Open Journal of Forestry, 2025, 15(3), 247-280
https://www.scirp.org/journal/ojf
ISSN Online: 2163-0437
ISSN Print: 2163-0429

Endangerment of Medicinal Plants in the Zoulabot Ancien Community Forest (Southeastern Cameroon)

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How to cite this paper: Afiong, N. N., Nkongo, T. M., Muhesi, E. K., Fils, P. B., Bile, A. N., Ottou, P. B. M., Fongnzossie, E. F., & Betti, J. L. (2025). Endangerment of Medicinal Plants in the Zoulabot Ancien Community Forest (Southeastern Cameroon). *Open Journal of Forestry, 15,* 247-280.
https://doi.org/10.4236/ojf.2025.153014

Received: January 29, 2025
Accepted: July 15, 2025
Published: July 18, 2025

Abstract

The importance of medicinal plants in maintaining and restoring health is well established. However, the high demand associated with poor harvesting practices is having a huge impact on these plants, affecting the availability of the resource for forest-dependent populations. The aim of the study was to identify endangered plant species for medicinal use in the Zoulabot Ancien Community Forest, Southeast Cameroon. Data were collected in the Yokadouma District (East Cameroon) through several activities including 1) ethnobotanical surveys conducted among villagers (specialized and non-specialized healers), 2) monitoring of villagers in their daily activity of collecting medicinal plants and 3) a floristic inventory in Zoulabot Ancien Community Forest. The endangerment of harvested species was analyzed using a set of 13 parameters, composed of internal constraints (6 parameters) and external constraints (7 parameters). The calculated vulnerability index ranges from 1.57 to 2.31, corresponding to medium to high vulnerability classes. Some of the species with high vulnerability indices are also classified in the IUCN red list as species requiring special ecological attention. These include *Diospyros crassiflora*, *Baillonella toxisperma* and *Streblus usambarensis*. The link between traditional uses, the monitoring and description of harvesting practices and the floristic potential of the solicited plants could be exploited to establish the vulnerability status of species at a local scale, for better monitoring of their sustainable harvesting.

Such a work could lead to the development of early warning systems as a decision-making tool for specific plants. With a view to minimizing the conflicts that might exist between the harvesting of the resource by populations and the concern to manage it sustainably, it would be interesting to adopt alternative policies, such as the substitution of harvested plant organs or even little-known plant species that are useful in other communities.

Keywords

Community Forest, Sustainable Management, Vulnerability Index, Alert System

1. Introduction

Tropical rainforests contain numerous resources in products and services that contribute generally to the well-being of populations (Jules et al., 2011; Ngueguim, 2013), due to food, health, energy, monetary needs and other aspects of human well-being (Mahapatra et al., 2005; Akinnifesi et al., 2008; Fandohan, 2011). Plant cover and the heritage of species that provide non-timber forest products (NTFPs) are gradually being degraded as a result of their non-rational use. In all ancient civilizations and on all continents, there are traces of the use of medicinal plants and their bioactive constituents in the treatment of various diseases (Islam et al., 2020; Islam et al., 2022; Nanjala et al., 2022). Currently, despite scientific advances in modern pharmacology, the therapeutic use of plants is endemic in some countries, particularly developing ones (Chaachouay et al., 2022; Muhesi et al., 2023b).

Since ancient times, humans, particularly the Baka, have depended on forests for food, medicine and other non-timber products (Chamberlain & Smith-Hall, 2024). They are recognized as the holders of endogenous knowledge on medicinal plants confirmed for their traditional uses (Afiong et al., 2024). To meet their needs, they harvest wood, bark, roots, leaves and fruit (Traoré et al., 2011). Indeed, traditional medicinal uses require the harvesting of trunk bark and roots. However, harvesting and/or harvesting techniques for these plant organs for medicinal recipes cause enormous damage (sap circulation, rooting, etc.), leading to progressive dieback and loss of tree vigor (Hahn-Hadjali & Thiombiano, 2000). Poorly managed harvesting of bark, stem and root tissues can lead to tree death. This harvesting causes physiological disorders, which influence fruit production and ensure the species' survival. These negative factors are responsible for the rarefaction and/or loss of plant communities (Betti, 2001a; Hahn-Hadjali & Thiombiano, 2000). Consequently, appropriate conservation actions will need to be proposed to ensure the sustainability of plant species.

The anthropogenic pressures threatening forest resources are mainly small-scale processes, affecting forest structure and species richness; directly or indirectly impacting these local communities and the indigenous peoples who depend on them (Cadman et al., 2024). While slash-and-burn agriculture and domestic energy needs are the main sources of deforestation in Africa today (Damette & Delacote, 2011), even legal logging can also threaten the survival of certain woody species (Jennings et al., 2001). Climate change, overexploitation, demographic pressure, livestock farming and bush fires all contribute to the loss of native plants (Assogbadjo et al., 2011).

Estimates of rainforest loss attributed to the expansion of crops, pastures, and forest plantations range from 62 to 80% (Pendrill et al., 2019; Hosonuma et al., 2012). In Cameroon, the indicators values for monitoring the forest cover reveal that the deforestation rate is estimated at 0.06%, while the rate of degradation at 0.07%. As deforestation, habitat degradation constitutes a parameter for reducing or disturbing the distribution area of species. In Cameroonian rainforests, previous floristic studies have argued that shifting cultivation negatively affects tree diversity (Zapfack et al., 2002; Evariste et al., 2010; Kabelong Banoho et al., 2020). In rural areas, deforestation is caused by land use change due to commodity production like subsistence agriculture, clearing for housing, illegal exploitation and the collection of firewood (Curtis et al., 2018). Shifting cultivation has been considered as a major cause of forest degradation or destruction (Hirai, 2014; Ichikawa, 2012). In particular, the practice of felling and burning trees has an impact on biodiversity conservation. It's causes massive disturbance to forests, resulting in considerable biodiversity loss and the simplification of forest structure (Norris et al., 2010). According Mukul & Herbohn (2016), shifting cultivation is also increasingly being recognized as a major cause of carbon stock loss under global warming. In Southeastern Cameroon, the Baka and the Konabembe of Zoulabot Ancien and Gribe obtain a part of their crops by cultivation (Yasuoka, 2011; Hirai et al., 2023), where they have been cleared their plots every year to successively harvest various crops. Among the both groups, the scale of land clearance in shifting cultivation, as well the techniques used such as felling and burning allows to discuss impact not only of their agriculture but also of resources exploitation on the forest (Hirai, 2014).

While anthropogenic factors degrading plant resources have been widely described in the literature, there are very few studies on species vulnerability or endangerment (Betti, 2001b; Traoré et al., 2011). Vulnerability corresponds to the degree of exposure to the risks of reduction, threat or disappearance of certain plant species caused by inappropriate harvesting methods in an environment subject to increasing anthropic pressure. Consequently, vulnerability assessment, taking into account anthropogenic factors, is a key factor in the success of sustainable plant resource management initiatives. This is why local perception is essential for a rapid assessment of the state of vegetation, especially for the identification of endangered species (Lykke, 2000). In the same line, Rives (2012) argues that information on the state of exploitation or use of forest resources, including woody species, organs in demand, harvesting techniques or standing potential, remain valuable sources for concerted and sustainable management.

Since 2018, efforts have been made between the Government of the Republic of Cameroon and the Japanese International Cooperation Agency (JICA) for the development of a research project called "Project for the Co-creation of Innovative Forest Resources Management Combining Ecological Methods and Indigenous Knowledge" (COMECA) whose main aim is to contribute to the conservation of biodiversity in the TRIDOM landscape. In this project, the forestry component aimed to empower local populations for the sustainable use of NTFPs in Zoulabot Ancien village (South East Cameroon), on the outskirts of the NKI National Park. It is in this logic that the present work finds its justification for detecting plants threatened with disappearance or exhaustion on the basis of certain factors linked to species and human intervention, in order to refine policies or measures for better preservation of the resources requested by populations. According to Betti (2001b), the determination of the vulnerability of species in the Dja Biosphere Reserve aims to develop on the outskirts village exploitation zones managed sustainably by the populations for rural development activities with a view to better valorization of secondary forest products. Ethnobotanical surveys, monitoring and description of harvesting practices as well as a floristic inventory constitute a reliable means for a rapid assessment of the state of vulnerability of medicinal plants, thus highlighting the risks of their rarefaction on a local scale (Traoré et al., 2011; Jdaidi et al., 2023). This with the aim of proposing avenues for their sustainable management in collaboration with local populations. The general objective of this article is to highlight potentially threatened species at the scale of the Zoulabot Ancien Community Forest. Specifically, it aimed to: 1) characterize the traditional uses of plants by Baka populations based in the periphery of the Zoulabot Ancien Community Forest, 2) appreciate the medicinal flora, 3) highlight the techniques and practices used to exploit the medicinal plants in question, and 4) assess the relative vulnerability of these medicinal plants on the basis of the elements identified.

2. Study Area and Methods

2.1. Study Area

The study was carried out in Yokadouma District located in the Boumba and Ngoko Division (East Cameroon Region). Specifically, in the Zoulabot Ancien Community Forest and surrounding Baka villages. The Zoulabot Ancien Community Forest is part of the dense humid semi-caducifolia forest, a semi-caducifolia forest sector sensus stricto (Letouzey, 1985). It is watered by an extensive network of streams, the main ones being: Môkà and Doumagoye, which flow into the Lèbèh river, a tributary of the Dja river, itself a tributary of the Ngoko, which is also a tributary of the great Congo river. The entire region is subject to the influence of a warm, humid equatorial climate of the classic Guinean type, with two rainy seasons interspersed with two dry seasons. The seasons are divided into the major rainy season (September-November), major dry season (December-February), minor rainy season (March-June), and minor dry season (July-August). The annual rainfall is generally 1500 - 1800 mm, and the mean monthly rainfall in the major dry season is <50 mm, whereas 100 - 250 mm is typical in the other three seasons. The average annual temperature is stable at approximately 24˚C. The altitude is in the range of 500 - 700 m, and the landscape consists of gentle rolling hills, with several small (1 - 5 m in width) and medium sized (5 - 10 m) rivers (Hirai et al., 2023). Vegetation is characterized by plant formations described as dense evergreen rainforest, alternating with semi-deciduous forest with large areas of swamp forest (PCD-Y, 2012).

2.2. Methodology

This section deals with the techniques and methods used to carry out the activities leading to the achievement of the set objectives.

2.2.1. Data Collection

The data collection method used is divided into three phases: ethnobotanical surveys, tradipratician monitoring and floristic inventories.

1) Semi-structured household surveys

Interviews were conducted with any or all consenting household members, regardless of gender, who could provide relevant information on the popular use of medicinal plants (Nana, 2023; Betti, 2001a). An interview guide was hired to facilitate exchanges/interviews by translating the local language into French and vice versa.

2) Monitoring medicinal plant harvesting techniques

For each species indicated in the treatment of a disease, the farmer or harvester was followed in his daily activity around the village or in the forest. The harvesting practices of plant organs used in the composition of the medicine were described. More detailed information was collected on : stem position, use, habitat type, morphological or biological type, circumference at chest height, circumference at 20 cm from the ground for shrubs, circumference at which debarking was started, height at start and end of debarking, thickness of all four sides of part of the bark, phenological condition (presence of flowers, fruit, young leaves, adult leaves, etc.), sanitary condition of the plant, and so on.), health status (dead, dying or alive), harvesting history (whether the tree has already been harvested or not), harvesting time, harvesting method (picking, harvesting), harvesting technique (Nana, 2023).

3) Floristic inventory

As recommended by Cameroonian forest inventory standards, the methodology used in this study combined the transect-based forest inventory approach with phytosociological methods. It consisted in establishing a 32 km long baseline running North-South from the Zoulabot Ancien village to Nki National Park. Along this line, 13 transects measuring 4000 m long × 25 m wide and running east-west with an equidistance of 2000 m between them were installed. Each transect was subdivided into 20 rectangular plots of 0.5 ha each (200 m × 25 m). In each plot, all plant species with a circumference at breast height greater than or equal to 31.4 cm (CBH ≥ 31.4 cm) or 10 cm in diameter were inventoried and identified. Information on each plant species included: GPS coordinates of each individual, local/vernacular name (Baka) of the species, circumference at breast height, use, phenological status, health status and type of plant formation.

2.2.2. Data Analysis

1) Relative vulnerability of medicinal plants

A species is said to be vulnerable if it is fragile and threatened with extinction if no control measures are taken. According to the International Union for Conservation of Nature (UICN, 2018), the risk of threat to plants is assessed according to several criteria classified into 11 categories, namely: Extinct (EX), Extinct in the Wild (EW), Regionally Extinct (RE), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Data Deficient (DD), Not Applicable (NA) and Not Evaluated (NE). In nature, the presence/absence of a species (plant or animal) in a given environment is regulated by various mechanisms that interact as "constraints". The notion of constraint means that not everything is possible for a given species, given the pressures it faces and its own structure (Barbault, 1997; Betti, 2001b). Constraints can be distinguished into two groups: "external" constraints (social, economic, competition) and "internal" constraints (morphological or physiological). The vulnerability of species will be examined at the level of villages sourcing from the community forest, using a number of well-defined parameters. Details of the choice, methods used for estimation and rationale for inclusion (impact on vulnerability) of each of these parameters are given below.

- Vulnerability linked to the specific characteristics of the medicinal flowering plant (internal constraints)

This is assessed floristically and structurally through the following six parameters: phytogeographical features, biotope, morphological types, and mode of scattering of seeds, density and diametric structure.

1. Phytogeographical features of species

a) Types: several types of phytochories can be observed:

- widely distributed species: pantropical (species widespread in tropical Africa, America and Asia), paleotropical (species present in tropical Africa, tropical Asia, Australia and Madagascar), afromalgachian (species distributed in continental Africa and Madagascar), afrotropical (species distributed throughout tropical Africa), cosmopolite (species widely distributed across the globe in both temperate and tropical zones);
- medium-distribution species or Guinean and Sudano-zambezian link species: Guinean-sudano-zambezian (species present in both the Sudanese, Zambezian and Guinea-congolese regional centers of endemism);
- species with reduced distribution or Guinean species: Guineocongolese (species widely distributed in the Congolese Guineo region), Centroguineo-con-

golese (species whose distribution covers the lower Guinean domain consisting of southern Nigeria to the Democratic Republic of Congo and Congolese).

b) Impact on vulnerability/endangerment: a restricted-range species is more vulnerable than a wide-range species. Similarly, a species that is scarce, dispersed or sparse is more vulnerable than a common species (Lejoly, 2001).

2. Biotope types/species habitats

a) Types: the main habitats selected are:

- primary or little-disturbed forests: these are natural or primitive forests with a high degree of naturalness, where human activity is little or barely perceptible;
- secondary forests: these are forests where the forest cover has been destroyed, resulting in low genetic diversity and high ecological fragmentation;
- hydromorphic forests and swamps: these are forests characterized by the presence of water in the environment. The plants that live here have particular morphological adaptations;
- croplands: these are lands with shifting cultivation, abandoned with regenerated trees that are capable of reaching a forest cover of at least 30%.

b) Impact on vulnerability: human activities and the harvesting of forest resources are currently leading to deforestation, forest degradation, secondarization or even banalization of forests, which are becoming increasingly scarce or fragile. A species typical of these formations will therefore be more vulnerable than a species inhabiting common environments (crops, gardens, ruderal environments).

3. Morphological types of species

a) Types: the morphological types identified in this work can only be distinguished in ligneous species: trees (woody plant with a large diameter trunk with a height greater than 7 cm in the adult state) and shrubs (small diameter woody plant with a height of between 4 and 7 meters in the adult state).

b) Impact on vulnerability: this parameter is introduced to measure the aptitude for stump rejection or growth. In general, woody plants will be more vulnerable than fast-growing herbaceous plants. Among woody plants, a distinction must be made between those with a single stem and those with several stems. According to Peters (1997 cit. Betti, 2001b), the harvesting of single-stemmed trees or shrubs makes them more vulnerable to over-exploitation than multi-stemmed subshrubs, which can easily sprout from the stump after cutting. Similarly, among herbaceous species, perennials will be more vulnerable than annuals due to their slow growth.

4. Types and modes of scattering of seeds.

a) Types: Seed dispersal are generally classified in the different types of diaspores and modes of scattering (Seidler & Plotkin, 2006; Vittoz & Engler 2007). They are divided into three groups and seven types:

- anemochory: seed dispersal by wind (pterochores, sclerochores and pogonoores);
- zoochory: seed dispersal by man or animals (sarcochores and desmochores);
- autochory: seed dispersal by the plant itself or gravity dispersal (ballochores

and barochores).

b) Impact on vulnerability: a species that can self-disseminate will be less vulnerable than another whose dissemination depends on external parameters (heterochory). Among species whose spread is linked to a foreign element, those spread by the wind will be less vulnerable than those spread by animals or man.

5. Density

a) Types: Density will be assessed on the basis of a threshold of 0.05 stems/ha. This is the limit used in forest management operations in Cameroon. Thus, density will be ranged as follows:

- low: when it is less than 0.05 stems per hectare;
- medium: between 0.05 and 1 stem per hectare;
- high: when it exceeds 1 stem per hectare.

b) Impact on vulnerability: species whose density is below the threshold are considered vulnerable with regard to this parameter. Furthermore, a species' vulnerability decreases with its density or abundance in the environment.

6. Population diameter structure

a) Types: the different stem distributions are divided into:

- inverted J structure: denoting constant regeneration over time, with no exploitation problems;
- bell-shaped: denoting a more or less marked deficit in the smaller diameter classes, and therefore a limited capacity for renewal of the species;
- bimodal: in this case, regeneration is assured, but numbers in the second rotation are likely to be limited;
- irregular and very irregular: this is generally the case for species whose individuals are poorly or very poorly represented. We note the partial or total absence of certain diameter classes. These are species whose exploitation may lead to local extinction.

b) Impact on vulnerability: a species vulnerability increases with its irregularity in the environment. In other words, a species performs well in an environment when it is present in all diameter classes.

Vulnerability linked to harvesting practices (external constraints)

Elements such as the popularity or frequency of quotations, the plant's organs and the number of organs used, the number of diseases treated and the pharmaceutical form of the medicine can lead to the vulnerability of the plant used. With regard to harvesting practices, these include harvesting methods and techniques, harvesting percentage and pressure of use.

7. Popularity of the species in local pharmacopoeia

a) Types: the frequency of respondents varies at three levels. These are proportions strictly below 20%, proportions between 20% and 60% excluded, and proportions greater than or equal to 60%.

b) Impact on vulnerability: The intensity and frequency of samples applied to a plant to treat several diseases has a considerable impact on it and does not allow a renewal of the resource (Guedje et al., 2010). Thus, a species vulnerability increases with its popularity or frequency of citation. The high frequency of use or high demand for plants in the therapeutic purposes subjects these species to high threat (Jdaidi et al., 2023). Some valued indigenous tree species used in the preparation of traditional herbal medicines have become threatened or extinct as a result of over exploitation or solicitation (Elachouri et al., 2021).

8. Number of diseases

Types: the rural populations especially the Baka have a great mastery of various uses of plants for the treatment of health problems. It is noticed among these plants, that some are used to treat several pathologies or physiological effects. This is the case of Alstonia boonei, called "Gouga" by the Baka which is used to treat more than a dozen diseases in Zoulabot Ancien village.

Impact of vulnerability: The more a plant is used to treat a several diseases, the more the pressure on it increases. According Ayéna et al. (2016), the solicitation of a specie in several medicinal therapies at the same time constitutes a high factor of its vulnerability.

9. Plant parts and number of parts used

a) Types: the plant organs mentioned are subdivided into aerial, superficial and underground parts: leaves, latex, sap, fruit, seed, stem bark, root bark, bulb, tuber, wood and whole plant.

b) Impact on vulnerability: a plant's vulnerability increases depending on whether or not the plant organ in question regenerates easily. If the organ used is an index of vulnerability, so too is the number of different parts sought on the same plant (Delvaux & Sinsin, 2003). Harvesting bark from stem tissue and roots slows the growth of woody plants and eventually kill them (Agbo et al., 2017; Betti, 2001b). The impact of harvesting on an individual plant will obviously vary according to the organ harvested (Cunningham, 2001). Organs are classified according to their importance for the plant's survival into highly damaging organs: roots, whole plant, young shoots; damaging organs: stem bark and sap; organs of little or no damage: leaves, flowers, seeds, nuts, bulbs. Thus, the harvesting of wood, fruits, the whole plant, and the roots constitutes a very significant alarming threat compared to the harvesting of leaves for the availability of these species (Jdaidi et al., 2023; Sidio et al., 2012). The harvest of fruits for example affects the process of regeneration or dissemination capacity, which depends on the availability of the seed, structure that contains and protects the plant embryo (Dassou et al., 2014; Adomou et al., 2017).

10. Pharmaceutical forms

a) Types: the elaborated drug formulations can be differentiated into liquid, solid and powder forms. These pharmaceutical forms include: ashes, powders, ointments, dried, macerated, decocted organs, fresh and raw organs, mashed, juices, softened, triturated, grated and some compound forms (softened juice, etc.).

b) Impact on vulnerability: Medicines in liquid form are more vulnerable than those in solid form, due to their low shelf-life, which results in high withdrawal rates and the durability of the medicine. Plants whose recipes allow for long shelf-life will also be less vulnerable than those that must be consumed immediately. Powders, ashes or ointments can be preserved longer than aqueous forms (maceration or decoction) or organs consumed fresh (Betti, 2001a, 2001b).

11. Harvesting methods and techniques

a) Types or illustrations: Two harvesting methods are observed: picking and collecting. In the picking mode, several techniques are used: debarking, scraping, notching, uprooting, piercing the tree and cutting the stem. More specifically, we note: simple, disordered or messy debarking, 1/4, 2/4 simple or 2/4 opposite, 3/4 and 4/4 or totally debarking, simple scraping, 1/4, 2/4 simple or 2/4 opposite, 3/4 and 4/4, simple notching, 1/4, 2/4 simple or 2/4 opposite, 3/4 and 4/4. A few types of debarking are illustrated respectively in order of severity on the plant in **Figures 1(a)-(f)**.

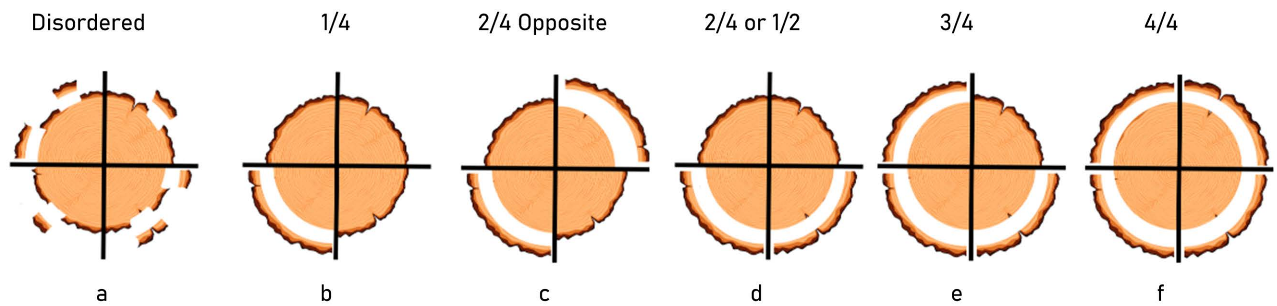

Figure 1. Types of bark harvesting (Nana, 2023).

b) Impact on vulnerability: picking is the most harmful method of harvesting compared to collecting; because the victims resulting from this method of harvesting can no longer ensure their physiological functions or potential for the regeneration of species (Traoré et al., 2011). Individuals whose plant organs are harvested will be traumatized and therefore more vulnerable than those whose parts are easily picked up from the ground (Betti, 2001a, 2001b). Leaf stripping, debarking, limbing, uprooting and felling are harvesting techniques whose threat level varies from high to very high respectively (Jdaidi et al., 2023). Bark removal, resulting in the loss of nutrients and moisture, fungal growth and insect attack, is a major source of stress for trees (Cunningham, 2014). Ring barking or 100% trunk is not a sustainable technique. Because a ring-barked tree or with a larger debarked surface area, has a greater effect on decline in crown health status, therefore the bark regeneration (Delvaux et al., 2010; Geldenhuys, 2004).

12. Percentage of debarking

a) Types or illustrations: harvesting intensity is assessed from the base of the tree trunk to the first large branch. In the course of our work, we identified some fifteen harvesting density classes, with amplitudes of 5 ranging from 0 to 80%. These classes include: [0-5 % [, [20-25% [, [45-50% [and [75-80% [considering that the faces represented are equivalent to those hidden (**Figure 2**).

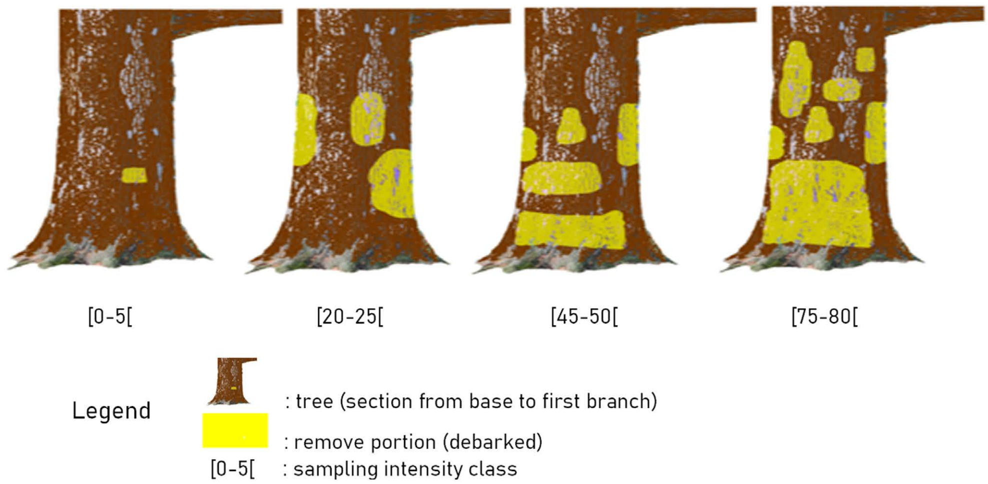

Figure 2. Tree bark harvesting intensity (Nana, 2023).

b) Impact on vulnerability: the survival of a species depends on the intensity of exploitation of its organs (Traoré et al., 2011; Ayéna et al., 2016). A tree with a high harvesting rate is more vulnerable than one with a low harvesting rate. Geldenhuys (2004) reveals that most of the Ocotea bullata trees which bark removed for more than 80% of the stem circumference was dying or dead. In fact, the rhythm of harvests and the quantities harvested amplify the obvious risks of scarcity in the immediate environment of the plants (Sidio et al., 2012). Harvesting intensity of bark significantly affected edge re-growth of plants (Mohammed et al., 2022). The regeneration of a fragment of bark is difficult to achieve on an intensively barked plant which will quickly lose its vigor and succumb prematurely to any type of biotic or abiotic attack (Agbo et al., 2017).

13. Use pressure

a) Types: Use pressure is the ratio between the density of medicinal citations and the density of stems counted during the floristic inventory of a species. It is evaluated over three intervals. The value can be between 0 and 25%, between 25 and 50% and over 50%.

b) Impact on vulnerability: plants that are subject to strong pressure due to their use, and whose number of individuals in the village terroir is low, are the most vulnerable. The high intensity of harvesting of plant organs for different uses would lead to the progressive reduction of the species requested due to their number of uses and frequency utilization (Ouattara et al., 2021).

2) Summary and calculation of the vulnerability index

By taking the various parameters into account, we can define a vulnerability index (Vi) for each species. A score is assigned to each element or parameter (**Table 1**). This index is obtained by calculating the average of the different scores corresponding to each parameter (P) for each species according to the formula: Vi = Pt/Np where Pt = P1 + P2 + ... + Pn and Np = total number of parameters considered. A species with an Vi between [0 - 1] is considered non-vulnerable or low vulnerability for its use. Another with an Vi between]1 - 2] is considered as moderately vulnerable, while a specie with an Vi between]2 - 3] is considered as vulnerable or very vulnerable, depending on the case (Betti, 2001a, 2001b; Nana, 2023).

Table 1. Different vulnerability indicators.

Relative vulnerability of species				
Code	Parameters	Low (scale = 1)	Medium (scale = 2)	High (scale = 3)
P1	Phytogeographical types	Widely distributed species	Moderately widespread species	Limited distribution species
P2	Biotope/habitat types	Ruderal, crop, garden	Secondary forest, forest edge	Primary forest, hydromorphic forest
P3	Type and methods of diaspore dissemination	Autochory (ballochore, barochore)	Anemochory (pterochore, pogonochore, sclerochore)	Zoochory (sarcochore, desmochore)
P4	Diametric structure	Inverted J	Bell, bimodal	Irregular
P5	Density	High ($D > 1$)	Medium ($0.05 \le D \le 1$)	Low ($D < 0.05$)
P6	Popularity	$Fq < 20\%$	$20\% \le Fq < 60\%$	$Fq \ge 60\%$
P7	Number of diseases treated	1 to 6	7 to 12	13 to 19
P8	Plant organ	Leaf, latex, sap	Fruit, seed	Stem bark, root, bulb, tuber, wood, whole plant
P9	Number of organs used	1 to 2	3 to 4	≤5
P10	Pharmaceutical forms	Ash, powder, ointment, dried organ	Macerated, decocted, fresh organ, mashed, juice, softened, triturated, grated, compound forms	/
P11	Harvesting method and technique	Collecting	Harvesting (simple scraping, simple debarking, 1/4 debarking)	Harvesting (2/4 debarking, 3/4 debarking, 4/4 debarking), piercing, cutting
P12	Percentage of debarking (Pd)	$Pd < 25\%$	$25\% \le Pd < 50\%$	$Pd \ge 50\%$
P13	Usage pressure (Up)	$Up < 25$	$25 \le Up < 50$	$Up \ge 50$

3. Results

3.1. Phytopharmaceutical composition

Of the 241 species inventoried, 110 were cited as medicinal during popular surveys and the description of harvesting practices. The flora inventoried and the medicinal flowering plants cited in the surveys at District and village level were compared using Sorensen's similarity coefficient and the chi-square test. At the District level, Sorensen's similarity coefficient and the chi-square test show a similarity of K = 57.5% and X2 = 41.4 respectively between the floras from the inventories and the district surveys. With regard to medicinal floras at the Zoulabot Ancien village level, Sorensen's similarity coefficient and the Chi-square test show a similarity of K = 58.7% and X2 = 23.2 respectively between floras from inventories and surveys within the village.

Medicinal species are distributed in 92 genera and 37 families. The most important families in terms of species richness are: Fabaceae (16 species), Malvaceae (10), Annonaceae (8) and Irvingiaceae (7). On the other hand, the most cited species are: Fabaceae (10.7% cited), Annonaceae (10.1%), Meliaceae (5.4%) and Myristicaceae (5.2%). **Table 2** shows the specific richness and their contribution in the different families.

Specifically, *Scorodophloeus zenkeri* (5.15% of citations), *Anonidium mannii* (4.39%) and *Greenwayodendron suaveolens* (4.10%), *Trichilia rubescens* (3.62%) and *Coelocaryon preussii* (2.24%) are the most represented species.

Table 2. Number of reported plant species and its relative contribution in different families.

Family	N. Plant species	%age of contribution
Fabaceae	16	14.5
Malvaceae	10	9.1
Anonaceae	8	7.3
Irvingiaceae	7	6.4
Meliaceae	6	5.5
Moraceae	6	5.5
Apocynaceae	5	4.5
Rubiaceae	5	4.5
Sapotaceae	4	3.6
Ulmaceae	4	3.6
Anacardiaceae	3	2.7
Myristicaceae	3	2.7
Olacaceae	3	2.7
Chrysoblanaceae	2	1.8
Ebenaceae	2	1.8
Euphorbiaceae	2	1.8
Pandaceae	2	1.8
Phyllantaceae	2	1.8
Rutaceae	2	1.8
Anisophyllaceae	1	0.9
Burseraceae	1	0.9
Cannabaceae	1	0.9
Clusiaceae	1	0.9
Combrataceae	1	0.9
Dracaenaceae	1	0.9
Flacourtiaceae	1	0.9
Huaceae	1	0.9
Ixonanthaceae	1	0.9
Lauraceae	1	0.9

Continued

Lecytidaceae	1	0.9
Lepidotryaceae	1	0.9
Loganiaceae	1	0.9
Putranjinaceae	1	0.9
Rhamnaceae	1	0.9
Rhizophoraceae	1	0.9
Sapindaceae	1	0.9
Thomadersiaceae	1	0.9
Total	110	100

3.2. Floristic Parameters

As stated above, the floristic parameters studied were: phytogeographical distribution or phytochory, habitat types, morphological types, types and modes of diaspore dissemination. Eight phytochories were identified. Guinean species abound (57.42% of citations), with Guinean-Congolese species predominating (27.40%), followed by Afrotropical species (5.89%). Four main biotope types were identified: little-disturbed forests (51.43% cited). These are followed by secondary forests (9.75%) and hydromorphic forests (2.05%). Six (6) types and three (3) modes of diaspore dissemination were identified. Zoochory is by far the main mode of diaspore dispersal, with sarcochores widely represented (54.05% of citations). This is followed by anemochory (6.35%), with pterochores the most abundant type (3.8%).

3.3. Structural Parameters

The floristic inventory was carried out on 13 transects covering a surveyed area (Sa) of 120.5 ha. The structure of the medicinal flora of Zoulabot Ancien was assessed using the following parameters: density of medicinal citations recorded during interviews (Dmc), abundance or number of stems (N), stem density (Sd), relative frequency (Rf), diametric structure (Ds) and use pressure (Up). **Table 3** presents the structural parameters of the medicinal plants cited.

Table 3. Structural parameters of plants listed for medicinal use.

N°	Name	Nmc	Ni	Dmc	N	Sd	Rf	Up	Ds
Family Anacardiaceae									
1	*Antrocaryon klaineanum* Pierre	1	1	1	37	0.31	69	3.23	Irregular
2	*Lannea welwitschii* (Hiern) Engl.	1	1	1	99	0.82	92	1.22	L
3	*Trichoscypha oddonii* Engl.	16	14	1.14	367	3.05	100	0.37	Irregular
Family Anisophylleaceae									
4	*Poga oleosa* Pierre	1	1	1	10	0.08	23	12.50	Irregular
Family Annonaceae									
5	*Annickia affinis* (Exell) Versteegh & Sosef	73	39	1.87	96	0.8	100	2.34	Irregular

Continued

6	*Anonidium mannii* (Oliv.) Engl. & Diels	38	20	1.9	1729	14.35	100	0.13	Irregular
7	*Cleistopholis glauca* Pierre ex Engl. & Diels	10	1	10	1	0.01	8	1000	Irregular
8	*Duguetia staudtii* (Engl. & Diels) Chatrou	3	3	1	99	0.82	85	1.22	Irregular
9	*Greenwayodendron suaveolens* (Engl. & Diels) Verdc.	67	42	1.6	1612	13.38	100	0.12	Irregular
10	*Hexalobus crispiflorus* A. Rich.	1	1	1	380	3.15	100	0.32	Irregular
11	*Xylopia hypolampra* Mildbr. & Diels	2	2	1	57	0.47	77	2.13	Irregular
12	*Xylopia quintasii* Engl. & Diels	11	5	2.2	23	0.19	54	11.58	Irregular
Family Apocynaceae									
13	*Alstonia boonei* De Wild.	224	74	3.03	161	1.34	100	2.26	Bimodal
14	*Funtumia elastica* (P. Preuss) Stapf	22	1	22	118	0.98	100	22.45	Irregular
15	*Picralima nitida* (Stapf) T. Durand & H. Durand	111	49	2.27	58	0.48	92	4.73	Irregular
16	*Rauvolfia vomitoria* Afzel.	3	3	1	30	0.25	54	4.00	Irregular
17	*Tabernaemontana crassa* Benth.	33	21	1.57	118	0.98	77	1.60	Irregular
Family Burseraceae									
18	*Santiria trimera* (Oliv.) Aubrév.	9	8	1.13	629	5.22	100	0.22	Irregular
Family Cannabaceae									
19	*Trema orientalis* (L.) Blume	1	1	1	87	0.72	31	1.39	Irregular
Family Chrysobalanaceae									
20	*Maranthes glabra* (Oliv.) Prance	1	1	1	178	1.48	100	0.68	Irregular
21	*Parinari excelsa* Sabine	4	4	1	4	0.03	31	30.33	Irregular
Family Clusiaceae									
22	*Garcinia kola* Heckel	1	1	1	4	0.03	15	30.33	Irregular
Family Combretaceae									
23	*Terminalia superba* Engl. & Diels	46	28	1.64	248	2.06	100	0.80	L
Family Draceanaceae									
24	*Dracaena arborea* (Willd.) Link	1	2	0.5	14	0.12	62	4.17	Irregular
Family Ebenaceae									
25	*Diospyros canaliculata* De Wild.	2	1	2	69	0.57	100	3.51	Irregular
26	*Diospyros crassiflora* Hiern	119	32	3.72	122	1.01	100	3.68	Irregular
Family Euphorbiaceae									
27	*Neoboutonia mannii* Benth.	3	3	1	42	0.35	92	2.86	Irregular
28	*Ricinodendron heudelotii* (Baill.) Pierre ex Heckel	26	20	1.3	164	1.36	100	0.96	Bimodal
Family Fabaceae									
29	*Afzelia bipindensis* Harms	9	6	1.5	7	0.06	15	25.00	Irregular
30	*Amphimas pterocarpoides* Harms	13	9	1.44	37	0.31	38	4.65	Irregular
31	*Baphia leptobotrys* Harms	1	1	1	3	0.02	23	50.00	Irregular
32	*Calpocalyx dinklagei* Harms	1	1	1	190	1.58	92	0.63	Irregular
33	*Cylicodiscus gabunensis* Harms	64	1	64	233	1.93	100	33.16	L
34	*Detarium macrocarpum* Harms	6	1	6	22	0.18	85	33.33	Irregular

Continued

35	*Erythrophleum ivorense* A. Chev.	23	2	11.5	13	0.11	23	104.55	Irregular
36	*Gilbertiodendron dewevrei* (De Wild.) J. Léonard	1	1	1	34	0.28	23	3.57	Irregular
37	*Millettia sanagana* Harms	10	10	1	31	0.26	62	3.85	Irregular
38	*Pentaclethra macrophylla* Benth.	21	16	1.31	608	5.05	100	0.26	L
39	*Pericopsis elata* (Harms) Meeuwen	10	8	1.25	16	0.13	23	9.62	Bell
40	*Piptadeniastrum africanum* (Hook. f.) Brenan	7	5	1.4	188	1.56	100	0.90	L
41	*Pterocarpus soyauxii* Taub.	29	22	1.32	457	3.79	100	0.35	L
42	*Scorodophloeus zenkeri* Harms	8	7	1.14	2031	16.85	100	0.07	Irregular
43	*Tessmannia africana* Harms	10	5	2	196	1.63	100	1.23	L
44	*Tetrapleura tetraptera* (Schum. & Thonn.) Taub	15	13	1.15	135	1.12	100	1.03	Irregular
Family Flacourtiaceae									
45	*Barteria fistulosa* Mast.	11	9	1.22	150	1.24	100	0.98	Irregular
Family Huaceae									
46	*Afrostyrax lepidophyllus* Mildbr.	20	15	1.33	466	3.87	92	0.34	Irregular
Family Irvingiaceae									
47	*Desbordesia insignis* Pierre ex Tiegh.	6	52	0.12	466	3.87	100	0.03	Irregular
48	*Irvingia excelsa* Mildbr.	22	13	1.69	206	1.71	100	0.99	L
49	*Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baill.	25	16	1.56	541	4.49	100	0.35	L
50	*Irvingia grandifolia* (Engl.) Engl.	26	13	2	132	1.1	100	1.82	L
51	*Irvingia robur* Mildbr	7	3	2.33	1	0.01	8	233.00	Irregular
52	*Klainedoxa gabonensis* Pierre ex Engl.	43	25	1.72	355	2.95	100	0.58	L
53	*Klainedoxa trillesii* Pierre ex Tiegh.	6	5	1.2	16	0.13	62	9.23	Irregular
Family Ixonanthaceae									
54	*Phyllocosmus africanus* (Hook. fil.) Klotzch	14	8	1.75	102	0.85	85	2.06	Irregular
Family Lauraceae									
55	*Beilschmiedia mannii* (Meisn.) Robyns & R. Wilczek	1	1	1	346	2.87	100	0.35	Irregular
Family Lecytidiaceae									
56	*Petersianthus macrocarpus* (P. Beauv.) Liben	25	15	1.67	403	3.34	100	0.50	Irregular
Family Lepidotryaceae									
57	*Lepidobotrys staudtii* Engl.	4	3	1.33	350	2.9	100	0.46	Irregular
Family Loganiaceae									
58	*Carpolobia alba* G. Don	1	1	1	2	0.02	15	50.00	Irregular
Family Malvaceae									
59	*Ceiba pentandra* (L.) Gaertn.	20	13	1.54	21	0.17	69	9.06	Irregular
60	*Cola acuminata* (P. Beauv.) Schott & Endl.	10	13	0.77	548	4.55	100	0.17	Irregular
61	*Cola gigantea* A. Chev.	1	7	0.14	6	0.05	31	2.80	Irregular
62	*Cola rostrata* K. Schum.	5	5	1	87	0.72	54	1.39	Irregular
63	*Eribroma oblongum* (Mast.) Pierre ex A. Chev.	2	2	1	90	0.75	100	1.33	L
64	*Mansonia altissima* (A. Chev.) A. Chev.	4	2	2	35	0.29	77	6.90	Irregular

Continued

65	*Nesogordonia papaverifera* (A. Chev.) Capuron	3	2	1.5	318	2.64	100	0.57	Irregular
66	*Octolobus spectabilis* Welw.	3	3	1	34	0.28	46	3.57	Irregular
67	*Sterculia tragacantha* Lindl.	4	1	4	90	0.75	100	5.33	Irregular
68	*Triplochiton scleroxylon* K. Schum.	9	6	1.5	68	0.56	54	2.68	Bimodal
Family Meliaceae									
69	*Entandrophragma candollei* Harms	6	18	0.33	65	0.54	54	0.61	Irregular
70	*Entandrophragma cylindricum* (Sprague) Sprague	40	3	13.33	258	2.14	100	6.23	Irregular
71	*Entandrophragma utile* (Sprague) Sprague	3	14	0.21	3	0.02	15	10.50	Irregular
72	*Leplaea cedrata* (A. Chev.) E. J. M. Koenen & J. J. de Wilde	6	5	1.2	23	0.19	54	6.32	Irregular
73	*Leplaea thompsonii* (Sprague & Hutch.) E. J. M. Koenen & J. J. de Wilde	9	5	1.8	359	2.98	100	0.60	Irregular
74	*Trichilia rubescens* Oliv.	9	6	1.5	1425	11.83	100	0.13	Irregular
Family Moraceae									
75	*Ficus exasperata* Vahl	13	16	0.81	31	0.26	23	3.12	Irregular
76	*Milicia excelsa* (Welw.) Berg	28	19	1.47	28	0.23	77	6.39	Irregular
77	*Musanga cecropioides cecropioides* R. Br. ex Tedlie	22	22	1	301	2.5	69	0.40	Bimodal
78	*Myrianthus arboreus* P. Beauv.	25	17	1.47	221	1.83	100	0.80	Irregular
79	*Streblus usambarensis* (Engl.) C. C. Berg	33	21	1.57	234	1.94	85	0.81	Irregular
80	*Treculia africana* Decne.	15	8	1.88	41	0.34	69	5.53	Irregular
Family Myristicaceae									
81	*Coelocaryon preussii* Warb.	1	10	0.1	881	7.31	100	0.01	Irregular
82	*Pycnanthus angolensis* (Welw.) Warb.	39	30	1.3	518	4.3	100	0.30	L
83	*Staudtia kamerunensis* Warb.	7	3	2.33	634	5.26	100	0.44	Irregular
Family Olacaceae									
84	*Heisteria zimmereri* Engl.	1	1	1	11	0.09	46	11.11	Irregular
85	*Strombosia grandifolia* Hook. f.	6	4	1.5	71	0.59	62	2.54	Irregular
86	*Strombosia pustulata* Oliv.	24	14	1.71	401	3.33	100	0.51	Irregular
Family Pandaceae									
87	*Microdesmis puberula* Hook. f. ex. Planch.	36	25	1.44	10	0.08	31	18.00	Irregular
88	*Panda oleosa* Pierre	30	22	1.36	559	4.64	100	0.29	L
Family Phyllantaceae									
89	*Margaritaria discoidea* (Baill.) Webster	1	1	1	78	0.65	100	1.54	Irregular
90	*Uapaca guineensis* Müll. Arg.	4	4	1	737	6.12	100	0.16	L
Family Putranjinaceae									
91	*Drypetes gossweileri* S. Moore	58	27	2.15	207	1.72	100	1.25	Irregular
Family Rhamnaceae									
92	*Maesopsis eminii* Engl.	14	7	2	51	0.42	85	4.76	Irregular
Family Rhizophoraceae									
93	*Anopyxis klaineana* (Pierre) Engl.	2	2	1	43	0.36	85	2.78	Irregular

Continued

Family Rubiaceae									
94	*Corynanthe johimbe* K. Schum.	21	4	5.25	49	0.41	23	12.80	Irregular
95	*Corynanthe pachyceras* K. Schum.	7	5	1.4	390	3.24	100	0.43	Irregular
96	*Massularia acuminate* (G. Don) Bullock ex Hoyle	32	24	1.33	93	0.77	100	1.73	Irregular
97	*Mitragyna stipulosa* (DC.) Kuntze	1	1	1	70	0.58	77	1.72	Bimodal
98	*Nauclea diderrichii* (De Wild.) Merr.	7	5	1.4	194	1.61	100	0.87	Bell
Family Rutaceae									
99	*Zanthoxylum gilletii* (De Wild.) P.G. Watterman	15	14	1.07	3	0.02	15	53.50	Irregular
100	*Zanthoxylum leprieurii* Guill. & Perr.	7	2	3.5	151	1.25	100	2.80	Irregular
Family Sapindaceae									
101	*Blighia welwitschii* (Hiern) Radlk.	10	7	1.43	250	2.07	100	0.69	Irregular
Family Sapotaceae									
102	*Baillonella toxisperma* Pierre	38	25	1.52	14	0.12	46	12.67	Irregular
103	*Chrysophyllum boukokoënse* (Aubrév. & Pellegr). L. Gaut.	2	7	0.29	106	0.88	54	0.33	L
104	*Chrysophyllum lacourtianum* De Wild.	27	1	27	206	1.71	100	15.79	Bell
105	*Chrysophyllum perpulchrum* Mildbr. Ex Hutch & Dalziel	2	7	0.29	72	0.6	31	0.48	Irregular
Family Thomandersiaceae									
106	*Thomandersia hensii* De Wild. & T. Durand	16	14	1.14	147	1.22	92	0.93	Irregular
Family Ulmaceae									
107	*Celtis adolfi-friderici* Engl.	22	16	1.38	388	3.22	100	0.43	Irregular
108	*Celtis mildbraedii* Engl.	12	8	1.5	475	3.94	100	0.38	Irregular
109	*Celtis philippensis* Blanco	3	3	1	67	0.56	77	1.79	Irregular
110	*Holoptelea grandis* (Hutch.) Mildbr.	11	9	1.22	12	0.1	54	12.20	Irregular

Legend: Nmc = number of medicinal citations; Ni = number of informants; Dmc = density of medicinal citations (Nmc/Ni); N = abundance or number of stems; Sd = stem density (N/Sa); Rf = relative frequency; Ds = diametric structure; Up = use pressure (Dmc /Sd); Sa = surveyed area.

3.4. Relative Vulnerability of Tradittherapeutical Plants

Several factors influence resource availability. The indicators used in this study highlight species that are potentially threatened and/or endangered at local level. In view of the fact that most herbaceous plants, lianas and sub-shrubs are not threatened by rarefaction or disappearance, given their ability to regenerate quickly, we have only taken into account trees and shrubs when assessing vulnerability.

3.4.1. Internal and External Constraints on the Relative Vulnerability of Medicinal Plants

Taking into account internal and external parameters, a total of 56 species were considered for the determination of their relative vulnerability at the local scale of the Zoulabot Ancien Community Forest. Internal vulnerability constraints include floristic and structural parameters such as phytochory, biotope types, diaspora dissemination modes, stem density and diametric distribution. Overall, with regard to these constraints, more than half of the species monitored are endemic (87.5% cited). Seventy-one percent (71.4%) of the habitats surveyed are relatively undisturbed. Animal dispersal is the most common mode of diaspore dissemination (75%). In terms of structural parameters, the average density is 2.7 stems/ha. The dominant diametric structure reveals an L-shaped stem distribution for all species. However, irregular-structure species are highly represented (78%).

External vulnerability constraints include: popularity, number of health problems treated, plant organ used, number of plant organs used, pharmaceutical forms, harvesting techniques, harvesting intensity and pressure of use. With regard to these parameters, the average popularity of species is 18%. With regard to the number of ailments treated, the population mentions an average of eight (8) pathologies. The most popular plant organ is the stem bark, with a frequency of 85%. On average, three (3) plant organs are used to make remedies. The decoctate is the dominant pharmaceutical form (36.7%) for medicinal recipes. Overall, the harvesting method most commonly used by the population is simple debarking (60%). Most trees (60%) are harvested at a harvesting intensity of between 0 and 5%. The average usage pressure is 27%.

3.4.2. Summary and Selection of Vulnerable Species

Overall analysis of the vulnerability of the fifty-six (56) species selected shows that vulnerability indices range from 1.57 to 2.31. Table 4 shows the vulnerability indices of these species and their correspondence with the IUCN and MINFOF red lists. Among which in descending order, *Picralima nitida* with Vi = 2.31 and considered as Least Concern according to Redlist of IUCN, *Baillonella toxisperma* (2.20; Vulnerable A1cd), *Greenwayodendron suaveolens* (2.18; Least Concern), *Diospyros crassiflora* (2.17; Vulnerable B1ab + 2ab), *Streblus usambarensis* (2.14; Critically Endangered), *Cleistopholis glauca* (2.14; Least Concern), *Drypetes gossweileri* (2.13; Not Evaluated), *Milicia excelsa* (2.10; Near Threatened), *Annickia affinis* (2.10; Least Concern) and *Strombosia pustulata* (2.08; Least Concern).

Table 4. Vulnerability index (Vi) for medicinal plants in Zoulabot Ancien Community Forest.

Medicinal plants	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	Vi	IUCN Categories	MINFOF Categories
Afrostyrax lepidophyllus	3	3	3	1	3	1	2	3	1	1.94	2.66	1	1	2.05	LC	Not threatened
Alstonia boonei	3	2	2	1	2	3	3	2.89	1	1.84	2.14	1	1	1.99	LC	Not threatened
Annickia affinis	3	2	3	2	3	2	2	3	1	1.83	2	1.42	1	2.10	LC	To protect
Anonidium mannii	3	3	3	1	3	2	2	3	1	1.84	2	1.15	1	2.08	LC	
Baillonella toxisperma	3	3	3	2	3	2	2	3	1	1.65	2.5	1.5	1	2.20	VU A1cd	To protect
Barteria fistulosa	3	2	3	1	3	1	1	3	1	1.71	2	1	1	1.82	LC	

Continued

Blighia welwitschii	3	3	3	1	3	1	1	3	1	2	2	1	1	1.92	LC	
Ceiba pentandra	1	2	2	2	3	1	2	2.8	2	1.81	2	1	1	1.82	LC	
Celtis adolfi-friderici	3	3	3	1	3	1	2	2.95	2	1.86	2	1	1	2.06	LC	
Celtis mildbraedii	3	3	3	1	3	1	1	3	1	2	2	1	1	1.92	LC	
Chrysophyllum lacourtianum	3	3	3	1	2	1	2	2	1	1.75	2	1	1	1.83	LC	
Cleistopholis glauca	3	3	3	3	3	1	2	2.8	1	2	2	1	1	2.14	LC	
Cylicodiscus gabunensis	3	3	1	1	1	1	3	2.96	2	1.86	2.61	1.57	1	1.92	LC	
Desbordesia insignis	3	3	3	1	3	2	1	3	1	1.66	2	1	1	1.97	LC	
Diospyros crassiflora	3	3	3	1	3	2	3	1.98	2	1.78	2	1.5	1	2.17	VU B1ab + 2ab	Threatened
Drypetes gossweileri	3	3	3	1	3	2	3	1.86	2	1.88	2	1	1	2.13	NE	
Entandrophragma cylindricum	3	3	2	1	3	1	3	1.97	1	1.87	2	1	1	1.91	VU A1cd	
Erythrophleum ivorense	2	3	1	2	3	1	2	3	1	1.83	2.6	1.6	1	1.93	LC	Not threatened
Ficus exasperata	1	2	3	2	3	1	1	1.61	1	1.66	3	1	1	1.71	LC	Not threatened
Funtumia elastica	3	2	2	2	3	1	1	2.09	1	1.66	2.5	1.75	1	1.85	LC	Threatened
Greenwayodendron suaveolens	2	3	3	1	3	2	3	2.64	2	1.84	2.57	1.35	1	2.18	LC	
Holoptelea grandis	3	3	3	2	3	1	1	3	1	1.88	2	1	1	1.99	LC	
Irvingia excelsa	3	3	3	1	1	1	2	2.77	3	1.82	2	1	1	1.97	LC	
Irvingia gabonensis	3	3	3	1	1	1	2	2.96	1	1.92	2.17	1	1	1.85	NT	Not threatened
Irvingia grandifolia	3	3	3	1	1	1	1	2.92	1	1.9	2	1	1	1.76	LC	
Klainedoxa gabonensis	3	3	3	1	1	2	2	2.93	2	2	2	1	1	1.99	LC	
Lepidobotrys staudtii	3	3	3	1	3	1	1	3	1	1.5	2	2	1	1.96	LC	
Leplaea thompsonii	3	3	3	1	3	1	1	3	1	2	2	2	1	2.00	NT A2cd	
Maesopsis eminii	3	2	3	2	3	1	1	3	1	2	2.27	1	1	1.94	LC	
Mansonia altissima	3	3	3	2	3	1	1	3	1	1	2	1	1	1.92	LC	To be exploited sustainably
Milicia excelsa	3	2	3	2	3	2	2	2.57	2	1.79	2	1	1	2.10	NT	
Musanga cecropioides	3	2	3	1	2	1	2	1.9	3	1.66	2.28	1	1	1.91	LC	

Continued

Myrianthus arboreus	3	2	3	1	3	1	2	2.04	2	1.85	2	1.5	1	1.95	LC	
Nauclea diderrichii	3	3	3	1	2	1	1	3	1	1.5	3	1	1	1.88	NT A2cd	
Neoboutonia mannii	1	3	1	2	3	1	1	3	1	2	2	1	1	1.69	NT	
Nesogordonia papaverifera	3	3	3	1	3	1	1	3	1	1	2	1	1	1.85	VU A1cd	
Panda oleosa	3	3	3	1	1	2	2	2.7	1	2	2	1	1	1.90	LC	
Petersianthus macrocarpus	3	2	2	1	3	1	3	2.92	2	1.84	2.25	1	1	2.00	LC	
Phyllocosmus africanus	3	2	3	2	3	1	1	3	1	1.85	2	1	1	1.91	LC	
Picralima nitida	2	2	3	2	3	2	3	2.9	3	1.85	2.57	1.71	1	2.31	LC	
Piptadeniastrum africanum	3	3	1	1	1	1	1	3	1	1.4	2	1	1	1.57	LC	
Pterocarpus soyauxii	3	3	2	1	1	2	2	2.65	2	1.77	2	1	1	1.88	LC	
Pycnanthus angolensis	3	2	3	1	1	2	1	2.84	1	1.8	2	1	1	1.74	LC	Not threatened
Ricinodendron heudelotii	3	2	3	1	2	2	2	2.92	2	1.88	2	1	1	1.98	LC	Not threatened
Scorodophloeus zenkeri	3	3	1	1	3	1	1	3	1	1.83	2	1	1	1.76	LC	
Streblus usambarensis	3	3	3	1	3	1	2	2.96	3	1.9	2	1	1	2.14	CR	
Strombosia grandifolia	3	3	3	2	3	1	1	3	1	2	2	1	1	2.00	LC	
Strombosia pustulata	3	3	3	1	3	1	2	3	2	1.88	2.2	1	1	2.08	LC	
Tabernaemontana crassa	3	2	3	2	3	2	1	2.12	2	1.66	2	1	1	1.98	LC	To be exploited sustainably
Terminalia superba	3	3	2	1	1	2	3	3	1	1.7	2	1	1	1.90	LC	
Tessmannia africana	3	3	1	1	1	1	1	2.8	1	1.75	2.33	1.33	1	1.63	LC	Not threatened
Tetrapleura tetraptera	3	3	1	1	3	1	2	2.73	1	1.75	2	1	1	1.81	LC	
Treculia africana	1	3	3	2	3	1	2	3	1	1.71	2	1	1	1.90	LC	
Trichilia rubescens	3	3	3	1	3	1	1	3	2	1.83	2	1	1	1.99	LC	
Uapaca guineensis	3	3	3	1	1	1	1	3	1	1	2	1	1	1.69	LC	
Xylopia hypolampra	3	3	3	2	3	1	1	3	1	1.75	2.42	1	1	2.01	LC	

Legend: (P1): Phytogeographic distribution type; (P2): Biotope type; (P3): Diaspora dissemination mode; (P4): Stem density; (P5): Diametric structure; (P6): Respondent Popularity or frequency; (P7) : Number of diseases treated; (P8): Plant organ indicated; (P9): Number of plant organs used; (P10): Pharmaceutical forms; (P11): Harvesting method and technique; (P12): Percentage of debarking; (P13): Usage pressure; Vi = Vulnerability index.

4. Discussion

4.1. Ethnopharmaceutical Flowering Plants

Of the 241 species inventoried in the Zoulabot Ancien Community Forest, 110 represent the medicinal floras cited in the popular surveys. A comparison of the floras from popular surveys and floristic inventories in the Zoulabot Ancien Community Forest reveals a high degree of similarity both at the level of the District as a whole (K = 51.2%) and of the Zoulabot Ancien village (K = 58.7%). This result reveals a good match between the species cited by the population during the popular surveys, and those obtained from the floristic inventories. It also supports the hypothesis that people use plants found on their land. According to Traoré et al. (2011), the concordance between ethnobotanical survey data and dendrometric inventory data reflects, on the one hand, people's good knowledge of their environment, and on the other hand, the reliability of ethnobotanical surveys as a means of rapidly estimating the state of a locality's vegetation. Some authors find higher or lower proportions of medicinal categories. Clovis et al. (2018) observe respectively 60 out of 214 (28.03%) and 70 out of 204 (34.3%) species used for health care in the community forests of Kompia and Nkolenyeng. In the same category, Magwede et al. (2019) listed 384 out of 574 (67%) total species of useful plants from Vhavenḓa. As for Hadonou-Yovo et al. (2019), 72 species out of 101 (71.3%) listed were classified as belonging in the medicinal use category in the Mono Biosphere Reserve (Benin); and 53 out of 426 (12.4%) species listed in the locality of Ziémougoulain, Ivory coast (Ouattara et al., 2021).

The medicinal flora, is composed of 110 species, is distributed in 92 genera and 37 botanical families. The uses of some of the species inventoried have also been recorded elsewhere, outside our study area. The most important families in terms of number of species are: Fabaceae (16 species), Malvaceae (10) and Annonaceae (8). On the other hand, the most cited are: Fabaceae (10.7% cited), Annonaceae (10.1%) and Meliaceae (5.4). This floristic richness is at odds with that of Abbas et al. (2013) who found 133 species out of 141 for medicinal purposes in Gilgit District (Pakistan); with Asteraceae (17 species), followed by Fabaceae (10 species) and Rosaceae (8 species) families as the most strongly represented. Specifically, *Scorodophloeus zenkeri* (5.15% of citations), *Annonidium mannii* (4.39%) and *Greenwayodendron suaveolens* (4.10%) are the most represented species. Hadonou-Yovo et al. (2019), on the other hand, found that *Ficus trichopoda* and *Diospyros mespiliformis* gave the highest ethnobotanical use values.

4.2. Relative Vulnerability of Medicinal Species

4.2.1. General Vulnerability

The floristic traits of species are factors in determining their vulnerability. Parameters taken into account include phytochories, habitat types, and types and modes of diaspora dissemination. Species with reduced zoning or endemic species are likely to disappear. Under the impact of strong anthropogenic action (bush fires, logging), these species are likely to be completely decimated. The most vulnerable species are those that are very popular, grow slowly, reproduce with difficulties, inhabit fragile or threatened environments, and have a very limited geographical distribution (Cunningham, 1996). According to Taita (2003), species whose fruits and seeds are consumed or used for other purposes may have dissemination problems. In nature, a J-shaped diameter distribution reflects a state of equilibrium (Bouko et al., 2007), itself synonymous with good natural regeneration (Puig, 2001).

People tend to harvest plant organs without concern for the sustainability of the resource. According to Houéssou (2010), harvesting is driven much more by the desire to satisfy health needs than by concern for the survival and preservation of the plant for subsequent harvesting. Any plant organ harvested indiscriminately, as well as elaborate medicinal forms, can lead to the loss of resource plants. The harvesting of wood, bark, roots, leaves, flowers and other plant organs is gaining ground in traditional medicine (Traoré et al., 2011). The exploitation of these plant organs has a considerable impact on the biological functioning of the tree, whose sapwood is very often exposed to parasite attack. This increases the vulnerability of the species involved, and can lead to death (Bayoi et al., 2021). Harvesting roots and certain fruits in their green state has a negative impact on the long-term survival of the species concerned (Badjare et al., 2021; Ouédraogo, 2008). Plants whose medicines are in aqueous form are more vulnerable to short shelf-life, unlike pharmaceutical forms such as powders or oils (Betti et al., 2012).

The impact of a particular use on a tree depends on the part used and the sampling method (Doumbia et al., 2021). Indeed, according to Hahn-Hadjali & Thiombiano (2000), intensive debarking leads to a loss of tree vigour. In other words, the species affected by this harvesting method are no longer able to perform their physiological functions to the best of their potential. The systematic debarking of trees by collectors leads to their decline in the more or less long term (Dibong et al., 2011).

Poor harvesting practices are responsible for increasing the mortality rate, a key factor in recovery inducing a long-term impact on the regeneration process (Danilović et al., 2015). Knowing the existence, on the one hand, of a clear relationship between the part of the plant harvested and species regeneration (Delvaux et al., 2009), and on the other hand, between the mode of harvesting and the intensity of harvesting on species regeneration (Gaoue & Ticktin, 2007), it is important to raise awareness of rational techniques for harvesting plant organs so as not to encroach on their sustainability. Numerous studies have revealed that the repeated harvesting of medicinal plants by their roots, leaves or bark causes serious consequences for the survival of certain species (Abera, 2014).

Soliciting a species for multiple uses (several health problems) or even several organs of the same species (root, bark, fruit), as well as its accessibility, increases the intensity of use, and in turn the pressure of use. This leads to environmental degradation, deterioration and even possible extinction of these species in the environment (Shopo et al., 2022; Lawin et al., 2016). The more a species or several of its plant organs are solicited, the greater the pressure on it (Ayéna et al., 2016). According to Traoré et al. (2011), the recurrence of this weakens the plants, making them vulnerable to the elements (wind, fire, drought) and to parasites. The resulting poor health of the plants leads to partial or total desiccation. Continued, uncontrolled harvesting of medicinal plants would lead to resource depletion, especially as the recovery potential of different species after bark harvesting depends on their sensitivity to harvesting and their ability to recover, as well as on the intensity of harvesting carried out on individual trees (Geldenhuys & Williams, 2006).

The confirmation of medicinal plants use is also an important parameter. For a species vulnerability increases with confirmation of its biological activity. This is the case of *Prunus africana*, recognized for its use in the treatment of prostate adenoma and prostate hyperplasia; and whose bark extracts are used in the manufacture of 19 drugs sold on the European and American markets (Cunningham et al., 2016; Betti et al., 2014; Komakech et al., 2020; Muhesi et al., 2023a). Due to its recognized and confirmed molecules of interest, demand for this species bark has increased significantly at the international level, leading to its indexation in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (Betti, 2013).

4.2.2. Specific Vulnerability

On the basis of the vulnerability indicators or parameters considered, the vulnerability index for medicinal species varies from 1.57 to 2.31. *Picralima nitida*, *Baillonella toxisperma*, *Greenwayodendron suaveolens*, *Diospyros crassiflora* and *Streblus usambarensis* have, in order of importance, the highest vulnerability indices (Vi > 2). They are therefore considered as the most vulnerable plant species. In Dja Reserve Biosphere, *Picralima nitida* also appears to the most vulnerable species, with a vulnerability index greater than 2.5 (Betti, 2001b). In comparison with the IUCN classification, *Streblus usambarensis* is listed as Critically Endangered (CR), *Baillonella toxisperma* and *Diospyros crassiflora* as Vulnerable (VU). While *Picralima nitida* and *Greenwayodendron suaveolens* are listed as Least Concern.

To ensure the sustainability of the Zoulabot Ancien Community Forest ecosystems, forest management must take into account the specific uses of the forest by local populations, the values of these uses, the availability of woody species, the frequency with which they are used, and the quantities harvested. Given the dependence of local communities on plants, it would be wise to be able to predict the regeneration capacity of the bark of these many exploited plants (Delvaux et al., 2013). The high use value reflects the degree of satisfaction of local communities with these species, and explains the strong pressure exerted on them. This is because the importance attributed to a species does not depend on its availability, but on its capacity to satisfy the needs of populations in the various categories of use (Dossou et al., 2012). The ever-increasing demand for bark and destructive harvesting techniques pose a major threat to NTFP-producing trees and to the survival of rural populations (Lange, 2006). The sustainable use of certain plant species used in traditional medicine is therefore possible insofar as the needs of populations can be reconciled with the safeguarding of biodiversity.

4.3. Ecological Status and Sustainable Management of Medicinal Plants

One hundred and ten (110) species from the pharmacofloristic background of the Zoulabot Ancien Community Forest were inventoried. Of these, 56 were selected for calculation of their relative vulnerability at local level. Some of these species are either on the I.U.C.N. red list (2024), or on the Cameroon forest administration (MINFOF) list of species to be protected or sustainably exploited, or on both lists (Appendix 1). The main categories for species on both lists are Critically Endangered (CR), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Not Evaluated (NE) according to IUCN and Threatened (T), to be protected, to be used sustainably, Not Threatened according to Cameroon environment administration (MINEPDED). Forty-six (46) species (i.e. 82% of the medicinal species selected) are of Least Concern (LC). These include *Myrianthus arboreus*, *Panda oleosa*, *Annickia affinis*, *Annonidium mannii*, *Alstonia boonei*, *Tetrapleura tetraptera*, *Barteria fistulosa* and *Pentaclethra macrophylla*. Many of these are considered Not threatened (*Erythrophleum ivorense* and *Ficus exasperata*) according to the national classification, while others are considered Threatened. This is the case of Funtumia elastica. Five (05) species are classified as *Near threatened* (NT and NT Acd): *Nauclea diderrichii*, *Leplaea thompsonii*, *Milicia excelsa*, *Irvingia gabonensis* and *Neoboutonia mannii*. Four (04) species were identified as having Vulnerable (VU) status, with the "VUA1cd" category predominating. These include *Baillonella toxisperma*, *Entandrophragma cylindricum* and *Nesogordonia papaverifera*. We also observe the category (VU B1ab + 2ab): *Diospyros crassiflora*. Some of these species are also classified in the national list as "threatened" and "to be protected".

Managing forest resources is a real challenge. This means taking into account the needs of local populations and preserving the forest heritage. According to Chungu et al. (2007) and Rankoana (2016), Indigenous knowledge and traditional practices need, as far as possible, to be incorporated into sustainable conservation and management prescriptions for forest resources. Indeed, forest ecosystems constitute a larder, a pharmacy, cultural sites, etc. for the populations who depend on them. Destructive or significant impact exploitation includes methods for which large volumes of organs are extracted from individuals or the population of trees, harvesting techniques leading to the elimination of exploited individuals, the intensity and frequency of harvests applied which often do not allow renewal of the resource (Guedje et al., 2010). The exploitation of medicinal plants could be achieved by applying good agricultural and harvesting practices (Grasser et al., 2012). However, the techniques used to harvest these resources are sometimes detrimental to their sustainability. Nonetheless, we note that local populations have already integrated the implementation of certain sustainable solutions. In Cameroon, for example, traditional management systems include weeding around useful species, enrichment planting or transplanting seedlings (Mpondo et al., 2012); selective felling of trees when creating fields or plantations; and the preservation of certain useful species (medicinal plants, fruit trees or timber species for construction and handicrafts) (Carrière & Mc Key, 1999). Some useful species are also the object of special care in natural forests or in fallow land and fields, to promote their growth and regeneration (Bonnéhin, 2000). According to the decision No. 0359/D/MINFOF/SG/SDAFF/SN from 28 February 2012, the administration in charge of forests recommends the use of 2/4 (2 over 4) opposite sides or 4/8 (4 over 8) opposite sides methods of harvesting as specific measures to consider prior to or during harvesting of the bark (Betti et al., 2016). These techniques used in Cameroon and DR Congo to harvest the bark of *P. africana* are also based on the best practices developed by PLANTECAM (Plante Camerounaise), a pharmaceutical industry which worked in Cameroon between 1972 and 1987 (Wilfried et al., 2022). The both methods recommended by the administration in charge of forests have proven to be less detrimental or sustainable for the resource with a high regeneration rate for exploited species such as Prunus africana (Betti et al., 2019; Muhesi et al., 2024).

Sustained domestic and/or commercial exploitation of medicinal plants should integrate environmental and popular education by raising awareness of sustainable harvesting techniques, the choice of species to exploit which should be determined by their medicinal and socio-economic importance (Mpondo et al., 2012), and a good knowledge of their ecological status.

It would also be beneficial to raise people's awareness of the potential of substitute species, in order to limit strong pressure on species already known and much in demand, and to carry out specific and precise tree studies. Because, the challenge with most debarked tree species seems to be a slow recovery rate or total absence of closure of the debarked area (Mohammed et al., 2022). The various points raised could then contribute to the controlled use and protection of medicinal plants on a zonal scale, not only to perpetuate traditional knowledge but also to ensure the conservation of natural resources. Species substitution has emerged as an adaptation strategy to limit pressure on certain species (Yaovi et al., 2021). Indeed, in several studies, populations opt either for the replacement of one plant by another, or, for the use of one part in place of another part of the same plant (Kaboré et al, 2015; Muhesi et al., 2023b).

5. Conclusion

The rapid vulnerability assessment method for exploited species was based on internal constraints (6 parameters) and external constraints (7 parameters). This index ranges from 1.57 to 2.31, corresponding respectively to medium to high vulnerability. *Picralima nitida*, *Baillonella toxisperma*, *Greenwayodendron suaveolens*, *Diospyros crassiflora* and *Streblus usambarensis* have the highest vulnerability indices. Some of the vulnerable species in our study are listed by the IUCN as requiring conservation priority. These include *Streblus usambarensis* (CR), *Diospyros crassiflora* (VU B1ab + 2ab) and *Baillonella toxisperma* (VU A1cd).

The combined consideration of several elements, such as traditional uses, harvesting techniques and the floristic potential of the plants, gives a better appreciation of the degree of vulnerability at local level of the plants used by the populations. The different uses of plants clearly indicate that the populations concerned make full use of the plant resources around them for their vital daily needs. This calls for a rational use of these ecosystem products to ensure a regular and sustained supply of medicinal plants. This information will provide a basis for decision-making on sustainable management of the species most used by local populations.

Proposals for adaptive measures or strategies that are not detrimental to the survival and long-term use of these species would constitute an alternative for minimizing the conflicts that could exist between the exploitation of the resource by local populations for their needs (medicinal, food, service and cultural) and the conservation of biodiversity. As solutions, we believe it would be beneficial to popularize species that are little known by local populations, but which are useful in other communities for the same diseases. These would serve as substitutes to limit pressure on familiar species, and at the same time, promote the exploration of non-damaging plant parts used to remedy health problems, in order to restrict the over-exploitation of other vegetative organs.

Acknowledgements

We would like to express our gratitude to JST/JICA SATREPS (JPMJSA1702) resulting from collaboration between Cameroon and Japan, and HNC (National Herbarium of Cameroon) for providing facilities. We also like to thank Dr Cédric Chimi, Mr Eric Ngansop and local people for their collaboration during the field data collection.

Conflicts of Interest

The authors declared no conflicting interests regarding the publication of this paper.

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