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Assessment of Woody Species Diversity and Ecosystem Services in Restored Manzonzi Forest Landscape, Democratic Republic of the Congo

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Abstract

Forests are important biodiversity reservoirs and require sustainable management to prevent deforestation and forest degradation. Forest landscape restoration (FLR) has been proposed as a sustainable initiative aimed at restoring ecosystem functions and improving the well-being of surrounding populations. In 2005, the World Wildlife Fund (WWF) initiated a project to protect 200 ha of savanna in Manzonzi landscape, Democratic Republic of Congo, on the outskirts of the Luki Biosphere Reserve. The biodiversity changes related to this ecological restoration project remain unpublished. To address this knowledge gap, floristic inventories of the protected Manzonzi landscape were carried out over a 12-year period and we assessed how changes in the floral composition of this landscape evolved and affected the provision of ecosystem services (ES). We found that protection of the savanna by banning recurring bush fires and fencing off the area promoted the richness and abundance of forest species, such as *Xylopia aethiopica* (Dunal) A. Rich, *Albizia adianthifolia* (Schumach.) W. Wight. These forest taxa replaced grassland species, such as *Hymenocardia acida* Tul. and *Maprounea africana* Müll. Arg., and served to benefit the local population, who use these forest taxa as food, fuelwood, and medicines. This study revealed that protected savanna improved woody biomass, plant diversity (richness/abundance), and carbon storage, significantly boosting essential ES for communities; yet these positive trends reversed when active monitoring ceased. Protecting savannas improves the environment and benefits communities, but stopping protection efforts can undo these gains, emphasizing the need for ongoing conservation.

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1. Introduction

Biodiversity supports the ecosystem services (ESs) upon which humanity depends for survival [1–3]. Forests, the ultimate reservoirs of biodiversity [4,5], provide habitats for some 60,000 tree species, 80% of all amphibian species, 75% of the world's birds, and 65% of all mammals [6]. Forests represent 662 billion tonnes of carbon, i.e., half of the planet's C stock [7]. Daily, humans use at least 40,000 species of plants and animals for food, shelter, clothing, and healthcare [8]. The FAO estimates that around a third of the world's population depends immediately on forest species and their products [9]. The tropical forests of central Africa, covering more than 3.6 million km^2, alone account for 10% of the world's biodiversity [10]. Almost half of these forests are present in the Democratic Republic of the Congo (DRC), one of the world's 16 mega-biodiversity countries, and the forests are characterized by a high level of endemism [6,10,11].

This rich biodiversity is threatened primarily by small-scale agriculture [12] and other anthropogenic factors such as pollution, forest fires, and the overexploitation of these forests for economic activities [13–17]. In response to these challenges, forest landscape restoration (FLR), in line with the Bonn Challenge which aims to restore 350 million hectares worldwide, has been promoted as a sustainable initiative to curb the degradation of forest biodiversity and restore the degraded, damaged, or destroyed (3-D) ecosystems with a view to sustainably improving the living conditions of local populations by maintaining and bolstering ecosystem services [18–21]. FLR is achieved through reforestation, assisted natural regeneration, agroforestry, and fencing [22–26].

In DRC, the province of Central Kongo is one of the most deforested areas in the country. Its forests, concentrated in the Mayombe region, have experienced an average 0.6% deforestation rate since the late 1980s, three times the national average [27]. Bush fires, as throughout sub-Saharan Africa, are transforming the surroundings of this residual forest into grasslands [28], favoring species extinction and habitat destruction [29,30]. To counter this trend, the World Wildlife Fund (WWF) initiated a project in 2005 to create 200 ha of "set asides" of savanna around Manzonzi on the outskirts of the Luki Biosphere Reserve, by suppressing recurrent bush fires and fencing off the area.

Studies on savanna protection and enclosure in Africa show positive results, including significant plant density and diversity gains. For instance, in Burkina Faso (2003–2011), savanna protection led to positive development in plant density and diversity, with a generic index of 1.25 [31]. Moroccan research confirmed that enclosure promotes natural regeneration of several forest species [32]. In Senegal's groundnut basin, enclosure increased species by over 52% in five years [33]. A 2014 Senegalese study further showed high regeneration in reserves, with species diversity rising from 27 to 50 within two years [34]. In DRC, a study documented forest regeneration in protected savannas, marked by increasing Fabaceae and Rubiaceae dominance [35]. Lubalega et al. (2018) further showed that enclosed forest species nearly doubled biomass gains compared to savanna species (53 vs. 37.6 tonnes ha^{-1}), demonstrating significant recovery potential [36]. However, these studies did not determine how these beneficial effects restored ecosystem services to support the regional population's well-being. Yet Tasi et al. (2026) reveal that in tropical Africa, savannas and protected lands provide multi-purpose species that deliver the varied ecosystem services most populations need for survival [37].

Based on these findings, we hypothesize that savanna protection will increase wood species diversity and biomass in Manzonzi, leading to higher carbon sequestration and ecosystem service value. To test this, we will inventory the species regenerated following savanna protection and then evaluate the effect of savanna protection on plant diversity over time, focusing on the services these diverse plants provide to local people.

The general objective of the current study is to evaluate the cumulative effect of a 12-year FLR process on biodiversity (species richness, diversity, and plant evolution) and carbon sequestration (biomass, CO_2-equivalent, and monetary value) by comparing restored savanna plots to control plots. Specifically, the study aimed to (i) assess the impact of FLR on wood production, stem number, species richness, species diversity, and the amount of CO_2-equivalent storage and corresponding monetary value as a function of time; (ii) assess the evolution of plant species over 12 years in the protected savanna and control plots; (iii) establish the similarities and differences between the restored and unrestored landscapes in terms of biodiversity, biomass, and carbon stocks; (iv) assess the potential for ES based on floristic composition.

This study is crucial for validating the effectiveness of FLR, showing how restored savannas recover their biodiversity and carbon (species, biomass, CO_2 storage) by monitoring long-term ecological restoration. By comparing restored areas with natural areas, the study establishes benchmarks by linking diversity to essential ecosystem services (such as climate regulation). It thus provides vital data for conservation, policy, and sustainable land management to combat degradation and climate change.

2. Materials and Methods

2.1. Study Site

This research was conducted in the Manzonzi defense system (5°43′45″ S, 13°15′0″ E) on the outskirts of the Luki Biosphere Reserve, Kongo Central Province, DRC (Figure 1).

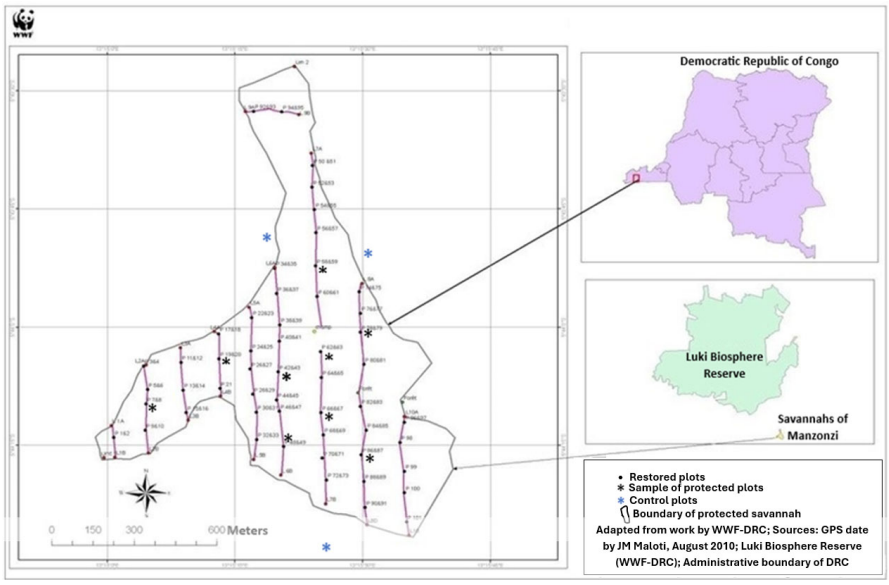

Figure 1. Manzonzi savanna fencing in 2005 on the outskirts of the Luki Biosphere Reserve [38]. These plots were randomly selected from among the undisturbed plots established along the paths represented by the purple trails in the system. Control plots were selected from outside the bush fire fencing system.

Regional climate is tropical humid (AW5; Köppen classification) [39]. Average annual rainfall is between 1200 and 1400 mm, and average annual temperature varies between 25 and 30 °C [40]. The regional climate is influenced by the Atlantic Ocean and, in particular,

the cold coastal Benguela current and the southeastern trade winds [41]. Local plant cover is characterized by a dominance of shrubby grassland subject to recurrent bush fires (Appendix A). Soils are generally ferrallitic and acidic [42] with a low cation content.

2.2. Sampling and Data Collection

Data were collected from the Manzonzi bush fire fencing system (Protected Manzonzi savanna), which became a forested landscape following restoration (Appendix A). Indeed, a permanent system of 10 trails linking 101 plots (each 50 × 80 m) was installed in 2010 to assess the dynamics of the installed fencing (Figure 1). In addition to these plots, found on either side of each layout, three plots of the same size were set up outside the fencing system to serve as controls and were subject to the savanna fire regime. In each fenced and control plot, all woody plants with a diameter greater than 5 cm were measured using a forestry compass, identified with the help of a botanist from the National Institute for Agronomic Study and Research (DR Congo), labeled, and numbered. In 2014, access to all 2010 trails was allowed, and the 2010 analyses were repeated in all plots. So far, no assessment has been carried out. To ensure the continuity of the study on biodiversity dynamics, nine of the twelve plots spared by bush fires in 2022 were randomly selected to be representative of the population. To guarantee the comparability of time series, data from these nine plots were retained for previous years (2010 and 2014). The other initial plots, returned to local communities for the use of ES, were excluded from dynamic monitoring, in accordance with the major objectives of the ecological restoration project. Three control plots, established in 2010 in the unrestored area, were maintained and monitored until 2022.

2.3. Dendrometric and Floristic Diversity Analyses

We first estimated wood production based on the basal area of stems of at least 5 cm dbh, aboveground carbon stock, abundance, species richness, and the Shannon index. Basal area (g, measured in m^2) was calculated as $g = \frac{\pi dbh^2}{4}$ [43], where dbh is the diameter at breast height (in m). This base area was then expressed per hectare (g, expressed in $m^2 \cdot ha^{-1}$). To determine sequestered carbon dioxide (CO_2) stocks, corresponding aboveground biomass was calculated following Chave et al. (2014) [44]:

$$\mathrm{AGB} = 0.0673 \times (\rho \cdot \mathrm{dbh}^2 \cdot H)^{0.976},$$

where AGB, ρ, dbh, and H are the dry aboveground biomass (in kg), specific density of wood (in $g \cdot cm^{-3}$), diameter at breast height (in cm), and total tree height (in m), respectively. This equation has shown to be remarkably efficient, robust, and accurate in pan-tropical studies. It has been revised by integrating biomass data for 4004 trees, including 1006 trees from tropical Africa [45]. Species-specific wood densities were obtained from the Global Wood Density Database available on https://datadryad.org/stash/dataset/doi:10.5061/dryad.234 (Accessed on 17 June 2022) [46]. For species not included in this database (approximately 0.01%), the average wood density of all the individual trees in the plots was considered [47]. As total tree heights were not measured, we estimated height by applying the equation of Kearsley et al., 2017 [48]:

$$h = 50.4531 \times (1 - \exp(-0.0471 \times dbh^{0.81197}))$$

where h and dbh are tree height (in m) and diameter at breast height (in cm), respectively. To determine the amount of sequestered carbon, we divided the total dry biomass by two, given that carbon represents half of the total dry biomass of the tree [49–51]. The carbon dioxide-equivalent (CO_2; in t. ha^{-1}) was determined by multiplying the amount of carbon by 3.67, the ratio of the molecular and atomic masses CO_2/C [52]. To highlight the

monetary value of sequestered carbon in the context of payments for ecosystem services, the CO_2-equivalent values were multiplied by 10 USD. ton^{-1}, which is on average the monetary value of the ecological service reported by the state of the voluntary carbon market [53].

To monitor the evolution of plant species over time in the fenced and control plots, we listed the inventoried species. An ethnobotanical survey was carried out using the appended questionnaire (Appendix B) to identify the use of these species. Given the involvement of human participants, this study received approval from Laval University's Ethics Committee for Human Research (no 2023-090).

We also calculated the abundance and relative dominance of each specific species using

$$\mathrm{SRA}(\%) = n/N \cdot 100,$$

where SRA is the specific relative abundance, n is the number of individuals of a given species in a plot, and N is the number of individuals of all species in a plot (total abundance of a species within a plot). Stem density was determined by expressing the number of individuals of all species per hectare.

We also determined the total dominance of a plot:

$$\mathrm{RDS}(\%) = g/G \cdot 100,$$

where RDS is the relative dominance of a species, g is the basal area of a given species (in m^2), and G is the basal area (in m^2) of individuals of all species in a plot (total dominance of a species within a plot). Species richness was determined by counting the number of species in the plot.

Given that abundance and species richness are not sufficient to assess species diversity, we applied the Shannon Diversity Index [54]:

$$H' = -\sum_{i=1}^{S} pi \cdot log_{2\ (\mathrm{pi})},$$

where H' is the Shannon Diversity Index; pi is the proportion of the abundance of a species present ($p_i = n_i/N$); n_i is the number of individuals counted for a species present; N is the total number of individuals counted, all species combined; and S is the total or cardinal number of species present. For a more thorough use of the Shannon index, we calculated Pielou's evenness index (J) as the ratio between H' and $H_{\max}$, where H' represents the Shannon index, and $H_{\max}$ or $\log_2(S)$ corresponds to a heterogeneous stand; this index varies between 0 and 1.

2.4. Statistical Analysis

For evaluating the changes between the protected and control plots, we applied a "before–after-control–impact (BACI)" design, often used in restoration ecology to evaluate the effectiveness of the applied restoration method [55–58], integrating all the data in the ecosystem services dynamics. It monitors impact and control groups both before and after an impact has occurred. Our setup was a repeated measures design in time (years 2010, 2014, and 2022) with randomized impact and control treatments in the landscape [59], using the Split-plot mathematical model as follows:

$$Y_{ijk} = \mu + \alpha_i + \beta_{j(i)} + \tau_k + (\alpha\tau)_{ik} + \varepsilon_{ijk}.$$

Using this linear model we assumed that Y_{ijk}, the data for treatment i in experimental unit (plot) j at time k, is equal to an overall mean μ plus the treatment effect α_i; $\beta_{j(i)}$ is the

random effect of experimental unit j receiving treatment i; τ_k is the effect of time; $(\alpha\tau)_{ik}$ is the effect of the interaction between time and treatment; and ε_{ijk} is the experimental error.

To assess the impact of fencing on measured ecological indicators as a function of time, we ran a two-way analysis of variance (ANOVA) with significance at $p < 0.05$. Data normality and variance homogeneity were verified before analyses, using the Shapiro–Wilk and Bartlett's tests, respectively [60]. The choice of this setup provided optimal test power. The power of ANOVA is optimal when the DF assigned to the experimental error b is equal to or greater than 10. In this study, the DF of experimental error was equal to 20. We then ran a multiple-comparison post hoc test (Tukey HSD test) to determine those means differing significantly from each other. Finally, to establish links between the protected savanna and the control plots in relation to the measured ecological indicators (i.e., stem density, basal area, CO_2-equivalent storage, species richness, and Shannon index within a plot), we ran principal component analysis (PCA) using the R package 4.3.2 with factoshiny. This was accompanied by a hierarchical ascending classification of individuals (protected and unprotected savanna plots). All analyses of the floristic inventory (Appendix C) were performed on R Studio version 4.3.2 [61].

3. Results

3.1. Measured Ecological Indicators

All ecological indicators (basal area, CO_2-equivalent storage, density, richness, and Shannon index) revealed significant interactions between restoration and time (Table 1, $p < 0.05$), meaning that their changes depended on both factors.

Table 1. ANOVA sources of variation (SV) and their degrees of freedom (DF) of measured ecological indicators, with the factors restoration—protected or restored savanna vs. control or unrestored savanna—and time—2010, 2014, and 2022. Experimental error A is the difference between the number of plots at each time and the number of levels in the restoration factor. The interaction between restoration and time is the product of the DF of restoration and time. The DF of the experimental units (E.U.) is the total E.U. minus 1. The B error is the DF of the E.U. minus the rest of the DF. NS (not significant), * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.

SV	DF	Basal Area				CO_2-Equivalent			
		SS	*MS*	*F*	*p*	*SS*	*MS*	*F*	*p*
Restoration	1	2.2131	2.2131	7.9049 **	0.0086	89,578	89,578	4.0889 NS	0.0521
Error A	10	4.1180	0.4118	-	-	302,722	30,272	-	-
Time	2	0.7004	0.3502	1.2509 NS	0.3007	29,438	14,719	0.6719 NS	0.5182
Restoration × Time	2	6.3421	3.1711	11.3269 ***	0.0002	531,578	265,789	12.1322 ***	0.0001
Error B	20	4.2808	0.2140	-	-	354,509	17,725	-	-
Total number/EU	**35**			**-**	**-**			**-**	**-**

SV	DF	Density				Species Richness				Shannon Index			
		SS	*MS*	*F*	*p*	*SS*	*MS*	*F*	*p*	*SS*	*MS*	*F*	*p*
Restoration	1	2333	2333.4	1.8291 NS	0.1864	710.45	710.45	44.1784 ***	0.000001	16.9974	16.9974	123.3947 ***	3.745×10^{-12}
Error A	10	10,007	1000.7	-	-	172.52	17.25	-	-	1.1664	0.1166	-	-
Time	2	6768	3384.1	5.9642 **	0.00656	197.72	98.86	6.1475 **	0.0058	2.8362	1.4181	10.2949 ***	0.00039
Restoration × Time	2	39,505	19,752.7	29.1091 ***	9.406×10^{-8}	132.35	66.18	4.1150 *	0.0263	1.1352	0.5676	4.1206 *	0.02623
Error B	20	5740	287.0	-	-	309.93	15.50	-	-	2.9660	0.1483	-	-
Total number/EU	**35**			**-**	**-**			**-**	**-**				

Specifically, Figure 2A and Table 2 show that the basal area in the unprotected savanna significantly declined from 2010 to 2014 (From 4.30 to 1.01 $m^2 . ha^{-1}$; $p = 0.049$) and 2022 (1.00 $m^2 . ha^{-1}$; $p = 0.048$), reaching levels significantly lower than protected areas in both 2014 (4.54 $m^2 . ha^{-1}$; $p = 0.005$) and 2022 (3.76 $m^2 . ha^{-1}$; $p = 0.041$), indicating restoration's critical role in stabilizing woody productivity. Nevertheless, while not statistically signifi-

cant, a noticeable visual decline in the basal area of the restored savannas was observed between 2014 and 2022, likely attributable to less rigorous monitoring during that period, highlighting a need for improved oversight.

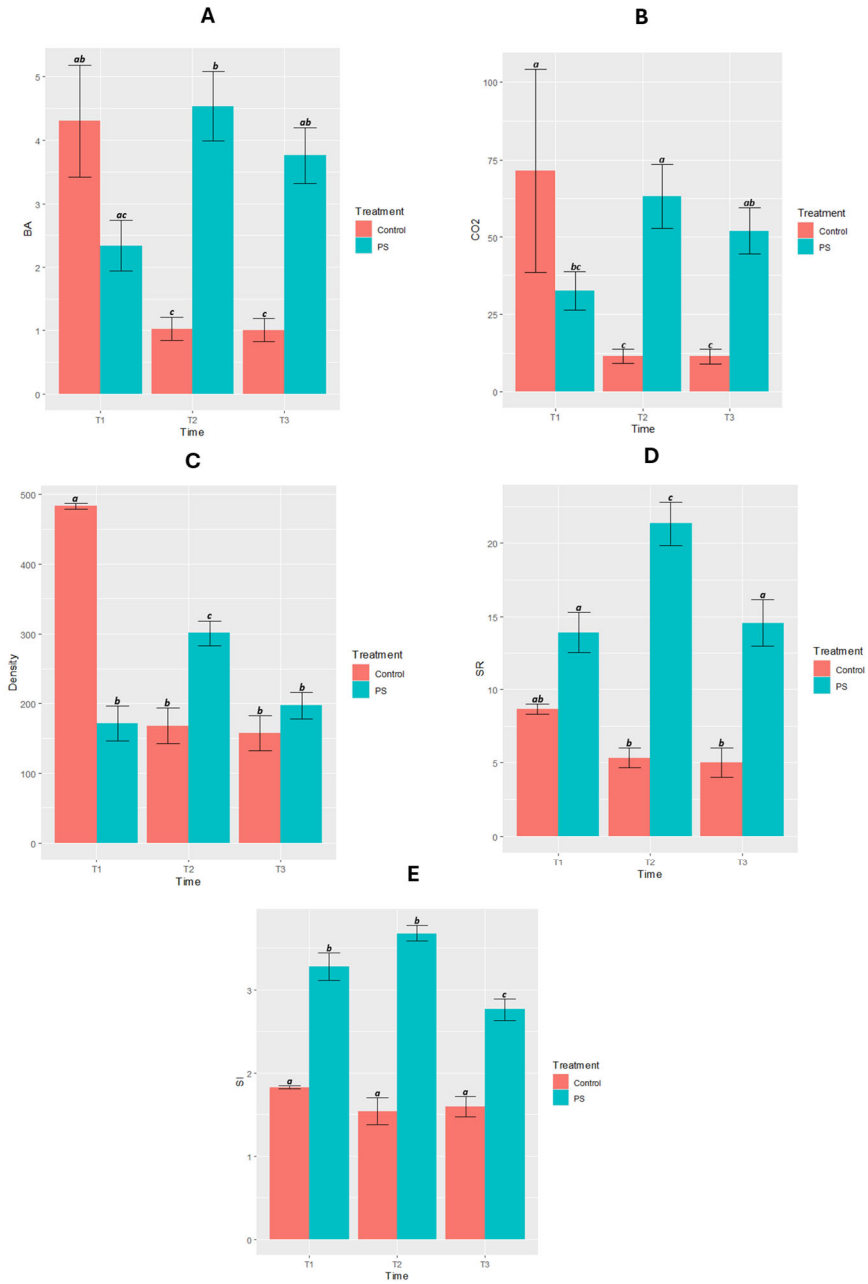

Figure 2. Pairwise comparisons of the means of (**A**) basal area (m^2. ha^{-1}); (**B**) CO_2 (t. ha^{-1}); (**C**) density (stems. ha^{-1}); (**D**) species richness (species. ha^{-1}); (**E**) Shannon index, value ranging from 0 to 5. PS: Protected savanna; Control: unprotected savanna. T1: 2010; T2: 2014; T3: 2022. Tukey's HSD test was applied to all means; means with the same letters are not significantly different ($p > 0.05$). Error bars show the variability of the plotted data. AcontrolT1 vs. AcontrolT2 ($p = 0.049$); AcontrolT1 vs. AcontrolT3 ($p = 0.048$); AcontrolT2 vs. ApsT2 ($p = 0.005$); AcontrolT2 vs. ApsT3 ($p = 0.04$); AcontrolT3 vs. ApsT2 ($p = 0.005$); AcontrolT3 vs. ApsT3 ($p = 0.041$); ApsT1 vs. ApsT2 (0.015); BcontrolT1 vs. BcontrolT2 (0.022); BcontrolT1 vs. BcontrolT3 ($p = 0.021$); BpsT2 vs. BcontrolT2 ($p = 0.014$); BpsT2 vs. BcontrolT3 ($p = 0.013$); BpsT2 vs. BpsT1 ($p = 0.041$); BpsT3 vs. BcontrolT2 ($p = 0.021$); BpsT3 vs. BcontrolT3 ($p = 0.019$); CcontrolT1 vs. CpsT1 ($p < 0.00001$); CcontrolT1 vs. CcontrolT2 ($p = 0.0001$); CcontrolT1 vs. CcontrolT3 ($p < 0.0001$); CcontrolT1 vs. CpsT3 ($p = 0.000012$);

CpsT2 vs. CcontrolT2 (p = 0.018); CpsT2 vs. CcontrolT3 (p = 0.009); CpsT2 vs. CpsT1 (p = 0.0006); CpsT2 vs. CpsT3 (p = 0.0075); DpsT2 vs. DcontrolT1 (p = 0.00064); DpsT2 vs. DpsT1 (p = 0.006); DpsT2 vs. DcontrolT2 (p = 0.0000202); DpsT2 vs. DcontrolT3 (p = 0.000014); DpsT2 vs. DpsT3 (p = 0.014); EpsT1 vs. EpsT3 (p = 0.04); EpsT2 vs. EpsT3 (p = 0.0002).

Table 2. Mean values of measured ecological variables. CO_2-eq: Carbon Dioxide-Equivalent; Density: Stem Density; SR: Species Richness; H′: Shannon Diversity Index; J′: Pielou's Evenness Index.

Ecological Indicators	Time					
	2010		2014		2022	
	Control	Protected Savanna	Control	Protected Savanna	Control	Protected Savanna
Basal area	4.30 ± 1.53 m^2. ha^{-1}	2.34 ± 1.21 m^2. ha^{-1}	1.01 ± 0.32 m^2. ha^{-1}	4.54 ± 1.66 m^2. ha^{-1}	1.00 ± 0.32 m^2. ha^{-1}	3.76 ± 1.31 m^2. ha^{-1}
CO_2-equivalent	71.42 ± 56.96 t. ha^{-1}	32.58 ± 18.44 t. ha^{-1}	11.45 ± 4.08 t. ha^{-1}	63.24 ± 30.72 t. ha^{-1}	11.44 ± 4.14 t. ha^{-1}	52.04 ± 22.62 t. ha^{-1}
Density	483.33 ± 7.63 stems. ha^{-1}	171.67 ± 73.12 stems. ha^{-1}	157.48 ± 40.31 stems. ha^{-1}	300.55 ± 51.69 stems. ha^{-1}	157.50 ± 43.37 stems. ha^{-1}	197.50 ± 57.54 stems. ha^{-1}
SR	8.67 ± 0.57 species. ha^{-1}	13.88 ± 4.11 species. ha^{-1}	5.33 ± 1.15 species. ha^{-1}	21.33 ± 4.50 species. ha^{-1}	5 ± 1.73 species. ha^{-1}	14.56 ± 4.75 species. ha^{-1}
SI (H′)	1.83 ± 0.03	3.28 ± 0.5	1.54 ± 0.28	3.68 ± 0.29	1.60 ± 0.22	2.76 ± 0.39
PEI (J′)	0.59 ± 0.03	0.88 ± 0.04	0.64 ± 0.08	0.84 ± 0.04	0.71 ± 0.20	0.72 ± 0.06

Unprotected savannas showed a sharp decline in CO_2-equivalent storage from 71.42 t. ha^{-1} in 2010 to 11.45 and 11.44 t. ha^{-1} in 2014 (p = 0.022) and 2022 (p = 0.021), respectively (Figure 2B and Table 2). Protected savannas, however, maintained higher CO_2-equivalent storage levels, with the 2014 protected savannas having the highest value. Notably, protected savannas experienced a substantial economic gain in carbon value between 2010 and 2014 (USD 325.80–USD 632.40 ha^{-1}, a gain of 94%), while unprotected savannas suffered a considerable loss in average value from USD 714.20 ha^{-1} in 2010 to USD 114.50 ha^{-1} in 2014 and USD 114.40 ha^{-1} in 2022 (a significant loss of 84%). These results highlight the critical role of restoration in preserving carbon stocks and associated economic benefits in landscapes. However, a decline in CO_2-equivalent storage of the protected savannas was observed between 2014 and 2022 (63.24–52.04 t. ha^{-1}, a loss of 18%), showing that restoration challenges persist.

Although the stem density of the unprotected savanna was initially high in 2010 (483.33 stems ha^{-1}), it declined drastically in 2014 (157.48 stems ha^{-1}; p = 0.0001) and 2022 (157.50 stems ha^{-1}; p < 0.0001) (Figure 2C and Table 3). In comparison, the stem density of the protected savanna was low in 2010 (171.67 stems. ha^{-1}) but significantly increased in 2014 (300.55 stems. ha^{-1}) and exceeded that of the unprotected savanna in both 2014 (p = 0.018) and 2022 (p = 0.009) (Figure 3C and Table 3). This stem density in protected savanna, unfortunately, declined between 2014 and 2022 (197.50 stems. ha^{-1}; p = 0.000012), likely due to the ineffectiveness of restoration monitoring methods after 2014.

Table 3. Changes in floristic composition from the protected plots. SRA: Abundance index in %; RDS: Dominance index in %; **: Most abundant and dominant species in 2022.

	Species	Family	Sampling Year						Ecosystem Services
			2010		2014		2022		
			SRA	RDS	SRA	RDS	SRA	RDS	
1	*Albizia adianthifolia* (Schumach.) W. Wight	Fabaceae (Mimosoideae)	3.9	6.5	2.4	3.0	10.4	14.2	Pollination, Firewood
2	*Albizia coriaria* Welw. ex Oliv.	Fabaceae (Mimosoideae)	-	-	0.1	0.2	-	-	Pollination, Timber

Table 3. *Cont.*

	Species	Family	Sampling Year						Ecosystem Services
			2010		2014		2022		
			SRA	RDS	SRA	RDS	SRA	RDS	
3	*Albizia gummifera* (J.F. Gmel) C.A. Sm	Fabaceae (Mimosoideae)	0.8	1.1	4.6	7.9	0.6	1.5	Pollination, Timber
4	*Albizia lebbeck* (L.) Benth	Fabaceae (Mimosoideae)	5.8	8.8	6.9	5.6	-	-	Pollination, Firewood
5	*Alchornea cordiflora* (Schumach. & Thonn.) Müll. Arg.	Euphorbiaceae	-	-	-	-	0.4	0.3	Pollination, Medicines
6	*Annona senegalensis* Pers.	Annonaceae	3.6	2.3	0.8	0.6	-	-	Food, Medicines
7	*Anthocleista vogelii* Planch	Longaniaceae	4.9	3.3	6.7	12.0	3.9	3.9	Medicines
8	*Antiaris welwitschii* Engl.	Moraceae	0.2	0.1	0.3	0.2	-	-	Timber
9	*Barteria nigritiana* Hook F.	Flacourtiaceae	0.2	0.1	0.7	0.4	-	-	Firewood
10	*Blighia unijugata* Baker	Sapindaceae	0.2	0.1	0.1	0.1	-	-	Pollination, Firewood
11	*Blighia welwitschii* (Hiern) Radlk	Sapindaceae	0.2	0.9	-	-	-	-	Pollination, Firewood
12	*Bridelia atroviridis* Müll. Arg.	Euphorbiaceae	-	-	2.2	1.0	-	-	Pollination
13	*Bridelia ferruginea* Benth	Euphorbiaceae	10.0	6.7	3.4	1.7	-	-	Pollination, Medicines
14	*Bridelia mycranta* (Hochst.) Baillon	Euphorbiaceae	-	-	-	-	0.1	0.1	Pollination
15	*Canthium oddonii* De Wildeman	Rubiaceae	3.7	4.5	6.5	8.7	4.4	7.4	Firewood
16	*Canthium odorata* (G.Forst.) Seem	Rubiaceae	-	-	-	-	0.1	0.1	Firewood
17	*Chrysophyllum africanum* A. DC	Sapotaceae	-	-	0.1	0.1	-	-	Firewood
18	*Crossopteryx febrifuga* (Afzel ex G. Don) Benth	Rubiaceae	3.9	2.6	-	-	-	-	Medicines
19	*Croton sylvaticus* Hochst. ex Krauss	Euphorbiaceae	0.7	0.9	0.7	0.7	1.4	1.8	Pollination, Medicines
20	*Dacryodes buettneri* (Engl.) H. J. Lam	Burseraceae	0.5	1.5	1.0	1.5	-	-	Food, Pollination, Timber
21	*Deinbolia acuminata* Exell	Sapindaceae	-	-	0.1	0.4	-	-	Pollination, Firewood
22	*Dracaena mannii* Baker	Agavaceae	0.2	0.8	0.1	0.5	-	-	Pollination
23	*Ficus capensis* Thunb	Moraceae	-	-	0.2	0.3	-	-	Pollination
24	*Ficus mucuso* Welw.	Moraceae	-	-	0.1	0.0	0.1	0.2	Medicines
25	*Ficus recurvata* De Wild	Moraceae	0.2	0.0	-	-	0.8	1.1	Medicines
26	*Funtumia latifolia (Stapf) Stapf*	Apocynaceae	-	-	-	-	1.0	0.8	Pollination, Craft Material
27	*Garcinia* sp.	Clusiaceae	-	-	0.2	0.2	-	-	Pollination, Medicines

Table 3. *Cont.*

	Species	Family	Sampling Year						Ecosystem Services
			2010		2014		2022		
			SRA	RDS	SRA	RDS	SRA	RDS	
28	*Hannoa klaineana* Pierre ex Engl.	Simarubaceae	-	-	0.1	0.0	0.1	0.5	Firewood
29	*Harungana madagascariensis* Lam	Hipericaceae	-	-	0.2	0.1	5.4	4.3	Pollination, Medicines
30	*Heinsia pulchella* (G. Don) K. Schum.	Rubiaceae	-	-	0.1	0.0	-	-	Medicines
31	*Holarrhena congolensis* Stapf	Apocynaceae	1.0	0.5	1.5	1.5	0.4	1.1	Firewood
32	*Hylodendron gabunense* Taub	Fabaceae (caesalpinioideae)	0.3	0.5	0.7	1.0	0.4	0.3	Firewood
33	*Hymenocardia acida* Tul.	Euphorbiaceae	10.4	9.6	5.9	6.6	4.9	3.8	Firewood
34	*Hymenocardia ulmoides* Oliv.	Euphorbiaceae	3.7	2.2	6.3	3.6	1.7	1.2	Medicines, Firewood
35	*Irvingia grandifolia* (Engl.) Engl.	Irvingiaceae	-	-	-	-	0.1	0.1	Pollination, Timber
36	*Isolona dewevrei* (De Wild. & Th. Dur.) Engl. & Diels	Annonaceae	0.5	0.6	-	-	-	-	Firewood
37	*Lannea welwitschii* (Hiern) Engl.	Anacardiaceae	6.2	6.5	7.7	6.2	2.5	3.3	Pollination, Medicines, Firewood
38	*Macaranga monandra* Müll. Arg.	Euphorbiaceae	-	-	2.6	2.1	0.6	0.4	Pollination, Firewood
39	*Macaranga spinosa* Müll. Arg.	Euphorbiaceae	4.2	4.0	5.2	2.3	1.7	1.2	Pollination, Firewood
40	*Maesopsis eminii* Engl.	Rhamnaceae	1.0	0.9	0.5	0.3	-	-	Pollination, Firewood
41	*Mangifera indica* L.	Anacardiaceae	-	-	-	-	0.1	0.1	Food, Firewood, Medicines
42	*Maprounea africana* Müll. Arg.	Euphorbiaceae	10.0	10.2	2.6	1.9	-	-	Firewood
43	*Maranthes glabra* (Oliv.) Prance	Rosaceae	-	-	0.2	0.1	0.1	0.1	Firewood
44	*Markhamia sessilis* Sprague	Bignogniaceae	1.5	2.1	1.5	2.5	0.3	0.2	Craft Material
45	*Microdesmis puberula* Hook. F. ex Planch	Euphorbiaceae	0.2	0.1	-	-	-	-	Firewood
46	*Milicia excelsa* (Welw) C.C. Berg	Moraceae	0.2	0.1	0.2	0.1	-	-	Timber
47	*Milletia versicolor* Welw ex Baker	Fabaceae (Faboideae)	1.5	0.5	1.9	1.8	0.7	0.3	Firewood
48	*Monodora myristica* (Gaertn.) Dunal	Annonaceae	0.3	0.9	0.5	0.7	-	-	Firewood
49	*Morinda lucida* Benth	Rubiaceae	0.2	0.8	-	-	-	-	Medicines
50	*Musanga cecropioides* R. Br ex Tedlie	Cecropiaceae	0.3	0.5	0.3	0.4	0.6	2.2	Firewood

Table 3. *Cont.*

	Species	Family	Sampling Year						Ecosystem Services
			2010		2014		2022		
			SRA	RDS	SRA	RDS	SRA	RDS	
51	*Myrianthus arboreus* P. Beauv.	Moraceae	0.2	0.8	0.1	0.4	-	-	Food
52	*Nauclea latifolia* Smith	Rubiaceae	3.4	2.7	0.8	1.2	0.3	0.2	Medicines
53	*Oncoba welwitschii* Oliv.	Flacourtiaceae	7.1	7.8	11.1	8.2	1.8	1.3	Pollination, Food
54	*Peucedanum fraxinifolium* Hiern ex Oliv.	Umbelliferaceae	-	-	0.1	0.1	-	-	Medicines
55	*Phyllanthus discoïdeus* (Baill.) Müll. Arg.	Euphorbiaceae	-	-	0.2	0.1	-	-	Medicines
56	*Pseudospondias microcarpa* (A. Rich) Engl.	Anacardiaceae	-	-	0.4	1.5	0.3	0.1	Pollination, Firewood
57	*Pteleopsis hylodendron* Mildbr.	Combretaceae	-	-	0.1	0.0	-	-	Firewood
58	*Pycnanthus angolensis* (Welw) Exell	Myristicaceae	0.2	0.5	0.3	1.1	0.3	0.2	Firewood
59	*Sorindeia gilletii* De Wild	Anacardiaceae	0.8	0.5	-	-	-	-	Firewood
60	*Sorindeia mayumbensis* Van Der Veken	Anacardiaceae	-	-	0.6	0.2	-	-	Firewood
61	*Spondias mombin* L.	Anacardiaceae	0.2	0.0	-	-	0.4	0.7	Pollination, Food
62	*Sterculia tragacantha* Lindl.	Malvaceae (Sterculioideae)	-	-	0.2	0.2	0.1	0.1	Pollination, Firewood
63	*Tetrorchidium didymostemon* (Baill) Pax et K.	Euphorbiaceae	4.7	4.9	3.9	3.8	1.3	0.9	Pollination, Firewood
64	*Treculia africana* Decne. ex Trécul	Moraceae	0.2	0.1	-	-	-	-	Pollination, Food
65	*Trichilia gilgiana* Harms	Meliaceae	0.7	0.7	0.6	1.0	0.1	0.2	Firewood
66	*Vernonia conferta* Benth	Asteraceae	0.8	0.8	0.9	0.8	2.7	2.6	Pollination,
67	*Vitex madiensis* Oliv.	Verbenaceae	-	-	0.3	0.1	-	-	Food
68	*Xylopia aethiopica* (Dunal) A. Rich **	Annonaceae	1.3	0.8	2.9	2.1	45.5	40.0	Pollination, Food, Medicines
69	*Xylopia chrysophylla* Louis ex. Boutique	Annonaceae	-	-	-	-	0.7	0.4	Firewood
70	*Xylopia hypolampra* Mildbr	Annonaceae	0.7	0.5	1.6	0.9	2.5	1.6	Pollination, Firewood
71	*Zanthoxyllum gilletii* (De Wild.) P.G. Waterman	Rutaceae	-	-	1.1	2.1	0.9	1.3	Pollination, Firewood
	Total		100	100	100	100	100	100	

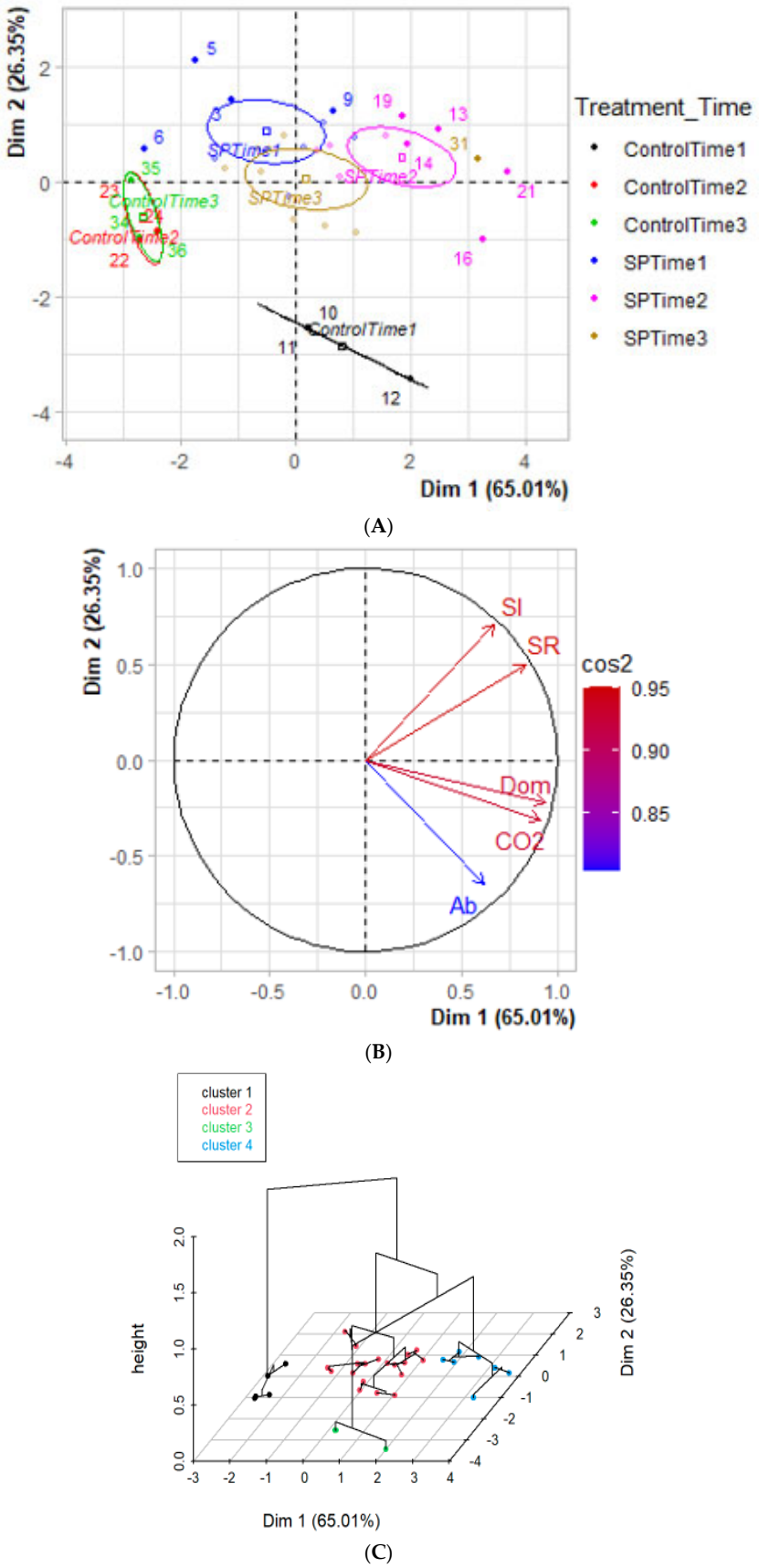

Figure 3. Principal component analysis (PCA) of the protected savanna plots and controls. Axis 1 (65.01%) and Axis 2 (26.35%) explain 91.36% of the total variability. (**A**) Plot of species: Labeled species

(number; refer to Tables 3 and 4) are those with the greatest contribution to the ordination. Labels are colored according to their modalities of the Treatment_Time variables. SP: savanna plots under protection; Control: unprotected savanna plots. Time1: 2010; Time2: 2014; Time3: 2022. Circles represent confidence ellipses around modalities. Overlapping circles do not significantly differ. (**B**) PCA ordination of variables. Labeled variables are those best represented on the plot. Variables are colored according to their representation (high cos2 values indicate high variable representation). Shannon index (SI), species richness (SR), total abundance (AB), total dominance (Dom), and carbon dioxide (CO_2) within a plot. (**C**) Hierarchical ascending classification of species produced four clusters of taxa.

Table 4. Changes in floristic composition from the unprotected plots. SRA: Abundance index in %; RDS: Dominance index in %; **: Most abundant and dominant species in all sampling years.

	Species	Family	Sampling Year						Ecosystem Services
			2010		2014		2022		
			SRA	RDS	SRA	RDS	SRA	RDS	
1	*Annona senegalensis* Pers.	Annonaceae	2.6	1.5	1.0	0.6	1.0	0.6	Food, Medicines
2	*Anthocleista vogelii* Planch	Longaniaceae	–	–	0.5	1.3	0.5	1.3	Medicines
3	*Bridelia ferruginea* Benth	Euphorbiaceae	6.0	4.3	3.0	1.7	4.0	2.9	Pollination, Medicines
4	*Crossopteryx febrifuga* (Afzel. ex G. Don) Benth.	Rubiaceae	2.6	1.2	1.0	0.7	1.0	0.7	Medicines
5	*Hymenocardia acida* Tul. **	Euphorbiaceae	43.4	56.1	55.2	58.1	58.7	61.2	Firewood
6	*Lannea welwitschii* (Hiern) Engl.	Anacardiaceae	0.5	0.9	–	–	–	–	Pollination, Medicines, Firewood
7	*Maprounea africana Müll. Arg* **	Euphorbiaceae	40.3	31.2	34.8	33.6	29.9	28.1	Firewood
8	*Morinda lucida* Benth	Rubiaceae	0.5	0.4	–	–	–	–	Medicines
9	*Nauclea latifolia Smith*	Rubiaceae	3.9	4.4	2.0	2.2	2.5	3.4	Medicines
10	*Ochna afzelii* R. Br. ex Oliv.	Ochnaceae	0.3	0.1	0.5	0.4	0.5	0.4	Medicines
11	*Psorospermum febrifugum* Spach	Clusiaceae	–	–	1.0	0.6	1.0	0.6	Medicines
12	*Vitex madiensis* Oliv.	Verbenaceae	–	–	1.0	0.8	1.0	0.8	Food
	Total	–	100	100	100	100	100	100	

Over time, protected savannas demonstrated superior species richness compared to unprotected ones. Notably, the 2014 protected savanna served as an extreme example, with markedly higher richness (21.33 species. ha^{-1}) than all other sites ($p < 0.05$; Figure 2D and Table 2). However, the decline in species richness from 2014 to 2022 (14.56 species. ha^{-1}; $p = 0.014$) reveals shortcomings in restoration monitoring, suggesting efforts were not rigorously assessed.

Protected savannas showed significantly higher species diversity (Shannon index, H′) and evenness (Pielou's Evenness, J′) compared to unprotected savannas (Figure 2E, Table 2; all pairwise $p < 0.001$). Furthermore, the 2010 and 2014 protected savannas differed significantly from the 2022 protected savanna ($p = 0.04$ and $p = 0.0002$, respectively). In 2022, protected savannas were still losing species despite restoration efforts, indicating that current management is not effectively rebuilding biodiversity.

3.2. Floristic Composition and Ecosystem Services Provided by Species

The flora of the surveyed protected plots comprised 71 species (Table 3) compared with 12 in the control plots (Table 4). Two species typical of grassy formations (*Hymenocardia*

acida and *Maprounea africana*) dominated the 2010 unprotected plots, together having an SRA and RDS exceeding 85%; this relative abundance and dominance increased over time to exceed 90%; These two species only provide firewood for the local population. (Table 3). The 2010 protected savanna plots featured several species for which their SRA and RDS increased significantly over time (Table 3). For instance, *Xylopia aethiopica* accounts for an exceptionally high proportion of both relative abundance and dominance, indicating strong dominance by a single species (almost half of the total SRA and RDS in 2022 accounts), as do *Albizia adianthifolia*, *Vernonia conferta*, and *Xylopia hypolampra*. Most of these species are typical of spontaneously restored forests and play a very important part in pollination (importance of melliferous plants) and in the supply of food, medicines, and firewood.

Forest species absent from the protected savanna plots in 2010 but that appeared in either 2014 or 2022 included *Alchorne acordiflora*, *Bridelia mycranta*, *Canthium odorata*, *Hannoa klaineana*, *Harungana madagascariensis*, *Xylopia chrysophylla*, and *Zanthoxyllum gilletii*, most of which provide the same types of ecosystem services as the forest species that are mentioned above. However, some species identified in the 2010 protected plots disappeared over time: *Albizia lebbeck*, *Antiaris welwitschii*, *Barteria nigritiana*, *Blighia unijugata*, *Blighia welwitschii*, *Dacryodes buettneri*, *Dracaena mannii*, *Maesopsis eminii*, and *Monodora myristica*. Although these species can develop in forests, they are neither characteristic of forests nor grassy formations, as they are transient. Some species typically found in grass-dominated savannas, such as *Hymenocardia acida*, *Hymenocardia ulmoides*, and *Maprounea africana*, were initially present in the 2010 protected plots; however, their abundance and dominance decreased considerably over time. In fact, *Maprounea africana* had disappeared completely by 2022. Relative to the control plots, the protected plots experienced greater change over time, with a shift from grass-dominated savanna to tree-dominated savanna over the 12-year period. Several transitional species came and went during this period. In the control plots, on the other hand, grassland species consistently dominated over the full study period.

3.3. Delineating Protected and Unprotected Plots Using PCA

The 2014 and 2022 protected savanna plots (as well as some protected plots in 2010) were richer in species (Figure 3). The confidence zone of the 2014 protected savanna plots did not overlap with those of the 2010 and 2022 protected plots, demonstrating a significant floristic difference associated with the studied variables. The protected savanna plots of 2014 and 2022, as well as the unprotected plots of 2010, were characterized by high values of RDS and CO_2-equivalent storage. Also, the unprotected plots of 2010 clearly stood out from other plots because of their high SRA values compared to other plots. However, the protected plots of 2014 and 2022 were also characterized by high SRA values. In addition, the control plots (unprotected plots) of 2010 and 2022 clearly stood out from other plots by their low species richness, plant diversity, SRA, RDS, and CO_2-equivalent storage. Four groups of plots were identified using the first two axes of the PCA (Figure 3C). The first group included plots with low biodiversity (low Shannon values) and species with low RDS, CO_2-equivalent storage, and SRA values. The second group included plots with high biodiversity (high Shannon values) and low SRA. The third class included plots characterized by abundant stems sequestering a large amount of CO_2, but less diversity (low Shannon values). The fourth class included plots that had a high number of species (high species richness values), were very rich in biodiversity (high Shannon values), and had dominant and abundant stems sequestering a large amount of CO_2.

4. Discussion

4.1. Ecological Indicators

The restored plots overall demonstrated positive forest regeneration, as savanna species lessened in abundance while key forest indicators, particularly *Xylopia aethiopica* became increasingly dominant, signifying successful habitat recovery. This indicates a transition from savanna to forest conditions over the period within the protected savannas. The implications include changes in ecosystem services such as carbon storage, water cycles, biodiversity, and habitat structure, and changes in the physical characteristics of the environment, like soil properties and reflectivity (albedo), as reported by [62]. However, a comparison between 2014 and 2022 reveals a decline in biodiversity and woody production, resulting in low biomass and Shannon index values, accompanied by a less equal species distribution. Lower biodiversity means fewer species to fill essential roles, making the ecosystem more fragile and less resilient [63]. Conservation efforts were initially effective, but subsequent human interventions, such as fire leakage and illegal cutting, appear to have altered this balance. To prevent irreversible loss, active monitoring and targeted strategies are essential.

In the control plots, savanna species (such as *Hymenocardia acida* and *Maprounea africana*) continued to dominate over the entire study period and were not replaced by forest species. Although the study's control plot sample was limited (n = 3), the findings indicate that savanna species remain dominant because of persistent factors, such as frequent fires, poor soil conditions that limit tree growth, and intense competition with grasses, actively inhibiting forest development and tree establishment [64]. These conditions create a stable environment where savanna species, adapted to disturbance, thrive and prevent the woody encroachment required for a forest biome to take over [65]. Lubalega et al. (2017) observed similar patterns on the Bateke Plateau, DR Congo [35]. In contrast, the replacement of savanna species by forest species in the protected savannas, illustrated by the greater abundance and dominance of forest species in 2014 and 2022 in comparison with 2010, suggests that ecological restoration has been successful in transforming a degraded landscape into a forest. It is simply a matter of implementing the necessary monitoring mechanisms to ensure ecological balance and prevent the general decline in biodiversity and biomass observed. This is consistent with the results of Lubalega et al. (2017) on the Bateke Plateau, where protected plots have also seen forest species replace savanna species [35].

4.2. Impact on Ecosystem Services

FLR, through suppressing recurrent bush fires and fencing, had a positive effect on the provision of ecosystem services around Manzonzi, DRC. Despite a 2022 downturn in wood productivity and biodiversity across restored lands, wood species diversity levels remain substantially higher than in original savanna ecosystems, with key forest species such as *Xylopia aethiopica* driving ecosystem services for local communities. This species is the most dominant and abundant, and provides food, medicine, wood, etc., for the population. This tree species has organs (e.g., branches, bark, leaves) that can benefit the population by becoming dominant. It should be noted here that the question of the provision of these ecosystem services can thus far be qualitative, determining whether or not these species provide ecosystem services, as mentioned by Tasi et al. (2025) [37]. A thorough study quantifying these services could clarify whether the quantity of these services has decreased as a result of this decline.

Furthermore, most other species regenerated in the set-aside system were also valuable to local communities for providing several ecosystem services, such as contributing to pollination and providing various medicines, firewood, and food, such as edible caterpillars,

mushrooms, honey, and vegetables needed by the population for their well-being. These beneficial species included *Albizia adianthifolia*, *Vernonia conferta*, *Xylopia hypolampra*, *Albizia gummifera*, *Bridelia atroviridis*, *Bridelia mycranta*, *Oncoba welwitschii*, *Pycnanthus angolensis*, *Spondias mombin*, and *Zanthoxyllum gilletii*. This underscores the effectiveness of these systems for both biodiversity conservation and human well-being, indicating that protecting and restoring ecosystems is a viable strategy for addressing challenges like food security, water stress, and climate adaptation [66]. For instance, Lonpi et al. (2023) demonstrated how many of these species provide food in the form of the caterpillars needed by the population of Mayombe, DRC [67]. Compared to these species, those from the control plots (mostly dominated by *Hymenocardia acida* and *Maprounea africana*) only provide firewood and medicines. In regard to ecosystem services in control plots, bush fires adversely affect floristic evolution [29,30,68]. Anthropogenically influenced savannas are generally poor in species, provide fewer ecosystem services, and are less beneficial for direct use by the population. The loss of species and the overall degradation of these ecosystems diminish their capacity to support wildlife, regulate natural processes, and provide direct economic or cultural value to people, ultimately impacting human well-being and the long-term sustainability of savanna environments [69].

Since most of the re-grown species in the set-aside system are melliferous, this potential can be exploited in beekeeping due to the quantities of nectar and pollen that bees can access [70]. Pollination, as a regulating service, also undoubtedly contributes to the dispersal of species and their regeneration [71–73]. Even if most of the regenerated species offer provisioning ecosystem services directly to the population, most of which are in the form of non-timber forest products (NTFP), the local population recognizes that species such as *Albizia coriaria*, *Albizia gummifera*, *Antiaris welwitschii*, *Dacryodes buettneri*, *Irvingia grandifolia*, and *Milicia excelsa* provide timber, although their supply is restricted. This highlights a potential management conflict, as the current use prioritizes NTFP over the use of these specific timber species, even though the local community values their timber potential. Opelele et al. (2022) drew up an inventory of the species present in the Luki Biosphere Reserve, such as *Entandrophragma utile*, *Prioria balsamifera, Terminalia superba*, and *Prioria oxyphylla*, which provide wood to local communities, although these taxa were absent from our survey data [74]. Apart from the potential for pollination, all combined species contribute to climate regulation by removing carbon dioxide from the atmosphere through photosynthesis and storing it as organic matter in their tissues [75]. This is fundamental to climate change mitigation, as more biomass means more carbon is removed from the atmosphere and stored in ecosystems [76]. However, the quantified decrease in CO_2-equivalent storage in restored landscapes between 2014 and 2022, rather than being limited to qualitative declarations as for other ESs, presents persistent restoration challenges. Considering this aspect has crucial implications for payments for ecosystem services and poverty reduction.

Maintaining and enhancing species diversity is vital because it bolsters food security by supporting essential ecosystem services like pollination, while also mitigating climate change through processes like carbon sequestration in forests [77]. Even if the cultural service of each species is not presented, the restored forest landscape is likely to attract tourists and encourage the creation of sacred sites. This is because the overall ecological integrity and aesthetic qualities of the restored landscape itself provide intrinsic value for recreation, mental well-being, and spiritual connection, which are fundamental components of cultural ecosystem services [78]. These contributions are vital for human well-being, supporting both individual livelihoods and the broader global ecosystem.

5. Conclusions

This study demonstrated how the fencing and fire suppression of savannas around the Manzonzi Forest (DRC) improved wood production and plant diversity over a 12-year period (2010–2022). The study reveals, however, that indicators of wood production and species diversity declined between 2014 and 2022. Based on qualitative statements, this decline does not appear to affect the provision of ecosystem services to the population. Relying solely on qualitative statements to confirm the impact on the provision of these services is a limitation, as quantifying ecosystem services would allow for the confirmation or refutation of their impact using indicators, as has been performed for CO_2. Given the approach taken in this study to supporting ecosystem services through the assessment of plant diversity, future studies should focus on the detailed quantification of the four types of ecosystem services (Provisioning, Regulating, Supporting, and Cultural) provided to the population following forest landscape restoration.

Author Contributions: J.-P.M.T. identified the theme and wrote the paper. He also analyzed and presented the data. J.-M.M.M.S., J.S.N., D.B., B.S.B., J.-F.B. and D.P.K. reviewed the article. In the end, all co-authors favored submitting the latest revised version to *Conservation*. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by Laval University Human Research Ethics Committees (protocol code 2023-090 and date of approval: 7 July 2023).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data may be available upon request.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Forest Inventory in the Restored Manzonzi Landscape

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

Figure A1. Photo taken by Deklerck in 2019 showing Manzonzi's savannas subjected to burning before they were protected (**a**). Photo of the forest inventory in the restored landscape of Manzonzi taken by Djo Nimy Nimy, 7 July 2022 (**b**).

Appendix B. Questionnaire on the Use of Inventoried Species

1. What is the use of each inventoried species in the protected savannah?
2. What is the use of each inventoried species in the unprotected savannah?
3. Do typical forest species offer the same ecosystem services as grassland species?
4. Which species are most widely used to provide ecosystem services?
5. Which ecosystem service is the most important of all those provided by the species inventoried?
6. What is the impact of the species inventoried on support services?
7. What is the impact of the species inventoried on regulating services?
8. What is the impact of inventoried species on socio-cultural services?
9. Is ecological restoration generally favorable to ecosystem services?
10. Any other relevant comments?

Appendix C

Table A1. Shannon Index (SI), Species Richness (SR), Abundance (Ab), Dominance (Dom)/Basal Area, and Carbon Stocks (CO_2) of species for each plot (Plot).

Plot	SI	Time	SR (Species)	Ab (Stem)	Dom (m^2)	CO_2 (t)
Plot1	3.58350922	2010	18	78	1.33695231	17.8354212
Plot2	3.35893579	2010	16	95	1.08545483	14.2318533
Plot3	3.445822	2010	14	56	0.55834695	6.88416184

Table A1. *Cont.*

Plot	SI	Time	SR (Species)	Ab (Stem)	Dom (m^2)	CO_2 (t)
Plot1	3.58350922	2010	18	78	1.33695231	17.8354212
Plot2	3.35893579	2010	16	95	1.08545483	14.2318533
Plot3	3.445822	2010	14	56	0.55834695	6.88416184
Plot4	3.80515775	2010	18	102	1.50182622	20.601693
Plot5	3.55907957	2010	14	26	0.24711094	3.52118398
Plot6	2.30647771	2010	7	33	0.30871617	3.83677567
Plot7	2.97800576	2010	11	108	1.20378573	15.7414656
Plot8	2.78716342	2010	9	61	0.73981933	10.3488995
Plot9	3.69264203	2010	18	59	1.43061933	24.2774345
Plot10	1.81773671	2010	9	196	1.37059038	15.4995062
plot11	1.80503754	2010	9	196	1.36430488	15.331242
plot12	1.85932219	2010	8	196	2.43021242	54.8730297
Plot1	4.00112217	2014	26	120	1.98380159	25.9396994
Plot2	3.93250847	2014	24	143	1.53342667	18.6706253
Plot3	3.1566786	2014	17	112	1.53100518	19.4899341
Plot4	3.49408177	2014	18	153	2.96810525	40.9767087
Plot5	3.80768945	2014	24	135	1.35512779	16.8532972
Plot6	3.499556	2014	16	106	1.16622245	15.1162569
Plot7	4.07805544	2014	25	122	1.52451154	18.8580289
Plot8	3.54433909	2014	16	88	1.40113145	20.9718554
Plot9	3.61388899	2014	26	103	2.86671027	50.7708816
Plot10	1.30898741	2014	4	76	0.4496043	4.91441557
plot11	1.84816074	2014	6	47	0.26645247	2.81019968
plot12	1.45736208	2014	6	79	0.51450565	6.01924694
Plot1	2.45792223	2022	12	94	1.86247844	26.6819827
Plot2	2.54137565	2022	15	119	1.94641535	25.104637
Plot3	2.57657094	2022	12	60	1.2860396	17.552878
Plot4	3.04409127	2022	13	65	1.17625656	14.9412976
Plot5	2.33723097	2022	12	94	1.51614822	20.3106132
Plot6	2.81086385	2022	14	62	1.03532473	13.3806504
Plot7	3.59211973	2022	26	100	2.60195001	41.0838829
Plot8	2.98209201	2022	17	64	1.15923933	15.0617878
Plot9	2.50451247	2022	10	53	0.98232702	13.2387433
Plot10	1.48996155	2022	3	76	0.4496043	4.83874738
plot11	1.84816074	2022	6	47	0.26645247	2.81019968
plot12	1.44732971	2022	6	79	0.51450565	6.08681453

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