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Structures of Forest Stands in Monospecific Reforestations Based on *Tectona grandis* Lf. (Verbenaceae) in the Sangoué Classified Forest in Côte d'Ivoire

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Abstract: Teak-based reforestation poses the challenge of sustainable development in terms of meeting economic, social and environmental needs. In order to meet the needs of populations for timber and contain anthropogenic pressures on flora, reforestation based on *Tectona grandis* is initiated in the Sangoué Classified Forest. Therefore, a diagnostic study is therefore essential to assess the effects of this practice on the environment. This study assessed the consequences of planting *Tectona grandis* on the conservation and restoration of the Sangoué classified forest. For this, the structural and floristic characteristics of teak stands at different stages of evolution were compared. The results showed that young plots have more plant species, are more diverse and more evenly distributed. Older plots have the highest densities and basal areas of stems, with an inverted J-shaped distribution. Young plots have the lowest densities and basal areas, as well as a more regular horizontal structure. The woody species introduced into reforestation are *Tectona grandis*, *Gmelina arborea* and *Cedrela odorata*. In the 33-year-old block, the total basal area value is 18.07 m² per hectare, then 13.72 m² per hectare in the 30-year-old block. As for the 25- and 28-year-old blocks, the basal area values per hectare are 12.61 m^2 and 9.39 m^2 respectively. Young plots promote natural regeneration and floristic diversity, while older plots present low floristic diversity with reduced structural balance. Introduced species have benefited more from teak planting than native ones. Teak planting may lead to profit, but it presents challenges for biodiversity. The impact of teak planting on the Sangoué classified forest differs depending on the stage of evolution of the stands. Therefore, it has advantages and disadvantages for forest restoration and conservation. The teak plantation needs to be adjusted to forest management.

Keywords: Plant biodiversity; Conservation; Silviculture; Classified forest.

INTRODUCTION

Reforestation is a common practice in tropical countries to restore degraded forests, produce wood and provide ecosystem services (Fayolle et al., 2014). Among the species used for reforestation, *Tectona grandis* Lf. is one of the most appreciated for its wood quality and its rapid growth (Badilla-Valverde and Murillo-Gamboa, 2022; Wirabuana et al., 2022). Teak-based reforestation has economic and social interests, particularly for job creation, income generation and the fight against poverty. It is an activity that has some ecological benefits such as carbon sequestration, soil protection and water conservation (Badilla-Valverde and Murillo-Gamboa, 2022). However, teak-based reforestation erodes the floristic composition and diversity of natural forests (Černý et al., 2023). We observe a reduction in the number of native and endemic species, a homogenization of forest populations, a reduction in ecological interactions and a loss of ecosystem services (Hitsuma et al., 2021). Teak-based reforestation therefore poses a sustainable development challenge in terms of meeting the economic, social and environmental needs of present and future generations (Černý et al., 2023).

In Côte d'Ivoire, beyond the rural domain, the practice of agriculture has intensified within state areas (Brou et al., 2004). The migratory flow, which has accelerated in the south of the country since the 1960s, has led to the rapid development of the coffee-cocoa duo with the harvesting of timber (Oszwald, 2005; AKA et al., 2016). The State has implemented a forestry policy to curb the effects of this deforestation. It manifested itself, among other things, in the creation of classified forests. This is how the Sangoué Classified Forest was created in 1973 (SODEFOR, 2022). This forest has suffered significant degradation due to agriculture, logging and fires (N'GUESSAN et al., 2022).

In order to reconstitute the forest cover, reforestation based on *Tectona grandis* is initiated in the Sangoué Classified Forest. This reforestation was to meet the population's needs for timber and then contain anthropogenic pressures on the flora (SODEFOR, 2022). After the first reforestation operations in the Sangoué Classified Forest, it is possible to attempt a diagnostic evaluation. The question of characterizing the structures and floristic compositions of populations based on *Tectona grandis* is required.

The objective of this study was therefore to improve knowledge on the changes brought about by the cultivation of *Tectona grandis* in the Sangoué classified forest. The study carried out to enhance understanding of the impacts of the *Tectona grandis* cultivation on the Sangoué classified forest (Oumé) in order to provide managers with decision-making data to guarantee the sustainability of forest management.

MATERIALS AND METHODS

Study site

Sangoué classified forest (Figure 1) has an area of 36,200 hectares and is located in the Gôh-Djiboua district between 5.61° and 5.36° West longitudes and between 6.12° and 6.33° North latitudes (SODEFOR, 2017). The climate is humid tropical with an average annual temperature of 26°C and an annual rainfall of 1400 mm. There are two rainy seasons (March-July and September-November) and two dry seasons (December-February and August) (Timeanddate, 2023). The vegetation is dense semi-deciduous forest.

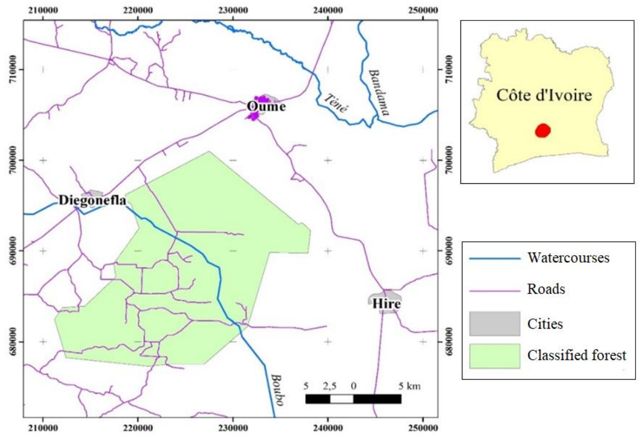

Figure 1: Location the Sangoué classified forest

Data collection

In the present study, the sampling device was installed in four reforestation blocks in the Sangoué Classified Forest. These are the 25-year, 28-year, 30-year and 33-year reforestation blocks. In each reforestation block of the Sangoué Classified Forest, 10 data collection plots were installed.

These devices are equidistant by at least 500 m. In each plot, the individuals of Tectona grandis as well as all the other plant species present were inventoried. The sampling device consists of a rectangular plot of 25 mx 200 m, or 5000 m² (0.5 ha). At the level of each plot, the age of reforestation and the previous cultivation of Tectona grandis were recorded. On each inventory plot, the plant species are identified and counted. The diameters at 1.3 m from the ground are measured for woody plants. The inventoried plants were identified using Hawthorne's identification key (1996). The determination of species names was based on the work of Lebrun and Stork (1997) and the nomenclature of families on APG IV (2016).

Data analysis

The qualitative diversity of reforestation plots based on *T. grandis* in the Sangoué Classified Forest, was evaluated through floristic richness and morphological type. Floristic richness is the number of species recorded within the limits of a territory, without taking into account their abundance (Aké-Assi, 2004). Biological types make it possible to characterize the vegetative system, physiognomy and habitat for each plant species (Raunkiaer, 1934). Biological types were used to describe the morphological characteristics of plant species in the reforestation blocks. These biological types, based on the classification according to Raunkiaer (1934), are Megaphanerophytes (MP), trees more than 30 m above the ground; Mesophanerophytes (mP), trees of sizes between 8 and 30 m; Microphanerophytes (mp), woody plants measuring between 2 and 8 m; Nanophanerophytes (np), woody plants between 0.5 and 2 m high; Chamephytes (Ch), cushion plants with a vegetative apparatus growing less than 40 cm from the ground buds; Hemicryptophytes (H), plants having an aerial vegetative apparatus and whose buds form on the

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collar; Therophytes (Th), annual plants which appear in the form of seeds during the unfavorable season during their cycle; Geophytes (G), plants whose multiplication organs are buried in the soil while degeneration of the aerial part is observed during unfavorable periods; epiphytes (Ep), plants that live on other host plants.

The quantitative diversity of the different reforestation blocks was assessed through the diversity index according to Shannon (1948) and fairness according to Piélou (1966). The diversity index (H) of Shannon (1948) is a measure of the specific diversity of a biological environment based on the relative abundance of species and specific richness in the environment. $H = -\sum_{i=1}^{s}(pi\ lnpi)$, with *pi*=*ni*/N where H is the Shannon index; *pi* is the relative abundance of species *i*; *ni* is the number of species *i*; N is the total number of surveys and S is the total number of taxa.

Piélou's equitability or regularity or equidistribution is a measure which makes it possible to compare the diversity of an environment in relation to the theoretical maximum diversity. It is calculated from the Shannon index and the number of species present in the environment. E=H/Hmax; where E is the Pielou fairness index; H is the Shannon index; Hmax is the total number of species recorded in the biotope concerned. Hmax is the maximum diversity or equifrequency. Hmax=*ln*S; where S is the total number of taxa.

Sørensen similarity coefficient (1948) is used to assess the diversity of pairs of samples along a gradient between two different biotopes (Condit et al., 2002). Cs=[2C/(a+b)]x100; where a and b are the numbers of species belonging to plots A and B respectively; This is the number of species common to the two plots.

The structural diversity of individuals in the reforestation blocks was evaluated through the density of species. Density (d) is defined as the number of individuals per unit area (Rollet, 1979). Density was used to know the number of individuals for a given area and the land occupation by species. D = N/S; where N is the number of stems recorded and s the total surface area in hectares.

The density analysis made it possible to highlight the abundance of species on the inventoried surface. It also made it possible to highlight the variability in the density of plant species between the different plots sampled.

The dynamics of reconstitution of species associated with *T. grandis* in the Sangoué Classified Forest was evaluated through three parameters, namely the distribution of stems by diameter classes, density and basal area. These three parameters made it possible to determine the local variations of this dynamic and the interaction of the phenomena at different scales of time and space. The distribution of stems by diameter classes is a method of demographic study of plant populations which makes it possible to assess the stability of a biotope. (Bouko et al., 2007; Jiagho, 2018). It made it possible to construct, for each biotope in the Sangoué Classified Forest, a histogram which provides information through the shape, balance and evolution of the populations of the species listed. The density of a stand varies within the plot depending on local conditions such as age, slope, drainage, aspect and silvigenetic stage (Guillemette et al., 2023).

The basal area also allows us to have a precise idea of the space occupied by the populations of species present in the biotope. studied (Rolet, 1979). The basal area corresponds to the sum of the horizontal sections of the trunks, taken by convention at 1.30 m from the ground (Rollet, 1979). It is calculated, for the entire population, by species or by groups of species (Jiagho, 2018). $S=\sum(D^2 x\pi/4)$, S is the basal area expressed in m^2/ha; D is the diameter obtained from the circumference, measured at 1.30 m above the ground. The different diversity indices were compared through an analysis of variance (Cuevas et al., 2004).

RESULTS

Floristic richness and floristic composition

Botanical inventories in the four plots of the Sangoué classified forest made it possible to draw up a list of 53 plant species distributed between 46 genera and 17 families. The 28-year block, with 44 plant species, has the greatest species richness, while the 30-year block has only 29 species. The 25-year and 33-year blocks have 38 species and 30 species, respectively. The Ficus genus is the most represented on all reforestation blocks with 4 species. These are *Ficus capensis*, *Ficus dicranostyla*, *Ficus exasperata* and *Ficus mucuso*. The genera *Blighia*, *Celtis*, *Cordia*, *Dialium* and *Myrianthus* are each represented by 2 species. The most represented family is that of Moraceae with 7 species. Then come those of the Sterculiaceae with 5 species and the Apocynaceae with 4 species. Finally, Bignoniaceae, Boraginaceae, Fabaceae, Mimosaceae and Ulmaceae each have 3 species.

Regarding stem densities per collection site, the inventories show that the 33-year-old block has 770.67±142 stems per hectare. It is followed by the 30-year block with 424.49±97 stems per hectare. The 25- and 28-year-old blocks have respectively 410.19±110 stems per hectare and 314.09±72 stems per hectare.

Figure 2 shows the spectrum of biological types according to the age of the plots. We observe a strong dominance of microphanerophytes in block 4 of 28 years. Block 1, aged 33 years, then block 2, aged 30 years, have the lowest numbers of microphanerophytes. As for mesophanerophytes, they are also predominant in the oldest plots. Young plots have fewer mesophanerophytes. Figure 3 presents the spectrum of chorological affinities of the species inventoried across all collections. We observe that Guinean-Congolese species are the most dominant chorological affinities in the inventoried plots with 66%, in all biotopes. Introduced species represent 83.41% of the total flora inventoried in the 25-year and 28-year blocks, which are the most recent. These introduced species are *Tectona grandis*, *Cedrela odorata* and *Gmelina arborea*. In the 30- and 33-year blocks, *Cedrela odorata* and *Tectona grandis* are the introduced species.

According to the IUCN red list of species with special status (2020), 36 listed species are of concern, *Cedrela odorata*, *Nesogordonia papaverifera* and *Pterygota macrocarpa* are vulnerable. *Cordia vignei*, *Milicia excelsa*

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and *Vepris suaveolens* are almost threatened.

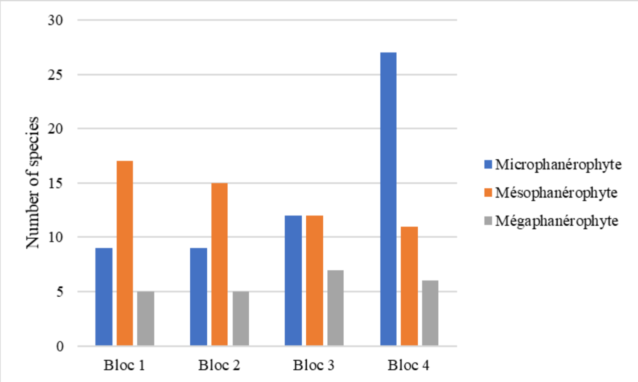

Figure 2: Spectrum of biological types depending on the age of the sampling plots (Block 1: 33 years; Block 2: 30 years; Block 3: 28 years; Block 4: 25 years)

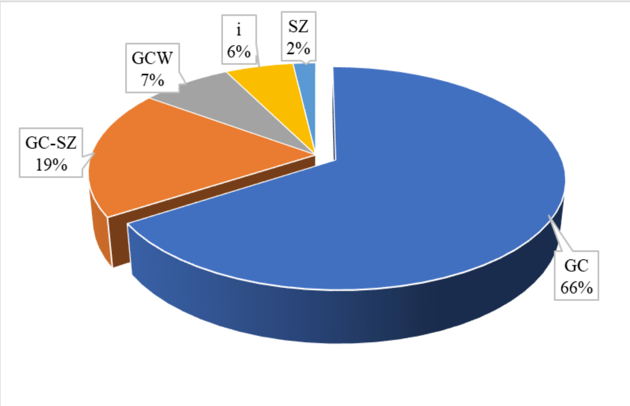

Figure 3: Spectrum of chorological affinities of all inventoried species (GC: Guinea-Congolese; GC-SZ: Guinea-Congolese and Sudanese transition zone; GCW: Endemic to West Africa; i: introduced; SZ: Sudano-Zambézian)

Table I presents Shannon diversity indices and Piélou equitability indices. Shannon diversity indices range from 1.65 ± 0.004 bits in 33-year-old plots to 3.85 ± 0.009 bits in 28-year-old plots. Young plots (25 and 30 years) are more diverse than old plots (F = 3.05 ± 1.4; P = 0.527). Equitability indices range from 0.388 ± 0.25 in 33-year-old plots to 0.82 ± 0.44 in 28-year-old plots. Individuals of the species inventoried in young plots are more evenly distributed than those in old plots (K = 0.78 ± 0.35; P = 0.64). The 25-year and 30-year blocks have intermediate Shannon diversity indices and equitabilities. Table II highlights the correlation matrix of Sorensen similarity coefficients. The floristic similarities are significant between the 25-year and 30-year reforestation blocks. On the other hand, they have values lower than 28% on all the other reforestation blocks.

Table I: Values of species diversity indices and species richness

Age of reforestation blocks	Shannon index	Fairness Index
25 years	2.30 ± 0.4^{ab}	$0.56 \pm ^{1.15a}$
28 years	3.85 ± 0.009^{b}	$0.82 \pm ^{0.4b}$
30 years	2.09 ± 0.9^{ab}	$0.55 \pm ^{0.12a}$
33 years	$1.65 \pm ^{0.004a}$	$0.388 \pm ^{0.25a}$
Test Statistics	*F= 3.05 ± 1.4* *P = 0.527*	*K = 0.78 ± 0.35* *P = 0.643*

Legend: The same superscript letter in a row indicates no significant difference between variables.

Table II: Similarity index values between reforestation blocks

	25 years	28 years	30 years	33 years
25 years	100	-	-	-
28 years	28	100	-	-
30 years	65	35	100	-
33 years	11	18	18	100

(Coefficient values according to Sorensen in percentage)

The horizontal structures of the different reforestation blocks have similar shapes (Figures 4, 5, 6 and 7). Individuals with diameters greater than 20 cm are more abundant on the 28-year-old, 30-year-old and 33-year-old plots. On all plots, individuals with diameters less than 10 cm are present in significant numbers.

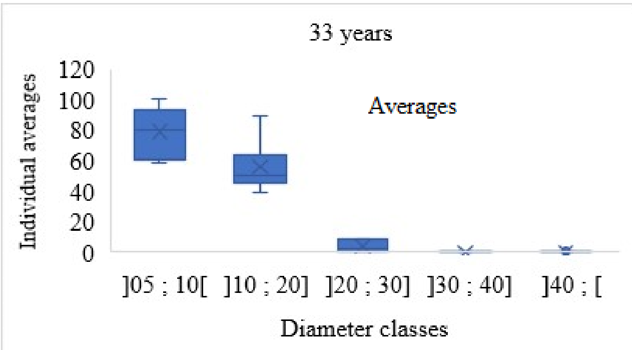

Figure 4: Woody plant diameter classes in 33-year-old reforestation blocks

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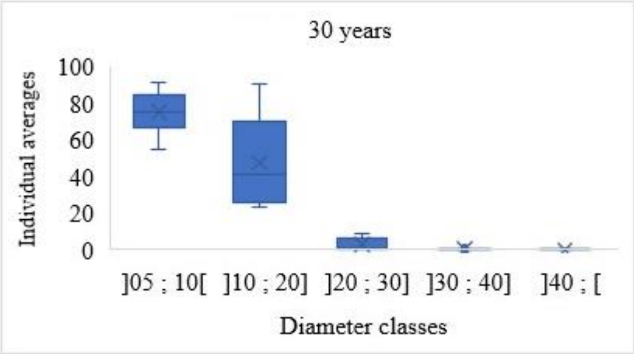

Figure 5: Woody plant diameter classes in 30-year-old reforestation blocks

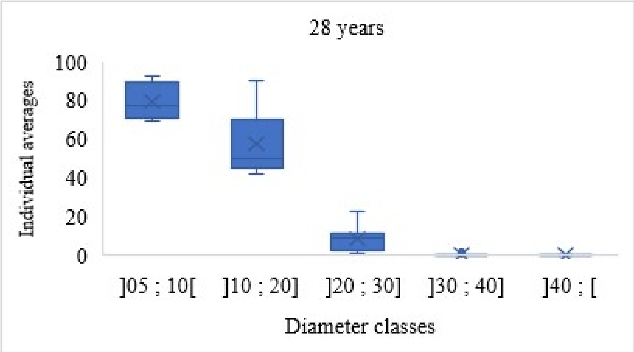

Figure 6: Woody plant diameter classes in 28-year-old reforestation blocks

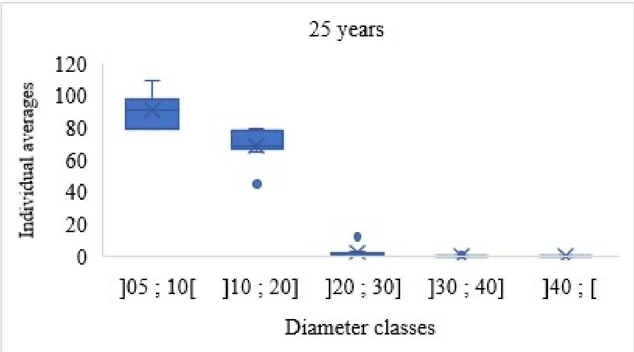

Figure 7: Woody plant diameter classes in 25-year-old reforestation blocks

The plots of the 25-year-old block have a basal area of 12.61 m^2 per hectare. The major species is *Tectona grandis* which covers 42.09% of the basal area. It is followed by *Cedrela odorata* with 23.04% coverage followed by *Gmelina arborea* (11.71%) and *Ficus exasperata* (11.46%). On the plots of the 28-year-old block, the total basal area is 9.39 m ^{2} per hectare. *Tectona grandis*, 39.69% cover, is the major species. It is followed by *Nesogordonia papaverifera* which represents 29.93% of the total basal area. *Vepris suaveolens* and *Newbouldia laevis* follow with 11.54% and 11.20% of the basal area respectively. *Baphiapubescens* (9.36%) and *Dictyandra arborescens* (7.02%) also occupy a significant basal area.

Floristic inventories carried out in the 30-year-old block provided a basal area of 13.72 m² per hectare. The most important species in the basal cover are *Tectona grandis* (40.16%) and *Cedrela odorata* (23.11%), all introduced by reforestation. Other local species such as *Ficus exasperata* (15.22%), *Gmelina arborea* (9.73%) and *Terminalia superba* (5.61%) have the highest coverage values. In the 33-year-old block, the total basal cover value is 18.07 m² per hectare. *Tectona grandis* (46.48%) and *Cedrela odorata* (45%) present the high values of total basal cover. They are followed by *Milicia excel* which occupies 2.43% of this basal cover.

DISCUSSION

This study made it possible to identify 53 floral species. Moraceae, Sterculiaceae and Apocynaceae are the most diverse families in the inventoried plots. The diversity and fairness indices observed have low values. This suggests that these populations are poor and not fairly distributed (Kokou et al., 2006). This situation could be linked to the nature of the inventory plots which are reforestation blocks having undergone phases of silvicultural treatment. Reforestation blocks are artificial forests with phases of wood harvesting.

Introduced species such as *Cedrela odorata* and *Gmelina arborea* are observed in the different reforestation blocks. The presence of these species in other distribution areas shows that they adapt better to the conditions of the local environment. They then behave like local species with an often more efficient dispersal mechanism. Neuba et al. (2014) showed that introduced plant species in Côte d'Ivoire proliferate to the detriment of other local species.

This work showed a clear dominance of microphanerophytes in the different reforestation blocks. This result could be due to the fact that these plants are adapted to shading and to competition for light (N'Dri et al., 2010). The abundance of microphanerophytes shows a tendency for vegetation to resume in these environments disturbed by wood removal and other silvicultural practices. No dynamics are observed in the population depending on the age of the plots. This may also reflect the effect of anthropogenic or natural disturbances having affected the plots at different levels of evolution of the reforestation plots. The dominance of Guinean-Congolese species was observed in all study plots. This demonstrates the recovery of the natural vegetation of the Sangoué classified forest, which is part of the Guinea-Congolese forest domain (Miabangana et al., 2016; Gbodjinou et al., 2022).

Species of least concern, vulnerable species and near-threatened species are observed across all inventories. This particularity of the site highlights the ecological importance of the Sangoué classified forest. These species are important for the conservation of biodiversity and for the ecosystem services they provide (Tiébré et al., 2016). However, they are threatened by deforestation, logging, poaching and bushfires.

The structural parameters present dense undergrowth with significant variations depending on the physiognomy of the higher strata. This density of the undergrowth is reflected by covering histograms which have very widened bases. The different plots have an average canopy coverage.

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This situation is also observed in intermediate degradation forests (Kouamé et al., 2021). Kouamé et al. (2021) reported that these forests which have undergone logging have more or less large openings in the upper strata due to the fall of felled trees. The reconstitution of the vegetation, in the exploitation zones, depends on several factors including the state of the surrounding vegetation and then the silvicultural exploitation techniques.

Differences in structure were more marked than differences in plant diversity between successional stages. Older plots had a greater amount of basal area. The increase in basal area as the age of the forest increases is a characteristic of secondary forests (Benavides, 2007). The species with the largest basal area values are the introduced species. This is explained by the high density of these reforestation species.

These are fast-growing forest species with high economic value, planted for the production of timber or service timber (Ouattara et al., 2023). They occupy the majority of space and light, thus limiting the development of other local species (Savadogo et al., 2020). This provision could constitute a threat to the plant diversity of the study site.

CONCLUSION

Botanical inventories in reforestation blocks aged 25 to 33 years identified 53 floristic species, including introduced species like *Cedrela odorata* and *Gmelina arborea*, and local species such as *Ficus*, *Blighia*, and *Celtis*. The cultivation of *Tectona grandis* (teak) has altered the flora, favoring introduced species of economic interest over native species of ecological value. Floristic richness and diversity are inversely proportional to the dominance of *Tectona grandis*, with plots dominated by teak showing higher density and basal area but lower diversity. Although teak-based reforestation is economically beneficial for the Sangoué classified forest, producing valuable wood, it negatively impacts ecological diversity. Balancing economic and ecological goals is essential for reforestation, especially in classified forests, to preserve biodiversity.

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Conflict of Interest

There are no conflicts of interest declared by the authors.

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