Novel ethnobotanical indices of harvesting pressure and vulnerability to supply disruption reveal conservation priorities across five communities in the Nimba Mountains, Guinea

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Research

Abstract

Background: Classic ethnobotanical indices such as UV, RFC, and CI capture the cultural importance of plant species but overlook the vulnerability of communities to resources shortages and the extent of destructive harvesting pressure. This pilot study aimed to validate three new indices, to quantify the dependence of five communities in the Nimba Mountains on plant resources and identify conservation priorities.

Methods: Three indices were developed: the harvesting-pressure index (C'), the use-dependence index (UD), and the supply-disruption vulnerability index (Am), built using the Analytic Hierarchy Process (AHP). A matrix combining Use value (UV) and C', together with the Jenks threshold and IUCN status, was used to rank conservation priorities.

Results: A total of 77.7% of species are used in traditional medicine. *Garcinia kola* and *Alchornea cordifolia* had the highest UV values (0.26) and the strongest C' scores (155 and 90), with 46.3% and 60% of their uses being destructive, respectively. *Garcinia kola* and *Xylopia aethiopica* are classified as Conservation Priority 1. The Am index ranged from low in Doromou (0.141) to critical in Zouguepo (0.927), with Serengbara (0.779) classified as having very high vulnerability. Zouguepo combines high medicinal dependence (55.8%), near-universal daily use (99.5%) and low species richness (35 species). UD was the dominant driver of Am ($\rho = 0.90$; $p = 0.03$).

Conclusions: The C', UD and Am indices provide an empirical, reproducible framework for prioritising conservation under data-limited conditions. As an exploratory pilot tool, their validation at a larger scale remains a priority avenue for further work.

Keywords: Ethnobotany; Analytic Hierarchy Process; Nimba Mountains; harvesting pressure; community vulnerability; conservation; indices; Guinea.

Background

The Nimba massif is a mountain range in West Africa stretching approximately 40 km along the border of Guinea, Liberia and Côte d'Ivoire. Designated as a Biosphere Reserve and inscribed on the UNESCO World Heritage list, its geographical isolation has produced a distinctive tropical ecosystem, characterized by rich biodiversity and a mosaic of vegetation ranging from montane savannah to dense humid forest (Couch &Davis 2024). It supports endemic fauna and flora as well as numerous species shared with other tropical ecosystems (Phillipson & Hooper 2019; Denys 2025). More than 2 000 animal species and over 100 plant species have been recorded to date, and the Nimba Mountains reserve in Guinea contains around 85% of the country's recorded biological diversity (Molmou & Couch 2025).

Despite its protected status, the Nimba Mountains reserve was added to the List of World Heritage in Danger in 1992, owing to mining pressure, primarily from the exploitation of the iron-ore deposits beneath its soil (Couch 2025). This mining activity has also led to an influx of people, resulting in population growth in the surrounding villages and placing additional pressure on forest resources. For local communities, the Nimba forest is a source of subsistence, healthcare and fertile ground for agriculture: forest products play a key role in food, health and economic security (Ticktin 2004). Local people rely on forest resources for food, timber and fibres, as well as on a traditional pharmacopoeia that remains the main recourse in areas where access to formal healthcare is limited (Camara *et al*. 2024). Plant species are often harvested destructively, threatening the sustainability of these resources. Yet communities' dependence on the exploited plant species remains poorly documented. Quantifying both the nature and intensity of this dependence is therefore essential for developing effective conservation strategies. To date, the tools available in ethnobotany are not well suited to this purpose. The multi-use cultural-importance index, the use-value index (UV; Zenderland *et al*. 2019), and the relative frequency of citation index (RFC; Tardío *&* Pardo-de-Santayana 2008) all capture a species' cultural importance but do not measure the vulnerability of the community that depends on it in the event of a shortage. Neither the threat of a species' disappearance through use, nor the impact such a loss would have on the community, is taken into account. According to Leonti *et al*. (2022) and Hoffman & Gallaher (2007), the gaps concerning spatial pressure and community vulnerability need to be filled. To address these gaps, this study proposes three new indices: the harvesting-pressure index (C'), the use-dependence index (UD) and the supply-disruption vulnerability index (Am). The study pursues three objectives. First, it aims to validate the C', UD and Am indices by testing their sensitivity to changes in weightings, their internal consistency and their validity. Second, it seeks to provide a preliminary quantification of how far several Nimba Mountain communities depend on plant resources, identifying the species and localities that warrant attention in participatory conservation strategies. Third, it proposes a reproducible methodological protocol that can be applied directly in subsequent studies at a regional or continental scale.

The present study was designed as an exploratory pilot study, intended to lay the methodological groundwork for analysing community dependence on forest plant resources ahead of a larger-scale application. It tests the feasibility and robustness of the proposed tools before they are deployed in larger protocols. It does not claim to produce results that can be generalised across the whole of the Nimba Mountains, still less across West Africa. Its scope is deliberately limited to what the field conditions of an initial investigation in a restricted-access protected area allow, and the indices proposed here should be regarded as pilot tools rather than fully validated metrics.

Materials and Methods

Study area

The study was conducted in Lola Prefecture, Guinea. Five villages bordering the Nimba Mountains reserve were selected: Keoulenta, Doromou, Serengbara, Gouamo and Zouguepo (Fig. 1). Three criteria guided the choice of these villages. First, they are distributed around the reserve and together capture the diversity of plant species present. Second, they are located along the boundary between the reserve's controlled-use zone and its strictly protected area. Third, they are inhabited by diverse communities (Manon, Guerzé, Toma, Malinké, Poular, Soussou, Kissi, and Allogène). whose customs might be expected to influence harvesting practices.

Ethical and legal procedures

This research was conducted in accordance with the ethical guidelines of the International Society of Ethnobiology (ISE) and applicable Guinean legislation. The study protocol was approved (case no. 2026/EEB/DRG/3) by the research ethics committee of the Nimba Mountains Biodiversity Research Institute (IReB-MN). For each participant, the free and informed consent form was read out, discussed and clarified before signature it was signed (ISE, 2006).

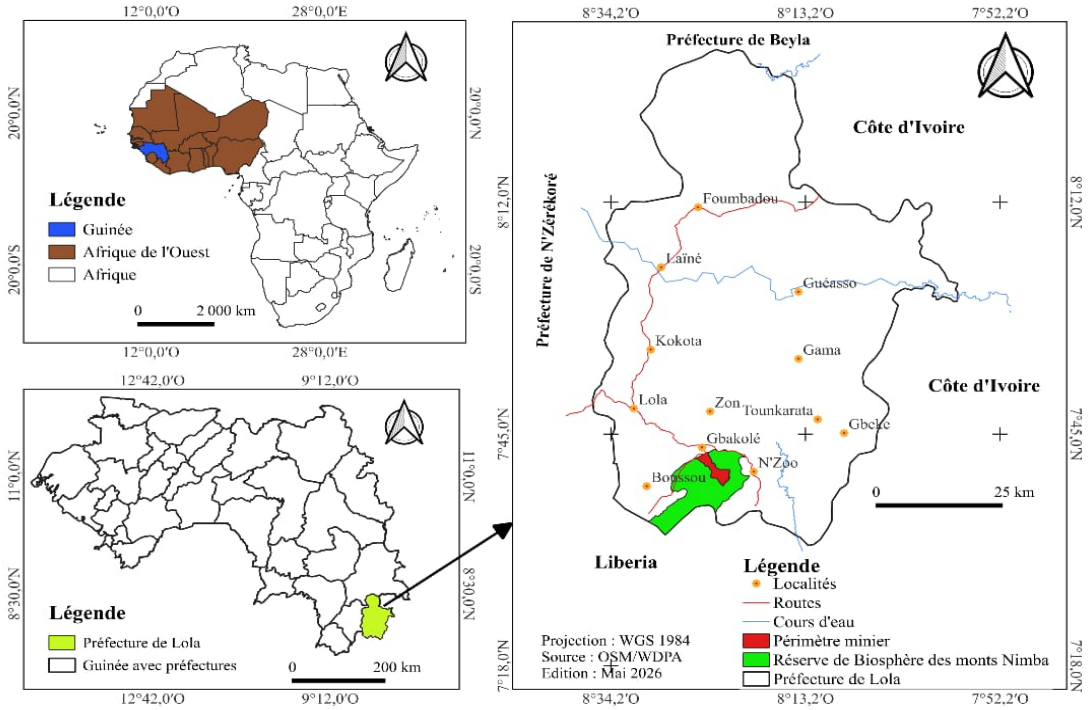


Figure 1. Location of the Lola prefecture, Guinea.

Data collection

Data were collected using semi-structured interviews conducted in March and May 2026. In each locality, after presenting the project to the village chief and the youth representative, we immersed ourselves in the daily life of the communities. Consent was obtained from each informant before each interview, which was conducted in the local language or in French according to the informant's preference. The confidentiality of individual data was guaranteed through anonymisation. Informants were selected by random sampling. The inclusion criteria were (i) a minimum age of 18; (ii) at least three months' residence in the locality; and (iii) free consent. A semi-structured questionnaire (Shackleton *et al*. 2020) was used, comprising two modules: (i) socio-demographic characteristics and (ii) plant-use inventories. In total, 876 use citations were collected from 111 informants.

Species identification

Herbarium specimens were not collected, owing to restrictions imposed by local communities and the site's protected status. As the primary aim of the study was ethnobotanical rather than floristic, all identifications were validated by triangulating vernacular names with at least three independent informants per locality, by cross-checking them with an IReB-MN botanist, and against, Flore de Guinée (Carrière 2000), Plants of the World Online www.plantsoftheworldonline.org, IUCN Red List on Threatened Species IUCN Red List of Threatened Species and The Plant List www.theplantlist.org. This approach is consistent with good ethnobotanical practice under ecologically or institutionally constrained collection conditions (Uprety *et al*. 2010; Thomas *et al*. 2009). Nevertheless, the absence of physical voucher specimens constitutes a limitation. Species identifications should be considered provisional and require future confirmation through voucher specimens deposited in an accredited herbarium. This constraint particularly applies to conservation-relevant species such as *Garcinia kola*, *Milicia regia* and *Terminalia ivorensis*.

Calculating the use-value index per species (UV)

The use-value index (Phillips & Gentry 1993a, 1993b; Hoffman & Gallaher (2007) measures the cultural importance of a plant species within a given community. It reflects the usefulness and versatility of the species. It is calculated as follows:

$$\mathrm{UVi} = \sum Uis \,/\, n$$

where ΣUis is the number of informants who cited species i for at least one use, and n is the total number of informants. When UV = 0, no informant reports any use for the species. When UV > 1, the species is important and cited by many people. When UV < 1, the species is little known and little used.

Construction of the new indices

Three new indices were developed to underpin the recommendations: the harvesting-pressure index (C') at the species level, the use-dependence index (UD) at the locality level, and the supply-disruption vulnerability index (Am).

Harvesting-pressure index (C')

The harvesting-pressure index (C') was developed at the species level to quantify both the intensity and the geographical extent of destructive harvesting. These two dimensions are not simultaneously captured by the ethnobotanical indices currently in use (Leonti *et al*. 2022). This index is based on the ecological-impact model proposed by Hall & Bawa (1993). The underlying data were classified into two categories: (i)destructive practices, defined as practices that damage or kill the harvested species, following Ticktin (2004) including bark-stripping, root or wood extraction, or felling; and (ii) non-destructive practices, including the collection of leaves, fruit, seeds or latex. The index was calculated following the formula:

$$C'i = N'dest, i \times Nlocs, i$$

where N'dest,i is the total number of destructive citations for species i, and Nlocs,i is the number of distinct localities in which it was cited. The index rests on the principle that a species harvested destructively across several localities is under geographically more dispersed pressure than a species with an equivalent number of destructive citations concentrated in a single locality. The harvesting-pressure index (C') takes no account of population size or regeneration rate; it was designed as a tool suited to data-limited settings.

Use-value dependence index (UD)

The use-value dependence index (UD) measures the degree of substitutability a plant species offers within the locality. It is the ratio between citations for a given type of use and total citations. In this study, only UDmed measuring dependence on plants as a substitute for healthcare, was used. This index corresponds to the proportion of plant-use citations in a locality that serve a medicinal purpose. Medicinal use was defined as any citation whose purpose was to treat, prevent or relieve a human ailment. It rests on the premise that a community in which a large proportion of documented plant uses are medicinal is more vulnerable to disruptions in plant-resource supply than a community with more diversified uses (Tardío & Pardo-de-Santayana 2008). It was obtained as follows:

$$UDmed = Ncit, med / Ncit, total$$

where Ncit,med is the number of medicinal citations and Ncit,total is the total number of citations for that locality. UD ranges from 0 to 1. Unlike species-centred indices (RFC, UV), UD is centred on the locality. A high UDmed indicates strong community dependence on plants for health needs.

Supply-disruption vulnerability index (Am)

The supply-disruption vulnerability index (Am) is assessed at the locality level. It measures a community's exposure to the risk of plant-resource depletion, combining three parameters: (i) use-value dependence, represented in this study by dependence on plants as a healthcare substitute (UDmed); (ii)local habits, captured by the frequency of daily plant use (UQ); and (iii) ecological resilience, characterised by species richness (S). The choice of these three components was informend by the work of Ticktin (2004). According to this author, a community is vulnerable to supply disruption when it depends on plants for healthcare, when this use is a daily occurrence, and when it has low local floristic diversity, thereby leaving fewer alternative resources available.

The raw values of UDmed, UQ and S were first calculated for each village, then normalised to a 0 to 1 scale using the formula (X - Xmin) / (Xmax - Xmin), giving the normalised values UD'med, UQ' and S'. The Analytic Hierarchy Process (AHP; Saaty 1990; Ouédraogo *et al*. 2014) was then used to derive normalised, robustness-weighted coefficients (w1, w2 and w3) summing to 1. Applying the AHP method to determine these weightings involved four steps:

(i) Construction of the comparison matrix

The three components of the Am index were compared pairwise by the authors using Saaty's (1990) scale (UD versus UQ, UD versus S, and UQ versus S), answering the question: 'How many times more important is this criterion than the other for measuring a community's vulnerability to supply disruption?' The resulting judgements were arranged in a square matrix $A = [a_{ij}]$ with dimension of 3 × 3. a_{ij} represents the importance of the criterion in row i relative to the criterion in column j. The diagonal equals 1, and the matrix is reciprocal ($a_{ij} = 1/a_{ij}$).

(ii) Normalisation of the matrix

To make the comparisons comparable, each column of the matrix is rescaled onto a (0, 1) range. To do this, each element a_{ij} is divided by the sum of the corresponding column j:

$$\overline{a_{ij}} = \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}}$$

This produces a second matrix A' (the normalised matrix), in which each column sums to 1, allowing the values to be interpreted as relative contributions.

(iii) Calculation of the weight of each criterion (w)

The weight vector w (w1, w2, w3) is obtained by averaging the elements of each row of the normalised matrix. This yields the principal eigenvector, identifying which of the three parameters is most important and ranking the indices (UD'med, UQ' and S') by order of consistency. To avoid introducing rounding error into the weighting, the weights were applied directly, without rounding to the nearest 0.05.

(iv) Checking judgement consistency, weighting sensitivity analysis and validation of the dominant factors

The Consistency Ratio (CR) was calculated to assess the consistency of judgements, as follows:

$$CR = \frac{CI}{RI}$$

where CR is the Consistency Ratio, CI is the Consistency Index ($CI = \frac{\lambda_{max} - n}{n - 1}$), λ_{max} is the average of the ratios $((A.w)i/wi)$ and RI is the random index, equal to 0,58 for n = 3 according to Saaty (1990). Judgements are considered acceptable when CR is below 0.10 (Saaty 1990).

To assess the reliability of the results under changes in weighting, a sensitivity analysis was carried out. The three weights were varied simultaneously across three levels each (-20%, 0%, +20%), giving 26 permutations. Each permutation was renormalised so that the weights summed to 1.

To confirm and validate the dominant factor of Am and the ranking of the normalised eigenvectors (w1, w2 and w3), a Spearman correlation between UDmed, UQ, S and Am were calculated across the five localities.

Conservation-priority matrix for exploited plant species

The use value of a species cited by at least a quarter of informants was used as the threshold (Tardío and Pardo-de-Santayana 2008). This restricts consideration to species enjoying a minimum degree of social consensus, ensuring that reported uses reflect shared knowledge within the community rather than isolated individual knowledge. The matrix plots species according to UV (y-axis) and C' (x-axis) across four priority categories (1, 2, 3 and 4). The priority threshold was set through a natural-breaks analysis using Jenks optimisation, based on the gaps between observed C' values. A ± 20% sensitivity analysis of UV and C' confirmed that species remained within their assigned category. IUCN status was overlaid as an independent criterion: any species classified as Endangered (EN), Vulnerable (VU) or Near Threatened (NT) was included in the matrix, so as to incorporate rare, heavily exploited species into the prioritisation.

Data analysis

Statistical validation of the heterogeneity in UDmed between localities used a chi-squared test comparing medicinal and non-medicinal citations across localities. Pairwise Fisher post-hoc tests with Bonferroni correction (α = 0.005) were applied to assess differences between villages.

Results

Socio-demographic characteristics of informants

A total of 111 informants participated across the five localities (Table 1). The average age was 45.4 years (ranging from 20 to 86 years). The education rate varied between 22.2% and 66.7% in Serengbara and Gouamo. The ratio of non-native residents ranged from 4 % at Keoulenta to 52.4% at Gouamo. Farming was the predominant occupation in all localities.

Table 1. Socio-demographic profile of informants by locality

Locality	n	Male	Female	Age (years)	Unschooled (%)	Non-native (%)	Farmers (%)
Keoulenta	25	18	7	36.4	36.0	4.0	96.0
Doromou	33	17	16	49.8	51.5	12.1	93.9
Serengbara	18	15	3	49.3	22.2	11.1	94.4
Gouamo	21	9	12	48.2	66.7	52.4	81.0
Zouguepo	14	10	4	42.1	28.6	21.4	100.0
Total	111	69	42	45.4	-	-	-

Use value (UV)

The majority of plant species (77.7%) are used in traditional medicine, with use values ranging from 0.04 to 0.26 (Fig. 2). *Garcinia kola* Heckel, *Alchornea cordifolia* (Schumach. & Thonn.) Müll.Arg. and *Xylopia aethiopica* (Dunal) A.Rich. have the highest use values, at 0.26, 0.26 and 0.25 respectively, and are used mainly for medicinal and aphrodisiac purposes. The species *Musanga cecropioides* R.Br. and *Ficus sycomorus* subsp. gnaphalocarpa (Miq.) C.C.Berg, both used in medicine, have the lowest use values, at 0.04 and 0.05.

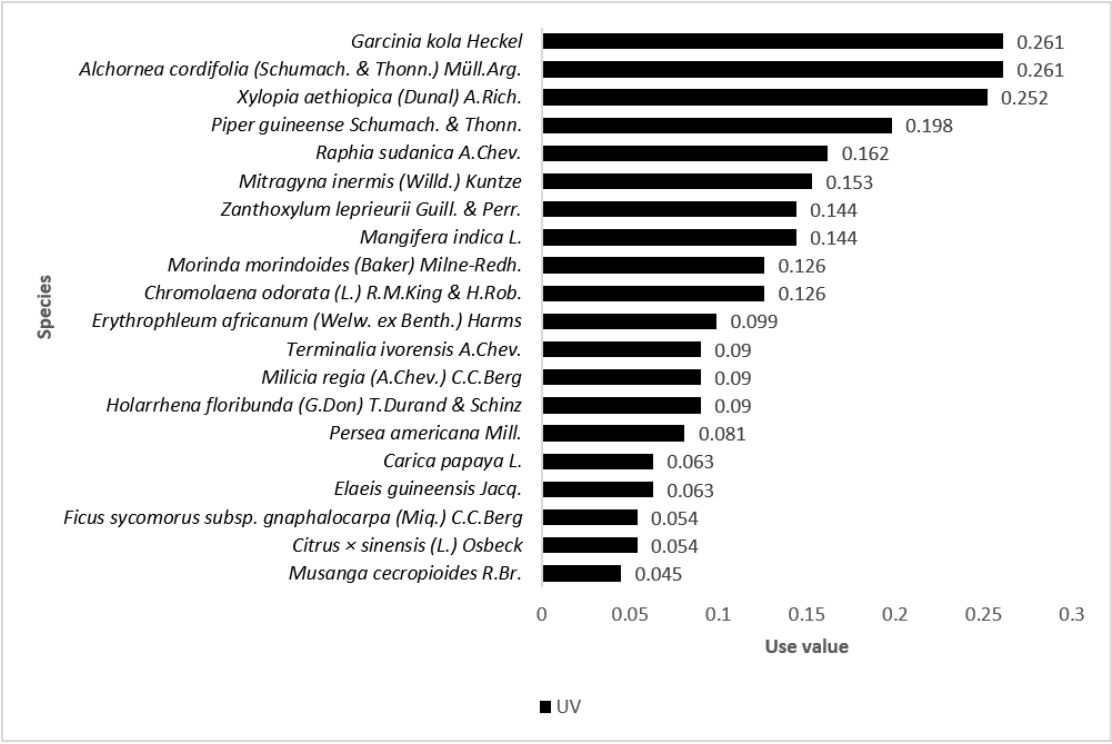


Figure 2. Use-value index (UV) of the main species exploited by local populations in five localities bordering the Nimba Mountains forests

Harvesting pressure (C')

The species *Garcinia kola* Heckel shows 46.3% destructive use across the five localities, giving it the highest harvesting-pressure index (C'), at 155 (Table 2). It is followed by *Mitragyna inermis* (Willd.) Kuntze, with 60% destructive harvesting and a C' of 90. *Terminalia ivoriensis* A. Chev. has the lowest C', at 16. Based on IUCN status, the species *Milicia regia* (A.Chev.) C.C.Berg (VU) and *Terminalia ivoriensis* A. Chev. (VU), with destructive harvest rates of 75% and 40% respectively, warrant particular attention. Characterization of research participants

Community dependence on medicinal uses (UDmed)

The medicinal-use dependence indices (UDmed) differed significantly between localities ($\chi^2 = 67.1$, $p < 0.001$), ranging from 22.7% at Doromou to 59.8% at Serengbara. The value at Doromou was significantly lower than those of all other localities ($p < 0.001$), whereas the values at Serengbara (59.8%), Gouamo (52.0%) and Zouguepo (55.8%) do not differ significantly from one another. Their p-values range between 0.24 and 0.57.

Table 2. Harvesting-pressure index (C') of the main species exploited by local populations in five localities bordering the Nimba Mountains forests

Species	Ntotal	Ndest	Nlocs	Destructive Use (%)	C'	Status IUCN
Garcinia kola Heckel	67	31	5	46.3	**155**	NT
Mitragyna inermis (Willd.) Kuntze	30	18	5	60.00	**90**	LC
Mangifera indica L.	38	18	4	47.36	**72**	LC
Morinda morindoides (Baker) Milne-Redh.	16	14	4	87.50	**56**	NE
Zanthoxylum leprieurii Guill. & Perr.	21	14	4	66.67	**56**	NE
Raphia sudanica A. Chev.	24	11	5	45.83	**55**	NT
Milicia regia (A.Chev.) C.C.Berg	12	9	5	75.00	**45**	VU
Xylopia aethiopica (Dunal) A. Rich.	47	9	5	19.1	**45**	LC
Erythrophleum africanum (Welw. ex Benth.) Harms.	17	11	4	64.70	**44**	LC
Alchornea cordifolia (Schumach. & Thonn.) Müll.Arg.	49	8	5	16.3	**40**	LC
Holarrhena floribunda (G. Don) T.Durand & Schinz.	13	9	4	69.23	**36**	LC
Carica papaya L.	9	6	5	66.7	**30**	DD
Terminalia ivoriensis A. Chev.	10	4	4	40.00	**16**	VU

Ntotal = total number of citations; Ndest = citations involving destructive harvesting (bark, root, wood, felling); Nlocs = number of localities in which the species was cited; C' = harvesting-pressure index; VU = Vulnerable; EN = Endangered; NT = Near Threatened; LC = Least Concern; NE = Not Evaluated; DD = Data Deficient (IUCN, 2023).

Documented medicinal uses

The documented medicinal uses cover 24 recurring conditions (Table 3). The most prominent are abdominal pain, malaria, headache, fever, general fatigue, diarrhoea, poisoning and pregnancy-related pain. Abdominal pain accounts for 25.4% of the conditions most often treated with plant species from the reserve. The species *Alchornea cordifolia and Xylopia aethiopica* are used for this purpose. Next comes malaria, accounting for 6.7% of uses (*Mitragyna inermis*, *Chromolaena odorata*), headache (*Piper guineense*, *Carica papaya*) and fever (*Alchornea cordifolia*, *Xylopia aethiopica*), accounting for 6.0% and 5.2% of uses,respectively.

Table 3. Main conditions treated with the forest pharmacopoeia in the five localities bordering the Nimba Mountains forests.

Target conditions	Number of citations	Medicinal uses (%)	Main species used for treatment
Abdominal pain	98	25.4	*Alchornea cordifolia*, *Xylopia aethiopica*
Malaria	26	6.7	*Mitragyna inermis*, *Chromolaena odorata*
Headache	23	6.0	*Piper guineense*, *Carica papaya*
Fever	20	5.2	*Alchornea cordifolia*, *Xylopia aethiopica*
General fatigue	18	4.7	*Garcinia kola*, *Raphia sudanica*
Diarrhoea	17	4.4	*Piper guineense*, *Mangifera indica*
Poisoning	17	4.4	*Erithrophleum africanum*
Constipation	12	3.1	*Carica papaya*, *Piper guineense*
Skin conditions	9	2.3	*Chromolaena odorata*, *Alchornea cordifolia*
Toothache	9	2.3	*Fagara leprieurii*
Abdominal pain (pregnancy)	9	2.3	*Alchornea cordifolia*, *Carica papaya*
Bloating	6	1.6	*Xylopia aethiopica*
Jaundice	5	1.3	*Raphia sudanica*, *Morinda morindoides*

Supply-disruption vulnerability index (Am)

Normalised values

The AHP matrix showed that UDmed is 1.5 times more important than UQ (UDmed versus UQ = 1.5) and twice as important as S (UDmed versus S = 2.0); UQ, in turn, is 1.5 times more important than S (UQ versus S = 1.5). The consistency ratio (CR = 0.0013), which was below the 0.10 threshold, confirms the reliability of these judgements, indicating that the resulting

weightings can be used without major risk of bias. The normalised principal eigenvectors (min-max, 0 to 1) derived from the normalised matrix show that the medicinal use-dependence index (UDmed) accounts for 45.99% of total importance (w1(UD) = 0.4599; Table 4), daily use (UQ) for 31.89% (w2(UQ) = 0.3189) and species richness (S) for 22.12% (w3(S) = 0.2212) of total importance. This hierarchy identifies the medicinal use-dependence index UDmed as the priority parameter.

Table 4. Construction and normalisation of the AHP matrix, and calculation of weights

	UDmed	**UQ**	**S**	**Interpretation**	**UD'med (normalised)**	**UQ' (normalised)**	**S' (normalised)**	**Weight w**
UDmed	1.000	1.500	2.000	UDmed is 1.5 times more important than UQ and 2.0 times more important than S	0.4615	0.4737	0.4444	0.4599 (w1)
UQ	0.667	1.000	1.500	UQ is 0.67 times as important as UD and 1.5 times more important than S	0.3077	0.3158	0.3333	0.3189 (w2)
S	0.500	0.667	1.000	-	0.2308	0.2105	0.2222	0.2212 (w3)
Total	2.167	3.167	4.500	-	1.0000	1.0000	1.0000	1.0000

S = species richness; S' = species richness normalised min-max (0, 1); UDmed = medicinal-dependence index; UD'med = medicinal-dependence index normalised min-max (0, 1); UQ = daily use; UQ' = daily use normalised min-max (0, 1); Am = supply-disruption vulnerability index.

Formulation of the supply-disruption vulnerability index (Am)

The supply-disruption vulnerability index (Am) was formulated as follows:

$$\mathbf{Am = (w1 \times UD') + (w2 \times UQ') + (w3 \times (1 - S'))}\ ,$$

i.e., Am = (0.4599 × UD'med) + (0.3189 × UQ') + (0.2212 × (1 - S'))

The interpretation of Am levels, divided into five equal intervals of 0.20, was validated by the authors (Table 5). The supply-disruption vulnerability index (Am) thus ranges from Low vulnerability at Doromou (0.141) to Critical vulnerability at Zouguepo (0.927). Serengbara and Zouguepo, with Am values of Critical (0.927) and Very High (0.779) respectively, are the most vulnerable and most exposed to supply disruption (Table 6). Zouguepo combines three aggravating factors: a substantial dependence on medicinal plants (55.8%), a high rate of daily use (99,5%) and the lowest floristic richness of the five localities (35 species).

Table 5. Interpretation grid for the supply-disruption vulnerability index

Value Am	**UDmed**	**Interpretation**
0.80 - 1.00	Critical	All three normalised components are simultaneously high. Priority intervention required.
0.60 - 0.79	Very High	UD'med high, with at least one other component also high. Urgent measures required.
0.40 - 0.59	High	UD'med moderate to high, with a substantial contribution from UQ' or (1 - S'). Monitoring should be strengthened.
0.20 - 0.39	Moderate	Low to moderate composite vulnerability. Periodic monitoring advised.
0.00 - 0.19	Low	All components are low. Low risk of supply disruption.

Am = supply-disruption vulnerability index; UDmed = medicinal-dependence index

Table 6. Supply-disruption index (Am) in the five localities bordering the Nimba mountains forests.

Locality	Number of citations	Raw S	Raw UDmed	Raw UQ	1 - S' normalised	UD'med normalised	UQ' normalised	Am	Am level
Keoulenta	210	43	0.395	0.667	0.100	0.452	0.031	0.240	Moderate
Doromou	207	44	0.227	0.807	0.000	0.000	0.444	0.141	Low
Serengbara	117	34	0.598	0.761	1.000	1.000	0.308	0.779	Very High
Gouamo	125	34	0.520	0.656	1.000	0.789	0.000	0.584	High
Zouguepo	217	35	0.557	0.995	0.900	0.890	1.000	0.927	Critical
Minimum	117	34	0.227	0.656	0.000	0.000	0.000	0.141	
Maximum	217	44	0.598	0.995	1	1	1	0.927	

S = species richness; S' = species richness normalised mimax (0, 1); UDmed = medicinal-dependence index; UD'med = medicinal-dependence index normalised min-max (0, 1); UQ = daily use; UQ' = daily use normalised min-max (0, 1); Am = supply-disruption vulnerability index.

Sensitivity testing and validation of the Am index

The sensitivity analysis showed that, for Gouamo and Serengbara, 19 of the 26 ±20% permutations produced a change in vulnerability category. Gouamo (0.584 (limit 0.60)) moved to the Very High Am level in 10 permutations (Am ranging from 0.503 to 0.653), and Serengbara (0.779 (limit 0.80)) moved to a Critical Am level in 9 permutations (Am ranging from 0.714 to 0.836). In every case these shifts represented a worsening rather than an improvement in risk. Zouguepo (Critical) and Doromou (Low) remained stable across all 26 permutations, and no locality dropped to a lower vulnerability category. The reliability of the conclusions is therefore preserved.

UDmed and Am are also positively and significantly correlated ($\rho = 0.90$; $p = 0.03$), confirming that UDmed is the principal driver of variation in the Am index (Table 7).

Table 7. Correlation coefficients between UDmed, UQ, S and Am in the five localities bordering the Nimba Mountains forests.

Comparison	Spearman correlation (ρ)	p-value
UDmed × Am	0.90	0.03*
UQ × Am	0.30	0.62
S × Am	- 0.66	0.21

S = species richness; UDmed = medicinal-dependence index; UQ = daily use; Am = supply-disruption vulnerability index.

Conservation priority

Species cited by at least a quarter of informants correspond to a use value (UV) of 0.25. In this study, C' ranges from 0 to 155. Jenks natural-breaks analysis identified a gap of 10 units between C' = 35 and C' = 45, providing the empirical basis for the Priority 1 threshold (C' ≥ 45). A ± 20% sensitivity analysis of UV (0,20 - 0.30) and C' (36 - 54) showed that *Garcinia kola* and *Xylopia aethiopica* remained Priority 1 species under every combination tested. The conservation-priority matrix classified the species into four categories according to the combined use value (UV) and harvesting pressure (C') (Fig. 3):

- Priority 1: UV ≥ 0.25 and C' ≥ 45; immediate conservation measures and annual monitoring.
- Priority 2: UV ≥ 0.25 and C' < 45; heavily used species subject to little destructive harvesting;
- Priority 3: UV < 0.25 and C' ≥ 45; bioindicator species of forest degradation;
- Priority 4: UV < 0.25 and C' < 45; species with low use and low pressure.

Accordingly, the species *Garcinia kola* (UV = 0.26 and C' = 155) and *Xylopia aethiopica* (UV = 0.26; C'= 45) were classified as Priority 1 species. The species *Alchornea cordifolia* (UV = 0.26; C' = 40) was classified as Priority 2. Six species, *Mitragyna inermis*, *Mangifera indica*, *Zanthoxylum leprieurii*, *Morinda morindoides*, *Raphia sudanica*, and *Milicia regia* are classified as Priority 3. Milicia regia (VU) and *Terminalia ivoriensis* (VU) have low use values, yet their harvesting is exclusively destructive (75% and 40% respectively). They therefore warrant attention on the basis of IUCN status, irrespective of their priority category.

Determinants of dependence on plant species use

Several factors are associated with this dependence. The surveyed population is made up mostly of farmers (between 81% and 100%; Fig. 4), who are the heaviest users of plant species. Daily use ranges from 65.6% at Gouamo to 99.5% at Zouguepo. Beyond farming, low levels of education and non-native status also emerge as important drivers of dependence. Illiteracy rates range from 22.2% at Serengbara to 66.7% at Gouamo, and the proportion of non-native residents' ranges from 4.0%

at Keoulenta to 52.4% at Gouamo. Gouamo and Zouguepo, which have the highest rates of illiteracy and non-native residents, also show the highest rates of medicinal dependence. Doromou, by contrast, has the lowest dependence rate (22.7%) despite a high illiteracy rate.

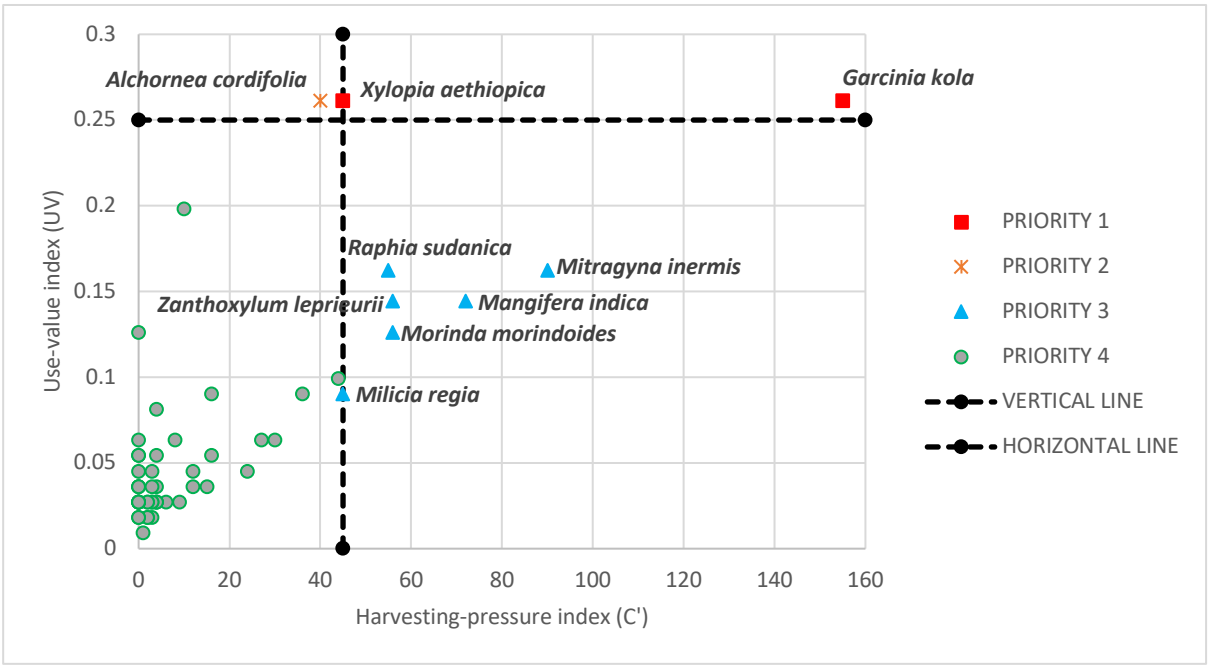


Figure 3. Conservation-priority matrix for plant species in the five localities bordering the Nimba Mountains forests

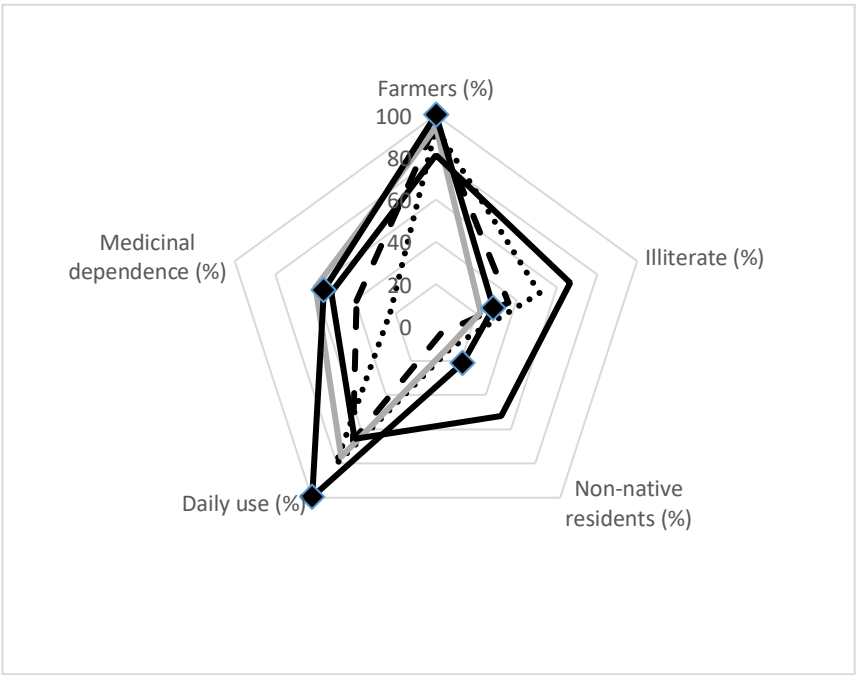


Figure 4. Indicators of dependence on plant species use in the five localities bordering the Nimba Mountains forests

Discussion

Validity and methodological contribution of the new indices

The C', UD and Am indices address aspects of human dependence on plants that current ethnobotanical indices fail to capture. The use-value index (UV), for example, indicates the proportion of informants who use a given plant species, but it does not distinguish a species harvested non-destructively by many informants from one harvested destructively across several areas. The harvesting-pressure index (C') seeks to fill this gap by simultaneously quantifying the intensity of destructive use and the geographical extent of the destructive pressure exerted on a plant species. Thus, *Garcinia kola*

obtains the highest C' (155), with 46.3% of its uses destructive across all five localities, whereas a species with an equivalent level of destructive use confined to fewer localities would score lower. This logic draws on the model of Hall & Bawa (1993) and answers the need for tools that work in data limited settings (Ticktin 2004).

The use-dependence index (UD) and the supply disruption vulnerability index (Am) address the dimension of community vulnerability. This dimension is not captured by species centred indices such as the relative frequency of citation index (RFC, Tardío & Pardo-de-Santayana 2008), the use-value index (UV) or CI (Leonti *et al*. 2022). Comparable multi-criteria approaches do exist; they have been proposed for tree species in Burkina Faso (Ouédraogo *et al*. 2014) and in West Africa more broadly (Gaoue *et al*. 2017), though these do not allow the simultaneous assessment of species-level pressure and locality-level vulnerability. The Am index, moreover, was built using the Analytic Hierarchy Process; a consistency ratio below 0,10 validates the resulting hierarchy. The positive, significant correlation between UDmed and Am confirms that medicinal dependence is the principal determinant of vulnerability, and the stability observed under ±20% sensitivity analysis strengthens confidence in the resulting ranking.

Conservation prioritisation and target species

The matrix crossing UV and C' places *Garcinia kola* and *Xylopia aethiopica* in Priority 1. Both species are subject to high use and heavy destructive pressure, a status that holds under sensitivity analysis. The Priority 1 designation reflects species that may be most heavily exploited by local communities, but it does not demonstrate a proven population decline or ecological degradation, which would require further ecological surveys that this study does not provide. Future studies should incorporate population size assessments, species abundance estimates, regeneration surveys and demographic trend analyses to validate the conservation status of these identified priority species. Management measures and annual monitoring are recommended for these species.

Incorporating IUCN status as an independent criterion also brings the species Milicia regia (VU) and *Terminalia ivoriensis* (VU) into Priority 3 despite a UV below 0,25. These species are subject to destructive-harvest rates of 75% and 40% respectively, an approach consistent with IUCN guidance for heavily exploited settings (Drapier *et al*. 2023). Treatment of abdominal pain, malaria and fever also relies heavily on *Alchornea cordifolia*, *Xylopia aethiopica*, and *Mitragyna inermis*. This therapeutic specialisation could heighten the risk of disruption should these species decline. The prominence of abdominal pain is consistent with ethnobotanical surveys conducted in forested Guinea (Baldé *et al*. 2020; Camara *et al*. 2025).

Conservation recommendations

Establish harvest quotas for *Garcinia kola*, promote planting in degraded areas, and develop community managed nursery programmes (Kouholi *et al*. 2026; Sodahlon *et al*. 2026).

In the case of *Xylopia aethiopica*, establish long-term population monitoring and draw up guidelines for the sustainable harvesting of bark to minimise damage to individual trees (Zdissou *et al*. 2025; Mariot *et al*. 2014).

For *Milicia regia*, support restoration and enrichment replanting initiatives, and conduct studies on regeneration and recruitment to assess the population's potential for recovery (Kissa *et al*. 2025).

Regarding *Terminalia ivorensis*, undertake urgent demographic and population assessments, and monitor regeneration, recruitment and population structure to determine the local conservation status (Konan *et al.* 2025; Bamigbaye *et al.* 2026).

Vulnerability gradient and socio-ecological determinants

The Am index shows that Zouguepo reaches the Critical threshold and Serengbara is classified as Very High. These high levels of dependence on forest plant resources are partly explained by the socio-demographic profile, namely farming, together with high rates of illiteracy and non-native residency. Doromou, however, is an exception. Despite high illiteracy, its dependence remains low, which suggests the influence of better access to healthcare facilities or alternative knowledge. These findings are consistent with Shackleton *et al*. (2020) on the determinants of NTFP dependence in West Africa. These authors showed that such dependence in West Africa is shaped by several factors, including a lack of alternatives. Stronger regional comparisons with ethnobotanical studies from Guinea (Baldé *et al*. 2020; Camara *et al*. 2025), Liberia, Côte d'Ivoire and the wider Upper Guinean Forest region would be needed to assess whether these patterns are consistent with those reported elsewhere in West Africa. This constitutes a priority avenue for further work.

Limitation of the study and new directions

These indices nonetheless have limitations. First, in its current formulation Am is not comparable across studies as its values depend on the range of localities sampled. This property is shared with other ethnobotanical indices (UV, ICF and RI), whose values depend on sampling context (number of informants, subjectivity), which vary by locality (Reyes-García *et al*. 2006). With five localities, Am is not yet fully validated and should be regarded as a pilot tool rather than a definitive metric. They remain useful, however, for ranking the importance of plant species within a single locality. Second, C' is a pressure index, not a sustainability index. It cannot establish that a species is overexploited in ecological terms, and should instead be read as a warning signal calling for complementary studies of population density and regeneration dynamics (regeneration rate, population size, proportion of reproductive individuals), rather than as a diagnosis of overexploitation. Third, the absence of herbarium vouchers introduces taxonomic uncertainty. Identifications are provisional pending future confirmation. Fourth, the sensitivity analysis reveals a degree of instability in the Am index. Of the 26 ±20% weighting permutations, only 14 are entirely stable, so Am conclusions for localities close to a threshold should be accompanied by a confidence interval. Fifth, the AHP weightings adopted here reflect the specific context of the Nimba Mountains and are not universally transferable. Recalibrating the weightings through expert judgement is required for each new application. Finally, social desirability bias may have affected self-reported interview data.

Conclusion

This study makes a methodological and empirical contribution to understanding the dynamics of plant-resource exploitation in the Nimba Mountains, Guinea. It combines novel indicators of harvesting pressure, community dependence and vulnerability to supply disruption, revealing differentiated risks across localities that current conservation approaches fail to capture. Ecological, social and economic dimensions therefore need to be combined within sustainable forest-management strategies for the Nimba Mountains. The proposed C', UD and Am indices provide a rigorous, reproducible and empirically grounded framework for prioritising conservation in data limited contexts. As exploratory pilot tools designed for a first investigation in a restricted access protected area, they should not be presented as fully validated metrics. Their value is proportional to the rigour with which their assumptions, limitations and conditions of application are declared. This pilot study opens up several avenues for further work. The most immediate is demographic validation of the species classified as Priority 1 (*Garcinia kola*, *Xylopia aethiopica*) through field surveys of regeneration rates and population structure. A second avenue is applying these indices in other forested areas of Guinea or West Africa, to build the baseline data needed to establish absolute anchor values for normalising Am.

Declarations

List of abbreviations: Not applicable.

Ethics approval and consent to participate: The participation of healers was subject to the acceptance of the Free and Informed Consent Form. The study complied with the ethical guidelines of the International Society of Ethnobiology and Guinean legislation.

Consent for publication: The participants provided consent for the publication of the data. All authors have read and approved the final version of this material.

Availability of data and materials: All datasets and AHP derivation matrices are archived and available

Competing interests: The authors declare no conflicts of interest.

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Author contributions: Design of the study: YFCA, SPL, SA, BB, OOT, PL; Carried out the data collection: OOT, YFCA; Carried out species identification**:** OOT, YFCA; Carried out the data analysis: YFCA; Wrote the first draft of the manuscript: YFCA; Review and final writing of the manuscript: YFCA, SPL, SA, BB, OOT, ST, PL; Translation: ST; Supervision: SA.

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