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RESEARCH ARTICLE

Resilience of Indigenous healthcare systems: Ethnobotanical approaches among the Baka, southeastern Cameroon

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Abstract

1. Indigenous Peoples rely on biodiversity and traditional knowledge for health and well-being, yet biological and cultural systems are threatened by ecological and social changes. Limited understanding exists on the factors that support the resilience of Indigenous Peoples' healthcare systems—the capacity of a healthcare system to adapt to disturbances while continuing to provide appropriate health services.
2. This study explores how medicinal plants and ethnobotanical knowledge contribute to the resilience of Indigenous Peoples' healthcare systems, working specifically with the Baka, forager-horticulturalists from Cameroon. The Baka rely on medicinal plants for their health but face several social and ecological challenges that affect their livelihood, culture and well-being. We explored how the Baka healthcare system prevents and treats different health issues with plant-based remedies, assessed the contribution of plant species in this system and evaluated potential threats to the Baka healthcare system. Using a mixed-methods approach combining free listing of medicinal plants, self-reported health recalls, walk-in-the-wood trips, individual knowledge surveys and botanical collection, we engaged 263 individuals (108 children and 155 adults) across two settlements. We developed indices to evaluate the resilience of the healthcare system.
3. We identified 281 medicinal plant species used to treat 104 health issues, resulting in a total of 1187 remedies (i.e. pairings of a single species with a specific health issue). Twelve species were used for many health problems (considered as having moderate-to-high multifunctionality), and 135 species were used in uncommon ways (considered atypical). Nine health issues were treated by a few plant species (considered low-redundancy issues). About 40 species were found to be under

pressure from logging, market demands or under conservation threats, with implications for the whole healthcare system.

4. By integrating different ethnobotanical methods, this research provides a detailed understanding of medicinal plant diversity and therapeutic redundancy within the Baka healthcare system. We discuss the potential of ethnobotanical indices to help assess the resilience of healthcare systems—and, broadly, social-ecological systems. We also discuss the implications of our insights for public health policies targeting the Baka and other Indigenous Peoples, as well as for the conservation of biocultural diversity.

KEYWORDS

Congo basin, medicinal knowledge, medicinal plants, social-ecological system, utilitarian redundancy

1 | INTRODUCTION

Plant-based remedies serve as the primary source of medicine for a substantial proportion of the population living in developing countries, helping to preserve their physical and mental health (Robinson & Zhang, 2011). This reliance is especially significant for Indigenous Peoples whose healthcare system is shaped by complex relations between cultural cosmovision, ethnoecological knowledge and local ecosystems (Gallois, Ambassa, & Ramirez-Rozzi, 2024; Redvers et al., 2022). However, environmental degradation driven by land-use changes, exploitation of natural resources, pollution, climate change and invasive alien species increasingly threatens these systems (Díaz et al., 2019), including the availability of medicinal plants. Concurrently, longstanding marginalization and land dispossession, as well as more recent challenges such as climate change and socio-economic shifts, threaten Indigenous People's knowledge systems (Fernández-Llamazares et al., 2021).

In this context, understanding the factors that contribute to the resilience of Indigenous Peoples' healthcare system is crucial. Drawing on relational thinking within sustainability science (West et al., 2020), we approach resilience not as a static attribute but as an emergent property of dynamic and interdependent relationships among people, plants, knowledge systems and ecosystems. Accordingly, we define 'healthcare system resilience' as the capacity of a healthcare system to absorb, adapt to and recover from internal and external disturbances, such as ecological, social or political stressors, while continuing to provide effective and culturally appropriate health services. This relational framing recognizes that health and healing practices are embedded within broader sociocultural-ecological systems, shaped by reciprocal interactions between biodiversity, cultural practices and place-based knowledge (Díaz & Pascual, 2025). As such, understanding resilience requires approaches that account for these entangled relationships and their role in shaping both the functional and adaptive structure of Indigenous Peoples' healthcare system (Albuquerque et al., 2024; Barnes et al., 2022; Gallois, Ambassa, & Ramirez-Rozzi, 2024; Polain et al., 2024). This perspective aligns with Indigenous Peoples' ontologies that do not separate health, land and knowledge, but understand them as co-created through lived relationships with the more-than-human world (Kimmerer, 2013).

In this line, some ethnobotanists have proposed a theoretical utilitarian framework that emphasizes the need to consider both the contribution of plant species to the healthcare system and the potential threats they face to assess the resilience of this system (de Medeiros et al., 2020). This work has resulted in the development of the *utilitarian redundancy index*, an index that builds on the notion that a higher degree of medicinal plant redundancy (where multiple plant species are used to address the same health issue) enhances the likelihood of effective treatment. In situations where one plant remedy is unavailable, alternative species can be used to treat the ailment, thereby contributing to the healthcare system's resilience (Albuquerque et al., 2024; de Medeiros et al., 2020). This framework also facilitates the identification of both strengths and threats to the healthcare system. For instance, health issues characterized by a low degree of medicinal plant redundancy (i.e. health issues treated by a single or few species) are more difficult to manage in the face of ecological or socioeconomic disturbances to the ecosystem. The loss or scarcity of these key species can significantly constrain the availability of remedies. Therefore, exploring the diversity of plant species used to treat different health issues can help identify those health issues that are most difficult to manage within a local healthcare system, thus contributing to understanding the resilience of the healthcare system.

Additionally, plant species can be used to treat or prevent a range of different health issues (Santoro et al., 2024), contributing differently to the healthcare system. Some species are multifunctional, used to treat multiple health problems, while others are specialized/atypical, targeting a single condition. By assessing the diversity of health issues treated by a plant species, it is possible to identify their distinct contribution to the healthcare system. This assessment is particularly relevant in the context of biodiversity loss, where certain species are more vulnerable than others. Understanding the degree of multifunctionality of a plant species within the healthcare system enables evaluation of how threats to these species might affect the overall system. For instance, the loss of a multifunctional species could compromise the treatment of multiple health issues simultaneously, whereas the loss of a specialized species would result in the disappearance of the sole treatment for that particular health issue.

In this study, we use this ethnobotanical approach (i.e. considering the relations between plant species and health issues) to explore the resilience of the Baka healthcare system. The Baka are forager-horticulturalists from southeastern Cameroon whose livelihoods depend on direct access to nature. With limited access to Western medicine, the Baka healthcare system primarily relies on the availability of plant species and their medicinal knowledge (Carson et al., 2019; Gallois, Ambassa, & Ramirez-Rozzi, 2024). However, livelihood changes, forest degradation, conflictual relations with their Bantu-speaking neighbours, and market integration challenge the Baka and their healthcare system (Carson et al., 2019; Dounias & Froment, 2006; Gallois et al., 2021; Gallois, Ambassa, & Ramirez-Rozzi, 2024; Hattori, 2014; Ramirez Rozzi, 2018). Drawing on previous studies (e.g. Afiong et al., 2024; Betti, 2004; Salali et al., 2016), our work assumes positive health outcomes of the traditional Baka healthcare system; it does not test it. In our work, we compare data collected in two settlements that differ in size, access to the market economy and proximity to health facilities. These differences serve as proxies for broader socio-ecological changes affecting the Baka, allowing us to examine how such changes may influence traditional healthcare practices and the resilience of the healthcare system. Specifically, the objectives of this work are: (1) to explore how the Baka healthcare system addresses diverse health issues with plant-based remedies; (2) to assess the relative contribution of different plant species to the Baka healthcare system; and (3) to evaluate potential threats to the Baka healthcare system. We hypothesize that different health issues are treated by varying numbers of plant species (H1); and that plant species vary in their contribution to healthcare, with some treating a greater number of health issues than others (H2). Given that previous findings showed similar health outcomes in the two study settlements (Gallois, Ambassa, & Ramirez-Rozzi, 2024; Gallois, van Andel, et al., 2024), we did not expect significant differences in medicinal plant redundancy related to health issues or species contributions between them. However, we expected that some species and health issues would be disproportionately impacted by socio-ecological changes, irrespective of settlement differences.

2 | CASE STUDY

The Baka are a forager-horticulturalist society mostly settled in the tropical evergreen and moist semi-deciduous forest of southeastern Cameroon. They live in villages along logging roads and have camps deeper in the forest where they spend weeks to months gathering wild edibles, hunting or working in cacao fields. While most Baka live in villages, some communities are settled permanently in forest camps and only visit villages sporadically (Leclerc, 2012). Some Baka also earn a living by working in the agricultural fields of the Nzimé, Bantu-speaking sedentary farmers from the study area and by exchanging forest products for agricultural produce with them and other Bantu traders (Gallois et al., 2020; Ramirez Rozzi, 2018). The relations with the Bantu farmers are complex (Hattori, 2014; Joiris, 2003; Köhler & Lewis, 2002) and represent an important source of conflict, with impacts for Baka health and well-being (Pyhälä, 2012).

For their livelihood, the Baka rely on both agriculture and foraging. Wild plants are crucial for their subsistence (Fongnzossie et al., 2023), including their diet (Billong Fils et al., 2020; Gallois et al., 2020), and medicine (Betti et al., 2013; Gallois, Ambassa, & Ramirez-Rozzi, 2024). The Baka society is egalitarian, characterized by shared responsibilities, allomaternal care and a permeable division of labour (Townsend, 2016). Communities are organized around extended families, clans and inheritance follows an ambilineal system (Townsend, 2016). Their way of life is deeply embedded in their cultural identity, expressed through celebrations that emphasize forest's abundance, joy and sharing (Hoyte & Mangombe, 2024). The Baka hold extensive ecological knowledge, which is shared across generations, with children learning early through oral transmission, observation, imitation and participation in daily subsistence activities (Gallois et al., 2017).

The Baka concept of health embraces physical, biological, ecological and spiritual dimensions, with some ailments believed to be caused by social or spiritual imbalance (Gallois, Ambassa, & Ramirez-Rozzi, 2024). They use both curative and preventive remedies. Previous work suggests that common ailments among the Baka include digestive and respiratory issues, malaria and malaria-like general symptoms and health concerns associated with the adoption of a sedentary lifestyle (Carson et al., 2019; Dounias & Froment, 2006; Gallois et al., 2021; Gallois, Ambassa, & Ramirez-Rozzi, 2024; Ramirez Rozzi, 2018). The Baka see their well-being as intrinsically linked to the forest's health, reflecting deep relational values (Hoyte & Mangombe, 2024). They have recognized health experts such as diviner-healers, midwives and other experts in specific issues such as hernias, sexual health and broken bones (Gallois, Ambassa, & Ramirez-Rozzi, 2024). When facing a health issue, the Baka mostly rely on their own knowledge, by first aiming to solve it within the household and then consulting other village members or specialists. They seldom leave the village for health assistance, such as going to hospitals or visiting healers from other settlements. The Baka use first and foremost medicinal plants. In a recent study conducted in the same settlements, we found that Western biomedicine was used only for 14% of the health issues reported and that no animal product was used as treatment (Gallois, Ambassa, & Ramirez-Rozzi, 2024).

3 | METHODS

We conducted research in two Baka settlements in the East region of Cameroon, located in the Lomie and Messok districts. The first settlement is a forest camp of about 300 individuals from four extended families. The camp is situated about 1 km from the logging road, near the Nzimé village, where some Baka families also have houses. The camp has limited access to shops, and the closest health centre is 12 km away. The second settlement is a larger village along the logging road, housing around 800 individuals from

11 extended families. Established by a Catholic mission in 1973, this village benefits from better access to health facilities, with a missionary medical centre, and a few shops (Ramirez Rozzi, 2018). The nearest Nzimé village is located about 8 km away (Gallois, Ambassa, & Ramirez-Rozzi, 2024).

The first author has lived with the Baka for more than 2.5 years over the last 12 years. One author of this work is a Baka man from the study area, who has collaborated with the first author for 12 years. The research originated from a request made by the Baka in 2019, during the first author's previous fieldwork, when a group of Baka approached the researcher to ask her to develop a study on their health and medicinal plants for documenting and revitalizing their knowledge. Data for this study were collected during two fieldwork periods of 6 weeks each in 2022 using a mixed-methods approach. We selected participants using a stratified convenience sampling, choosing available individuals across predefined strata. This approach aimed to ensure a balanced representation across sex (female and male), life stage (children and adults), health expertise (health experts and non-experts) and extended family groups. This strategy was designed to maximize the diversity of health issues and related knowledge present in the area. We worked with children between 6 and 16 years of age. After this age, the Baka generally consider themselves as adults (Gallois et al., 2017; Ramirez Rozzi, 2018). Recognized health experts included *nganga*, diviner-healers, midwives and experts in specific issues. During a first community meeting, participants made a list of recognized expert healers (12 were reported in the village, seven in the forest camp). Participation was entirely voluntary, and respondents were invited to share only the knowledge they felt comfortable disclosing. At no point were participants asked to reveal sacred, sensitive or restricted knowledge. In total, 263 Baka participated in this study, comprising 146 females and 117 males, 108 children and 155 adults. One participant engaged in all methods, six in three methods, 116 in two methods and 140 in one method.

Before the onset of the study, we obtained approval from the Ethical Committee of the Autonomous University of Barcelona (CEEAH5926) and a research permit from the Cameroon Ministry of Scientific Research and Innovation (00098/MINRESI/B00/C00/C10/C13). Upon arriving at the settlements, we presented the research objectives during a community meeting and then obtained the Free Prior Informed Consent of all individuals willing to participate. As agreed during these meetings, the time spent by the participants was compensated in kind (rice, salt and soap). Throughout the study, we followed the Code of Ethics of the International Society of Ethnobiology (ISE (International Society of Ethnobiology), 2006) and the charter of Ethical Research Involving Children (Graham et al., 2015). We anonymized all the information. The complete list of plants reported in our study, including local and scientific names and pictures, was shared with the Baka communities through written support, as requested by the Baka themselves. Following the communities' request and to protect the Baka's intellectual property, we do not publish medicinal plant recipes with their scientific and vernacular names.

3.1 | Data collection

We used five complementary methods (Figure 1).

3.1.1 | Free listing

Participants were asked to name all the medicinal plant species they knew, answering the question '*Which medicinal plants do you know?*'

3.1.2 | Self-reported health recall surveys

We asked one adult per household to report all the health issues affecting them and other members of their household during the 3 months prior to the interview, and the plant species they had used to address them.

3.1.3 | Individual knowledge surveys

We asked informants to report on the medicinal plant species they knew for addressing 18 health issues, categorized based on their prevalence in the communities: very frequent, moderately frequent and rare. Health issues mentioned in the survey included physical ailments as well as culturally bound health issues (e.g. related to sorcery, charms). The selection of these health issues was done using a dataset obtained during previous research in the same settlements that compiled 136 health issues reported by the Baka (Gallois, Ambassa, & Ramirez-Rozzi, 2024). Nine health issues were selected according to their occurrence in Baka communities: three were randomly selected from the frequently occurring ailments, three from ailments occurring with medium frequency and three from the low-occurrence group. Additionally, nine health issues, three specifically affecting men, three women and three children, were selected (see Gallois, Ambassa, & Ramirez-Rozzi, 2024).

Botanical vouchers, that is herbarium specimens of the plants reported in the three previous methods, were collected.

3.1.4 | Walk-in-the-wood trips

Participants were asked to guide us on a trip in the surrounding forest to show us all the medicinal plant species they knew and describe the health issues the plants addressed. Vouchers were collected on the spot.

3.1.5 | Focus group interviews

We asked our informants to verify the local names of the vouchers collected and gathered further information on timber and non-timber forest product species.

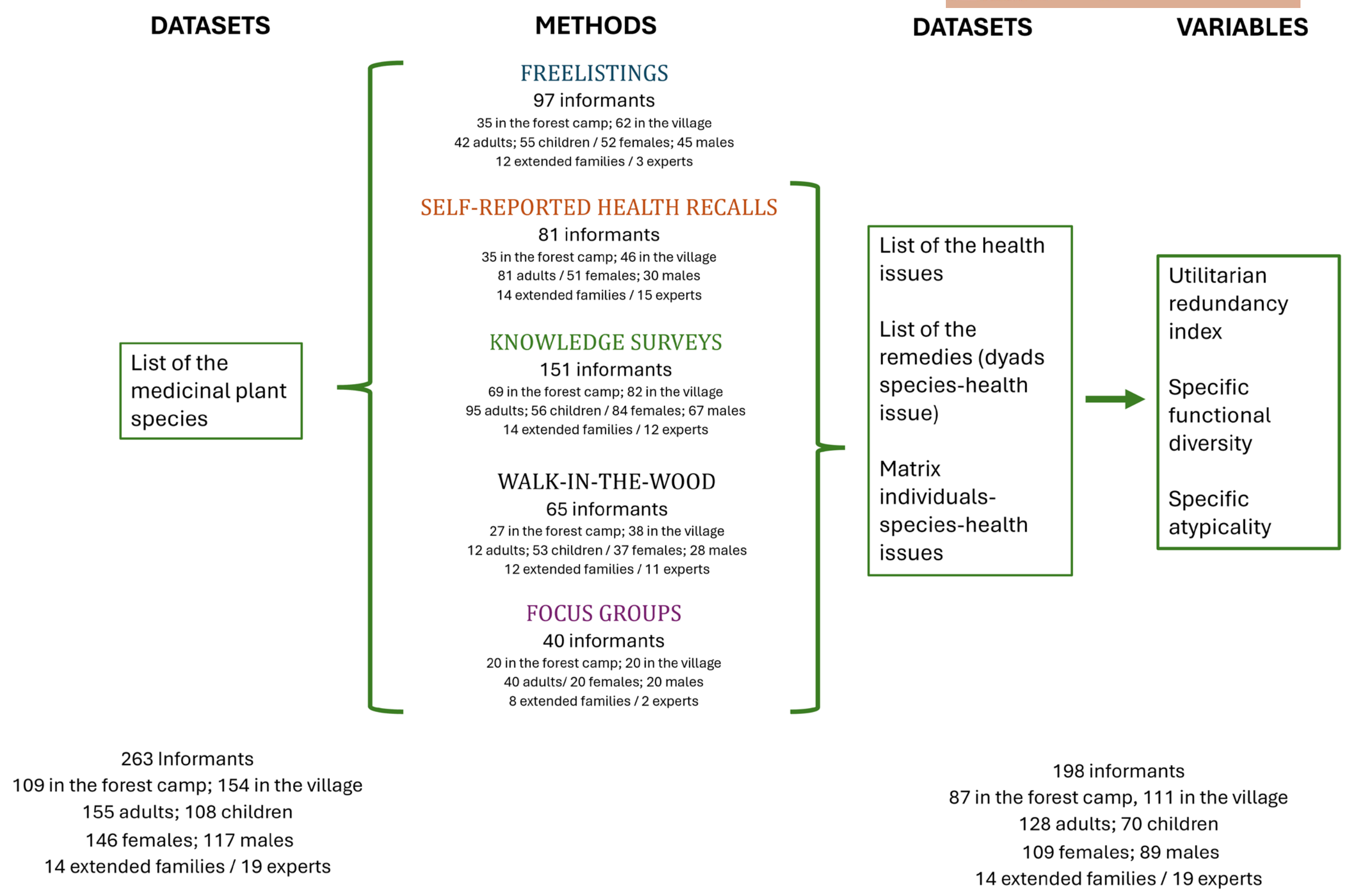

FIGURE 1 Methodological design and sampling approach. The 'Methods' column lists the data collection methods used with the respective sample. The 'Datasets' columns show the organized datasets derived from these methods. The 'Variables' column indicates the variables constructed from specific datasets. The lists appearing at the bottom display the composition of the final samples used for each dataset.

For each informant, we also recorded their sex, estimated age and genealogical information, including details on household and extended families. For each plant species, we gathered the conservation status by referring to the Red List of the IUCN (https://www.iucnredlist.org/en).

We conducted interviews in Baka language, spoken by the first author and helped by the fourth author. Health issues mentioned were translated into French and English and then categorized following the International Classification of Diseases—ICD—11th edition (World Health Organization, 2022).

Vouchers collected were identified and deposited in the Herbier National de Yaoundé, Cameroon and Naturalis Biodiversity Center, the Netherlands (see Supporting Information S1 for the complete list of plants). In this research, we considered *species* as both identified species and unidentified taxa that had a unique local name, either in the Baka, Nzimé or French language.

3.2 | Data analysis

We first compiled the information gathered through all the methods to elaborate an exhaustive list of medicinal plant species known and used in both settlements ($n=263$ informants; Figure 1). Then, we used the data from the self-reported health surveys, knowledge surveys and walk-in-the-wood trips to create the list of health issues and the list of remedies used to treat them. We defined remedies as the pairings of a single plant species with a specific health issue (e.g. thyme for headache). These data were provided by a total of 198 informants (87 in the forest camp and 111 in the village). We used this information to create a matrix with individuals in rows and species followed by health issues in columns (i.e. a species used for two health issues will appear twice). From this matrix, we derived (i) the total number of health issues reported for each species; (ii) the number of species reported for each health issue; and (iii) the total number of individuals who reported each species and who reported each remedy.

We used the information to create the following measures, calculated in both communities separately:

- *Utilitarian redundancy index—Uredit* (de Medeiros et al., 2020). For each health issue, we quantified the relation between the number of species reported to treat the health issue and the number of people who know the species that treat the health issue, expressed as

$$\text{Uredit} = \text{NSp} + \text{SC}$$

NSp: Total number of species mentioned for the health issue, SC: Species' contribution calculated as $\frac{\sum S_i}{N}$, where S_i represents the number of people who mentioned the species i as a treatment for the health issue and N the total number of individuals interviewed.

- *Specific functional diversity index–SpecDiv*. For each species, we calculated the number of health issues the species treated in relation to the number of individuals that know the different uses of the species, calculated as

$$\text{SpecDiv} = \text{NHis} + \text{HC}$$

NHis: Total number of health issues mentioned for the species, HC: Health issues contribution calculated as $\frac{\sum S_i}{N}$, where S_i represents the number of people who mentioned that the health issue i is associated to the species and N is the total number of individuals interviewed.

- *Specific atypicality index–SpecA*. For each species, we calculated its atypicality as the distance of the species to the commonly reported uses of plants. This measure captures how unusual the uses of a particular species are in comparison to other species. Following the concept developed by Goldberg et al. (2016), we calculated the specific atypicality index of plant SpecA_i as the cumulative Jaccard distances between the uses of a plant and those of others, normalized by the number of uses and applied to an inverse transformation. The formula is:

$$\text{SpecA}_i = 1 - \left(\frac{1}{1 + \frac{D_i}{|U_i| - 1}} \right)$$

where $|U_i|$ is the total number of documented health issues for species i, and D_i is the sum of the Jaccard distances between the uses of plant i and other species. Values close to 1 indicate highly unique uses. The Jaccard distance between the uses of two species i and j is calculated as:

$$d_{ij} = \frac{-\log\left(\text{similarity}_{ij}\right)}{\gamma}$$

where similarity_{ij} is the Jaccard similarity between the uses of plants i and j; and $\gamma = 1$ is the adjustable parameter that scales the distance.

To explore how plant-based remedies address various health issues, we compared the utilitarian redundancy index values of the different health issues. The higher the utilitarian redundancy index, the more likely the health issue is addressed, meaning it is easier to find alternative remedies. To assess the relative contribution of different species to the Baka healthcare system, we explored the diversity of species and assessed species' functional diversity and atypicality. Finally, to assess the threats to the Baka healthcare system, we: (1) compared the utilitarian redundancy index values between settlements, (2) explored the relationship between treatment redundancy for the health issues and species atypicality index; and (3) assessed species' exposure to logging, commercial harvest and conservation status. Our analyses were conducted on Stata and R platforms (See Supporting Information S2 for further details).

4 | RESULTS

The Baka reported 281 medicinal species, from which we identified 228 at the species level and 24 at the genus level (208 species identified from voucher collections and 44 from the literature) (Supporting Information S1). For 29 species, we could not collect a voucher or link the local name to a plant species from the literature, so they remained unidentified. Twenty-two species were identified as medicinal during the walk-in-the-wood trips, but no Baka name was known to our informants (one had a Nzimé name). The 252 species identified (including 24 crops) belong to 86 families and 204 genera. Fifty-eight species were reported only in the forest camp, and 55 were reported only in the village. Sixty-two species were collected by one method, while 61 were reported in all four methods (Figure 2).

The documented species were used to treat 104 different health issues (77 in the forest camp and 75 in the village; Figure 3). Most of them were culturally bound health concepts (20 issues) like attracting luck, fighting sorcery or resolving conflicts. Other categories included digestive (gastrointestinal) issues ($n = 14$; e.g. diarrhoea and stomach ache); infectious and parasitic diseases ($n = 11$; e.g. abscess and venereal diseases); and respiratory conditions ($n = 10$; e.g. cough and trouble with breathing). Twenty-eight health issues were unique to the forest camp and 27 to the village (Supporting Information S3).

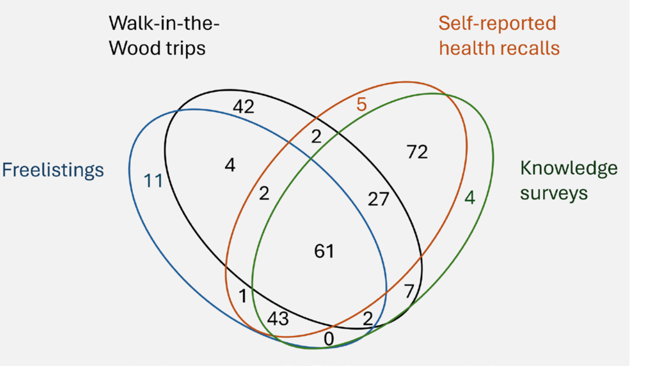

FIGURE 2 Overlap of species with medicinal properties reported with different data collection methods ($N = 263$ informants).

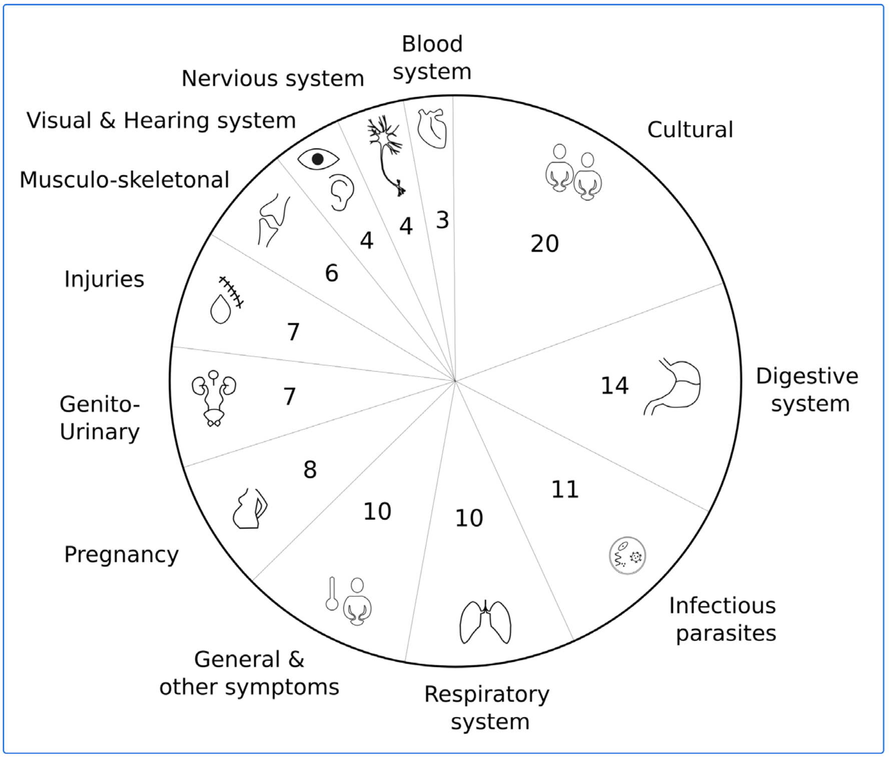

FIGURE 3 Number of health issues reported in our study, by categories following the International Classification of Diseases (n=104, 198 informants).

4.1 | Baka reported health issues and utilitarian redundancies

The 104 health issues were treated by a variable number of species each. Indeed, in total, 1187 remedies, that is pairings between a specific health issue and a single plant species, were reported. Some issues were treated with only one species, but one issue was treated with as many as 59 species (avg = 9 species per ailment; Std = 13.7). Overall, the average utilitarian redundancy index was 9.17 in the forest camp (Std = 13.2; min = 1, max = 54) and 10.22 in the village (Std = 15, min = 1, max = 61), meaning that every health issue is known to be treated, on average, by nine species. Seven of the 10 ailments with the highest utilitarian redundancy were shared across settlements, with three of them scoring above 40 in the utilitarian redundancy index in both settlements: *kotuba* (cough, >53); *ko na bubo* (stomach pain, >46); and *jiyo* (malaria and malaria-like symptoms, >43) (Figure 4). Some health issues were addressed by more plant species in the village than in the forest camp, such as *jiyo* (60 in the village vs. 43 in the forest camp); *nzom* (hepatitis, 25 vs. 11); and back pain (36 vs. 24). Some issues were addressed by more species in the forest camp, such as worms (28 in the forest camp vs. 18 in the village) (see Supporting Information S3). Over two-thirds of the health issues had a utilitarian redundancy index below 10, including 57 of the 77 health issues reported in the forest camp and 54 of the 75 reported in the village. Finally, 48 health issues had a utilitarian redundancy index of 1 in both settlements, meaning that they were treated by only one species. Of these, 11 were cultural illnesses, six were infectious and parasitic diseases, six were respiratory, and four were musculoskeletal and connective diseases (Supporting Information S3). As many as 43 of the 57 health issues treated with a single species were named during the walk-in-the-wood trips with health experts or children.

4.2 | Plant species contribution to the healthcare system

The 281 species varied substantially in their number of uses: some species had only one use whereas others had as many as 23 uses (avg = 4.4, Std = 4.4 ailments per species), suggesting different contributions to the healthcare system. The specific functional diversity index averaged 3, ranging from 1 to 18 (forest camp: avg = 3.34, Std = 3.1, min = 1, max = 16.38; village: avg = 3.61, Std = 3.4, min = 1, max = 18.05), meaning that every plant species is known to treat, on average, three health issues.

Among the 10 most functionally diverse species in each settlement, six were shared between settlements (Supporting Information S1) and had specific functional diversity above 10, namely: *Alstonia boonei*, *Greenwayodendron suaveolens*, *Irvingia gabonensis*, *Microdesmis puberula*, *Tabernaemontana crassa* and *Myrianthus arboreus* (Table 1).

In contrast, some species were atypical, in the sense that their uses were infrequently reported or their reported uses were not commonly cited together. Specifically, 135 species had an atypicality of 1, meaning that their medicinal uses are particularly distinctive within the Baka healthcare system. Among them, 69 treated several health issues (including 11 species reported in both settlements), while 66 treated a single health issue (five species were common to both settlements; Supporting Information S1).

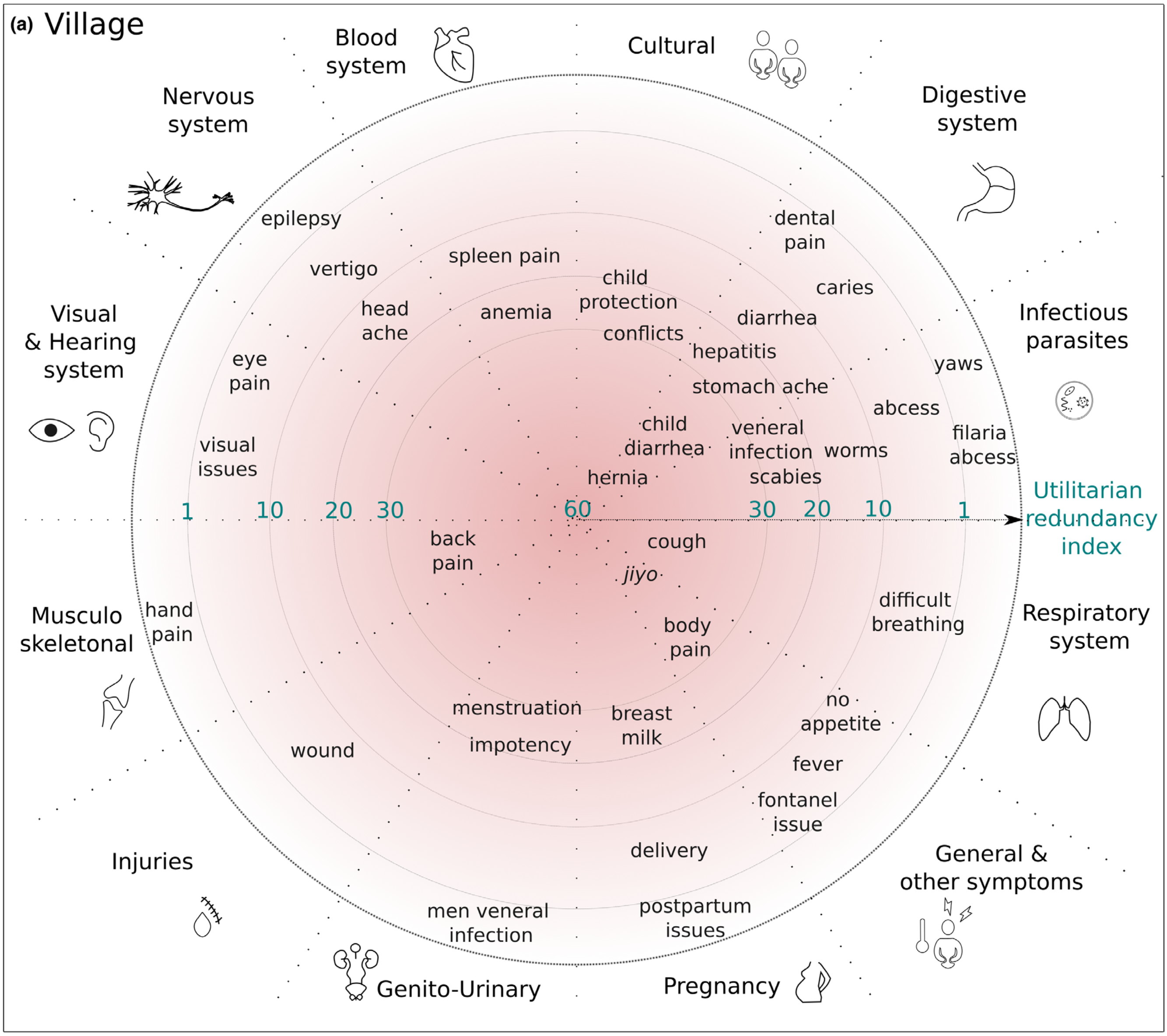

FIGURE 4 Distribution of health issues according to their utilitarian redundancy index (center = highest score, periphery = lowest), by categories of the International Classification of Diseases: (a) village (N = 101 informants); (b) forest camp (N = 80). *Jiyo* refers to malaria and malaria-like symptoms.

4.3 | Potential threats to the healthcare system

To further identify potential threats, we analysed health issues that had few reported plant remedies (Utilitarian redundancy index ≤1), combined with high specificity (Specific Atypicality = 1) and the threats affecting the plant species used for treatment.

Ten species with high atypicality were each the sole treatment reported for a distinct health issue (Table 2). In the forest camp, individual species were uniquely used to address children's respiratory issues ('*asue*'), poor hunting luck, venereal infection, physical and spiritual vulnerability, snake bites and female sterility. In the village, single species were exclusively used as charms and to treat circumcision wounds and children's digestive issues.

Additionally, we recorded 37 species that were either logged, sold or presented conservation threats (Table 3). Of these, eight were felled for timber, 19 yielded products sold at the local market, and two species were included in the Red List of the IUCN as endangered (*Amphimas tessmannii* and *Pericopsis elata*), nine as vulnerable and seven as near threatened (including *I. gabonensis*) (Table 3). Ten of these species had high atypicality (Specific Atypicality index = 1) and five exceeded the average specific functional diversity (avg = 9; Table 3; Figure 5).

5 | DISCUSSION

By applying multiple ethnobotanical indicators, this study brings evidence of the extensive diversity of medicinal plant species used by

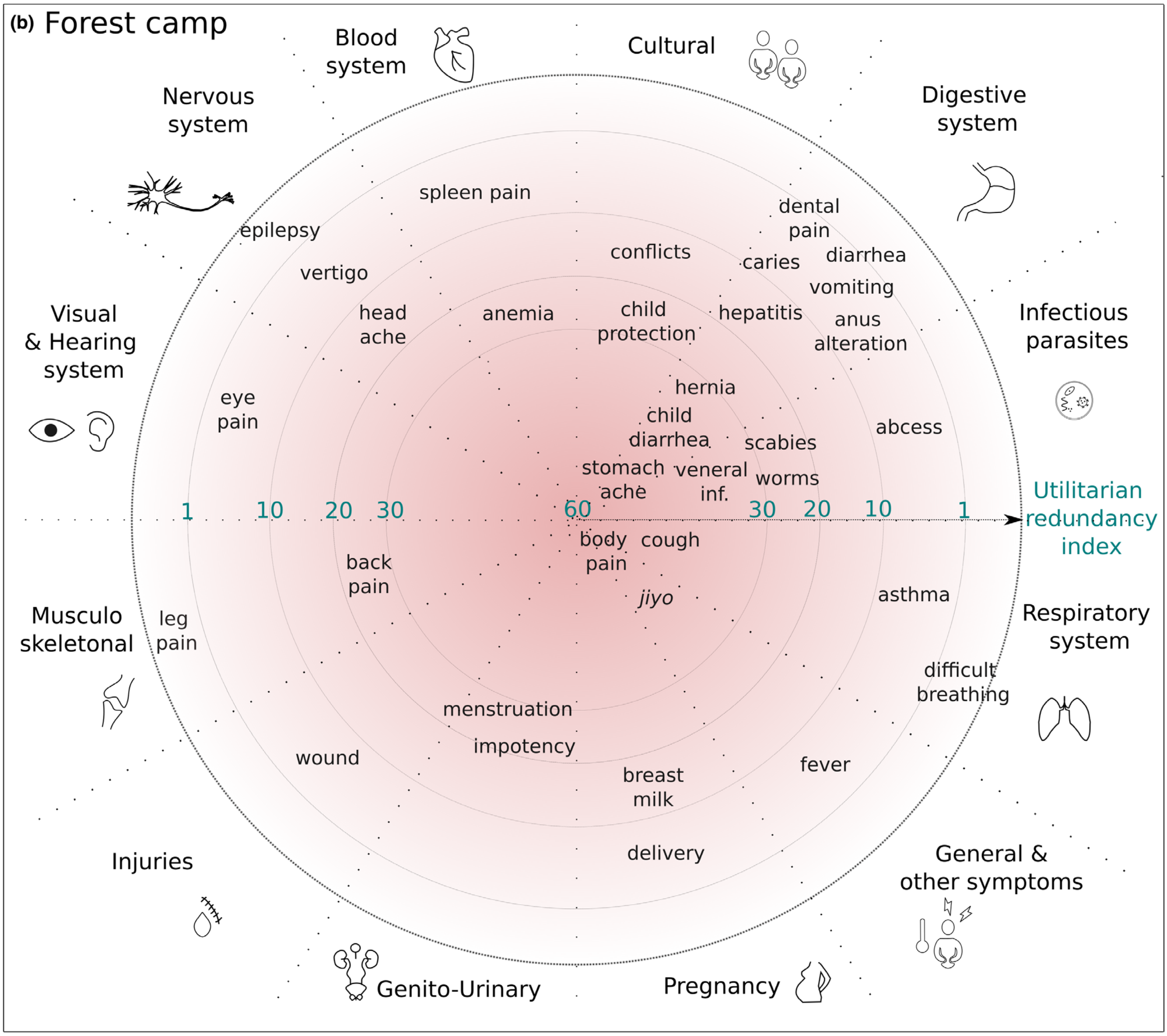

FIGURE 4 (Continued)

the Baka and their role in sustaining their healthcare system. Our results also show evidence of the potential threats to the healthcare system. Understanding these relationships between humans and plants provides a valuable lens for assessing the resilience of the Baka healthcare system in particular, while also contributing to broader frameworks of healthcare system resilience, public health policies and biocultural conservation.

5.1 | Baka healthcare system resilience

Our results show that, on average, each health issue is addressed by nine plant species known by our informants. This value is close to the values reported in a similar study conducted in Brazilian rural communities relying on farming and harvesting, such as in Morrão de Cima (Utilitarian redundancy index = 11.8); Sucuruiuzinho (11.5); and Sucruiu (7) (de Medeiros et al., 2020). Unlike the study conducted in Brazil, which only included those remedies reported by more than 10% of the informants (de Medeiros et al., 2020), our study considered all remedies mentioned across the different data collection methods. While our approach is more inclusive, it is important to note that we likely did not capture restricted or sacred knowledge held exclusively by specialists, as participants were only invited to share information they felt comfortable disclosing. Therefore, our results may not be directly comparable to those of the Brazilian study. Our goal was to provide a comprehensive overview of the diversity of non-restrictive knowledge within the studied population. Including specialist knowledge might have resulted in a higher number of health issues treated by a single species—often reported only by recognized experts—and, consequently, a lower utilitarian redundancy index value (Albuquerque et al., 2024). As such, the values obtained here should be interpreted as conservative estimates relative to those reported in previous research.

A significant number of health issues showed low-to-intermediate medicinal plant redundancy values (utilitarian redundancy index <10), consistent with studies conducted in Brazilian communities, where a large number of plant species were used for a few, more frequent diseases and where many less frequent or rare health issues were known to be treated only by a small number of species (de Medeiros et al., 2020; Nascimento et al., 2016). This explanation could also be applied to our case study, where health issues such as cough ('*kotuba*') and malaria and other malaria-like symptoms ('*jiyo*') had a high-utilitarian redundancy index and were frequently reported (Gallois, Ambassa, & Ramirez-Rozzi, 2024). The finding also aligns with previous work reporting the high occurrence of infectious and respiratory diseases and children's digestive issues among small-scale and forager societies from Central Africa (Froment, 2014) and beyond (Gallois, Ambassa, & Ramirez-Rozzi, 2024). Future studies should further explore the relation between utilitarian redundancy, disease frequency and the medical history of local communities.

TABLE 1 List of the 10 species with the highest specific functional diversity index, per settlement ($n = 198$ informants).

Species	Baka name	Specific Diversity Index	
		Village	Forest camp
Alstonia boonei De Wild.	Gùgà	18.05	11.11
Greenwayodendron suaveolens (Engl. & Diels) Verdc.	Botunga	16.41	14.38
Annonidium mannii (Oliv.) Engl. & Diels	Ngbé	16.29	3.03
Irvingia gabonensis (Aubry-Lecomte ex O'Rorke) Baill.	Pèke	15.22	11.17
Microdesmis puberula Hook.f. ex Planch.	Pipi	14.29	16.38
Tabernaemontana crassa Benth.	Pando	14.26	14.32
Cylicodiscus gabunensis Harms.	Boluma	13.54	6.48
Haumania danckelmanniana (J.Braun & K.Schum.) Milne-Redh.	KpàsElE	13.25	5.07
Pentaclethra macrophylla Benth.	Mbalaka	12.32	9.15
Myrianthus arboreus P.Beauv.	Ngàta	12.19	11.18
Capsicum sp.	Alamba	9.23	11.53
Manniophyton fulvum Müll.Arg.	Kusa	8.22	11.17
Sida acuta Burm.f.	Tandanda	8.15	12.36
Milicia excelsa (Welw.) C.C.Berg	Bangui	7.19	9.36

Our findings also contribute to expanding the geographical scope of research on the resilience of Indigenous Peoples' healthcare systems, which has predominantly focused on the Americas (Albuquerque et al., 2024). By categorizing Baka health issues using the World Health Organization classifications, our results can be compared with data from other settings while preserving local contexts. In this sense, our approach contributes to developing locally grounded comparative studies (Brondizio et al., 2021; Sterling et al., 2017) and could, therefore, enhance the depth and applicability of the utilitarian redundancy framework, contributing to a more comprehensive assessment of the resilience of Indigenous Peoples' healthcare systems. We also note that, while this methodological framework has been developed for health and for plants, it could be easily expanded to other components of the socio-ecological systems and human–nature relations.

5.2 | Plants' contribution to the healthcare system

Our study provides evidence, supported by voucher identification and local terminologies, of the rich diversity of plant species used as medicine by the Baka. With 281 medicinal plant species recorded in only two settlements, this study documents one of the highest numbers reported among the Baka (Afiong et al., 2024). This result probably reflects the inclusion and participation of a broad range of

TABLE 2 List of 10 species with a high-specific atypicality index treating health issues covered by only one species.

Family	Species	Baka name or voucher number
Araceae	*Cercestis congensis* Engl.	Jepame
Commelinaceae	*Pollia condensata* C.B.Clarke	SG132
Malvaceae	*Ceiba pentandra* (L.) Gaertn.	Kulo
Musaceae	*Musa* sp.	Taabu
Piperaceae	*Piper umbellatum* L.	Ndebelembe
Rubiaceae	*Geophila* cf. *afzelii* Hiern.	SG151
Rubiaceae	*Geophila obvallata* (Schumach. & Thonn.) Didr.	Sv143
Rubiaceae	*Hexasepalum sarmentosum* (Sw.) Delprete & J.H.Kirkbr.	SvB21
Thomandersiaceae	*Thomandersia hensii* De Wild. & T.Durand	SvB86
Unidentified		Njombo na bili

TABLE 3 List of the species reported in this study ($n=263$ participants) that are locally sold, logged or present in the Red List of the IUCN.

Family	Species	Baka name	IUCN state	Sold	Logged
Fabaceae	*Amphimas tessmannii* Harms	Kanga	en		
Fabaceae	*Pericopsis elata* (Harms) Meeuwen	Mobaye[b]	en		
Fabaceae	*Albizia ferruginea* (Guill. & Perr.) Benth.	Elonda[b]	nt		
Clusiaceae	*Garcinia kola* Heckel	Mbele[b]	vu		1
Ebenaceae	*Diospyros* cf. *crassiflora* Hiern	Lembe	vu	1	1
Euphorbiaceae	*Ricinodendron heudelotti* (Baill.) Heckel	Gobo	vu	1	
Huaceae	*Afrostyrax lepidophyllus* Mildbr.	Ngimbà	vu	1	
Malvaceae	*Rhodognaphalon brevicuspe* (Sprague) Roberty	Tenonu[b]	vu		1
Malvaceae	*Sterculia oblonga* Mast.	?Egboyo[b]	vu	1	1
Meliaceae	*Entandrophragma utile* (Dawe & Sprague) Sprague	Gbokulo	vu		
Ochnaceae	*Ochna calodendron* Gilg & Mildbr.	Molembengoi[b]	vu		
Sapotaceae	*Baillonella toxisperma* Pierre	Mabe	vu	1	1
Fabaceae	*Guibourtia demeusei* (Harms) J.Léonard	Paka[b]	nt		
Gnetaceae	*Gnetum* cf. *africanum* Welw.	Koko	nt	1	
Irvingiaceae	*Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baill.	Pèke[a]	nt	1	
Meliaceae	*Leplaea thompsonii* (Sprague & Hutch.) E.J.M.Koenen & J.J.de Wilde	Njombo	nt		
Moraceae	*Milicia excelsa* (Welw.) C.C.Berg	Bangui[a]	nt		
Rubiaceae	*Nauclea diderrichii* (De Wild.) Merr.	Muese[b]	nt		
Anacardiaceae	*Trichoscypha patens* (Oliv.) Engl.	Mongola[b]	lc	1	
Annonaceae	*Annickia affinis* (Exell) Versteegh & Sosef	Epue[a]	lc	1	
Annonaceae	*Xylopia parviflora* Spruce	Monjie	lc	1	
Arecaeae	*Laccosperma secundiflorum* (P.Beauv.) Kuntze	Kao	lc	1	
Calophyllaceae	*Mammea africana* Sabine	Boto	lc		1
Fabaceae	*Amphimas pterocarpoides* Harms	Ekela	lc		1
Fabaceae	*Pentaclethra macrophylla* Benth	Mbalaka[a]	lc	1	
Fabaceae	*Stemonocoleus micranthus* Harms	Moobito	lc		1
Fabaceae	*Tetrapleura tetraptera* (Schumach. & Thonn.) Taub.	Jaga	lc	1	
Irvingiaceae	*Desbordesia glaucescens* (Engl.) Pierre	Ntuo	lc		1
Irvingiaceae	*Irvingia robur* Mildbr.	Kombele[b]	lc	1	
Irvingiaceae	*Klainedoxa gabonensis* Pierre	Bokoko[a]	lc		1
Malvaceae	*Bombax buonopozense* P.Beauv.	Ndombi	lc		1
Malvaceae	*Mansonia altissima* (A.Chev.) A.Chev.	Mbambanja	lc		1
Pandaceae	*Panda oleosa* Pierre	Kana	lc	1	
Piperaceae	*Piper guineense* Schumach. & Thonn.	Manjembe, pokombolo	lc	1	
Sapotaceae	*Gambeya lacourtiana* (De Wild.) Aubrév. & Pellegr.	Bambu	lc	1	1
Rutaceae	*Vepris* cf. *afzelii* (Engl.) Mziray	Tanda	nd		1
Solanaceae	*Solanum erianthum* D.Don	Ndaka	nd	1	

Abbreviations: en, endangered; lc, least concerned; nd, no data; nt, near threatened; vu, vulnerable.

[a]Specific Diversity Index above 9.

[b]Specific Atypicality = 1.

FIGURE 5 Species under potential threats (logged, sold or conservation threat) with high-functional diversity index. Clockwise from top-left: (a) bark of *Milicia excelsa*; (b) dried fruit of *Irvingia gabonensis*; (c) trunk of *Annickia affinis*; (d) leaf of *Pentaclethra macrophylla*; (e) fresh kernels of *Klainedoxa gabonensis*. Photo credit: S. Gallois.

community members, with diverse gender, age, recognized healing expertise and from different families. If so, our findings emphasize the importance of incorporating a diversity of socio-demographic attributes in ethnobotanical research, something that needs to be done using respectful and adapted methods. Diversity of socio-demographic attributes helps avoid the underrepresentation of some social groups, such as women and children, a tendency that remains common in research among Baka (Afiong et al., 2024) and in ethnobiology more generally (Díaz-Reviriego et al., 2016; Gallois, van Andel, et al., 2024).

Results from this work complement previous ethnobotanical studies conducted with the Baka (Afiong et al., 2024; Betti, 2004; Betti et al., 2013; Gallois et al., 2020; Gallois, van Andel, et al., 2024) and contribute to the broader effort to document local biocultural diversity. While some of the most frequently reported and multi-functional species were also documented in previous studies, such as for instance *A. boonei* and *Haumania danckelmanniana* among the Baka (Betti, 2004; Hattori, 2006), our study reports more than 30 species—mostly herbs—that, to our knowledge, have not been documented as medicinal in previous work conducted among this society. Further research should explore the differences and commonalities of Baka medical knowledge with other ethnic groups, as a way to explore the variation, cultural transmission and history of the human–plant interactions in the Congo basin (Salali et al., 2016; Teixidor-Toneu et al., 2018). It will also contribute to documenting the biocultural uniqueness in tropical Africa, still underrepresented in global assessments (Cámara-Leret & Bascompte, 2021).

By exploring the functional diversity and atypicality of medicinal plant species known and used by the Baka, our insights also highlight the globally significant, yet specifically uneven, contribution of plants to the local healthcare system, as hypothesized beforehand. We argue that all species, not only the ones with multiple or unique roles, are important to assess the resilience of healthcare and, more broadly, of social-ecological systems. For instance, we identified several species that play multiple roles in the Baka healthcare system, and which are also important for the health of other communities in Cameroon (Jiofack et al., 2010; Kidik-Pouka et al., 2015), the Democratic Republic of Congo (Kasika et al., 2016), Nigeria (Lawal et al., 2022) and across tropical Africa (Bosch et al., 2002). The multifunctionality of these species might even be larger when considering other roles in Baka culture and livelihood. For instance, 73 of the medicinal species also serve as food (Gallois et al., 2020), and some are also used in fishing and hunting (Fongnzossie et al., 2023). Beyond the scope of our study, further systematic research is needed to accurately determine the multifunctionality of the local flora used by the Baka and thus draw a more accurate overview of locally important flora in the entire region.

Conversely, some species are essential because they serve specific issues that other species do not cover. Drawing on previous studies (Santoro et al., 2024), we used atypicality as a measure of uniqueness. We identified species that are not commonly known, revealing a higher diversity of medicinal species, including those with singular roles in the system. These species contribute to the resilience of the healthcare system, and their disappearance could create vulnerabilities (Albuquerque et al., 2024). For instance, 10 species were the sole treatment for nine health issues, emphasizing the uniqueness of these species. In sum, by assessing both species' multifunctionality and atypicality, our study provided evidence of key pillars for the Baka healthcare system, contributing to the documentation of culturally important species. Recognizing the cultural value of these species supports effective conservation strategies that integrate both cultural and biological diversity (Mattalia et al., 2024). Our approach also considers the cultural foundations of human–plant relationships embedded within Indigenous Peoples' healthcare systems. Several issues categorized here as 'cultural symptoms and diseases', such as avoiding social conflicts, protecting against bad spirits and nourishing the forest spirit—*jengi*, reflect the Baka's holistic concept of health (Gallois, Ambassa, & Ramirez-Rozzi, 2024). Documenting the richness of this healthcare system—shaped by long-term human-biodiversity relationships—contributes to the growing body of work advocating for a relational perspective in understanding the human–nature interface (Pratson et al., 2023; West et al., 2020).

5.3 | Threats towards local healthcare systems and local biocultural diversity

Our research highlights current and potential threats to the Baka healthcare system, with significant implications for public health policies, research and conservation efforts.

First, we found that both studied settlements exhibited similar levels of utilitarian redundancy, despite reporting different medicinal species and remedies. As expected, the contribution of plant species to healthcare varies between settlements, and some health issues might be more challenging to treat in one settlement compared to the other. However, no major contrasts were reported—such as cases where a health issue was treated by numerous species in one settlement but by none in the other, or where a single plant species addressed multiple health issues in one site but had no reported use in the other. The presence or absence of specific plant species in one settlement might be explained by differences in accessibility to the surrounding environment. Although both communities are located within a similar ecological region, factors such as walking distance to forest or forest degradation may differ, potentially influencing local availability of medicinal plants. These aspects, however, were beyond the scope of our study and warrant further investigation. In any case, the finding that both settlements had similar levels of utilitarian redundancy suggests that variation in medicinal knowledge and resources does not significantly affect the resilience of the healthcare system. Such differences might rather reflect variations in the medical histories of the settlements and the influences of missionaries on the villagers' perceived health, as highlighted in recent work (Gallois, Ambassa, & Ramirez-Rozzi, 2024). Furthermore, it indicates that, despite the effect of market dynamics and access to formal health facilities, the Baka maintain both their knowledge and access to medicinal plants. However, further studies are necessary to compare these findings with other Baka communities, especially those closer to towns, where access to biodiversity and local knowledge is more limited, as reported among the Bayaka from Congo (Salali et al., 2020).

Our findings also reveal that not all health issues were addressed by an equal number of plants, as initially hypothesized. Health issues with lower redundancy scores may be more challenging to treat. Notably, some issues, particularly those affecting children, such as '*asue*' (respiratory issues) and '*kombe*' (epileptic crisis), were recently reported also as a concern by the communities (Gallois, Ambassa, & Ramirez-Rozzi, 2024). Venereal infections and female sterility, which show low-redundancy scores in our study, had also been identified as significant health challenges in previous research conducted among the Baka, with their increase related to sedentarization and growing integration to the market (Carson et al., 2019; Dounias & Froment, 2006; Ramirez Rozzi, 2018). Identifying health issues that are difficult to treat with the local healthcare system might help guide public health priorities. Addressing these low-redundancy health issues effectively requires strong partnerships between local public health practitioners and the Baka to develop culturally relevant interventions (Gallois, Ambassa, & Ramirez-Rozzi, 2024).

Finally, we also assessed various pressures on the local flora, finding that approximately 40 species are either currently threatened or at risk (according to the IUCN) primarily due to logging and market demands. For instance, some species are declining due to commercial harvesting, such as *Gnetum africanum* and *Baillonella toxisperma*, which also provide edible products (Levang et al., 2015). Several of these species, reported in both settlements, treat multiple health issues and are part of the Baka diet (Gallois et al., 2020). Therefore, the threats to these species are potential disturbances to the overall Baka healthcare system, but also, more broadly, to their subsistence and livelihood. Considering the importance of these species for the local culture and livelihood, stronger priorities should be established to conserve them as well as the associated cultural knowledge.

6 | CONCLUSION

Our research provides evidence of the richness of medicinal plant species known and used by the Baka, as well as the intimate link between the ecological, social and cultural aspects embedded within Indigenous Peoples' healthcare system. Building on a relational perspective, we understand resilience as emerging from the ongoing interactions among people, plants and knowledge systems. In this sense, the resilience of local healthcare systems can be assessed as their capacity to absorb, adapt to and recover from disturbances while continuing to provide care that is effective and culturally meaningful. Through a mixed-methods approach, we have shown how local biodiversity and associated knowledge contribute to this resilience: the richness of the medicinal plant species and remedies contributes to a broad therapeutic repertoire, uncommon uses reflect the depth of Baka knowledge, while pressures on key species and low redundancy in some health issues reveal important vulnerabilities. Taken together, these findings emphasize the importance of protecting biodiversity and respective knowledge, thereby strengthening resilient, culturally grounded healthcare systems in the face of socio-ecological change.

AUTHOR CONTRIBUTIONS

Authors from different countries, including Cameroon, conducted this study. All authors were engaged early on with the research and study design to ensure that the diverse set of perspectives they represent was considered from the onset. Sandrine Gallois led the research at all stages. Sandrine Gallois and Appolinaire Ambassa reviewed together the cultural adequacy of the methods to be developed. Sandrine Gallois, Appolinaire Ambassa, Stijn van Bemmel and Tinde van Andel collected the data, with Appolinaire Ambassa ensuring accurate translation and identified the specimens. Sandrine Gallois, Miroslav Pulgar, Appolinaire Ambassa, Chiara Broccatelli and Eric Ngansop analysed the data. All authors contributed to the writing of the manuscript. Whenever possible, our research was discussed with local stakeholders to seek feedback on the questions to be tackled and the approach to be considered, and literature published by scientists from the region was cited.

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CONFLICT OF INTEREST STATEMENT

The authors declare having no conflict of interest.

DATA AVAILABILITY STATEMENT

The datasets used in this research are available upon reasonable request to the authors. As agreed with the Baka, no data combining species with their cultural uses will be made public or available. The aggregated datasets generated and analysed during the current study will be available in the repository CORA, https://doi.org/10.34810/data2045.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Supporting Information S1. List of the medicinal plant species reported, with their respective scientific and local names, voucher number, domestication status, IUCN concern classification and utilitarian redundancy and atypicality indices.

Supporting Information S2. Further description of data analysis.

Supporting Information S3. Reported name of the health issues, reported descriptions, their English equivalence and approximation to the International Classification of Diseases 11th edition of the World Health Organization (ICD-11, WHO), with their respective Utilitarian redundancy Index-Uredit and data collection methods. When no specific name but a developed explanation was provided, the cell 'Names in Baka (or French)' was left blank.

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