Received: 3 June 2020 | Revised: 27 July 2020 | Accepted: 11 August 2020

DOI: 10.1111/aje.12790

ARTICLE

African Journal of Ecology WILEY

Protection influence on grassland structure in Widou Thiengoly's grazing areas at Ferlo

Eric Sylvain Badji[1] | Aly Diallo[2,3] | Moustapha Bassimbé Sagna[1] | Oumar Sarr[1] | Mariama Dalanda Diallo[3,4,5] | Daouda Ngom[1] | Aliou Guissé[1,3,5]

[1]Department of Plant Biology/Laboratory of Ecology and Eco-hydrology, Cheikh Anta Diop University of Dakar (UCAD), Dakar, Senegal

[2]UFR ST, Department of agroforestry, Assane Seck University of Ziguinchor (UASZ), Ziguinchor, Senegal

[3]OHM Tessekere CNRS, Cheikh Anta Diop University, Dakar, Senegal

[4]UFR S2ATA, Gaston Berger University of Saint Louis (UGB), Saint Louis, Senegal

[5]UMI, Health, Society (CNRS, UCAD, USTTB, UGB), Dakar, Senegal

Correspondence
Aly Diallo, UFR ST, Department of agroforestry, Assane Seck University of Ziguinchor (UASZ), Ziguinchor, Senegal.
Email: aly.diallo@univ-zig.sn

Funding information
Investissements d'avenir " program, Grant/Award Number: ANR-11-LABX-0010; OHIM Tessekere (UCAD, CNRS); UMI 3189 " Environnement, Santé, Sociétés " (UCAD, CNRS, CNRST, USTTB, UGB); Labex DRIIHM

Abstract

This work consisted of analysing the impact of protection on the Widou Thiengoly's grasslands structure. Data were collected from three selected sites by the quadrat point methodology, consisting of reading the herbaceous on a 10 m line. These sites were the 2013 defended plot (site A), the 2009 semi-protected plot (site B) and the unprotected grazing areas or off plot (site C). The results revealed a floristic composition of 45 species, belonging to 34 genera and 17 botanical families. The number of species identified was 28 in site A, 31 in site B and 29 in site C. Despite a certain similarity noted in the number of species, the herbaceous vegetation was more balanced in 2013 plot than in 2009 plot and in off plot where it tended to be homogeneous. The herbaceous cover in October 2015 was 99.8% in the 2013 plot; 98.8% in the 2009 plot; and 96.8% in the unprotected sites. The vertical stratification of herbaceous cover showed a better development at the intermediate strata (between 20 cm and 50 cm) in all the sites except in off plot where small grasses dominated. In this study, protection improved the specific balance, while semi-protection had a positive effect on the specific richness and growth of the grasses.

KEYWORDS
height, herbaceous, protection, structure, Widou Thiengoly

Résumé

Ce travail a consisté à analyser l'impact de la protection sur la structure des prairies de Widou Thiengoly. Les données ont été collectées sur trois sites sélectionnés en utilisant une méthodologie à quatre points, consistant à étudier les plantes herbacées sur un tracé de 10 m. Ces sites étaient la parcelle protégée de 2013 (site A), la parcelle semi-protégée de 2009 (site B) et les zones de pâturage non protégées ou hors parcelle (site C). Les résultats ont révélé une composition floristique de 45 espèces appartenant à 34 genres et 17 familles botaniques. Le nombre d'espèces identifiées était de 28 sur le site A, 31 sur le site B et 29 sur le site C. Malgré une certaine similitude constatée dans le nombre d'espèces, la végétation herbacée était plus équilibrée sur la parcelle de 2013 que sur la parcelle de 2009 et dans les zones hors parcelle, où elle avait tendance à être homogène. En octobre 2015, la couverture herbacée sur la parcelle de 2013 était de 99,8%, 98,8% sur la parcelle de 2009 et 96,8% sur les sites

 © 2020 John Wiley & Sons Ltd

non protégés. La stratification verticale de la couverture herbacée a démontré un meilleur développement au niveau des strates intermédiaires (entre 20 cm et 50 cm) sur tous les sites, sauf dans les zones hors parcelle où les petites graminées dominaient. Dans cette étude, il apparaît que la protection a amélioré l'équilibre spécifique, tandis que la semi-protection a eu un effet positif sur la richesse spécifique et la croissance des graminées.

1 | INTRODUCTION

The 'Sahel' corresponds to an ecological and climatic zone located between the 100–150 mm isohyets on the north and the 500–700 mm isohyets between the Saharan and Sudanese zones (Akpo, 1990). In recent decades, the Sahelian ecosystems have been severely degraded due to climatic change and anthropogenic pressure. This situation has not left behind the herbaceous stratum and is detrimental to the local economy based mostly on pastoral activities (Diallo, 2011). Due to the adverse effects of climate change and anthropogenic pressure on the local economies, the Sahelian countries have launched the Great Green Wall project to combat desertification and rehabilitate degraded soils. The Great Green Wall, or Great Green Wall Initiative for the Sahara and Sahel, is developed by the African Union to address the adverse socio-economic and environmental effects of land degradation and desertification in the Sahara and Sahel (Dia and Duponnois, 2017). Before its implementation, programmes such as the Senegal-German project and the Autonomous Pastoralist Project in the Ferlo (PAPF) were carried out in the Ferlo (Sahelian part of Senegal) to combat desertification and improve the living conditions of local populations. In support of these programmes, numerous studies have been carried out to gain a better understanding of the characteristics of Sahelian ecosystems. These works provided a good understanding of the processes behind the establishment of herbaceous settlements (Grouzis et al., 1986; Cissé, 1986 and Carrière, 1989), their water (Cornet, 1981) and trophic (De Vries and Djiteye, 1982; Breman & De Ridder, 1991) determinism, as well as pasture production models (Hiernaux, 1984). The study carried out within the framework of the autonomous pastoralist project in the Ferlo (PAPF) between 1995 and 2008 gave us a good understanding of the influence of protection on the herbaceous layer, notably through the results provided by Miehe (1998). However, the conclusions of this project are drawn with caution. Hence, this study's initiated to provide new knowledge on the role of protection on Widou's grassland stand to update or reinforce the results of the PAPF. It contributed to give some information useful for the management of the Great Sahelian Green Wall. The study was conducted in Widou Thiengoly in three sites, namely the 2013 plot, the 2009 plot and the communal grazing area or off plot. The general objective was to describe the variation in floristic parameters under different protection conditions. Specifically, it was first all necessary to establish the floristic composition in each study site and then to evaluate the soil cover by grasses and finally to assess vertical stratification of the herbaceous layer in both sites.

2 | MATERIALS AND METHODS

2.1 | Study area

2.1.1 | Geographical location

Located 15° 20 N` latitude and 16° 21 W longitude, Widou Thiengoly is in the western part of the northern Ferlo (Akpo, Gaston, & Grouzis, 1995). Ferlo (Sahelian part of Senegal) extends from the Senegal River valley to the fringes of the groundnut basin over more than 60 000 km^2 (Wane et al., 2006). Administratively, Widou is located in the Louga region, in the department of Linguère, more precisely in the municipality of Tessékéré (Figure 1).

2.1.2 | Climate

Widou's climate is typically Sahelian with two alternating seasons (Figure 2), a rainy and a dry season (Ndiaye et al., 2013). The rainy season lasts between two to three months, most often between July, August and September (Figure 2). The annual rainfall varies between 200- and 400-mm/year with a high irregularly in time and space (Akpo et al., 1995). These authors reported a coefficient of variation of the annual rainfall between 30% and 40%. The dry season extends over eight to nine months (October to June) and is characterised by the absence of the herbaceous stratum around March. The lowest temperatures in the zone are recorded during December, January and February and are around 19°C and 21°C. While March, April, May and June are the hottest months with temperatures fluctuating between 40°C and 43°C; the air humidity reaches its maximum in August/September with 74% and its minimum in February/March with 31%. The average monthly evaporation is 401 mm/year in May and 104 mm/year in September (Diallo, Faye, Ndiaye, & Guisse, 2011).

2.1.3 | Geomorphologic characteristics

Widou belongs to the sandy Ferlo, which is an integral part of the dune formations of the Senegal-Mauritanian basin (Bakhoum, 2013). The succession of these formations makes it possible to distinguish most often three types of primary dunes: the Ogolian system or red dunes oriented NE-SW, which is the orientation of the central continental winds and the Harmattan; the Ogolian dunes of NNE-SW

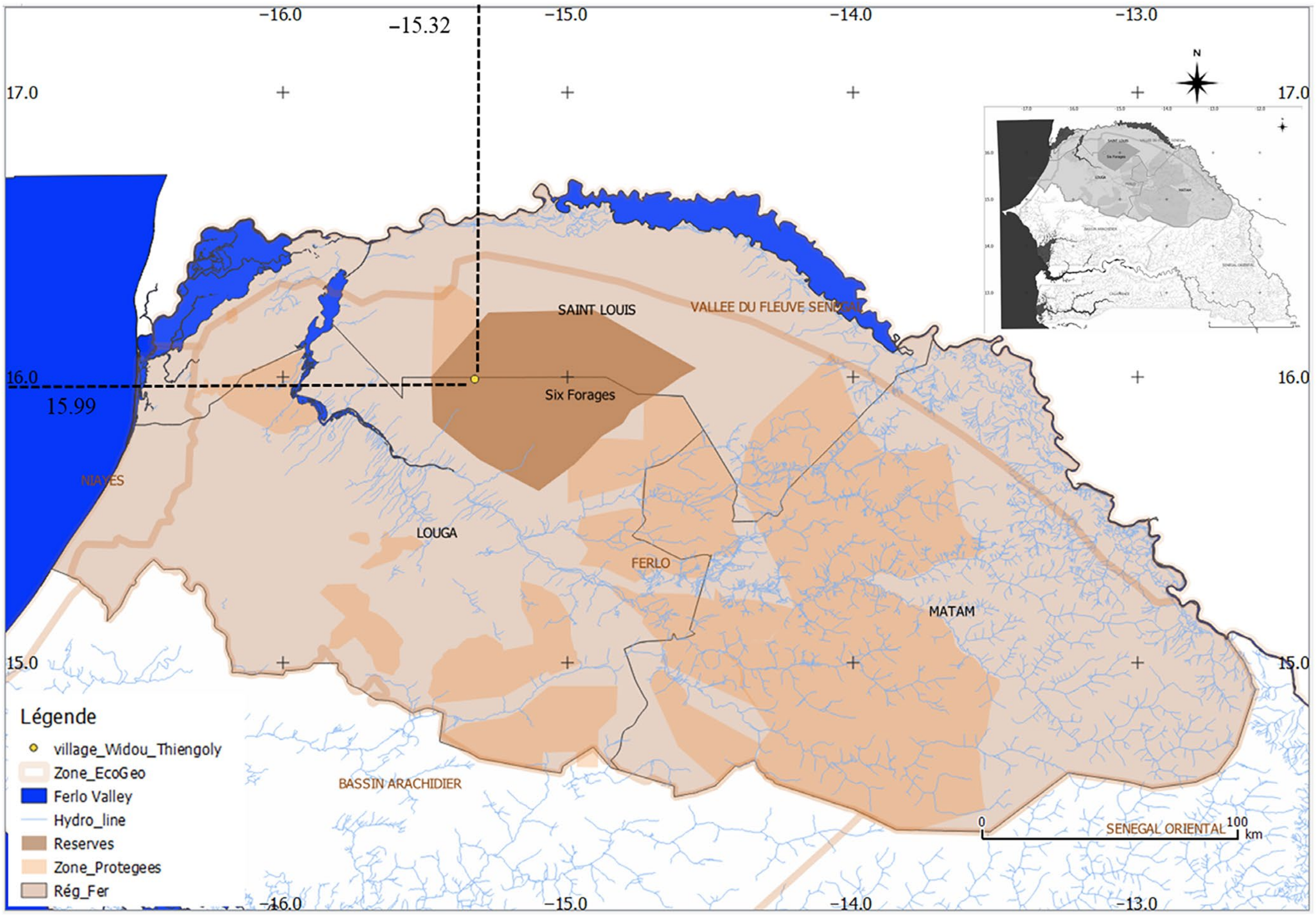

FIGURE 1 Geographical situation and location of Widou Thiengoly

orientation, also called transverse dunes, are separated by clayey longitudinal depressions with temporary waterlogging (lowlands) and the recent erg which presents three reliefs units (depressions or lowlands, slopes and peaks or mounds).

The nature of the soils differs depending on whether one is on a dune top or a downslope (Diouf, 2003). Lowlands have higher clay content than dune tops. According to Bakhoum (2013), three soil units are observed in Widou. These are the ferruginous tropical soils that may or may not leach out, the ferruginous subarid red-brown isohumic soils and an association of the two first units.

2.1.4 | Vegetation

The study area is located in the thorny steppe domain, where pterophytes and phanerophytes predominate. Adaptation to the severity of climatic conditions explains the prevalence of these biological types in the area (Akpo et al., 1995). Towards October and September, at the end of the rainy season, the vegetation of Ferlo takes the form of a continuous herbaceous carpet strewn of trees and shrubs. The woody vegetation is characterised by a majority of woody plants such as *Balanites aegyptiaca*, *Calotropis procera* and *Boscia senegalensis* (Sagna, 2015). The herbaceous stratum is dominated by annual species, including grasses (*poaceae*) with narrow, folded or coiled blades (*Schoenefeldia gracilis*, *Aristida mutabilis*, *Cenchrus biflorus*, *Chloris barbata*) (Diallo, 2011). Legumes (*Zornia glochidiata*, *Alysicarpus ovalifolius*) with other families (Bakhoum, 2013) can also be found in the region. This vegetation distribution is characteristic of a pseudo-steppe.

2.2 | Methods

2.2.1 | Plot choice and floristic data collection

The present work was carried out at three sites in October 2015; this time of year, when the grassland flora is still present, coincides with the end of the rainy season (Figure 3). The level of protection is one of the parameters that motivated the choice of sites. The 2013 plot (site A) is reforested and fenced and benefits from integral protection. The concept of integral protection resides in the fact that a custodian is assigned to this plot. The 2009 plot (site B) is also reforested and fenced. However, since it has no security guard, its fence is breached in places to allow animal access, giving this site the status of semi-protected plot. The third site which is the community pastures that do not benefit from any protection is given the status

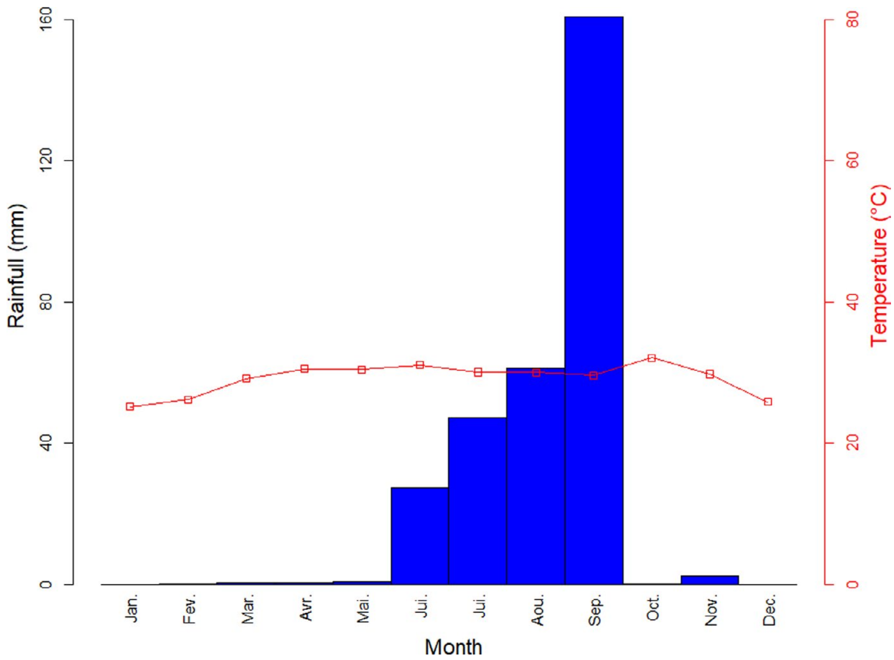

FIGURE 2 Widou Thiengoly's average rainfall and temperature from 2015 to 2019

of off plot (site C). This site C acts as a control to enable interpreting the results obtained in the first two sites.

The vegetation surveys were carried out using the 'double meter' method suggested by Daget and Poissonnet (1971). This method, described in length by (Daget and Poissonnet, 1969, 2010), is an adaptation of the 'quadrat point' method developed in New Zealand by Levy and Madden in 1933. The method consists of identifying species located at 100 points regularly arranged along a 10 m line (a line marked by a Penta decametre) in the vegetation to be studied. The method was chosen since it best suits the Sahelian herbaceous formations with an average height that is greater than 25 cm, but lower than 1m. Its use in the field consists of defining a 10 m line with a tape measure that is tightly stretched over the plant canopy and secured by two stakes at both ends (Figure 4). All along this line and for every 10 cm, a more or less fine needle graduated in decimetres is projected vertically into the herbaceous vegetation. The reading consists of counting all species in contact with the stem and the number of contacts of each species along the graduated portions of the needle. The main disadvantage of this method, like all needle methods, is that the needles used in quadrat observations are sometimes very thin.

Five lines of readings were randomly installed at each site. The choice of 5 lines per site, instead of the generally applied 3 lines, was guided by the precaution of accurately estimating their composition (Onana, Mvondo Awono, Abba, & Ottou, 2008). The information obtained was recorded in a card where 500 reading points were reserved for each species on the 10 m portion.

2.2.2 | Data processing

The data from the field were processed with Excel spreadsheet and R studio 1.2.5001.exe software. Using the R software, we carried out a correspondence factorial analysis (CFA) of the species collected as well as their hierarchical classification. With excel, we processed the data and calculated the following concepts.

The specific frequency of presence at the point (SPF) is the percentage of points where the species was encountered. It also indicates the ground cover (Daget and Poissononnet, 2010).

$$\text{SFP}\% = \frac{\text{ni} * 100}{N}$$

ni: number of points where the species (i) is present. *N*: total number of reading points

Specific contribution presence (SCP) corresponds to the ratio of the specific frequency of a species to the sum of the specific frequencies of all species. It expresses the relative importance of species at different periods and is similar to the index of abundance dominance (Ngom, Bakhoum, Diatta, & Akpo, 2012).

$$\text{SCP}\% = \frac{\text{FSPi} \times 100}{\sum \text{FSPi}}$$

SFPi: species (i) - specific frequency

The contact-specific contribution (CSC) expresses the ratio between the number of contacts of a species and the sum of contacts of all species (expressed as a percentage). This CSC is used to represent the vertical structure (pyramid) of the vegetation of the species of which it is composed (Daget and Poissonnet, 2010).

$$\text{CSCi} = \frac{\text{Ci} \times 100}{\text{Cn}}$$

Ci: number the species contacts (i); Cn: number of all species contacts.

Species are identified directly in the field based on the flowering plants of tropical Africa (Lebrun & Stork, 1991, 1992, 1995, 1997), the vascular plants of Senegal (Lebrun, 1973) and the flora

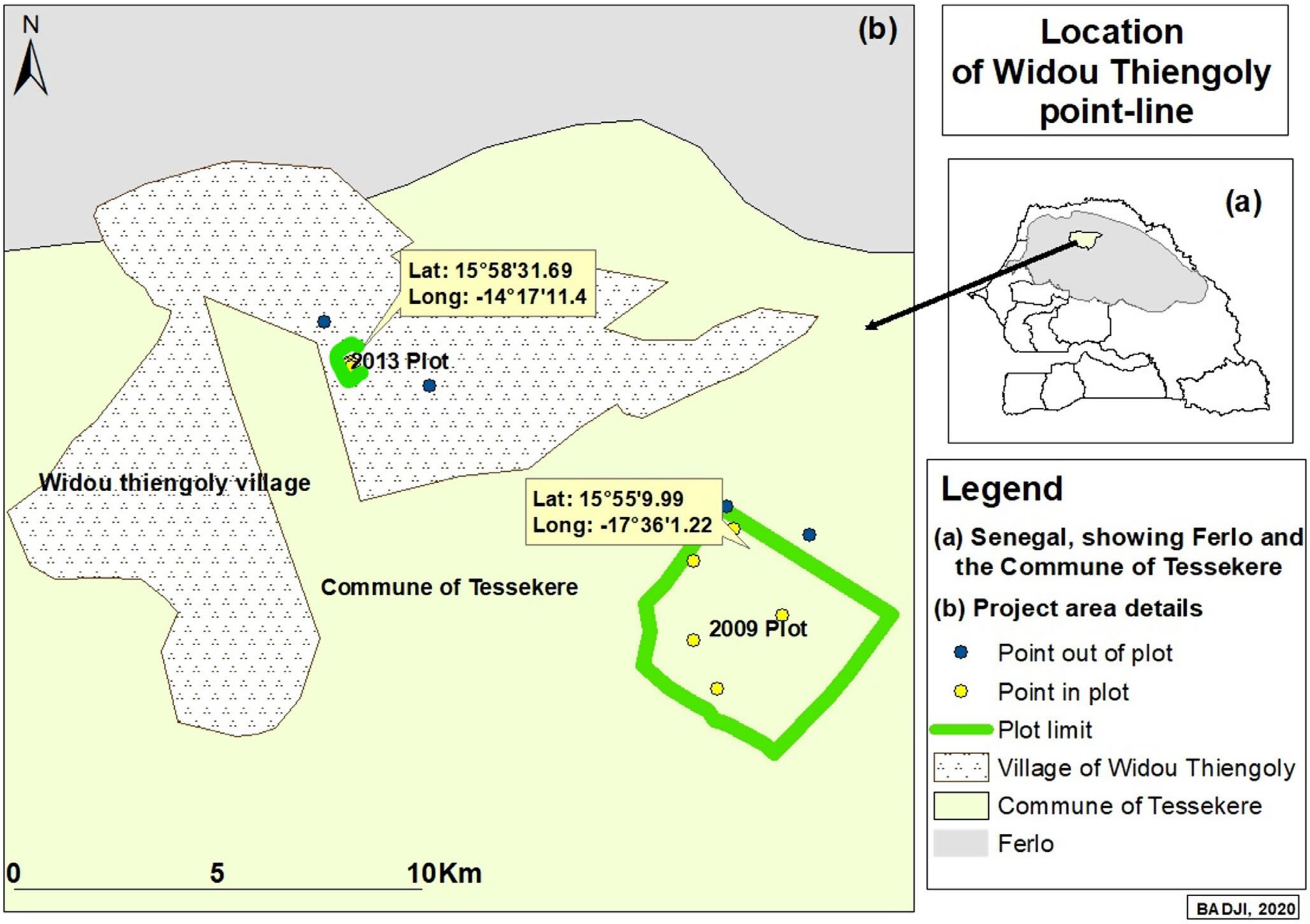

FIGURE 3 Location map of the study sites in the Widou station

FIGURE 4 Representation of the permanent line in the field

of Senegal (Berhaut, 1967). Species not identified in the field were put into an herbarium and transported to the laboratory of plants ecology of Cheikh Anta Diop University at Dakar, where they were recognised.

3 | RESULTS

3.1 | Analysis of the floristic composition of herbaceous plants

The grassland flora recorded at Widou on all sites in October 2015 comprised 45 species (Table 1). They belong to 34 genera, ascribed to 17 botanical families, and their distributing frequency varied according to the plot considered. The best-represented genera were *Ipomea*, *Phyllanthus*, and *Brachiaria*, which each contain three *species*. This group of 3 genera was followed by a second group of genera such as *Achyranthes*, *Aristida*, *Corchorus*, *Eragrostis* and *Indigofera*, which includes two species. The other genera were each composed of a single species. The *Poaceae* family (17 species and 13 genera) was the most represented with 37.8% of the flora recorded, followed by the Fabaceae family with 5 species and 4 genera, representing 11.11% of the species. On site level, the grassland at the site A contained 28 species grouped to 25 genera and 14 families. *Eragrostis*, *Brachiaria*, *Ipomea* and *Phyllanthus* were the best-represented genera in the plot, each with 2 species. *Enteropogon prieurii*, *Indigofero hirsuta* and *Cyperus esculentus* were the dominant species in the

TABLE 1 absence (–) or presence (+) according the site of species recorded at Widou in October 2015

Family	Species	2013 Plot	2009 Plot	Off Plot	Family	Species	2013 Plot	2009 Plot	Off Plot
Aizoaceae	*Gisekia pharnancioides*	+	+	–	*Poaceae*	*Aristida adscensionis*	–	+	+
Amaranthaceae	*Achiranthes argentea*	–	+	–		*Aristida mutabilis*	+	+	+
	Achiranthes aspera.	+	–	–		*Brachiaria lata*	–	+	+
Amaryllidaceae	*Pancratium tranthum*	–	+	–		*Brachiaria orthostakys*	+	–	–
Capparidaceae	*Cleome viscosa L.*	–	+	+		*Brachiaria ramosa*	+	+	+
Commelinaceae	*Commelina forskalaei*	–	+	–		*Cenchrus biflorus*	+	+	+
Convolvulaceae	*Ipomeae coptica*	+	–	–		*Chloris barbata*	+	+	+
	Ipomeae Kotschyana	–	+	–		*Dactyloctenium aegyptium*	+	+	+
	Ipomeae triloba	+	–	–		*Digitaria horizontalis*	+	+	+
Cucurbitaceae	*Momordica charantia*	+	–	–		*Dinebra retroflexa*	–	–	+
Cyperaceae	*Abilgardia hispudula*	–	–	+		*Diplachne fusca*	–	+	+
	Cyperus esculentus	+	–	+		*Enteropogon prieurii*	+	+	+
Euphorbiaceae	*Phyllanthus maderapatensis*	–	+	+		*Eraragrostis ciliaris*	+	+	+
	Phyllanthus niruri	+	–	–		*Eragrostis tremula*	+	+	+
	Phyllanthus pentandrus	–	+	+		*Pennisetum violaceum*	–	+	–
Fabaceae	*Aysicarpus ovalifolius*	+	+	+		*Schoenefeldia gracilis*	+	+	+
	Indigofera aspera	–	+	–		*Tripogon minimus*	+	+	+
	Indigofera hirsuta L.	+	+	+	*Portulacaceae*	*Portulaca oleracea*	+	–	+
	Tephrosia purpurea	–	+	–	*Rubiaceae*	*Oldenlandia corymbosa*		–	+
	Zornia glochidiata	+	+	+		*Spermacoce ruelliae*	+	–	+
Nyctaginaceae	*Boerhavia erecta.*	+	+	+	*Tiliaceae*	*Corchorus aestuans*	–	+	+
	Rogeria adenophyllia	+	–	–		*Corchorus tridens*	+	+	+
					Tribulaceae	*Tribulus terrestris*	+	+	–

TABLE 2 Value of the dimensions used to represent the CFA

	Dimension 1	Dimension 2
True value	0.292	0.060
Inertia (%)	83.034	16.966
cumulated %	83.034	100

Abberivation: CFA, Correspondence factor analysis.

canopy. In the site B, the herbaceous stratum included 31 species distributed in 25 genera and 11 families. The most abundant genera were *Phyllanthus*, *Indigofera*, *Aristida*, *Brachiaria*, *Eragrostis* and *Corchorus* and had 2 species. The herbaceous flora in the off plot was composed of 29 species distributed in 24 genera and 9 families. The dominated genera were *Phyllanthus*, *Aristida*, *Brachiaria*, *Eragrostis* and *Corchorus* and comprised 2 species each. In the site B and the site C, the dominant species of the canopy were *Enteropogon prieurii*, *Indigofero hirsuta*, *Dactyloctenium aegyptium* and *Schoenefeldia wgracilis*.

A correspondence factor analysis (CFA) was performed based on the specific contributions of the species presence (Table 2). The projection of the herbaceous species recorded in the Widou station on the factorial plane is given in Figure 5. The two axes explain 100% of the information provided by the CFA. Figure 5 illustrates the distribution of species recorded at the Widou station according to their specific contribution to the three study sites. Species contribution is higher when the colour goes from blue to red. The distribution shows that *A. ovalifolius*, *I. hirsute*,

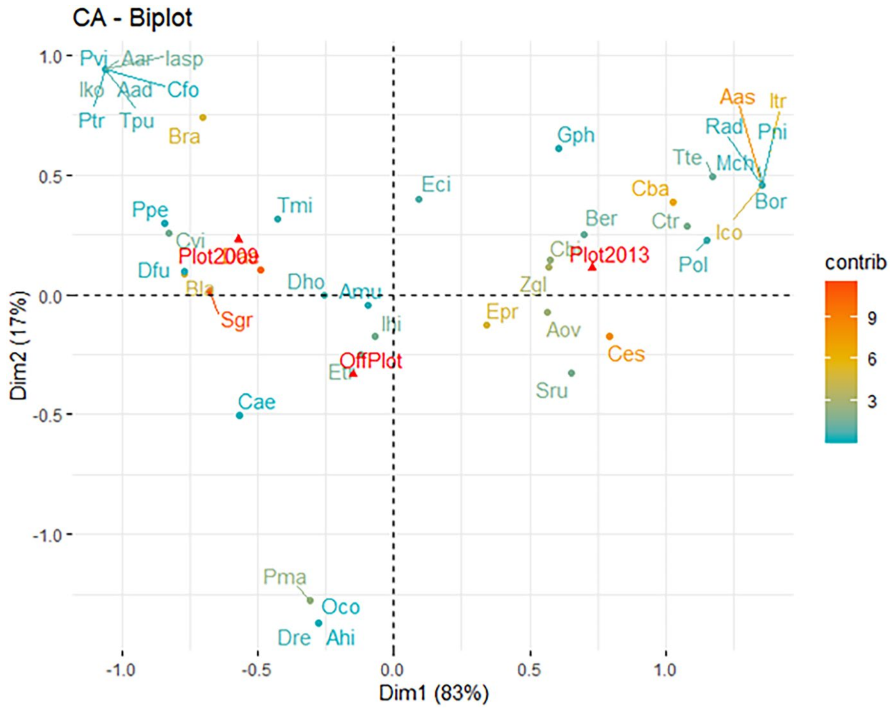

FIGURE 5 Distribution of species in the three study sites according to their specific contribution presence. Gph = *Gisekia pharnancioides;* Aar = *Achiranthes argentea;* Aas = *Achiranthes aspera;* Ptr = *Pancratium trianthum;* Cvi = *Cleome viscosa;* Cfo = *Commelina forskalaei;* Ico = *Ipomeae coptica;* Iko = *Ipomeae Kotschyana;* Itr = *Ipomeae triloba;* Mch = *Momordica charantia;* Ahi = *Abilgardia hispudula;* Ces = *Cyperus esculentus;* Pma = *Phyllanthus maderapatensis;* Pni = *Phyllanthus niruri;* Ppe = *Phyllanthus pentandrus;* Aov = *Alysicarpus ovalifolius;* Iasp = *Indigofera aspera;* Ihi = *Indigofera hirsuta;* Tpe = *Tephrosia purpurea;* Zgl = *Zornia glochidiata;* Ber = *Boerhavia erecta.*; Rad = *Rogeria adenophyllia;* Aad = *Aristida adscensionis;* Amu = *Aristida mutabilis;* Bla = *Brachiaria lata;* Bor = *Brachiaria orthostakys;* Bra = *Brachiaria ramosa;* Cbi = *Cenchrus biflorus;* Cba = *Chloris barbata;* Dae = *Dactyloctenium aegyptium;* Dho = *Digitaria horizontalis;* Dre = *Dinebra retroflexa;* Dfu = *Diplachne fusca;* Epr = *Enteropogon prieurii;* Eci = *Eragrostis ciliaris;* Etr = *Eragrostis tremula;* Pvi = *Pennisetum violaceum;* Sgr = *Schoenefeldia gracilis;* Tmi = *Tripogon minimus;* Pol = *Portulaca oleracea;* Oco = *Oldenlandia corymbosa;* Sru = *Spermacoce ruelliae;* Cae = *Corchorus aestuans;* Ctr = *Corchorus tridens;* Tte = *Tribulus terrestris*

Z. glochidiata, *B. erecta*, *A. mutabilis*, *B. ramose*, *C. biflorus*, *C. barbata*, *D. aegyptium*, *D. horizontalis*, *E. prieurii*, *E. ciliaris*, *E. tremula*, *S. gracilis*, *T. minimus* and *C. tridens* are common to the three study sites. *C. viscosa*, *P. maderaspatensis*, *P. pentandrus*, *B. lata*, *D. fusca* and *C. aestuans* were found in the site B and the site C. *G. pharnancioide* and *T. terrestris* were common between the site A and the site B, while *C. esculentes*, *P. oleracea* and *S. ruelliae* were present in both site A and site C. The species linked by arrows around a point on the figure are those that are site-specific. Thus, *M. charantia*, *B. orthostachys*, *R. adenophylla*, *P. niruri*, *I. coptica*, *I. triloba*, and *A. aspera* were specific to plot 2013 (site A). Species specific to site B are *P. violaceum*, *A. argentea*, *C. forskalae*, *I. aspera*, *T. purpurea*, *A. adscensionis*, *I. kotschyana* and *P. trianthum*, while those solely identified of the site C are *A. hispidula*, *O. corymbosa* and *D. retroflexa*.

Figure 6 classified the species based on their distribution in the three study sites, highlighting 4 clusters in Figure or groups of species. The group 1 or Cluster 1 contains species which were specific to the site B and those highly presented in the plot composition to the two other sites. It includes 16 species, among which we can mention *S. gracilis*, *D. aegyptium*, *B. ramosa*, *I. aspera*, *T. purpurea*, *C. forskalae*, etc. These species include eight grasses, precisely 47.06% of the *Poaceae* recorded in the station and 2 *Fabaceae* with 40% of legumes. The group 2 contained 5 species found in the site C and in the site B. Among these 5 species, *A. hispidula*, *D. retroflexa and O. corymbosa* were only present in the site C, while *P. maderapatensis* and *C. aestuans* appeared in both the site B and site C where they were more frequent. Group 3 consisted of 12 species with nearly similar specific contributions in at least two sites. This group can be subdivided into 4 subgroups. The first subgroup comprised *D. horizontalis*, *A. mutabilis*, *I. hirsute* and *E. tremula* which were relatively homogeneously distributed in the three study sites. The second subgroup contains *C. esculentes*, *S. ruelliiae*, *E. prieurii* and *A. ovalifolius* mostly observed in the site A and site C although the last two species also appeared in the site B. The third subgroup is composed of the 3 species *Z. glochidiata*, *B. erecta* and *C. biflorus* more widespread in the site A but also present in the other study sites. The fourth and last subgroup contains only one species (*E. ciliaris*) recorded in the study sites but no longer observed in the site A and site B. The cluster 3 included 6 *Poaceae* representing 35.29% of the grasses in the herbaceous stand recorded in Widou. Group 4 harboured 12 species, some of which were only observed in the site A (*Momordica charantia*, *Brachiaria orthostakys*, *Rogeria adenophylla*, *Phyllanthus niruri*, *Ipomea triloba*,

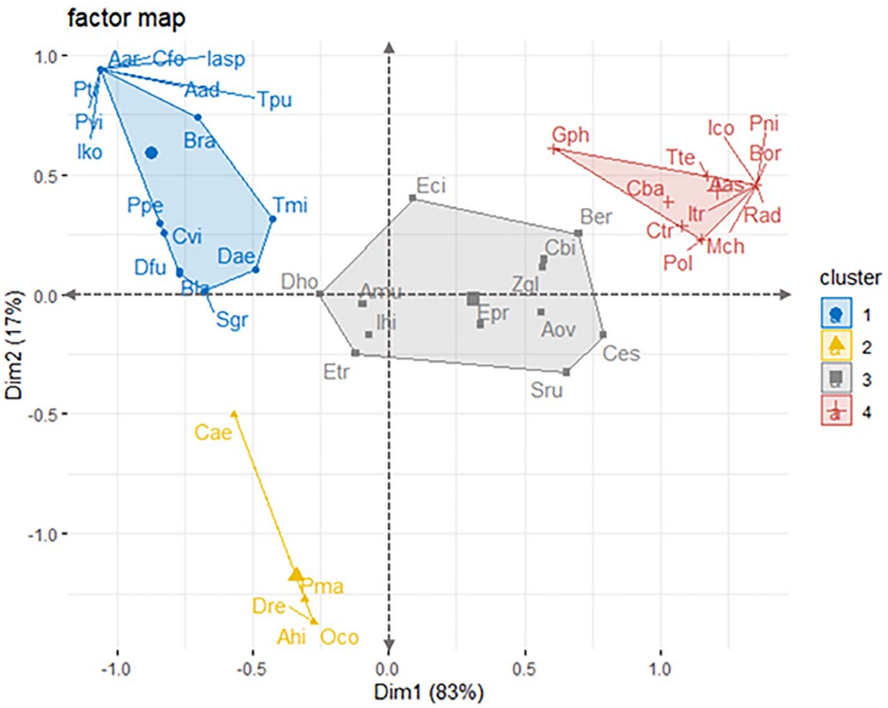

FIGURE 6 Factor classification of species found in Widou. Gph = *Gisekia pharnancioides;* Aar = *Achiranthes argentea;* Aas = *Achiranthes aspera;* Ptr = *Pancratium trianthum;* Cvi = *Cleome viscosa;* Cfo = *Commelina forskalaei;* Ico = *Ipomeae coptica;* Iko = *Ipomeae Kotschyana;* Itr = *Ipomeae triloba;* Mch = *Momordica charantia;* Ahi = *Abilgardia hispudula;* Ces = *Cyperus esculentus;* Pma = *Phyllanthus maderapatensis;* Pni = *Phyllanthus niruri;* Ppe = *Phyllanthus pentandrus;* Aov = *Alysicarpus ovalifolius;* Iasp = *Indigofera aspera;* Ihi = *Indigofera hirsuta;* Tpe = *Tephrosia purpurea;* Zgl = *Zornia glochidiata;* Ber = *Boerhavia erecta.;* Rad = *Rogeria adenophyllia;* Aad = *Aristida adscensionis;* Amu = *Aristida mutabilis;* Bla = *Brachiaria lata;* Bor = *Brachiaria orthostakys;* Bra = *Brachiaria ramosa;* Cbi = *Cenchrus biflorus;* Cba = *Chloris barbata;* Dae = *Dactyloctenium aegyptium;* Dho = *Digitaria horizontalis;* Dre = *Dinebra retroflexa;* Dfu = *Diplachne fusca;* Epr = *Enteropogon prieurii;* Eci = *Eragrostis ciliaris;* Etr = *Eragrostis tremula;* Pvi = *Pennisetum violaceum;* Sgr = *Schoenefeldia gracilis;* Tmi = *Tripogon minimus;* Pol = *Portulaca oleracea;* Oco = *Oldenlandia corymbosa;* Sru = *Spermacoce ruelliae;* Cae = *Corchorus aestuans;* Ctr = *Corchorus tridens;* Tte = *Tribulus terrestris*

TABLE 3 Frequencies, specific compositions and overall coverage of the herbs met in Widou and by site

	(mean) Frequencies (%)	Overall recovery (%)	(mean) SPC (%)
Settlement	7.73	98.47	2.22
Plot 2013	12.32	99.80	3.57
Plot 2009	10.02	98.80	3.22
Off plot	13.37	96.80	3.45

Abberivation: SPC, Specific Presence Contribution.

Achyranthes aspera and *Ipomea coptica*) and others were observed in the 3 sites, but with a higher contribution in the site A (*Tribilus terrestris*, *Chloris barbata*, *Corchorus tridens*, *Portulaca oleracea* and *Gisekia pharnancioides*).

In sum, the results reported in Figure 6 show that of the 45 species recorded at Widou, the species in group 1 thrive best in semi-protected conditions (plot 2009); those in cluster 2 thrive best in site C where no protection was established; while cluster 4 includes species that thrive best in protected environments (site A).

On the other hand, group 3 species do not have a preferred environment; they can develop normally regardless of the level of protection of the plot.

3.2 | Frequencies, specific contributions and recovery

The frequencies, recoveries and specific contributions of species are reported in Table 3.

The specific frequencies, recoveries, as well as specific contributions (SCP) are very similar regardless of the site. However, there is some variability in the specific contributions depending on the protection status of the site. In the site A, species that contributed most were *E.prieurii* (18.28%), *I. hirsuta* (12.61%), *C. esculentus* (8.44%), *A. mutabilis* (6.71%), %) and *Z. glochidiata* (5.96%). The best contribution within the site B was from *D. aegyptium* (22.86%), *S. gracilis* (15.07%), *I. hirsuta* (14.04%), *A. mutabilis* (8.43%) and *E. prieurii* (6.89%). This plot also contained more leguminous plants. In the site C, the dominant species were *I. hirsuta* SCP = 19.17%; *E. prieurii* SCP = 14.49%; *D. aegyptium* SCP = 14.49%; *S. gracilis* SCP = 10.37%;

and *E. tremula* SCP = 9.95%. These are the same as those in the site B except for *Aristida mutabilis*.

3.3 | Vertical structure of the herbaceous stratum

We assessed the vertical stratification of the different grass formations with the help of pyramids built from the Specific Contact Contributions (SCC) of all the grasslands surveyed (Figure 7).

The vertical structure of the herbaceous stratum is given in Figure 7a. It showed that the herbaceous canopy is more pronounced between the lower (0–20 cm for 39.83% of contacts) and intermediate strata (20–50 cm for 48.63% of contacts). These strata polarised more than 88% of all contacts. Nevertheless, it can also be seen that the grass cover reaches 1.20 m in height due to the presence of some individuals of *E. prieurii*, *C. biflorus* and *S. gracilis*, which grow over 50 cm (11.54% of the contacts).

Figure 7b shows the vertical structure of grassland within the site A. It is similar to that which stands with the most contact observed in the intermediate (50.98% of contacts) and lower strata (40.38% of contacts). In site A, the grass height did not reach 100 cm. The vertical physiognomy of the herbaceous layer in site A was influenced by medium-sized species such as *I. hirsuta* (maximum height 50 cm), *C. esculentus* (40 cm), but also by higher species such as *E. prieurii* (maximum height 90 cm).

In the site B, the vertical structure of the grassland showed in Figure 7c. In this plot, we find the lowest percentage of contact between 0 cm and 20 cm (i.e. 35.06% of contacts). The structure of the pyramid shows that the vegetation is relatively high with the highest number of contacts recorded between 20 cm and 50 cm (i.e. 54.5%

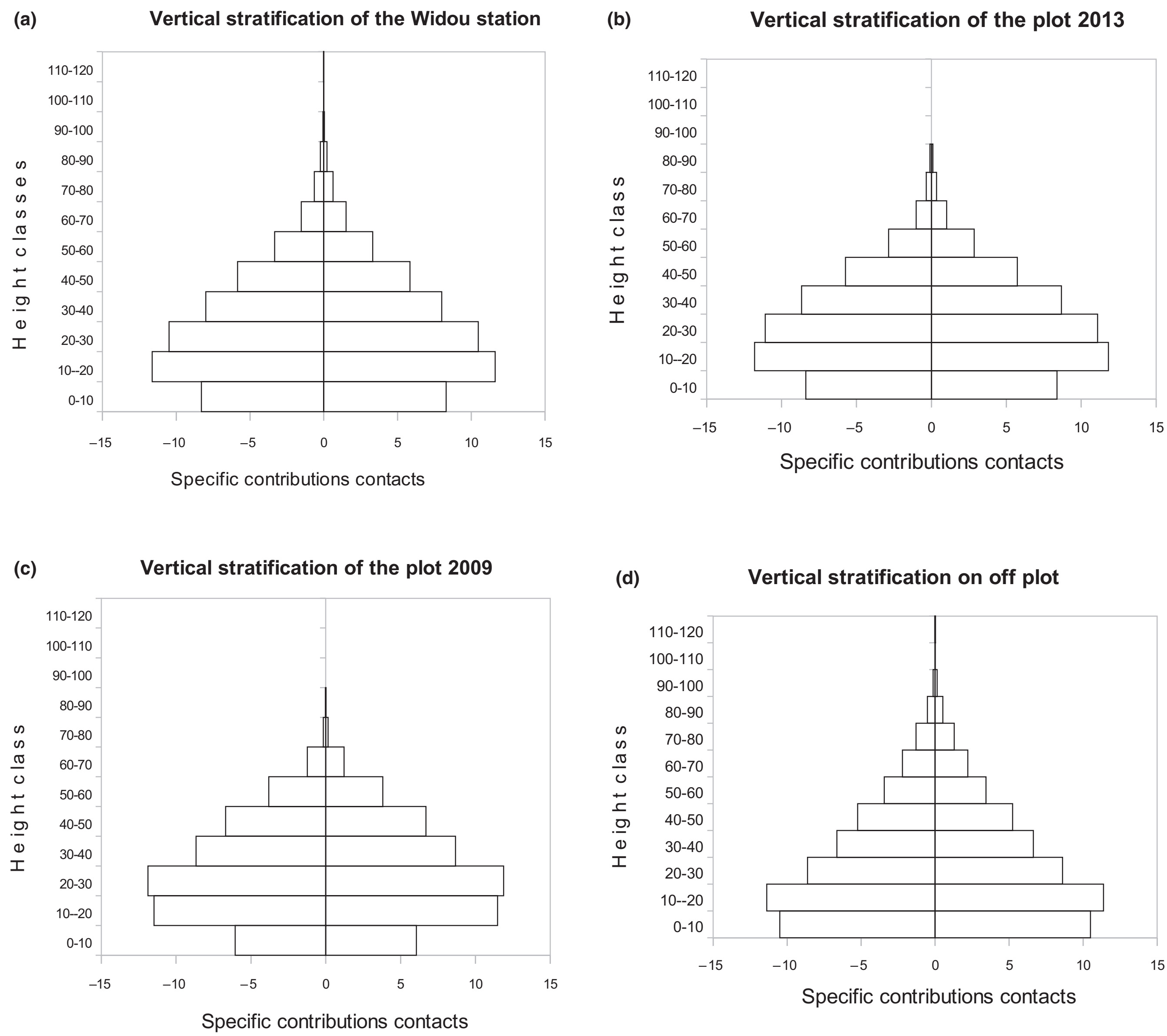

FIGURE 7 Vertical stratification of the herbaceous stratum of the Widou stand (a), plot 2013 (b), plot 2009 (c) and off plot (d)

of). However, as in the site A, the height of the tallest individuals of the site does not reach 1 m.

Figure 7d illustrated the vertical structure of the grasslands in site C. The herbaceous cover in the community grazing is similar to that of the other sites with little species. The site C has a slightly higher more at the lower level (43.76% of contacts) compared to the intermediate level (40.97% of contacts). In site C, the percentage of contacts from the upper strata is higher (15.27% of contacts). The elevation of the pyramid above 1 m is due to the presence of some individuals, such as *S. gracilis*, whose height reached 120 cm.

Overall, the intermediate strata were the most developed in all the three sites except in the site C which had many small grasses.

4 | DISCUSSION

This floristic survey was conducted in Widou in October 2015, tagging the end of the rainy season when the land cover is still present. We identified 45 species from the 3 study sites that clustered into 34 genera and 17 families. These results were close to the 53 species reported by Bakhoum (2013) in the same station in June and September 2011. However, the composition of the grasslands varied according to the study site. Site A contained 28 species, site B had 31 species, and site C harboured 29 species. This distribution indicated a nonsignificant difference in terms of species number between the three sites. Other parameters, such as the specific frequency and the overlap, were also similar. They were 99.80%, 98.80% and 96.80% in site A, site B and site C, respectively. This result seems to indicate that the protection does not have a significant effect on these grass cover parameters during the year 2015. These results could be explained by this year's good rainfall regime (323 mm). Indeed, one of the conclusions of the PAPF would be that herbaceous production is primarily determined by the rainfall regime of the year regardless of the grazing regime (Hiernaux, 2006). However, we found some variability in the specific contributions depending on the protection status of the site. In addition to the *Poaceae* and *Fabaceae* that dominated the site A, other families or species such as *C. esculentus*, *A. aspera* and the *Ipomea* were also present. The *Poaceae* and *Fabaceae* dominated the other study sites. In site B, the *Poaceae* alone contributed to 78.06%, while in the site C, it contributed to 66.58%. This result shows that the protection contributes significantly to balancing the abundance of the different species in the stand. The total absence of protection seems to be advantageous for the development of some species or families in place of others. Such a result can be explained by the fact that defensive measures would favour the development of species that are more sensitive to trampling by cattle, but also shade species such as *Achyranthes* (Diatta & Faye, 1996). For Grouzis (1992), cattle grazing can affect the seeds and flora, which are selectively consumed before maturation and dissemination of seeds, thus reducing their reproductive potential. Thébaud et al. (1995) suggested that good rainfall leads to a heterogeneity of the herbaceous stratum with a balanced combination of grasses and legumes in closed or controlled grazing areas. Whereas outdoors, the herbaceous cover is more homogeneous and is more abundant in drought-resistant pioneer grasses (Bechir & Mopate, 2015). However, unprotected areas are poorer in fodder legumes such as *Z. glochidiata*. These observations of Thiébaud et al. (1995) are entirely consistent with those of Hiernaux (2006), who stated that forage grazing would favour grasses and some well-prepared drought-resistant legumes such as *Sch. gracilis*, *D. aegyptium*, *A. mutabilis*, *A. ovalifolius and B. ramosa*. They also promote homogeneity and stabilised herbaceous vegetation.

The predominance of *Poaceae* in this study could be explained by the fact that the species belonging to this family are resistant to different disturbances, developing a strategy that allows them to maintain and grow in a disturbed environment (Ousseina, Fortina, Marichatou, & Yenikoye, 2013). Moreover, *Poaceae* taxa are known to have a very high possibility of regrowth and are found in all surveys (Diallo, 2015). Previous works (Akpo, Banoin, & Grouzis, 2003; Cornet, 1981; Grouzis, 1992) revealed that annual grasses largely dominated the herbaceous vegetation of the Sudano-Sahelian savannahs. Our result is consistent with that of Kiema (2006), who also noted a prevalence of *Poaceae* in a study conducted in Burkina Faso.

Other observations showed that the vertical structure of the grass cover was more developed in the intermediate strata at all study sites except in the off plot where the grasses were small. Furthermore, the accumulation of straw due to the absence of grazing would hinder the growth of these grasses (Cissé, 1986), which could explain the absence of grasses over 1 metre in the site A. The absence of tall grasses in site A could also be due to the specific balance that the protection brings by favouring the development of other small species. In site B and especially in the community pastures, the high percentage of contact in the lower strata was mostly the result of juvenile grazing of seedlings and trampling by cattle. Grazing during the growing season directly affects the growth of the grazed plants (Hiernaux & Le Houérou, 2006).

5 | CONCLUSION

This study evaluating the influence of the protection on the structure of the grasses layer following the installation of the Great Green Wall (GGW) at Ferlo has proved to be instructive. Indeed, protection level seemed to have no noticeable effect on parameters such as coverage, specific frequency and number of species. However, analysis of the specific contributions enabled us to identify some disparities according to the protection level. Of the 45 species at the station, 12 were indifferent to protection status as they had relatively similar specific contributions, while 16 flourished best in semi-protected conditions, 12 in enclosed areas, and 5 in the site C. In the perimeters under grazing influence, the *Poaceae* mostly dominates the herbaceous layer, contrasting with site A where, although grasses dominate, the development of other species or families such as *C. esculentus*, *A. aspera* and *Ipomoea* was noted. These observations indicate that the protection contributes significantly to balancing the abundance of the species or families in the stand. The absence of protection seems to benefit the development of some species or families to the detriment of other species. The vertical structure of grasslands was most developed in the intermediate strata at all study sites except in the site C where the grasses were short. In protected areas, grass growth was more influenced by the accumulation of straw over the seasons. In contrast, in areas accessible to cattle, vertical canopy structure was influenced by the grazing regime. Thus, in the context of integrated land management programmers (pastoral use of reforestation plots), protection and partial protection seem appropriate to ensure that the animal gets maximum benefit of the herbaceous vegetation.

ACKNOWLEDGEMENTS

Our thanks go out very sincerely to UMI 3189 'Environnement, Santé, Sociétés' (UCAD, CNRS, CNRST, USTTB, UGB), the Labex DRIIHM, 'Investissements d'avenir' programme ANR-11-LABX-0010 and the OHIM Tessekere (UCAD, CNRS), for the financial support, without which this work could not be materialised.

CONFLICT OF INTEREST

The authors have declared that no competing interests exist.

DATA AVAILABILITY STATEMENT

The results presented are from studies carried out in the Ferlo, in the Sahelian zone of Senegal. They are more particularly from the Great Green Wall, which corresponds to a pan-African reforestation project. It is a 24-page manuscript, containing 7 figures and 3 tables as illustrations. I would like to point out that the results are original and are not subject to any conflict. The data are available.

ORCID

Aly Diallo https://orcid.org/0000-0001-7567-3187
Mariama Dalanda Diallo https://orcid.org/0000-0003-2239-5843

REFERENCES

Akpo, L. E. (1990). *Dynamique des systèmes écologiques sahéliens: structure spécifique, productivité et qualité des herbages le forage de widu thiengoly*. DEA Biologie Végétale, FST/UCAD, 65 p.

Akpo, L. E., Banoin, M., & Grouzis, M. (2003). Effet de l'arbre sur la production et la qualité fourragères de la végétation herbacée : Bilan pastoral en milieu sahélien. *Revue de Médecine Vétérinaire*, *154*(10), 619–628.

Akpo, L. E., Gaston, A., & Grouzis, M. (1995). *Structure spécifique d'une végétation sahélienne. Cas de Wiidu Thiengoli (Ferlo, Sénégal). Bull. Mus. natl. Hist. nat.*, Paris, 4ème sér., 17, section B, Adansonia, nos 1-2: 39-52.

Bakhoum, A. (2013). *Dynamique des ressources fourragères: indicateur de résilience des parcours communautaires de Tessékéré au Ferlo, (nord-Sénégal)*. Thèse 3eme cycle FST/UCAD 118 p.

Bechir, A. B., & Mopate, L. Y. (2015). Analyse de la dynamique des pâturages autour des ouvrages hydrauliques des zones pastorales du Batha Ouest au Tchad. *Revue, Afrique SCIENCE*, *11*(1), 212–226.

Berhaut, J. (1967). *Flore du Sénégal*. (éd.). Clairafrique, Dakar, 485 p.

Breman, H., & De Ridder, N. (1991). *Manuel sur les pâturages des pays sahéliens*. DLO - Centre de Recherches Agrobiologiques (CABO-DLO) Ed. KARTHALA, ACCT, CABO DLO et CTA, ISBN : 2-86537-339-8 569 p.

Carrière, M. (1989). *Les communautés végétales sahéliennes en Mauritanie (Région de Kaedi); analyse de la reconstitution annuelle du couvert herbacé*. Thèse doctorat sciences, université de Paris-Sud, Orsay, 238 p.

Cissé, A. M. (1986). *Dynamique de la strate herbacée des pâturages de la zone sahélienne* (p. 211). Agronomique, Wageningen: Thèse, Univ.

Cornet, A. (1981). *Le bilan hydrique et son rôle dans la production de la strate herbacée de quelques phytocénoses sahéliennes au Sénégal*. Thèse de Docteur-Ingénieur, Université des Sciences et Techniques du Languedoc, Montpellier, 354 p.

Daget, P., & Poissonet, J. (2010). *Prairies et pâturages : Méthodes d'étude de terrain et interprétations*. Doc. CNRS/CIRAD 955 p.

Daget, P., & Poissonet, P. (1969). *Etude comparée de diverses méthodes d'analyse de la végétation des formations herbacées denses et permanentes* (p. 120). Montpellier: C.E.P.E.- CNRS.

Dia, A., & Duponnois, R. (2017). *La Grande Muraille Verte - Jachères et production fourragère*. (éd.). IRD Editions, http://books.openedition.org/irdeditions/3322. 46 p.

Diallo, A. (2011). *Caractérisation de la végétation et des sols dans les plantations d'Acacia senegal (l.) Wild dans la zone de Dahra - sud Ferlo sableux*. Thèse doctorat de 3eme cycle Univ. Cheikh Anta Diop 118 p.

Diallo, A., Faye, M. N., Ndiaye, O., & Guisse, A. (2011). Variations de la composition de la végétation herbacée des plantations d'Acacia senegal (l.) Wild de la zone de Dahra (Ferlo). *International Journal of Biological and Chemical Sciences*, *5*(3), 1250–1264.

Diallo, M. D., Ndiaye, O., Diallo, A., Saleh, M. M., Bassene, C., Wood, S. A., … Guissé, A. (2015). Influence de la litière foliaire de cinq espèces végétales tropicales sur la diversité floristique des herbacées dans la zone du Ferlo (Senegal). *International Journal of Biological and Chemical Sciences*, *9*(2), 803–814.

Diatta, M., & Faye, E. H. (1996). *Effet de quelques années de protection sur la jachère en zone sahélo soudanienne du Sénégal: Structure et production primaire*. In *Floret* : 33-41.

Diouf, M. (2003). *Caractéristiques fondamentales de la feuillaison d'une espèce ligneuse sahélienne: Acacia tortilis (forsk.) hayne. Variations selon les microsites topographiques au Ferlo (nord Sénégal)*. Thèse de doctorat de 3eme cycle Univ. Cheikh Anta Diop 104 p.

Grouzis, M. (1992). *Germination et établissement des plantes annuelles sahéliennes*. ACTIQUES/ORSTOM Éditions 16 p.

Hiernaux, P. H. Y. (1984). *Bilan d'une saison des pluies 1984 très déficitaire dans le Gourma (sahel malien)*. 1ère campagne de suivi et télédétection expérimentale. CIPEA, Doc. Prog. AZ 140, Bamako.

Hiernaux, P. (2006). *Le suivi écologique de Widou Thiengoly : Un patrimoine scientifique à développer et valoriser*. Doc. Ministère Environnement et Protection de la Nature Direction Eaux & Forêts, Chasses et Conservation des Sols Projet Autopromotion Pastorale dans le Ferlo 47 p.

Hiernaux, P., & Le Houérou, H. N. (2006). *Les parcours du Sahel*. *Revue Sécheresse*. vol. 17, n° 1-2.

Kiema, A. (2006). *Régénération des pâturages naturels en région sahélienne par le labour et l'ensemencement d'*alysicarpus ovalifolius. *Revue Cahiers Agricultures*. vol. 15, n° 5, septembre-octobre. 8 p.

Lebrun, J. P. (1973). *Enumération des plantes vasculaires du Sénégal*. Maisons-Alfort, IEMVT, ét. Bot., 2, 209 p.

Lebrun, J. P., & Stork, A. L. (1991). *Enumération des plantes à fleurs d'Afrique tropicale: volume I*. Conservatoire du jardin botanique de Genève, 249 p.

Lebrun, J. P., & Stork, A. L. (1992). *Enumération des plantes à fleurs d'Afrique tropicale: volume II*. Conservatoire du jardin botanique de Genève, 257 p.

Lebrun, J. P., & Stork, A. L. (1995). *Enumération des plantes à fleurs d'Afrique tropicale: volume III*. Conservatoire du jardin botanique de Genève, 341 p.

Lebrun, J. P., & Stork, A. L. (1997). *Enumération des plantes à fleurs d'Afrique tropicale: volume IV*. Conservatoire du jardin botanique de Genève, 712 p.

Levy, E. B., & Madden E. A., (1933). The point method for pasture analysis. *New Zealand Journal of Agriculture*, *46*, 267–279.

Miehe, S. (1998). *Inventaire et suivi de la végétation dans le périmètre expérimental à Widou Thiengoly dans le cadre du Projet Sénégalo-Allemand d'autopromotion pastorale dans le Ferlo (PAPF)* (p. 49). Saint-Louis (Sénégal), G.T.Z.

Ndiaye, O., Diallo, A., Sagna, M. B., & Guissé, A. (2013). *« Diversité floristique des peuplements ligneux du Ferlo, Sénégal »*, VertigO - la revue électronique en sciences de l'environnement [En ligne], Volume 13 Numéro 3 | décembre 2013, mis en ligne le 24 janvier 2014, consulté le 03 février 2014. URL : http://vertigo.revues.org/14352; DOI : 10.4000/vertigo.14352.

Ngom, D., Bakhoum, A., Diatta, S., & Akpo, L. E. (2012). Qualité pastorale des ressources herbagères de la réserve de biosphère du Ferlo (Nord-Sénégal). Revue. *International Journal of Biological and Chemical Sciences*, *6*(1), 186–201. https://doi.org/10.4314/ijbcs.v6i1.17

Onana, J., Mvondo Awono, J. P., Abba, D., & Ottou, J. F. B. (2008). Application de la méthode des points quadrats au suivi de la dynamique des pâturages soudano-sahéliens du Cameroun. Revue. *International Journal of Biological and Chemical Sciences*, *2*(2), 224–229. https://doi.org/10.4314/ijbcs.v2i2.39741

Ousseina, S., Fortina, R., Marichatou, H., & Yenikoye, A. (2013). Dynamique du peuplement herbacé de la station sahélienne expérimentale de Toukounous (filingué – Niger). *International Journal of Biological and Chemical Sciences*, *7*(2), 657–671. https://doi.org/10.4314/ijbcs.v7i2.22

Penning De Vries, F. W. T., & Djiteye, M. A. (1982). *La productivité des pâturages sahéliens. Une étude des sols, végétations et de l'exploitation de cette ressource naturelle* (p. 525 p.). Wageningen: Centre for Agricultural Publishing and Documentation.

Sagna, M. B. (2015). *Ethnobotanique, écologie, suivis phénologique et caractérisation physico-chimiques et nutritionnelles du dattier du désert (Balanites aegyptiaca (L.) Del) dans le Ferlo du Sénégal*. Thèse doctorat de 3eme cycle d'écologie végétale et d'agroforesterie Univ. Cheikh Anta Diop 133p.

Thébaud, B., Grell, H., & Miehe, S. (1995). *Vers une reconnaissance de l'efficacité pastorale traditionnelle : les leçons d'une expérience de pâturage contrôlé dans le nord du Sénégal*. Programme zones arides de International Institute for Environment and Development (IIED) dossier n°5. 39 p.

Wane, A., Ancey, V., & Grosdidier, B. (2006). *Les unités pastorales du Sahel sénégalais, outils de gestion de l'élevage et des espaces pastoraux : Projet durable ou projet de développement durable ?* Document Développement durable et territoires, Dossier 8 | 2006; URL: http://developpementdurable.revues.org/3292 DOI : 10.4000/développement durable.3292 ISSN : 1772-9971. ISSN : 1772-9971.

How to cite this article: Badji ES, Diallo A, Sagna MB, et al. Protection influence on grassland structure in Widou Thiengoly's grazing areas at Ferlo. *Afr J Ecol*. 2020;00:1–12. https://doi.org/10.1111/aje.12790