Local perceptions, uses and conservation status of *Detarium senegalense* in the Dahomey Gap (West Africa)

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Abstract

Several species, including *Detarium senegalense*, face exploitation without regard for conservation or regeneration status, posing a severe threat and contributing to their decline. Few studies addressed conservation strategies of *Detarium senegalense*. This paper aimed to document the indigenous knowledge of local communities regarding *D. senegalense* and its conservation status in the Dahomey Gap region. Data were collected through semi-structured individual interviews and focus groups involving 404 participants from thirty-eight villages, representing four phytogeographic zones in the Dahomey Gap. Collected data included local names, recognition criteria, abundance measures, and uses of *D. senegalense*. This data supported calculations of knowledge diversity, evenness index, organ usage frequency, and vulnerability indices. The Student Newman and Keuls test were used for multiple comparisons and Correspondence Analysis examined the relationships between variables. Analysis showed that most respondents were familiar with the species (75.0%), but only half possessed knowledge of its uses. The diversity of knowledge was unevenly distributed among the respondents (IE <0.5). Significant variations in knowledge were observed among phytogeographic zones and ethnic groups, while no substantial differences were found based on gender or age. The study identified the almond as the primary organ of interest for local populations due to its involvement in international trade. The timber obtained from the tree was also used. Natural habitats of *D. senegalense* were found to be in decline, with logging being identified as the main cause of habitat destruction according to 58.5% of respondents. Consequently, the vulnerability index indicated that *D. senegalense* is highly vulnerable in its natural environment with vulnerability indices higher than 2.5 in all phyto-districts. Considering the nutritional and medicinal value of *D. senegalense*, we emphasize the need to investigate structural, morphological, and molecular aspects for conservation and sustainable use.

Keywords: *Detarium senegalense*, endogenous knowledge, Vulnerability indices, Natural habitat, Plant organs

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INTRODUCTION

Natural ecosystems are indispensable suppliers of resources that serve to diverse human needs, including sustenance, artisanal materials, medicinal remedies, and spiritual significance (Lykke *et al*., 2004; Ipbes, 2019). Among these ecosystems, forests play a crucial role in conserving biodiversity by providing habitats for numerous animal and plant species. Moreover, they represent a significant reservoir of natural resources for many tropical countries, making substantial contributions to biodiversity and ecological balance (N'Guessan *et al*., 2019). In the context of food resources, edible woody species refer to trees and shrubs that produce leaves, flowers, fruits, seeds, or other parts suitable for human consumption (Ouédraogo, 2010).

In sub-Saharan Africa, in addition to agriculture, livestock rearing, and fishing, the collection of non-timber forest products (NTFPs) stands out as a significant source of income, food, and medicinal resources for rural communities (Ezebilo and Mattsson, 2010; Mawunu *et al*., 2017; Tchat-chambe *et al*., 2017a and b; Mawunu *et al*., 2019). In West Africa, phytogenetic resources particularly fruit trees, play a vital role in ensuring food security and the population health (Diop, 2013; Sourou *et al*., 2016). Various parts or organs of many woody plants are extensively used in traditional medicine and daily practices, including timber for construction and service purposes (Fandohan *et al*., 2008). Wild fruits are often consumed directly at the collection or harvesting sites, while others are commercially marketed, providing income for households, and contributing to food security and improved health and nutrition of the population. The significant contribution of fruit trees to these aspects is attributed to their rich diversity (Bowe and Haq, 2010).

While forest biodiversity holds crucial importance for African rural populations, several forest species are threatened in their natural habitats due to human activities and climate variations. The potential disappearance of numerous woody species is imminent, driven not only by over-exploitation but also by improper harvesting practices and inadequate regeneration (Betti, 2001; Ouédraogo, 2008; Traoré, 2008; Agali, 2009; Belem, 2009). Many rural households rely on non-timber forest products to fulfill their nutritional, health, and construction needs (Heubach *et al*., 2011; Shackleton *et al*., 2015). According to Traoré *et al.* (2011), these species, which are beneficial to rural communities, face threats in their natural habitats due to deforestation, vegetation fires,

extensive cattle grazing, charcoal production, abundant use of firewood, slash-and-burn cultivation, illegal logging, and uncontrolled movement of genetic material for plantation establishment. Consequently, there is an urgent necessity to conserve agroforestry species in general (Boffa, 2000; Belem, 2008; Devineau *et al*., 2009), with particular attention to edible species.

Enhancing our comprehension of the motivations behind the use of these plants is crucial for capturing and safeguarding local knowledge associated with indigenous species. This knowledge is vital for conservation efforts and the formulation of effective domestication strategies (Chekole *et al*., 2015). The integration of indigenous knowledge in the development of management and conservation strategies for native plant resources is essential to ensure their effectiveness (Avocèvou, 2011). This underscores the need for a deeper understanding of the capacity of available natural resources and their usage by the population.

Several studies have highlighted the importance of forest products, particularly the diverse services they provide to communities living near forests (Larwanou *et al*., 2010; Lougbégnon *et al*., 2011; Thiombiano *et al*., 2012; Yameogo *et al*., 2013; Houètchégnon *et al*., 2013; Dangbo *et al*., 2019; Dossa *et al*. 2019). According to Masengo *et al*. (2021 a and b), the sustainability of phytogenetic resource management depends on considering the social, cultural, and economic values held by local communities. However, several species are coveted and exploited without regard for their conservation status and, especially, their regenerative capacity, posing a serious threat and contributing to their decline. *Detarium senegalense* is a prominent example, widely used for various purposes such as food, medicinal applications, timber, and more, in several West African countries including Nigeria, Senegal, Togo, and Benin. In Nigeria, the flour derived from *D. senegalense* almonds is widely consumed and holds considerable importance in the food and pharmaceutical industries (Sowemimo *et al*., 2011; Malami *et al*., 2021). A decoction prepared from the bark is believed to be effective in treating conditions like haemorrhage, pneumonia, diarrhea, stomach disorders, digestive issues, and facilitating placenta expulsion after childbirth (Sowemimo *et al*., 2011). In Benin, this species faces numerous threats to its survival in the short, medium, and long term, including its use as timber wood and the existence of almond trade routes to Nigeria, Ghana, and Togo (Neuenschwander *et al*., 2011). In addition, Atato *et al*. (2010) and Dangbo *et al*. (2019a) highlighted the substantial involvement of *D. senegalense* seeds in commercial trade in Togo. In this context, the survival of this species now relies on appropriate exploitation approaches coupled with techniques for natural and/or assisted regeneration while considering its vulnerability.

The vulnerability of a plant species refers to its susceptibility to the risks of decline or extinction due to inadequate harvesting methods, increasing human pressures, and climate variability within its habitat (Traoré *et al*., 2011). In the context of conserving this highly important forest species, it is crucial to assess its vulnerability, considering anthropogenic factors. To achieve this, it is essential to obtain reliable data on the diverse uses of the species and the level of threats across different socio-cultural groups in Benin and Togo within the Dahomey Gap.

Hence, the present study had as objective to document the endogenous knowledge of local communities regarding *D. senegalense* and its conservation status in the study area.

MATERIAL AND METHODS

Study area

The study was conducted among communities living near forested areas, whether classified or not, where *D. senegalense* is found. According to Adomou *et al*. (2005), Akoegninou *et al*. (2006), Atato *et al*. (2010), and Dangbo *et al*. (2019b), *D. senegalense* is present in the Guinean, Guineo-Sudanian, Sudanian-Guinean, and Sudanian zones. Therefore, the specific focus was on the phyto-districts of Borgou Sud and Bassila in Benin, as well as zones III and IV in Togo, all located within the Dahomey Gap in West Africa. An exploratory survey was conducted in the study area to identify potential communities for the main surveys. As a result, four municipalities (in Benin) and four prefectures (in Togo) were selected, namely Tchaourou, Ouèssè, Bantè, and Bassila in Benin, and Tchamba, Est-Mono, Akebou, and Wawa in Togo (Figure 1). In total, thirty-eight villages and hamlets scattered across all eight administrative units (municipalities or prefectures) were surveyed.

Economically, agriculture is the main activity among the communities in the study area. The crops grown include maize, yam, rice, cowpea, Bambara groundnut, and others. Perennial plantations such as cashew, coffee, cocoa, teak, and gmelina are also established. Livestock rearing, predominantly practiced by the Fulani and agro-pastoralists, is of the sedentary or transhumance husbandry type. Feeding and watering of the livestock mainly rely on natural grazing, typically along watercourses and ponds. Two types of hunting are practiced: traditional hunting with rudimentary weapons during the dry season and illegal hunting using sophisticated or crude firearms. Vegetation fires are used both in soil preparation for agriculture and in hunting activities. Fishing, on the other hand, takes place in the major watercourses during the dry season. Trade appears to be the main activity for women, constituting a significant source of income, particularly in the sale of staple foods, forest products such as firewood, charcoal, and NTFPs (fruits, seeds/nuts, or other plant parts). The communities consist of several ethnolinguistic groups and practice diverse religions, including Animism, Islam, and Christianity.

Sampling and data collect

The survey was conducted during July, November, and December 2020, as well as January and February 2021. The selection of survey locations was based on an exploratory study carried out in the areas where *D. senegalense* is known to occur, as reported in previous studies conducted in Benin and Togo (Adomou *et al*., 2005; Akoegninou *et al*., 2006; Atato *et al*., 2010; Dangbo *et al*. 2019b). The

exploration aimed to study the distribution and relative abundance of the species in each phytogeographic zone of Benin and Togo. Additionally, it sought to identify the localities closest to the natural habitats in each zone where the populations have an interest in *D. senegalense*. During these preliminary surveys in the study area, it was observed that on average, 21.4% of the respondents had knowledge of the uses and habitat of the species. Thus, the sample size for the study was determined using the normal approximation of the binomial distribution proposed by (Dagnelie, 1998; Levy et Lemeshow, 2008).

$$N = U^2 1 - \alpha/2 \frac{pi(1-pi)}{\delta 2}$$

With N the sample size, pi (21.4%) the proportion of individuals who know and/or have knowledge of at least one use of the species, $U^2 1\text{-}\alpha/2$ the value of the standard normal variable for a risk α ($\alpha = 0.05$; $U^2 1\text{-}\alpha/2 = 1.96$), and δ the margin of error set at 4%. The sample size N was calculated to be 403.8 respondents, rounded up to 404 respondents.

Each respondent, as well as focus groups, participated in a semi-structured individual questionnaire. The questionnaire encompassed the following sections: (i) gathering socio-demographic information of the respondents, including name, age, gender, ethnic group, and phytogeographic zone, (ii) exploring the diverse uses of different parts of the species, (iii) identifying criteria for distinguishing individuals of the species, and (iv) investigating the various pressures affecting the species and its habitat. Individual and group surveys, typically consisting of 2 to 5 participants, were conducted. The use of focus groups facilitated the collection of reliable information, as it encouraged discussions and interactions among the group members, resulting in data that was collectively endorsed (Assogbadjo, 2008). In addition, observations and field verification phase was carried out. This phase involved locating the natural habitats of *D. senegalense* in the study area, which served two main purposes: firstly, to corroborate the field observations with the interview data, and secondly, to identify the sampling points for the forest inventories

Data analysis

For data analysis, the respondents were grouped into different levels of stratification (phytogeographic zone, age category, ethnic groups, and gender) based on the classification proposed by Houehanou *et al.* (2008) and Amouzoun *et al.* (2019). To explore the variations in this variable based on socio-demographic characteristics of the respondents, a generalized linear model of the Poisson family was applied.

To document local perceptions about the uses and dynamics of *D. senegalense* populations, several analytical approaches were employed. Firstly, a dynamic cross-tabulation table of different variables was created to compare various uses of *D. senegalense* organs and identify the most used ones. To assess species uses knowledge of respondents, a response rate was calculated to evaluate the level of knowledge and use of *D. senegalense* organs among different ethnic groups surveyed.

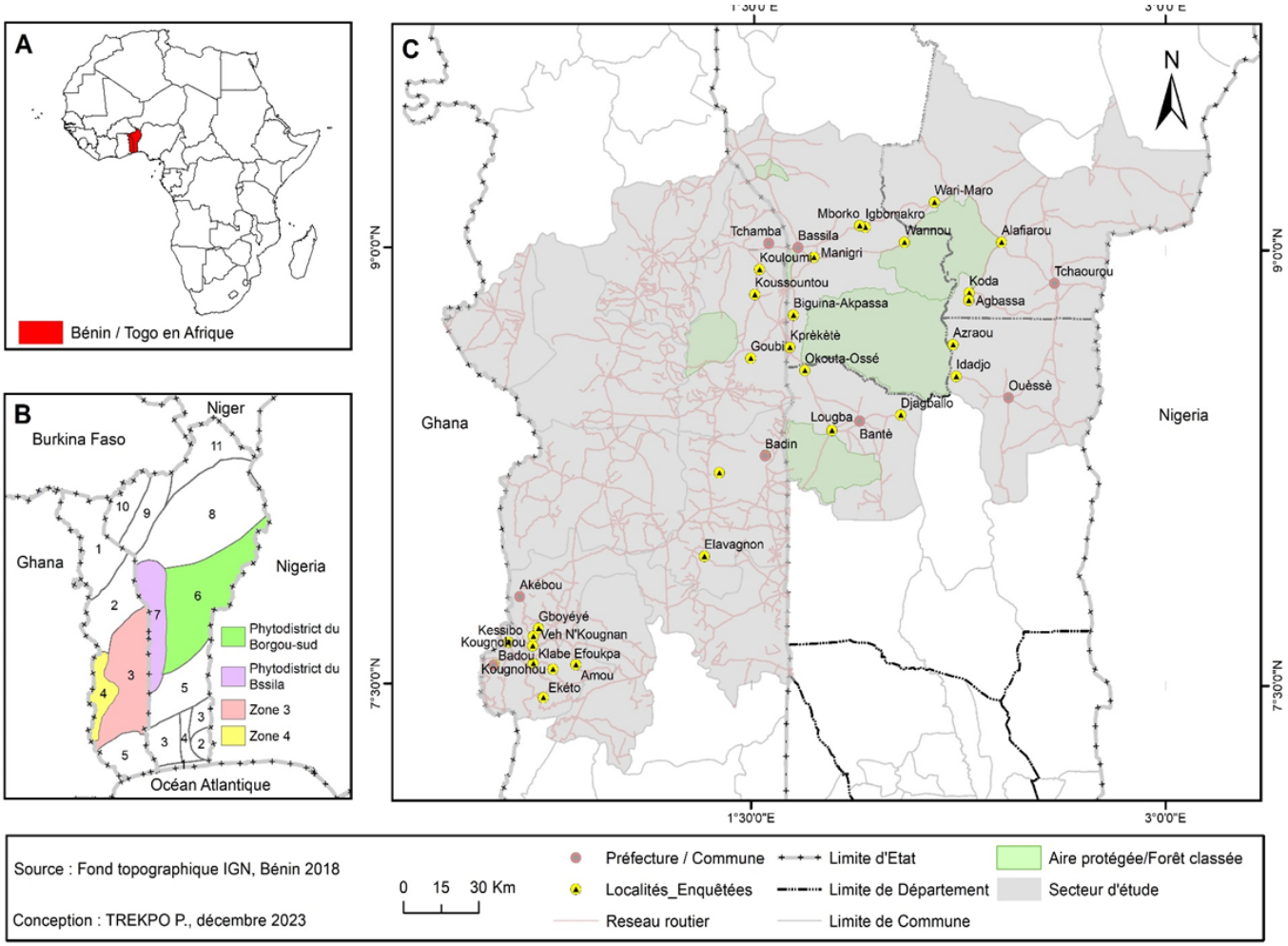

Figure 1: Location of survey sites

The Student Newman and Keuls test were used for multiple comparisons of knowledge levels. Additionally, an Analysis of Correspondences was conducted to examine the relationships between these organs and different ethnic groups. Ethnobotanical indices were calculated to determine the distribution of knowledge within the surveyed ethnic groups (Table 1). Furthermore, the diversity of uses for each *D. senegalense* organ were determined based on the diversity and evenness index (Table 2).

To investigate the conservation status, particularly the level of degradation of natural habitats, the threats facing the species, and its vulnerability across different socio-cultural groups, the following ethnobotanical parameters were computed. These parameters include the frequency of use and the vulnerability index of the species (Table 1). Additionally, the proportion of responses per type of habitat degradation factor was calculated. All analyses were performed using R software, version 4.2.3.

Table 1: Ethnobotanical parameters

Parameters	Formula	Interpretation	References
Diversity index of respondents (ID)	The Shannon and Weaver diversity index was computed using the formula: $ID=-\Sigma(ni/N)\log(ni/N)$ ni represents the number of use categories cited by a specific interviewee i, and N represents the total number of use categories cited by all respondents for the species.	Quantifies the extent to which respondents are aware of and use the species, while also assessing the distribution of this knowledge among the respondents. A low ID indicates that only a small number of individuals are familiar with and use the species, while a high index suggests that a large proportion of respondents are knowledgeable about and actively use it. The index value ranges from 0 to m, where m represents the number of respondents who use the species.	Byg et Baslev (2001)
Pielou's evenness index of respondents (IE)	Diversity value (ID) divided by the maximum index of the diversity value obtained. The formula is IE =ID/IDmax	The Pielou's evenness index measures the level of homogeneity in respondents' knowledge. It varies between 0 and 1. An index value (IE) below 0.5 indicates that knowledge of respondents is not evenly distributed, suggesting a lack of homogeneity. Conversely, an IE value of 0.5 or higher indicates homogeneity, implying that only a few respondents possess extensive knowledge of multiple uses for the species.	Byg et Baslev (2001)
Frequency of use (FU) of each organ	$FU = 100\ \frac{np}{N}$ np, the number of respondents citing a given organ and N, the total number of respondents.	FU is typically measured by recording the number of times a specific plant organ is mentioned or reported in interviews. This information helps researchers understand the significance and importance of different plant organ in the local knowledge and practices of the studied population. A high FU for a particular plant organ suggests that it plays a crucial role in the daily lives or traditional medicine of the community. Conversely, a low frequency of use may indicate that the plant organ is less relevant or less commonly used.	Agbo *et al.,* 2017
Vulnerability index	$IV = \frac{\sum ni}{9}$	To evaluate the influence of *D. senegalense* organ usage across various use categories, the vulnerability index (IV) was computed by applying a vulnerability scale assigned to specific parameters, as previously employed by different researchers. The parameters considered in this study encompassed the frequency of use (FU), the number of use categories (NU), the types of plant organs used, the method of organ collection, the stage of development, the type of biotope, the type of morphology, the abundance, and the natural regenerative capacity. Based on the vulnerability scale used by Betti (2001), the assessment of vulnerability by each parameter ranges from 1 to 3. A value of 1 represents a low level of vulnerability, 2 signifies a medium level of vulnerability, and 3 indicates a high level of vulnerability. In this study, vulnerability index (Iv) was interpretated following the thresholds used by Traoré et al. (2011) and Yaovi et al. (2021): weakly vulnerable if Iv < 2, moderately vulnerable if 2 ≤ Iv < 2.5, and highly vulnerable if Iv ≥ 2.5.	Betti *et al.,* 2001, Traoré *et al.,* 2011; Masengo *et al*. 2022

Table 2: Assessment scale of vulnerability of *D. senegalense*

Parameters	Vulnerability to uncontrolled exploitation (*)		
	Low (scale = 1)	Medium (scale = 2)	High (scale = 3)
Frequency of use (FU)	FU < 20%	20% ≤ FU < 60%	FU ≥ 60%
Number of use (NU)	NU < 2	2 ≤ NU ≤ 4	NU ≥ 5
Used organs	Leaf; latex	Fruit; branch;	Almond; flowerbark; root
Collection method	Collecting	-	Picking; cutting
Stage of development	Old or senescent	Adult	Young
Biotope (forest)	Everywhere	Any vegetation type	Gallery forest or semi-deciduous forest
Type of morphology	-	-	Tree
Abundance	High	Medium	Low
Natural regenerative power	High	Medium	Low

(*) Traoré et al., 2011; Dassou et al., 2014; Agbo et a l., 2017; Masengo et al. (2022)

RESULTS

Ethnobotanical perceptions and uses of *D. senegalense*

Socio-demographic characteristics of respondents

In relation to the phytogeographic zones, Borgou Sud stood out as the most prevalent, representing 35.2% of the respondents, followed by Zone III at 24.1%. As for ethnicity, the Nago and related groups constitute the majority, accounting for nearly 50% of the surveyed population, while the Akposso come in at a distant second with 9.36%. In terms of age categories, adults between 31 and 59 years old make up over two-thirds of the respondents. Lastly, regarding gender, the proportions are almost equal, with approximately 50% of the respondents being female and 50% being male (Table 3).

Table 3: Socio-demographic data of the respondents

Category	Socio-cultural layers	Percentage of respondents
Phytodistricts	Borgou sud	35.2
	Bassila	23.4
	Zone III	24.1
	Zone IV	17.2
Ethnic groups	Nago & ap	49.5
	Peulh & ap	5.91
	Anii & ap	7.39
	Ditammari & ap	0.74
	Lokpa & ap	1.72
	Bariba	4.43
	Fon & ap	1.97
	Akposso	9.36
	Ewé & ap	3.20
	Kabiè & ap	3.20
	Akebou & ap	3.69
	Moba & ap	1.48
	Lama & ap	3.94
	Losso & ap	3.45
Age classes	Young (age ≤ 30)	22.7
	Adult (30 < age < 60)	62.6
	Old man (age ≥ 60)	14.8
Gender	Female	49.5
	Male	50.5

Nomenclature

D. senegalense, also known as "arbre à suif, grand détar" in French and "dattock tree" in English, has different local names depending on the sociolinguistic groups present in the Dahomey Gap. These names are sometimes made up of two words. Examples include "N'Ténékpé N'toudja or N'tutèdiakpé" among the Anii, "Ôlô odo" among the Nagot (Table 4).

Knowledge about the species according to sociolinguistic groups

Across the entire study area, an average of 75% of the respondents were familiar with *D. senegalense*, either the tree itself or one of its organs and/or its natural habitat. However, only 50.2% were aware of at least one use of the species. Analysis indicated a significant difference in knowledge between phyto-districts and between ethnic groups. However, knowledge did not differ significantly by gender or age (Table 5). The number of uses was highest in phyto-districts IV (0.93 ± 0.31) and lowest in the Borgou Sud phytodistricts (0.03 ± 0.18). Regarding usages of the species by ethnic groups, the number of uses was highest among Moba, Ditamari, Akebou, Kabiè and Akposso, with frequencies ranging from 0.90 to 1.17. However, Fon, Peulhs, Bariba and Nagot recorded a low level of use, with frequencies lower than 0.48.

Knowledge about *D. senegalense* exhibited greater diversity in Zone IV and among the Kabiè and Moba communities (a minority) within the study area, primarily because most respondents were non-natives. Conversely, knowledge was comparatively lower in Borgou Sud phyto-district and among the Fon and associated groups (Figure 2).

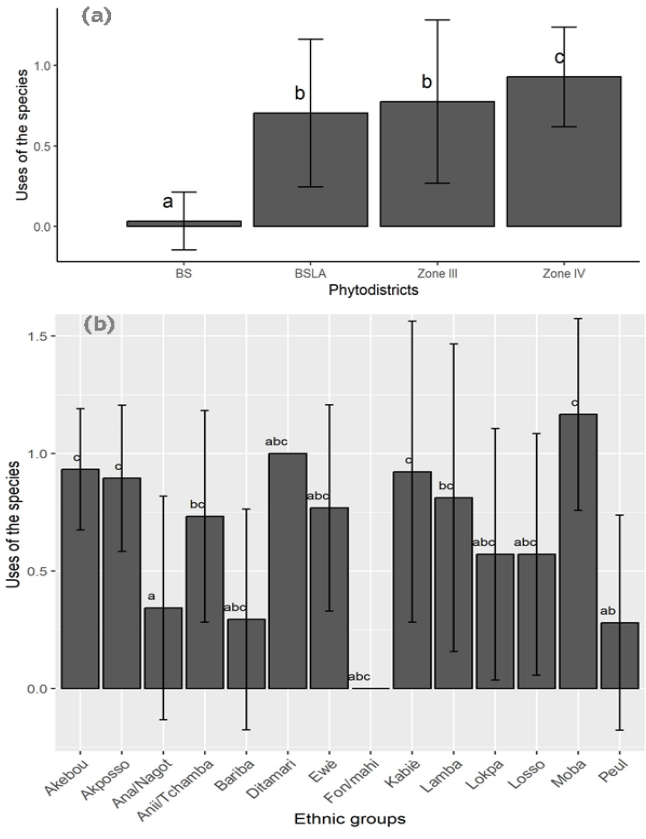

Figure 2: Changes in knowledge of uses by phytodistrict (a) and ethnic group (b)

Table 4: Some names of *D. senegalense*

Ethnic group	Designation	Comments
Anii	*N'Ténékpé N'toudja ou* N'tutèdiakpé	Forest and river trees
Bariba	*Bèssègonou*	
Nagot	Ôlô odo; Iyèrè agbo; Akoko	Living tree at the water's edge
Akposso	Akpa, Kpèkpè	Betor tree (commercial name of the almond)
Peulh	Kenikedje, *Konkheyir*	
Fon	Dokpa, Dakpa	
Lokpa	*Kpahalè*	
Losso	Kpaayé	Water tree

Diversity and evenness indices

The study computed and presented the Shannon-Weaver diversity index (ID) and evenness index (IE) based on different factors such as phyto-districts and sociocultural layers (Table 6). The diversity index (ID) ranged from 1.61 to 23.3, with low evenness index (IE) values below 0.5, indicating diverse and heterogeneous knowledge among the respondents. Regarding gender, the knowledge diversity among women was relatively more homogeneous compared to men. Similarly, different ethnic groups show varying knowledge diversity, with all groups displaying heterogeneity. Among age groups, adults demonstrate more homogeneous knowledge diversity than the youth and the elderly.

When considering the entire study area regardless factors or categories, the evenness index remained low (0.323), indicating that the distribution of knowledge diversity among the respondents were not uniform.

Socioeconomic perceptions of *D. senegalense*

The findings revealed that local trade of *D. senegalense* almonds was common. In the phyto-district of Bassila, a significant number of women (58%) recognized the existence of a well-organised market for *D. senegalense* almonds, while this percentage was lower (ranging from 17% to 24%) in the other three zones studied. As for sector animation, the presence of some individual intermediaries was approved by both men and women

Table 5: Variation in knowledge levels by socio-cultural category

Socio-cultural categories	Socio-cultural layers	Number of uses per respondent	Results of ANOVA
Phytodistricts	Zone IV	0.93 ± 0.31	$\chi2$ = 293.438 p = 0.000
	Zone III	0.78 ± 0.51	
	Bassila	0.71 ± 0.46	
	Borgou Sud	0.03 ± 0.18	
Ethnic groups	Akebou	0.93 ± 0.26	$\chi2$ = 132.20 p = 0.000
	Akposso	0.90 ± 0.31	
	Ana/Nagot	0.34 ± 0.48	
	Moba	1.17 ± 0.41	
	Ditamari	1.00 ± 0.00	
	Kabiè	0.92 ± 0.64	
	Lamba	0.81 ± 0.65	
	Ewé¨	0.77 ± 0.44	
	Anii	0.73 ± 0.45	
	Bariba	0.29 ± 0.47	
	Peulh	0.28 ± 0.46	
	Fon/mahi	0 ± 0	
	Lokpa	0.57 ± 0.53	
	Losso	0.57 ± 0.51	
Age	Young	0.57 ± 0.52	$\chi2$=0.112 p=0.95
	Old man	0.524 ± 0.521	
	Adult	0.48 ± 0.53	
Gender	Female	0.53 ± 0.53	$\chi2$=0.43 p=0.51
	Male	0.50 ± 0.52	

Table 6: Ethnobotanical knowledge of *D. senegalense* at different stratification levels

	Socio-cultural categories	Number of respondents aware of at least one use	ID	IE
Phytodistricts	BS	5	1.61	0.02
	BSLA	62	20.0	0.30
	Zone III	72	23.3	0.35
	Zone IV	65	20.9	0.32
Ethnic groups	Bariba	5	1.61	0.02
	Anii	22	7.08	0.11
	Ditamari	3	0.97	0.02
	Lokpa	4	1.29	0.02
	Nago	69	22.2	0.34
	Peul	7	2.25	0.03
	Ewè	11	3.54	0.05
	Kabiè	10	3.31	0.05
	Lamba	11	3.63	0.06
	Losso	8	2.57	0.04
	Akebou	14	4.51	0.07
	Akposso	34	10.9	0.17
	Moba	6	1.97	0.03
Age classes	Adult	104	33.6	0.51
	Young	46	14.8	0.22
	Old man	54	17.4	0.26
Gender	Female	104	33.6	0.51
	Male	100	32.3	0.49

in varying proportions (42% and 85%, respectively). In Benin, the sale channel of seeds involved traders of both genders in equal percentages (100% each) in Bassila, but women (72.2%) were the primary sellers in Borgou Sud. In Togo, it was unanimously recognized that men from zone III and women from zone IV participated in the seed trade (Table 7).

Conservation status and vulnerability of *D. senegalense*

Frequency of use of *D. senegalense*

Several ways of using *D. senegalense* were observed, leading to populations using various plant parts, but in different proportions. Frequencies of use (FU) were determined for each plant parts (Figure 3). The most used part of *D. senegalense* was its seed or almond, followed by the wood. However, other parts, including fruit (pulp), leaf, bark, or root, were not used very extensively. This observation was in line with the on-site findings, where both men and women were primarily involved in activities related to fruit gathering for almond extraction and the use of wood for various purposes associated with *D. senegalense*.

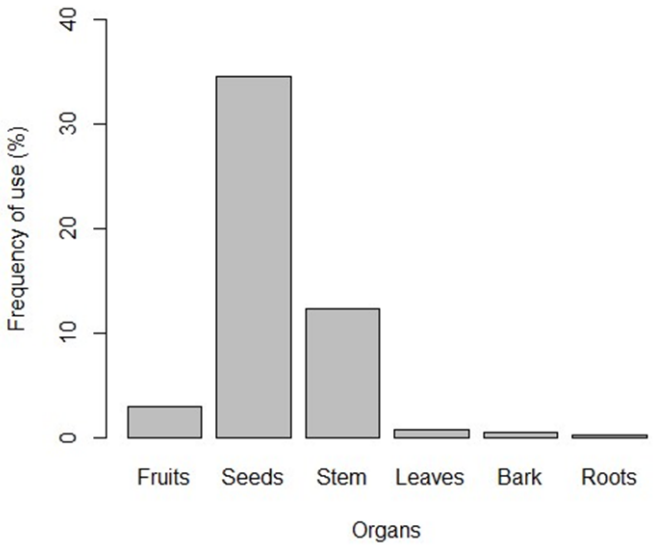

Figure 3: ***Frequency of use of D. senegalense organs***

Drivers of degradation of natural habitats of *D. senegalense*

The natural environments where *D. senegalense* was found correspond primarily to wet areas along watercourses, semi-deciduous dense forests, and foothills of mountains, regardless of the ethnic background of those surveyed. Most of the respondents who were acquainted with this species agreed that the existing individuals of *D. senegalense* were mostly mature specimens. This observation raised concerns about the natural regeneration of the species, highlighting the necessity of implementing measures to ensure its sustainability. Certain trees are spared during deforestation, especially in specific areas like the Akposso plateau, among the Akebou people, and the Ana (related to Nago) community. However, some of these preserved trees were unfortunately exploited for timber and charcoal production.

The investigations carried out among the local populations living near potential sites where *D. senegalense* is or was present revealed a range of perceptions regarding the level of habitat degradation, varying from low to very high (Figure 4). However, it is noteworthy that regardless of the phyto-district, most respondents (rang-

Table 7: Perception of socio-economic importance by gender and phyto-district

Phyto-districts	Selling seeds		Well-organised sector		Existence of intermediaries		No sector	
	M	F	M	F	M	F	M	F
Bassila	100	100	21	58	74.5	42	4.53	0
Borgou Sud	64.4	72.2	21	17	49	55	30	28
Zone III	100	97.1	17	12	83	85	0	3
Zone IV	98	100	18	24	80	76	2	0

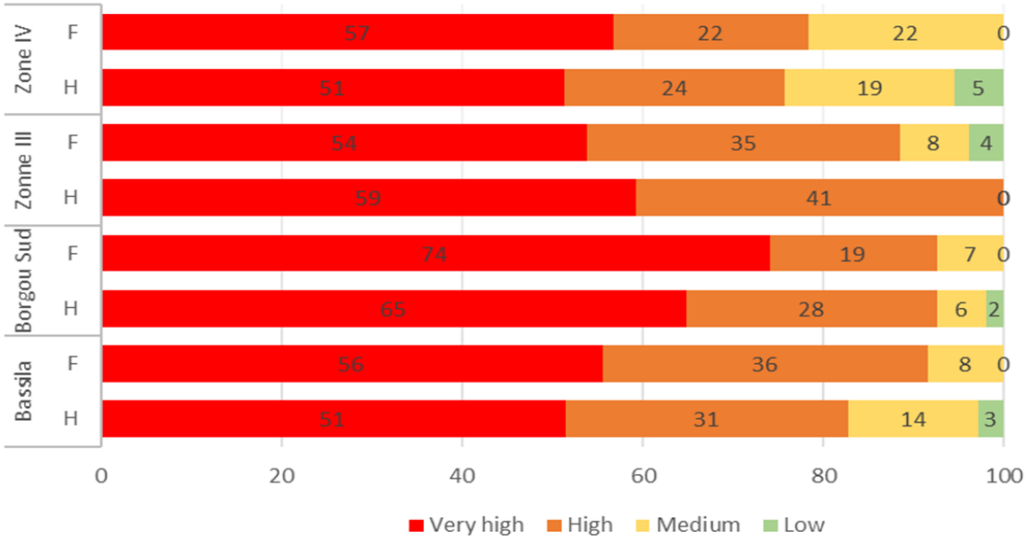

Figure 4: ***Perception of the level of degradation of natural habitats according to gender and phyto-districts***

ing from 51.3% to 74.1%) expressed concerns about a very high level of habitat degradation. This concern was particularly prominent in Borgou Sud phyto-district, where over 64% of men and 74% of women held the opinion of a significantly increasing level of degradation. Furthermore, the farmers who had *D. senegalense* trees in their garden or field claimed that they obtained them naturally and not through planting.

Almost all men and women, regardless of age or ethnicity, stated that currently, to locate *D. senegalense* trees, one must venture deeper into protected forests or other designated areas in the phyto-districts of Bassila, Borgou Sud, and Zone III. This suggests that the natural habitats and *D. senegalense* individuals were experiencing various factors leading to their destruction. However, in Zone IV, *D. senegalense* could be found in coffee, cocoa, and kola plantations, as well as in home gardens.

This habitat loss of *D. senegalense* could be explained by several drivers with various level (Table 8). In Borgou Sud, Bassila and zone III, most of respondents identified forest products exploitation (illegal and abusive logged for timber and charcoal) as the main anthropogenic drivers of habitat degradation of the species. This phenomenon was cited with high frequency in Borgou Sud phyto-district (approximately 90% of both men and women). Nevertheless, agriculture was identified as the main factor of degradation of the natural habitats of the species in Zone IV, followed by deforestation caused by logging activities. Additionally, in other phyto-districts, agriculture was acknowledged as a secondary cause of habitat degradation for the species. The study has revealed that among respondents in the Bassila phyto-district, approximately 17% attributed negative impacts on the species' habitats to fruit gathering. However, in all four phytogeographic zones, lower than 10% of respondents assumed other activities that might negatively influence the habitats. These activities included vegetation fires, grazing, and climate change (Table 8). Interestingly, these findings align well with observations in the field. Indeed, most of *D. senegalense* trees were found in protected areas within the Bassila, southern Borgou, and Zone III phyto-districts where agricultural activities were prohibited, providing a more favorable environment for the species. In contrast, Zone IV, where agriculture is conducted without significant constraints, houses *D. senegalense* trees within open vegetation formations, making them more vulnerable to habitat degradation.

Vulnerability of *D. senegalense* in the different phyto-districts

Table 9 presents the vulnerability index of assessed parameters. The average vulnerability index of *D. senegalense* across the four zones was 2.58. It was 2.56 for the phyto-districts Borgou Sud and Bassila, then for zone III, and 2.67 for zone IV. These values are closer to 3 and indicate that the species is vulnerable in all studied phyto-districts.

Table 8: Frequency of citation about the drivers of degradation of *D. senegalense* habitats

Drivers	Bassila		Borgou sud		Zone III		Zone IV	
	M	F	M	F	M	F	M	F
Exploitation	42,9	63,9	92,6	88,9	70,4	76,9	20,4	12,4
Agriculture	28,6	27,8	1,85	7,41	29,6	11,5	77,5	81,6
Fire	2,86	0	3,70	3,70	0	3,85	0	0,00
Grazing	2,86	0	1,85	0	0	3,85	0	2,70
Fruit harvesting	17,1	0	0	0	0	0	0	2,70
Climate change	5,71	8,33	0	0	0	3,85	2,70	5,41

Table 9: Vulnerability indice for D. senegalense in the study area

Parameters	Assessment results by phyto-district			
	Borgou sud	Bassila	Zone III	Zone IV
Frequency of use (FU)	1	1	1	2
Number of use (NU)	2	2	2	2
Used organs	3	3	3	3
Collection method	3	3	3	3
Stage of development	2	2	2	2
Biotope (forest)	3	3	3	3
Type of morphology	3	3	3	3
Abundance	3	3	3	3
Natural regenerative power	3	3	3	3
Vulnerability index (Iv)	**2.56**	**2.56**	**2.56**	**2.67**

DISCUSSION

Ethnobotanical and ethno-ecological knowledge of *D. senegalense* in the Dahomey Gap

Most respondents indicated that the species inhabits areas gallery forests, moist semi-deciduous forests, foot of hills and valleys. This perception was evident in certain local names for the species, particularly among the Nagots and related communities, where it is referred to as "Ôlô Odo, meaning "millstone" or "hollow" of the river. This traditional knowledge aligns with the field observations made during verifications and georeferencing of the species occurrences, and with the findings of previous researchers such as Arbonnier (2019), Adomou (2005), Akoègninou *et al.* (2006), Dangbo *et al.* (2019), Dossa *et al.* (2019), and Houénon *et al.* (2021).

In this study, the diversity of knowledge was heterogeneous, indicating that species is used for multiple purposes within each ethnic group. However, this diversity becomes more consistent when considering gender and age, with values of evenness index (IE) like those found for *Chrysophyllum albidum* and *Mansonia altissima* by Lougbégnon *et al.* (2016) and Wédjangnon *et al.* (2016), respectively (0.40 and 0.11). The values obtained in the present study are lower than those obtained by Masengo *et al.* (2021a) *for Lippia multiflora* (IE = 0.98). This result confirmed some previous studies that have shown that ethnobotanical knowledge was globally influenced by gender (Lougbegnon *et al.*, 2011), educational level (Dassou *et al.*, 2015) and profession of respondents (Beltràn-Rodriguez *et al.*, 2014). Thus, knowledge about the species' usage was not evenly distributed among the participants. These findings are consistent with previous studies that reported several uses of *D. senegalense* in Togo (Dangbo *et al.*, 2019a) and in Benin (Dossa *et al.*, 2020a). For instance, *D. senegalense*, as a wild species, has specific parts, such as almonds obtained from crushing ripe fruits, which are central to commercial activities. The documented ethnobotanical knowledge about the species was closely in line with the results found by Dangbo *et al.* (2019a) in Togo, where over 90% of the population reported having a good understanding of the species, especially concerning the usage of almonds. Other uses were identified, notably, wood for timber, leaves, roots, and bark, corroborating the findings of Dangbo *et al.* (2019a), Dossa *et al.* (2020) and Houenon *et al.* (2021). The almond trade was the most important use category, followed by timber, but the food and ritual categories are virtually absent. Like Houénon *et al.* (2021), our results showed that *D. senegalense* fruits were not usually consumed. This finding may be linked to the fact that the fruits of this species were not considered in the eating habits of local populations.

Several studies (Amaku *et al.*, 2021; Olayiwola, 2021; Olatunji *et al*, 2021; Margaret 2021) have confirmed various physical, biochemical, pharmacological, and medicinal properties of some main parts of *D. senegalense*. Research conducted by Malami *et al.* (2020) in Nigeria identified *D. senegalense* as one of the medicinal plants used for cancer treatment. Moreover, Sowemimo *et al.* (2011) reported that the leaves are consumed as vegetables and are also employed in treating conjunctivitis. The leaf decoction is used to relieve itching and treat skin infections, as mentioned by the same authors. Additionally, the seeds are used as thickeners in specific culinary preparations. These results indicate that despite the increasing demand for *D. senegalense* in the subregion, only a limited number of culinary and medicinal applications are currently made from its organs.

Regarding the dynamics of *D. senegalense* populations, it was noted that the observation was consistent across phytodistricts. The low abundance of *D. senegalense* population was mentioned by most respondents. This finding confirmed the results of Dangbo *et al.* (2019b), Dossa *et al.* (2019), and Houénon *et al.* (2021), who also reported low individual density of *D. senegalense* in their respective study areas. The excessive and systematic harvesting of fruits for almond commercialisation was considered one of the main underlying causes of this situation (Adomou *et al.*, 2011; Dangbo *et al.*, 2019a; Dossa *et al.*, 2020b; Houénon *et al.*, 2021). In Togo, the sale of almonds contributes to the income of local populations (Dangbo *et al.*, 2019a). Additionally, there was intense cutting-down of adult individuals of the species. There is a trade of *D. senegalense* almonds in zone IV. The commercial name given to the seed is "bethor". The profit generated by this commerce for the collectors was low due to the informal nature of the entire commercialisation chain, despite the desire of communities to see this trade well-organized and structured to ensure better valorisation and conservation of the species. These results were not in line with those of Diop (2008), who reported significant income derived from the ditax trade both for collectors and the state. This author stated that *D. senegalense* holds a prominent position in the list of important forest fruit species in the Senegalese economy.

The almonds of *D. senegalense* were not yet directly consumed by local communities but were subject to commercial transactions. These results corroborated those of Dangbo *et al.* (2019a). Regarding the actors involved in the collection of *D. senegalense* fruits, the present results revealed that both women and men participate in this activity. These findings were in line with Atato *et al.* (2010), who concluded that *D. senegalense* seeds were collectively harvested, with even men participating. This highlighted the importance of women in the management of forest resources. Despite their participation in the exploitation of forest resources, they are often overlooked in the forest policy development. This results in a limited consideration of their needs and strategic interests during the implementation of management plans (Bauer, 2010). However, the lack of gender consideration represents a threat for resources.

Conservation status and vulnerability of *D. senegalense* in Dahomey Gap

This study revealed that the existing populations of *D. senegalense* consist mainly of older specimens, and natural regeneration is minimal or virtually absent. The natural habitats of the species are undergoing significant decline

due to deforestation and agricultural activities. These findings are consistent with previous research by Houénon *et al*. (2021) and Sambiéni *et al.* (2015), which also reported declining populations and high levels of degradation of forest ecosystems in Benin. Similarly, other studies in West Africa have shown a general trend of vegetation regression (Adjonou *et al*., 2010; Houéssou *et al*., 2012; BNTD, 2016; Bouko *et al*., 2016; Adingra, 2017; Silue *et al*., 2023). This concordance of the perception of the populations in the study area with the results of previous studies demonstrated the relevance of exploring endogenous knowledge about the spatio-temporal dynamic of natural habitats of *D. senegalense*. Indeed, several authors have reported that, in addition to the scientific understanding of past vegetation, it is crucial to consider the insights of local communities. These insights help identify any change in the floral landscape (Ali *et al*., 2023; Hahn-Hadjali and Thiombiano, 2000). Similarly, in the context of managing natural resources holistically, Busquet (2006) highlighted the critical value of considering the traditional ecological knowledge of local communities. The author also pointed out that human perceptions significantly influence the definition of conservation policies, as conservation practices often align with prevailing social values.

The vulnerability of a species is influenced by various factors, including the usage, the specific organ harvested, the frequency of use, the collection method, the abundance of the species, and the stage of development (Traoré *et al*., 2011; Ayéna *et al*., 2016; Nzuki, 2016; Ngbolua, 2020). Additionally, the species morphological type (Dassou *et al*., 2014), the biotope (Masengo *et al*., 2022), and its natural regenerative capability play significant roles. This vulnerability increases when the harvested plant organ struggles to regenerate, or its collection leads to the systematic cutting-down of the entire tree (Betti, 2001). According to Guigma *et al*. (2012), the survival of a species is adversely affected by every exploited organ. The vulnerability index values observed in different studied phytogeographic zones were in line with the findings of Agbo *et al*. (2017) and Masengo *et al*. (2022). These results can be attributed to the fact that for *D. senegalense*, significant organs are obtained from large trees, particularly in the case of fruit and almond collection, which is usually gathered from the ground rather than being plucked from the tree. As mentioned above, the main threats to species lie in the cutting of trees and the limited natural regeneration, which firmly establishes its vulnerability. In the Dahomey Gap, the exploitation, transformation, and trading of NTFPs offer opportunities to address food shortages and generate substantial financial gains during periods of scarcity, as demonstrated by studies of Mawunu *et al*. (2019; 2020), and Ngbolua *et al*. (2019b; 2021). In addition to its very low capacity for natural regeneration, the mode of exploitation and social conditions of communities of West Africa make *D. senegalense* highly vulnerable in the Dahomey gap. Given that *D. senegalense* does not yet possess a notable significant economic value like the baobab (*Adansonia digitata*), the African locust bean (*Parkia biglobosa*), shea tree (*Vitellaria paradoxa*), or butter tree (*Pentadesma butyracea*), for instance, there is still an opportunity for future research to emphasize the improvement techniques for its regeneration and domestication. It is imperative to rely on the conviction of local populations who have lived for decades with natural resources and confronted with perpetual environmental changes because they are the first to identify solutions and strategies for better adaptation (Ali *et al*., 2023).

CONCLUSION

The study has revealed that *D. senegalense*, a well-known indigenous plant resource, facing several threats making it vulnerable in Dahomey Gap. Local knowledge about the species varies across different phyto-districts and ethnic groups. However, the diversity of knowledge was evenly distributed based on gender and age. The main use of the species was the collection, processing, and commercialisation of its almonds. Logging and agriculture posed significant threats to the natural habitat of *D. senegalense*, making it highly vulnerable in the studied areas. To preserve the species, the study recommended supporting natural regeneration and exploring domestication strategies. Conservation efforts should involve local communities and their traditional knowledge. Collaboration is essential in developing comprehensive conservation plans that consider the vulnerability of *D. senegalense* and its sustainable use.

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