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Impacts of Restoration Projects on a Sahelian Woody Vegetation after 21 Years: The Simiri Plateaus (Niger) Case Study

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Authors' contributions

This work was carried out in collaboration between all authors. Author LA designed the study, performed the statistical analysis, wrote the protocol, collected the field data and wrote the first draft of the manuscript. Authors BMM and HR participated to the data collection and the statistical analysis. Author AM managed the data collection. Author JS managed the analyses of the study, the literature searches and proofread the final draft manuscript. All authors read and approved the final manuscript.

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ABSTRACT

To face the soil and vegetation degradation in Niger, anti-erosion structures, such as scarification of the surface of the ground, half-moons, benches, trenches, stony cordons, were built in 1989 on three Simiri plateaus. Native and introduced woody species were planted and grasses were sown within the structures. This study aims at evaluating what has become the restoration of the woody vegetation cover compared to an un-restored woody cover located on a nearby similar site. Dendrometric parameters and alpha and beta diversities of the four woody stands in 36 sampled

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plots were analyzed and compared. The following dendrometric values were found significantly lower in the control than in the restored stands: 3.9% against 12.4-16.8% for the recovery rate, 4.3 against 6.3-10.2 cm for the largest stem diameter, 0.2 against 0.8-1.2 m²/ha for the basal area, and 1.6 against 2.0-2.5 m for the tree height. However, the number of stems per trees was found significantly greater in the un-restored stand (6.6) than in the restored ones (1.8-2.7). The values of dendrometric parameters remained low, as well as the alpha and beta diversities whatever the stand. Nevertheless, population perceptions on the restoration impacts that were collected through focus groups indicated positive impacts on downstream crop yields.

Keywords: Degradation; regeneration; desertification; diversity; half-moon; Zarmaganda.

1. INTRODUCTION

Natural resources (soil, water, vegetation) in Niger suffer from desertification because of the combination of recurring drought periods (1973, 1984, 1996, 2005), and human activity increase with population growth [1]. The impact on the already meager natural resources is a considerable decrease in primary production (cultivated or not) that exposes populations to a precarious food situation [2].

Woody vegetation is an important part of the forage in Africa [3,4]. In Zarmaganda (Niger), vegetation located on plateaus is used for pasture, gathering and hunting. In 1989, to cope with the current degradation of the vegetation cover on nine plateaus in this area, a project called Agro-Sylvo-Pastoral Project, in collaboration with the National Institute of Agronomic Research of Niger and the Anti-Erosion Measures Programm, built anti-erosive structures in which vegetation was planted and sown. Their main objective was to restore sustainable availabilities in forage, firewood, and timber and non-timber forest products. The anti-erosive structures were half-moons, benches, trenches, and stony cordons. After scarification of the soil surface, revegetation included tree plantations, and direct sowing of herbaceous species. Village management committees were expected to insure maintenance of the anti-erosive structures and sustainable use of the new vegetation cover. However, no fence was set up to protect them from pasture and cutting. The state of the flora on these sites before the restoration was described [5,6,1] but in addition, to assess the degree of success of these restoration, inventories were conducted in 2010 on the restored sites and compared to that of an un-restored site, other things being supposed equal. This paper provides some of the first results obtained on the woody cover.

2. MATERIALS AND METHODS

2.1 Study Sites

The inventory was conducted in the Simiri area of 2233 km², 78 km away from Niamey, in the northern part of the Ouallam department, Tillabéri region (Fig. 1). Population of the area increased from 101627 inhabitants in 2010 [7] to 103057 inhabitants in 2014 [8], while its density changed from 45.5 to 46.15 inhabitants per km². The climate is Sahelian according to the classification of Breman and Kessler [9]. The annual average minimum temperature is 23.49 ± 0.42°C, the maximum is 37.13 ± 0.62°C, and the mean annual rainfall recorded at the Tillabéri weather station (the nearest) between 1980 and 2009 is 385.76 ± 100.35 mm [7]. Agriculture and livestock farming are the dominant activities. Valleys are covered by sand and alluvial soils in the shallows, ferruginous soils leached at the slopes, and skeletal soils of regosol and lithosol types, formed of clayey sandstone, on plateaus of the continental terminal [10,11]. The most degraded soils constitute large sets of lateritic cuirasses [1].

The vegetation of "Tiger bush" until the 1970s and degraded, has become a bush that could be described as "leopard bush" [10] since the 1980s and consists of shrubs groves very scattered. The flora is dominated by Combretaceae (*Guiera senegalensis* J. F. Gmel., *Combretum micranthum* G. Don., *Combretum nigricans* Lepr. …), with *Piliostigma reticulatum* (DC.) Hochst, *Balanites aegyptiaca* (L.) Del., *Boscia senegalensis* (Pers.) Lam. Ex Poir., *Maerua crassifolia* Forsk, *Acacia macrostachya* Reichenb. ex DC., *Lannea acida* A. Rich., *Croton zambesicus* Mull. Arg., *Acacia ataxacantha* DC., *Gardenia sokotensis* Hutch., *Grewia flavescens* Juss., *Boscia angustifolia* A. Rich. [5,6,1].

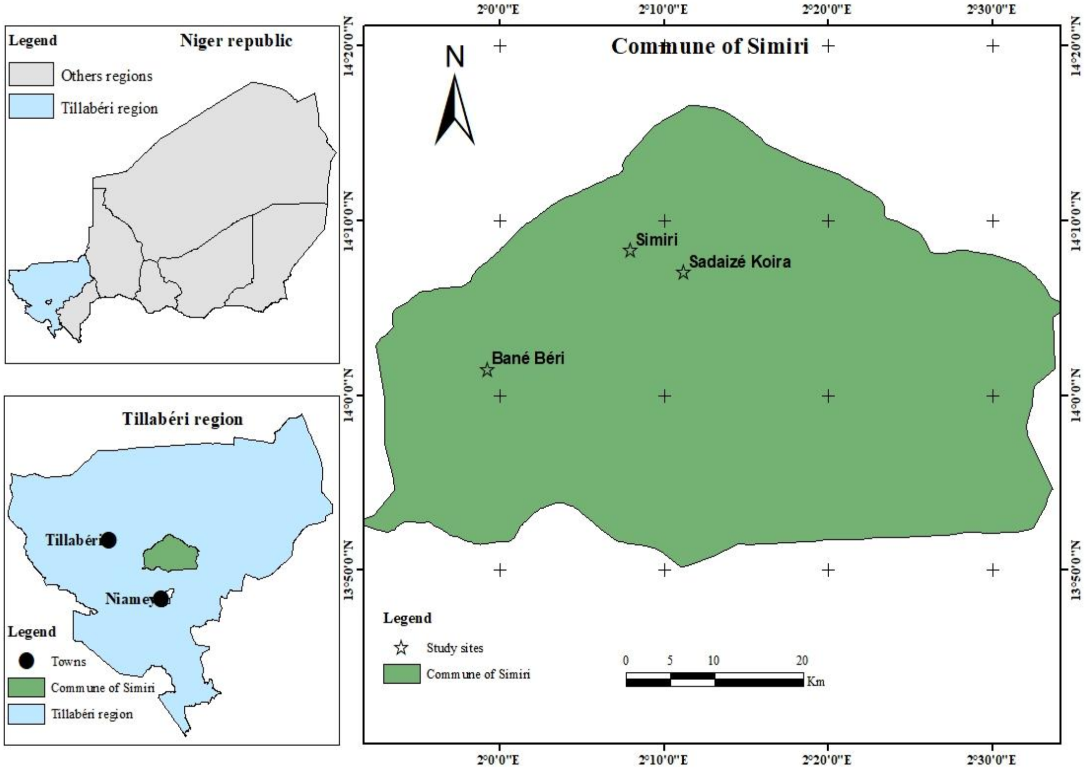


Fig. 1. Location of the study area

We conducted inventories on sites on which restoration of the vegetation cover was conducted in 1989, i.e., on plateaus near the three following villages : Banné Béri, Simiri and Sadeizé Koira. A total of seven woody species were planted and distributed as follows: six on the Simiri plateau (*Acacia nilotica*, *Acacia raddiana*, *Acacia senegal*, *Bauhinia rufescens*, *Prosopis juliflora* and *Ziziphus mauritiana*), five on Sadaizé Koira plateau (*Acacia holosericea, A. nilotica*, *A. senegal*, *P. juliflora* and *Z. mauritiana*) and six on the Bané Béri plateau (*A. holosericea, A. nilotica*, *A. raddiana, A. senegal*, *P. juliflora* and *Z. mauritiana*).

2.2 Measurement Equipment

The field equipment used during this study is composed of:

- A measuring tape for measuring the size of the plots and the diameter of trees and shrubs;
- A string and milestones for the delineation of inventory plots;
- A GPS to determine the geographic coordinates of the plots;
- A graduated stem for measuring the height of trees and shrubs;
- Data collection sheets.

2.3 Woody Vegetation Inventory

In 2010, plots of 1000 m² (50 m x 20 m) were sampled, separated from each other by 200 m along 11 transects of one kilometer long separated from each other by 200 m. A total of 30 plots were delimited in the restored vegetation, among which 15 are on the Simiri plateau, six on the Sadaizé Koira plateau, nine on the Bané Béri plateau. Six plots were delimited in the un-restored vegetation on the Simiri plateau, 500 m away from the restored vegetation. In each plot, an exhaustive inventory of all the trees with a diameter of the largest stem greater than-or equal to-1 cm was made. The following observations were recorded: scientific name of the species, diameter of the largest stem at 20 cm from the ground, the largest diameter of the crown and the diameter perpendicular to it (the crown being assimilated to an ellipse), height from the ground to the top of the crown, and pruning or cutting traces.

Comparison between restored and un-restored sites involves the following biometric parameters: the diameter distribution within the populations of the planted species and the species already in place, the alpha and beta diversities.

2.4 Analysis of the Woody Species Inventories

For each sampled plot, the following parameters were calculated:

- In each plot, the recovery rate (R) of each tree was obtained by the formula (1).

$$R\ (\%) = \frac{rx100}{S} \text{ with } r = \frac{\pi}{4}\sum_{i=1}^{n} Dixdi \quad (1)$$

r = recovery of all trees in the plot (in m²); *Di* is the largest diameter of the crown and *di* the perpendicular diameter to the largest (m) for each tree i; s = plot area (m²).

- The density of trees (*Dt*)
- The number of stems per tree (*Ns*).
- The average diameter of the largest stem (*Ds*).
- The total basal area (*G*), from the formula (2).

$$G\ (m^2/ha) = \frac{\pi}{40000a}\sum_{j=1}^{n} dj^2 \quad (2)$$

dj is the diameter (in cm) of the stem j, *n* = total number of stems in the plot and *a* the area of the plot (in ha);

- The average height of the tree (*H*).
- Regeneration density (*Dr*), in stems per hectare by the formula (3).

$$Dr = \frac{nr}{a} \quad (3)$$

The number of trees (*nr*) of which the largest stem diameter is comprised between 1 and 5 cm.

- The number of trees per hectare (*NTC / ha*) bearing pruning or cutting traces.

To compare dendrometric parameters between plateaus, an analysis of variance (ANOVA) and a Tukey simultaneity test were performed with Minitab 16 software.

The largest stem diameter values were clustered in size classes of 2 cm wide, and planted and unplanted species were distinguished.

In addition, using Minitab 16 software, the parameters of the Weibull's theoretical distribution of the largest stem diameters were compared between plateaus. In the Weibull's theoretical distribution, the probability density function is [12,1314]:

$$f(x) = \frac{c}{b}\left(\frac{x-a}{b}\right)^{c-1} exp\left[-\left(\frac{x-a}{b}\right)^{c}\right] \quad (4)$$

"x" is the diameter of the largest stem. "f" (x) is the probability density value at point x.
"a" is the "position" parameter that determines the threshold (the smallest diameter considered); it is equal to 0 if all categories of trees are considered in the inventory (from seedlings to mature trees) ; it is different from zero if the trees considered have a diameter ≥ a.
"b" is the "scale" or "size" parameter that indicates the dispersion of the distribution. When its value is high, the distribution is widespread.
"c" indicates the « shape » of the distribution curve. c <1 corresponds to an inverted J-shapes distributions, which characterizes multispecific or uneven stands, composed mainly of young trees. c = 1 corresponds to an exponentially decreasing distribution, which characterizes populations on the verge of extinction, 1 < c < 3.6 corresponds to distributions following left dissymmetrical bell curves, and corresponding to stands being predominantly composed of trees with low to medium diameter. c = 3.6 corresponds to normal distributions, following a symmetric bell curve characteristic of even-aged or monospecific stands. c> 3.6 corresponds to distributions following right dissymmetrical bell curves characteristic of stands predominantly composed of old trees [15].

The Weibull's theoretical distribution model was chosen for its great flexibility of use and the diversity of curve shapes it allows to simulate according to the values taken by its (theoretical) parameters [16]. To test the significance level of the fit between observed and the Weibull distributions, a log-linear analysis was performed [17] with the SPSS 20 software.

2.5 Analysis of the Specific Diversity

The Shannon-Weaver [18] index (H) was calculated to evaluate species diversity in the woody stand of a given plateau (alpha diversity). This index indicates the weight of each species in the cover. It is calculated as followed :

$$\boldsymbol{H} = -\sum_{k=1}^{S} pk \log_2 pk \quad (5)$$

S = total number of species
pk = relative frequency of species (number of feet of species k / total number of feet).

It is expressed in bits and ranges from the lowest diversity (0 bit) to the highest (4.5 bit). It increases with the number of species contributing to the woody cover.

The diversity is low when $H < 3$ bits, average when $3 \leq H < 4$ and high when $H \geq 4$ bits.

The Piélou equilability index (E) was also calculated by the following formula (6).

$$E = \frac{H}{Hmax} \text{ and } Hmax = \log_2 S \tag{6}$$

The Piélou equitability index varies between 0 and 1. It tends to 0 when a few number of species dominate, i.e., of which the number of trees is significant higher than that of the other (dominated) species, and to 1 when the distribution of the number of trees by species is not significantly different.

To assess the diversity between the plateaus (beta diversity), which corresponds to the extent of substitution of species between the plateaus, the coefficient of Sorensen [19] was calculated. It expresses the degree of similarity between two plateaus and is calculated as followed (7).

$$Is = \frac{2j}{a+b} \tag{7}$$

a is the number of species in plateau 1; *b* that of species in plateau 2 and *j* that of species common to both plateaus.

2.6 Focus Group Design

Focus groups were conducted on the past vegetation restoration and the environmental changes observed until now. Eight focus groups were conducted during august 2010: One at the city hall, one at the environment service, one with each the village chief and one with one group of farmers in each village who were selected according to their experience and participation to the vegetation restoration.

3. RESULTS

3.1 Impact of Restoration on Dendrometric Characteristics

The recovery rate, the diameter of the largest stem, the basal area and the tree height were significantly ($p < 0.05$) lower in the un-restored stand than in the restored ones (Table 1). However, the number of stems per tree is greater in the un-restored stand, and there is no significant difference ($p = 0.28$) in the density of trees bearing traces of pruning/cutting. Among the restored stands, only the stand on the Simiri plateau has a total trees density significantly higher and a regeneration density higher but not significantly, than that of the un-restored stand (located on the same plateau). The lowest regeneration density is observed in the restored stand on Bané Béri plateau but the difference is not significant compared to Sadaizé Koira plateau.

Table 1. Averages of the dendrometric parameters according to the site

Parameter	RPS		RPSK		RPBB		URP		P value
	m	σ	m	σ	m	σ	m	σ	
R (%)	12.39^{a}	3.51	13.62^{a}	2.28	16.76^{a}	6.30	3.88^{b}	2.36	< 0.001
Dt (trees/ha)	204.67^{a}	50.27	121.67^{b}	19.41	125.56^{b}	33.58	95.00^{b}	27.39	< 0.001
Ns	2.72^{b}	2.55	2.03^{bc}	1.33	1.78^{c}	1.54	6.63^{a}	3.66	< 0.001
Ds (cm)	6.3^{c}	3.29	7.57^{b}	5.11	10.23^{a}	3.69	4.29^{d}	3.22	< 0.001
G (m²/ha)	0.81^{a}	0.35	0.79^{ab}	0.16	1.17^{a}	0.65	0.21^{b}	0.10	0.001
H (m)	2.00^{b}	0.82	2.15^{b}	0.87	2.49^{a}	0.77	1.69^{c}	0.67	< 0.001
Dr	76.00^{a}	47.48	45.00^{ab}	13.78	15.56^{b}	20.07	65.00^{a}	17.61	0.002
NTC (trees/ha)	12.67^{a}	12.23	5.00^{a}	5.48	10.00^{a}	14.14	3.33^{a}	5.16	0.28

RPS: Restored plateau of Simiri; RPSK: Restored plateau of Sadaizé Koira; RPBB: Restored plateau of Bané Béri; URP: Unrestored plateau; m: average; σ: standard deviation; R: Recovery rate; Dt: Density of trees; Ns: Number of stems per tree; Ds: Diameter of the largest stem; G: Basal area; H: Height of the tree; Dr: Density of regeneration (number per hectare of feet whose diameter of the largest stem is between 1 and 5 cm); NTC: Number of trees per hectare bearing pruning/cutting traces). Averages not sharing any letter are significantly different for a given parameter, at the probability threshold α = 0.05

3.2 Impact of Restoration on Woody Species Diversities

A total of 17 species were found in the restored stands compared to eight in the un-restored (Fig. 2). *A. holosericea* now strongly dominates on the two plateaus where it was planted 21 years ago (Bané Béri and Sadaizé Koira). It is followed by *A. senegal* and *A. raddiana*. However, some plant species such as *B. rufescens* at Simiri, *A. nilotica* at Bané Béri and Sadaizé Koira, *Z. mauritiana* at Sadaizé Koira, did not give satisfactory results in terms of recovery. Among the un-planted species, *G. senegalensis* dominates in the restored stand of Sadaizé Koira and *C. micranthum* in the un-restored stand (Fig. 2).

3.3 Impacts of Restoration on the Distribution of the Diameters of the Largest Stem (Weibull's Model)

The log-linear analysis indicates that there is no significant difference between the observed data and the theoretical Weibull distribution for all stands ($p> 0.05$). For all the planted species, the diameters *of the largest stem* follow a bell shape distribution with a left asymmetry (1 <c <3,6, Fig. 3). For the un-planted species in the restored stands of Simiri and Bané Béri (Figure 3b and 3f) the diameters follow an "inverted J" shape distribution (c <1).

3.4 Comparison of Diversity Indices between Stands

In all stands, alpha diversity is relatively low (< 3) but equitability is high (> 0.5), except on the restored plateau of Bané Béri where it is just average (0.5) (Table 2).

3.5 Perception of the Population about the Impact of Restoration Activities

During the interview, all the groups involved in this study stated that the effects of the vegetation restoration are positive. The main effects were an increase in wood and fodder availabilities on the plateaus and an improvement of crop yields on the slopes and the shallows.

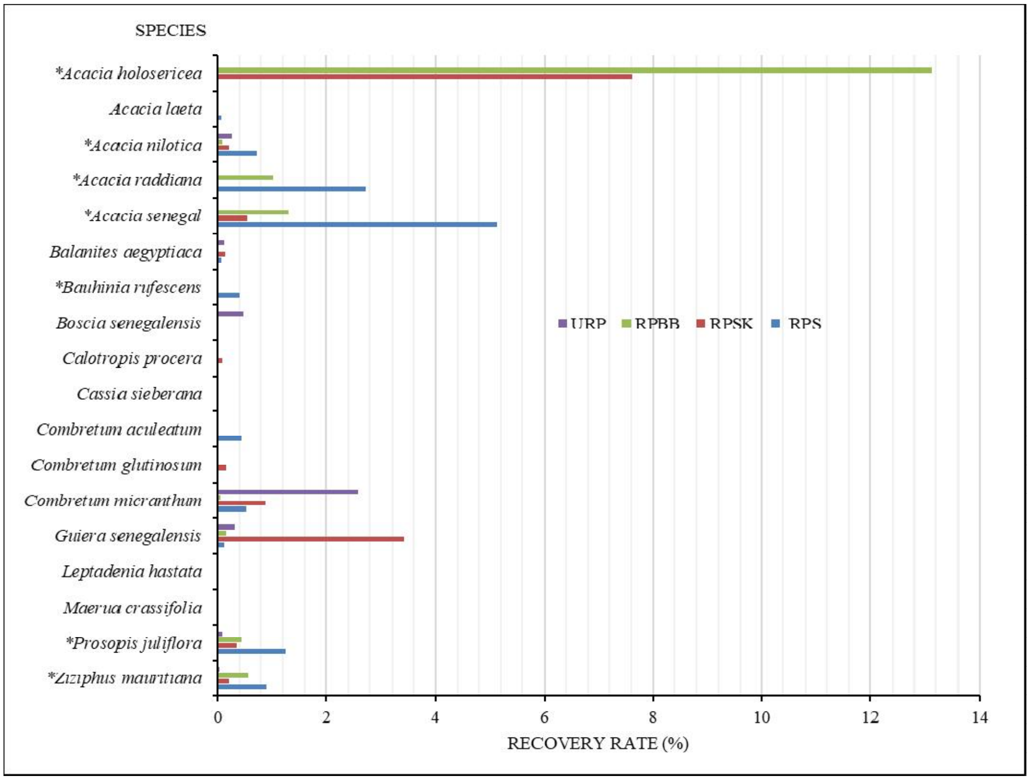
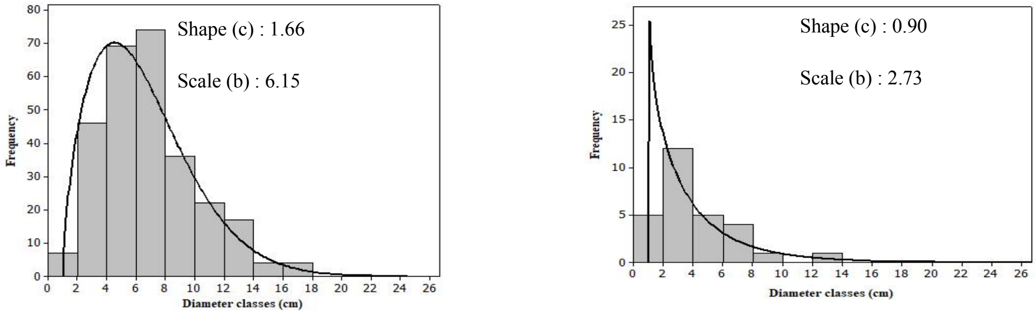


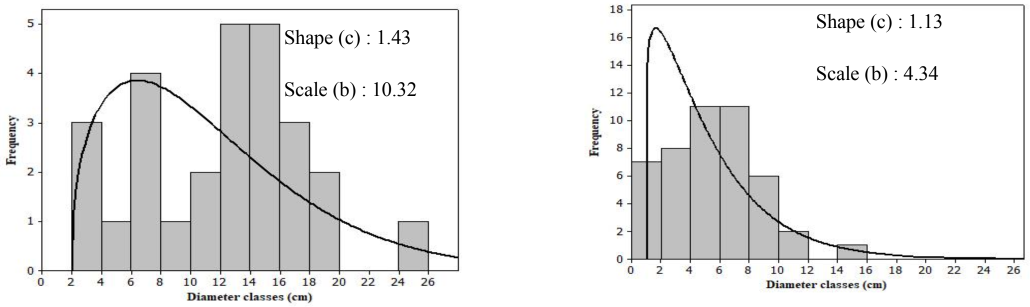
Fig. 2. Recovery rates and contributions of the species to the cover of each plateau

RPS: Restored plateau of Simiri; RPSK: Restored plateau of Sadaizé Koira; RPBB: Restored plateau of Bané Béri; URP: Un-restored plateau



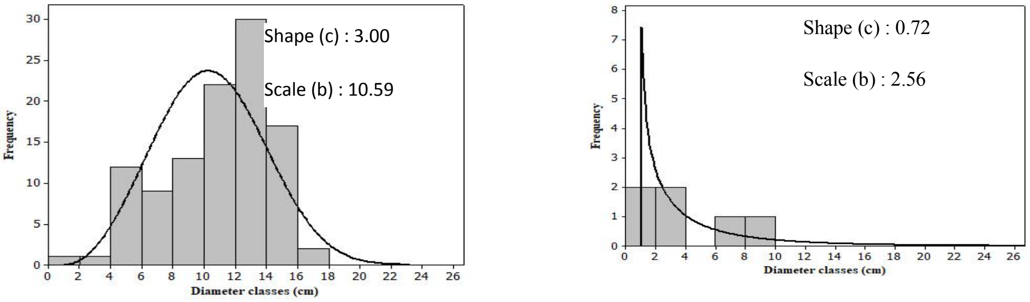
a. Planted species on the restored plateau of Simiri

b. Other species on the restored plateau of Simiri



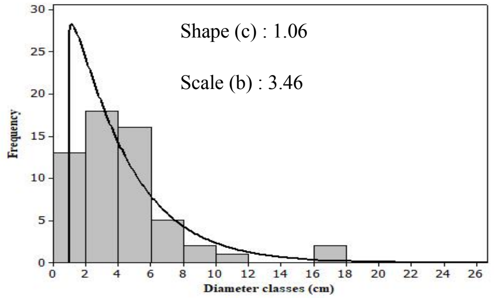
c. Planted species on the restored plateau of Sadaizé Koira

d. Other species on the restored plateau of Sadaizé Koira



e. Planted species on the restored plateau of Bané Béri

f. Other species on the restored plateau of Bané Béri



g. All species on the un-restored plateau

Fig. 3. Diameter structure of the population of planted species and other species on the sites

Table 2. Shannon diversity indices (H), maximum diversity (Hmax) and Piélou equitability (E)

	H	Hmax	E
RPS	2.56	3.58	0.72
RPSK	2.25	3.32	0.68
RPBB	1.66	3.32	0.50
URP	2.20	3	0.73

RPS: Restored plateau of Simiri; RPSK: Restored plateau of Sadaizé Koira; RPBB: Restored plateau of Bané Béri; URP: Un-restored plateau

With indices less than 0.5, the similarity between plateaus is low (Table 3).

Table 3. Sorensen Diversity Indices (Is)

	RPS	RPSK	RPBB
RPSK	0.39		
RPBB	0.39	0.41	
URP	0.38	0.4	0.4

RPS: Restored plateau of Simiri; RPSK: Restored plateau of Sadaizé Koira; RPBB: Restored plateau of Bané Béri; URP: Un-restored plateau

4. DISCUSSION

4.1 An Apparent Successful Restoration

For all species, the diameter of the largest stem, the tree height, and the recovery rate indicate greater availability of wood in restored than in un-restored stands. Clandestine cutting due to insufficient forest agents to control the area and the lack of closure explain the lack of significant difference between the four stands in the number of cut trees. Although relatively infrequent (Table 1), these cuts weaken stands growth limiting the restoration success. However, on the three restored sites, the flora is clearly dominated by the planted species, confirming the success of the restoration. Furthermore, among planted species, there is a clear dominance of *A. holosericea.* The values of the dendrometric parameters more generally, tend to be higher on the restored plateaus than on the un-restored plateau. Abdoulaye et al. [2] obtained similar results on other sites (Boukanda and Gasikaina in the Tillabéri region) where stands were restored by the same techniques.

Our results are in line with those of CRESA (Centre régional d'enseignement spécialisé en agriculture) of Niamey [20], where, using satellite images from Laba and Tama sites (Tahoua region), the authors observed an increase of 10 to 20 times more trees in restored area, despite a large increase in human population. *C. micranthum and G. senegalensis* occupie the first place on the control site and among the un-planted species in terms of recovery rates with high numbers of stems per tree, tree density and regeneration density, due to the high vegetative regeneration capacity of the species by suckering and layering allowing them to survive in unfavorable conditions [21,22,23]. *C. micranthum* is also considered as an indicator of soil poverty [24].

The strong dominance of *A. holosericea*, from Australian origin, is due to its rapid germination and growth compared to the other species, even in semi-arid areas [25,26]. Introduced species such as *A. holosericea*, are often invasive [27] and comme to predominate over native species, as supported by our results. Although they are much less used by local human populations. Invasive introduced plants have adverse effects on agriculture, forestry and human health [28,29] and are the second largest global threat to biodiversity after direct habitat destruction [30,29]. In the Western Cape in South Africa, Australian Acacias were judged invasive and destroyed for to be replaced by natives species [31]. In our study, the dominance of *C. micranthum* and *G. senegalensis* on the un-restored plateau is consistent with previous observations on plateaus of the same geological nature [32,33,34,35].

The "inverted J" distribution (c <1) observed at the un-planted species (*C. micranthum*, *G. senegalensis*, *A. laeta*, *B. aegyptiaca*, *C. aculeatum*) of the restored plateaus of Simiri and Bané Béri is characteristic of a current significant regeneration. However, even in the case of the left dissymmetrical bell distribution, c values close to 1 (case of the control site and un-planted species of the restored plateau of Sadaizé Koira) reflect a good proportion of young trees.

The relationship between ecological restoration and the ecosystem services concept is highlighted by Alexander et al. [36] by using case studies from four continents (Africa, America, Asia and Oceania). In our case, the increase in crop yields and the availability of wood and pasture on the plateaus highlighted by the population could be due to a decrease of runoff on the plateaus by anti-erosion structures and vegetation. In fact, for many authors [37,38,39,40], the vegetal cover density in restored stands contributes to soil fixation and preservation, limiting erosion and substrate removal while promoting sedimentation, a better water balance, and, therfore, installation of new species. In China, policies for ecosystem services incuding converting cropland on steep slopes to forest and grassland have global implications because they increase vegetative cover, enhance carbon sequestration, and reduce dust to other countries by controlling soil erosion [41,39]. Rudolf et al. [42], using also case studies from the five continents, highlighted the benefits of investing in ecosystem restoration.

4.2 But Still Precarious and Vulnerable Stands

The left dissymmetrical bell distribution ($1 < c < 3.6$) of the diameter of the biggest stem observed in all sites reflects the predominance of trees of small or medium size. This result may be explained by tree cutting or the low water availibility in the studied area and can be compared with those found by Patrik and Mary [43] in Namibia where decrease in annual rainfall, increase in livestock numbers and increased human population are the causes of land degradation. The absence of several classes of contiguous diameter is a clear indication of disturbance [23] which may be anthropogenic or climatic. If the sites were fenced, the anthropogenic pressure would be limited because in Senegal, exclusion of wood collection by fencing in dryland savannah had a positive effect on the woody plants regeneration [44]. The planted species on the studied sites, although mostly part of the flora in the Sahel, were not present on these sites before their introduction [5,6,1]. Local species, given their regenerative capacity, are therefore more suitable for these ecosystems restoration. However, the first reforestations had favored the use of introduced species for their rapid growth by neglecting the question of their sustainable adaptation to the environment. These results support the idea of authors [45,46] who think that species to use must be chosen according to their adaptability to the environments that we want to restore. For many authors [47,48,49], native species contribute to restore the biogeochemical nitrogen cycle, higher species richness in degraded soils and promote carbon sequestration.

The species diversity observed at all the sites ($H = 1.66–2.56$) is low compared to that observed in the same region (2.8) in 2012 on a site of long term ecological monitoring [50]. This could be explained by dominance of *A. holosericea*, *A. raddiana* and *A. senegal* introduced on the sites. In the Western Cape in South Africa, Patricia et al. [51] compared vegetation after invasion by dense stands of alien trees to a control stand and found that species richness was lower for invaded sites. Nevertheless, Pablo & Gloria [52] found a positive effect of an invasive tree (*Pinus radiata*) on the regeneration of native woody species in Spain. In central Senegal, despite greening, an impoverishment of the woody vegetation cover was observed in the studied sites, indicated by an overall reduction in woody species richness, a loss of large trees, an increasing dominance of shrubs [53]. In our case, this situation represents a threat to the biodiversity of the studied sites because, according to Aronson et al. [54], one of the major objectives of ecosystem restoration is to improve biological diversity, which is one of the ecosystem health indicators. The relatively low similarity between the sites could be explained by the difference of species planted according to the site or by the different un-planted species regeneration.

5. CONCLUSION

This study showed a relative positive impact of the vegetation restoration with an improvement in most of the dendrometric parameters (recovery rate, stem diameter, height) on the restored sites compared to the control site. Despite this relative improvement, the values of these parameters remain low. Diversity, which is a fundamental vital attribute, also remains low because of the dominance of an introduced invasive species which do not guarantee the maintenance of the native species on the long term. This study raise awareness on the necessity to assess both species adaptative traits and local usefulness to improve the impacts of vegetation restoration.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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