

Natural regeneration of woody species in *Acacia mangium* and *A. auriculiformis* stands in Anguédédou, Abidjan, Côte d'Ivoire

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Abstract. Kouadio KR, Kougbo MD, Touré SG, Coulibaly B, N'guessan AK, Bakayoko A. 2024. Natural regeneration of woody species in *Acacia mangium* and *A. auriculiformis* stands in Anguédédou, Abidjan, Côte d'Ivoire. *Asian J For* 8: 174-183. In the current context of climate change, forest landscape restoration is promoted to reverse forest ecosystem degradation. In Côte d'Ivoire, leguminous plants, notably Australian Acacias, have been introduced since 1980 at Anguédédou to restore the fertility of degraded farmland. The introduction of Acacias was seen as a potential disturbance to the local flora, as these non-native species are sometimes invasive. However, observation of these *Acacia*-based landscapes revealed good regeneration of woody species. The aim of this study was to assess the natural regeneration of woody plants under Acacias stands and its relation with stand ages. We assessed the floristic composition and studied the dynamics of natural regeneration of local woody species in four *Acacia* stands as a function of age. The results showed that the most widespread family of naturally regenerating plants in *Acacia* stands is Fabaceae. We noted an increase in the number of species as a function of stand age. The number of species rose from 20 (3-year-old stand) to 51 (27-year-old stand), with 28 species and 24 species in the 8-year-old and 11-year-old stands respectively. In all stands, mesophanerophytes represent the dominant plant life form. The Shannon-Wiener diversity index of natural regeneration increased from 1.66 ± 0.44 (3-year-old *Acacia* stand) to 2.45 ± 0.36 (27-year-old *Acacia* stand). In contrast, as the *Acacia* stands aged, the regeneration index decreased, with values of 1 (for the 3-year-old and 8-year-old *Acacia* stands), 0.94 (for the 11-year-old *Acacia* stand) and 0.81 (for the 27-year-old *Acacia* stand). This study shows that Acacias improve the local flora by promoting natural regeneration and the development of woody species.

Keywords: Acacias, forest restoration, natural regeneration

INTRODUCTION

The health of the world's forests is a major global concern as maintaining their ecological functions has a positive impact on living beings. Forests play an important role in mitigating climate change effects. Forests are the major ecosystems that maintain the microclimate and act as carbon sinks by sequestering and storing carbon (Verkerk et al. 2022). Every year, almost a third of global carbon emissions -2.6 billion tonnes of carbon dioxide- from fossil fuel combustion are absorbed by forests (IUCN 2022). In addition, forests deliver a wide range of ecosystem goods and services (Gosain et al. 2015; Awasthi et al. 2022a). These include the provision of timber and non-timber products, the protection of biological diversity, the supply of food and medicines and the maintenance of cultural and recreation services (Nakajima et al. 2017; Akujärvi et al. 2021; Mason et al. 2022; Hu et al. 2022).

Despite their importance role, many forest ecosystems in the world are threatened by anthropogenic activities (Trumbore et al. 2015) including agricultural expansion and intensification, invasion of invasive species and infrastructure development (Htun et al. 2011; Bargali et al. 2019; Fartyal et al. 2022; Negi et al. 2024; Pandey et al.

2024). Over the past three decades, global forest cover has declined by 420 million hectares, although the rate of deforestation fell from 16,106 ha per year in the 1990s to 10,106 ha per year between 2015 and 2020 (FAO 2020). Various disturbances on forest ecosystems cause biodiversity loss, disturb microbial activities and nutrient cycling and reduce forest productivity (Manral et al. 2020; Vibhuti et al. 2020; Padalia et al. 2022).

The loss of plant diversity is a major challenge faced by forest ecosystems in maintaining ecological sustainability (Hua et al. 2022; Bisht et al. 2023). To address such problem, reforestation efforts are promoted in tropical regions where deforestation and land degradation remains the major threats (Chazdon 2014; García et al. 2014). As a result, numerous international reforestation initiatives are being carried out in tropical countries. The aim of these commitments is the resilience of forest functions by halting deforestation and forest degradation and increasing forest cover (Curtis et al. 2018; Song et al. 2018; Chazdon et al. 2020). The downward trend in deforestation is therefore partly the result of global forest recovery through the regeneration of forest species in deforested areas (Garcia et al. 2020).

There are many approaches in forest restoration, from large-scale reforestation, agroforestry, natural regeneration, artificial regeneration and so on. All these practices have the same objective, namely to re-establish the ecological mechanisms that accelerate the recovery of forest formation, ecological functioning and biodiversity toward a climax forest (Elliot et al. 2013). However, across forest restoration efforts globally, they differ in planning, implementation and financial resources. Clearly, large-scale reforestation projects are very costly and therefore difficult to implement in many countries around the world. On the other hand, natural forest regeneration does not involve high economic costs (Fagan et al. 2020; Garcia et al. 2020; Holl and Brancalion 2020). Thus, forest restoration using natural regeneration approach seems indispensable, because it minimizes the implementation budgets (Garcia et al. 2020). Several methods are used to stimulate the natural regeneration of forest species. The process of natural regeneration is vital for forest ecosystems, as it enables these biotopes to renew themselves and conserve biodiversity. Natural regeneration impacts the stability and evolutionary succession of forests (Jin et al. 2018; Johnson et al. 2021; Zhang et al. 2022).

In Côte d'Ivoire, Australian Acacias were introduced in 1982 at Anguédédou to restore wasteland abandoned due to the loss of fertility caused by agricultural overexploitation (Kouadio et al. 2016). These wastelands originate from clandestinely established cultivation stands in the classified forest of Anguédédou. Thus, these Acacias were intended to contribute to forest reconstitution, but their presence has raised concerns for the local flora. Indeed, these leguminous plants can be invasive for native species and prevent their development. However, good plant diversity has been observed under *Acacia* stands in Anguédédou, Côte d'Ivoire (Kouadio et al. 2018). This raises questions as to whether *Acacia* stands promote the regeneration of

woody species and whether the floristic diversity of natural woody regeneration improves with stand age.

The aim of this work is to analyze the floristic composition of the natural regeneration of woody flora and to characterize the regeneration potential of woody species under two *Acacia* species (*Acacia mangium* Wild and *Acacia auriculiformis* A.Cunn. ex Benth.). Specifically, the objectives of the present study were to assess (i) the diversity of woody flora and their regeneration pattern and (ii) characterize the effect of the age of *Acacia* stands on the natural regeneration process of woody species. Ultimately, this article will demonstrate that leguminous trees can contribute to forest restoration by promoting spontaneous regeneration of forest woody species.

MATERIALS AND METHODS

Study area

This study was conducted in the classified forest of Anguédédou, located in the District of Abidjan (southern Côte d'Ivoire) at the coordinates of 5°22'-5°26' N and 4°04'-4°13' W (Figure 1). The dominant vegetation in the study area is dense evergreen rainforest (Guillaumet and Adjahoun, 1971). The climate is tropical equatorial, characterized by abundant annual rainfall (around 2,000 mm) and four seasons: a long rainy season (April-July), a short dry season (August-September), a short rainy season (October-November) and a long dry season (December-March). Average monthly temperatures range from 24.2°C to 27.4°C, with average monthly relative humidity ranging from 78 to 87% (Bi et al. 2010). The area's relief is marked by high plateaus (40 to 50 m and 100 to 120 m), mid-altitude plateaus (8 to 12 m), plains and deep valleys ranging from 12 to 40 m (Kablan 2016).

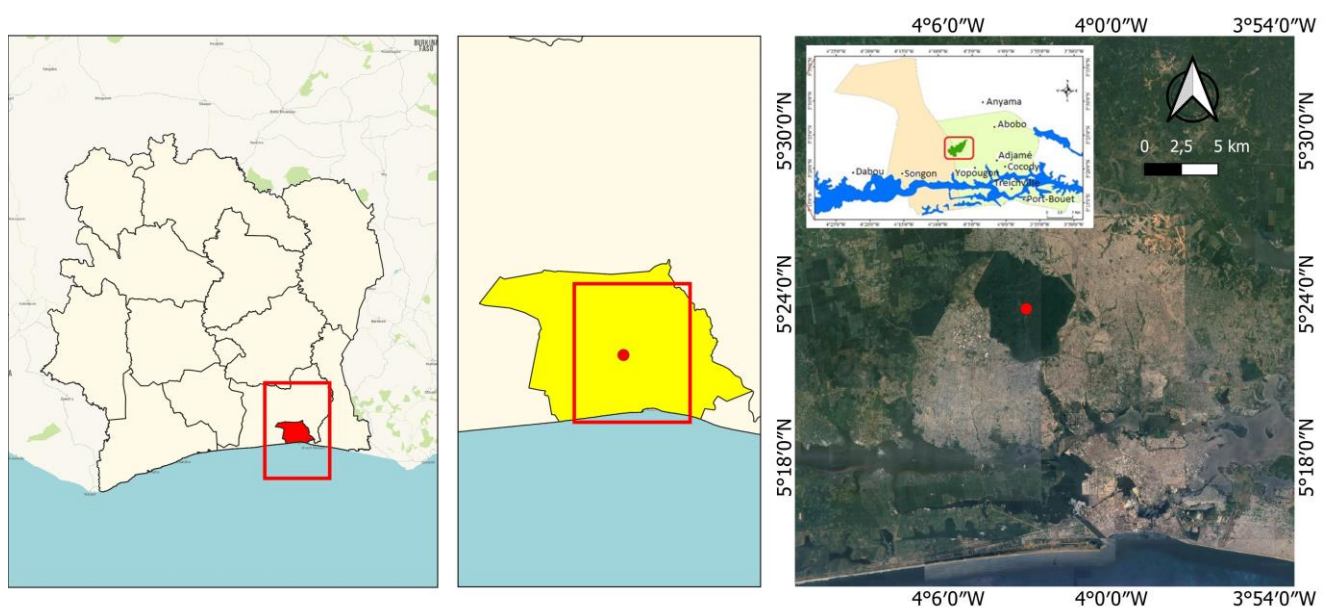


Figure 1. Map of study area in the classified forest of Anguédédou, District of Abidjan, Côte d'Ivoire

Data collection

A system of rectangular stands (50 × 35 m) was set up in the *Acacia* stands to collect data by means of floristic inventories. Four stand classes were defined based on the age of the *Acacia* species, i.e. 3 years (parc3), 8 years (parc8), 11 years (parc11) and 27 years (parc27). On each rectangular stand, five square plots (6x6 m) were installed, one at each corner and in the center of the stand. We combined the area survey (in the square stands) and the roving inventory (in the rectangular stands). All species present were first inventoried, then diameter measurements were taken on individuals at breast height, i.e., 1.30 m above ground level. To study natural regeneration, all individuals with a diameter of less than 5 cm were taken into account. This dendrometric threshold, already used by Assédé et al. (2015), makes it possible to minimize the inclusion in regeneration of mature individuals of shrub species predominantly present in the stands studied. Species were determined in the field or by laboratory identification (herbarium) of plant species samples collected. The nomenclature adopted was APG IV (2016).

Floristic analysis

Floristic analysis of natural regeneration focused on floristic composition and three regeneration parameters, namely specific regeneration rate, stand regeneration index and stand regeneration importance value. The life cycle of a tree is characterized by three stages following Baboo et al. (2017) as adults (dbh ≥ 10 cm), perches (3.2 ≤ dbh < 10 cm) and seedlings (dbh < 3.2 cm; height ≥ 30 cm). In this study, regeneration individuals have a diameter of less than 5 cm and a height greater than or equal to 30 cm.

Floristic composition

Floristic composition expresses the total number of taxa (families, genera, species) recorded, their taxonomic distribution and their biological and ecological characteristics. The parameters of floristic composition be considered in this study are floristic richness and biological types.

Floristic richness

In the sample of a plant community studied or in an ecosystem, the number of species, genera and families encountered represents floristic richness (Marcon 2015).

Plant life-form

This study considers only phanerophytes according to Raunkiaer (1934). The interest of addressing these plant life-form for natural regeneration is the prediction of the vertical structure of the future regenerated forest stand under acacias. Depending on the height of the species, a distinction must be made between: (i) megaphanerophytes (MP), trees with a height of over 30 meters; (ii) mesophanerophytes (mP), trees between 8 and 30 meters tall; (iii) microphanerophytes (mp), shrubs between 2 and 8 meters tall; (iv) nanophanerophytes (np), shrubs less than 2 meters high.

Species diversity index

The species diversity of natural regeneration was addressed using the Shannon-Wiener index (Shannon-Wiener 1963). This is a diversity index used to compare distinct plant communities. It associates the number of species and the relative abundance of each species in a given community. Its value commonly varies between 1.5 and 3.5 (Magurran 1988). The Shannon Index (H') is calculated by the following formula:

$$H' = - \sum_{i=1}^s p_i \cdot \log_2(p_i)$$

Where:

S: Total number of species present,

p_i : Abundance percentage of species present ($p_i = n_i/N$),

n_i : number of each present species individuals

N: total number of all species individuals;

\log_2 : base-2 logarithm

Species regeneration rate (SRR)

The specific regeneration rate is used to assess the relative abundance of a species within the natural regeneration of a group of stands. It is expressed as a percentage and is obtained by dividing the number of regenerating individuals of a species by the total number of regenerating individuals in the stand or stand concerned. Regeneration individuals are young individuals, i.e. those with a diameter of 5 cm or less. The Specific Regeneration Rate (SRR) is determined using the formula below:

$$SRR = \left(\frac{n}{N} \right) \times 100$$

Where :

n: Number of seedlings of each species,

N: Total number of surveyed seedlings

Regeneration index (RI)

The value of each stand's regeneration index (RI) is determined by the ratio of the number of regenerating individuals (diameter ≤ 5 cm) to the number of individuals of all diameters. This index is used to assess the age of the stand and has range between 0 and 1. The older the stand, the more the RI tends towards 0, while the younger the stand, the more the RI tends towards 1. The formula for calculating the Regeneration Index is as follows:

$$RI = \frac{r}{T}$$

Where:

r: number of regeneration individuals (diameter ≤ 5 cm)

T: number of all diameters individuals

Regeneration Importance Value (RIV)

The Regeneration Importance Value (RIV) was developed in this study to assess the weight of natural regeneration within each stand type. It is an index that

integrates the number of species resulting from natural regeneration and the regeneration rate of each species. For every stand, the higher the RIV, the more remarkable the level of natural regeneration. The RIV formula is as follows:

$$RIV = \left(\frac{r}{T}\right) \cdot \sqrt{sp}$$

Where:

r: number of regeneration individuals (diameter \leq 5 cm)

T: number of all diameters individuals

sp: number of natural regeneration species in the stand

Statistical analysis

All data were entered into an Excel spreadsheet and processed using R software. The mean Shannon-Wiener diversity indices of the different stands were compared using a one-factor analysis of variance (ANOVA 1), and a Fisher test was performed to distinguish statistically different means. The significance level chosen for this test was 5%. A factorial analysis of correspondences (FAC) was carried out to observe the distribution of woody regeneration species according to the age of the *Acacia* stands. This distribution is based on the relative abundance of species expressed by the specific regeneration rate.

RESULTS AND DISCUSSION

Floristic richness

In total, the natural regeneration of woody flora included 67 species belonged to 55 genera and 30 families. The Fabaceae family was the best represented with 14.93% of species, followed by Annonaceae (10.45%), Sapindaceae (10.45%), Meliaceae (5.97%) and Moraceae, Olacaceae and Rubiaceae with 4.48% of species each (Figure 2). The remaining 31 families accounted for 44.76% of species in natural regeneration.

At Parc3, the natural regeneration contained 20 species belonged to 18 genera and 12 families. This stand was dominated by Fabaceae and Sapindaceae, each accounting for 15% of species (Figure 3.A). These two families were ahead of four others, which individually accounted for 10% of species, namely the Apocynaceae, Malvaceae, Meliceae and Olacaceae (Figure 3.A). Parc8 consisted of 28 natural regeneration species belonged to 27 genera and 17 families. In this stand, the Fabaceae was the most dominant with 20.69% of species, followed by Sapindaceae with 10.34% (Figure 3.B). In third place, there were five families with 6.9% of species, namely Annonaceae, Apocynaceae, Lecythidaceae, Malvaceae, Meliaceae and Rubiaceae (Figure 3.B). At Parc11, the natural regeneration comprises 24 species belonged to 22 genera and 14 families. This stand was heavily populated by the Fabaceae and Sapindaceae families, which accounted for 20.83% and 16.67% of species respectively (Figure 3.C). These families were followed by Annonaceae, Apocynaceae and Euphorbiaceae, which each accounted for 8.33% of species (Figure 3.C). At Parc27, there were 51 naturally

regenerating species belonged to 43 genera and 26 families. The dominant families were Annonaceae and Fabaceae, each with 11.76% of species (Figure 3.D). These two families were followed by the Sapindaceae with 9.8% of species, the Meliaceae with 7.84% and the Apocynaceae with 5.88% (Figure 3.D).

Plant life-form

The most widespread plant life-form in all four stand age groups were mesophanerophytes (Figure 4). They accounted for almost half of the species found on the other stands. At Parc3, 50% of species were mesophanerophytes, while at Parc8, Parc11 and Parc27, respectively 41.38, 41.67, and 47.06% of the species recorded were mesophanerophytes (Figure 4). Next in order of preponderance were microphanerophytes with 35% at Parc3, 37.93% at Parc8 and at Parc11 with 37.5% of species (Figure 4). This order is overturned at Parc27, where microphanerophytes ranked third with 21.57% of species (Figure 4). Finally, the extremes (nanophanerophytes and megaphanerophytes) were the least represented in the stands. These two plant life-forms accounted for 15% of species at Parc3, with 10% nanophanerophytes and 5% megaphanerophytes (Figure 4). At Parc8, we counted 6.9% nanophanerophytes and 13.79% megaphanerophytes, while Parc11 contained 12.5% nanophanerophytes and 8.33% megaphanerophytes. At Parc27, we recorded 7.84% nanophanerophytes, with the exception of megaphanerophytes, which ranked second with 23.53% of species (Figure 4).

Species diversity index

The Shannon-Wiener diversity index of the stands was less than 2.5. It was estimated at 1.66 ± 0.44 for Parc3; 2.09 ± 0.14 for Parc8; 1.98 ± 0.37 for Parc11 and 2.45 ± 0.36 for Parc27 (Table 1). Statistical analysis of these values showed significant differences between them ($F = 7.308$; $P = 0.001$) and three groups emerged (Table 1). The lowest index was for Parc3, and the highest was for Parc27. Between these two values, we had the second group, made up of roughly equal Shannon indexes, corresponding to Parc8 and Parc11 (Table 1).

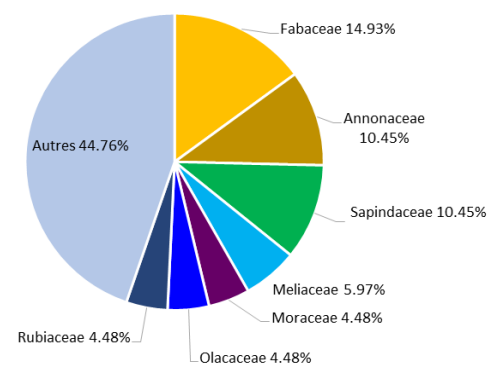


Figure 2. The proportion of naturally regenerating species of each family across all stands

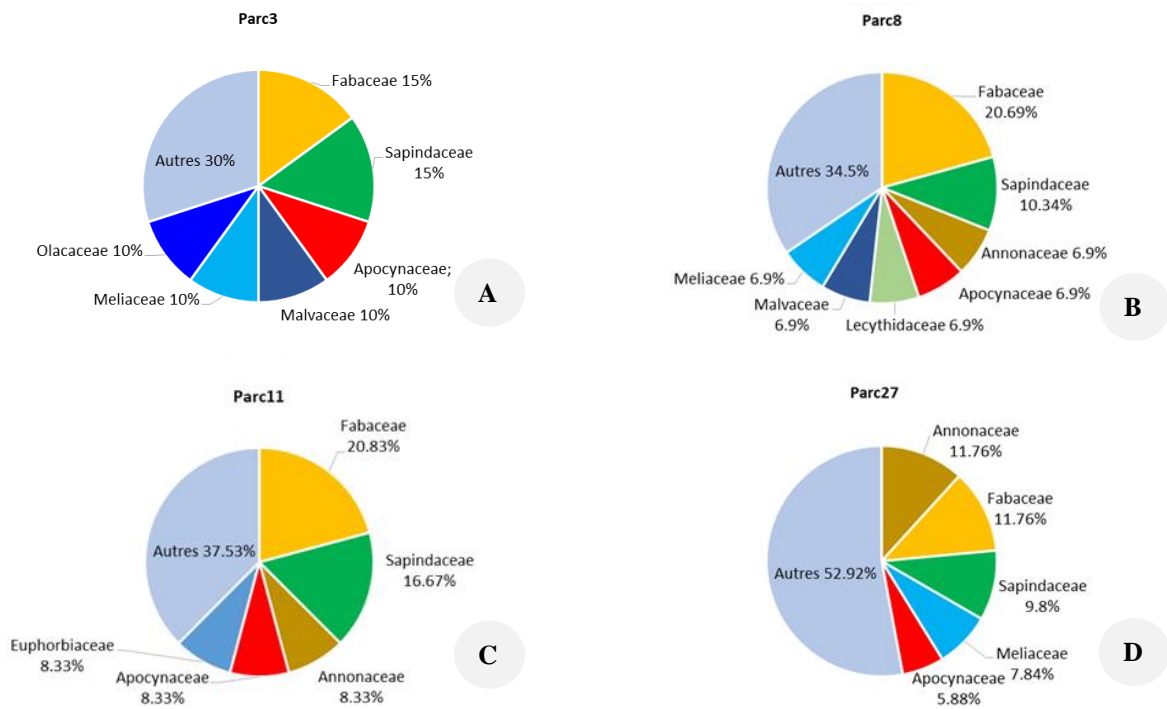


Figure 3. The proportion of naturally regenerating species of each family at each stand age. A. Parc3; B. Parc8; C. Parc11 ; D. Parc27

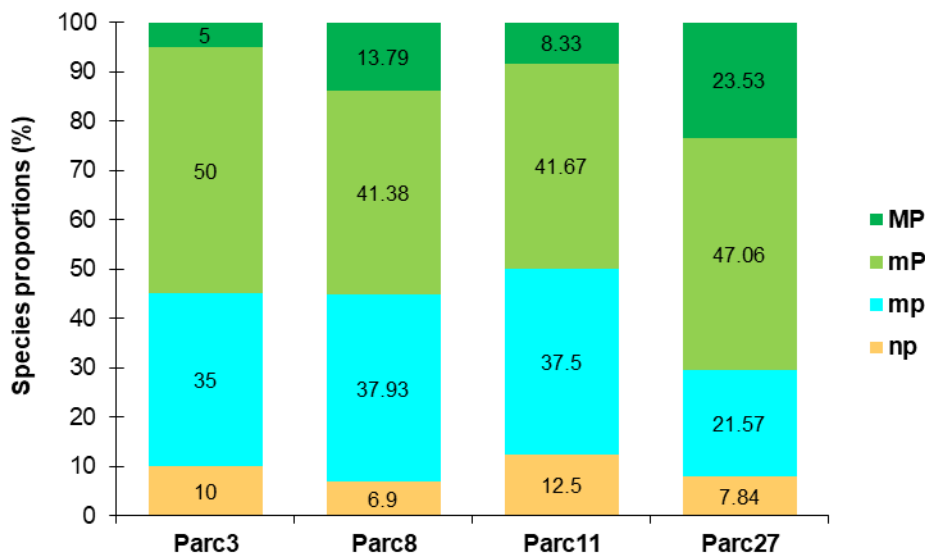


Figure 4. Plant life-form of natural regeneration vegetation at each stand. Note: MP: Megaphanerophytes, mP: Mesophanerophytes, mp: Microphanerophytes, np: Nanophanerophytes

Table 1. Shannon-Wiener species diversity index of naturally regenerating plant at each stands

	Shannon index
Parc3	1.66±0.44b
Parc8	2.09±0.14ab
Parc11	1.98±0.37ab
Parc27	2.45±0.36a
Statistical parameters	F=7.308 ; P=0.001

Table 2. Eigenvalues and percentage inertia of factorial analysis of correspondences (FAC) main axes

Axes	dim1	dim2	dim3
Eigenvalue	0.362	0.285	0.174
Percentage of variance (%)	44.08	34.70	21.22
Cumulative percentage of variance	44.08	78.78	100

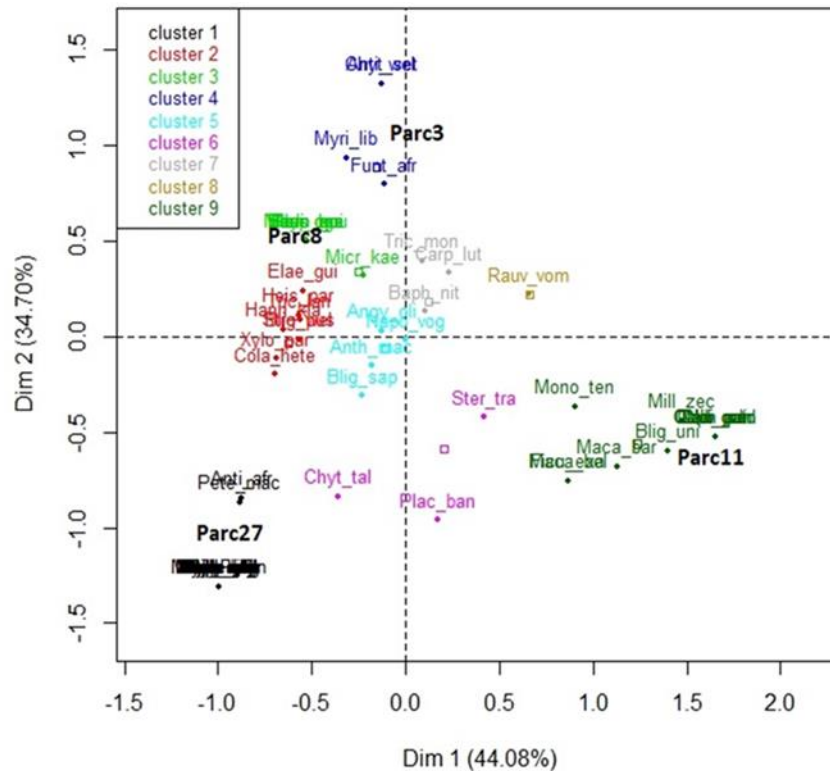


Figure 5. Diagram of species distribution on the factorial plane (F1 and F2)

Specific regeneration rate (SRR)

At Parc3, the dominant naturally regenerating species was *Funtumia africana* with SRR of 21.62%, followed by *Baphia nitida* (16.22%), *Microdesmis keayana* (12.16%) and *Rauvolfia vomitoria* (10.81%). These species were the most important in the natural regeneration of Parc3, with a cumulative SRR of 60.81%. At Parc8, *M. keayana* dominated with a SRR of 22.22%, followed by *B. nitida* (15.15%), *Cola heterophylla* (11.45%) and *Angylocalyx oligophyllus* (7.74%). These four species largely dominated the other twenty-five species at this stand, which had a cumulative SSR of 43.43%. At Parc11, *B. nitida* was the most widespread naturally regenerating plant with an SRR of 15.83%, followed by *R. vomitoria* (14.17%), *Macaranga barteri* (10%) and *Millettia zechiana* (7.5%). At Parc27, *B. nitida* was the most abundant with a SSR of 10.18%, followed by *C. heterophylla* (9.12%), *Chrysophyllum subnudum* (7.02%) and *M. keayana* (7.02%), while the remaining 47 species had an accumulative SSR of 66.66%.

Species distribution by stand age

Three factorial axes (Dim1, Dim2 and Dim3) explained the distribution of species within stands, which varied from 0.174 to 0.362, i.e. from 21.22 to 44.08% (Table 2). The FAC revealed that the distribution of species within the stands is mainly represented by the factorial plane formed by the Dim1 and Dim2 axes (Figure 5). The observation is therefore made on these two axes, which accounted for 78.78% of total inertia. The Dim2 axis (34.7%) discriminated the oldest stands (Parc11 and Parc27) from

the youngest (Parc3 and Parc8) and the Dim1 axis (44.08%) separated the oldest stands from each other (Figure 5). The FAC revealed nine groups of species distributed according to the age of the *Acacia* stands. Species such as *Myrianthus libericus*, *Antiaris welwitschii*, *Chytranthus setosus* and *F. africana* are mainly found at Parc3. Species such as *Vismia guineensis*, *Massularia acuminata*, *M. keayana*, *Heisteria parvifolia*, *Hannoa klaineana*, *Xylopiia parvifolia* and *A. oligophyllus* were found at Parc8. *Ceiba pentandra*, *Monodora tenuifolia*, *M. zechiana*, *M. barteri*, *Blighia unijugata*, *Ficus exasperata*, *Macaranga beillei*, *Albizia adianthifolia* were more widely distributed at Parc11. Finally, species such as *Piptadeniastrum africanum*, *Sphenocentrum jollyanum*, *Entandrophragma angolense*, *Antiaris africana* and *Petersianthus macrocarpus* were more common at Parc27.

Regeneration index (RI) of the stand

At Parc3, we recorded 74 young individuals out of a total of 74 individuals in this stand, giving a value of 1 as the stands regeneration index (Table 3). The same trend was observed at Parc8, where the RI was equal to 1, suggesting that all the individuals inventoried were young individuals (Table 3). At Parc11, we recorded 129 individuals of all diameters, including 121 young individuals, giving us a RI of 0.94 for Parc11 (Table 3). Finally, the RI for Parc27 is estimated at 0.81, i.e. 285 of the 350 individuals in this block are young (Table 3). The regeneration index in the stands regressed with age (Figure 6).

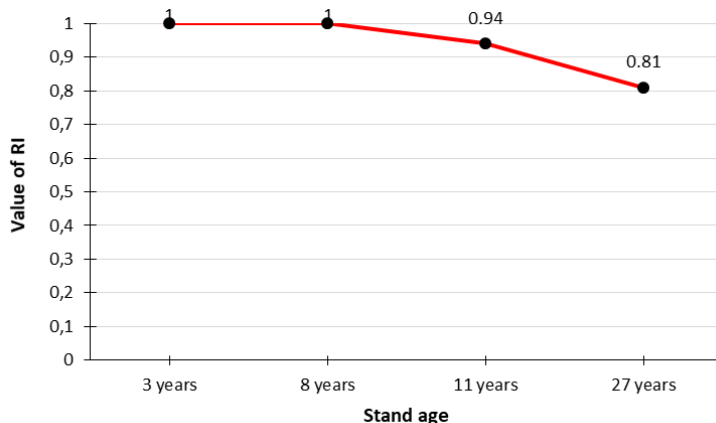


Figure 6. Trend of regeneration index according to stand age

Table 3. Assessment of regeneration indices for the different blocks of stands with varying ages

	Stand3	Stand8	Stand11	Stand27
Young individuals (diameter ≤ 5 cm)	74	300	121	285
Total individuals (individuals of all diameters)	74	300	129	350
Regeneration index (RI)	1	1	0.94	0.81

Table 4. Summary of regeneration importance values for the different stand blocks

	Stand3	Stand8	Stand11	Stand27
R	74	300	121	285
T	74	300	129	350
Sp	20	29	24	51
RIV	4.47	5.39	4.6	5.8

Stand regeneration importance value (RIV)

The natural regeneration of the flora was most important at the oldest stand (Parc27) where the RIV was 5.8 (Table 4), while the lowest RIV (4.47) was recorded at the youngest stand (Parc3). The other two stands, Parc8 and Parc11, had RIV of 5.39 and 4.6 respectively (Table 4).

Discussion

In the *Acacia* stands, we have recorded the typical species inventoried by Tiébré et al. (2015). All the stands differ in species composition and regeneration pattern because in the dissected landscapes, bioclimatic conditions change rapidly and may vary within short distances resulting in a pronounced heterogeneity of soil types (Bäumler 2015; Awasthi et al. 2022b) hence influence the distribution of vegetation and their regeneration pattern (Bargali et al. 2019; Manral et al. 2022). Vegetation cover in any ecosystems varies in space and time because of variation in topography, climate, weathering processes, physico-chemical properties of soil and microbial activities (Paudel and Sah 2003; Manral et al. 2023) and several other biotic and abiotic factors (Pandey et al. 2023).

Vegetation and its regeneration therefore vary within short distances according to parent rocks, soil types and land use pattern. This proves the restoration capacity of the local flora under the *Acacias*, which seem to offer the soil seed stock optimal germination conditions. At all stands, the flora of the natural regeneration is dominated by the Fabaceae family. These results are in line with those of Ameja et al. (2022), who conclude that regenerating environments are dominated by Fabaceae. The abundance of species in this family would depend on their effective and successful dispersal strategies on the one hand, and their high potential for adaptation in more varied ecosystems on the other (Yemata and Haregewoien 2022). After this family, we have, to a lesser extent, the Sapindaceae and Apocynaceae as preponderant families. Commonly, these families appear as the most important in forests of the same study area with Apocynaceae concerning the Anguédédou forest (Tiébré et al. 2015) and Fabaceae and Apocynaceae in the Mabi forest (Amba et al. 2021). Our results show that natural regeneration under *Acacias* retains the characteristics of dense evergreen forests in Côte d'Ivoire.

Analysis of the Shannon-Wiener index recorded in the various stands suggests that woody regeneration under *Acacias* is moderately diverse. Indeed, in all stands, around 20% of the species inventoried account for more than half of the individuals found. As pointed out by Barmo et al. (2019), the Shannon-Wiener index is minimal when the stand is dominated by one species and other species are poorly represented. However, natural regeneration becomes increasingly diverse as the age of *Acacia* stands increases. This observation can be explained by the proliferation of

woody species over time, encouraged by the reduction in herbaceous cover due to the presence of arborescent legumes. Thanks to their role in fixing atmospheric nitrogen, leguminous trees exert control over grasses and weeds (Kouadio et al. 2018). Indeed, a two-thirds reduction in herbaceous cover was observed after thirteen years of leguminous presence in native grasslands in Uruguay (Jaurena et al. 2016). *Acacia* stands are unfavorable environments for the propagation of herbaceous flora, creating ideal conditions for the regeneration of woody species. Furthermore, some authors (Carnus et al. 2006; Paquette and Messier 2013) claim that the aging of forest tree plantations is a factor reinforcing the availability of ecological niches as well as the high and diverse presence of species. All *Acacia* stands, whatever their age, are home to all the biological types of arborescent phanerophytes, which are varied forms of woody plants. This observation follows the logic of the floristic composition of tropical forests, since phanerophytes make up the majority of the flora at the expense of other biological types, which are in reduced proportions. Acacias are arborescent leguminous plants that control herbaceous flora. Moreover, thanks to their tree cover, these species create a microclimate that prevents the colonization of the environment by herbaceous species. The variability of vascular plant species is proof that *Acacia* stands provide a suitable environment for the regeneration and growth of woody species. Also, some authors (Keil and Chase 2019; Liang et al. 2022) have established a link between environmental conditions and the diversity of woody species and forest tree species. In other words, when the undergrowth is rich and diverse, the environment becomes favorable to interactions and the presence of several plant species (Yang et al. 2023). Moreover, the diversity of tree species in forest communities is fundamental to the conservation of ecosystem services such as carbon storage, groundwater protection, wood supply and soil stabilization (Esquivel et al. 2020; Hua et al. 2022; Duan et al. 2023).

Over time, the diversity of naturally regenerating plants has improved. This result could be explained by an average accumulation of nitrogen in the soil from the nitrogen fixed by the roots of these tree legumes. This activity of the *Acacia* rhizosphere leads to an improvement in soil productivity in these *Acacia* stands. Indeed, total nitrogen is an edaphic factor influencing vegetation growth, regeneration and the development of a plant stand (Qian et al. 2014). When the nitrogen stock in the soil is moderate, it stimulates the uptake and activity of soil nutrients (Luo et al. 2022), resulting in improved vegetation productivity (O'Sullivan et al. 2019). The ultimate goal of vegetation recovery is to increase biodiversity and ecosystem stability (Midolo et al. 2019; Li et al. 2021). Natural regeneration is an effective method of restoring vegetation, helping to store soil carbon, fix soil nitrogen, restore degraded ecosystems and improve soil quality (Hu et al. 2021). It helps to increase the diversity of plants in the understory and ensures the sustainable restoration of the forest canopy (Wang et al. 2019). In addition to this, vegetation restoration helps to increase the soil carbon sink, and especially the reservoir of biodegradable carbon contained

in the soil (Liu et al. 2020; Hu et al. 2021). Soil carbon is very important, as it is involved in the nitrogen fixation process by *Acacia* roots. There is a symbiosis between the *Rhizobiums* (soil nitrogen-fixing bacteria) and the roots of leguminous plants, which provide these bacteria with carbon as a source of energy. In return, the *Rhizobiums* use their energy source and become active, fixing nitrogen for the leguminous roots that host them. Previous studies (Ferguson et al. 2019; Roy et al. 2020; Yang et al. 2022) have explained that legume root nodules host *Rhizobium*. Supplied with nutrients by legumes, these bacteria convert atmospheric nitrogen into reduced forms that can be used by host plants. It is worth pointing out that a forest's resilience process relies on seed germination, seedling establishment and survival (Taeroc et al. 2019), which in reality depend on environmental conditions. Through their role in capturing nitrogen, Acacias improve soil fertility, creating edaphic conditions favorable to natural regeneration. In the process of forest resilience, seedlings resulting from seed germination survive and grow thanks to numerous biotic and abiotic factors, including water, nutrients and soil properties (Rozendaal et al. 2019; Zhang et al. 2022). The other striking fact is the decline in the regeneration index as the stands age. This finding would mean that there is a progressive maturity of regenerated woody flora under the Acacias marked by the increasing proportion of mature individuals. This proves that the individuals that regrow in the natural regeneration process initiated under the Acacias are developing well.

In conclusion, we noticed that the presence of Acacias on a degraded portion of the Anguédédou Forest has restored soil fertility and tree cover in these areas. The new environmental conditions created by the Acacias have encouraged the regeneration and development of woody species. Therefore, there is a good natural regeneration of woody species under Acacias planted in a degraded forest landscape. We noted an increase in the species richness and an improvement in the specific diversity of the regenerated woody flora as the *Acacia* stands aged. These results show that Acacias, in addition to their agronomic benefits, can be used to naturally regenerate a forest at lower cost. Our study leads us to conclude that tree legumes in general, and Acacias (notably *A. mangium* and *A. auriculiformis*) in particular, are useful species both in agricultural systems and in forestry. These Acacias species therefore appear to be strategically important species in the management of agroforestry systems and forest restoration.

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