

Abundance and Diversity of Woody Undergrowth Reservoir as Indicator of Suitable Vegetation Patch for Natural Regeneration

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Abstract

The diversity, abundance and height structure of naturally regenerated woody species were analyzed and compared for undergrowth reservoir associated with vegetation patches as bowal, shrubland and woodland for understanding the effect of vegetation conditions on spatial distribution of woody plants in Sudanian ecosystem. All undergrowth individuals (height < 1.5 m) were recorded by species and the total height and collar diameter were measured in 50 subplots of 5 m × 5 m (or 25 m²) laid out in each vegetation patch during rainy season. In total 52 undergrowth species and 2224 stems arranged in 38 genera and 21 families out of which 25, 36 and 38 species were found in bowal, shrubland and woodland respectively and 15 shared species. Combretaceae, Caesalpinaceae and Mimosaceae families were the most abundant and species density was significantly higher ($P < 0.05$) in shrubland and woodland than bowal, and increase diversity in only shrubland ($P = 0.002$) comparing with bowal. Undergrowth was abundantly concentrated in small height class as canopy benefit and indicate a specific-site distribution. Results also showed that bowal had a particular vegetation which vary in function of tree community characters in place ($P < 0.05$) while woodland and shrubland are similar vegetation patches. As conclusion, the study vegetation patches form suitable regeneration niches for the undergrowth reservoir of limited number of species which in return can be predictor of species richness and abundance and thus the structure of tree community. Woody undergrowth community could be considered in biodiversity management and degraded land restoration.

Supplementary works could be undertaken to understand the characteristics of seed bank for bowal, shrubland and woodland regarding the undergrowth and tree communities.

Keywords

Biodiversity Conservation, Burkina Faso, Regeneration, Spatial Heterogeneity, Sudanian Ecosystems

1. Introduction

Restoring woody community for conservation goal with its species diversity based-naturally occurrence in savanna and woodland ecosystems in arid and semi-arid regions have always been of broad concerns for vegetation management by plant ecologists, biologists, evolutionists and environmentalists. One reason is the fluctuation observed in woody species composition and diversity, discontinuous structure and pattern of woody stratum within or between landscape which reflect the magnitude and instability of species establishment and recruitment [1] [2]. Although many efforts have been conceded and are increasingly underway [3] [4] [5] [6] to overcome these concerns, the mechanisms or way in which plant species colonize or regenerate and recruit in a given area and vegetation condition vary largely in the literature [7] [8] [9] [10] [11]. It is reported in West Africa, in Sudano-Sahelian ecosystems that many woody species asexually regenerate naturally in the landscapes of *Daniellia oliveri*, *Detarium microcarpum* or *Isobertinia doka* [9] while species as *Crossopteryx febrifuga* is able to recruit and resist in a wider range of fire conditions than *Piliostigma* sp [8]. According to Do *et al.* [12] undergrowth species decline in disturbed vegetation. These authors have recorded 54 woody species in high human impacted forest, 66 in low impacted and 56 in intact forest at seedling stage against 55, 73 and 77 at sapling stage and 90, 102 and 98 at tree stage respectively and significant increase in sapling density for high impacted forest and similar distribution in seedling density.

Obviously, in many arid and semi-arid regions, the natural vegetation is the main source that supplies with natural resources and environment benefits for local resident well-being [11] [13] [14]. Several species are overharvested for household needs and others are ecologically used for land protection. The recurrent tree pruning of many species maintain these trees in juvenile stage while the loss of many natural habitats generated by the constant change or transformation of arable lands for agriculture extension and/or urbanization purposes lead to modify the vegetation structure and conditions [15] [16] and thereafter hind their natural regeneration by suppressing seed production. These factors also act to reduce the size of plant population. Whenever the conditions of vegetation shape the woody tree strata [17], the dynamic and quality of the natural undergrowth successfully established and recruited remains the main responsible of the future composition and structure in particular woody community. It is suggested that

the undergrowth ability to escape disturbance effects and changing environment and therewith their performance to grow can be very considerable [7]. Therefore, the characteristics of natural woody vegetation widely varied from site to site in the same landscape as the clue of limited establishment and recruitment in woody community. Subsequently, some species that escape changing environment manage to reproduce abundantly, persist and recruit in the conditions of the new habitat and the others either decline or perish and hereafter jeopardize the stability of local biodiversity inside the same phytogeographical edge. During their investigations Attua *et al.* [15] have observed among study zones, the preponderance of the species of Fabaceae family in both least and medium human activities while the species of Fabaceae, Malvaceae and Moraceae families were most represented under higher activities.

In Sudanian Africa, strong soil compaction and moisture deficit are also factors that lead natural population regression in savanna. Therefore, quantifying the regeneration status of woody species in these ecosystems become indisputable subject to understand the distribution and assemblage of species in a given area despite the effects of ecological interactions [4]. Previous research have highlighted that the success or fail of species to establish is guided by the probability and quality of undergrowth to establish while its recruitment is influenced by habitat type or microsite characteristics and/or their interactions [10] [18]. When scarce woody vegetation may be benefit for savanna native species dense vegetation patch as woodland may facilitate shade tolerant and/or forest native undergrowth species to establish [19] [12] [20] [21]. For [19] the undergrowth number of *Vitellaria paradoxa* was significantly higher under the tree crowns of *Parkia biglobosa* and *V. paradoxa* than outside crown cover. According to [21] seedling density was higher *Eucalyptus camaldulensis* plantation forest (2567 stems/ha) in comparison with the native woodland (2267 stems/ha) almost similar whereas unprotected site better promote seedling emergence with the highest density than in protected one across phytogeographical regions [22]. Comparatively few or no attention has been addressed at understanding the characteristics of the woody undergrowth reservoir along vegetation patches as shrubland and woodland in the same landscape. Therefore, current investigation was undertaken to assess the regeneration potential of woody species in secondary disturbed ecosystems that could be candidate for conservation and/or restoration for particular woody species populations, or might be equivalent to the same area at different times. The aim of this study was to characterize the community of woody undergrowth and the relationship between undergrowth and trees of the same species across vegetation patches as habitats or regeneration niches. We specifically assessed firstly, 1) the species composition and diversity of undergrowth; 2) the density and structure of undergrowth stem; 3) whether the species richness and stem density of undergrowth community vary in function of those of tree community within area and secondly, 4) the regeneration status of the most shared species within area relating to the conspecific tree community to find out the preferred regeneration niche. As research question

“How important is undergrowth community in secondary disturbed vegetation patch?”

2. Material and Methods

2.1. Study Site Description

The field work was carried out in a sub-urban forest in West part of Burkina Faso at an altitude of 300 m a.s.l. This sub-urban forest is located in the north-west of Bobo-Dioulasso the second main city of the country (11°N - 12°N and 4°10'W - 4°30'W). The local climate is characterized by the alternance of a dry and a rainy season. Data recorded by local meteorology department from 1999 to 2019 showed that the rain season lasts from April to October (7 months) with an average rainfall of 1038.68 ± 174.31 mm per annum while a total rainfall of 1320 mm and 1349.8 mm were recorded in 2018 and 2019 respectively. The dry season lasts from November to March (4 months). January is the coldest month with 15.89°C and April the hottest with 40.42°C.

Soils based on sedimentary rocks are considered as Lixisols according to the FAO classification system [23]. These soils are slightly deep (>85 cm) and dominated by a loamy-sandy texture (57.5%) with the presence of sandy structures (17.5%), sandy loamy (15%) and other structures (10%) (BUNASOLS, 1985) in [24].

The local vegetation is savannah of South-Sudanian domain included in the Sudanian regional centre of endemism [25]. This vegetation is a mosaic patch constituted of opened tree and bush savannah, wooded and opened woodlands [26] with annual and/or perennial grasses and bare lands.

2.2. Study Plant Community

We considered vegetation patches on bowal outcrop (opened canopy), shrubland (semi-opened) and woodland (closed canopy). This is because the vegetation patches or canopy conditions can modify the regeneration degree through the distribution, floristic composition, diversity and structure of naturally occurred woody undergrowth reservoir. According to [27], woodland is defined by the abundance of individuals of species *Anogeissus leiocarpus* (DC.) Guill. & Perr., *Combretum* spp, *Detarium microcarpum* Guill. & Perr., *Isoberrlinia doka* Craib & Stapf., *Pterocarpus erinaceus* Pair., *Terminalia* spp and *Vitellaria paradoxa* var. *paradoxa* Gaertn f. The mean density was 497.00 ± 180.62 stems·ha⁻¹ and height 5.43 ± 0.73 m. Shrubland shelter *Acacia macrostachya* Reichenb. ex DC, *Combretum* spp, *Lannea* spp, *Gardenia* spp, *Maranthes polyandra* (Benth.) Prance, *Crossopteryx febrifuga* (Afzel. ex G. Don) Benth, *Sarcostemma viminale* (L.) R.Br with a total height not over 2 m above soil surface and annual grass layer as *Loudetia togoensis* (Pilg.) C. E. Hubb., and *Pennisetum pedicellatum*. The shrubland is dominated by woody shrub species with an opened layer (stem density 620.00 ± 175.94 stems·ha⁻¹ and mean height 5.24 ± 0.40 m) and annual grass layer, with occasional tree saplings. Bowal (plural: bowé) also refers to a shrubland but corresponds to an “edaphico-climatic” grassy formations of the

semi-desert plateaus fossilized by an outcropping or sub-outcropping breastplates, and with hydromorphic silts [28]. Soil surface is interrupted by crusted soils and mushroom-shaped mounds erected by *Cubitermes* spp (humivorous) at 99 ha^{-1} [29]. Annual grass as *Loudetia togoensis* was recurrent with some scattered shrub species during rainy season on bowal. The average density was 436.00 ± 235.10 stems- ha^{-1} and height, 4.52 ± 0.78 m. These few scattered shrubs disappear during the dry season leaving to discover a bare soil.

2.3. Experimental Design and Undergrowth Inventory

We firstly delimited 30 contiguous plots of $50 \text{ m} \times 20 \text{ m}$ [30] randomly in the state forest of Dinderesso following transect lines that included the direction of the rainwater flow. All tree species which stem dbh was equal to or greater than 5 cm were systematically recorded and measured in the 30 plots (or 3 ha) or tree-plots as adult community. We identified 58 species belonging to 42 families and 18 genera, with Combretaceae ($168 \text{ trees}\cdot\text{ha}^{-1}$), Fabaceae ($111.67 \text{ trees}\cdot\text{ha}^{-1}$), Sapotaceae ($64.67 \text{ trees}\cdot\text{ha}^{-1}$), Caesalpinaceae ($63 \text{ trees}\cdot\text{ha}^{-1}$) the most abundant families in terms of tree density [31]. The density and height of trees in at plot scale was affected by the type of vegetation assemblage.

In each major plot, 50 subplots of $5 \text{ m} \times 5 \text{ m}$ (or 25 m^2) were established on bowal, shrubland and woodland. Among these subplots, 5 were laid with one subplot at the centre and one subplot at each of the 4 corners (diagonally arranged) for collecting undergrowth data in tree-plots. In total, 150 subplots were established and considered.

Data on undergrowth plant communities were collected in the rainy season during which all the woody species as seedlings, saplings and trees are leafy and identifiable. This period also corresponded to that of the abundant emergence of the undergrowth of many species either by seed germination or resprouting of the remaining stem or sucker [10]. Inventory was proceeded from August to November 2018. Undergrowth species were identified using vegetation community characteristics and botanical criteria of [27] and by comparing morphologically with trees of the same species. The sample of undetermined species were taken to be later identified at laboratory with referring to available data on African woody species. Scientific name were cross-checked according to [32] and [33]. For all live individual of which the diameter at breast height (dbh) less than 5 cm and total height of stem equal to or less than and 150 cm were systematically counted as woody undergrowth contrary to adult tree (mature). The total height of undergrowth individual was measured using a graduated perch of 7 m, at each 50 cm and their collar diameter was measured with calliper (0.01 mm precision). Only the tallest stem was considered in case of more than stem for individuals.

2.4. Undergrowth Data Analysis

We used the number of 25 m^2 subplots in which undergrowth species occurred

in each tree-plot (1000 m²). We firstly explored the data on undergrowth plant community alone to assess species richness (S) and floristic composition. Species richness was determined based on the number of species identified (S) and as species density which refers to the number of species identified in the total area of each subplot [34]. Species density is thus expressed as the number of species (S) at 100 m² of area. Species name were written in full for the first time and, generic name was used thereafter. When more than one species were identified in the same genus, the generic name was abbreviated and followed by specific epithet.

The species diversity of undergrowth was calculated and the Simpson's index of diversity I (Equation (1)) [35] was calculated for each subplot of 5 m × 5 m to evaluate the species diversity as the probability that two random individuals belong to the same habitat:

$$I = 1 - D = 1 - \frac{\sum_{i=1}^{i=s} ni(ni-1)}{N(N-1)} \quad (1)$$

where N is the total number of woody undergrowth recorded, s the number of species and ni the total number of individuals of species i . The Simpson's index of diversity (I) consider the number of species present in a community and the abundance of each species as single statistic. Its values range from 0 (low diversity) to 1 (high diversity).

For assessing the height distribution in undergrowth community, all the recorded individuals growing on bowal, shrubland and woodland were separated into six different height classes as]0 - 25],]25 - 50],]50 - 75],]75 - 100],]100 - 125],]125 - 150] with their corresponding density in each community.

We noted species richness and abundance as total number of species and stem per unit of area or density. Since the size of sampled areas for undergrowth and tree communities were different, both species richness and abundance were balanced by the sampled plots (trees) or subplots (undergrowth) and then standardized per 100 m² of area. This method also has been used by [10] for facilitating the comparison of species between various areas.

The mean values of 1) species density, 2) Simpson's index of diversity, 3) the mean density and collar diameter of undergrowth stem were calculated for each vegetation patch and compare to find out the regeneration niche preferences of woody species. The variation of undergrowth stem density among habitats or vegetation patches was analyzed using the one-factor ANOVA of Minitab 15 and then the test of multiple comparisons of mean values were performed when the observed differences were significant at probability $P = 0.05$ based on Tukey's (HSD) test. In addition, the test of linear regression was used to highlight the relationships that could exist between undergrowth and tree communities in each habitat regarding their characteristics. These analysis involved both species richness and stem density to evaluate which of bowal, shrubland and wood shows good undergrowth reservoir as suitable niche of natural regeneration.

3. Results

3.1. Effects of Vegetation Patch on Alpha Diversity of Undergrowth

We recorded overall 52 undergrowth species and 2224 stems that belonged to 38 genera and 21 families along the study period. Among these species, 25, 36 and 38 species were identified in bowal, shrubland and woodland respectively (Appendix). The families of Combretaceae (6 species), Caesalpiniaceae (4 species), and Mimosaceae (3 species) were largely represented in bowal while Combretaceae (9 species), Caesalpiniaceae (6 species), Euphorbiaceae (3 species), Rubiaceae (3 species) dominated in shrubland. The families of Combretaceae (7 species), Caesalpiniaceae (6 species), Rubiaceae (4 species), Euphorbiaceae (3 species) and Mimosaceae (3 species) prevailed in woodland.

All the three vegetation patches shared 15 species with each other while 3 species were common in bowal and woodland, and 13 species were found in both shrubland and woodland (Appendix). Only 1 species as *Opilia celtidiflora* Endl. S. Walp. was found in both bowal and shrubland. In fact, 6 species were solely identified in bowal, and 7 species in each of shrubland and woodland respectively. The occurrence of species *O. celtidiflora* in bowal seems to be accidentally and linked to fruit (or seed) dispersal process.

The calculated values of species richness as species density at 100 m² unit of area and Simpson's index of diversity I of undergrowth community were lower for bowal, higher for shrubland, and intermediate for woodland (Table 1). Statistically, vegetation patching significantly influenced the species density (Anova, $F = 38.08$, $P < 0.0001$) and Simpson's index of diversity I (Anova, $F = 7.15$, $P = 0.003$). Importantly, the pairwise comparison of mean value revealed that species density was strongly increased for shrubland ($P < 0.0001$) and woodland ($P < 0.0001$) in comparison with bowal while it did not differ significantly between shrubland and woodland ($P = 0.618$), and between woodland and bowal ($P = 0.078$) (Table 1). In contrast, the difference observed in the Simpson's index of diversity was only significant for shrubland ($P = 0.002$) comparing with bowal whereas it was insignificant between shrubland and woodland ($P = 0.311$) and, between woodland and bowal ($P = 0.078$). The test of Tukey discriminated two homogeneous groups (a et b) relating to specific density and stem density (Table 1): bowal (a) is species-poor site and shrubland-woodland together form a rich-species site (b). In return, undergrowth community in bowal (a) was less diversified and shrubland (b) more diversified vegetation regarding the undergrowth characteristics.

3.2. Effects of Vegetation Patch on the Structure of Undergrowth

Undergrowth individuals were counted in 50×25 m² (or 125 m²) per vegetation patch. The overall density of undergrowth ranged from 35.28 ± 19.11 stems·100 m⁻² (or 441 individuals·125 m⁻²) on bowal to 76.88 ± 21.02 stems·100 m⁻² (961 individuals·125 m⁻²) in woodland. This density was lower for bowal and intermediate for shrubland (Table 1). The most abundant families were Combretaceae,

Table 1. Species density, Simpson's index of diversity and abundance of woody undergrowth at subplot-level on bowal, shrubland and woodland in the study site (mean \pm standard deviation).

Variables	Subplot location			F	P.
	Bowal	Shrubland	Woodland		
Subplot no.	50	50	50		
<i>Species diversity of undersgrowth</i>					
Number of observed genus	23	28	33		
Number of observed family	13	18	19		
Number of observed species	25	36	38		
Species density (no. species 100 m ⁻²)	4.72 \pm 2.83 ^a	13.52 \pm 1.83 ^b	12.48 \pm 2.62 ^b	38.08	<0.0001
Simpson's index of diversity I (1-D)	0.63 \pm 0.24 ^a	0.88 \pm 0.03 ^b	0.78 \pm 0.08 ^{ab}	7.15	0.003
<i>Undergrowth abundance</i>					
Number of observed stems	441	822	961		
Mean stem density (no. stems·100 m ⁻²)	35.28 \pm 19.11 ^a	65.76 \pm 11.82 ^b	76.88 \pm 21.02 ^b	14.7	<0.001
Mean stem collar diameter (cm)	1.21 \pm 0.77 ^a	1.18 \pm 0.91 ^a	1.07 \pm 0.83 ^b	5.55	0.004
Minimum diameter (cm)	0.10	0.10	0.10		
Maximum diameter (cm)	6.70	7.50	10.00		

Mean values with different letter(s) across the same line for each vegetation type are significantly different (at $P < 0.05$) according to Tukey's HSD test.

Mimosaceae, Caesalpiniaceae, Sapotaceae and Euphorbiaceae (Appendix) with abundant individuals.

At the scale of vegetation patches, the families of Caesalpiniaceae and Combretaceae were prevalent in bowal whereas Combretaceae, Mimosaceae were substantially represented in shrubland and woodland respectively.

Out of the shared species, *Detarium microcarpum* Guill. & Perr., *Guiera senegalensis* Lam. and *Diospyros mespiliformis* Hochst. ex A. DC. were abundantly represented in bowal. Depending on site characteristics, species as *G. senegalensis*, *Dichrostachys cinerea* (L.) Wight & Arn. and *Vitellaria paradoxa* var. *paradoxa* C.F. Gaertn were the most abundant species in shrubland whereas the undergrowth of *D. cinerea*, *G. senegalensis* and *V. paradoxa* dominated in woodland.

When we calculated the value of the ratio of shared undergrowth species over tree communities among patch, we noticed a preponderance of undergrowth individuals compared with adult tree within species (Appendix). There was much more undergrowth than adult trees as limited regeneration of these species. Undergrowth density was significantly different across vegetation type (Anova, $F = 14.7$, $P < 0.001$ in Table 1). According to Tukey's test the mean density of undergrowth was higher for shrubland ($P = 0.002$) and woodland ($P < 0.0001$) than bowal but this observed difference between shrubland and woodland was not significant ($P = 0.355$). Regarding the abundance distribution of undergrowth

individuals, bowal (a) refers to a particular vegetation set and pool community of shrubland-woodland (b) form the other homogeneous vegetation.

The collar diameter of undergrowth varied from 1.07 ± 0.83 cm in woodland to 1.21 ± 0.77 cm in bowal as the highest value (**Table 1**). The minimum collar diameter recorded in each area was the same while the maximum ranged from 6.70 cm in bowal to 10 cm in woodland indicating the development level of their underground systems.

The mean values of stem collar diameter remarkably varied from one site to another (Anova, $F = 5.55$, $P = 0.004$). Difference observed in these mean values was strongly higher for bowal ($P = 0.006$) and shrubland ($P = 0.032$) compared with woodland while it was not significant between bowal and shrubland ($P = 0.849$) showing similar community (**Table 1**). The multiple comparison of mean values indicated two homogeneous groups as bowal-shrubland (a) and woodland (b) in term of stem collar diameter.

3.3. Effects of Vegetation Patch on Height Class Distribution

The abundance distribution of undergrowth varied according to the height classes (**Figure 1**). This distribution was in bell-shaped and represented a gauss-type structure reflecting poor regeneration and recruitment on bowal regarding the tendency curve shape (**Figure 1(a)**). Most individuals in this community or 92% occurred as aggregated in the midst height classes between 50 and 100cm tall. In contrast, the tendency curve showed that the distribution of undergrowth stems was in reverse J shape for the shrubland and woodland communities (**Figure 1(b)** and **Figure 1(c)**). There was a decrease in undergrowth abundance from]25 - 50],]50 - 75],]75 - 100],]100 - 125] to]125 - 150] in shrubland and woodland towards higher height class. The incidence of undergrowth individuals in height class]0 - 25] and those with height > 100 were scarce. Such distribution seems to be linked to canopy degree and indicate distribution as specific-site (bowal) vs. similar homogeneous distribution model in both shrubland and woodland communities.

3.4. Relationship between Undergrowth and Tree Communities

The linear regression analyses were performed to explore the relationship between tree community as explanatory variable and undergrowth community as response variable (specie and stem densities). The expected results highlighted positive relationship between undergrowth and tree communities (Anova, $P < 0.05$) in bowal while it was statistically good between undergrowth and tree stem densities only in woodland (Anova, $P < 0.05$) (**Table 2**). The observed species richness of undergrowth was 53% explained by that of tree species and their stem densities at 42% by that of tree density for bowal. In shrubland, undergrowth and tree communities were almost independent ($P > 0.05$) with weak relationship between them. Only few variations of undergrowth species richness (26.50%) and stem density (16.20%) was explained respectively by species richness

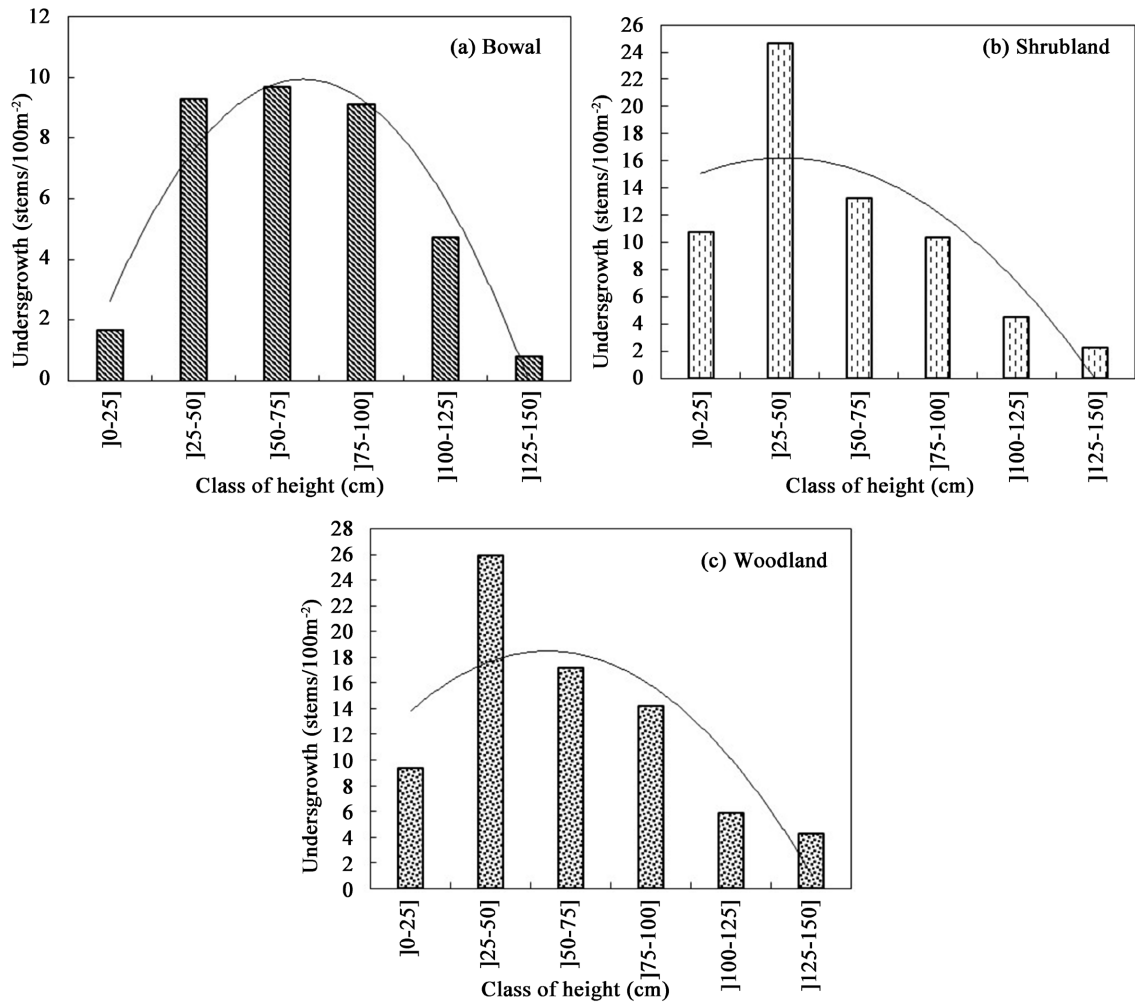


Figure 1. Pattern of the height class pattern of woody undergrowth recorded in 2018 in bowal (a), shrubland (b) and woodland (c).

Table 2. Linear relationship between the species richness and stem density of woody undergrowth and tree communities for each vegetation patch.

	Subplot location		
	Bowal	Shrubland	Woodland
Species richness (no. species·100 m ⁻²)			
Regression equation	6.34x - 0.79	3.09x + 8.30	1.53x + 10.9
R ²	52.50%	26.50%	3.00%
ANOVA, P	0.018	0.128	0.630
Density (stems·100 m ⁻²)			
Regression equation	5.78x ² +14.7	2.40x ² +52.5	7.51x ² + 42.4
R ²	42.20%	16.20%	55.80%
ANOVA, P	0.042	0.249	0.013

Regression equation corresponded to species richness (or stem density) = a x (with x = species number·100 m⁻² or x = stem density (stems·100 m⁻²) + b; P: probability.

Table 3. Ratio of woody undergrowth over tree densities (stems-100 m⁻²) for the most 15 shared species in the study vegetation patches.

Species name	Bowal			Shrubland			Woodland		
	Undergrowth	Tree	Ratio	undergrowth	Tree	Ratio	Undergrowth	Tree	Ratio
<i>Annona senegalensis</i>	0.40	0.02	20.00	1.44	0.06	24.00	2.16	0.08	27.00
<i>Burkea africana</i>	0.72	0.03	24.00	1.20	0.37	3.24	0.48	0.07	6.86
<i>Cassia sieberiana</i>	0.88	0.44	2.00	0.48	0.02	24.00	0.08	0.01	8.00
<i>Combretum nigricans</i>	0.08	0.03	2.67	0.24	0.16	1.50	0.48	0.08	6.00
<i>Daniellia oliveri</i>	0.08	0.03	2.67	0.56	0.15	3.73	0.56	0.53	1.06
<i>Detarium microcarpum</i>	10.08	1.1	9.16	1.36	0.30	4.53	0.80	0.01	80.00
<i>Dichrostachys cinerea</i>	0.40	-	-	10.56	-	-	28.48	0.01	2848
<i>Diospyros mespiliformis</i>	1.52	0.04	38.00	0.16	0.01	16.00	0.72	0.09	8.00
<i>Flueggea virosa</i>	0.48	-	-	1.52	-	-	1.12	-	-
<i>Gardenia ternifolia</i>	0.64	-	-	1.20	-	-	2.08	-	-
<i>Guiera senegalensis</i>	4.72	0.11	42.91	12.48	0.05	249.60	17.44	0.03	581.33
<i>Holarrhena floribunda</i>	0.80	-	-	0.08	-	-	0.72	-	-
<i>Pteleopsis suberosa</i>	0.72	-	-	3.12	0.49	6.37	2.08	0.04	52.00
<i>Terminalia macroptera</i>	0.64	0.22	2.91	4.00	0.39	10.26	2.64	0.19	13.89
<i>Vitellaria paradoxa</i>	0.72	0.08	9.00	5.76	0.9	6.40	4.40	0.96	4.58

and density of woody tree. Among the shared undergrowth species (**Table 3**), *G. senegalensis* and *D. mespiliformis* had high undergrowth density compared with their corresponding trees in bowal while *D. cinerea* and *G. senegalensis* had relatively abundant undergrowth over tree ratio in shrubland and woodland. From the overall 15 shared undergrowth species, *Flueggea virosa* (Roxb. ex Willd.) Voigt, *Gardenia ternifolia* Schumach. & Thonn. and *Holarrhena floribunda* T. Durand & Schinz did not exist as tree in the study areas.

4. Discussion

The present research analyzed the characteristics of woody undergrowth community in natural vegetation patches as habitats or regeneration niche in a state forest. Our results revealed that the type of vegetation or habitats importantly affects woody undergrowth community through establishment and recruitment. In accordance with our first specific objective, woody undergrowth associated with woodland sheltered higher number of species corresponding to 73.08% of the total counted species versus bowal with 48.08% (the lowest rate) and shrubland 69.23% (intermediate rate). At the scale of occupied surface, the species density (species.100 m⁻²) of undergrowth community was lower in bowal but it was similar between both shrubland and woodland. Ecological undergrowth species were also represented and but differed between the three types of vegeta-

tion. The species of Caesalpiniaceae (*Burkea* sp) and Mimosaceae (*Acacia* sp) families were the most abundant and frequent in each of the vegetation patches. Species richness observed in study areas may indicate that of viable seeds and propagules (mainly seed stock) that were stored on the floor or underground relatively to their dispersal system and have emerged during the favourable conditions of humidity and temperature. Nonetheless this significant difference may certainly result from the chance of species undergrowth to abundantly establish, grow and co-exist during their early stage [36] and hereafter influence the species diversity as response to heterogeneous areas described in community plant material (see Section 2.2). Current results on species richness are consistent with previous studies carried out in different climate zones [37] [38] [39] [40] [41]. By using a theoretical model during their investigation, [37] have demonstrated a positive effect of canopy composition (adult tree composition) on the undercanopy composition and shrub diversity through the modification of the soil conditions in where they grow. Therefore, in function of their ecological adaptive strategy, a many species may persist under particular canopy conditions as bowal (plenty opened), shrubland (light opened) and woodland (full cover) as area specific-species because vegetation patch likely act as filter or refuge for them to the detriment of area sensitive species [42]. This is the case of shared undergrowth species that can abundantly colonize and grow simultaneously in these three vegetation patches but their persistence is driven by their plasticity profile.

Regarding the second specific objective, species diversity in each vegetation patch was the consequence of capability to occur on bowal, shrubland and woodland leading to the co-existence of few species richness and abundant with uneven stem density even if the observed difference in the value of Simpson's diversity index for shrubland and woodland was insignificant. In shrubland, the most common families were Caesalpiniaceae, Combretaceae and Mimosaceae and highly contributed to increase the species diversity of undergrowth reservoir through the species number representing each of them in study sites during sampling period (see Appendix). Although the community associated with bowal sheltered lower species richness and diversity relating to shrubland, its diversity was similar with that of woodland undergrowth community as the proven of preference regeneration niche for each species. Current observations corroborate that obtained by [42] [43]. By comparing plant diversity between bowé (plural of bowal) and adjacent woodlands, these authors have pointed out lower woody species occurring on bowé with the predominance of *A. macrostachya*, *C. glutinosum*, *C. nigricans*, *D. microcarpum* and *L. microcarpa* individuals as resistant species to drought and with high regeneration potentials whereas Fabaceae family was well represented along the Njoro and Kamweti rivers by *Acacia* sp [44]. Therefore the low species diversity of woody undergrowth on bowal may result from the stressful soil conditions (edaphic factors), such as incrustated soil surface, absence of litter (bare soil) leading to water deficiency. Such in-

crusted soil certainly reduce significantly space available for tree species to establish or prevent undergrowth to take root.

While vegetation patches significantly differ in species diversity, the overall abundance of undergrowth individuals evolved across sites and so did collar diameter and height class distribution. Our results showed that the density of undergrowth was significantly lower on bowal only in where the density value was twice that observed in shrubland and woodland (see **Table 1**). Such a reduced stem density of undergrowth community on bowal may depict limit in undergrowth establishment with scattered individuals [43] while shrubland and woodland together appeared with aggregated individuals as positive effect of canopy extend for undergrowth establishment contrary to [45]. Another explanation of unbalanced distribution in the different habitats may be that some species better fit a given environment than others at both undergrowth and adult tree stages. The co-existence of undergrowth individuals of the same and different species in each community is linked to the type of growing niche and their relationships with the existing ecological factors.

Besides, density distribution, undergrowth community on both bowal and shrubland had larger stump trunk in view of the collar diameter value. These communities constitute similar homogeneous group for stem collar diameter but differed from woodland. One may question whether the size of stem (big trunk) respond to an edaphic heterogeneity or to particular stress (competition with established species) in place or ontogenic factor? This is because high densities of undergrowth are likely to be correlated with small undergrowth sizes on each area. The higher collar diameter found on bowal mainly give an insight on the fact that woody undergrowth develop priority their underground systems as environment-feedback for a good anchoring, storing much nutrients and water to face unfavourable conditions for survival. Report indicated that undergrowth with larger stem diameter tend to survive better than small stem diameter and, are strong competitors [46]. Interestingly, most undergrowth individuals were under 100 cm tall and the proportion of those in the upper height class decreased on bowal (bell-shaped or gauss distribution). This fact may indicate that the high densities of undergrowth are likely to be correlated with small undergrowth sizes on each area. As for the distribution of undergrowth observed in shrubland and woodland, we can state that woody species roughly emerged jointly from propagules and/or soil seed stock (germination by seed) as response to favourable conditions (study period) and only the most successful species may be recruited in taller groups. This variation may also result from higher mortality rate or a slow growth that individuals experience along their life cycle and hereafter inducing a decreased density in taller groups (e.g. density in shrubland) corresponding to an instable communities and extreme vulnerability at early stage. Broadly, the three vegetation patches have a poor recruitment status regarding a gauss type structure observed, although some species abundantly established successfully in detail contributing to increase stem density. This is a case of *D. cinerea*, *D. microcarpum* in scrubland and woodland, and *D. mespiliformis* in bowal. Similar

result was reported for *Boswellia papyrifera* population by [47] in Ethiopia where species exhibited a poor regeneration status.

Globally, the recruitment of woody species open to criticism because of the preponderance of undergrowth as regards adult trees through shared species as undergrowth > trees. Nevertheless the variation of undergrowth species and stem density was significantly related to adult tree on bowal solely whereas 55.80% variations in woodland resulted from adult stem density only as the regression analysis results. This strong relationship suggest that woody undergrowth species successfully regenerated abundantly beneath adult trees but decline during undergrowth to tree transition in both bowal and woodland. Establishment pattern was likely promoted by the way adult tree may act on habitat conditions as facilitator or inhibitor during growth process.

5. Conclusion

Our results showed that undergrowth reservoirs varied across vegetation patches as response to the degree of heterogeneity in the study sites. In the Dinderesso state forest. These undergrowth reservoirs and may be an indicator of the species richness of soil propagules and/or seed stock. The three vegetation patches ranged into two homogeneous groups as the undergrowth community linked to bowal and that of shrubland-woodland. A particular undergrowth vegetation set is growing in bowal as area specific-species and stem density which positively vary in function of the associated tree community characters. Bowal as well as shrubland and woodland acts as suitable regeneration niche with reservoir for limited number of species that favourably co-exist. We may state that the co-existence of undergrowth of the same and different woody species and afterwards tree individuals in a particular community is in function of woody species themselves (intrinsic factors as biotic), habitat-specific biotic (protection from stand canopy) and the type of growing niche and their different interrelated mechanisms. Nonetheless, the main driver of observed distinction is the edaphic factors at small spatial scale (bowal) but undergrowth reservoir remain connected with family existing in its surroundings. Furthermore, this reservoir constitutes an indicator of species richness and abundance and hereafter a predictor of the physiognomy of woody tree community in place. The woody undergrowth community should be considered in the program of diversity management and degraded land restoration or other area similar to bowal. Based on the results of this study, field works could be undertaken to understand the characteristics of seed bank for bowal, shrubland and woodland regarding the undergrowth and tree communities and various conditions as the infiltration of soil water and biotic factor effects.

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Data Availability Statement

All data supporting the results of this study are available from the corresponding author (Traoré Saran) on decent demand.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix. Complete List of Undergrowth Species and Stem Number (Density Stems·100 m⁻²) in 50 Subplots Laid in Each Vegetation Patch

Species-name	Family	Number of undergrowth (N)			Density (stems·100m ²)		
		Bowal	Shrubland	Woodland	Bowal	Shrubland	Woodland
<i>Acacia dudgeoni</i> Craib ex Hall.	Mimosaceae	-	-	1	-	-	0.08
<i>Acacia erythrocalyx</i> Brenan	Mimosaceae	-	9	-	-	0.72	-
<i>Acacia macrostachya</i> Reichenb. ex DC	Mimosaceae	2	-	-	0.16	-	-
<i>Annona senegalensis</i> Pers.	Annonaceae	5	18	27	0.4	1.44	2.16
<i>Anogeissus leiocarpus</i> (DC.) Guill. & Perr.	Combretaceae	-	1	37	-	0.08	2.96
<i>Baissea multiflora</i> A. DC.	Apocynaceae	-	-	1	-	-	0.08
<i>Bridelia ferruginea</i> Benth	Euphorbiaceae	-	2	-	-	0.16	-
<i>Bridelia micrantha</i> (Hochst.) Baill.	Euphorbiaceae	-	28	28	-	2.24	2.24
<i>Burkea africana</i> Hook.	Caesalpiniaceae	9	15	6	0.72	1.2	0.48
<i>Cassia arereh</i> Delile	Caesalpiniaceae	-	3	7	-	0.24	0.56
<i>Cassia sieberiana</i> DC.	Caesalpiniaceae	11	6	1	0.88	0.48	0.08
<i>Celtis integrifolia</i> Lam.	Ulmaceae	4	-	1	0.32	-	0.08
<i>Combretum glutinosum</i> Perr. ex DC.	Combretaceae	23	-	-	1.84	-	-
<i>Combretum micranthum</i> G. Don	Combretaceae	6	-	-	0.48	-	-
<i>Combretum molle</i> R. Br ex G. Don	Combretaceae	-	6	-	-	0.48	-
<i>Combretum nigricans</i> Lepr. ex Guill & Perr.	Combretaceae	1	3	6	0.08	0.24	0.48
<i>Crossopteryx febrifuga</i> Benth.	Rubiaceae	-	-	2	-	-	0.16
<i>Daniellia oliveri</i> (Rolfe) Hutch. & Dalz.	Caesalpiniaceae	1	7	7	0.08	0.56	0.56
<i>Detarium microcarpum</i> Guill. & Perr.	Caesalpiniaceae	126	17	10	10.08	1.36	0.8
<i>Dichrostachys cinerea</i> (L.) Wight & Arn.	Mimosaceae	5	132	356	0.4	10.56	28.48
<i>Diospyros mespiliformis</i> Hochst. Ex A. DC	Ebenaceae	19	2	9	1.52	0.16	0.72
<i>Entada africana</i> Guill. & Perr.	Mimosaceae	86	-	3	6.88	-	0.24
<i>Flueggea virosa</i> (Roxb. ex Willd.) Voigt	Euphorbiaceae	6	19	14	0.48	1.52	1.12
<i>Gardenia aqualla</i> Stapf & Hutch.	Rubiaceae	-	11	2	-	0.88	0.16
<i>Gardenia erubescens</i> Stapf & Hutch.	Rubiaceae	-	8	6	-	0.64	0.48
<i>Gardenia ternifolia</i> Schumach. & Thonn.	Rubiaceae	8	15	26	0.64	1.2	2.08
<i>Grewia bicolor</i> Juss.	Tiliaceae	-	-	4	-	-	0.32
<i>Guiera senegalensis</i> Lam.	Combretaceae	59	156	218	4.72	12.48	17.44
<i>Holarrhena floribunda</i> T. Durand & Schinz	Apocynaceae	10	1	9	0.8	0.08	0.72
<i>Hymenocardia acida</i> Tul.	Euphorbiaceae	-	-	4	-	-	0.32
<i>Isoberlinia doka</i> Craib & Stapf	Fabaceae	-	-	1	-	-	0.08
<i>Jatropha curcas</i> L.	Euphorbiaceae	2	-	-	0.16	-	-

Continued

<i>Khaya senegalensis</i> A. Juss.	Meliaceae,	-	18	11	-	1.44	0.88
<i>Lannea acida</i> A. Rich., Guill. & Perr.	Anacardiaceae	-	1	2	-	0.08	0.16
<i>Lannea velutina</i> A. Rich., Guill. & Perr.	Anacardiaceae	6	-	-	0.48	-	-
<i>Maranthes polyandra</i> (Benth.) Prance	Chrysobalanaceae	-	12	-	0	0.96	-
<i>Opilia celtidifolia</i> (Guill. & Perr.) Endl. ex Walp.	Opiliaceae	1	7	-	0.08	0.56	-
<i>Parinari curatellifolia</i> Planch. ex Benth.	Chrysobalanaceae	-	2	4	-	0.16	0.32
<i>Piliostigma thonningii</i> (Schumach.) Milne Redh.	Caesalpiniaceae	-	43	2	-	3.44	0.16
<i>Prosopis africana</i> Taub.	Fabaceae.-	-	45	4	-	3.6	0.32
<i>Pteleopsis suberosa</i> Engl. & Diels	Combretaceae	9	39	26	0.72	3.12	2.08
<i>Pterocarpus erinaceus</i> Poir.	Fabaceae	-	9	1	-	0.72	0.08
<i>Saba senegalensis</i> (A. DC.) Pichon	Apocynaceae	20	-	-	1.6	-	-
<i>Securidaca longepedunculata</i> Fresen	Polygalaceae	-	21	-	-	1.68	-
<i>Strychnos spinosa</i> Lam.	Loganiaceae	5	-	1	0.4	-	0.08
<i>Terminalia avicennioides</i> Guill. & Perr.	Combretaceae	-	9	24	-	0.72	1.92
<i>Terminalia laxiflora</i> Engl.	Combretaceae	-	24	11	-	1.92	0.88
<i>Terminalia macroptera</i> Guill. & Perr.	Combretaceae	8	50	33	0.64	4	2.64
<i>Terminalia mollis</i> M.A. Lawson	Combretaceae	-	6	-	-	0.48	-
<i>Vitellaria paradoxa</i> var. <i>Paradoxa</i> C. F. Gaertn.	Sapotaceae	9	72	55	0.72	5.76	4.4
<i>Vitex doniana</i> Sweet	Lamiaceae	-	-	1	-	-	0.08
<i>Vitex simplicifolia</i> Oliv.	Lamiaceae	-	5	-	-	0.4	-
		441	822	961	35.28	65.76	76.88