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Reforestation Initiatives in the Lubumbashi Charcoal Production Basin (DR Congo): Plant Diversity Selection, Management Practices, and Ecosystems Structure

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Abstract: The sustainability of reforestation initiatives depends on the involvement of local communities, whose lack of ownership compromises efforts to combat deforestation in the Lubumbashi Charcoal Production Basin. This study assesses reforestation activities in two village areas (Milando and Mwawa), based on individual interviews (50 individuals/village area) and floristic inventories carried out in two types of habitats (reforested and unexploited) for each village area. The hypotheses tested were the following: (i) Reforested habitats and tree species were selected collaboratively, ensuring an inclusive approach; (ii) ecological parameters—density per hectare, quadratic mean diameter, basal area, and floristic diversity—of reforested sites were comparable to those of unexploited *miombo* due to protection allowing natural recovery; and (iii) ethnobotanical and floristic patterns reflect varying levels of anthropogenic disturbance and the limited diversity of species used in reforestation. Thus, the interviews gathered data on habitat and woody species selection for reforestation and management practices, while the inventories assessed the condition of these reforested habitats in terms of density per hectare, basal area, quadratic mean diameter, and floristic diversity. The results show that in both village areas, the selection of habitats for reforestation was carried out concertedly (22.00–44.00% of citations). Woody species were chosen according to the needs of local communities (40–52%) and the availability of seeds (18.00–44.00%). Furthermore, management practices for these reforested habitats include planning/assessment meetings (26.00–38.00%) and maintenance activities, such as firebreaks (38.00–46.00%) and surveillance of reforested habitats (24.00%). Additionally, these practices are being increasingly neglected, jeopardizing reforestation efforts. However, density/ha, basal area, quadratic mean diameter, and floristic diversity did not show significant differences between reforested and unexploited habitats, particularly at Milando ($p > 0.05$). Furthermore, floristic similarity is 55.56% for reforested habitats and 93.75% for unexploited habitats but remains low between reforested and unexploited habitats (40.00–47.62%). This similarity between ethnobotanical and floristic lists is also low (43.75–31.58%). Finally, a total of 442 woody individuals were recorded in reforested habitats and 630 in unexploited ones, with Fabaceae dominating both habitat types. Despite some cited reforestation species like *Acacia polyacantha* being absent, *Brachystegia spiciformis* emerged as the most prevalent species in both reforested and unexploited areas. The results of the present study suggest a sustainable and continuous management of these reforested habitats for an effective reconstitution of the forest cover. To reinforce the sustainable management of these reforested habitats, it is recommended that decision-makers conduct awareness-raising campaigns and establish payment for environmental service mechanisms to motivate communities.

Keywords: restoration; deforestation; forest degradation; *miombo*; sustainable management; local community forest concession

1. Introduction

Forests are crucial terrestrial ecosystems, harboring 80% of the Earth's biological diversity and numerous endemic species [1,2]. For this, they play an important role in the atmospheric carbon sequestration and provide essential ecosystem services such as dendro-energy and non-timber forest products, supporting both rural and urban populations [3].

Globally, forests cover approximately 4.1 billion hectares, or 31% of the Earth's land surface [4]. In Africa, forests represent around 675 million hectares [5,6], of which almost 12% is covered by *miombo* [7,8], a forest dominated by woody species of the genera *Brachystegia*, *Julbernardia*, and *Isoberlinia* [9,10]. This forest covers between 2.7 and 3.6 million km^2 of the Zambezi ecoregion [11], providing a livelihood for over 100 million people [12,13]. It's high biodiversity and significant endemism, make the forest a priority for conservation [14,15].

However, increasing anthropogenic pressures—mainly shifting agriculture, dendro-energy production, timber exploitation, and bushfires—are driving *miombo* deforestation and degradation [16–23]. In the Zambezi region, deforestation rates range from 2% to 22%, with the highest level in countries where populations are highly dependent on forest resources [24], such as the Democratic Republic of Congo (DRC).

The DRC, despite its high forestry potential, has the highest deforestation rate in the Congo Basin, averaging −0.4% between 2001 and 2019 [3]. Southeastern DRC, particularly Katanga, has experienced a dramatic decline in *miombo* cover, from over 70% in 2000 to 43% in 2010 [25]. In the Lubumbashi Charcoal Production Basin—an area supplying dendro-energy to Lubumbashi—the deforestation rate reaches 1.51%, six times the national average [20]. Local communities similarly perceive this forest loss, as indicated by the perception maps of N'tambwe et al. [26]. This rapid deforestation is driven by poverty, socio-economic challenges, and urbanization, which exacerbate resource overexploitation and threaten community well-being [27,28].

To counteract deforestation and degradation, forest cover restoration is a key solution [8,29]. This process aims to restore forest structure, composition, and ecological functions, which are essential for sustaining local communities [30]. Natural regeneration is a viable approach in resilient habitats where forests can recover autonomously, but in areas with severe degradation, active reforestation is necessary to restore ecosystem services and mitigate further losses [13,31–34].

The success of these reforestation efforts depends heavily on local community involvement in project management, particularly in selecting appropriate habitats and tree species.

Engaging local populations ensures greater acceptance and sustainability of restoration initiatives [28,35–37]. This engagement of the local community would be facilitated by integrating traditional knowledge and local perceptions into restoration programs, fostering long-term commitment and enhancing natural resource management [24,36,37]. Several studies emphasize the importance of community participation in reforestation programs across Africa [6,38–41], including in the Zambezi region and the DRC [33,42–45]. However, research in this field in the Lubumbashi region remains limited. While existing studies acknowledge the need for reforestation and community engagement [46–48], they often lack a detailed assessment of how local participation directly influences project outcomes.

This study addresses that gap by evaluating the sustainability of reforestation efforts in anthropized *miombo* habitats within the Lubumbashi Charcoal Production Basin. By highlighting the key role of local communities in forest restoration, this study deepens understanding of sustainable reforestation strategies in degraded *miombo* landscapes. It investigates three key hypotheses: (i) Reforested habitats and tree species were selected collaboratively, ensuring an inclusive and participatory approach; (ii) ecological parameters, such as density per hectare, quadratic mean diameter, basal area, and floristic diversity of reforested sites, are statistically comparable to those of unexploited *miombo*, as these areas have been protected to allow natural recovery; and (iii) ethnobotanical and floristic similarities or differences reflect varying levels of anthropogenic disturbance and the limited diversity of species used in reforestation efforts. The findings will inform future reforestation policies and practices, ensuring more effective and community-driven conservation efforts.

2. Materials and Methods

2.1. Study Environment

The present study was carried out in the Lubumbashi Charcoal Production Basin in Haut-Katanga province, in the Democratic Republic of the Congo (Figure 1). This basin is situated at an altitude of between 1200 and 1300 m and at 11°40′ S–27°29′ E. According to Koppen's classification system, the climate prevailing in this Lubumbashi Charcoal Production Basin is of the *Cw* type [49]. This type of climate is characterized by two seasons including a rainy season (November to March) and a dry season (May to September), separated by two transition months (April and October). Average annual rainfall is 1270 mm, and average annual temperature ranges from 17 to 26 °C [9,10].

In the Lubumbashi Charcoal Production Basin, the primary vegetation is *miombo*, which is gradually being replaced by savannah, particularly around built-up areas, due to human activities [16,20]. The soils in this region are ferralsols with poorly differentiated horizons [50]. The population of the Lubumbashi region remains highly dependent on natural resources, particularly though slash-and-burn agriculture and dendro-energy production [28]. Moreover, most of this population lives on less than $1.25 a day, expressing a high level of poverty, food insecurity, and deprivation [27].

2.2. Methods

2.2.1. Village Areas Selection and Sampling

To assess the effectiveness and sustainability of forest cover restoration activities, two village areas: Milando (Lwisha) and Mwawa in the Lubumbashi Charcoal Production Basin were selected. These village areas were identified as having intense anthropogenic activities, notably agriculture and charcoal production [28]. In addition, Milando and Mwawa benefited from reforestation activities initiated in 2018 as part of the implementation of forest concessions for local communities (FCLC). These activities involved the participation of local communities, NGOs (APRONAPAKAT: Action pour la Protection de la Nature et des Peuples Autochtones du Katanga; BUCODED: Bureau Conseil en Développement Durable), the provincial environment coordination, and the FAO (Food and Agriculture Organization of the United Nations). In these village areas, 100 individuals, 50 per village area, were selected for ethnobotanical surveys using the snowball method [51,52], between 3 August and 15 September 2024. This number was determined due to the lack of official statistics concerning individuals familiar with reforestation issues in both village areas.

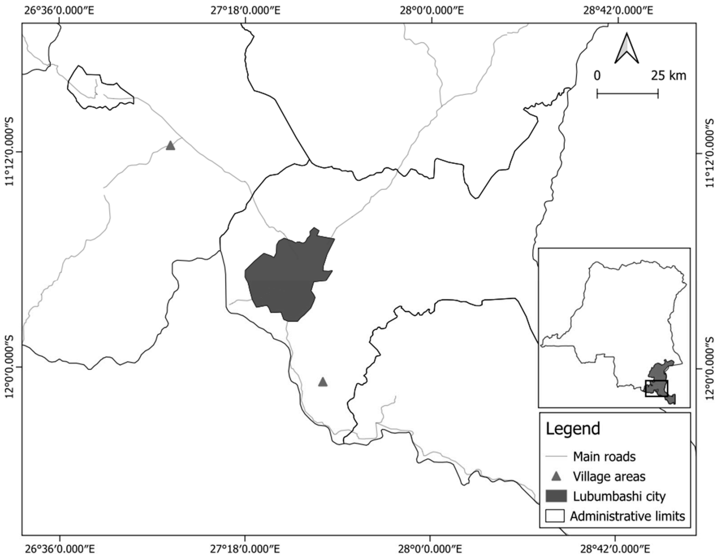


Figure 1. Location of the city of Lubumbashi (gray polygon) and its rural area (white space around the city of Lubumbashi). The triangles represent the village areas covered by the present study. The geographic coordinates used to locate these two village areas were taken from reforested habitats using GPS.

2.2.2. Data Collection

Ethnobotanical surveys were carried out using a semi-directive method [53], enabling the participants' discourse to be guided by pre-defined themes [54]. These surveys provided qualitative insights into local community involvement in reforestation, focusing on habitat and woody species selection, as well as habitat management practices (Supplementary Material). Forest management refers to all technical and practical actions aimed at preserving, restoring, and sustainably exploiting forests, including planning, reforestation, biodiversity monitoring, fire control, and conservation [55]. The identification of unknown woody species cited under their vernacular names during these ethnobotanical surveys was carried out using existing floras (Flora of Zambia, Flora of Zimbabwe, World Flora) and identification manuals [9,56–58]. Field trips with some of the respondents also enabled us to identify species cited and described in the local language, particularly those whose identification was difficult through the manuals.

Additionally, floristic inventories were carried out in reforested habitats and unexploited forests in each village area. In this study, unexploited forests refer to areas with no discernible signs of human activity over a historical period spanning decades to centuries [20]. This classification relies on evidence from historical records, remote sensing data, and field observations, focusing on indicators like intact canopy structures, the absence of logging infrastructure, and the presence of old-growth tree species. While some areas may have undergone minimal activities, such as selective harvesting or shifting cultivation, these are deemed insignificant if they left no lasting impact on the forest's structure. Identifying such forests helps isolate natural ecological processes from human influence, providing a reference point for studying forest dynamics in their undisturbed state. Thus, 40 floristic inventory plots were randomly installed, 20 in Milando village area

(10 in reforested habitat and 10 in patches of unexploited forest) and 20 others in Mwawa. Plot dimensions were determined based on previous studies [59,60], which had shown that 50 m × 20 m (1000 m^2) are adequate dimensions for floristic studies in *miombo* [13,60]. In these plots, all woody individuals with a diameter at breast height (*DBH*) ≥ 10 cm were counted and measured using forest tape [61]. These data on individual diameters allowed the establishment of the diameter structure of each inventoried habitat, while the counting enabled the calculation of individual density per unit area (hectare; [62]).

2.2.3. Data Analysis

To determine the criteria used when selecting habitats and woody species for reforestation, the citation frequency (C_f; Equation (1); [63]) was calculated with the *ethnobotanyR* package under R software version 4.3.2, based on individual interviews. This frequency is based on the principle that the most frequently cited criteria directly influence the choice of habitats and species for reforestation. It is calculated by the following equation:

$$C_f = \frac{S}{N} \times 100 \quad (1)$$

where *s* represents the number of respondents citing the criterion and *N*, the total number of respondents. If C_f approaches 0, the criterion had little influence on the choice, while an C_f close to 100 indicates a strongly favored criterion.

Furthermore, to characterize and compare reforested and unexploited habitats in both village areas, the diametric structure of inventoried individuals, density per hectare (*N*; Equation (2)), and the importance value index were calculated (*IVI*; [13,59]). The diametric structure reveals forest composition and dynamics, possibly indicating tree growth and the effects of environmental disturbances [62]. Density measures the number of individuals per hectare, while relative density reflects the proportion of a woody species within the habitat [63].

$$N = \frac{n_i}{a} \quad (2)$$

where n_i is the number of individuals of a wood species on a plot and *a* is the area of the plot expressed in a hectare.

Additionally, the *IVI* assesses the ecological dominance of woody species, with a higher value indicating greater ecological significance of the species within the forest ecosystem [60,64]. This index is calculated by the following equation (Equation (3)):

$$IVI = RDo + RD + RF \quad (3)$$

where *RDo* represents relative dominance (Equation (4)), while *RD* and *RF* correspond to relative density and frequency (Equations (6) and (7), respectively).

Relative dominance measures the basal area occupied by all individuals of a species over a hectare. However, relative density expresses the proportion of individuals of a species within all individuals in the habitat, while relative frequency indicates the proportion of a species out of wood species [59,60].

$$RDo = \frac{g_i sp}{g_i Tsp} \times 100 \quad (4)$$

where $g_i sp$ is the basal area of a species and $g_i Tsp$ is the sum of all basal areas of all woody species inventoried. However, g_i, the basal area of each individual measured (expressed in m^2/plot area), is calculated using the equation below (Equation (5)):

$$g_i = \frac{\pi D^2}{4} \quad (5)$$

with D, the diameter at breast height (DBH) of an individual, measured at 1.30 m from the ground.

$$RD = \frac{n_i}{N} \times 100 \quad (6)$$

where n_i is the number of individuals of a species and N is the total number of individuals surveyed.

$$RF = \frac{f}{F} \times 100 \quad (7)$$

while f is the frequency of a woody species (Equation (8)), expressing the probability that a woody species occurs in each of the installed floristic inventory plots (surveys), and F is the sum of all frequencies.

$$f = \frac{n}{Np} \quad (8)$$

where n is the total number of plots where the species was surveyed, and Np is the total number of plots.

However, quadratic mean diameter (DBH_m, Equation (9)) and basal area (GBA, Equation (10)) were calculated. The quadratic mean diameter, expressed in cm, is used for trees with several trunks at 1.3 m height. In this study, DBH_m was used to determine the mean diameter of trees in both reforested and unexploited habitats. The basal area, a common metric in forest management (expressed in m^2/ha), represents the cross-sectional area of tree trunks measured at breast height (1.3 m) [62,65]. In addition, the averages of species, genera, and families of individual trees inventoried in each habitat were calculated [65].

$$DBH_m = \sqrt{\frac{1}{n}\sum_{i=1}^{n} d_i^2} \quad (9)$$

where di is the diameter at breast height (DBH) of each tree trunk or branch, measured at 1.3 m above the ground, and n is the total number of such trunks or branches measured.

$$GBA = FE\sum_{i=1}^{m} g_i \quad (10)$$

with m being the number of woody individuals inventoried in the plot, and FE being the extension factor related to plot area (m^2), used to extrapolate g_i values to the hectare [62].

To highlight statistical differences at the 5% significance level among the parameters characterizing these two habitat types, the non-parametric Kruskal–Wallis test [66] was applied to density/ha, quadratic means diameter, basal area, and floristic richness. This test was used given the non-normality of the data confirmed by Shapiro's test [67]. In the case of significant differences, the Dunn-Bonferroni post hoc test enabled pairwise comparison of means [68,69].

To compare floristic diversity between the reforested and unexploited habitats, the Shannon, Simpson, and Piélou indices were calculated from floristic inventory data [2]. The Shannon index assesses specific heterogeneity and the distribution of individuals between species, while Simpson measures the probability of encountering two individuals of the same species consecutively. Piélou's equitability index estimates the ratio between observed diversity and maximum possible diversity [2,60].

Finally, to compare the plant species lists from individual interviews and floristic inventories in each village area, Jaccard's similarity index (J; Equation (11)) was calculated [70]. All these analyses were carried out using R (dendrometry package) and Past (version 4.05) software.

$$J = \frac{a}{a+b+c} \quad (11)$$

where a is the total number of woody species inventoried in the two habitats being compared; b and c, respectively, the number of woody species inventoried in one of the two habitats but absent in the other.

3. Results

3.1. Habitats and Species Selection Criteria for Reforestation and Management of Reforested Habitats

3.1.1. Choice of Habitats for Reforestation in Village Areas

Over 70% of respondents reported that reforestation habitats were chosen either through concertation among stakeholders or by village chiefs. Specifically, in Milando village area, the choice of habitats was strongly influenced by the village chief, whereas in Mwawa, it resulted from consultation involving the community, the NGO, the public environmental service, and the village chief (Table 1).

Table 1. Factors influencing the choice of habitats used for reforestation in both village areas. n = number of people surveyed. The sum of frequencies does not add up to 100%, as the proportions of those with no answer to this question have been removed from the table.

Selection Criteria	Reforested Habitats (%)	
	Milando (n = 50)	Mwawa (n = 50)
Choice of the village chief	48.00	24.00
Choice of the village chief and NGO	6.00	4.00
Choice of the village chief and notables	14.00	12.00
Consultation	22.00	44.00

3.1.2. Choice of Woody Species for Reforestation in Village Areas

More than 70% of respondents reported that woody species used for reforestation were selected based on their usefulness and the availability of seeds. In Milando, the availability of seeds was the main factor, while in Mwawa, the choice of woody species was primarily based on the needs of the local community. Other criteria, such as the use of timber and adaptation to soil types, influenced the selection of certain woody species, particularly in Mwawa (14% of respondents; Table 2).

Table 2. Criteria for choosing woody species for reforestation in the rural area of Lubumbashi. n = number of people surveyed; -: the choice criterion was not cited in the village area concerned.

Selection Criteria	Reforested Habitats (%)	
	Milando (n = 50)	Mwawa (n = 50)
Timber	-	4.00
Village chief and notables	-	6.00
Choice of NGO	16.00	16.00
Seed availability	44.00	18.00
NTFP sources	40.00	52.00
Soil type	-	4.00

3.1.3. Management Practices on Reforested Habitats Within Village Areas

Around 75% of respondents report that the management of reforested habitats relies mainly on planning and assessment meetings, the installation of firebreaks, and surveillance by forestry brigades. Specifically, the holding of such meetings and the installation of firebreaks are frequently mentioned in both village areas. In addition, plant nursery maintenance was particularly highlighted as a key activity in Mwawa, in contrast to Milando where this maintenance is less reported (Table 3).

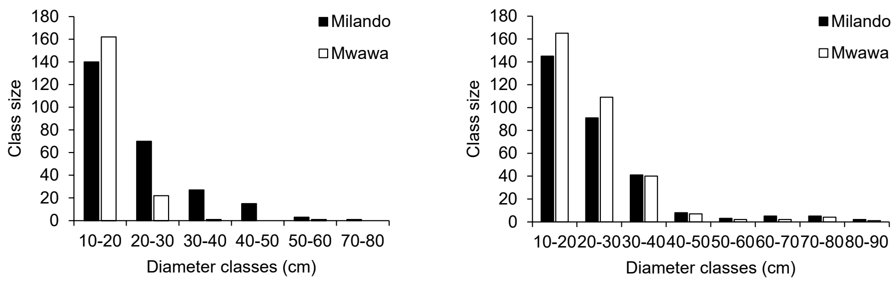
Table 3. Management practices for reforested habitats in the rural area of Lubumbashi. n = number of people surveyed; -: management practice was not cited in the village area concerned.

Management Practices	Reforested Habitats (%)	
	Milando (n = 50)	Mwawa (n = 50)
Firebreaks	38.00	46.00
Plant nursery	-	4.00
Planning/assessment meetings	38.00	26.00
Surveillance (Brigade)	24.00	24.00

3.2. Forest Recovery in Reforested Habitats Compared to Unexploited Miombo in Both Village Areas

3.2.1. Diameter Structure of Individuals Inventoried in Reforested and Unexploited Habitats Within Village Areas

Most individuals inventoried in reforested and unexploited habitats have a diameter at breast height (*DBH*) of between 10 and 40 cm. In the reforested habitat of Mwawa, many individuals are in the 10–20 cm *DBH* class, while in Milando, these individuals are distributed across all diametric classes. However, the unexploited habitats in both village areas show a similar diametric distribution, presenting increasingly large trees compared to the reforested habitats. Furthermore, the 'inverted J' structure in both habitat types (reforested and unexploited) highlights juvenile predominance, active regeneration, and gradual forest recovery, especially in reforested areas (Figure 2).



(**a**) (**b**)

Figure 2. Diametric structure of habitats in both village areas: (**a**): reforested habitats; (**b**): unexploited habitats.

3.2.2. Density per Hectare and Ecological Importance of Woody Species Inventoried Within Reforested and Unexploited Habitats in Both Village Areas

A total of 442 woody individuals were inventoried in reforested habitats, including 256 in Milando and 186 in Mwawa, belonging to 26 genera (Milando: 17; Mwawa: 21), and 13 families (Milando: 7; Mwawa: 11). In unexploited habitats, 630 individuals were counted: 300 in Milando and 330 in Mwawa, belonging to 37 species (35 per habitat), 27 genera (Milando: 25; Mwawa: 21), and 17 families (Milando: 15; Mwawa: 12). The Fabaceae family dominates in both habitat types, accounting for 60.94% and 74.73%, respectively, in the reforested habitats of Milando and Mwawa, and 70.67% and 76.97% in the unexploited habitats.

Some wood species cited by respondents as chosen for reforestation, such as *Acacia polyacantha*, *Afzelia quanzensis*, and *Anisophyllea boehmii*, were not recorded in either reforested or unexploited habitats. Nevertheless, of these woody species, *Brachystegia spiciformis*, *Diplorhynchus condylocarpon*, and *Isoberlinia angolensis* are the most represented in reforested habitats, while *B. spiciformis* remains dominant in unexploited habitats (Table 4).

Table 4. Floristic list of woody species cited during interviews and those recorded in reforested and unexploited habitats across both village areas. Woody species are listed in alphabetical order. Density per hectare; IVI: Index of importance values; Re: Reforested habitat; Un: Unexploited habitat; -: the woody species was not inventoried in the concerned village area; *: the species was cited during the interviews and recorded during the floristic inventories; +: the species was cited during the individual interviews but not recorded during the floristic inventories.

Species	Families	Density/ha				IVI			
		Milando		Mwawa		Milando		Mwawa	
		Re	Un	Re	Un	Re	Un	Re	Un
Acacia polyacantha Willd.	Fabaceae	- +	-	-	-	-	-	-	-
Afzelia quanzensis Welw.	Fabaceae	- +	-	- +	-	-	-	-	-
Albizia adianthifolia (Schumach.) W. F. Wight	Fabaceae	- *	6	37	14	-	8.36	55.73	15.24
Albizia antunesiana Harms	Fabaceae	20 *	8	6 *	9	24.37	10.77	10.82	8.78
Albizia versicolor Welw. ex Oliv.	Fabaceae	-	1	7	1	-	1.39	12.50	1.29
Anisophyllea boehmii Engl.	Anisophylleaceae	- *	4	- *	1	-	4.81	-	1.40
Baphia bequaertii De Wild.	Fabaceae	-	11	7	12	-	11.67	10.13	10.80
Bobgunnia madagascariensis (Desv.) J.H.Kirkbr. and Wiersema	Fabaceae	8 *	2	5 *	4	9.88	2.85	11.91	3.51
Brachystegia boehmii Taub.	Fabaceae	5 *	-	10 *	-	13.70	-	13.36	-
Brachystegia floribunda Benth.	Fabaceae	-	-	- +	-	-	-	-	-
Brachystegia spiciformis Benth.	Fabaceae	23 *	59	10 *	70	24.59	42.38	15.94	49.86
Brachystegia wangermeeana De Wild.	Fabaceae	24	98	15	108	31.99	69.52	20.54	68.83
Combretum collinum Fresen.	Combretaceae	-	1	-	1	-	1.94	-	1.88
Combretum molle R.Br ex G. Don	Combretaceae	-	1	-	2	-	1.96	-	3.41
Combretum zeyheri Sond.	Combretaceae	-	-	1	-	-	-	2.03	-
Dalbergia boehmii Taub.	Fabaceae	2	-	-	-	3.51	-	-	-
Diplorhynchus condylocarpon (Müll. Arg.) Pichon	Apocynaceae	15 *	8	21	8	16.72	9.26	29.01	8.77
Ekebergia benguelensis Welw. ex C.DC.	Meliaceae	-	1	-	-	-	1.43	-	-
Erythrina abyssinica (Hochst.) A. Rich.	Fabaceae	4	-	12	-	5.80	-	27.58	-
Erythrophleum africanum (Welw. ex Benth.) Harms	Fabaceae	-	4	-	3	-	5.20	-	4.01
Faurea rochetiana (A.Rich.) Chiov. ex Pic. Serm.	Proteaceae	-	-	1	-	-	-	1.89	-
Ficus sp.	Moraceae	-	-	1	-	-	-	1.97	-
Isoberlinia angolensis (Benth.) Hoyle and Brenan	Fabaceae	20 *	7	19 *	12	22.81	8.89	24.26	13.34
Julbernardia globiflora (Benth.) Troupin	Fabaceae	4	-	1	-	6.88	-	1.97	-
Julbernardia paniculata (Benth.) Troupin	Fabaceae	12 *	5	4 *	2	12.94	6.33	7.04	1.93
Lannea discolor (Sond.) Engl.	Anacardiaceae	2	4	-	4	3.04	3.70	-	3.46
Maranthes floribunda (Baker) F.White	Chrysobalanaceae	-	-	1	-	-	-	1.87	-
Markhamia obtusifolia (Boulanger) Sprague	Bignoniaceae	-	3	-	3	-	10.34	-	10.72

Table 4. *Cont.*

Species	Families	Density/ha				IVI			
		Milando		Mwawa		Milando		Mwawa	
		Re	Un	Re	Un	Re	Un	Re	Un
Marquesia macroura Gilg	Dipterocaerpaceae	- *	18	1 *	8	-	32.40	1.88	17.00
Monotes africanus Gilg	Dipterocaerpaceae	3	1	2	1	4.90	2.10	2.67	2.06
Monotes katangensis De Wild.	Dipterocaerpaceae	7	12	3	6	8.34	8.41	4.69	4.64
Mystroxylon aethiopicum (Thunb.) Lœs.	Celastraceae	-	1	-	1	-	2.04	-	1.99
Ochna schweinfurthiana F.Hoffm.	Ochnaceae	-	2	4	6	-	2.73	7.98	6.69
Olax obtusifolia De Wild.	Olacaceae	-	-	-	1	-	-	-	1.49
Parinari curatellifolia Planch. ex Benth.	Chrysobalanaceae	2 *	3	5 *	6	2.96	3.38	10.02	6.84
Pericopsis angolensis (Baker) Meeuwen.	Fabaceae	29 *	7	2 *	5	32.44	8.12	2.83	6.87
Philenoptera katangensis (De Wild.) Schrire	Fabaceae	1	-	-	-	1.47	-	-	-
Phyllocosmus lemaireanus (De Wild. & T. Durand) T. Durand and H. Durand	Ixonanthaceae	-	1	-	4	-	1.60	-	3.63
Pseudolachnostylis maprouneifolia Pax	Phyllanthaceae	5	2	-	1	4.69	2.79	-	1.26
Psorospermum febrifugum Spach	Hypericaceae	-	1	-	-	-	1.39	-	-
Pterocarpus angolensis DC.	Fabaceae	1 *	4	4 *	14	1.45	5.30	7.97	13.89
Pterocarpus tinctorius Welw.	Fabaceae	3 *	-	-*	-	6.42	-	-	-
Salacia rhodesiaca Blakelock	Celastraceae	-	-	1	-	-	-	2.00	-
Strychnos cocculoides Baker	Loganiaceae	-	3	-	1	-	3.69	-	1.67
Strychnos innocua Del. subsp. innocua	Loganiaceae	1	-	-	-	1.42	-	-	-
Strychnos pungens Soler.	Loganiaceae	-	1	-	1	-	1.64	-	1.56
Strychnos sp.	Loganiaceae	-	2	-	2	-	3.17	-	2.95
Strychnos spinosa Lam.	Loganiaceae	-	1	-	1	-	1.50	-	1.41
Syzygium guineense (Willd.) DC. subsp. Macrocarpum (Engl.) F. White	Myrtaceae	- *	-	2 *	-	-	-	4.27	-
Uapaca kirkiana Müll. Arg.	Phyllanthaceae	43 *	10	2 *	7	36.46	11.64	2.64	8.14
Uapaca nitida Müll. Arg.	Phyllanthaceae	15	7	1	7	15.05	5.91	2.43	5.38
Uapaca pilosa Hutch. var. pilosa	Phyllanthaceae	7	-	1	-	8.15	-	2.07	-
Uapaca robynsii De Wild.	Phyllanthaceae	-	1	-	3	-	1.39	-	3.90
Vitex doniana Sweet	Lamiaceae	-	-	-	1	-	-	-	1.39

3.2.3. Dendrometric and Floristic Parameters of Woody Individuals Inventoried Within Reforested and Unexploited Habitats in Both Village Areas

Overall, floristic parameters (number of species, genera, and families per hectare) show no statistically significant differences between reforested and unexploited habitats. However, reforested habitats, particularly in the Mwawa village area, show significantly lower values for density ($p < 0.05$), quadratic mean diameter, and basal area ($p < 0.001$; Table 5). These results indicate that *miombo* is recovering in reforested habitats, although this process remains less advanced than in unexploited habitats.

Table 5. Dendrometric and floristic parameters of individuals inventoried in the reforested and unexploited habitats. Mean ± standard deviation. Letters indicate significant differences at the $p < 0.05$ significance level.

Parameters	Reforested Habitats		Unexploited Habitats	
	Milando	**Mwawa**	**Milando**	**Mwawa**
Dendrometric parameters				
Density (individuals/ha)	256.00 ± 111.77 ab	186.00 ± 64.15 b	300.00 ± 97.18 a	330.00 ± 123.47 a
Quadratic mean diameter (cm)	21.94 ± 3.11 a	14.97 ± 2.54 b	24.64 ± 4.71 a	22.73 ± 3.11 a
Basal area (m^2/ha)	11.52 ± 5.52 a	3.40 ± 1.17 b	17.23 ± 7.70 a	15.89 ± 6.72 a
Floristic parameters				
Taxa/plot	10.40 ± 3.10 a	9.10 ± 2.92 a	10.30 ± 3.43 a	11.20 ± 2.86 a
Type/plot	8.30 ± 2.71 a	7.70 ± 2.71 a	8.30 ± 2.58 a	9.00 ± 2.11 a
Families/plot	3.60 ± 1.43 a	3.90 ± 2.03 a	5.00 ± 2.21 a	5.10 ± 2.23 a

3.2.4. Floristic Diversity Indices of Reforested and Unexploited Habitats in Both Village Areas

The Simpson and Shannon diversity indices range from 0.0834 to 0.1633 and from 2.503 to 2.809, respectively, with higher values in unexploited habitats. This indicates greater biodiversity in these habitats, where the probability of two randomly selected individuals belonging to the same species is lower. Piélou's equitability, which ranged from 0.7039 to 0.8593, remained almost similar between reforested and unexploited habitats, suggesting a relatively uniform distribution of species in both habitat types (Table 6).

Table 6. Diversity index between reforested and unexploited habitats in the Lubumbashi Charcoal Production Basin.

Indices	Milando Reforested	Milando Unexploited	Mwawa Reforested	Mwawa Unexploited
Simpson	0.0834	0.1581	0.08689	0.1633
Shannon	2.731	2.531	2.809	2.503
Piélou's equitability	0.8593	0.712	0.8342	0.7039

3.3. Similarities Between Ethnobotanical and Floristic Lists of Habitats in Both Village Areas

Jaccard's similarity index varies between 31.58% (between the ethnobotanical list and that of the floristic inventory in the reforested habitat at Mwawa) and 93.75% (between the unexploited habitats). This similarity remains low (below 50%), particularly between the ethnobotanical lists and those of the floristic inventories of reforested habitats in the two village areas. However, the ethnobotanical lists of these two village areas show a similarity of up to 66.67% (Table 7). These observations indicate a high dissimilarity between the ethnobotanical lists and the woody species present in the reforested habitats, while highlighting a high similarity between the floristic lists within unexploited habitats.

Table 7. Jaccard's similarity index of ethnobotanical and floristic lists in both village areas. Values are presented in percentages. -: Less informative comparison.

	Milando Reforested	Milando Unexploited	Mwawa Reforested	Milando Ethnobotany
Milando unexploited	40.00			
Mwawa reforested	55.56	-		
Mwawa unexploited	-	93.75	47.62	
Milando ethnobotany	43.75	-	-	
Mwawa ethnobotany	-	-	31.58	66.67

4. Discussion

4.1. Involvement of Local Communities in Decision-Making on Reforestation in Both Village Areas

Habitats and woody species for reforestation were selected through concertation, involving local communities, public services, NGOs, and international organizations (Tables 1 and 2). These results underline a participatory approach to reforestation, valuing the environmental perception and endogenous knowledge of local communities. This habitats and species selection approach stems from NGDOs promoting participatory methods to satisfy funding agency requirements [35]. This has led to consideration of the environmental perception of local community members when choosing habitats for reforestation. Indeed, in Milando, reforestation targeted habitat degraded by dendro-energy production, while in Mwawa, it was concentrated in post-cultivation fallows, as indicated by the perception maps of N'tambwe et al. [26]. These habitats were selected because they had been abandoned by local communities after being exploited for agriculture and charcoal production. In addition, *miombo* species were chosen for reforestation, to meet the specific needs of local communities (Table 2). Indeed, these species will help maintain the floristic composition, structure, and functions of the forests, thus ensuring the continuity of ecosystem services for the local communities [71]. This contributes to the involvement of local communities in the reforestation process, thereby reinforcing its success [72]. For illustration, other reforestation activities previously conducted in the Lubumbashi region using primarily exotic species, such as *Acacia auriculiformis* A.Cunn. ex Benth. and *Leucaena leucocephala* (Lam.) de Wit [73], have not yielded satisfactory results. Indeed, these exotic species have proven to be invasive, threatening local biodiversity [74] and providing ecosystem services that are less comparable to those of *miombo* woody species [75]. This has led to low community participation and limited sustainability of the reforestation processes. This situation highlights the importance of a participatory approach, which greatly enhances the success of reforestation and its adoption by local communities [37]. Indeed, the active and equitable involvement of the various stakeholders, in particular local communities, ensures that their needs and interests are considered, guaranteeing greater inclusiveness and relevance of the actions carried out. Furthermore, incorporating traditional knowledge enriches restoration strategies, offering adapted and culturally relevant solutions [76]. These results align with studies in Africa [40,77] and the *miombo* ecoregion, particularly Tanzania [78] and Mozambique [44], emphasizing the value of incorporating local cultures and knowledge in reforestation planning.

However, reforested habitat management practices primarily include planning and assessment meetings, as well as maintenance actions, and surveillance carried out by forestry brigades (Table 3). This can be explained by the fact that, following the implementation of the project to reforest anthropized habitats, local communities are striving to sustain these initiatives despite the interruption in funding. These practices are essential to ensure the sustainability of reforestation and promote the restoration of forest cover. Nevertheless, the implementation of certain activities, such as plant nursery maintenance and the creation of firebreaks, has dwindled, particularly in Mwawa. This is due to a lack of motivation on the part of local communities, attempts to expropriate reforested land, and insufficient post-project monitoring. Nevertheless, interruptions in funding are a recurring challenge in forest administration, often stemming from economic constraints, shifting priorities, and administrative changes [36]. In the LCPB, these disruptions were primarily linked to governance issues, including inefficiencies, a lack of financial transparency, and policy shifts [27]. Such challenges led to delayed budgets, diminished donor confidence, and operational setbacks [79]. Restoring funding will require strengthened governance, financial reforms, and renewed trust from donors [80]. While current efforts and policy measures may help recover financial support, sustaining long-term funding will depend on the upper-Katanga province's ability to enact effective reforms and maintain accountability in forest management.

Furthermore, reforestation often leads to land appropriation, particularly in regions where land tenure is governed by local rulers or lineage leaders [81]. Indeed, reforestation increases the value of degraded habitats, prompting stakeholders, including local communities, to claim ownership or usage rights. These claims can arise due to perceived improvements in land productivity and potential commercial opportunities like timber or charcoal production. Based on the foregoing, sustainable management of reforested habitats requires ongoing action to strengthen ecosystem resilience [76]. Thus, the gradual reduction in these practices exposes reforested habitats to anthropogenic pressures, notably late and repetitive bushfires, which characterize the miombo ecoregion [82–85], and especially the Lubumbashi region [23]. This threat is compounded by intensive tree-cutting for dendro-energy and agriculture, practices that are increasingly observed around reforested habitats. These activities are among the main drivers of deforestation and degradation of *miombo* [86,87], particularly in the Lubumbashi region [20,22,88]. However, before reforestation efforts, communities in the *miombo* woodlands relied on practices like shifting cultivation, selective harvesting, and controlled burning, which supported rotational land use and forest regeneration [89]. Charcoal production, once small-scale and tied to subsistence, has grown unsustainable in response to rising demand and agricultural expansion, outpacing natural regeneration [13,90]. Population growth, urban migration, and reduced fallow periods have further strained land resources [18,88]. Additionally, weakened communal land governance—driven by economic changes, governance shifts, and events like the COVID-19 pandemic—has disrupted sustainable management [91,92]. Extensive land clearance has altered ecological processes, reducing the land's capacity for natural recovery [13]. These challenges have increased dependence on external reforestation efforts, emphasizing the need to integrate local knowledge for long-term sustainability [13].

Weak management and maintenance practices for green spaces, resulting in the exponential degradation of these habitats, have already been reported in Burundi [93]. The results of the present study confirm the findings of previous research conducted in the *miombo* ecoregion [34,94,95], highlighting the importance of continuity of management practices, such as bushfire control, in the reforestation process. These practices are essential for mitigating anthropogenic pressures and promoting the rapid regeneration of forest cover in reforested habitats.

4.2. Reconstitution of Forest Cover Within Reforested Habitats in Both Village Areas

The results show statistically similar values between reforested and unexploited habitats, for dendrometric parameters, and more particularly for floristic parameters (Figure 2; Tables 4–6). This shows that the *miombo* forest cover is recovering in reforested habitats, compared with unexploited habitats in the Lubumbashi region. Indeed, the values for diameter structure, individual density/ha, quadratic mean diameter, basal area, and floristic diversity increasingly resemble those of unexploited *miombo* and findings by N'tambwe et al. [34]. This is attributed to reforestation efforts, habitat protection, and management measures like firebreaks and monitoring, which support woody species growth while reducing anthropic pressure. These results align with studies in Mozambique [60,85,96], confirming that, in the absence of human activity, degraded *miombo* habitats gradually restore their forest cover to the pyroclimax stage [11,97]. Nevertheless, this reconstitution is a function of the level of anthropogenic degradation experienced by the habitats and the resilience of woody species to these disturbances [13,60]. This also explains the low values represented by the reforested Mwawa habitat in terms of dendrometric parameters, compared with other habitats. Indeed, the reforested habitat at Mwawa would have undergone a high degree of anthropization, compared with that at Milando, thus explaining this difference in dendrometric parameter values particularly. In addition, the increasingly rare application of management practices works against the biodiversity conservation and reforestation efforts devoted to *miombo*. The results of the present study corroborate those of other research conducted in the *miombo* ecoregion [2,13,21,60,98–100], showing that habitat composition and floristic diversity are negatively correlated with anthropogenic disturbance.

4.3. Similarity Between Ethnobotanical and Floristic Lists of Reforested and Unexploited Habitats in Both Village Areas

The similarity between the ethnobotanical and floristic lists of reforested habitats remains low (Table 7). Some woody species present on the ethnobotanical lists are absent from the floristic inventory lists, and vice versa. This situation can be explained on the one hand by the fact that, during the floristic inventory, the individuals of certain species chosen for reforestation were still juveniles, with a diameter (*DBH*) below the pre-counting level set at $\geq$10 cm for the present study. This lower diameter of these individuals would be justified by the slow growth exhibited by most *miombo* woody species, as attested by previous studies [2,101], leading to this situation during floristic inventories [102]. Furthermore, the availability of woody species in a reforested habitat depends on these ecological requirements and the technical problems that may arise during the reforestation operation. Indeed, the requirements of a woody species in terms of ecological factors, particularly the physico-chemical properties of the soil, influence its ability to recover, survive, and establish itself in a habitat [103]. On the other hand, this situation can be explained by the fact that reforested habitats were already teeming with individuals of other woody species, leading to this difference between ethnobotanical and floristic lists.

However, the similarity of floristic inventory lists within reforested and unexploited habitats is low. This situation can be explained by the anthropogenic disturbances experienced by these reforested habitats in the past. Indeed, the composition and floristic diversity of habitats is inversely correlated with anthropogenic disturbance [13,21,99]. These findings align with studies in the Zambezi region [60,99] and Lubumbashi [34], showing that floristic diversity remains low in habitats affected by anthropogenic disturbances compared to unexploited habitats.

It is worth noting that local knowledge of unexploited miombo forests, even among communities primarily interacting with degraded areas, is shaped by cultural ties and long-standing practices. Sacred sites and seasonal activities in less disturbed forests provide insights into typical species composition. Observations of intact forest patches within degraded landscapes help identify species characteristic of unexploited environments. Generational knowledge transfer, especially from elders, preserves information about historically abundant species [104]. Communities also recognize shifts in species composition caused by exploitation, retaining an ecological memory that enables them to identify species once prevalent in unexploited miombo, even when such ecosystems are now rare or inaccessible.

4.4. Implications of Results for Optimized Management of Reforested Habitats in the Lubumbashi Charcoal Production Basin

The *miombo* forest cover is in full recovery within the reforested habitats of the Lubumbashi Charcoal Production Basin. However, the mechanisms (firebreaks and surveillance) that can regulate human activities are increasingly neglected in these village areas. This leads to a proliferation of human activities around these habitats, affecting efforts to combat deforestation and forest degradation in the Lubumbashi Charcoal Production Basin. In response to this issue, environmental education is one of the potential solutions. Indeed, through awareness campaigns, environmental education would increasingly promote the involvement of local communities in the management of these reforested habitats [105]. It would also promote adherence to regulations protecting reforested habitats and regulating activities like bushfires, charcoal production, and agriculture—key drivers of deforestation and degradation [20,106]. Environmental education, previously implemented after reforestation projects in Malawi, Lesotho, and Tanzania, has proven effective in raising community awareness for sustainable habitat management [107]. However, this awareness-raising may not produce the expected results, due to the mistrust and lack of confidence that plague relations between governance players in the Lubumbashi region [28]. The solution to this problem would be to organize dialog frameworks between the different stakeholders, to renew mutual trust.

Improving land tenure laws and forestry policies is a crucial alternative. Stronger legislation would protect habitats managed under local community forest concessions (LCFC) from pressures by concessionaires, farmers, and dendro-energy producers. Indeed, cases of habitat invasion under biodiversity conservation/preservation status have already been reported in the Lubumbashi charcoal production basin, resulting in the degradation of the vegetative cover of these habitats [48]. Additionally, the reform of forestry policy would help address anthropogenic invasions of these habitats through appropriate sanctions [37,108]. This will only be possible with the support of accredited public services and the advocacy of NGOs and international agencies [109]. Strengthening the existing monitoring framework is essential to ensure continuous oversight and evaluate the outcomes of reforestation activities after project implementation.

However, historically, communities in the *miombo* woodlands region relied on sustainable rotational land use, integrating shifting cultivation, selective harvesting, and controlled burning to promote forest regeneration [89]. However, population growth, agricultural expansion, and evolving land tenure systems have disrupted these practices, shortening fallow periods and increasing land pressure [110,111]. Political shifts promoting permanent settlement and intensified agriculture have further clashed with traditional methods that emphasize ecological balance [112]. Reforestation efforts, focused on rapid recovery and active management, often conflict with the historically passive approach of local communities, leading to misunderstandings. The threat of land grabbing tied to reforestation also undermines trust and discourages participation. Without alignment with local knowledge, such initiatives risk fueling land conflicts and compromising sustainability [113].

Furthermore, in Haut-Katanga, land is officially state-owned, but customary authorities and local communities exert informal control. The lack of clear land titles and weak enforcement of property rights frequently results in disputes, especially when reforested areas become targets for conservation or resource extraction [81,114]. Indeed, tenure systems managed by local rulers or lineage leaders have shown their limitations, as evidenced by studies conducted in Kongo Central (DR Congo) [81], particularly in the Lubumbashi region [27]. Resolving these challenges requires transparent land governance, formal recognition of reforestation efforts, and mechanisms to equitably distribute the benefits of restored landscapes [115,116].

Finally, mechanisms to encourage local communities to become involved in the sustainable management and expansion of reforested habitats, such as payment for environmental services (PES), is a solution that decision-makers need to implement. Indeed, PES is an incentive mechanism designed to encourage the protection, restoration, or enhancement of natural ecosystems [117]. This concept is based on the idea that beneficiaries of environmental services (governments, and companies) pay local communities for the adoption of practices that maintain or improve forest ecosystems [118]. This type of PES has already been initiated in the *miombo* ecoregion in Zimbabwe, with convincing results in terms of sustainable management of forest resources [90]. However, this will need to be accompanied by equitable distribution and reasoned use of PES dividends, to prevent conflicts between stakeholders [119].

The present study does not address social risks, such as land conflicts or inequalities in the distribution of benefits between local communities, which could compromise the sustainability of reforested habitats. Such information would enrich the current results and help develop strategies to ensure the long-term sustainability of these habitats.

5. Conclusions

This study evaluated the sustainability of reforestation efforts in two anthropized *miombo* habitats (Milando and Mwawa), using individual interviews and floristic inventories in two habitat types (reforested and unexploited) within each village area. The results confirm that habitats and woody species for reforestation were selected concertedly, aligning with the environmental perceptions and needs of local communities. Indeed, these habitats were selected in consultation with local communities, public services, NGOs, and international organizations, while the woody species were chosen according to the local communities' needs. This participatory approach fosters the sustainability of reforested habitats by involving local communities in activities such as planning, maintenance, monitoring, and assessment. The results also confirm that the *miombo* forest cover is recovering in reforested habitats, with dendrometric and floristic parameter values approaching those of unexploited *miombo*. Indeed, the averages of dendrometric (diameter structure, density/ha, quadratic mean diameter, basal area) and floristic parameters (taxa, genera, families) showed no significant differences between reforested and unexploited habitats. Finally, these results confirm that there are similarities and dissimilarities between the ethnobotanical and floristic lists of reforested and unexploited habitats. Certainly, high similarities were found between the floristic lists of these different habitats, while dissimilarities were observed between the ethnobotanic lists and these floristic lists. Unexploited areas contain more woody individuals. While *Acacia polyacantha* was mentioned for reforestation but not detected, *Brachystegia spiciformis* dominated both habitat types, along with the Fabaceae family. Although this study does not address social risks, such as land conflicts or inequalities in the distribution of benefits, it nevertheless highlights the importance of including local communities to ensure the sustainable success of reforestation projects. To promote forest cover restoration in reforested habitats, policymakers should revive environmental education and raise awareness among local communities about adopting reforestation-friendly practices. Strengthening land tenure, particularly in reforested habitats, is crucial to secure local community rights and ensure sustainable management. Regular monitoring, paired with proportionate penalties for violations, is essential to protect these habitats from human activities. Finally, introducing a payment for environmental services (PES) mechanism would further incentivize sustainable practices, aligning local interests with long-term forest cover restoration goals.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/ecologies6010017/s1. File S1: Survey Questionnaire on Reforestation Activities.

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