

Effects of land use changes on *Cordyla pinnata* (Lepr. ex A. Rich.) Milne-Redh. stand distribution: A multipurpose threatened species in Senegal (West Africa)

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Abstract

Cordyla pinnata (Lepr. ex A. Rich.) Milne-Redh. is a multipurpose forage species that provides significant ecosystem goods and services to the local community in sub-Saharan Africa. Analysis of the ecological patterns of the species' population structure is crucial for sustainable management and conservation. It is important to understand how changes in land use influence the natural stand of *Cordyla pinnata*. This study aimed to: (i) determine the floristic composition of the natural stands of *Cordyla pinnata*; (ii) assess the population structure of species; and (iii) assess the influence of land use types on the demographic parameters of species. Forest inventories were carried out in 140 plots, equally distributed between four land use types (farmland, fallow, rangeland, protected area) in Senegal. The data collected included the dbh, the crown diameter, the total height, and the regeneration. The land use types were compared based on woody species diversity and dendrometry parameters of populations. An ANOVA was used for the analysis of density and morphological features data. The floristic composition of *Cordyla pinnata* natural stands was relatively distinct between the four land-use types. Protected areas and rangelands are the highest diversity. The density of *Cordyla pinnata* individuals decreased significantly from protected areas (393.63 ± 24.21 stems/ha) to farmlands (140.40 ± 46.70 stems/ha; $p < 0.001$). The diameter classes distribution showed a stable population of *Cordyla pinnata* in all four land-use types. In contrast, the height class distribution of regeneration individuals revealed an instable state. This study highlighted the negative impact of land use change on *Cordyla pinnata* populations. Therefore, it is essential to reduce anthropic pressure on lands in order to better conserve natural habitats of *Cordyla pinnata* and the associated biodiversity.

1. Introduction

African woodlands provide many ecosystemic service for rural population [1]. Its serve as the primary energy source for most households [2, 3]. In rural areas, they not only meet subsistence needs but also provide a substantial cash income through the trade of forest products [4]. In Senegal, the woodlands and rangelands provide important supplying timber, firwood, medicines, food, fiber and carvings for both rural and urban population [5]. The high demand for timber and non-timber forest products is putting pressure on forests, threatening the stability and sustainability of ecosystem services [6]. For several years now, the West Africa Sahelian zone has been faced with an accelerated degradation of its plant cover due to human action and climatic conditions [7, 6]. Overgrazing pressures have strongly reduced woody vegetation in rangelands and other types of land use [8]. In this context, it is important to understand the distribution pattern of multipurpose species in order to sustain forest ecosystem services. The stability of these woody species is therefore crucial to the sustainability of ecosystems and the services they provide to mankind [9]. However, the intense exploitation of woody species limits the seed production needed to ensure regeneration [10].

In West Africa semi-arid areas, demographic growth has led to an expansion of agricultural lands and a high level of exploitation of woody species of high food and socio-economic value [11, 10]. Among these species is *Cordyla pinnata* (Lepr. ex A. Rich.) Milne-Redh., a promising multipurpose plant. The species is

most commonly found in the dry forest, woodland and savanna in Senegal [12]. *Cordyla pinnata* is a plant with high medicinal and nutritional value [13]. Its fruit plays an important role in times of famine and is eaten with couscous [13]. Its trunk bark decoction, roots and leaves are used to treat gastrointestinal disorders in humans and livestock [13]. The wood is widely used for building houses and making utensils such as mortars [14].

Despite its multipurpose widely recognized, little information is available on the *Cordyla pinnata* species population's status in its occurrence regions, particularly in Senegal. Diop et al. [15] conducted research on the regeneration status of the species in a savanna subjected to fire and grazing in Senegal. While it is important to know the species population status and threats, it is not yet clear how land use change affects the species population. Such information provides a basis for engaging in sustainable land use while preserving the species products and services. Many studies have shown that land use and climatic variability as well as plant propagation mechanisms are factors that influence the regeneration and structure of woody plant stands [16] [17]. The range of *Cordyla pinnata* in Senegal land use types includes protected areas, fallows, rangelands and farmlands. Throughout its distribution range, adult populations and regeneration of *Cordyla pinnata* are threatened by changes in land use and climatic condition as demonstrated by previous work for many multipurpose species [18, 10, 6]. Many studies have been carried out on the uses relating to *Cordyla pinnata*. These studies have particularly focused on the species ecosystem services [19], its mode of regeneration and its medicinal importance [15, 20]. However, the issue of conservation and sustainable management of *Cordyla pinnata* is poorly documented. Indeed, knowledge on the impact of land use changes on the adult population and regeneration of the species is limited. Hence, a better understanding of the effects of this influence on the stand structure and diversity of *Cordyla pinnata* may help in the sustainable management of the species in rangelands and agroforestry systems. This study aims to assess the effect of land use types on the natural stand's diversity and the population structure of *Cordyla pinnata*. Specifically, it: (i) Assess the floristic diversity of *Cordyla pinnata* natural stands according to the four-land use types; (ii) Analyze the population structure and tree morphology of *Cordyla pinnata* across the four-land use types; (iii) Analyze the impact of land use on *Cordyla pinnata* regeneration according different land use types.

We expected to detect significant variations across the land use types. We also expected that the structure of *Cordyla pinnata* stands is more stable in protected areas than in the others land use types due to the strong anthropic pressures on the species populations.

2. Methods

2.1. Description of study area

The research was conducted in the silvopastoral zone of Ferlo located in Sudano-Sahelian zone of Senegal (Fig. 1). Agriculture, mainly rain-fed, and extensive livestock farming are the region's main socio-economic activities. The silvopastoral zone of Senegal covers a total area of 101.609 km², equivalent to more than 1/3 of the national territory [21]. It is located in the Sahel belt and is characterized by two

seasons: a dry season that extends from November to June and a rainy season from July to October. The climate is characterized by low to moderate annual rainfall, ranging from a minimum of 200 mm to a maximum of 980 mm. The mean annual temperature varies between 26.9 and 28.7°C [22]. As elsewhere in the pastoral Sahel, the vegetation is dominated by annual herbaceous species, with scattered trees and shrubs [23].

2.2. Study species

Cordyla pinnata is a tree of the Fabaceae family that grows in Sudanian savannahs and dry forests (Arbonnier, 2019). The tree is 12–15 m tall, with a regular, straight bole and a dense, rounded crown. Leaves alternate, imparipinnate, with 5–10 pairs of alternate or opposite leaflets, glabrous. Blades oval or elliptical, with rounded and indented apices. *Cordyla pinnata* is the main agroforestry species in the study area (Diop et al., 2012). Its multipurpose uses in the study area can be a factor of its stand degradation [5]. Its use as a food supplement, medicinal, its resistant wood used to build houses, its leaves used to fertilize soils and its ecological importance make *Cordyla pinnata* a species with a future for rural and urban populations, hence the choice of this species for the study.

2.3. Sampling and data collection

An exploratory survey was carried out in the study area to identify the different types of land use, i.e., protected areas, rangelands, fallows, and farmlands. These types of land use were selected based on the presence of *Cordyla pinnata* stands. In each study site, an oriented sampling design based on the presence of the species was used. A total of 140 plots of varying size equally distributed between the four land use types were installed. The inventory unit was a plot of 1000 m² (50 m × 20 m) in protected areas and 2500 m² (50 m × 50 m) in rangelands, farmlands and fallows distant to 100 m each [26] 27, 18]. Within each plot, all woody species associated with *Cordyla pinnata* were inventoried. The data collected covered the total height and the dbh of trees and shrubs with dbh ≥ 5 cm. Individuals with a diameter at breast height (dbh) < 5 cm were considered as regeneration individuals. The specimens being collected were numbered, pressed, and dried for further identification. Further identification of all specimens was done by comparison with authentic specimens, following [28], illustration and taxonomic keys from flora of Senegal.

2.4. Data analysis

2.4.1. Effect of land use types on floristic diversity of *Cordyla pinnata*

Inventory data collected in the four land use types were analyzed to determine the floristic composition associated with the *Cordyla pinnata* stands. Diversity indices such as the Shannon diversity index and evenness of Pielou (Table 1) were calculated and compared between the four land use types using a non-parametric Kruskal-Wallis test due to the lack of normality in the collected data. To compare woody species richness between land use types, generalized linear models with Poisson error distribution were used [29]. Non-metric multidimensional scaling (NMDS) analysis was conducted to compare floristic

compositions between four land use types for habitats hosting *Cordyla pinnata*. It was supplemented by the similarity analysis (ANOSIM) between plant communities. These analyses were based on Jaccard's similarity index. The Importance value index (IVI) for each woody species was calculated using the Curtis and Macintosh (1951) formula (Table 1). Species with an IVI ≥ 8 were selected as being ecologically significant in each land use types [30].

2.4.2. Effect of land use types on the variation of *Cordyla pinnata* dendrometric parameters

The stands structure of *Cordyla pinnata* was analyzed based on tree density (adults and regeneration trees), basal area (BA), mean diameter (Dm) and mean height (Table 1). To detect whether the structural parameters of the species changed between land use types, the non-parametric Kruska-Wallis's test were applied because the conditions of normality and homogeneity of variance were not fulfilled [31]. To compare the density of adult individuals and regenerations between land use types a generalized linear model with a poisson error distribution was used [32]. All statistical analyses were performed using R software R 4.3.2.

2.4.3. Structure of *Cordyla pinnata* stands

The diameters of the trees measured were grouped into 5 cm classes in order to interpret the results. The distribution of diameter classes for each type of land use was used to fit a theoretical value of the three parameter Weibull distribution whose probability function is written according to the following formula [33]:

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

where, x is the tree diameter; f (x) is the probability density value at point x; a is the position parameter; it is equal to 0 if all categories of individuals are considered (regenerations, juveniles and adult trees); it is non-zero if the trees considered have a diameter greater than or equal to a (in this case, a = 5 cm), b is the scale parameter linked to the central value of the diameters of the trees in the stand, and c is the shape parameter linked to the diameter structure considered. In this way, the parameters of the distribution are used to better appreciate and analyze the living conditions of the stand as following [34]

Table 1

Floristic and dendrometric parameters used to describe *Cordyla pinnata* stands composition in each land use types

Parameters	Formula	Definition	References
Mean diameter of trees (Dm, in cm)	$Dm = \frac{\sum_{i=1}^n di}{n}$ where n is the number of trees and di the stem diameter	Average diameter of all trees found in the stand	
Basal area of trees (G, in m ² per ha)	$G = \sum_{i=1}^n di^2$ Where s is the area of the plot and di the diameter	Sum of the cross-sectional areas at 1.3m above ground level of all <i>Cordyla pinnata</i> trees on a plot	Philip (2002)
Mean height of trees (Hm, in m)	$Hm = \frac{\sum_{i=1}^n hi}{n}$ Where n is the number of trees and hi the height of tree.	Average height of all trees found in the stand	
Mean density of regeneration (individuals per ha)	$Nr = \frac{\sum_{i=1}^5 dri}{sq}$ where ni is the number of trees and sq the area of sub-plots	Average number of seedlings and juveniles of <i>Cordyla pinnata</i> per hectare	
Tree-density of the stands (N in trees/ha)	$N = \frac{n}{s}$ where n is the number of trees and s is the area of the plot	Average number of trees per plot expressed in trees/ha	
Relative dominance (RDO)	RDO = 100× (Total area of a species)/ (Total basal area of all species)		
Relative density (RD)	RD = 100× (Number of individuals of a species)/ (Total number of individuals)		
Relative frequency (RF)	RF = 100× (Frequency of a species)/ (Sum of all frequencies)		
Relative diversity (Rd)	Rd = 100× (Number of a species in family)/ (Total number of species)		
Importance value index (IVI)	IVI = relative dominance + relative density + relative frequency		Curtis and Macintosh (1951)

3. Results

3.1. Floristic composition of *Cordyla pinnata* stands according to land use types

A total of 85 woody species belonging to 53 genera and 21 families were inventoried in the four land use types. The largest families were Fabaceae (28.34%), follows by Combretaceae (12.56%), Malvaceae (6.21%), and Rubiaceae (4.72%).

Analysis of woody stand diversity showed variation between land use types. The highest average number of species is observed in protected areas (11.40 ± 2.03) and rangelands (11.47 ± 1.76), while farmlands (4.09 ± 1.34) have a lowest diversity in woody species (Table 2).

Analysis of the Shannon index showed that land use types significantly influenced species abundance ($F = 117.1$; $p = 0.001$). The number of abundant species varied from 1.66 ± 0.33 in fallow lands to 0.97 ± 0.44 in farmlands. However, species abundance did not vary significantly between rangelands (2.32 ± 0.18) and protected areas (2.26 ± 0.21).

A comparison of the average evenness of species between the four land use types indicated that there was a significant difference between rangelands, protected areas and farmlands ($F = 43.3$; $P < 0.001$). On the other hand, no significant difference was observed between rangelands (0.95 ± 0.02) and protected areas (0.93 ± 0.02) (Table 2).

Table 2
Diversity index (Mean $\pm$ S.E) of woody species associated to *Cordyla pinnata* according to land use types

Land use types	Shannon index	Pielou evenness	Species richness
Protected areas	2.26 ± 0.21^a	0.93 ± 0.02^a	11.40 ± 2.03^a
Rangelands	2.32 ± 0.18^a	0.95 ± 0.02^a	11.47 ± 1.76^a
Fallows	1.66 ± 0.33^b	0.82 ± 0.09^b	7.63 ± 2.05^b
Farmlands	0.97 ± 0.44^c	0.68 ± 0.18^c	4.09 ± 1.34^c
R-squared	0.76	0.54	0.73
F/Chi-square	117.1	43.3	95.26
P	< 0.001	< 0.001	< 0.001

Values with different letters in the same column indicate significant differences between types of land use.

The nonmetric multidimensional analysis performed on the species found in the *Cordyla pinnata* habitats of the four land use types showed the distinction of the ellipses, but with their partial overlap.

This thus indicates an heterospecific composition of woody trees that is more or less distinct from one phytogeographical zone to another, but with the presence of a common floristic background (Fig. 2). Variation in woody heterospecific tree in habitats of *Cordyla pinnata* was significant from one phytogeographical zone to another (ANOSIM; $R = 0.831$; $p = 0.001$).

The most dominant species associated with *Cordyla pinnata* varied according to the type of land use. In the rangelands the most dominant species were *Parkia biglobosa* (Jacq.) R.Br. ex G. Don (29.48%), *Borassus aethiopum* Mart (20.04%), *Mitragyna inermis* (Willd.) K. Schum. (8.63%) and *khaya senegalensis* (Desr.) A. Juss. (5.03%); while in the protected areas the dominant species were *Cordyla pinnata* (21.40%), *Sterculia setigera* Delile (18.50%), *Parkia biglobosa* (Jacq.) R.Br. ex G. Don (14.18%) and *Ficus thonningii* Blume (9.39%) (Table 3). Fallows are dominated by *Combretum glutinosum* Perr. ex-DC (36.98%), *Guiera senegalensis* J.F.Gmel. (7.28%), *Combretum nigricans* Lepr. ex Guill. & Perr. (6.04%) and *Senegalia macrostachya* Reichenb. ex-DC. (5.41%). However, the most dominant species in the farmlands were *Adansonia digitata* L. (58.24%), *Balanites aegyptiaca* (L.) Delile (23.50%), *Vachellia nilotica* (L.) Willd. ex Delile and *Anogeissus leiocarpa* (DC.) Guill. & Perr. (3.57%).

Table 3

List of the eight forages species with a high importance value index according to the land use types

Land use types	Species	Relative frequency (%)	Relative density (%)	Relative dominance (%)	Importance value index (%)
Rangelands	<i>Borassus aethiopum</i> Mart	6.55	7.50	20.05	34.10
	<i>Parkia biglobosa</i> (Jacq.) R.Br. ex G. Don	1.75	1.62	29.48	32.84
	<i>Mitragyna inermis</i> (Willd.) K. Schum.	8.52	13.24	8.64	30.39
	<i>Cassia sieberiana</i> DC	6.77	7.50	1.98	16.25
	<i>Piliostigma thonningii</i> (Schumach.) Milne-Redh.	7.42	7.21	1.59	16.22
	<i>Combretum glutinosum</i> Perr. ex-DC	5.68	5.88	0.91	12.47
	<i>Guiera senegalensis</i> J.F.Gmel.	6.11	6.18	0.16	12.45
	<i>Strophanthus sarmentosus</i> DC	5.46	5.44	0.11	11.01
Protected areas	<i>Cordyla pinnata</i> (Lepr. ex A. Rich.) Milne-Redh.	7.20	12.27	21.41	40.88
	<i>Sterculia setigera</i> Delile	4.40	3.01	18.50	25.91
	<i>Parkia biglobosa</i> (Jacq.) R.Br. ex G. Don	0.80	0.93	14.19	15.92
	<i>Sclerocarya birrea</i> (A.Rich) hoscht	4.00	3.47	6.89	14.36
	<i>Prosopis africana</i> (Guill. & Perr.) Taub.	3.60	3.01	7.56	14.17
	<i>Combretum fragrans</i> F. Hoffm.	6.00	6.71	0.70	13.41
	<i>Ficus thonningii</i> Blume	2.40	1.62	9.39	13.41

Land use types	Species	Relative frequency (%)	Relative density (%)	Relative dominance (%)	Importance value index (%)
	<i>Terminalia laxiflora</i> Engl. & Diels	4.40	5.79	2.29	12.48
Fallows	<i>Combretum glutinosum</i> Perr. ex-DC	12.50	37.90	36.99	87.39
	<i>Guiera senegalensis</i> J.F.Gmel.	9.52	9.29	7.28	26.10
	<i>Combretum micranthum</i> G. Don	8.33	7.33	5.22	20.88
	<i>Vachelia seyal</i> Del. var. seyal	7.74	4.89	5.41	18.04
	<i>Combretum nigricans</i> Lepr. ex Guill. & Perr.	6.55	4.89	6.04	17.48
	<i>Grewia bicolor</i> Juss.	7.14	3.42	3.94	14.51
	<i>Commiphora africana</i> (A. Rich.) Engl.	4.76	5.13	3.94	13.84
	<i>Balanites aegyptiaca</i> (L.) Delile	6.55	4.16	2.89	13.59
Farmlands	<i>Balanites aegyptiaca</i> (L.) Delile	23.33	56.83	23.51	103.67
	<i>Adansonia digitata</i> L.	4.44	1.44	58.24	64.12
	<i>Anogeissus leiocarpa</i> (DC.) Guill. & Perr.	12.22	5.40	3.57	21.19
	<i>Vachelia nilotica</i> (L.) Willd. ex Delile	8.89	4.68	4.14	17.71
	<i>Combretum glutinosum</i> Perr. ex-DC	8.89	4.32	3.01	16.22
	<i>Cassia sieberiana</i> DC	4.44	7.55	1.98	13.97
	<i>Guiera senegalensis</i> Juss	5.56	2.88	0.13	8.56

Land use types	Species	Relative frequency (%)	Relative density (%)	Relative dominance (%)	Importance value index (%)
	<i>Vachelia seyal</i> Del. var. <i>seyal</i>	3.33	4.68	0.48	8.49

3.2. Effect of land use types on the structural parameters of *Cordyla pinnata*

The results of the analyses of variance showed that all dendrometric parameters of *Cordyla pinnata* varied significantly between the four land-use types (Table 4). The highest mean density was recorded in protected areas (393.63 ± 24.21 individuals/ha) while the lowest density was recorded in farmlands (140.40 ± 46.70 individuals/ha). The mean basal area was 4.5 times higher in the protected areas (4.01 ± 6.35 m²/ha) than in the farmlands (0.87 ± 0.78 m²/ha). The mean diameter and mean height are higher in protected areas, with values of 32.82 ± 19.04 cm and 8.39 ± 2.36 m respectively. The lowest values for mean diameter (20.60 ± 5.41 cm) and mean height (5.62 ± 0.94 m) were recorded in fallows (Table 4).

Table 4

Demographic characteristics of *Cordyla pinnata* populations (Mean $\pm$ S.E) according to land use type

Land use types	Density (trees/ha)	Basal area (m ² /ha)	Stem diameter (cm)	Tree height (m)
Protected areas	393.63 ± 24.21^a	4.01 ± 6.35^a	32.82 ± 19.04^a	8.39 ± 2.36^a
Rangelands	340 ± 26.40^b	1.13 ± 1.32^b	27.38 ± 13.64^{ab}	7.78 ± 1.42^a
Fallows	206.56 ± 41.94^c	1.18 ± 0.73^b	20.60 ± 5.41^{ab}	5.62 ± 0.94^b
Farmlands	140.40 ± 46.70^d	0.87 ± 0.78^b	25.63 ± 9.96^b	5.78 ± 1.09^b
F-statistic	271.1	5.49	3.262	19.85
P	< 0.001	< 0.001	0.0245	< 0.001

Values with different letters in the same column indicate significant differences between types of land use.

3.3. Effect of land use changes on variation of *Cordyla pinnata* stands structure

The diameter class distribution of woody species in the four land use types reflected reversed J-shape form (Fig. 3). The most numerous individuals were in the 5–20 cm diameter class. This means, that species frequency was greatest in the lower diameter classes, gradually declining toward the higher classes. The parameter “c” of the Weibull distribution ranged between 0.72 and 1.41, which confirms this trend.

3.4. Variation of *Cordyla pinnata* natural regeneration across land use types

Mean density, mean height and mean diameter of regenerations varied between the four land use types (Table 5). Mean density ($X^2 = 0.65$; $P < 0.001$) varied significantly between land use types. The highest mean densities were observed in protected areas (44.54 ± 17.81 individuals/ha), while the lowest densities were recorded in farmlands (7.47 ± 2.22 individuals/ha). However, no significant differences were recorded in mean heights ($X^2 = 0.005$; $P < 0.4848$) and mean diameters ($X^2 = 0.003$; $P < 0.3501$) between the four land-use types (Table 5).

Table 5
Mean (Mean $\pm$ S.E) values of structural parameters of *Cordyla pinnata* regenerations according to land use type

Land use types	Protected areas	Rangelands	Fallows	Farmlands	R-squared	P
Density (trees/ha)	44.54 ± 17.81^a	15.92 ± 6.73^b	17.77 ± 4.89^b	7.47 ± 2.22^c	0.6564	< 0.001
Stem diameter (cm)	3.85 ± 1.84^a	3.46 ± 0.55^a	3.59 ± 1.90^a	4.42 ± 3.12^a	0.003	0.3501
Tree height (m)	3 ± 0.62^a	2.90 ± 1.36^a	2.62 ± 0.64^a	2.63 ± 1.06^a	0.005	0.4848

Values with different letters in the same column indicate significant differences between types of land use.

The height class structure according to the values of the shape parameter c of the Weibull distribution showed low regeneration in all four land use types. The shape parameter c varied between 0.76 and 1.97 (Fig. 4), which characterizes a population with low regeneration potential due to exogenous actions, especially in the small diameter classes.

4. Discussion

4.1. *Cordyla pinnata* stands diversity across land use types

85 species belonging to 53 genera and 21 families were recorded in *Cordyla pinnata* stands. The recorded species richness was higher than that reported by Ndong et al. [35] in the Ferlo, Senegal (42 species), but lower than that reported by Ganaba et al. [36] in a Peri-Urban Park in Leo, Burkina Faso (81 species). The highest species diversity was recorded in protected areas and rangelands. These results could be attributed to the variation in environmental conditions and the way in which each land use type is managed [13]. The findings of this study show the need for protected areas in the conservation of woody species. Previous studies by Balima et al. [27] reported that agricultural land use threatens

species diversity and modified the ecosystem function. In line with our results about the woody species richness variation, Berhanu et al. [37] and Taonda et al. [38] showed that woody species richness varies according to land use with an increasing richness from farmlands to protected areas. Similar results were found in other previous studies, particularly those by Sabo et al. [39] in soudano-sahelian zone of Burkina Faso and Balima et al. [27] in tropical West African savanna ecosystems. In contrast, heavily disturbed areas, such as fallows and farmlands, showed very low species diversity. This indicates a reduction in biodiversity and highlights the harmful impacts of the disturbances associated with negative agriculture practices Berhanu et al. [37]. Farmlands are often affected by major disturbances such as fires, grazing, deforestation and the extraction of firewood [40, 41]. According to Guèye et al. [42], *Cordyla pinnata* is one of the most important trees to protect in eastern Senegal.

A high IVI score indicates a strongly associated species within the community, which can be used to compare the ecological significance of different species [43]. The high importance value index of *Cordyla pinnata* in protected areas indicates that protected areas offer more stable and less disturbed environments, promoting the growth and survival of the species. On the other hand, pastures and fields may be subject to anthropogenic pressures (such as intensive grazing or agriculture), reducing the abundance and diversity of these species. Land use causes differences in species composition within climate zones. Thus, *Cordyla pinnata* is typically found in association with other important species, such as *Lannea acida* A. Rich., *Anogeissus leiocarpa* (DC.) Guill. & Perr, and *Tamarindus indica* L [44].

4.2. Effect of land use on the structural parameters of *Cordyla pinnata* populations

The density of *Cordyla pinnata* varied significantly according to the four types of land use. Protected areas and pastoral zones showed comparable and significantly higher densities than cultivated areas and fallow land. This situation results from the detrimental effects of agricultural practices, particularly intensive and repeated land clearing, the selective cultivation of utilitarian species by farmers, and slash-and-burn farming. These results corroborate those of numerous studies [27, 18, 45] which have also shown the negative impact of these agricultural practices on the density of woody species. The higher density in protected areas compared to fallows and farmlands can be explained by the fact that adult trees of *Cordyla pinnata* are associated to agriculture in the farmlands. As such it becomes difficult to cultivate annual crops with a high density of trees on farms. Several authors have shown that agricultural land affects species density [46, 47]. The higher density in fallows compared to farmlands is due to the gradual recovery of vegetation.

Protected areas have a much higher basal area than rangeland, fallow, and farmland. This underscores the importance of protected areas for conservation and their ecological potential compared to other of land use types [46, 38]. The difference in basal area between protected areas and other types of land use could be due to environmental condition, threat level, species diversity and tree age. These findings corroborate those of several authors who reported the negative impacts of land-use pressure on the

basal area of woody species [37, 48]. Consequently, *Cordyla pinnata* is threatened by extinction in the Senegalese Ferlo rangelands.

The largest stem diameters were recorded in protected areas, whereas the smallest stem diameters were observed in fallow lands. The reduction in stem size in fallows and farmlands can be attributed to an interaction between agricultural practices, environmental conditions and management methods, while in protected areas growth is generally less affected. Similar results indicating the degradation of tree populations were reported for *Cordyla pinnata* in Senegal savanna [49], for *Boswellia dalzielii* in topographic units in Burkina Faso [50], and *Detarium microcarpum* in land use types in Burkina Faso [38].

4.3. Effect of land use on *Cordyla pinnata* stands structure

The distribution of *Cordyla pinnata* diameter classes show a stable structure across land use. However, the lack of trees with large stem diameters in the stands could result in the decline of species regeneration, as large trees are the most effective seed producers [51]. Most of the recorded diameter classes fall between 5 and 15 cm in protected areas and rangelands, whereas they range from 5 to 30 cm in farmlands and fallow lands. Due to this Dbh distribution, the Weibull distribution model showed an inverted J-shaped. This aligns with findings on the natural regeneration of *Cordyla pinnata* in the Senegalese Savanna [15] and the dynamics of the *Cordyla pinnata* in agroforestry park of southern Senegal [14]. The scarcity of individuals in the larger classes in the four land use types could be due to the illegal exploitation of larger trees for useful purposes, unfavorable ecological conditions and selective logging. The local population depends on forest resources for firewood, food, building materials, forage, and medicines ([3, 52]. This dependence can reduce seed availability, leading to a regeneration deficit [51]. Typically, when trees are logged without replacement, their structures decrease [53]. The results agree with previous studies reporting that several multi-purpose species such as *Bombax costatum*, *Boswellia dalzielii* and *Detarium microcarpum* are highly threatened or endangered in Burkina Faso [10, 50, 38].

4.4. Effect of land use on *Cordyla pinnata* natural regeneration across land use types

Analysis of the juvenile stages of *Cordyla pinnata* is essential not only to understand the current status of the population but also to predict its future. This will inform appropriate conservation and management strategies. The size-class distribution of young individuals indicates that the species is under a significant stage of regeneration and recovery from disturbance.

The instability observed in regeneration, regardless of land-use type, revealed difficulties in recruitment and passage between different classes of the juvenile population of the species. This instability is believed to be associated with the pressure experienced by the species, leading to insufficient regeneration and thus a threat to its survival. Human pressure and bush fires, which depend on the density and state of desiccation of the herbaceous layer during the dry season, lead to the significant and continuous loss of natural regeneration of *Cordyla pinnata* [15]. The high density of the herbaceous

layer hinders the growth and development of young shoots, limiting their establishment [54, 55]. Furthermore, according to the same authors, the low number of individuals observed in the 2-2.5 size class for certain land use types could also be attributed to bushfires, which have altered fruit germination capacity due to burning. In addition, land clearing and reduced tree density for agricultural purposes unsustainable logging of *Cordyla pinnata* for firewood also leads to a reduction in the density of mature trees, affecting the species' fruit and seed production. Previous studies have shown that *Cordyla pinnata* wood is used various materials confection, including kitchen utensils, poles, posts, dugout canoes, and furniture [12, 56]. According to the same authors, *Cordyla pinnata* is the species most appreciated by local populations because of the income it generates from the sale of its by-products (wood, fruit, etc.) in addition to its many services. Thus, fruit collection reduces the seed production potential of edible tree species and compromises their regeneration [57, 58]. This aligns with the findings of the authors, who noted that species whose fruits and/or seeds are consumed frequently encounter regeneration issues [15, 14]. To ensure the survival and sustainable management of the species, more rigorous conservation measures should be implemented to integrate the species into reforestation strategies and plantations.

4.5. Implication for *Cordyla pinnata* stands conservation

This study investigated the impact of land use on *Cordyla pinnata* regeneration, stand structure, and size characteristics across four land use types in Senegal. Findings reveal that human disturbances significantly contribute to the instability of *Cordyla pinnata* stands. While protected areas exhibit relatively high seedling densities, poor recruitment is hampered by illegal debarking, fires, and wind damage. To ensure a stable population in the medium term, assisted natural regeneration must be implemented to improve the transition between growth stages. Additionally, agricultural practices that maintain sufficient individuals in agroforestry systems can help to conserve *Cordyla pinnata*. We also suggest that livestock farmers be involved in the management and protection of this tree, which has good fodder value. Given the high demand for different parts of the species, promoting sustainable harvesting practices and reducing exploitation rates are critical for effective species conservation. These actions collectively support the long-term conservation of *Cordyla pinnata* and its integration into sustainable land-use systems.

Conclusion

The floristic composition of *Cordyla pinnata* natural stands varies according to the land use types. The density of *Cordyla pinnata* individuals decreases in protected areas to farmlands. This study also showed that *Cordyla pinnata* has a low regeneration rate due to climatic conditions and overexploitation. Consequently, it is important to raise awareness among pastoralists and agro-pastoralists on the need to preserve species in farmlands and rangelands. Assessing the impact of land use on the structural parameters of *Cordyla pinnata* has shown that basal area, density and stem diameters determine the structure of *Cordyla pinnata* populations. To ensure the survival and sustainable management of *Cordyla pinnata*, rigorous conservation measures are essential. This includes integrating this species into

reforestation strategies and plantation projects. Some initiatives such as, agroforestry program, community-based conservation projects will not only promote natural regeneration of the species but also strengthen its resilience despite environmental and human pressures. Raising awareness among local communities on the importance of the species and involving stakeholders from the agro-pastoral and agricultural sectors are crucial to ensure sustainable management and biodiversity preservation.

Declarations

Author contribution statement

Idrissa Sawadogo: Writing original draft, Visualization, Software, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation and Conceptualization. **Philippe Bayen:** Writing original draft, Visualization, Software, Methodology, Data curation, Conceptualization and draft editing. **Prospère Sabo:** Visualization, Methodology, Formal analysis, Data curation, Conceptualization, Writing-review editing. **Faustine Akossoua Kouassi:** Visualization, Resources, Methodology, Data curation, Conceptualization and draft editing. **Nadine Worou:** Visualization, Resources, Methodology, Supervision, Project administration, Data curation, Conceptualization and draft editing

Declaration of Competing Interest

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

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Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Consent for publication

Not applicable

Ethics approval and consent to participate

Not applicable

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Figures

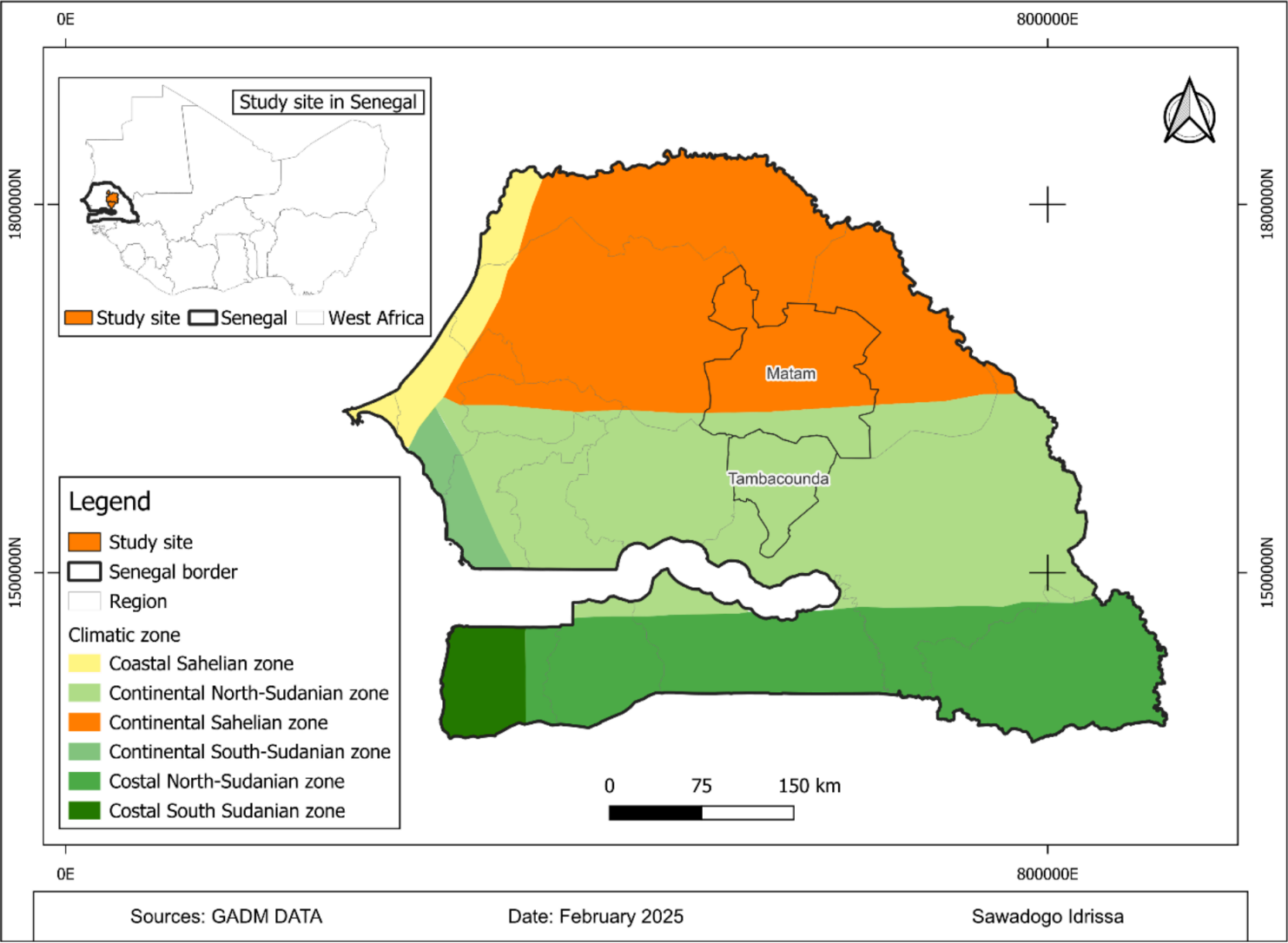


Figure 1

study sites

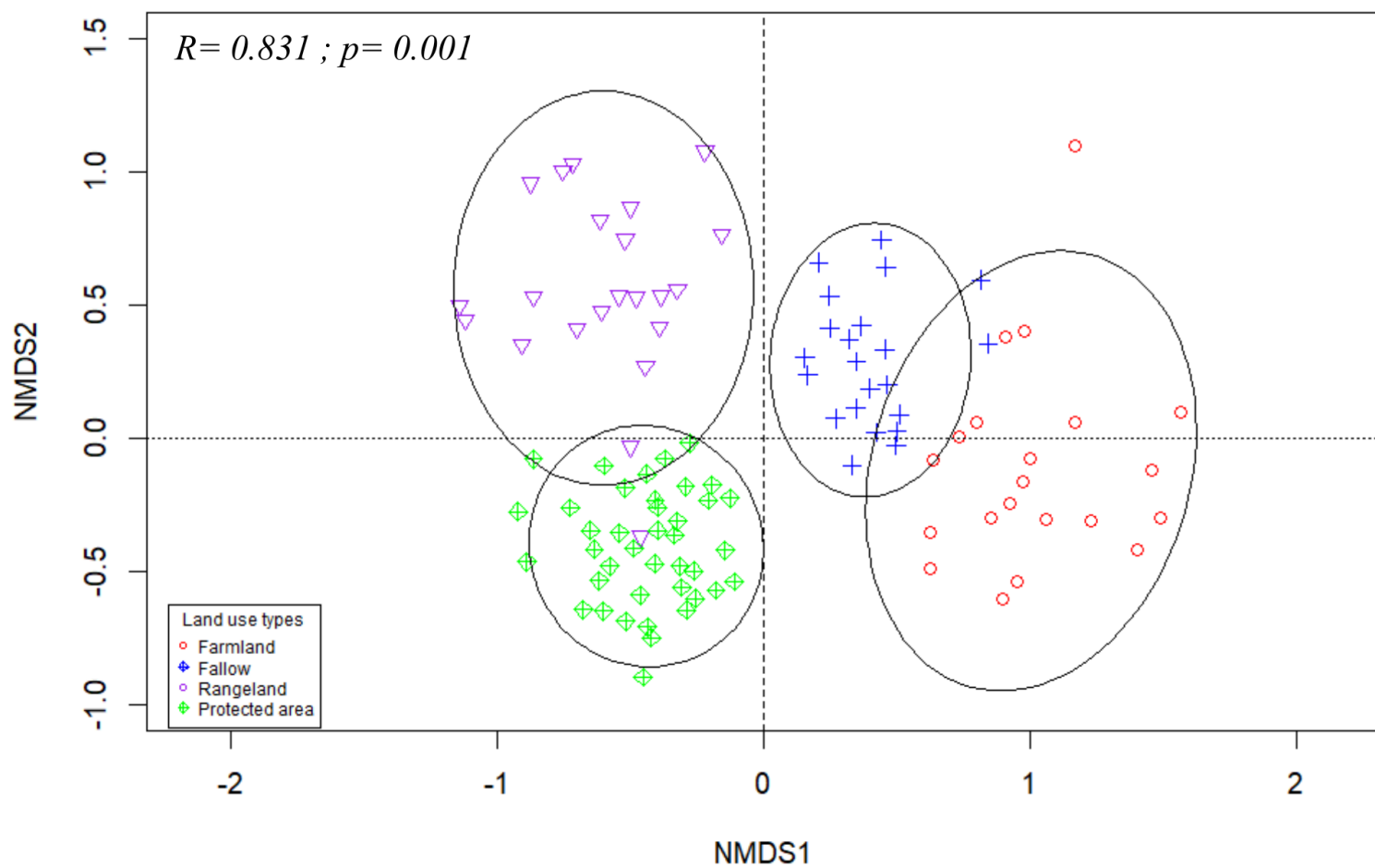


Figure 2

Non-metric multidimensional scaling (non-metric fit= 0.967) of the presence-absence data of species and analysis of similarity

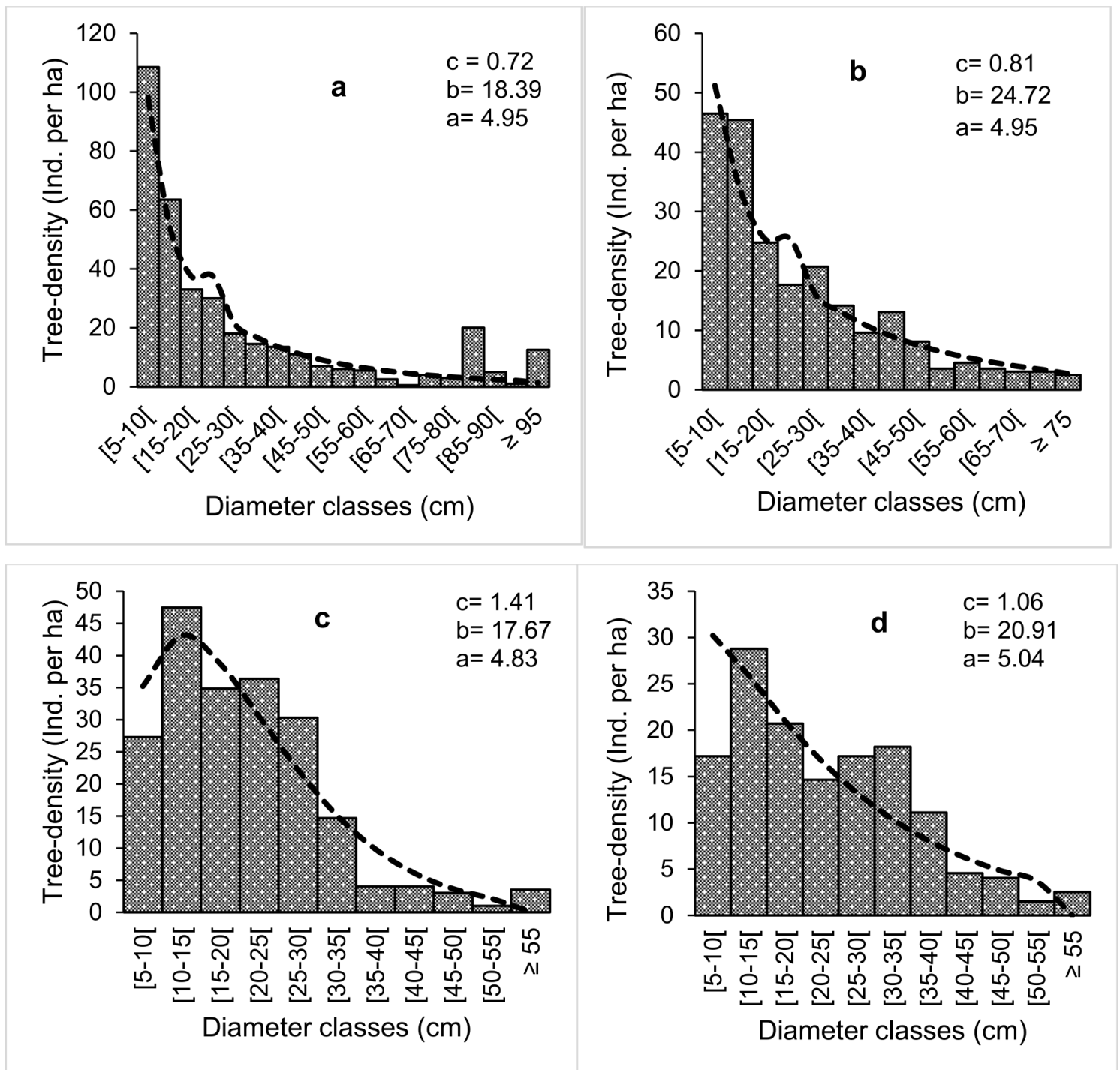


Figure 3

Stem diameter structure according the four land use types: a: rangeland; b: protected areas; c: fallows; d: farmlands

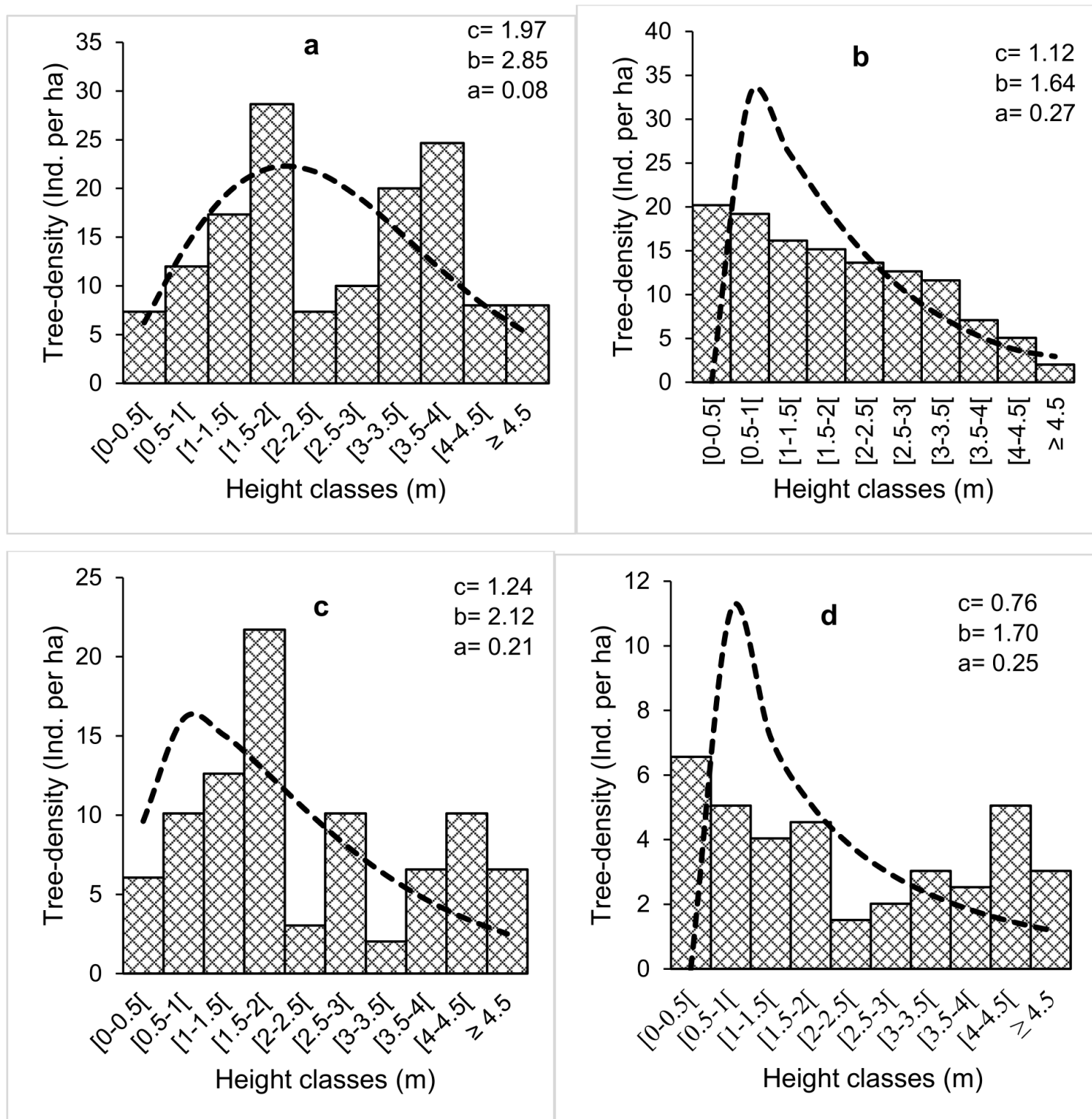


Figure 4

Height structure of *Cordyla pinnata* regeneration stands according to land use type: a: rangelands; b: protected areas; c: fallows; d: farmlands.