Ecosystem services of woody species along an ecological disturbance gradient in Sudanian savannas of western Burkina Faso (West Africa)

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Research

Abstract

Background: Ecosystem services (ES) are increasingly threatened by intense human pressure leading to species over-exploitation and ecosystem degradation. This study aims to assess the potential ES delivered by woody species under varying ecological disturbance levels and land use/land cover classes through indigenous knowledge.

Methods: To this end, ethnobotanical surveys were conducted in three areas of Burkina Faso: the Watershed of Dano, villages surrounding the Total Wildlife Reserve of Bontioli, and the Game Ranch of Nazinga. A total of 240 open-ended interviews were conducted to record the provisioning, regulatory, supporting, and cultural services provided by woody species. The Index of the capacity to provide ecosystem services of Species was applied to quantify ES across different ecological disturbance levels.

Results: Results identified 129 woody species providing 15 distinct ES across all categories. Agroecosystems contributed of the highest level of ES provision, surpassing even savanna ecosystems with lower ecological disturbance level. Notably, even heavily modified areas showed considerable ES provision, emphasizing local practices that sustain valuable species. Promoting agroforestry is essential to enhance local capacity for biodiversity conservation and sustainable ES management.

Conclusions: To secure long-term provisioning, local communities should be sensitized about the full spectrum of ES, including support, regulation, and cultural dimensions.

Keywords: agroforestry, conservation, indigenous knowledge, land use, woody species

Background

Human-modified landscapes are complex socio-ecological systems. In the face of current climate change, the future of human well-being will be shaped by our capability to manage these complex environments to provide multiple ecosystem services (ES) that meet societal demands (Reyers *et al.* 2013, Jiang *et al.* 2021, Anley *et al.* 2022, Zhao *et al.* 2025). ES represent a human-centered perspective on ecosystems and nature by defining benefits that humans derive from nature (MEA 2005). The main services provided are provisioning, regulating and cultural services, all of which have a direct impact on human well-being. In addition, there are supporting services needed to maintain these three services (MEA 2005).

The United Nations (UN) Sustainable Development Goal 15 (SDG 15) stipulates those healthy ecosystems provide all populations with multiple benefits, including clean air, water, food, materials and medicine (UN 2017). However, without biodiversity, no ecological good or service can exist (Limoges 2009). Biodiversity on the ecosystem level may be represented by the land cover unit which refers to plant communities describing main characteristics of the land surface such as forest, savanna, desert, water, bare soil (Lillesand *et al.* 2008). The purpose for designating land cover units is defined by land use (Agarwal *et al.* 2002, Lillesand et al. 2008). Changes in local land use may have a great impact on biodiversity through loss, modification or fragmentation of habitats, degradation of soils and water resources, and overexploitation of local species (Lambin et al. 2003, Wezel & Lykke 2006, Soulama *et al.* 2015). The different levels of biodiversity (genetic, taxonomic and functional) are necessary for the efficiency and stability of ecosystem functioning, as demonstrated by numerous studies (Cardinale *et al.* 2011, Lefcheck *et al.* 2015). Few services are provided by a single species, as the ecological functions underpinning them are most often based on the diversity of living objects (Cardinale *et al.* 2012). Therefore, biodiversity is necessary for the full range of services to be available (Anley *et al.* 2022). Following from this strong relationship between living diversity, ecosystem functioning and service provision, the current loss of biodiversity is leading to a decline in the provision of most services, with the notable exception of provisioning services.

Current research on the relationship between ES and land use/land cover unit (LULC) demonstrated that the specificity of each LULC gives its own capacity for the provision of the ES concerned. For example, Burkhard *et al.* (2009) demonstrated that the capacity to provide ES such as food varies according to the LULC. Similarly, the spatialization of ES provision, in particular carbon sequestration by various LULCs, shows that the quantities of carbon sequestered depend on the LULC class (Le Clec'h *et al.* 2014, Dimobe *et al.* 2018). Vatitsi *et al.* (2023) conducted remote sensing analyses to quantify multi-temporal changes in plant species use and LULCs between 1984 and 2021, as well as landscape configuration, ecosystem quality and ES valuation. Although the changes observed in ecosystems were not significant over this period, ecosystem quality appears to have been affected by fragmentation. These studies have highlighted the close link between landscape configuration and ecosystem quality, emphasizing the impact of anthropogenic activities on the provision of ES. The dynamics of ES provision are correlated with those of LULCs, making it possible to predict future provision of ES with tools such as the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) and the patch-level land use simulation (PLUS) models (Rahimi *et al.* 2020, Liu *et al.* 2024)

In the face of increasing anthropogenic pressure, it is urgent to increase the resilience of LULC for sustainable provision of ES. This resilience requires adoption of sustainable consumption patterns, in order to reduce the need to overexploit resources, as recommended by SDG 12 (UN 2017). The local populations of Sudanian savannas abundantly use woody species for their daily needs (Taïta 2003, Sop *et al.* 2012, Ouédraogo *et al.* 2014, Zizka *et al.* 2015, Savadogo *et al.* 2017). Woody species participate in the provision of local populations with the four categories of ES (provisioning, regulating, cultural and supporting) and contribute to their well-being. Local populations are usually in contact with woody species and know them better than herbaceous species (Dan Guimbo *et al.* 2012, Guigma *et al.* 2012, Sop *et al.* 2012, Guigma *et al.* 2014, Soro *et al.* 2014). The former are constantly available for various uses in each season and thus contribute highly to the provision of ES (Zerbo *et al.* 2011, Ouédraogo *et al.* 2014). Quantifying the benefits of local ecosystems can help managers and decision makers justify the importance of these sites for conservation for current and future generations (Neugarten *et al.* 2018).

In this study, effects of species availability on ES provision were assessed across different LULC classes in the South-Sudanian phytogeographic area. Three areas of different ecological disturbance level were selected with low, moderate, and high ecological disturbance level. This study aims to assess the relationship between ES in LULC classes in Sudanian savannas of Burkina Faso. Specifically, this study aims to (1) identify the woody species most important for the provision of ES, based on indigenous knowledge, (2) analyse the ES provided by different LULC classes, and (3) assess the effect of ecological disturbance level on the ES provision capacity. We hypothesize that near-natural vegetation provides more ES than disturbed vegetation.

Materials and Methods

Study area

The study was carried out in the South-Sudanian phytogeographical sector of Burkina Faso (Fontès & Guinko 1995) between latitudes 10°45' N - 11°25' N and longitudes 1°15' W and 3°15' W (Fig. 1). Three study sites were selected: the Watershed of Dano (WD), The Total Wildlife Reserve of Bontioli (TWRB) and the Game Ranch of Nazinga (GRN). We chose these sites to study three levels of land-use intensity, based on LULC data via multitemporal Landsat images, with WD being the most highly disturbed site and GRN the least disturbed site (Dimobe *et al*. 2015, 2017). Agrosystems and grazing characterize the Watershed of Dano (WD). The TWRB is a protected area of IUCN category I underlying several human pressures, notably agriculture and grazing. WD and TWRB are both located in the southwestern region of the country. GRN, a protected area of IUCN category VI, is devoted to hunting. It is located in the south-central region (Bélemsobgo *et al.* 2010).

The vegetation in the study area is a mosaic of dry forests and savanna with a dense cover of tall grasses (White 1986). The widespread land cover units in the three study sites are shrub savannas, tree savannas, wood savannas, dry forests, and gallery forests (Nacoulma *et al.* 2019). The prominent woody species encountered are Vitellaria paradoxa C.F. Gaertn, Terminalia laxiflora Engl., Terminalia macroptera Guill. & Perr., Isoberlinia doka Craib & Stapf, Piliostigma thonningii (Schum.) Milne-Redhead, Terminalia leiocarpa (DC.) Baill., Detarium microcarpum Guill. & Perr. and Lannea acida A. Rich. The dominant grass species are Andropogon gayanus Kunth, Andropogon chinensis (Nees) Merr., Hyparrhenia subplumosa Stapf, Hyparrhenia involucrata Stapf, Loudetia togoensis (Pilger) C.E. Hubbard, and Schizachyrium sanguineum (Retz.) Alston. (Fontès & Guinko 1995, Dimobe *et al.* 2015, 2017, Stein *et al.* 2018, Nacoulma *et al.* 2019).

The study area's climate is classified as Sudanian, exhibiting a unimodal rainy season that typically extends for a period of five to six months, commencing in May or June and concluding in September or October. The mean annual rainfall recorded over a 30-year period (1986-2015) was found to be 1,048.73 ± 146.7 mm. Agriculture, livestock farming and gold panning constitutes the main activities of the populations in the study area (Senghor 2010). The total population of the study area is 1,662,371 (INSD, 2022).

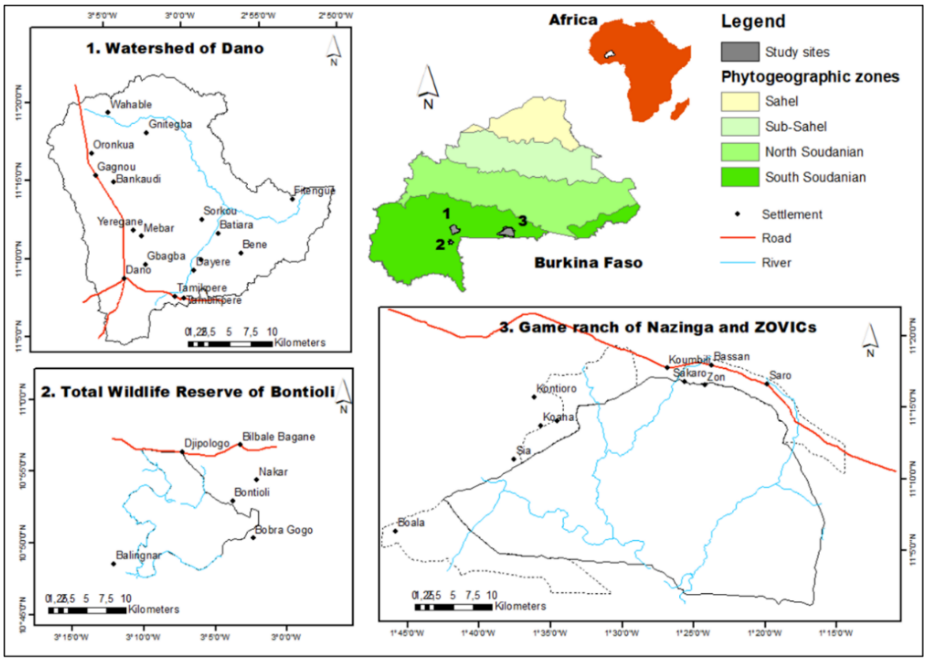

Figure 1. Location of the study areas.

Data collection

Sampling design and ethnobotanical survey

Seventeen villages were randomly selected based on their proximity (distance less than 10 km) to the study sites with the outlook of five villages per indigenous socio-cultural group at each study site. Within the WD, there were two indigenous socio-cultural groups, with only two villages found for the *Pougouli* and five villages for the *Dagara*; around the TWRB five villages for the *Dagara*; and five villages for the *Kassena* around the GRN. Random sampling of villages was combined with stratified random sampling of informants in each village. The strata considered were socio-cultural groups (indigenous groups, dominant migrants) and gender (Houehanou *et al.* 2011, Nabaloum *et al.* 2022). Random sampling techniques were chosen as they are more representative of the population and more robust, ensuring that all members of the population have an equal chance of being selected (Espinosa *et al.* 2014). Interviews were conducted during the dry season, from December 2016 to March 2017, because during this period the local population is not busy with farm work. In accordance with ethnobotanical ethical protocols (International Society of Ethnobotany 2006), prior informed consent was obtained at the community level through local authorities and individually reaffirmed by each informant at the beginning of each interview. Semi-structured individual surveys were conducted, with the assistance of translators, in the indigenous (*Pougouli, Dagara* or *Kassena*) or dominant migrants (*Mossi*) languages. In each village and for each socio-cultural group, ten informants (five men and five women), selected at random, were interviewed with their consent, making a total sample of two hundred and forty informants. However, we encountered villages with no migrants, particularly in the WD and TWRB sites; this is due to the specific nature of the local populations (the *Dagara* and the *Pougouli*), who are introvert sociocultural groups little open to exterior influence. Nevertheless, in the TWRB, we encountered two villages that had accepted migrants. Thus, there were 10 villages with no migrants, notably the 7 villages in the WD and 3 villages in the TWRB. This brings the total number of interviewers to 240 (Nabaloum *et al.* 2022). The minimum age for informants was 20 years, as informants of this age and older have memories of events that occurred 10 years ago (Sop *et al.* 2012, Bouayyadi *et al.* 2015). The information collected relates to the use of plant species and the relevant plant parts. At the end of the survey in each community, the guided tour method, or "walk-in-the woods" method, was used to identify the plants cited by their vernacular names in the interviews. The field visit was carried out with some members of the village who had good knowledge about the species (Albuquerque *et al.* 2014). During the field visit, fresh species samples were collected and pressed to associate corresponding vernacular and scientific species names. The unknown species were identified with the floras of Berhaut (1967), Poilecot P (1999), the field handbook of Arbonnier (2012), the catalogue of Thiombiano *et al.* 2012, and the Analytical Flora of Burkina Faso and Mali (Cesar *et al.* 2024). The identified samples were confirmed with the samples of the Ouagadougou herbarium located at the University Joseph Ki-Zerbo.

Sources of data on forest inventories

Forest inventory data were obtained from Dimobe *et al.* (2015, 2017, 2018), comprising an extensive spatial dataset of 252 plots distributed across the three study sites. Plots were randomly established across five LULC classes (gallery forest, wood savanna, tree savanna, shrub savanna and agroecosystem). In total, 85 plots were sampled in TWRB, 82 in WD and 85 in GRN. Woody species inventories were conducted in homogeneous vegetation areas. Plot sizes corresponded the standard inventory guidelines for Burkina Faso (Thiombiano *et al.* 2016). The plot sizes were thus 2,500 square metres in the agroecosystems; 1,000 square metres were used in the natural savannah and 500 square metres in the gallery forest. Within each plot, diameter at breast height (DBH, measured at 1.3 m above the ground) and total height (H) were recorded for all woody species individuals with DBH ≥ 5 cm. Overall, 8915 individual woody plants were measured, including 3620 at TWRB, 2685 at GRN and 2610 at WD. The final LULC classes retained for analysis were agroecosystems (including fallows) and nearly undisturbed vegetation (gallery forests, wood savanna, tree and shrub savannas).

Data Analysis

Woody species used for ecosystem services

Species were then classified and enumerated by use category and corresponding ES for each study site. To assess the occurrence of useful species across LULC classes, species richness was determined for each LULC class and presented graphically as Barplot. Species were subsequently ranked according to the cited uses), distributed among four ES categories: provisioning, regulating, cultural and supporting services (Nabaloum *et al.*2022).

To identify most species valued by local populations, use values (UV) were calculated based on both the number of distinct uses cited and the number of informants mentioning each species (Albuquerque *et al.* 2014). Higher UVs indicate greater local importance and preference for a species. The UV were calculated per study site as shows in equation 1:

$$UVs = \sum_n Ui \quad (1)$$

Where *Ui* is the number of uses mentioned by each informant, and *n* is the total number of informants.
The data were analysed using descriptive statistics, relative frequency citation, and preference ranking. Ethnobotanical data were organized using Microsoft Excel spreadsheets.

Dendrometry parameters by land use/ land cover classes

To quantify the ecological importance of each woody species by survey plots, its relative dominance within the survey plots (expressed per hectare) was calculated following standard dendrometric formulas (Malaisse *et al.* 2013, Bhadra & Pattanayak 2017, Akhtar *et al.* 2025) in equation 2:

$$\text{Basal area (individual)} = \text{DBH}^2 \times (\pi/4) \quad (2)$$

Where DBH represents the diameter at breast height.

The basal area per species was obtained by summing individual basal areas of all measured trees of the species (equation 3), expressed in square meters per hectare (m^2/ha).

$$\text{Basal area (species)} = \sum_n \text{basal area of species individuals} \quad (3)$$

The relative dominance was computed as shows in equation 4:

$$\text{Relative dominance} = (\text{total basal area of the species}) / (\text{total basal area of all species}) \times 100 \quad (4)$$

The ecological importance of each woody species by land use/ land cover classes, the IVI (importance value index) was computed using the equation 5 (Ouédraogo *et al.* 2025, Horn *et al.* 2026):

$$\text{IVI} = \text{Relative dominance} + \text{Relative density} + \text{Relative frequency} \quad (5)$$

where

$$\text{Relative density} = (\text{number of individuals of the species}) / (\text{total numbers of individuals}) \times 100 \quad (6)$$

$$\text{Relative frequency} = (\text{frequency of the species}) / (\text{frequency of all species}) \times 100 \quad (7)$$

Theoretically, the relative dominance, density, and frequency vary from 0 to 100%, while the IVI ranges from 0 to 300%.

Relationship between use preference and species availability

The relationship between species availability (Importance Value Index; IVI) and species preference (Use values; UV) among local populations was assessed following methods described by Torre-Cuadros & Islebe (2003) and Ouédraogo *et al*. (2020). Only species found both in ethnobotanical surveys and floristic inventories (Ouédraogo *et al.* 2020) were included. The normality of the distributions of the Importance Value Index (IVI) and the Utility Value (VU) was tested using the Shapiro-Wilk test. As the distributions were found to be non-normal ($p < 0.05$) in this study, Kendall's non-parametric correlation was applied to assess the relationship between availability and usage. The Kendall correlation test was chosen due to the presence of tied ranks in the data. A correlation coefficient close to 1 indicates a strong relationship between species availability and local preference. All statistical analyses were conducted with R software version 4.2.1 (R core team 2021).

Quantification of ecosystem services

To account for disturbance effects, data were aggregated by study site following the methodology of Ouédraogo *et al.* (2014). All four categories of ES were included in this analysis. The ES provided by woody species in each plot were quantified using the following equations:

The number of citations of a species for a specific service reflects its perceived importance. Therefore, the service-specific weight Psi of each species was calculated as shows in equation 8:

$$\text{Psi} = \text{Nsi} / \text{Nt} \quad (8)$$

where Nsi is the number of citations of species i for service s, and Nt is the total number of citations for all species for service s.

The combination of ethnobotanical citations and floristic inventories allowed ES to be quantified at the plot scale. Since the contribution of a species to ES depends on its abundance within plots, the contribution Csi of species i to service s in a given plot was calculated as shows in equation 9:

$$Csi = Psi \times \text{relative dominance} \quad (9)$$

Where Csi is the contribution of species i to service s, calculated per hectare based on the species' relative dominance within the plot.

The total weight Psf of a given plot f for a specific service s was computed by summing the contributions Csi of all woody species in that plot (equation 10):

$$Psf = \sum Csi \quad (10)$$

To evaluate the average capacity of different land-cover classes to provide ES, a matrix was constructed with the four ES categories on the x-axis and the main land-cover classes on the y-axis. The average capacity, CAPm, of LULC class to provide a specific service was calculated as the mean weight (Psf) across the n plots within that class (equation 11):

$$CAPm = (\sum_n Psf) / n \quad (11)$$

Finally, to estimate the total provision of services within each level of ecological disturbance, total capacity (CAPt) was calculated. CAPt corresponds to the sum of each land-cover class's CAPm multiplied by its proportional area within the land-use intensity zone (Appendix 1). The proportions of LULC were obtained from the area (in hectares) of each LULC class, as documented in Dimobe *et al.* (2015, 2017, and 2018).

$$CAPt = \sum (CAPm \times \text{LULC area}) \quad (12)$$

Example of calculation

The example calculation of species weight value presented in Table 1 shows five species and the number of citations received by each in the provisioning services category (here, food supply, energy supply and medicinal use) in the GRN. Thus, the weight of *Vitellaria paradoxa* for provisioning services in the GRN can be calculated using equation 5: Nsi = 157 and Nt = 329, therefore Psi = 157/329 = 0.48.

Table 1. Example of species weight calculation.

Species	**Food supply**	**Energy supply**	**Medicinal use**	**provisioning service**	$P_{provisioning}$
Bombax costatum	13	0	0	13	0.04
Detarium microcarpa	58	30	28	116	0.35
Khaya senegalensis	0	21	17	38	0.12
Mitragyna inermis	0	0	5	5	0.01
Vitellaria paradoxa	95	49	13	157	0.48
Total	166	100	63	329	1

Note: $P_{provisionning}$, weight of species for provisioning service

Using equation 6, the Csi of Vitellaria paradoxa for provisioning services at the Psf of the tree savanna in provisioning services is (157/329) × 35.83 = 17.20.

For the same species in shrub savanna, the Csi is (157/329) × 39.86 = 19.13.

For each of the two LULCs, the Psf for provisioning services is the sum of the species contributions calculated using equation 10. Table 2 shows that the Psf for the tree savanna is 25.06 and 29.79 for the shrub savanna.

Statistical analysis

As the normality of the distributions was not confirmed (Shapiro-Wilk test, p-value = 0.05), non-parametric methods were employed. A Chi-squared test was used to compare ES weights (Psf) among the different LULC classes. Additionally, the ecosystem service provision capacities per hectare across the three levels of ecological disturbance are presented as medians accompanied by the interquartile range (IQR), as these parameters are more robust to outliers. Median differences were tested using the Kruskal-Wallis test, followed by Dunn's test with a Benjamini-Hochberg correction to adjust the p-values. All analyses were conducted using R version 4.2.1. (R core team 2021).

Table 2. Example of LULC weight calculation

Species	$P_{provisionning}$	Relative dominance in tree savanna	Csi in tree savanna	Relative dominance in shrub savanna	Csi in shrub savanna
Bombax costatum	0.04	3.03	0.12	0	0
Detarium microcarpa	0.35	21.6	7.56	30.47	10.66
Khaya senegalensis	0.12	1.06	0.13	0	0
Mitragyna inermis	0.01	5.73	0.06	0	0
Vitellaria paradoxa	0.48	35.83	17.20	39.86	19.13
Psf		25.06		29.79	

Note: Csi, species contribution to the *Psf,* weight of LULC for the provisioning service category

Results

Woody species used by local populations

A total of 129 woody species, belonging to 92 genera and 34 families, were identified across the three study sites. For the most dominant families, Fabaceae (24% of all families), Combretaceae (10%) and Malvaceae (8%) were prevalent in all three areas. The number of woody species cited by populations bordering TWRB was higher (95 species) than those recorded in GRN (91) and WD (86). Some species used at these three study sites serve multiple purposes. *Diospyros mespiliformis* Hochst. ex A. DC., *Khaya senegalensis* (Desv.) A. Juss., *Vitellaria paradoxa* C. F. Gaertn. and *Saba senegalensis* (A. DC.) Pichon were cited in 14 of the 15 ecosystem services identified. The proportions of species used per ES are as follows (Table 3).

Provisioning services

Medicinal uses were the most common. The building service, which involved the lowest number of species was not cited in GRN. Building materials were sourced from *Khaya senegalensis* (Desv.) A. Juss., *Terminalia leiocarpa*, *Burkea africana* Hook., *Pterocarpus erinaceus* Poir., *Terminalia macroptera*, and to a lesser extent, *Trichilia emetica* Vahl, *Tapinanthus* spp., *Prosopis africana* (Guill. & Perr.) Taub and *Pseudocedrela kotschyi* (Schweinf.) Harms with the contribution of exotic (introduced) species such as *Azadirachta indica* A. Juss. and *Tectona grandis* L.f.

Regulating services

Wind protection was provided by large tree species such as *Vitellaria paradoxa* C.F. Gaertn, *Parkia biglobosa* (Jacq.) R. Br. ex G. Don f., *Faidherbia albida* (Delile) A. Chev. Del., *Khaya senegalensis*, and *Lannea microcarpa*. Erosion prevention was supported by species with strong root systems, including *Adansonia digitata* L, *Diospyros mespiliformis* Hochst. ex A. DC., and *Mitragyna inermis* (Willd.) Kuntze. In general, species that provide wind protection also contribute to erosion prevention and shading.

Cultural services

Religious significance was associated with totemic species or those believed to shelter spirits. The most frequently quoted species for this service included *Afzelia africana* Sm. ex Pers., *Adansonia digitata*, *Diospyros mespiliformis*, and *Gardenia erubescens* Stapf & Hutch. Additionally, *Adansonia digitata* was the most frequently mentioned species for touristic value.

Supporting service

The indication and enhancement of soil fertility are provided by *Faidherbia albida*, *Vachellia nilotica* (L.) P.J.H. Hurter & Mabb., *Senegalia gourmaensis* (A.Chev.) Kyal. & Boatwr., *Isoberlinia doka*, *Terminalia leiocarpa*, and *Daniellia oliveri* (Rolfe) Hutch. & Dalziel, among other species.

Species richness of woody species used in the levels of ecological disturbance

A total of 63 woody species were recorded in the floristic inventory at WD, out of the 86 species used by the local population. At TWRB, 67 species were recorded in the forest inventories, out of the 95 species used by the riparian population. At GRN, the floristic inventory recorded 50 species, out of the 91 useful species (Table 4). These findings indicate that a significant portion of the species used by local populations are present in the surrounding protected areas.

Agroecosystems were the poorest in woody species providing ES, consisting mainly of species with high socio-economic value, such as *V. paradoxa, P. biglobosa, D. mespiliformis, L. microcarpa, F. gnaphalocarpa, P. erinaceus,* and *F. albida*.

In contrast, tree savannas and wood savanna had high species richness (Table 4), with species predominantly belonging to Fabaceae, followed by Combretaceae. However, these ecosystems contained smaller proportions of species with significant socio-economic value.

Appendix 2 provides details on the occurrence of species providing ES across the three levels of ecological disturbance.

Table 3. Proportion of species used for ecosystem services across the three study sites

Ecosystem services	**WD (n = 86)**	**TWRB (n = 95)**	**GRN (n = 91)**	**Total study area (n = 129)**
Provisioning (%)	94.19	98.94	92.31	95.35
Medicinal use (%)	86.05	89.47	59.34	81.4
Energy supply (%)	43.02	53.68	46.15	56.59
Food supply (%)	54.65	52.63	42.86	53.49
Fodder supply (%)	47.67	27.36	42.86	51.94
Crafts (%)	32.56	38.94	41.76	45.74
Building (%)	11.63	9.47	0	9.3
Regulating (%)	66.28	43.15	42.86	57.36
Wind protection (%)	43.02	33.68	23.08	37.21
Erosion prevention (%)	30.23	28.42	19.78	33.33
Shading (%)	31.39	24.21	19.78	27.91
Pest control (%)	23.25	14.74	20.88	27.91
Water purification (%)	15.12	6.31	9.89	15.5
Cultural (%)	61.63	41.05	46.15	54.26
Religion (%)	43.02	31.58	27.47	42.64
Ceremonies (%)	34.88	31.58	24.17	37.98
Tourism (%)	4.65	0	20.88	17.83
Supporting (%)	30.23	23.16	29.67	36.43
Soil fertility (%)	30.23	23.16	29.67	36.43

Note: WD, Watershed of Dano (high disturbance level); TWRB, Total Wildlife reserve of Bontioli (moderate disturbance level); GRN, Game Ranch of Nazinga (low disturbance level)

Table 4. Number of woody species providing ecosystem services recorded in the study site

Land use/ land cover class	**WD**	**TWRB**	**GRN**
Study site	63	67	50
Agroecosystem	19	16	10
Shrub savanna	23	28	28
Tree savanna	44	47	49
Wood savanna	58	56	38
Gallery forest	42	28	22
P-value	1.358e-05	5.304e-06	4.226e-06

Note: WD, Watershed of Dano (high disturbance level); TWRB, Total Wildlife reserve of Bontioli (moderate disturbance level); GRN, Game Ranch of Nazinga (low disturbance level)

Relationship between use preference and species availability

Kendall's correlation coefficients indicate a significant positive relationship between local species use preference and their availability, with values of tau = 0.38 ($p < 0.001$) at WD; tau = 0.25 ($p = 0.001$) at TWRB, and tau = 0.37 ($p < 0.001$) at GRN (Fig. 2). These results suggest that local use preferences are strongly linked to species availability, leading to increased pressure on certain species. The use value and the importance value indices for species of this study is reported in Appendix 3.

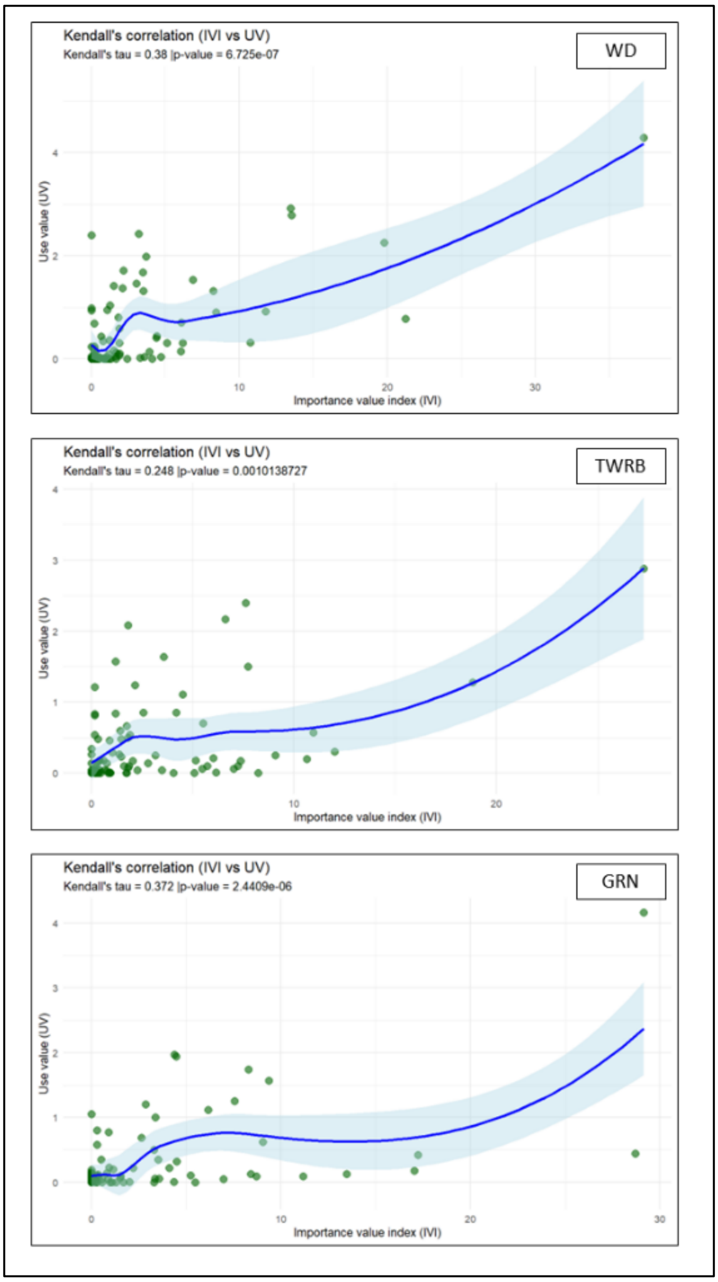

Figure 2. Kendall's correlations between Importance Value Indices (IVI) and Use Values (UV) in the three study sites
Note: IVI, Important Value Index; UV, Usage Value; WD, Watershed of Dano (high disturbance level); TWRB, Total Wildlife reserve of Bontioli (moderate disturbance level); GRN, Game Ranch of Nazinga (low disturbance level)

Ecosystem services of the different land use/land cover classes

The results of the ES mean provision capacity of woody vegetation (Fig. 3) show that WD (*CAPm* = 10.70 ± 11.51) and GRN (*CAPm* = 10.21 ± 13.78) provide more ES than TWRB (*CAPm* = 6.82 ± 9.33) with P-value <0.001. Specifically, we observe that:

- in GRN (Fig. 3), tree savannas (*CAPm* = 12.24 ± 7.08) followed by shrub savannas (*CAPm* = 8.66 ± 5.45) and wood savannas (*CAPm* = 7.67 ± 5.08) are the best-performing providers of ES;

- in TWRB (Fig. 3), agroecosystems (*CAPm* = 16 ± 13.95) followed by wood savannas (*CAPm* = 6.76 ± 6.59) and tree savannas (*CAPm* = 6.33 ± 4.98) are the best-performing providers of ES;

- in WD (Fig. 3), agroecosystems are the best-performing ES providers (*CAPm* = 18.23 ± 15.85), followed by tree savannas (*CAPm* = 11.67 ± 8.45) and wood savannas (*CAPm* of 9.71 ± 7.09).

The sites under anthropogenic pressure (WD and TWRB) present a strong variance in ES mean capacity scores, with strong differences in ES supply mean capacities between agroecosystems and other LULC classes (Fig. 3). Agroecosystems, the anthropogenically shaped LULC showed the highest overall ES supply.

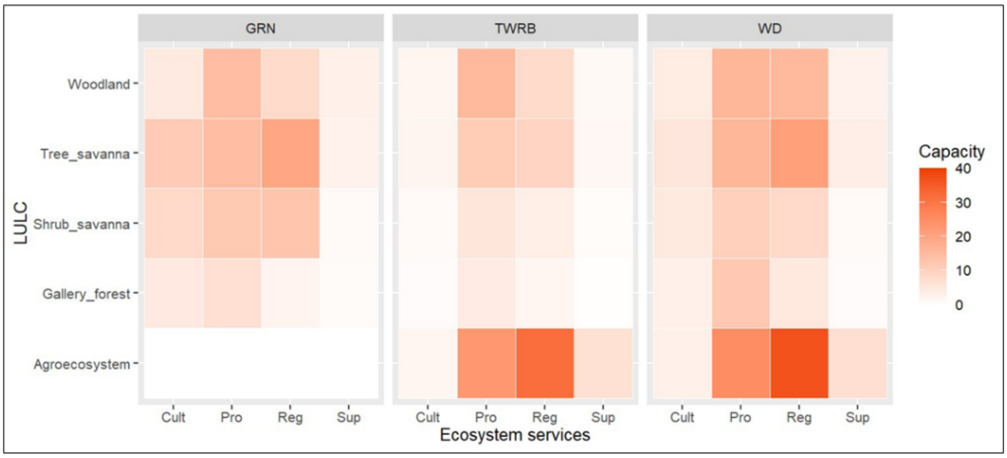

Figure 3. Heatmap of the assessment of the different land use/land cover class capacities (*CAPm*) to provide selected ecosystem services at three study sites.

Note: Cult, cultural services; Pro, provisioning services; Reg, regulating services; Supp, supporting services; WD, Watershed of Dano (high disturbance level); TWRB, Total Wildlife reserve of Bontioli (moderate disturbance level); GRN, Game Ranch of Nazinga (low disturbance level)

Ecosystem services at ecological disturbance levels

The mean capacity to provide ES is significantly different in woody species at the three sites (Table 5). Provisioning and regulating services are provided most at all sites.

Table 5. Comparison test of the means of ecosystem service provision (*CAPm*) per hectare at the three levels of ecological disturbance.

Study sites		**WD**	**TWRB**	**GRN**
Ecosystem services	Provisioning	16.17 ± 3.89 a	11.54 ± 9.87 a	14.62 ± 2.54 a
	Regulating	15.44 ± 13.08 a	8.03 ± 5.96 a	13.10 ± 11.86 a
	Cultural	4.34 ± 1.37 b	2.04 ± 0.98 b	8.29 ± 6.65 ab
	Supporting	2.85 ± 2.63 b	1.41 ± 1.14 b	2.9 ± 1.89 b
P-value		0.003532	0.009904	0.022

Note: WD, Watershed of Dano (high disturbance level); TWRB, Total Wildlife reserve of Bontioli (moderate disturbance level); GRN, Game Ranch of Nazinga (low disturbance level)

The results for total ES supply capacity (*CAPt*) in LULCs grouped into agroecosystems and savannas for each site (Fig.4) indicate a higher ES supply capacity in the 87,390 ha of GRN savannas, with a provisioning service capacity of 1154281.14, a cultural service capacity of 793826.86, a regulating service capacity of 1301131.21, and a supporting service capacity of 171306.26. In the particular case of the WD, the capacity to provide ecosystem services is greatest in agroecosystems. The 21,704 ha of agroecosystems have a provisioning service capacity of 551275.76, a cultural service capacity of 70971.33, a regulating service capacity of 806078.02, and a supporting service capacity of 154747.88. The lowest supply capacities are observed at TWRB, which has a total surface area of 13605 ha.

Figure 4. Total capacity (*CAPt*)to supply ecosystem services at different levels of land-use intensity
Note: Cult, cultural services; Pro, provisioning services; Reg, regulating services; Supp, supporting services; WD, Watershed of Dano (high disturbance level); TWRB, Total Wildlife reserve of Bontioli (moderate disturbance level); GRN, Game Ranch of Nazinga (low disturbance level)

Discussion

Woody species used by local populations

A total of 129 woody species is used by the population across the three levels of ecological disturbance studied. The exotic species recorded in this species (*Anacardium occidentale, Azadirachta indica* .and *Tectona grandis*) are non-invasives in Burkina Faso (Bationo *et al.* 2004, Noba *et al.* 2017). Among the used species a predominance of the Fabaceae and Combretaceae families. Zerbo *et al*., (2011) underline the predominance of these plant families in medicinal plants used by the *San* socio-cultural group in the West of Burkina Faso. These two plant families constitute the main part of the woody flora in the savannas of Burkina Faso (Thiombiano *et al*. 2010). The significant positive correlation between the use of local species and their availability shows that the population is familiar with its environment and makes abundant use of local species. As the usefulness of species in the savannas increases, they become more extensively used, which can result in over-exploitation and increased vulnerability (Ouédraogo *et al.* 2020). However, the diversity of species used for an ecosystem service could help to overcome the problem of the vulnerability of plant species. One solution that should be promoted is the substitution of the most threatened species with those that are sufficiently abundant in the vegetation for the same ecosystem service (Kaboré *et al.* 2015, Agbani *et al.* 2018). The abundance of certain useful species results from the management of local populations who voluntarily introduce them and/or keep them in agroecosystems as a measure of sustainable use in order to have a high quantity to meet their needs. Agroecosystems, although with a reduced number of woody species that provide ES, bring together the species most used by local populations for their own consumption or for selling their non-timber forest products (Ganaba *et al.* 2025, Nabaloum *et al.* 2025, Zomboudre & Hien 2025). The sale of products from species conserved in agroecosystems contributes to the variation of income of local populations and thus ensures their financial well-being. This financial motivation does not exclude other benefits in terms of ES that these species provide to populations. In fact, in addition to provisioning services, species also provide regulatory, cultural and supporting services which meet the requirements of local people, their livestock and their arable soils (Olivier & Sanou 2003, Dimobe *et al.* 2018, Cissé *et al.* 2019, Nabaloum *et al.* 2022). For example, *Piliostigma thonningii*, *Faidherbia albida* are species specially preserved in fields because they contribute to soil fertility. Other main reasons for maintaining woody species in the agroecosystems are difficulty of removal and provision of microhabitats (e.g., termitaria) not used for cropping (Kristensen & Lykke 2003).

Ecosystem services of land use/land cover classes at the land-use intensity levels

In WD, agroecosystems, tree savannas and wood savanna play a significant role in providing ES. The high CAPm values of agroecosystems, tree savannas and wood savanna are attributable to the abundance and prevalence of useful woody species they contain, as evidenced by their high IVIs for the most widely utilized species. Agroecosystems offer distinct advantages as a land-use system shaped by local populations to meet their needs (Assobadjo *et al.* 2012, Cissé *et al.* 2019, Nabaloum *et al.* 2022). The practice of agroforestry in these areas is a key factor in their superior performance in terms of ES. The primary reason for leaving trees in agroecosystems is the commercial value of their edible fruit, medicinal uses and soil fertility (Kristensen & Lykke 2003, Olivier & Sanou 2003). For example, *Vitellaria paradoxa, Parkia biglobosa, Adansonia digitata and*

Tamarindus indica are very appreciated for their edible fruit and medicinal use. Similarly, species such as *Faidherbia albida* and *Piliostigma thonningii* are kept in agroecosystems for their medicinal uses and their contribution to soil fertility (Nabaloum *et al.* 2022, Zomboudre & Hien 2025). Consequently, local populations should be receptive to awareness-raising and development actions which take into account their well-being (Hien *et al.* 2021). In contrast, gallery forests at different levels of ecological disturbance have the lowest CAPm levels, despite having high tree cover. Indeed, in gallery forests, tree cover is high but woody species richness is low (Kaboré *et al.* 2013) due to the dominance of one or two species. Consequently, this LULC class offers few ES. It must be acknowledged that the CAPm calculated for the potential services provided by plant communities focus solely on woody species.

The low mean provision of ES by woody species in TWRB could be explained by unsustainable use of woody species in this protected area (IUCN\PACO 2009, Dimobe *et al.* 2015). As plant resources are abundant in the collective consciousness, the riparian populations of TWRB do not make efforts to maintain and conserve woody resources. However, the WD populations are aware of the fragility of the resources, which they see becoming scarcer day by day, and take care to maintain and conserve the plant species that are useful to them by adopting mass agroforestry (Traoré *et al.* 2011, Dimobe *et al.* 2018, Cissé *et al.* 2019).

In contrast, RGN is characterized by tree and shrub savannas, which are significant providers of cultural services (Dimobe *et al.* 2017). Consequently, cultural services are more prevalent in this study site. While tourists are attracted by RGN's rich and varied fauna, the diversity and abundance of its flora contribute to its aesthetic appeal, providing shelter and habitat for animals. The conservation efforts of forestry managers, notably through surveillance of the ranch territory and practice of early fires, contribute to the maintenance of vegetation cover (Dimobe *et al.* 2017), and thus the ES they provide. The population of GRN participates in the management of the ranch and benefits from the financial incomes of tourism; they do not take interest in the degradation of the forest (Nabaloum *et al.* 2022).

The total capacity to provide ES highlights the importance of the size and conservation status of the study area for providing ES in natural savannas. In protected areas, forest authorities' conservation measures in favour of biodiversity are more restrictive, thereby favouring biodiversity and improving the supply of ES (Ouédraogo *et al.* 2020).

The present study has identified certain limitations in the methodology employed. Notwithstanding the integration of socio-ecological frameworks and cultural ecosystem services, which enriches the analysis, a number of methodological limitations must be noted. Firstly, the abundance of utilitarian species is not solely the result of proactive management. It is important to note that passive conservation (i.e. the preservation of pre-existing individuals during land clearing) and active introduction (i.e. deliberate planting) are practiced by local communities in agroecosystems (Coulibaly *et al.* 2022, Fayama *et al.* 2023). In addition, the validity of ethnobotanical data is subject to recall bias (omission of less valued species) and the 'shifting baseline' phenomenon (Dossou *et al.* 2012; Hadonou-Yovo *et al.* 2019). Consequently, the calculated service provision indices provide only a minimal indication of the actual capacity of ecosystems.

Implications for conservation

This study shows the high Psf weight of all studied LULC classes in providing regulating and provisioning services. The calculated indices are based on perceptions of ES by local populations and give an anthropocentric connotation to these indices. The informants cite abundantly the services which directly address their essential needs (notably provisioning services). According to Ouédraogo *et al.* (2014), the most vulnerable plant community could be determined by locating the one that provided the most services, notably the agroecosystems in our study. But through their management of agroecosystems, local populations ensure the provision of ES in their immediate environment by conserving useful species in their agroecosystems. Agroecosystems, including agroforestry, need to be protected because they help to protect other LULC classes from anthropogenic pressures. This implies paying greater attention to intensification of agroforestry in agroecosystems with diversification of tree species preserved in the agroecosystems. In Nabaloum *et al. (*2022), the local populations, aware of the degradation of the ecosystems, had proposed to reinforce the awareness of the necessity of sustainable management of the species providing ES and the biodiversity of the savannas. The preservation is done by populations once they know the services provided by ecosystems. In addition, the harvesting and value chains of non-timber forest products from these ecosystems provide an economic argument in favour of conservation (Nabaloum *et al.* 2025).

In addition to this awareness, it will be appropriate to initiate environmental education through training adapted to each community by respecting their spirituality, knowledge, and traditional management practices and local development (Savadogo *et al.* 2017, Osman *et al.* 2022). Thus, local populations can participate sustainably in the conservation of biodiversity and the increase in availability and productivity of species providing ES (Ouédraogo *et al.* 2014). Sustainable management of the savannas involves tree planting and assisted natural regeneration of species providing ES in fields and near habitations, as well as their reintroduction into unprotected areas. The planting and conservation of multiple tree species facilitates the full utilisation of the multiple services provided by ecosystems. Multi-species management can better realise the full potential of ecosystem services that are valuable from economic, ecological, and cultural perspectives (Gamfeldt *et al.* 2013). Furthermore, the planting of these species will contribute to the implementation of the REDD+ mechanism through carbon sequestration, providing an additional source of income for local communities (Ouédraogo *et al.* 2026).Despite their low Psf in the provision of ES, gallery forests constitute the interface with the important ecological function of water and nutriment flow control between the river and the surrounding vegetation (Solefack *et al.* 2018, Nacoulma *et al.* 2019). Furthermore, the ecological functions of savannas ensure the formation and maintenance of soils and the ability to support a wide diversity of plant and animal species which contribute directly or indirectly to the provision of ES (Dufrêne & Maebe 2017).

Conclusion

Agroecosystems have been found to provide the greatest number of ES due to their sustainable management. Moreover, the proximity of species occurring in agroecosystems, combined with our understanding of their use, increases their vulnerability. It should be noted that knowledge about a species' virtues is directly correlated with levels of exploitation; the more a species' virtues are known about, the more it is exploited. In fact, in agroecosystems of the study areas, local populations practice agroforestry through preservation of the species useful in their fields. Intensification of agroforestry in agroecosystems could help avoiding human occupation and overexploitation in the other LULC classes which contribute to the conservation of savanna biodiversity. The savannas in the protected area without human pressure (RGN) have the highest total capacity to provide ES. However, in addition to the services they provide directly to humans, plant species provide vital functions for ecosystems such as supporting services (soil fertilization) and regulating services (wind protection, water purification and erosion prevention). These supporting and regulating services help maintaining the supply of provisioning services to humans while contributing enormously to the maintenance and conservation of savanna ecosystems. It is in this perspective that the promotion of regulating, cultural and supporting services of species in ecosystems becomes important. Thus, local populations will be able to become aware of the importance and the necessity of the conservation of the natural ecosystems, in particular the savannas and the gallery forests. Finally, to extend this ethnobotanical study, we recommend combining this local knowledge with rigorous biophysical inventories. This comparison of community perceptions with empirical realities in the field will help consolidate the overall understanding of the ecosystem.

Declarations

List of abbreviations: ES - Ecosystem Service**;** WD - Watershed of Dano; TWRB - Total Wildlife Reserve of Bontioli; GRN - Game Ranch of Nazinga; LULC - Land Use/Land Cover; IVI - Importance Value Index; UV - Use Value; Cult - cultural services; Pro - provisioning services; Reg - regulating services; Supp - supporting services;

Ethics approval and consent to participate: The research was conducted with a focus on individual liberty, customs, and beliefs. The objectives of the work were first explained to the chiefs of the village and each participant, and their authorisation to conduct the study was obtained. Prior to the administration of the questionnaire, individual consent to participate in the study was obtained. The study's participants were exclusively individuals who had voluntarily consented to partake in the research.

Consent for publication: Not applicable

Availability of data and materials: The datasets used and/or analysed in the current study are available upon reasonable request to the corresponding author.

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Author contributions: A.N. conceived the work with advices from A.T. A.N. and K.D. collected the data processed them and performed the statistical analyses. A.N. wrote the paper with contributions of K.D., I.O., D.G. and A.T. D.G. coordinate the research project in the WASCAL program. A.T. supervised the work. All authors read and approved the final manuscript.

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