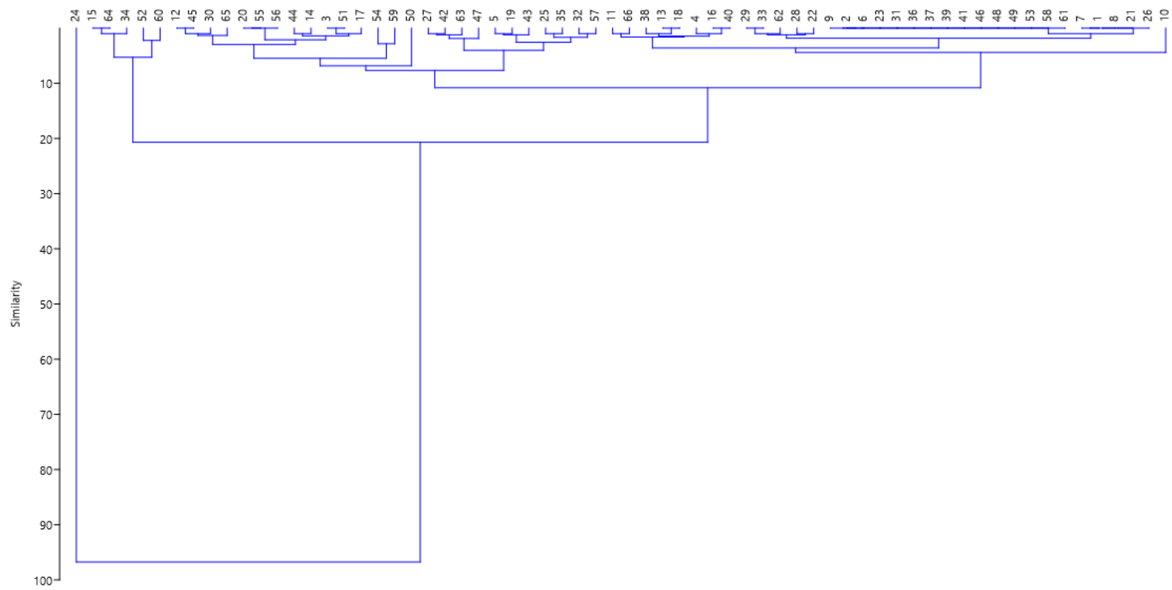

Figure 7: Clustering of plant species populations in the study area. Each number represents the species name shown in Table 1.

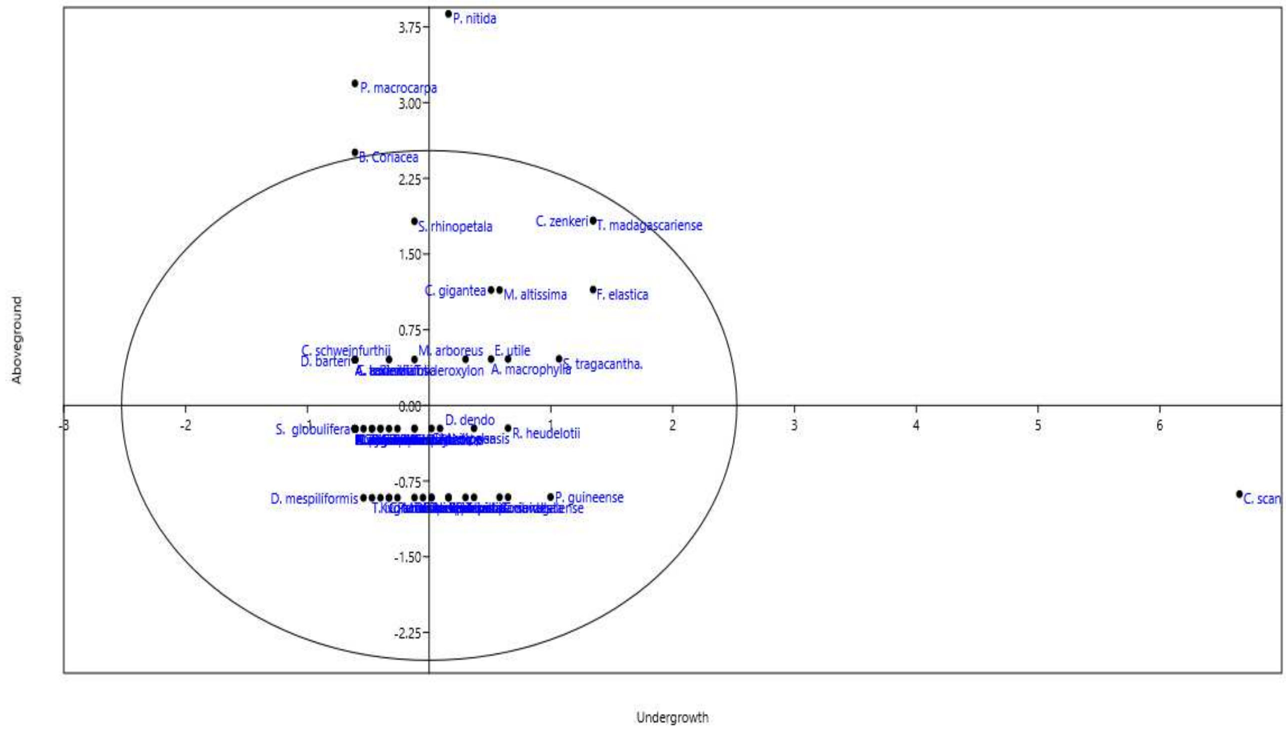

Figure 8: Principal Component Analysis showing variations in the distribution of plant species with regards to the aboveground and undergrowth.

Figures

Figure 1

The Enrichment Plantation showing the study area

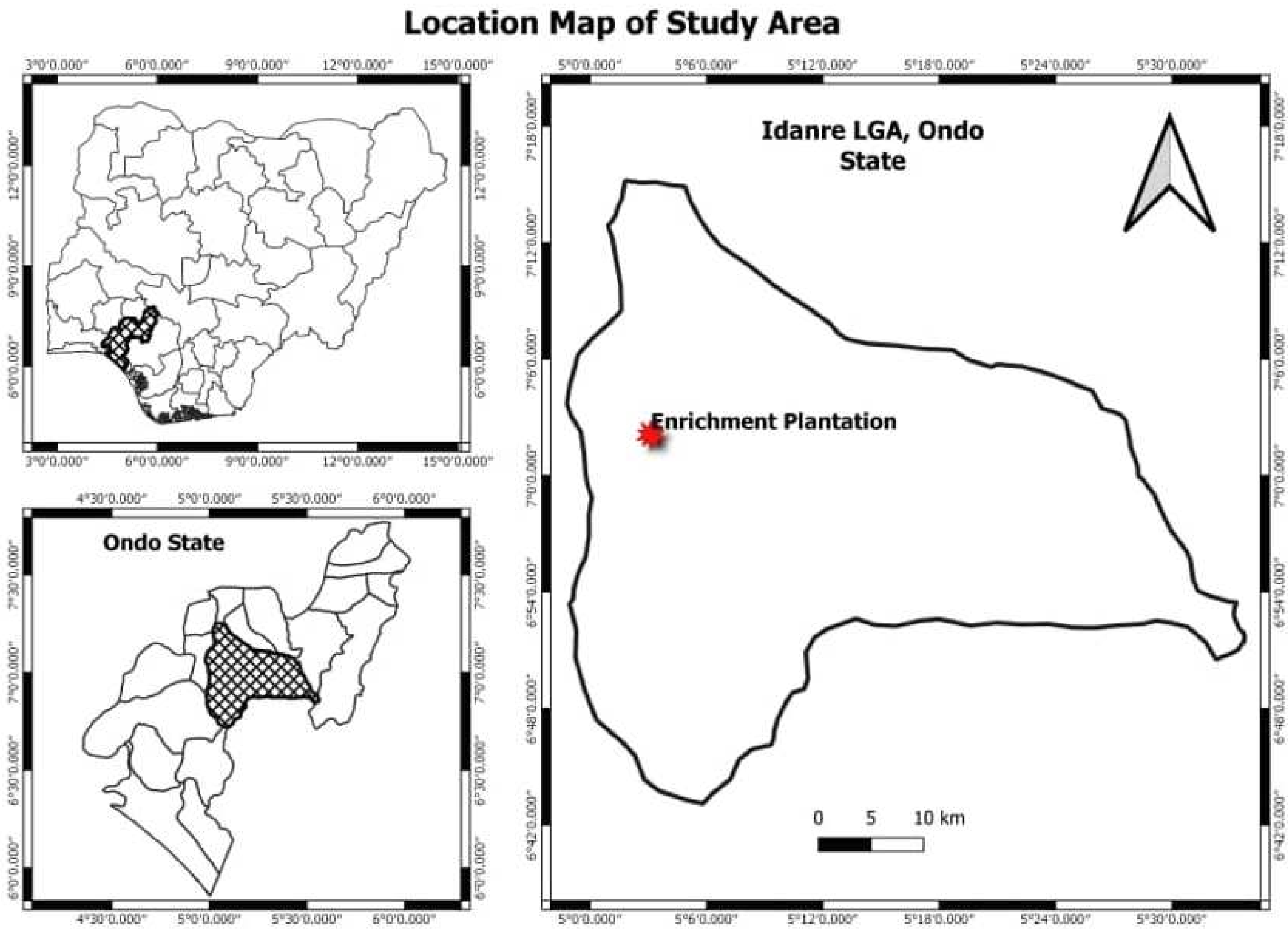

Figure 2

Map of the study area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

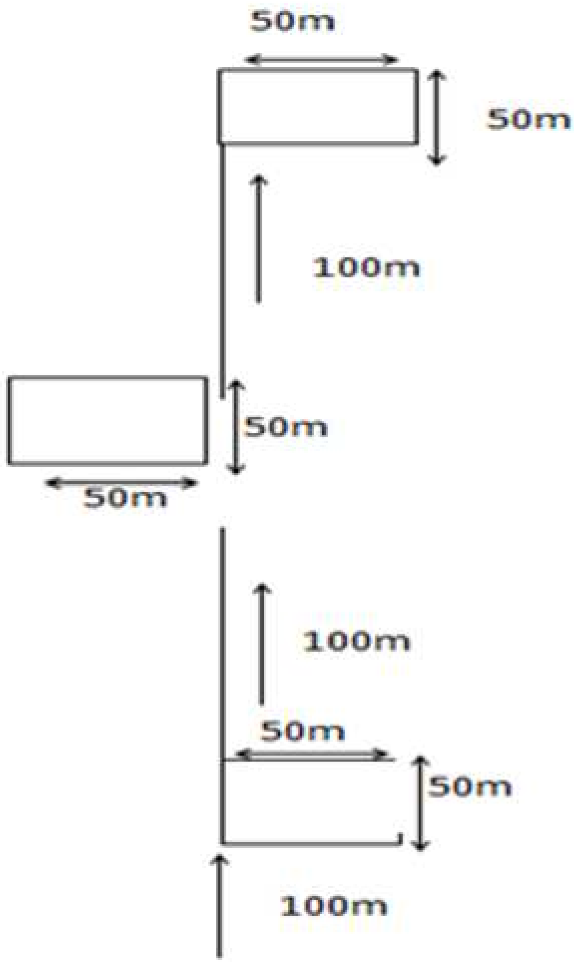

Figure 3

Systematic line transects sampling technique for the study area

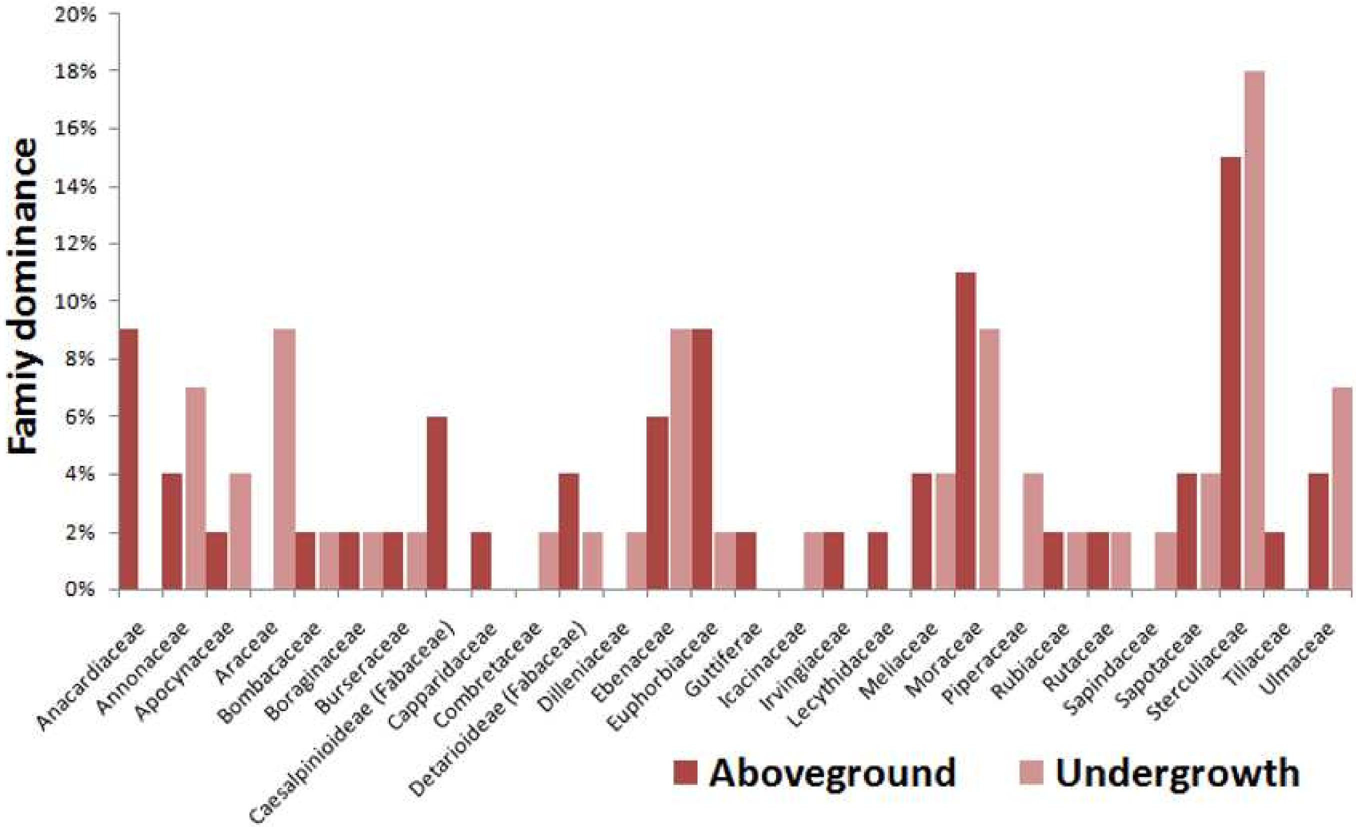

Figure 4

The family composition in the study areas consisting of total number of tree families.

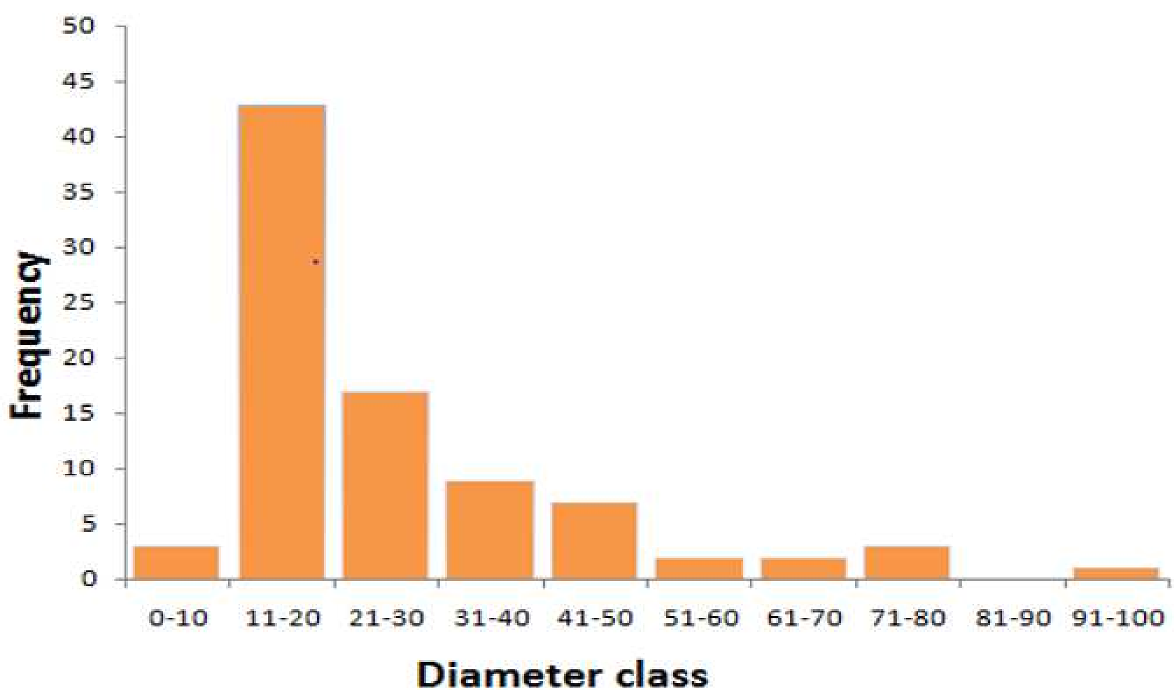

Figure 5

Diameter class showing diameter distribution among the aboveground tree species in the study area

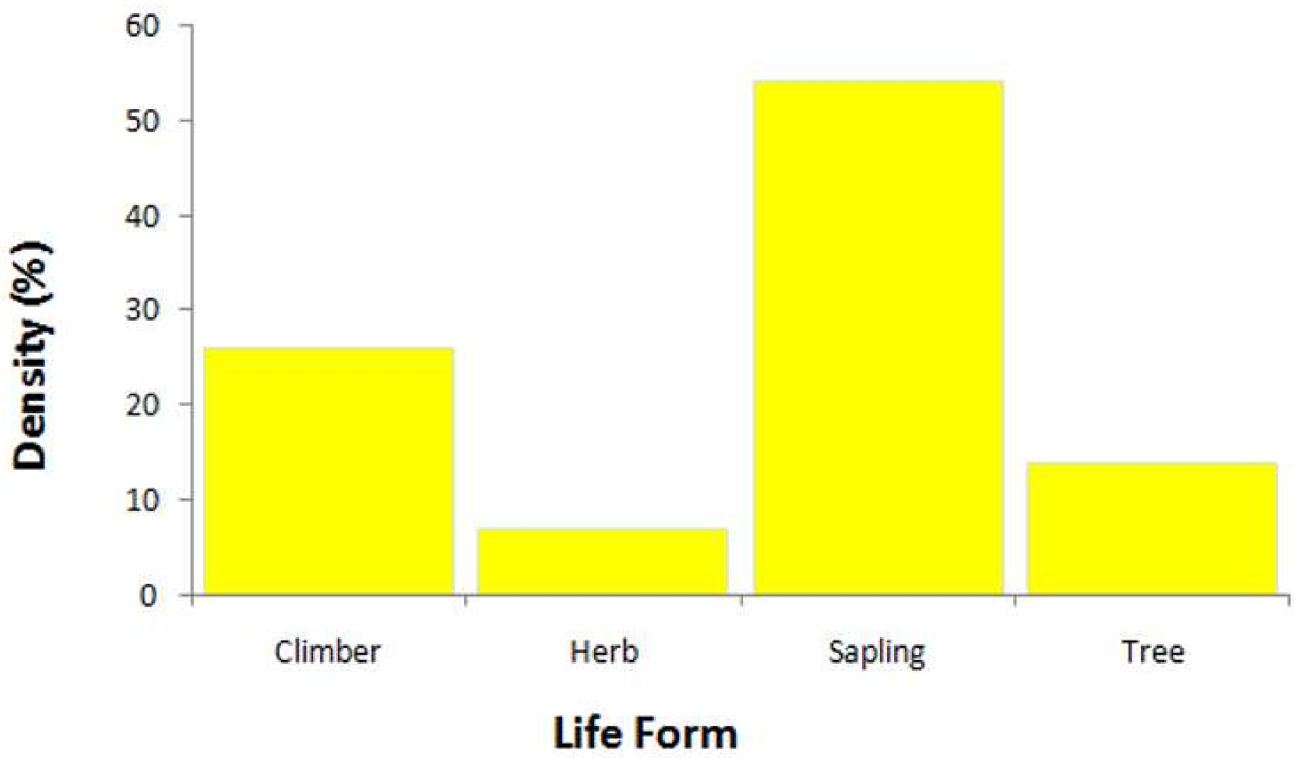

Figure 6

The different life forms of the Enrichment Plantation

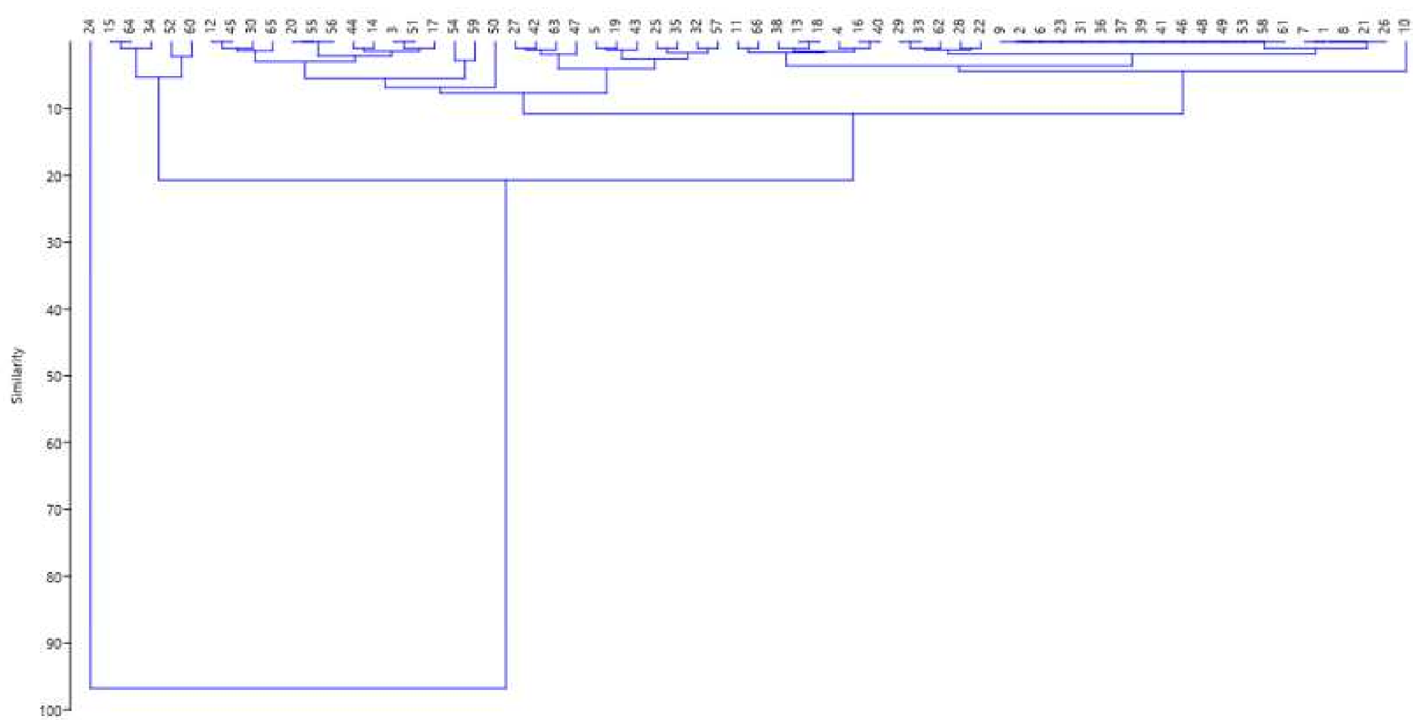

Figure 7

Clustering of plant species populations in the study area. Each number represents the species name shown in Table 1.

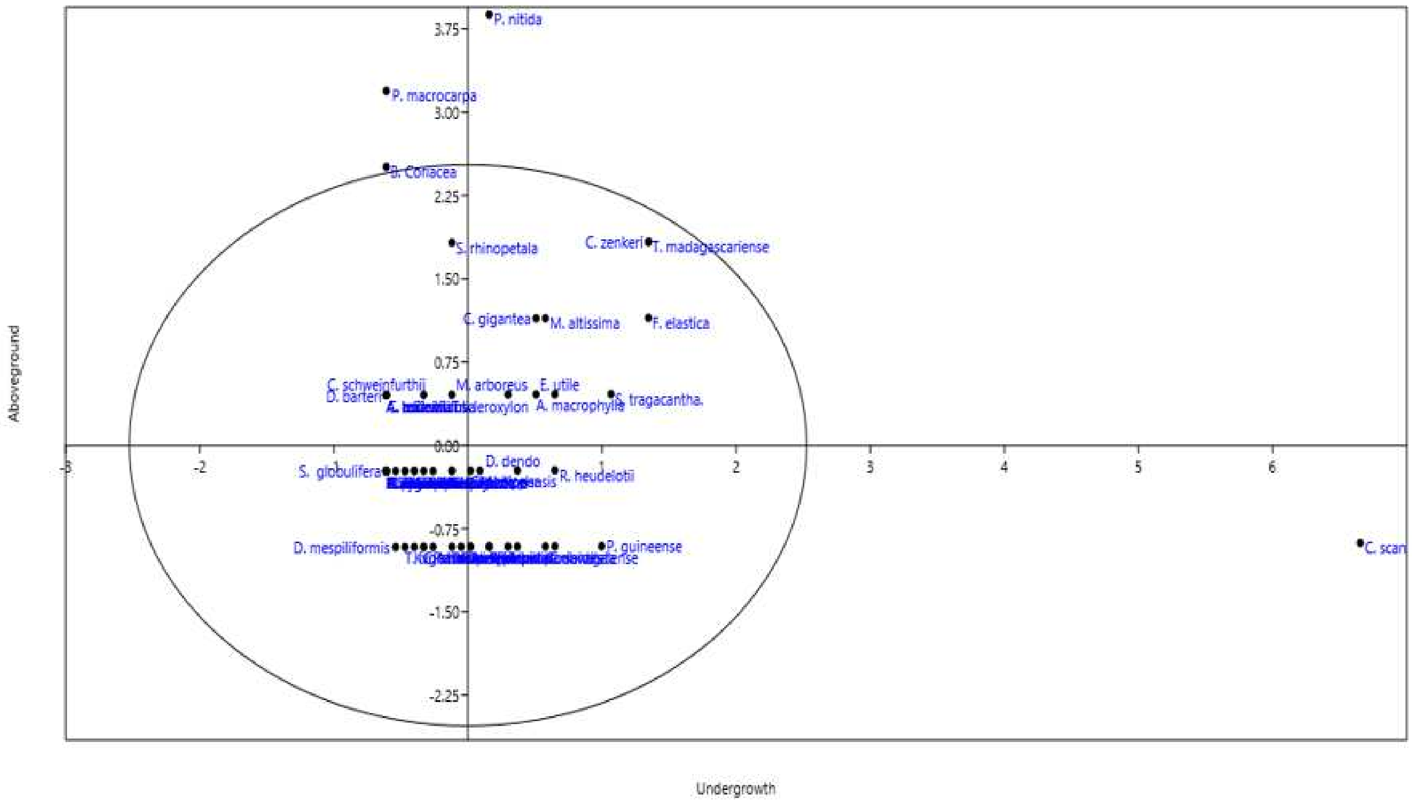

Figure 8

Principal Component Analysis showing variations in the distribution of plant species with regards to the aboveground and undergrowth.