Exclosure area decreases the spread of the invasive plant Senna obtusifolia (L.) and enhances forage value of Sahelian rangelands

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Exclosure area decreases the spread of the invasive plant *Senna obtusifolia (L.)* and enhances forage value of Sahelian rangelands

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Abstract

Background: Sahelian rangelands constitute the main source of livestock feeding but are continuously degrading due to the climate change and human pressures. This degradation has led particularly to the invasion of rangelands by the less palatable plant species called *Senna obtusifolia*. This study aimed to restore the degraded Sahelian rangelands through grazing exclusion on herbaceous vegetation initially invaded by *Senna obtusifolia*.

Methods: Plant species composition, species diversity, aboveground biomass, density, height, and cover rate of the herbaceous vegetation were monitored across plots with different invasion levels over four consecutive years. Pastoral value was assessed using an index of specific quality of each species of the herbaceous vegetation.

Results: We found that aboveground biomass, plant cover, and species diversity of companion species decreased significantly ($P < 0.05$) with the levels of *Senna obtusifolia* invasion. During the monitoring period, aboveground biomass, density and height of the invasive plant *Senna obtusifolia* progressively decreased in the fenced plots. In contrast, similar floristic attributes of the companion species increased (88%). Indeed, species with low or no pastoral value were significantly ($P < 0.05$) less abundant than those with medium and high pastoral value throughout the four years monitoring time.

Conclusions: Our findings highlight how exclosure simultaneously contributes to restore the herbaceous vegetation of Sahelian rangelands while controlling the proliferation of *Senna obtusifolia*. Sahelian rangeland management systems that include at least four years of exclosure before opening to grazing are an effective solution to control the spread of the less palatable and plant invasive species *Senna obtusifolia.*

Keywords: Aboveground biomass; Exclosure; Pastoral value; Rangeland degradation; *Senna obtusifolia;* Diversity

Introduction

In the West African Sahelian zone, animal husbandry involves a large proportion of the population, provides families with substantial foreign currency, and is one of the main economic activities (Ayantunde et al. 2020; Banerjee et al. 2022; Ilboudo et al. 2025). Livestock production systems are 87 per cent extensive (FAO 2019) and derive most of their feed from forage resources (Koutchoro et al. 2025), mostly from natural rangelands (UICN 2015; Bambara et al. 2024). These forage resources are included in the provisioning ecosystem services (Puydarrieux and Devaux 2013; Balay et al. 2015) generated by other services such as regulation services (decomposition, water purification, erosion and flood control, carbon storage, and climate regulation…). Unfortunately, we are still faced with the continuing degradation of these rangelands (Aboh et al. 2012; Hiernaux et al. 2016) due to a combination of factors, including climate change and human activities, that play a major role (Zampaligre et al. 2013; Hamann et al. 2021). Degradation is a transition from a functional natural habitat to an undesirable state, including reduced biodiversity and ecosystem services (Ombega et al. 2017; Schreiner et al. 2024). Currently, the areas set aside for livestock farming are suffering from a lack of effective management and are therefore increasingly degraded. This degradation has led to a reduction in forage, constraining livestock to overgraze (Ayantunde et al. 2011; Gebreyesus 2017). As a result, rangelands are unable to regenerate properly, leading to the proliferation of less palatable and unplatable invasive plant species (Zare et al. 2022a; Requena-Mullor et al. 2023). Invasive plant species are reported to be one of the main causes of biodiversity loss, as they disrupt the establishment of native species and have an impact on their structure and composition (Pearson et al. 2018; Brazeiro et al. 2024), hinder the restoration of natural habitats (D'Antonio and Meyerson 2002; Campoe et al. 2010). Consequently, they lead to extinctions and compromising both biodiversity conservation and human well-being (Zare et al. 2022b; Świerszcz et al. 2024). *S. obtusifolia* belongings to the Fabaceae family is one of the herbaceous species with low forage value (Kiema et al. 2012) most commonly found in Sahelian rangelands (Kadeba et al. 2015, Zerbo et al. 2016). Its invasion leads to a reduction in biological diversity and forage quality (Gebrekiros and Tessema 2018; Ouedraogo et al. 2021). Indeed, *S. obtusifolia* has become a rangelands invader and can outcompete grass species, crowding out grazing animals and creating unproductive monocultures on semi-arid rangelands (Palmer and Pullen 2001; Gebreyesus 2017). The invasion of this species has reached such a critical level that it is essential to propose effective solutions. In this regard, the methods typically used to control invasive plants include cultural, mechanical, biological, and chemical approaches (Cai and Gu 2016; Chaves et al. 2020). Due to its accessibility and lower cost, the use of chemical herbicides remains the most widely used of all these methods (Kettenring and Adams 2011), despite the collateral consequences for human health and soil quality (Jabran et al. *2015*; Nicolopoulou-Stamati et al. 2016; Chauvel 2019). Certainly, some herbicides can effectively control invasive plants (Espeland et al. 2017). However, some of these plants have developed resistance to the action of other chemical molecules (Jabran et al. 2015, Meuller-Steover et al. 2016). Furthermore, using herbicides in restoration raises concerns about direct and indirect effects on non-invasive plants (Van Bruggen et al. 2018). To solve this problem, alternative methods to control invasive plants in rangeland need to be investigated. That would be sustainable for both the environment and husbandry. Field observations show that *S.*

obtusifolia is less invasive in less degraded areas. This is the case in protected areas found in some locations in the Sahel where a high diversity of herbaceous species occurs. Abebe et al. (2006) confirmed that species diversity is higher in Area Exclosure (AE) than in degraded rangeland. Area Exclosure (AE) were defined as areas that are closed to grazing and human activities for a certain period through appropriate barriers, e.g. fencing, to promote the restoration of vegetation (Isaksson et al. 2007; Birhane et al. 2017; Teketay et al. 2018; Gautschi et al. 2024). They are also applied to areas where activity involves the exclusion of undesirable species or practices from degraded sites (Yanoff and Muldavin 2008; Aerts et al.2009). The use of exclosure as a traditional method of managing and rehabilitating degraded land has been mentioned by several authors (Tesfay et al. 2020; Cao et al. 2021; Solomon et al. 2022; Mengistu et al. 2023; Mengist et al. 2025). However, despite several studies on biological invasion, relatively little is known about the current status of invasive plant species in restoration sites worldwide (Weidlich et al. 2020). The objectives of this study were therefore to (1) assess the effect of duration of protection on the composition and floristic dynamics of the local community vegetation; (2) to assess the competitiveness of *S. obtusifolia* on field; (3) to restore forage quality of the degraded rangelands invaded by *S. obtusifolia*.

We assumed that Exclosure reduces the spread of *S. obtusifolia* while enhancing rangeland forage quality. *S. obtusifolia* exhibits lower performance compared to companion species. While previous greenhouse experiments have shown that *S. obtusifolia* has not been competitive (Zare et al. 2022b), field-based assessments are necessary to validate these findings.

Methodology

Study area

The study was carried out in the Sahelian zone of Burkina Faso, specifically in the protected area of the commune of Dori in the northern part of the country (Figure 1). This area exclosure

(AE) fenced off with stakes and wire mesh covering 207.4 ha (UICN 2017) was created in 2017 on a former overgrazed site that had gradually become invaded by *S. obtusifolia.* The main surrounding villages are Bafélé (Dori sector 8), and Djomga.The area is characterized by a dry tropical climate with a humid season from June to September and a dry season from October to May The annual average rainfall recorded varies from 400 mm to 600 mm when annual average temperature is 29.8°C (Kissou et al. 2018). Over the four years of monitoring (from 2020 to 2023), rainfall averaged 605.4 ± 150 mm, in line with the normal average for the region. Temperatures varied less, with a minimum average of 22.9°C and a maximum average of 37.1°C (table 1). The vegetation is characterized by 21.6% shrub-steppe and 78.4% grass steppe. The soils are hydromorphic, iso-humic, gravelly, sodic and contain iron sesquioxide (PCD 2015). The commune's production systems are characterized by the coexistence of agro-pastoral activities (UICN 2017). Fulani are the majority local socio-cultural group (MEF 2008) and most of them are livestock farmers (Ouedraogo et al. 2021).

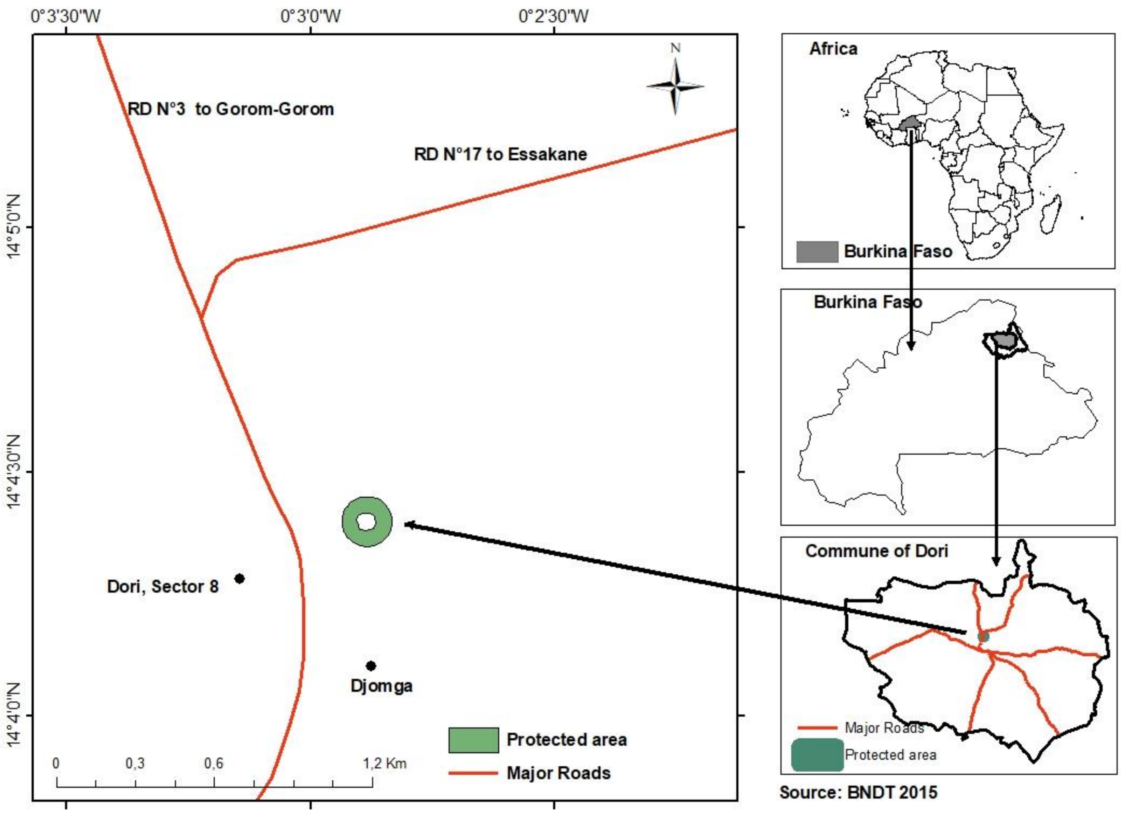

Figure 1: Mape of study area and site location

Herbaceous vegetation sampling

Data on the biomass, density and height of *S. obtusifolia* and the biomass of companion species were collected in the protected area over four consecutive years in 40 permanent plots of 100 m^2 (10 m x 10 m). Each plot representing a certain level of *S. obtusifolia* invasion, was marked with four white-painted iron stakes and the GPS coordinates were recorded. Three sub-plots of 1 m^2 size were settled in the plot. In total of 120 sub-plots (3 sub-plots x 4 levels of *S. obtusifolia* invasion x 10 replicates) were sampled. The stratified inventory method, oriented toward the presence of the species, was adopted and based on the invasion levels of *S. obtusifolia* which are as follows:

-non-invaded levels or level T with 0% cover of *S. obtusifolia* meaning this invasive species is absent in the plot;

-lightly invaded levels or level A with 5 to 30% cover of *S. obtusifolia* corresponding to the step from contamination/introduction to the beginning of establishment, but *S. obtusifolia* always remains subordinate to other species in the plot;

-intermediate invaded levels or level B with 30 to 60% cover of *S. obtusifolia* corresponding to the step when the invasive plant is dominant in the plot;

-high invaded levels or level C with *S. obtusifolia* cover exceeding 60% in the plot corresponding is reached when the invasive plant is completely abundant or even monospecific.

In permanent plots, herbaceous species were listed and each assigned to an abundance-dominance coefficient according to the Braun-Blanquet (1982) scale. Within each plot, three (03) sub-plots of 1 m^2 size were set up to count the density, measure the height and clip the above-ground biomass of *S. obtusifolia* and of the other herbaceous species called also companion species. *S. obtusifolia* was separated from the other herbaceous plants and the fresh weight of each pile was determined using a 50 kg ± 10 g precision electronic spring balance. A

100 g sample was taken from each pile using a 5 kg ± 1 g precision electronic balance. These herbaceous samples were firstly dried on the site and then in the laboratory in an oven for 72 hours at 75°C to obtain a constant dry weight, and finally used to determine the dry biomass. On field, the non-determined plant species were pressed, dried and brought at lab for identification in the herbarium of the University Joseph KI-ZERBO.

Pastoral value

The pastoral value of the rangelands was assessed using the forage spectrum of the herbaceous vegetation. According to Daget and Poissonet. (2010), pastoral value is a synthetic index characterizing grazed vegetation and accounts for the species composition of the rangeland and the Index of specific quality of species. In this study, pastoral value was evaluated through the proportions of the different categories of forage species (Akpo et al. 2000). Based on the literature, each herbaceous species inventoried was assigned an Index of specific quality. This value reflects the zootechnical interest, i.e. the bromatological value of each herbaceous species (Daget and Poissonet 2010). It places species in relation to one another, from the least to the most palatable, on arbitrary scales. These scales include four classes ranging from 0 to 3 (Akpo et al. 2000, 2002); Ngom et al. 2012). Class 0 refers to species with No Pastoral Value (NPV), class 1 to species with Low Pastoral Value (LPV), class 2 to species with Medium Pastoral Value (MPV), and class 3 to species with High Pastoral Value (HPV). These different groups of NPV, LPV, MPV, and HPV species constitute the fodder species categories (Akpo et al. 2002). Herbaceous species cover rate in the same category of forage species was then determined.

Data analysis

Based on the vascular plant catalogue of Burkina Faso (Thiombiano et al. 2012), the floristic diversity of the herbaceous stratum from protected area was assessed by compiling a list of plant species, genus and families. Within family diversity, relative diversity of family (RDF) was calculated for each family on the basis of the four years of monitoring using following equation. RDF = (number of species in a family / total number of species) × 100

Analyses of variance (ANOVA) were used to test the effect of duration of protection on biomass, density and height of *S. obtusifolia* and on the biomass of other species in the herbaceous stratum at the 5% level using R software version 4.1.0. The Shapiro-Wilk normality test indicated that the vegetation taxonomic richness data were not normally distributed. Consequently, the non-parametric Kruskal-Wallis's test was used. Species richness, Shannon diversity, Simpson diversity index, Piélou equitability and Sørensen similarity were calculated using Pc-ord 6.0.4 software. Species richness (S) is the number of species that were inventoried in a specific area (plot). To quantify the heterogeneity of the specific diversity of an environment, the Shannon Diversity Index (H) is used. In general, H ranges on average from 0 to 5 bits. High values reflect species richness and therefore favourable environmental conditions. The Simpson Diversity Index (D) can be used to measure biodiversity within a population or community. The index takes into account both the number of different species (richness) and their relative abundance (evenness). With this index, 0 represents lower diversity and 1, high diversity. Piélou equity (E) represents the equal distribution of all individuals present per species. The index varies from 0 to 1 and indicates a regular distribution of individuals between species with values close to 1 and the dominance of one species or a small number of species with values close to 0. The Sørensen similarity index allowed to compare the floristic similarity in the herbaceous vegetation layer between the four years of monitoring. The formula for calculating the increase in the diversity of herbaceous species based on species richness is often derived from ecological diversity indices. One of the most commonly used measures is Shannon's Diversity Index (H), which incorporates both species richness and evenness (Shannon,1948).

Shannon Index (H)

$$H = -\sum_{i=1}^{s} Pi \ln Pi$$

Where:

S= total number of species (species richness)

pi = proportion of individuals belonging to the i- species

Percentage Change in Diversity:

Increase (%) = (H after – H before / H before) ×100

To identify the most dominant plant species, the importance value index (IVI) of each species was calculated according to the level of invasion in each study area. It was calculated from the sum of relative frequency and relative dominance, which were obtained using the following formulae:

$$\text{Frequency} = \frac{\text{Number of plots where the species appears}}{\text{Total number of plots}} x100$$

$$\text{Relative frequency} = \frac{\text{Frequency of a species}}{\text{Sum of all species frequencies}} x100$$

$$\text{Relative dominance} = \frac{\text{Total cover rate of a species}}{\text{Sum of total cover rate of all species}} x\ 100$$

Importance value index = Relative Frequency + Relative Dominance

Species with an importance value index greater than 5 (IVI ≥ 5) are considered dominant herbaceous species (Zerbo et al. 2016).

Results

Interannual change in floristic composition under the exclosure experiment

A total of 128 species belonging to 37 families and 80 genera were recorded during the four monitoring years (Table 1). Poaceae (40%) followed by Fabaceae (22%) were dominant families (Figure 2). Indeed, Species richness increased with the length of land protection from

67 species for year 1 to 100 species for year 4 (Table 1). The same trend was found for genera and families.

Table 1: Taxonomic richness of herbaceous vegetation

Monitoring years	Species richness	Genus	Family
Global	128	80	37
Year1	67	47	18
Year 2	82	55	21
Year 3	96	63	24
Year 4	100	70	27

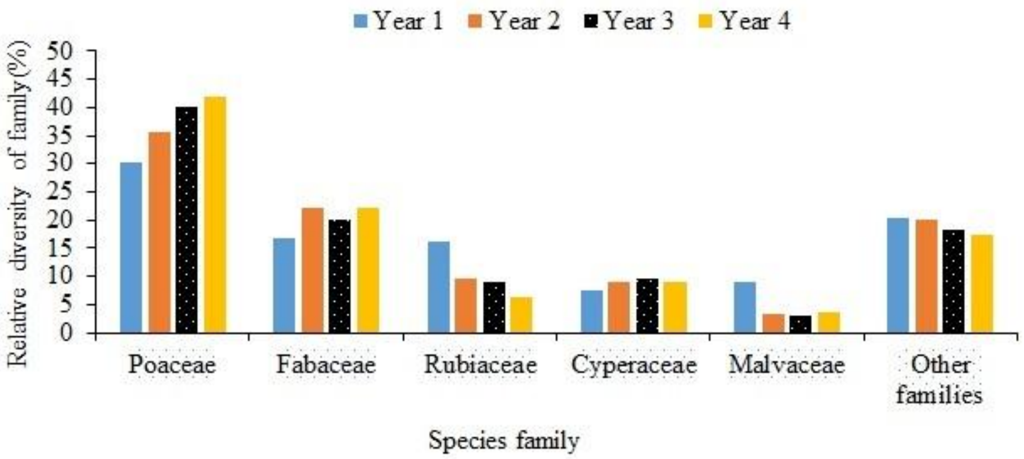

Figure 2: Relative diversity of families along the four monitoring years

Dynamic of the diversity and floristic similarity in herbaceous vegetation along monitoring years

During the four consecutive monitoring years, a significant variation ($P < 0.05$) was found in the mean species richness per plot, the Shannon diversity index, the Piélou fairness and the Simpson index. The low diversities were recorded in the first three years while the last year was found to be more diversified (15.32 ± 4.63 %). Shannon's diversity index varied in a similar direction with the species richness and reached 2.27 ± 0.34 for year 4 (Table 2). Percentage change in diversity is 88%. We found the same increasing trend for the Piélou and Simpson indices (Table 2). The species composition of the herbaceous vegetation varied during the four consecutive monitoring years. The Sørensen index showed a floristic dissimilarity between the vegetation of the four monitoring years (Table 3).

Table 2: Alpha diversity index (Mean ± Standard deviation)

	Year1	Year2	Year3	Year 4	F	P
S	7.85 ±3.85a	8.17± 3.54a	10.27 ± 3.81a	15.32 ± 4.63b	30.11	< 0.001
H	1.39 ± 0.49a	1.56 ± 0.41a	1.78 ± 0.31a	2.27 ± 0.34b	36.86	< 0.001
E	0.70 ± 0.16a	0.78 ± 0.11b	0.79 ± 0.05b	0.84 ± 0.06b	12.27	< 0.001
D	0.64 ± 0.18a	0.73 ± 0.11b	0.78 ± 0.07b	0.86 ± 0.07c	24.85	< 0.001

Levels not connected by the same letter are statistically different. S: species richness index; H: Shannon diversity index; E: Pileou equitability index; D: Simpson diversity index; F: Fisher's value; F-value; P: p-value or probability at the 0.05 significance level.

Table 3: Similarity between floristic composition of herbaceous vegetation according to Sørensen's index values

Years	Year1	Year2	Year3	Year4
Year1	1			
Year2	0.3973	1		
Year3	0.2279	0.4361	1	
Year4	0.1597	0.267	0.4559	1

Effects of the protection on *S. obtusifolia* density, height and biomass and on biomass of companion species

The duration of protection had a significant effect ($p < 0.05$) on the density, height and biomass of *S. obtusifolia* and also on the biomass of companion species.

In fact, density and height of *S. obtusifolia* decreased with the duration of protection. The same is true of its biomass, which has declined significantly over time whereas the biomass of companion species increased significantly (Table 4).

Table 4: Changes in density, height, biomass of *S. obtusifolia* and biomass of companion species from year1 to year 4

	Year1	Year 2	Year 3	Year 4	F	P
Density of *S. obtusifolia* ($Ind.ha^{-1}.10^4$)	80.23 ± 70.98^a	43.13 ± 34.07^b	25.70. ±25.08^c	12.72 ± 6.51^c	44.66	0.0001
Heigh of *S. obtusifolia* (cm)	103 ± 24.67^a	84.61 ± 20.36^b	76.08 ± 21.15^c	63.67 ±18.62^d	54.02	0.0001
Biomass of *S. obtusifolia* ($t. ha^{-1}$)	2.30 ± 1.61^a	1.25 ± 0.86^b	0.704 ±5.2^c	0.46 ± 0.36^c	64.44	0.0001
Biomass of other species ($t. ha^{-1}$)	1.17± 0.69^a	2.0 ± 0.93^b	2.66 ± 1.11^c	3.46 ± 1.3 1^d	79.36	0.0001

Levels not connected by the same letter are statistically different.

$Ind.ha^{-1}\cdot10^4$: individuals per hectar.10^4; cm: centimeter; $t. ha^{-1}$: tonne per hectar

Effects of protection on the biomass of *S. obtusifolia* and its companion species is measured and compared based on the level of invasion from year 1 to year 4

The duration of protection had a significant effect ($p < 0.05$) on *S. obtusifolia* invasion. There was a gradual decline in the above-ground biomass of *S. obtusifolia* in lightly, moderate and heavily invaded levels. In contrast, the biomass of other species of herbaceous vegetation increased in the four invasion levels. The control plot had no contamination over time (figure 3)

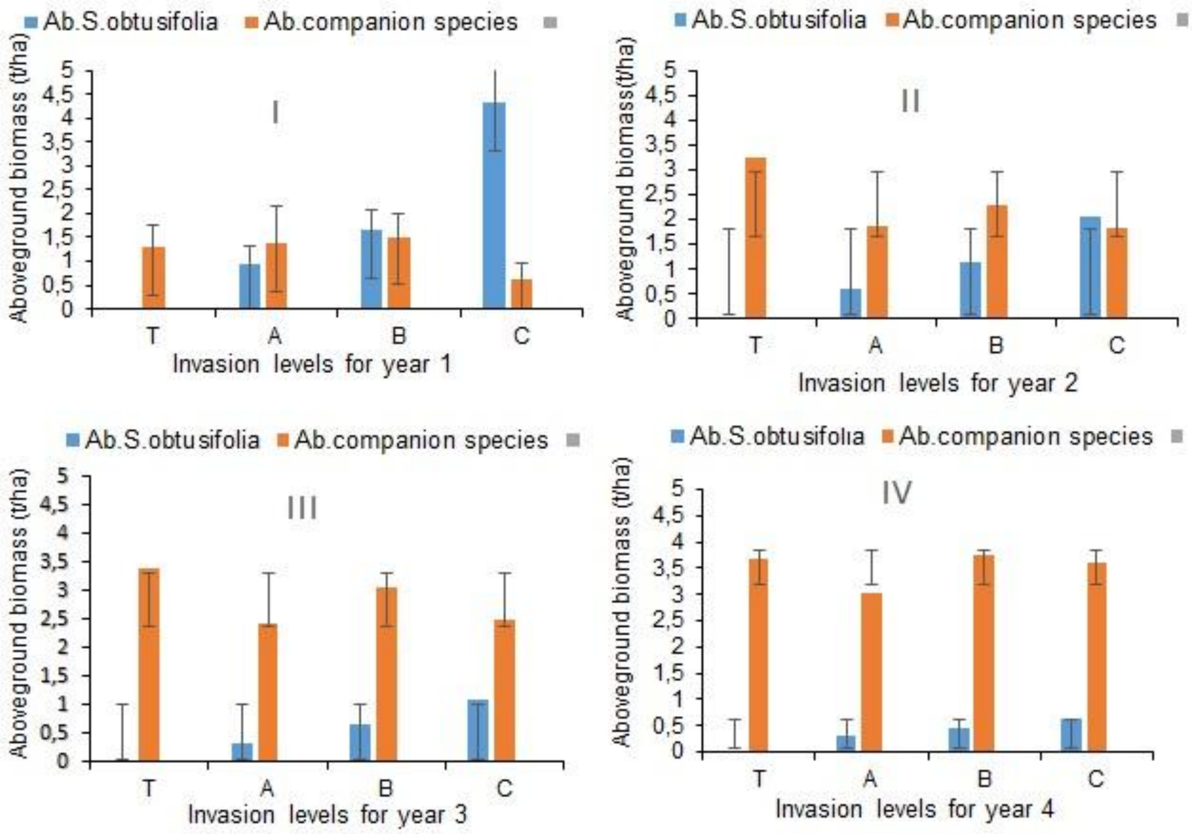

Figure 3: Interannual dynamic of the aboveground biomass (Ab) of *S. obtusifolia* and companion species by level of invasion (I) for year 1, (II) for year 2, (III) for year 3 and (IV) for year 4. T; non-invaded level with 0% cover of *S. obtusifolia*, A; lightly invaded level with 5 to 30% cover of *S. obtusifolia,* B: intermediate invaded level with 30 to 60% cover of *S. obtusifolia,* C; high invaded level with *S. obtusifolia* cover exceeding 60% in the plot corresponding

Temporal variation of the most dominant herbaceous species

In this study, four categories of dominant species with a relative importance value index over five were highlighted (Table5).

The category 1-species that were dominant at the beginning of our experiment for year 1 and remained dominant throughout the four years were *Schoenefeldia gracilis, Spermacoce filifolia, Panicum laetum* and *Chamaecrista mimosoides*. These species except *Spermacoce filifolia* have medium pastoral value.

The category 2-species that were dominant for year 1 and declined progressively were *Senna obtusifolia*, *Acanthospermum hispidum* and *Chloris pilosa*. In this category except *Chloris Pilosa*, species have no or low pastoral value.

The category 3-species that becomed dominant with time were *Brachiaria lata, Cenchrus pedicellatus, Alizicarpus ovalifolius* and *Zornia glauchidiata.* All of these species have high pastoral value.

The category 4-species are those whose dominance and decline vary from one year to the next. These are mainly *Echinochloa colona, Chrysanthellum americanum.*

Table 5: Herbaceous species with importance value index (IVI ≥ 5) in bold

Species	Pastoral value	Year 1	Year 2	Year 3	Year 4
Schoenefeldia gracilis	*MPV*	**7.70**	**6.49**	**8.27**	**15.28**
Spermacoce filifolia	*NPV*	**6.89**	**7.07**	**11.26**	**6.84**
Panicum laetum	*MPV*	**5.26**	**8.05**	**8.79**	**6.16**
Chamaecrista mimosoides	*MPV*	**5.26**	**6.09**	**9.30**	**5.80**
Senna obtusifolia	LPV	**44.59**	**33.05**	**13.47**	3.62
Acanthospermum hispidum	*NPV*	**6.48**	2.51	1.11	0.19
Chloris pilosa.	*HPV*	**5.04**	**5.87**	4.64	4.02
Brachiaria lata	*HPV*	3.93	**7.58**	**9.03**	**12.27**
Cenchrus pedicellatus	*HVP*	2.17	**10.97**	**11.54**	**11.69**
Alysicarpus ovalifolius	*HPV*	1.47	2.96	2.86	**7.27**
Zornia glochidiata	*HPV*	2.51	**7.38**	**6.67**	**5.46**
Echinochloa colona	*MPV*	4.69	**6.33**	**6.47**	2.99
Chrysanthellum americanum	*NPV*	0.37	3.49	**6.21**	1.73
Dactyloctenium aegyptium	*HPV*	4.21	3.68	**5.58**	4.85
Setaria pumila	*HPV*	1.26	1.01	**5.67**	1.03
Cyperus rotundus	*MPV*	1.11	4.85	**5.29**	3.51
Cyperus iria	*MPV*	4.83	3.19	4.44	**5.05**

A species is dominant if its importance value index (IVI) is greater than or equal to 5. The values in bold in the table 5 are those with IVIs greater than 5.

PV: Pastoral value; MPV: Medium pastoral value; HPV: High pastoral value; LPV: Low pastoral value; NPV: No pastoral value

Some herbaceous species appeared only in three or four years after protection (Table 6). Most of them have high pastoral value. This is the case of *Andropogon fastigiatus* and *Andropogon gayanus* (Table 6)

Table 6: Herbaceous that emerged with the duration of protection

Life form	Herbaceous species	Year1	Year2	Year3	Year4
	Aeschynomene indica (HPV)	-	-	0.57	1.03
	Andropogon fastigiatus (HPV)	-	-	0.57	2.32
	Andropogon gayanus (HPV)	-	-	-	1.11
	Andropogon pseudapricus (HPV)	-	-	0.56	1.00
	Hackelochloa granularis (HPV)	-	-	-	1.86
Herbaceous species	*Indigofera stenophylla (HPV)*	-	-	0.77	0.51
	Ipomoea triloba (HPV)	-	-		0.76
	Ipomoea asarifolia (HPV)	-	-	-	0.73
	Ipomoea eriocarpa (HPV)	-	-	-	1.62
	Stylosanthes erecta (HPV)	-	-	-	3.70
	Tribulus terrestris (NPV)	-	-	-	0.73

HPV: High pastoral value; LPV: Low pastoral value; NPV: No pastoral value

Interannual variation in rangeland forage quality across the levels of *S. obtusifolia* invasion

The cover of species with low pastoral values and no pastoral values increased with the invasion of *S. obtusifolia* in the first two years of monitoring. However, the cover rate of species of medium and good pasture value declined (Figure 4). Furthermore, in the two last monitoring years (year 3 to 4), the cover of species of low pastoral value and no pastoral value had decreased significantly in favour of species of medium pastoral value and high pastoral value (Figure4).

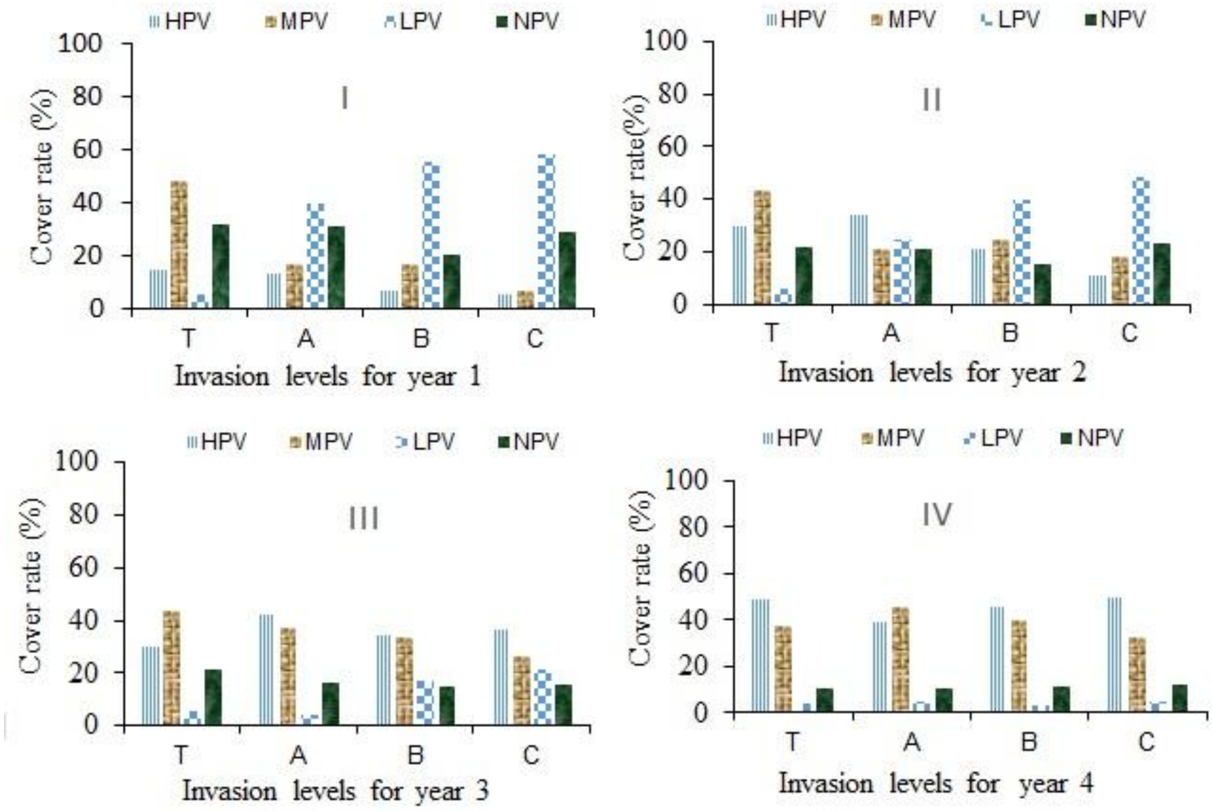

Figure 4: Forage spectrum at different levels of invasion

HPV: High pastoral value, MPV: medium pastoral value, LPV; low pastoral value, NPV: no pastoral value; T; non-invaded level with 0% cover of *S. obtusifolia*, A; lightly invaded level with 5 to 30% cover of *S. obtusifolia,* B: intermediate invaded level with 30 to 60% cover of *S. obtusifolia,* C; high invaded level with *S. obtusifolia* cover exceeding 60% in the plot corresponding

Discussion

Long land protection boosts plant diversity in Sahelian rangelands

Protecting the land in the Sahel region for just a few years has led to a noticeable improvement in plant diversity. Studies, such as Debeko et al. (2024), have documented a significant increase in plant species richness, reflected in measurable changes in vegetation composition. Shannon and Simpson diversity indices increased significantly, alongside Pielou's evenness values, reflecting both greater species diversity and more balanced distribution. These trends indicate that *Senna obtusifolia* continues to recover from previous dominance and demonstrate the ecological benefits of continued protection. In this study, the diversity of herbaceous species reached 88% after four years of protection, indicating a measurable improvement in biodiversity. This increase can be attributed to the exclusion of grazing pressure, which favoured the recovery of palatable forage plants and other sensitive species. Observations from related studies indicate comparable outcomes. For instance, Carmona et al. (2021) documented an increase of 30% in herbaceous biodiversity following only three years of grazing protection, marked by rapid colonization by both annual and perennial species.

Similarly, Siqueira et al. (2022) discovered that a period of four years involving the exclusion of grazing animals resulted in an increase in the diversity of native herbaceous species. This rise in diversity was particularly notable among species of fast-growing pioneers and those that can fix nitrogen in their tissues. These observations are corroborated by subsequent studies, including that by Wang et al. (2023), which noted an increase in the diversity of herbaceous species, ranging from 20% to 40%, subsequent to the implementation of protection, accompanied by a shift toward more palatable and perennial species. The diversity indices documented in our study were found to be higher than those recorded by the aforementioned researchers. This discrepancy can potentially be explained by the fact that the increase in herbaceous diversity in the protected area, previously invaded by *Senna obtusifolia*, may be attributed to two key factors. First, soil protection and conservation measures implemented at the onset of the invasion likely allowed a dormant seed bank previously suppressed by anthropogenic disturbance and *Senna obtusifolia* dominance to germinate. Second, the sharp decline in *Senna obtusifolia* invasion likely freed up resources (light, water, and nutrients), triggering secondary succession and enabling the temporary establishment of various pioneer species. Despite this apparent setback, the long-term protective measures ultimately resulted in a net gain in biodiversity, thereby reinforcing the established positive correlation between protection duration and plant diversity in Sahelian rangelands.

Vegetation composition varied significantly over time, as indicated by Sørensen's similarity index, which showed low similarity among years. This dynamic change is consistent with natural plant succession in undisturbed areas, in which some species decline while others thrive (Szirmai et al. 2022; Świerszcz et al. 2024). *Senna obtusifolia* and *Schoenefeldia gracilis* were among the most dominant species. They are being replaced by other species with high forage value, such as *Brachiaria lata*, *Pennisetum pedicellatum*, and *Zornia glauchidiata*. Such annual fluctuations highlight the ongoing reorganization of herbaceous vegetation following grazing exclusion. Studies confirm that cessation of grazing revitalizes vegetation and allows species recovery (Abourouh et al. 2005). In addition, the intensity of natural regeneration correlates with the duration of protection (Métro and Sauvage 1955; Tessema et al. 2021), reinforcing that long-term conservation efforts yield the greatest ecological benefits.

Effect of protection duration on *S. obtusifolia* performance

Decrease in the biomass, density and height of *S. obtusifolia* was observed during monitoring. This could be partly explained by the discontinuation of grazing in this protected area. In fact, this area has become inaccessible to livestock thanks to the exclosure erected. According to some authors, such as Thiombiano et al. (2012) and Ouedraogo et al. (2021), livestock favour the spread of dry seeds of *S. obtusifolia.* However, site protection stopped this spread. This led to a decrease in the density of *S. obtusifolia* as his seed bank in the soil was not renewed. Specifically, protection over the last two years has resulted in regression of *S. obtusifolia* and species of low or no forage value. The regression of these species has favoured the release of space in favour of other herbaceous species. Our results are in agreement with those of Conedera et al. (2010) who observed that over a 6-year monitoring period, herbaceous species with high pastoral value became increasingly abundant, replacing those with low pastoral value.

This shift in species dominance may be influenced by competitive interactions, as demonstrated by Zare et al. (2022b) in greenhouse experiments, where *Pennisetum Pedicellatum* or *Cenchrus pedicellatus* exhibited greater competitive ability than *S. obtusifolia* when grown together in the same container.

This decline in density after four years may therefore be because seeds become less viable as they remain in soil longer. Indeed, some authors (Creel et al. 1968; Senseman and Oliver 1993) claim that *S. obtusifolia* seeds have a hard coat and can remain viable in the soil seed bank for more than 5 years. However, other authors have found that *S. obtusifolia* seeds lose viability relatively quickly when stored in dry conditions (Ewart 1908; Doll et al. 1976; Binggeli 2005). These authors showed that the total germination rate of seeds in storage for three years was 22%. They also found that *S. obtusifolia* seeds stored for 9 years had germinated between 9 and 10% of the seeds buried in the soil.

In contrast to the invaded levels where *S. obtusifolia* density, biomass, and height decreased significantly over time, the control levels were not infested by *S. obtusifolia* over time. These results indicate the role that animals can play in the dispersal of *S. obtusifolia* seeds on invading rangelands and in the pressure on other plant species. The absence of livestock reduced the spread of *S. obtusifolia* within exclosure.

Protection enhances the pastoral value of Sahelian rangelands invaded by *S. obtusifolia*

The dominance of *S. obtusifolia* over the other species of herbaceous stratum during the two consecutive years of monitoring was probably due to the high stock of seeds of this species dispersed during grazing and their good germination ability. Our results corroborate those of Thiombiano et al. (2012); Ouédraogo et al. (2021) and Zare et al. (2022b) who found that livestock promoted *S. obtusifolia* seed dispersal in soil and subsequent high germination. However, the significant decline in this species in the two last years of monitoring is thought to be due to the depletion of the non-renewed seed stock as a result of the removal of grazing and the occupation of space by other species prevented by grazing. *Cenchurs pedicellatus, Alizicarpus ovalifolius,* and *Andropogon sp* are species that are highly pastoral value. Stopping grazing has therefore helped them to re-establish. The number of years required for an evolutionary change in the number of plant species following a change in practices varies greatly from one context to another. It often depends on a combination of factors. In one protected area, Jeangros and Berthola, (2002) observed the appearance of ten new species in four years.

Conclusion

The establishment of the exclosure has effectively mitigated grazing pressure, reducing the proliferation of *S. obtusifolia* while facilitating the recovery of high-pastoral-value herbaceous species. Moreover, the implementation of protection measures has contributed to the reemergence of various herbaceous that had previously been diminished by human disturbance. These findings underscore the efficacy of exclosures as a viable strategy for controlling invasive species like *S. obtusifolia* and promoting the restoration of ecologically and economically valuable vegetation. The enhancement of productivity and forage quality in degraded rangelands through the implementation of exclosures represent a promising strategy for sustainable land management and biodiversity conservation. Subsequent research endeavours may encompass the exploration of long-term vegetation dynamics and the economic viability of expanding the present approach on a broader scale.

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Additional information

Competing interests

The authors declare that they have no competing interests

Ethical statement

No ethical statement was reported.

Authors' contributions: AZ, BI, and PCB carried out the field work. AZ, BI, PCB and ICET performed the statistical analysis, and drafted the manuscript. OO designed the research project, gave the practical advices, supervised the work, read and improved the drafted manuscript. All the authors read, revised and approved the final manuscript.

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