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First evaluation of the use of assisted natural regeneration by central african farmers to restore their landscapes

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ABSTRACT

On the outskirts of the city of Bangui, the capital of the Central African Republic, fuelwood production, slash-and-burn agriculture and artisanal timber exploitation are causing deforestation and forest ecosystem degradation.

Within the framework of the REDD+ Component of the South-West Regional Development Project, the implementation of Assisted Natural Regeneration during weeding (ANRw) in the slash-and-burn system was proposed and set up by 23 volunteer farmers on 24 fields with an average area of 0.22 ha in two villages (Boteke and Salanga).

The objective of the study was to characterise the floristic structure of the juvenile woody vegetation resulting from ANRw in these two villages. More specifically, it aimed to: 1) describe the methods used to inform and raise awareness amongst farmers who volunteer to practise ANRw; 2) identify the main species conserved by the farmers; 3) identify the reasons or factors that motivated farmers to choose these species; 4) identify the biological and ecological characteristics of these species; and 5) evaluate the height growth of young trees preserved by ANRw over a 14-month period.

The third inventory of the 24 plots (volunteers' fields) gave 1,668 woody plants preserved by ANR on 5.35 ha (312 trees ha^{-1}), divided into 42 genera, 47 species and 23 families.

These results show that ANRw is a simple technique to implement and can help maintain trees in fields in areas where pressure on the forest is high. In the supported villages, communities have shown an interest in applying this technique to reintroduce trees in the fields. This technique should be popularised in other places to improve the sustainable management of anthropized forest landscapes. In addition, volunteers who have tested ANRw say they are willing to continue practicing it. However, despite this genuine initial enthusiasm, this restoration drive will need to be monitored and supported due to the current context of extreme poverty and economic, social and political instability.

1. Introduction

On the outskirts of the city of Bangui, the capital of the Central African Republic, fuelwood production, slash-and-burn agriculture and artisanal timber exploitation are causing deforestation and forest ecosystem degradation in the non-permanent forest estate, as is the case around most large Central African cities (Gond et al., 2016). In Central Africa, the area of undisturbed tropical moist forest decreased from 223 Mha in 1990 to 187 Mha in 2020, a loss of 17% which has accelerated over the last decade (Vancutsem et al., 2021).

The consumption of wood energy in the urban area of Bangui (1.1 million inhabitants) has been estimated at 590,000 Mg $year^{-1}$ of equivalent wood in 2018 (Gazull et al., 2019), and demand for artisanal sawn timber at 79,000 m^3 $year^{-1}$ (Dubiez et al., 2019a). With a growing urban population, demand will rise further, and in the absence of sustainable management of wood resources, the forest massifs will continue to deteriorate.

The forest massif of south-western CAR is largely occupied by forest concessions (14) covering 3690,000 ha and protected areas (4) covering 539,000 ha. These two forms of land use cover nearly the entire south-

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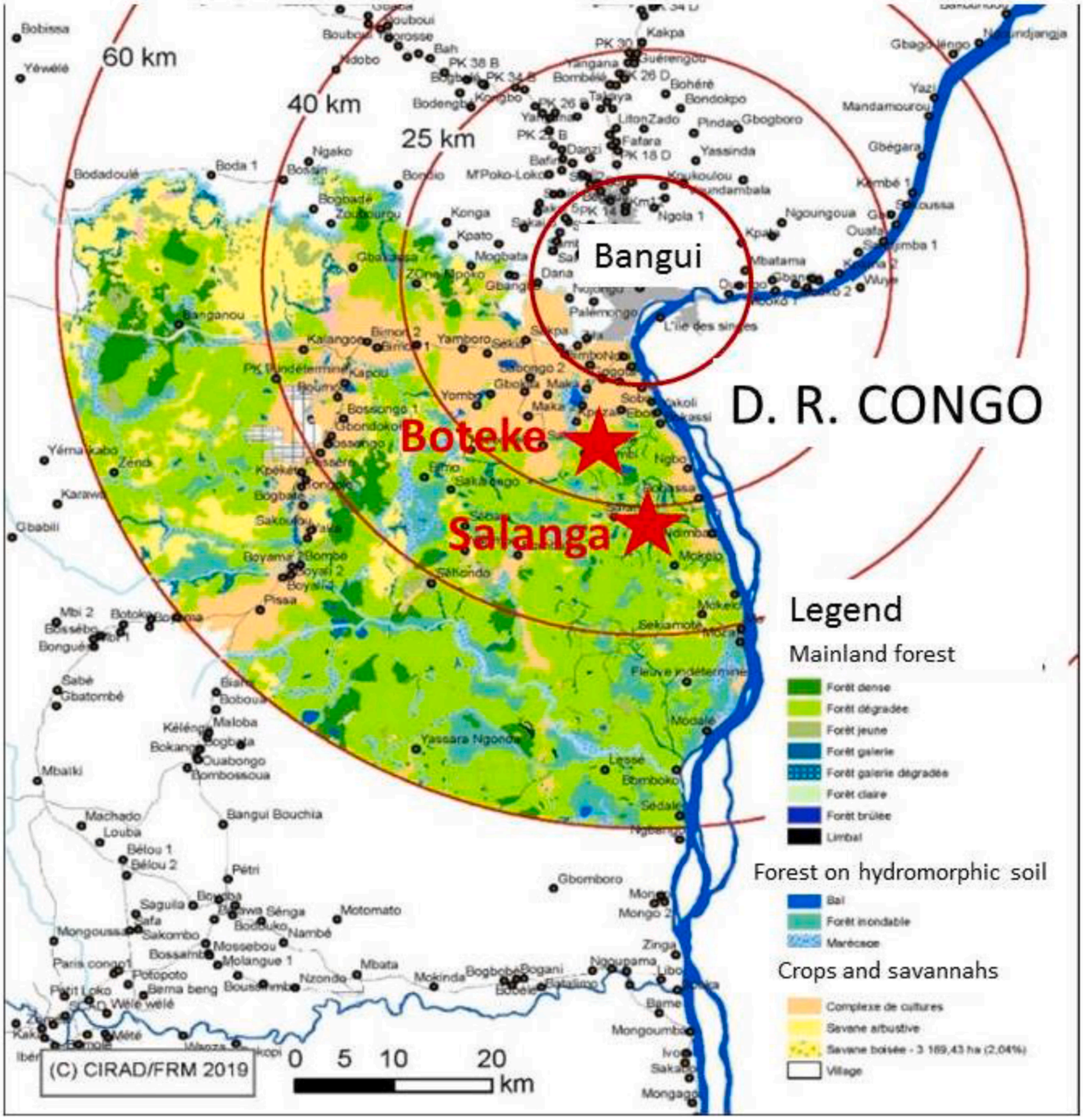

Fig. 1. Land use, in 2016, in the south-western zone of the Bangui wood supply basin. (Map CIRAD-FRM, 2019).

western forest massif. Since agriculture is officially prohibited in protected areas and in most of the forest concessions, pressure from rural populations on the non-permanent forest estate is high due to the small areas available, although illegal logging is taking place in the forest concessions closest to the city of Bangui.

South of the city of Bangui, a gradient of degradation can be determined (Dubiez and Gazull, 2019). The first ring, located between 10 km and 25 km from the centre of Bangui, is a landscape dominated by a crop mosaic (a patchwork of fields, fallow lands and anthropogenic savannahs). The second ring (25–40 km) is characterised by a patchwork of fields, fallow lands, anthropogenic savannahs and degraded forests. Finally, the third ring (40–60 km) is characterised by a forested landscape, but the first signs of exploitation are visible along access routes (roads, hydrographic network) (Fig. 1).

Within the framework of the REDD+ Component (*R*educing Emissions from Deforestation and forest Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries) of the South-West Regional Development Project (PDRSO), financed by agence française de développement (AFD) since 2016, new agroforestry systems have been proposed and set up by volunteer farmers in the first and second rings. In the first ring, improved fallows with plantations of *Acacia auriculiformis* have been set up in grassy savannahs with *Imperata cylindrica*, where natural tree regeneration is very rare due to the repeated passage of fires. This system, inspired by the Mampu system developed on the Bateke Plateau in the Democratic Republic of Congo (DRC) (Bisiaux et al., 2009), is a sequential agroforestry system alternating food crop (cassava, maize) production and charcoal (*Acacia auriculiformis*) production (Dubiez et al., 2019b).

In areas where natural tree regeneration is still important, farmers from the villages of Boteke (first ring) and Salanga (second ring), located in the Botambi forest reserve, were accompanied in the implementation of Assisted Natural Regeneration during weeding (ANRw) within the slash-and-burn system. ANRw is an agroforestry technique that consists of selecting and preserving seedlings, shoots and suckers of forest species according to their recognised usefulness to farmers (edible caterpillars, firewood, charcoal, sawing, medicinal, fertility conservation, shade for crops that cannot withstand full sun) to restore plant cover. At the time of each weeding of the crops, the farmer or salaried personnel eliminate (s) all grasses, shrubs, lianas and trees that have grown spontaneously between the crops, with the exception of the young plants that have been selected. In the past, the application of this ANRw technique in rural

Fig. 2. Training volunteers in ANR techniques (source photo: Arnot Kpolita, 2019).

areas has been accompanied most often by support from development agencies and administrations, as was the case for the EU-funded Makala project in DRC (R. Peltier et al., 2014). This support involves helping rural communities in terms of raising awareness of environmental degradation, technical training, organisation and sometimes material support or even subsidies (Péroches et al., 2019). The aim of this ANRw was to increase the productivity of agricultural and wood products in already degraded areas while increasing the biodiversity and above-ground biomass of these landscapes in order to limit further forest clearing. In contrast, when actions to regenerate the tree component are taken at the initiative of farmers, this is referred to as farmer managed natural regeneration (FMNR) (Binam et al., 2015).

PDRSO thus supported the testing of ANRw between June and July 2019 on 24 fields (12 in the village of Boteke and 12 in the village of Salanga) by 23 volunteer farmers.

In a first step, prior to this study, PDRSO agents approached village authorities, who brought the population together in a series of meetings. During these meetings, the project's approach was explained, the ANR technique as it had been used in the DRC was described, and volunteers were sought to adapt this method to local conditions. In particular, the volunteers were asked to consider the value of tree species that they could keep in their fields when weeding (Dubiez et al., 2019a). It should be pointed out that these fields had previously been set up by the farmers using the traditional technique of slash-and-burn cultivation of primary or secondary forests, which is the most widely used cultivation system in the region.

The main objective of this article is to evaluate the first stages of the establishment of the trees selected by ANRw in the two villages. More specifically, it aims to:

- describe the methods used to inform and raise awareness amongst farmers who volunteer to practise ANRw;
- identify the main species conserved by the farmers;
- identify the reasons or factors that motivated farmers to choose these species;
- identify the biological and ecological characteristics of these species;
- evaluate the type of reproduction, vegetative or sexual, and the height growth of young trees preserved by ANRw over a 14-month period.

1.1. Study environment

Two pilot villages, Boteke and Salanga were selected. These villages are located in the Botambi Forest Reserve, which was classified in 1950 by the Ministry of Water, Forests, Hunting and Fishing. In the reserve, farmers cultivate and harvest forest products in a way that is not legal, but is in fact tolerated by the government. Boteke is located 30 km from Bangui at 04° 11' 33.6'' North latitude and 018° 29' 28.9'' East longitude, and Salanga is located 40 km from Bangui at 04° 07' 28.8'' North latitude and 018° 30' 34.6'' East longitude.

Boteke and Salanga have populations of about 500 and 1000 inhabitants, respectively, mainly composed of the Gbaka ethnic group. In Boteke, the production of palm wine, a product of slash-and-burn agriculture, is the main income-generating activity, followed by the sale of agricultural products (manioc, maize). Agriculture, gathering, hunting (trapping) and fishing are the main subsistence activities. In Salanga, artisanal sawing, the sale of agricultural products (taro, plantain banana, pineapple) and gathering (wild pepper, edible caterpillars) are income-generating activities. In both villages, the main crops are cassava, maize, plantain banana, taro, yams and oil palm. Livestock farming is of lesser economic importance as livestock products are mainly used for ceremonies and social obligations (mainly goats and, to a lesser extent, chickens and pigs). Fishing and gathering are carried out according to the seasons. Small trade is flourishing and varies according to the seasons (caterpillar season, fishing season).

Despite the specificities of each of these communities, they form a unit in terms of the strategy pursued to exploit the environment. These populations all live to varying degrees on slash-and-burn agriculture and make use of all forest resources, both animal and plant, without implementing any kind of sustainable management practices. This is leading to deforestation and the progressive degradation of forest ecosystems in terms of biodiversity, biomass and soil fertility.

It should be noted that oil palm (*Elaeis guineensis*) has a special place

Fig. 3. Marking with a stake and measuring a selected plant with a tape measure (Source photo Arnot Kpolita, 2019).

in this type of slash-and-burn agriculture. Indeed, it is a local species, relatively resistant to fire, whose extension is favoured by slash-and-burn agriculture provided that farmers keep young individuals when clearing the land. It is therefore a species that is conserved by practically all farmers, without the need to disseminate ANR. The oil palm tree, which can go through multiple cycles of felling and burning over several decades, is used for the production of fruit from which palm oil is extracted. It is then felled and its terminal bud is "bled" for the production of palm wine before the majority of its stipe is split to make slats. For the purposes of this study, this species, which is not a tree and which is already well known and managed by farmers, will not be considered.

2. Material and methods

2.1. Raising public awareness

Awareness campaigns were carried out amongst farmers in the villages of Boteke and Salanga in the presence of village authorities. They were led to reflect on the importance of the forest and the consequences of deforestation. The objective of the campaigns was to encourage farmers to keep spontaneous and some introduced trees in their fields to limit the impact of agricultural clearing on forest landscapes (sustainable productivity for populations, preservation of part of the biodiversity, carbon storage, reduction of climate impact).. Farmers were made aware of the new ANRw techniques. At the end of the awareness-raising meetings, farmers volunteered to try the ANR technique in their fields.

2.2. Training of farmers on ANR techniques

Practical training was organised for the volunteers. In their fields, they were introduced to ANRw techniques by Emilien Dubiez and Laurent Gazull, specialists in tropical forest management and researchers at CIRAD-Montpellier (Dubiez and Gazull, 2019). These researchers made the first selections of young plants with the farmers in their fields at the time of the first weeding (Fig. 2). This choice led to discussions between researchers and farmers sometimes agreeing, and sometimes disagreeing, with the reasons for the choice. As the ANRw work progressed, farmers became more autonomous and took ownership of the technique.

It should be noted that the fields established by slash-and-burn are cluttered with trunks and branches, half-calcined, which makes some areas of the fields very difficult to access. The selection of young trees therefore is not homogeneous over the entire plot.

These information and co-construction campaigns, intended to adapt the method to local conditions and to villagers' needs, were also relayed by NGOs in French and in the local Gbaka language (Abiya et al., 2021).

2.3. Implementation of ANRw and initial measurements

The implementation of ANRw activities in the villages of Boteke and Salanga began in June and July 2019. During this period, true seedlings and resprouts of forest species were selected by the farmers and researchers to be kept in the fields because of their usefulness (firewood, charcoal, pharmacopoeia, edible caterpillars). The selected plants were marked with a yellow paint stake, the type of reproduction, vegetative (resprouts) or sexual (seedlings) and the species were determined and their height was measured (first inventory) (Fig. 3).

2.4. Second measurement campaign

A second inventory was carried out during January and February 2020. Measurements were carried out and new plants were selected. During this new selection, made in the presence of researcher A. Kpolita, it cannot be denied that he had a certain influence on the choice of trees due to his social position, but he took care to make the farmers as autonomous as possible in their choices. Since the stakes of the first selection had, for the most part, been eaten by termites, it was not certain that all of the trees selected during the first weeding were selected during the second. Since the fields are not bounded by landmarks made of durable materials and farmers enlarge their fields every year, there is some uncertainty about re-measuring exactly the same field limit with each measurement, but this is limited by the use of GPS by the researcher.

The selection of new seedlings during each round of crop weeding is an innovation on what was done in DRC (R. Peltier et al., 2014). This enriches the agroforestry system in terms of numbers and biodiversity, but it changes the method of scientific monitoring of growth in terms of the number of individuals, diversity and height of the tree stand. Unlike in DRC, where the same young trees were monitored for growth, here a stand is monitored, and each time new trees are measured, the stand is enriched.

The circumference of woody plants with a height $\geq$ 2.5 m was measured at 0.30 cm and 1.30 m above the ground. For woody plants with a height of strictly less than 2.5 m (woody $<$ 2.5 m), their height was simply measured. The circumference of large trees on field boundaries and indoors was measured at 1.30 m above the ground. A decametre was used for the measurements. It was used to delimit the plots with the help of a GPS (GPS points were taken every 10 m around the field's perimeter). The decametre was also used to measure the distance between the selected seedlings and the nearest trees. In addition, a tape measure was used to measure the height of juveniles less than 2.5 m tall, and the height of the largest trees was estimated with a dendrometer.

2.5. Third measurement campaign

A third inventory campaign was carried out during August and September 2020, the same measurements were carried out and new plants were selected.

Fig. 4. Representation of the ANR study plots in the village of Boteke, positioned on an older Google Map image dated 3/04/2019.

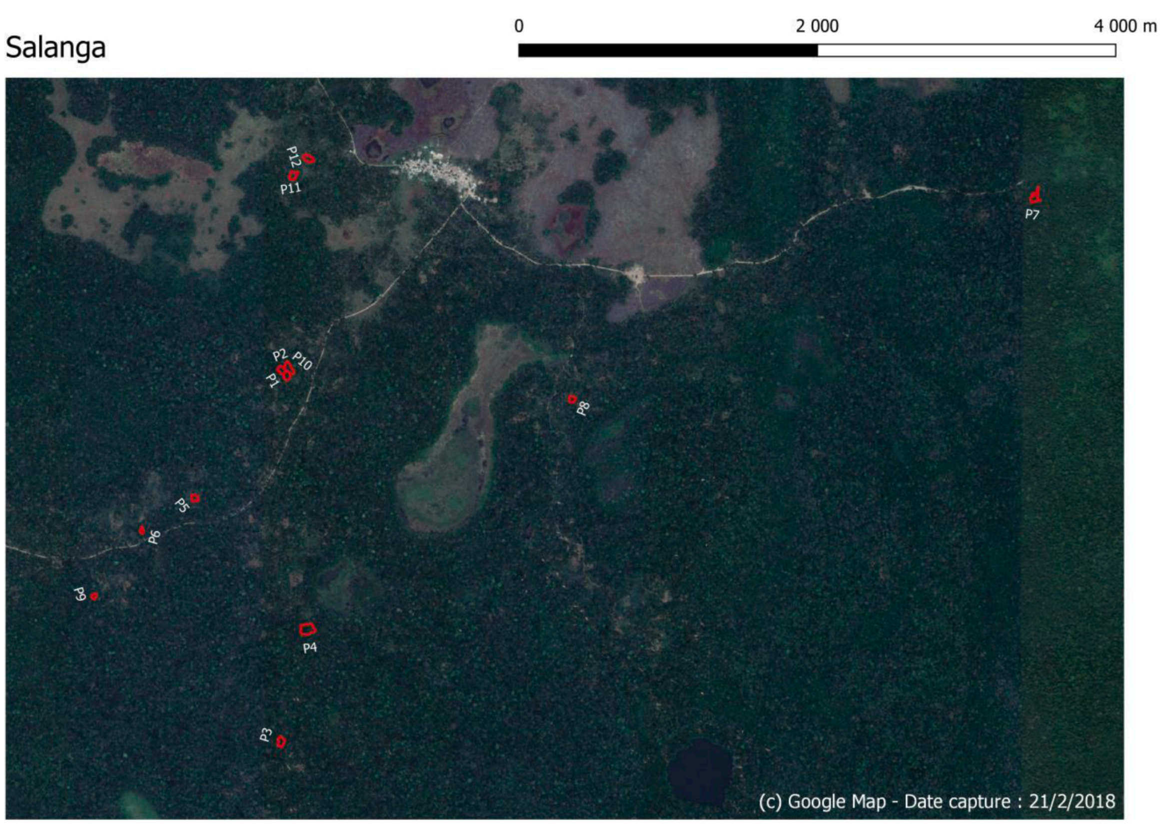

Fig. 5. Representation of the ANR study plots in the village of Salanga, positioned on an older Google Map image dated 21/02/2018.

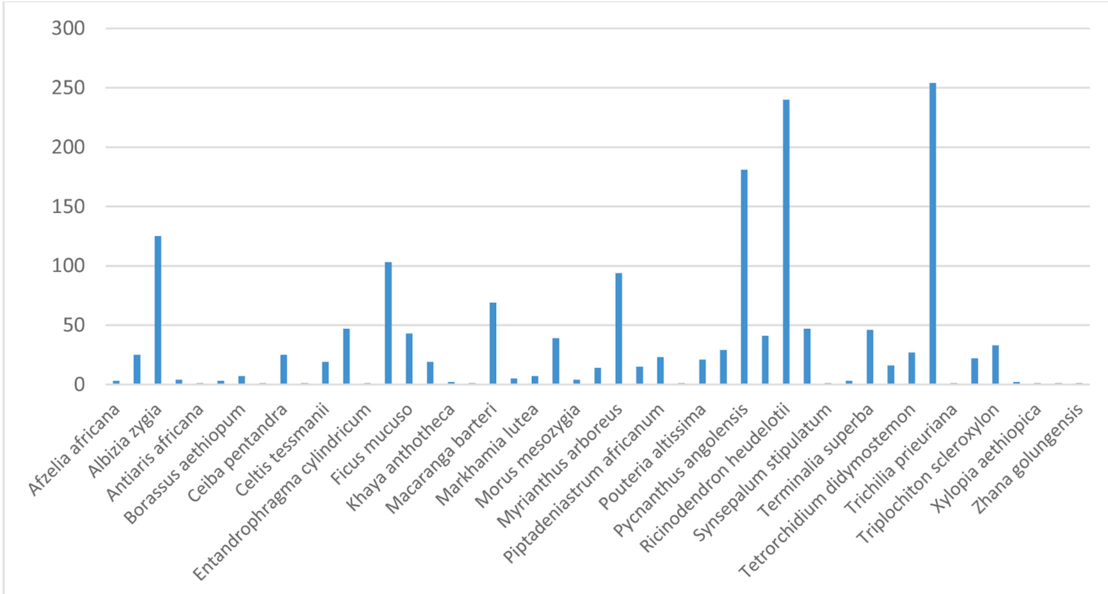

Fig. 6. Number of individuals per species conserved for 14 months in the 24 plots monitored. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.6. Species identification

Species identification was carried out by a botanist accompanied by two para-taxonomists who were familiar with the names of the species in the local languages. The botanical species were identified on the basis of morphological criteria. Flora such as the flora of Gabon, the flora of Cameroon and the flora of Central Africa were used to confirm the species. The nomenclature of species follows that of Lebrun and Stork (1991, 1992, 1995 and 1997).

2.7. Species life traits

Information on the biological types (large trees, medium trees, shrubs and small trees) and temperament (degree of tolerance of species to light) of the species was gathered on the basis of literature and field observations in order to better understand the evolution of vegetation in both environments (Doucet, 2003). The majority of these results are currently being processed and will be published later.

2.8. Inventories data analysis

The data from the inventories were entered and analysed with Excel and Excel Stats. The different spectra of woody species were elaborated when possible. Maps were produced using CIRAD's specialised documentation mapping software.

2.9. Preliminary socioeconomic study

In this preliminary study, interviews were conducted with farm heads (one woman and 22 men) covering "reasons for the adoption of ANRw and the choice of preserved trees species". In addition, the first indicators of the farmers' desire to restore their forest environment were observed in both villages.

In a later phase of the evaluation of the farmers' perception of the

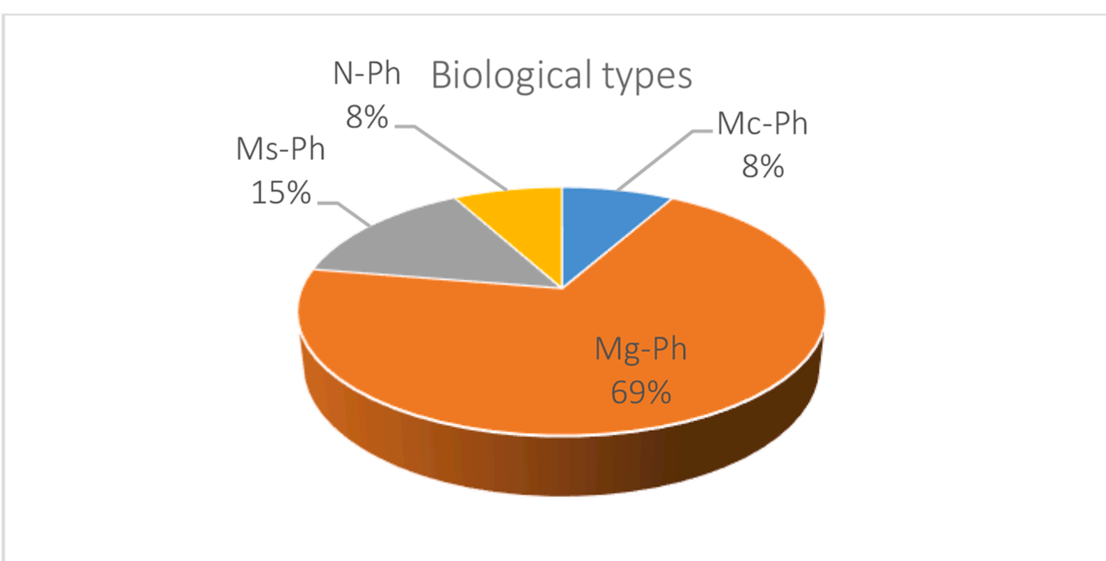

Fig. 7. Spectrum of biological types of woody species conserved by farmers.

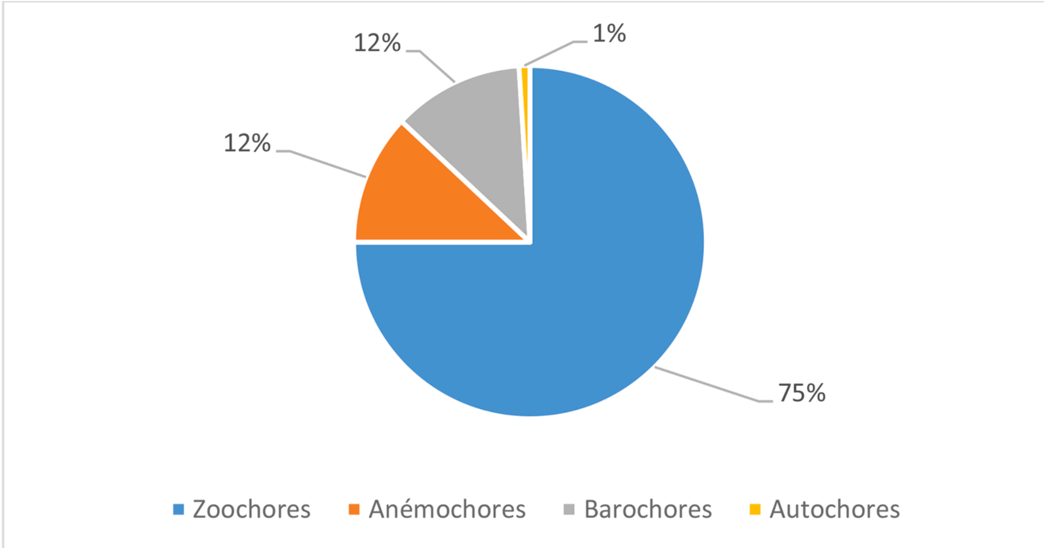

Fig. 8. Spectrum of dissemination of woody species kept by farmers during the 2nd selection.

ANRw technique, comprehensive semi-structured interviews (Sibelet et al., 2013) will be carried out with farm heads and other available farm members. The main variables which will be studied will include: farm activities practiced (crop production, livestock production, non-farming activities), means of production (agricultural surface area, available paid or family labour, agricultural equipment and materials), household size, ex-post evaluation of ANRw, of the choice of preserved trees species and of desire to continue to cultivate the fields using this technique.

3. Results

3.1. Mapping and area measurement of plots

The ANR study plots were represented using a GIS and positioned on a Google Map using images taken in 2019 of Boteke (Fig. 4) and Salanga (Fig. 5). On these images, it can be seen that the forest landscapes of the village of Boteke are much more degraded than those of Salanga.

The total area restored by ANRw in the two villages was 5.35 ha, i.e., an average area of 0.22 ha per farmer.

3.2. Floral richness of the trees measured during the 3rd selection

The third inventory of the 24 plots (volunteers' fields), carried out fourteen months after ANRw was first practiced, gave 1668 woody plants divided into 42 genera, 47 species and 23 families. The families best represented in terms of number of individuals are *Euphorbiaceae* (341 individuals), *Moraceae* (320 ind.), *Ulmaceae* (274 ind.), *Myristicaceae* (228 ind.) and *Mimosaceae* (189 ind.). Of the 1668 species inventoried, five species are the most represented (Fig. 6). They are *Trema orientalis* (254 individuals or 15.2%) *Ricinodendron heudelotii* (240 individuals or 14.4%), *Pycnanthus angolensis* (181 individuals or 10.9%), *Albizia zygia* (125 individuals or 7.5%) and *Ficus exasperata* (103 individuals or 6.2%). These five species alone account for 54.1% of all individuals inventoried in the 24 plots monitored.

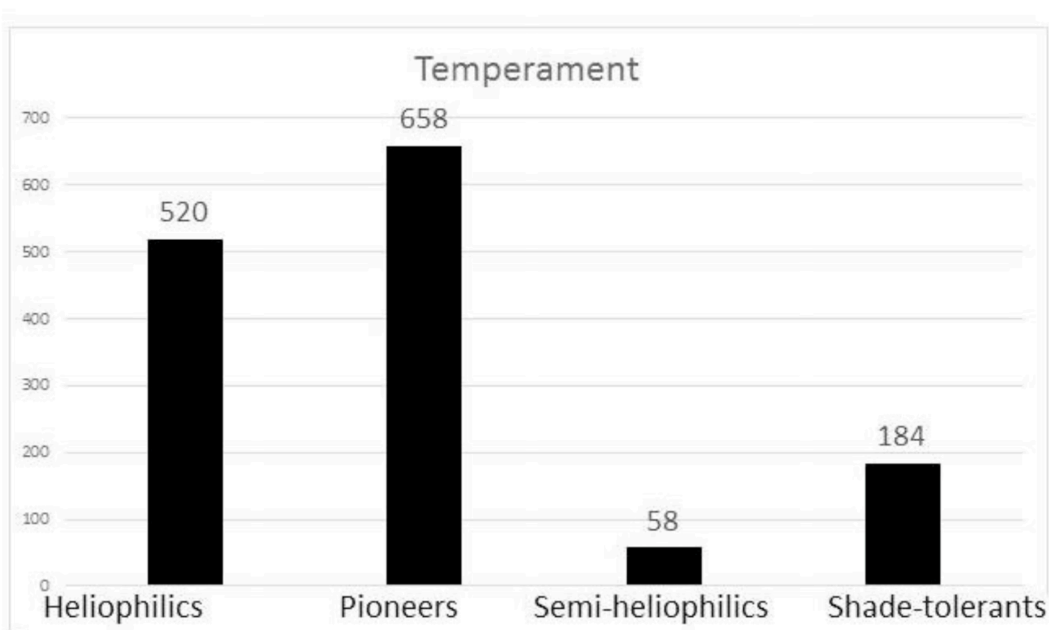

Fig. 9. Light temperament of woody species preserved by farmers during the 2nd selection.

Table 1
Proportion of true seedlings and of resprouts for the 14 species most represented in the ANRw, in the villages of Salanga and Boteke, in 2019.

Species	Resprouts Salanga	Boteke	Salanga+Boteke	% of Resprouts In ANR	Seedlings Salanga	Boteke	Salanga + Boteke	% of Seedlings In ANR
Ricinodendron heudelotii	5	1	6	2%	57	251	308	98%
Albizia zygia	33	60	93	99%	0	1	1	1%
Pycnanthus angolensis	51	41	92	99%	0	1	1	1%
Draceana arborea	17	17	34	97%	1	0	1	3%
Myrianthus arboreus	13	22	35	100%	0	0	0	0%
Ficus exasperata	12	20	32	97%	0	1	1	3%
Terminalia superba	8	7	15	52%	0	15	15	48%
Aubrevillea kerstingii	1	25	26	100%	0	0	0	0%
Ceiba pentandra	1	1	2	8%	16	9	25	92%
Pouteria altissima	16	8	24	96%	0	1	1	4%
Staudtia kamerunensis	12	8	20	100%	0	0	0	0%
Albizia adianthifolia	11	5	16	100%	0	0	0	0%
Rauvolfia caffra	15	0	15	100%	0	0	0	0%
Trema orientalis	3	0	3	20%	12	0	12	80%
Total of 14 species	198	215	413	53%	86	279	365	47%

3.3. Biological types of woody species conserved by farmers during the 2nd selection

Note: For the parameters studied in Chapters 3.3, 3.4 and 3.5, analyses could not be carried out for the 3rd selection. Those of the 2nd selection are given by default.

The biological spectrum of the 1420 woody trees surveyed shows a dominance of megaphanerophytes (Mg-pH) or large trees (986 individuals) over mesophanerophytes (Ms-pH) or medium trees (Fig. 7). Megaphanerophytes are represented by the following species: *Ceiba pentandra, Terminalia superba, Ricinodendron heudelotii, Albizia zygia, Pycnanthus angolensis, Triplochiton scleroxylon, Entandrophragma angolense, Morus mesozygia, Staudtia kamerunensis, Piptadeniastrum africanum,* and *Pouteria altissima.*

Mesophanerophytes (Ms-pH) or medium trees are represented by the following species: *Myrianthus arboreus, Ficus mucuso,* and *Macaranga barteri*. Microphanerophytes (Mc-pH) or small trees are *Ficus exasperata, Dracaena arborea, Rauvolfia caffra* and *Tabernaemontana crassa.* Nanophanerophytes (N-pH) or shrubs are only represented by *Trema orientalis.*

3.4. Method of dissemination of woody species preserved by farmers during the 2nd selection

The analysis of the modes of dissemination of species shows a dominance of zoochores (Zoo: 73%) followed by anemochores (Ané: 13%) and barochores (Baro: 13%) (Fig. 8). Autochores are very poorly represented (Aut: 1%). Zoochores species (whose fruits are spread by animals) are represented by *Ricinodendron heudelotii, Pycnanthus angolensis, Myrianthus arboreus, Ficus exasperata, Dracaena arborea, Trema orientalis, Morus mesozygia, Rauvolfia caffra, Staudtia kamerunensis, Macaranga barteri, Milicia excelsa, Pouteria altissima* and *Pterygota bequaertii.*

Anemochore species (diaspores dispersed by the wind) are represented by *Ceiba pentandra, Terminalia superba, Entandrophragma angolense, Piptadeniastrum africanum, Alstonia boonei, Petersianthus*

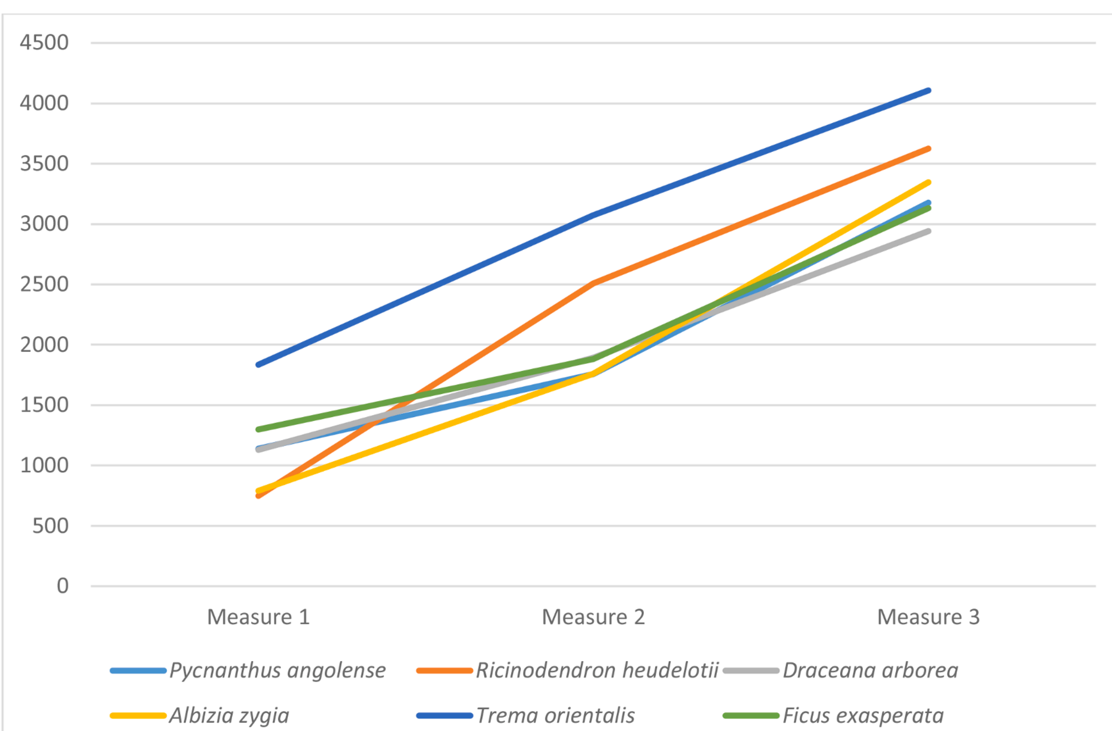

Fig. 10. Evolution of the mean height in mm over a 14-month period of the population of the main species preserved by ANRw in Boteke and Salanga.

Table 2
N, Mean height (cm) and standard deviation (cm) of *Albizia zygia, Draceana arborea, Ficus exasperate, Pycnanthus angolensis, Ricinodendron heudelotii* and *Trema orientalis* in the three measurement campaigns.

Species	First measurement campaign			Second measurement campaign			Third measurement campaign		
	N	Mean height (cm)	Standard deviation (cm)	N	Mean height (cm)	Standard deviation (cm)	N	Mean height (cm)	Standard deviation (cm)
Albizia zygia	94	79	64.9	152	176	100.5	125	334.6	93.7
Draceana arborea	35	113	59.1	64	189.4	83.8	47	294.1	73.3
Ficus exasperata	33	129.8	99.9	95	188.2	108.2	100	313.2	88.3
Pycnanthus angolense	92	113.9	93.3	207	175.7	115.1	164	317.7	106.4
Ricinodendron heudelotii	313	74.8	118	244	250.8	196.5	217	362.5	150.4
Trema orientalis	15	183.5	62.1	113	307.4	112.9	254	410.7	127.9

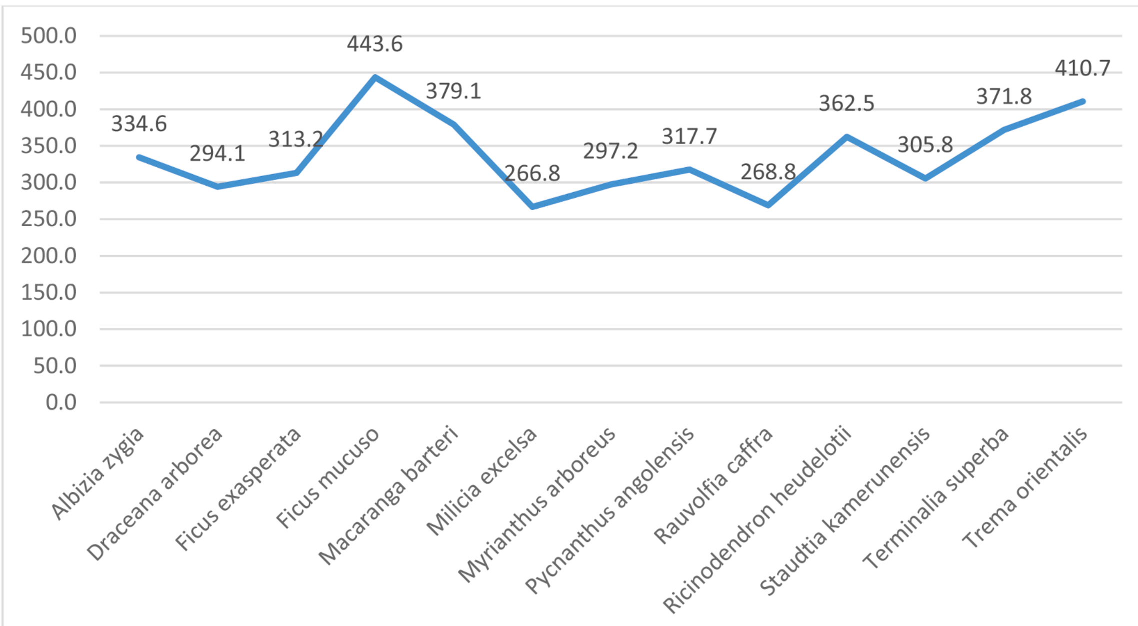

Fig. 11. Mean height (in cm) of species with $N > 30$, 14 months after slash-and-burn.

macrocarpus, Triplochiton scleroxylon and *Funtumia elastica*. The barochorous species are *Albizia zygia, Tetrapleura tetraptera* and *Albizia adianthifolia*. The autochorous species (diaspores dispersed by the plant itself) are represented by *Afzelia bipindensis*.

3.5. Light temperament of woody species preserved by farmers during the 2nd selection

Pioneer species are abundant in the inventoried plots (Fig. 9). These environments are heavily deforested and degraded, hence the abundance of pioneer species which are healing species of the environment. Pioneers are represented by *Musanga cecropioides, Trema orientalis, Triplochiton scleroxylon, Ricinodendron heudelotii, Macaranga barteri, Ficus exasperata* and *Albizia zygia*. The heliophilic species are *Celtis mildbreadii, Entandrophragma angolense, Milicia excelsa, Morus mesozygia, Pycnanthus angolensis, Terminalia superba, Pterygota bequaertii* and *Pouteria altissima*. Semi-heliophiles are *Alstonia boonei, Ficus mucuso, Albizia adianthifolia* and *Petersianthus macrocarpus*.

Shade-tolerant species are *Myrianthus arboreus, Dracaena arborea, Rauvolfia caffra, Tabernaemontana crassa* and *Trilepisium madagascariensis.*

3.6. Proportion of true seedlings and of resprouts in the ANRw, in 2019

Of the 14 species most represented in the regeneration retained by farmers at the time of the first ANRw action, only four species show good renewal via seedlings. These are *Ricinodendron heudelotii, Terminalia superba, Ceiba pentandra* and *Trema orientalis*. Table 1 shows that for all of the main species, renewal largely occurs via resprouting. It is not possible to prove that the difference between the rate of true seedlings and of resprouts, for all species, is significant between the village with the most degraded forest (Boteke) and the one with the least degraded forest (Salanga).

3.7. Initial height growth of the population of trees preserved by ANRw during 14 months

The average heights of the main tree species retained by farmers were measured in June-July 2019, January-February 2020 and August-September 2020 (Fig. 10 and Table 2).

Taking into account only the megaphanerophytes and mesophanerophytes kept by ANRw, the mean height is given in Fig. 11. For species with more than 30 observations, a mean height of 348.2 cm (± 145.8 cm) 14 months after slash-and-burn is noted.

3.8. Reasons given by farmers for species conservation by ANRw

3.8.1. Products of the species conserved by farmers

Species were selected and protected by farmers because of their usefulness (edible caterpillars, sawing, firewood and charcoal, pharmacopoeia) (Table 3). Due to their various uses, these species play an important role in the household economy (self-consumption and cash

Table 3
Usefulness of species protected by the ANRw in the village area of Boteke and Salanga.

Species	Number of individuals		Uses
	Boteke	Salanga	
Afzelia bipindensis	11		Sawn timber; Firewood; Charcoal
Albizia adianthifolia	9	15	Caterpillars; Firewood; Charcoal
Albizia zygia		64	Caterpillars; Firewood; Charcoal
Alstonia boonei	6	2	Treatment of intestinal parasites
Ceiba pentandra	27	21	Treatment of dental cavities
Celtis mildbreadii	1		Firewood; Charcoal
Celtis tessmanii		2	Firewood; Charcoal
Dracaena arborea	52	12	Childbirth treatments
Entandrophragma angolense	6	1	Caterpillars; Sawn timber
Ficus exasperata	45	50	Firewood
Ficus mucuso	9	9	Firewood; Charcoal
Funtumia elastica		6	Native glue; Firewood; Charcoal
Macaranga barteri		22	Pharmacopoeia
Milicia excelsa		8	Sawn timber; Firewood
Morus mesozygia	18	4	Firewood; Charcoal
Musanga cecropioides	2		Drinking water reserve
Myrianthus arboreus	28	39	Edible fruits; Firewood
Petersianthus macrocarpus	3	2	Caterpillars; Firewood; Charcoal
Piptadeniastrum africanum	38		Caterpillars; Firewood; Charcoal
Ricinodendron heudelotii	190		Caterpillars
Pouteria altissima	5	45	Sawn timber; Firewood; Charcoal
Pterygota bequaertii		10	Caterpillars; Firewood
Pycnanthus angolensis	48	159	Caterpillars; Firewood; Charcoal
Rauvolfia caffra	20	30	Pharmacopoeia
Ricinodendron heudelotii		54	Caterpillars
Staudtia kamerunensis	18	43	Firewood; Charcoal
Tabernaemontana crassa	3		Pharmacopoeia
Terminalia superba	38	11	Firewood; Charcoal; Pharmacopoeia
Tetrapleura tetraptera		3	Firewood; Charcoal; Edible fruits
Trema orientalis	83	30	Lumber
Trilepisium madagascariensis	1		Firewood; Charcoal
Triplochiton scleroxylon	3	27	Caterpillars; Sawn timber
Number of individuals	**751**	**669**	

income). The collection of non-timber forest products, artisanal sawing and the production of fuelwood are economically profitable activities for local communities, which motivates them to keep valuable plants in their fields during weeding.

3.8.2. Depletion of forest products and the first indicators of farmers' desire to restore their forest environment

Generally speaking, to justify their interest in conserving trees in their fields, farmers point to the fact that a significant part of their needs for food, drink, medicines, clothing, basketry, house building products, tools, etc. had been met in the past by harvesting forest products. However, the forest massif of Botambi (classified forest) has been undergoing heavy deforestation in recent years due to slash-and-burn agriculture, artisanal sawing and anarchic tree felling. The villages located in this area are now suffering the consequences of the remoteness of the forest, which is resulting in a shortage of the basic necessities found in the forest. This shortage is not entirely covered by agriculture, animal husbandry or the purchase of manufactured products in cities, especially in times of unrest and civil war, as has been the case for the past twenty years. These negative impacts of deforestation have led to an increased awareness amongst the population. Some individual initiatives thus have been taken by farmers for a modest effort to reforest the vegetation cover. Fig. 12 shows the chief of Boteke village who bought some *Khaya anthotheca* seedlings to plant near his house. This forest species produces a bark containing substances with medicinal, euphoric and aphrodisiac virtues (hence their use in maceration in palm wine).

In the same vein, Fig. 13 shows a farmer in the village of Botambi (close to Boteke) who, aware of the gradual disappearance of the forest and the consequences, obtained Ayous (*Triplochiton scleroxylon*) seedlings that would later produce not only edible caterpillars but also sawn timber. Indeed, Ayous is the species most exploited by artisanal sawyers on the outskirts of Bangui (Dubiez et al., 2019a).

However, these individual planting initiatives only involve a few dozen seedlings per year at the level of the two villages, which can in no way compensate for the population's need for wood and non-wood forest products.

3.8.3. Edible caterpillar production, the main driver of the ANRw effort

Due to the scarcity of game and the difficulties of livestock farming, the main source of protein for the populations comes from the consumption of insects, and in particular tree caterpillars. The marketing of edible caterpillars is an important source of income for farmers, but the main host species of edible caterpillars are also the main tree species exploited by loggers such as Sapelli (*Entandrophragma cylindricum*) and Ayous (*Triplochiton scleroxylon*). With the progressive depletion of the woody cover, these caterpillars are becoming rare. A desire to enrich village territories with caterpillar-bearing trees has become the main force driving the acceptance of the ANR technique promoted by the PDRSO project. In fact, all tree species known by farmers to carry caterpillars have been conserved. For example, *Ricinodendron heudelotii* was one of the species most protected by farmers. It is a species that produces caterpillars of various yellow or black colours called *Kourouka* in the Gbaka language, whose hairs fall out when the caterpillar becomes mature. When they are young, they can be collected on the trunks of trees, but when they are mature, they fall down and are collected on the ground around the foot of the tree. *Pycnanthus angolensis* also is appreciated for its production of the *Soussouka* caterpillar (small, black, hairless), but it is also a highly valued source of wood energy. Tree and caterpillar pairs that also have been mentioned are *Albizia zygia, Albizia adianthifolia* and *Piptadeniastrum africanum* bearing the *Nguénguéré* caterpillar. Similarly, *Petersianthus macrocarpus* or (*Essia*) is appreciated for its production of *Kourouka* caterpillars.

3.8.4. Wood production motivates the conservation of some trees, but to a lesser extent than NTFPs

Some species have been retained for wood energy. These are *Celtis tessmanii* ("*Bourounda* gives a pleasant taste to food" said a village woman), *Staudtia kamerunensis, Myrianthus arboreus, Morus mesozygia, Afzelia bipindensis, Terminalia superba, Albizia zygia, Albizia adianthifolia, Petersianthus macrocarpus* and *Piptadeniastrum africanum*.

Other species have been preserved for their medicinal virtues, for example the bark of *Ceiba pentandra* is used to treat tooth decay. The leaves of *Dracaena arborea* are used in childbirth. *Trema orientalis* is used for carpentry. Valuable species such as *Triplochiton scleroxylon* (ayous), *Pouteria altissima* (aniegra), *Milicia excelsa* (iroko), *Entandrophragma angolense* (tiama), *Afzelia bipindensis* (doussié) are preserved for their precious timber.

These choices of agroforestry species conserved by ANR based on their usefulness confirms the observations made by Peltier (2019) in various African countries.

3.8.5. What is the future for the plots where ANRw has been practiced?

The majority of farmers who participated in the ANRw trial campaign said they were thinking of continuing slash-and-burn agriculture. To do so, they will clear the plots where they have been practicing the selections again after eight to ten years. During the enriched fallow period, they will harvest various NTFPs, and then, at the time of felling, firewood or service wood. Then they will make further selections in the next cropping cycle, based on their previous experience. Only the village chief of Boteke stated that he would like to change his cropping system towards sustainable agroforestry. He would like to be able to harvest timber, fruits, a wide variety of NTFPs including some harvested

Fig. 12. Planting of Khaya by the village chief of Boteke showing a certain awareness of deforestation (source photo: Arnot Kpolita, 2019).

Fig. 13. Enrichment of a Botambi field by planting young ayous (*Triplochiton scleroxylon*) (source photo. Arnot Kpolita, 2019).

from vines (Guinea pepper, rattan, edible leaves of *Gnetum africanum*), caterpillars and various crops that provide shade (coffee, yams, etc.) or grow in clearings (maize, cassava, etc.) when large trees are felled.

4. Discussion

The ANRw activities in the villages of Boteke and Salanga, after three rounds of selections during weeding, have made it possible to preserve 1668 juvenile woody plants on 24 plots, 12 of which are in the village of Boteke and 12 in Salanga, on a total restored area of 5.35 ha (312 trees ha^{-1}). The families best represented in terms of number of individuals are *Euphorbiaceae* (341 individuals), *Moraceae* (320 ind.), *Ulmaceae* (274 ind.), *Myristicaceae* (228 ind.) and *Mimosaceae* (189 ind.). It is known that the forest of south-west Central Africa is a *Sapotaceae* and *Ulmaceae* forest (Yongo, 2004). The relatively low numbers of individuals in these two families can be explained by human pressure on the forest massif. Indeed, the exploitation of species for fuelwood due to slash-and-burn agriculture and artisanal sawing are at the origin of the regression of forest cover and the scarcity of valuable timber stocks in the forest perimeters of Bangui. These types of illegal exploitation are those which are described as anarchic by Yongo (2004).

Of the 24 plots, 19 are located in fallow land and five in forest areas.

The abundance of species in the fallow plots clearly shows their degree of tolerance to light, which justifies the spectrum of species temperaments dominated by pioneer species, evidence of forest reconstruction. Furthermore, the mode of species spread dominated by the abundance of zoochorous and anemochorous species is evidence of the secondarisation of the environment.

The main species protected by farmers have shown good regeneration in both types of environments. As *Ricinodendron heudelotii* is a light species, its regeneration through sowing in the fallow plot environment was very remarkable and was a species coveted by all farmers, hence its significant presence (20 plots out of 24) within the plots evaluated. Similarly, *Pycnanthus angolensis* (heliophilic), showed good regeneration ability (stump rejection) in the plots located in the forest environment. According to Cordonnier et al. (2006), plant species are distributed according to their tolerance of environmental factors, which confirms our observations.

The seedlings kept by farmers are mostly true seedlings (about 47%) and resprouts (about 53%) of large trees and the regeneration density is devoted to the 10 to 30 cm diameter classes constituting the future floristic potential. In unmanaged fallows, true seedlings are often dominated by pioneer species, especially invasive ones. In contrast, in ANRw-managed plots, true-seedlings are protected and favoured at the time of weeding, which allows them to emerge before the crop is abandoned. This is particularly interesting for *Ricinodendron heudelotii, Terminalia superba, Ceiba pentandra* and *Trema orientalis*, four species that reproduce largely via seedlings and are of particular interest to farmers for the production of edible caterpillars and timber. It is known that tree generation is quicker with resprouting, and that the amount of resprouts is usually a function of the length of cultivation prior to abandonment back to fallow. However, in our case, it was not possible to distinguish clearly between the village where the forest is least degraded (Salanga) and the one where it is most degraded (Boteke), probably due to the heterogeneity of the farmers' plots.

The main species showed good regeneration due to the conditions of the environment favourable to the establishment of juvenile individuals in both types of environments. This argument is supported by Traoré, (2012), who hypothesizes that "variations in juvenile density could be related to the complex interaction between factors involving species characteristics, soil type, climatic conditions and seed regeneration mechanisms in soil seed stocks, as well as the ability of the species to have sprout rejection".

Indeed, as rainfall is good and the soil is fertile in the study area, for species with more than 30 observations, the mean height was 348.2 cm (± 145.8 cm) 14 months after slashing-and-burning. The species are mainly pioneer and heliophilic, hence their rapid growth. These results are better than those obtained by Peltier et al. (2013) who, over 16 months of monitoring ANRw activities on the Bateke Plateaus (DRC), observed a height growth of 141 cm in woody trees. However, the comparison is only indicative and has no scientific value since in DRC, the same individuals were monitored for growth, whereas in CAR, monitoring was carried out on a stand in which new individuals were added to each selection. On the other hand, soil and climate conditions are different in the ANRw trial plots in CAR and DRC.

The preliminary results of tree measurements and in particular the distribution of diameter classes should be viewed with great caution, since the ages of the plots are not the same; at the time of the ANRw, some plots had just been opened while others had been open for six months or one year… similarly, some plots were weeded and others not.

Table 2 shows a strong variation in the number of individuals between the three measurement dates. This is partly due to the fact that farmers selected new individuals during each round of weeding and removed others. In addition, between two weedings and two selections by ANRw, new areas of the field become accessible (decomposition of tree branches) or inaccessible (development of lianas, etc.), which changed the areas on which selections were made and measurements were taken. For the six main species, the number of individuals increased from 582 in the first selection to 907 in the third selection. Some individuals selected during the first weeding may die or be eliminated during subsequent rounds of weeding, either by accident or because they are considered troublesome or too close together. The task therefore is one of monitoring a complex stand, which cannot be compared to monitoring a forest plantation, and this explains the high standard deviations observed.

In the future, it will be necessary to better describe the plots and their pedology, history, particular practices, etc. It also will be necessary to describe the farmers' practices and analyse the stands in terms of burning, thinning, weeding (subcontracting or not, women or men, frequency), cultivation intensity (number of rotations and associations), etc.

The enthusiasm shown by volunteers and local authorities is positive proof of the acceptance of ANRw in the two villages. This was shown by the large number of plants kept by the farmers. The reasons that have motivated local communities to conserve forest species are economic and medicinal, but depending on the level of deforestation and environmental degradation, some farmers are keen to rebuild vegetation, and see the practice of ANRw as a quick and easy way to restore woody vegetation or create an agroforestry system (Peltier, 2019).

The species protected by farmers are those that produce caterpillars, medicines, firewood and charcoal for cooking, which confirms the preliminary observations made by PDRSO experts (Dubiez and Gazull, 2019; Gazull and Peltier, 2020). The ANRw experiment carried out in the villages of Boteke and Salanga was very much appreciated by the local authorities (village chiefs, group leaders, judges) who asked for the massive involvement of their communities. In fact, farmers who are aware of the poverty in their villages, the very advanced state of deforestation and degradation of the forest landscape, but above all of the benefits they derive from the forest (caterpillars, fruit, sawing, firewood, timber), find ANRw to be a means of improving their living conditions and restoring the degraded landscapes around their villages. According to the farmers, the income from harvesting non-timber forest products (caterpillars, pepper fruits, *Maranthaceae* leaves, artisanal sawing) and the sale of products from slash-and-burn agriculture (palm wine, plantain banana, taro, manioc), enable them to meet multiple needs (construction of sheet metal houses, clothing, schooling, dowry).

The results obtained make it possible to assert that ANR is indeed an effective and inexpensive tool for restoring degraded or deforested environments. This conclusion corroborates those drawn by Peltier et al. (2013 and R. 2014), who assert that ANR makes it possible to sustainably reconstitute agroforestry systems. Many other authors also have claimed that ANR is a tool for restoring degraded Sahelian forest environments (Baggnian et al., 2013; I. 2014 and 2019; Larwanou et al., 2006; Lawali et al., 2018).

It also should be noted that the role played by the PDRSO project in the local communities was one of the factors in the success of ANRw in the villages. To this end, various activities have been organised by the project with these communities, including capacity-building training on the sustainable management of forest resources, the setting up of field schools dedicated to the technical training of farmers on agroforestry and the supply of field equipment (machetes, boots) to the ANR volunteers. These PDRSO technical frameworks, followed by awareness-raising by CIRAD experts in the area, have led to a real increase in awareness, as it is certain that these communities had very little notion of sustainable forest management prior to the project's activities and the arrival of ANRw.

Evidence of this is demonstrated by the virtual absence of woody trees in the old fallow areas of villages in the first ring of forest degradation, closer to Bangui, where only *Chromolaena odorata* and *Imperata cylindrica* colonise these environments. These facts also demonstrate that the proximity of rural development projects to local communities is also a factor in the success of tree resource management in the fields, even though many authors attest to the success of ANR through the presence of management committees (Baggnian, 2019).

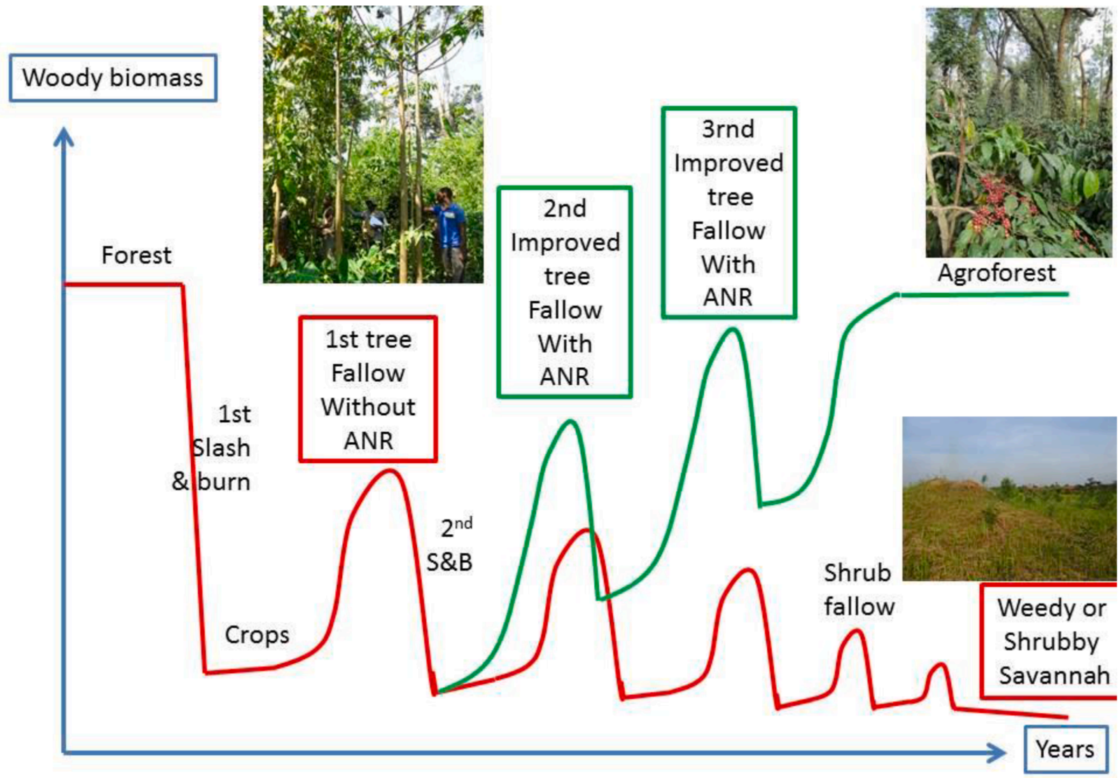

Fig. 14. Theoretical diagram of the evolution of the above ground woody biomass of a plot cultivated in slash-and-burn agriculture, with ANRw (green curve) or without ANRw (red curve) adapted from Floret and Pontanier (2001). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Nonetheless, the choice made by the majority of farmers regarding the future management of their plots, namely to continue with slashing-and-burning, is problematic insofar as a progressive degradation of biodiversity and soil fertility is possible, despite the desired use of the ANRw in the future. However, this choice is a "lesser evil" compared to the practice of slashing-and-burning without any concern for the management of the tree component, which is known to lead to the transformation of forests into savannahs. This militates in favour of monitoring these methods much more thoroughly and over a long period, if the financial means and political conditions allow it.

The choice made by the village chief of Boteke to gradually move towards the construction of an agroforestry system seems the most desirable in the eyes of the scientists, as it ensures the long-term maintenance of biodiversity, soil fertility and the storage of carbon in the above-ground biomass (Fig. 14). However, since it is reserved for an elite with sufficient land under their control, it is not certain that the regular increase in fires in the surrounding degraded forests will spare these agroforests, nor that the heirs of the current leader will not raze this agroforest in order to reap the timber capital quickly.

5. Conclusion

In the forested landscapes surrounding the city of Bangui, heavy deforestation and environmental degradation lead each year to a significant decline in the forest massif and the advance of the savannah with *Imperata cylindrica*. The assisted natural regeneration during weeding technique was tested in the villages of Boteke and Salanga with 23 volunteers on 24 fields. It emerged that the main tree species conserved by the volunteers showed good regeneration in the two villages. Woody plants showed good growth, and a good density of stems was observed on former forest environments and on former fallow environments after slashing-and-burning. These convincing results show that when managed correctly by local communities, ANRw can be an effective tool to restore tree cover that is currently in danger of disappearing across large areas.

As the communities are willing to take ownership of the technique, the State should popularise it for the sustainable management of the anthropized forest landscapes. In addition, volunteers who have tested ANRw say they are willing to continue practicing it. However, despite this genuine initial enthusiasm, this restoration drive will need to be monitored and supported due to the current context of extreme poverty and economic, social and political instability.

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CRediT authorship contribution statement

Arnot Kpolita: Data curation, Writing – original draft, Visualization, Investigation, Resources. **Emilien Dubiez:** Methodology, Software, Data curation, Validation. **Olga Yongo:** Supervision. **Régis Peltier:** Conceptualization, Writing – review & editing, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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