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Uneven transmission of traditional knowledge and skills in a changing wildmeat system: Yangambi, Democratic Republic of Congo

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Introduction: Indigenous communities typically hold diverse traditional ecological knowledge (TEK) of their social-ecological system. Much of this knowledge is embodied as skills related to subsistence practices within a specific landscape and is associated with community values and norms. Ways of knowing often reflect the different activities traditionally undertaken by men and women. The incursion of external forces, including urbanization, the cash economy and migration tends to diminish transmission of traditional embodied skills. Knowledge can be lost as culturally significant environments degrade or species become extirpated. Lack of opportunity to develop traditional knowledge and skills can diminish feelings of place and identity, and thus capacity for local environmental stewardship.

Methods: The Yangambi region, Democratic Republic of Congo is a hunting territory of the Turumbu ethnic group. We used questionnaires to explore how levels of wildmeat knowledge and skill may have changed over time among the Turumbu.

Results: The responses showed lower levels of self-reported skill among women who started to participate in the last 10-15 years. This pattern partly reflects the period of 'apprenticeship' but may also suggest diminished learning opportunity in recent years. Skills in cooking, smoking, and selling wildmeat persisted at a higher level than skills in curing disease and gathering wild produce. There was a much more marked pattern for men, with diminishing levels of wildmeat skill reported for around 35-40 years, and even earlier for knowledge of traditional medicine and wildmeat taboos. Questions about mentoring suggested that women have maintained knowledge pathways between mother and daughter, while men showed a shift toward increased learning from uncles.

Discussion: Gender differences in sharing and learning TEK may be linked to the type of skills that remain valuable in a changing social, ecological, and economic context. Men traditionally undertake the capture elements of hunting, while

women deal with wildmeat processing, marketing, and cooking. The Yangambi wildmeat system has evolved from subsistence to a strongly market-driven economy during the lifetime of our study participants. This shift may partly explain why market-based kills such as food smoking and selling have endured longer than hunter's nature-based knowledge.

KEYWORDS

traditional ecological knowledge, TEK, social-ecological systems, wildmeat, hunting, indigenous, learning

1 Introduction

Indigenous communities typically hold diverse traditional ecological knowledge (TEK) of their social-ecological system. Much of this knowledge is embodied as skills related to subsistence practices of hunting and gathering, and is associated with community values and norms and a broader cosmovision (Magni, 2017). Such embodied skills are strongly interwoven with sense of place, identity and cultural continuity in a relevant natural context, i.e., a 'taskscape' (Ingold, 2000); they connect body, mind, and environment (Raymond et al., 2018). Knowledge in this context is the link between feelings of care and responsibility for nature and practical agency relative to stewardship (embedded sustainable use) of local resources and ecosystems (Enqvist et al., 2018; Shephard et al., 2023).

Personal assimilation of TEK is a lifelong process, and older practitioners are expected to have deeper knowledge, e.g., of medicinal plants (Ayantunde et al., 2008), rare fishes (Braulik et al., 2022), forest succession (Schmidt et al., 2021) etc. Specific ways of knowing and relating to nature usually differ with gender in Indigenous communities, reflecting the activities traditionally undertaken by men and women (Souto and Ticktin, 2012; Gachuiri et al., 2022). Such differences seem to vary with scale, i.e., national, continental, or global (Torres-Avilez et al., 2016). Men can have more knowledge redundancy, e.g., of several plants that have the same medicinal function, but women may share information more widely and become more influential in knowledge transmission (Torres-Avilez et al., 2019). Skills and knowledge are passed on through everyday activities, local stories and songs (Reyes-García and Fernández-Llamazares, 2019). Children observe and imitate adults during the process of daily life (Lew-Levy et al., 2017; van Vliet et al., 2022b). Such cultural transmission of TEK is a dynamic process that reflects ambient conditions (Gómez-Baggethun and Reyes-García, 2013) and ongoing relations between mind, body and environment through time (Cooke et al., 2016). It allows for integration of new experiences and insights that could enhance food security and income generation, while enriching the cultural environment (Reyes-García et al., 2013).

Traditional skills and knowledge are acquired by humans through practice of significant and often cyclical activities within their taskscape. This process requires multi-generational participation and mentoring that helps build relational values linked to sense of place, identity and care (West et al., 2018). Incursion of outside forces, including urbanization, the cash economy and significant in- and out-migration tends to diminish development and transmission of traditional embodied skills (Kik et al., 2021). Skills no longer necessary for survival may be lost or retained at a lower level of mastery as traditional lifestyles, links to place and modes of education change (Ohmagari and Berkes, 1997). Important knowledge can also be lost as culturally significant environments degrade or species become extirpated (Turvey et al., 2018). Loss of LEK and reduced opportunity to acquire skills may diminish capacity for good environmental stewardship, by reducing feelings of personal and communal responsibility for nature (Reid et al., 2021). Losing this emotional connection to a social-ecological system may occur in tandem with erosion of resource boundaries and sanctioning mechanisms that are key to self-governance (Ostrom, 1994), cumulatively impairing efforts in community-based wildlife management (Benyei et al., 2022). This unravelling can have serious implications for the resilience of Indigenous communities, reducing capacity to endure environmental shocks such as pest infestation (Bentley and Rodriguez, 2001), extreme weather events (Kuhnlein and Turner, 2020) or climate change (Gómez-Baggethun and Reyes-García, 2013).

Indigenous knowledge, livelihoods and culture are currently the focus of a renewed effort by many communities seeking to re-establish their identity and attain legal recognition of territorial rights and responsibilities (Macfarlane and Olive, 2021; Lindstrom, 2022). This renaissance, and its associated benefits for biodiversity conservation, may be compromised by loss of embodied Indigenous knowledge (Fernández-Llamazares et al., 2021; Kik et al., 2021). It is important to understand how and when development of traditional knowledge and skills proceeds over time, and whether this process is uneven within a community, e.g., between genders.

The Yangambi region, Democratic Republic of Congo (DRC) is an extensive hunting territory of the Turumbu ethnic group. The Turumbu are a riparian people thought to be part of the larger Bantou group of Topoke-Lokele-Turumbu-Basoko; they speak several languages including Lombo and Lingala. The Turumbu are known for their traditional hunting skills, and the wildmeat system around Yangambi is extremely important to local food security (van Vliet et al., 2022a). The forest in this region remains relatively healthy, but there has been significant decline among important target species (van Vliet et al., 2018) and strong shifts in

the hunting social-ecological system (Shephard et al., in review). Various aspects of Turumbu traditional knowledge and culture may have been lost to colonization and modernity (Koy and Ngonga, 2017). We used questionnaires to explore how individual levels of embodied wildmeat knowledge and skills may have changed over time, and how this knowing is shared across living generations of Turumbu men and women in the Yangambi region.

2 Methods

2.1 Data collection

2.1.1 The study area and hunting system

Yangambi town is in the North-East of the DRC, about 100 km West of Kisangani City in the Tshopo Province (Figure 1). As is typically observed in Congo Basin forests, the landscape around Yangambi is characterized by a superposition of land tenures combining the existence of the Yangambi Man and Biosphere Reserve (YBR) created in 1979, the legally contested Ngazi Forest Reserve, a logging concession to the north-West of the YBR and Turumbu customary land. In practice, due to the lack of human and financial resources, the YBR has no official management plan, its limits are contested, and it is not under any specific form of management. Deforestation in the YBR may not differ from bordering areas (Kipute et al., 2023).

Our focus within this landscape was the hunting territory of Weko, a Turumbu village located 30 km to the north of Yangambi town. The territory of Weko covers an area of about 30 000 ha. In Weko, the main livelihoods are shifting cultivation, hunting, fishing, canoe construction and gold mining. The village of Weko provides around 66% of the wildmeat biomass sold in the town of Yangambi - an equivalent of about 97.6 tons of smoked meat per year. Despite this large catch, food security is poor because most of the hunting occurs for commercial purposes, with more than 80% of the biomass being sold to the Yangambi market. The main species sold are small monkeys and red duikers, followed by blue duikers, bush pigs and brush tailed porcupines (van Vliet et al., 2018).

2.1.2 The questionnaire

A set of standardized questions was used to elicit perceptions of local knowledge and skills related to various aspects of the wildmeat hunting system, and to explore how these dimensions might differ among practitioners across the observed gradient of age and experience. The questionnaire was first developed in French, and conversations predominately in Lingala and Turumbu. Each respondent was first asked to record how old they were when they started to learn specific wildmeat skills, and how old they are now. Time in the system (age now minus age at start) was then calculated as a period of 'participation' in years (Shephard et al., 2021). This variable provided the basis for plotting time series of perceived wildmeat knowledge and skills in the community. The sets of questions were developed through a series of preliminary discussions with separate groups of young and old men and women. Each group was asked to describe what they perceived as the most important skills and knowledge (related to wildlife) that characterize a Turumbu woman or man. The groups then ranked these criteria for man- or womanhood. We selected all the consistently reported characteristics and used these to formulate relevant questions.

Following this approach, the number and type of skills, and the resulting sets of questions differed for men and women based on key

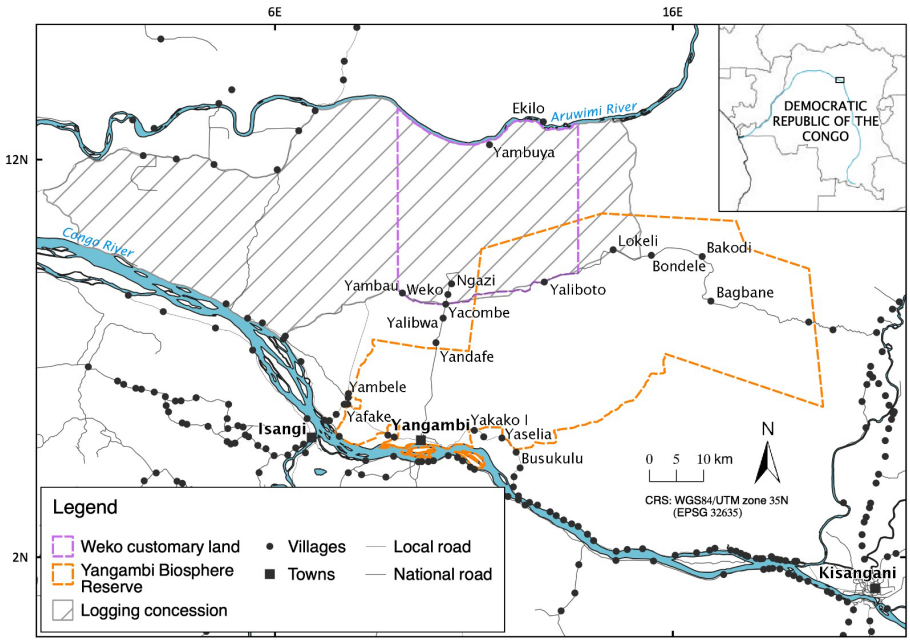

FIGURE 1
Map of the study area around Yangambi in DRC.

TABLE 1 Questions about wildmeat knowledge and skills presented to each of women and men in the study community.

Characteristic skills for Turumbu women	Questions
Butchering game	What is your level of knowledge and skill in butchering game?
Cooking game	What is your level of knowledge and skill in cooking game?
Curing disease with wild animal parts	What is your level of knowledge and skill in using animal parts to cure disease?
Gathering game in the forest	What is your level of knowledge and skill in gathering game?
Selling game	What is your level of knowledge and skill in selling game?
Smoking game	What is your level of knowledge and skill in smoking game?
Knowing which meats are taboo	What is your level of knowledge about taboo meat for women?
Characteristic skills for Turumbu men	**Questions**
Knowledge of baits for traps	What is your level of knowledge and skill in using bait for traps?
Being able to manufacture cartridges	What is your level of knowledge and skill in making cartridges?
Curing diseases with animal parts	What is your level of knowledge and skill in using animal parts to cure diseases?
Hunting game	What is your level of knowledge and skill in hunting?
Being able to organize the logistics for a hunting trip	What is your level of knowledge and skill in preparing for a hunt?
Processing and butchering game	What is your level of knowledge and skill in processing game?
Understanding customary rules for sharing game	What is your level of knowledge about the rules of sharing game?
Smoking game	What is your level of knowledge and skill in smoking game?
Knowing which meats are taboo	What is your level of knowledge about eating taboo species?
Targeting game	What is your level of knowledge and skill in shooting accurately at game?
Setting traps	What is your level of knowledge and skill in setting traps?
Recognizing tracks and sounds in the forest	What is your level of knowledge and skill with animal tracks and sounds?

Each question is based on community perceptions of the wildmeat knowledge and skills that characterize a Turumbu woman or man respectively.

traditional tasks identified for each group (Table 1). Questions were phrased as "what is your level of knowledge and skill…?" For example, the women's groups indicated that a Turumbu woman should be able to butcher game skillfully, and so the first question to women was 'What is your level of knowledge and skill in butchering game?' (Table 1). Respondents were asked to select their perceived level according to a 6-point Likert scale extending from "no idea" to "I can do it myself and train others." Each respondent was also asked who taught them the skill referred to in each question. They could select from "Mother", "Father", "Aunt", "Uncle", "Friends" and several other close relations. The reported level of skill and the identified primary mentor for each skill were the main information used in the subsequent analysis.

2.2 Data analysis

The first objective was to explore whether the level of self-reported wildmeat expertise changed over the observed range of experience ('participation', years to present) for respondents. Each of the set of possible responses to the questions (Table 1) was coded numerically as follows: "I can do it myself and train others" (score 4), "I can do it by myself" (score 3), "I can do it if someone helps" or "I have seen it done" (score 2), and "I have heard about it" or "I have no idea" (score 1). The responses referring to lower levels of skill (scores 1 and 2) were paired because they were each relatively uncommon. An important aspect of this analysis was to identify the typical age at which men and women each started to learn and participate in their characteristic skills, and how quickly they attained a self-reported higher skill level (at least score 3 or 4). This information was presented in plots that show starting age, current age and perceived current skill level (Figures 2, 3).

Reported skill levels then needed to be evaluated in relation to the length of participation (years up to the present) for each respondent and skill. Responses were collated into nine participation increments (bins), representing from 5 up to 50 years' experience, with 3-6 (usually 4-5) respondents per increment. The proportion of respondents reporting each skill level (score 1-4) at each participation increment was then expressed using a Likert plot (diverging stacked bar charts, Figures 4, 5) for each skill question (Table 1). The plots therefore provide time series of perceived wildmeat knowledge and skill across the observed participation gradient (Shephard et al., 2021), revealing if and when the proportion of people reporting higher skill levels may have diminished. The question of changing skill levels over time was also tested statistically by fitting linear regression models to the proportion of respondents in each career increment that reported a high level of skill (score 4). Two models were fit for each male and female skill, allowing either a straight line or a quadratic curve. The two models were compared using AIC to identify best fit for each skill, but a p-value for the effect of participation length was reported for each model.

The second objective was to consider whether the most frequently reported wildmeat mentor tended to differ between people with longer and shorter periods of participation in Turumbu skills. Reported mentor was aggregated across all skills questions and then plotted for men and women across three participation bins (0-15, 15-35 and >35 years up to the present). This plot provided a simple summary of the primary transmitters of knowledge reported across three consecutive time periods. Because the primary mentor seemed to change for men (not women), a table of observed values for men was then provided for additional insight.

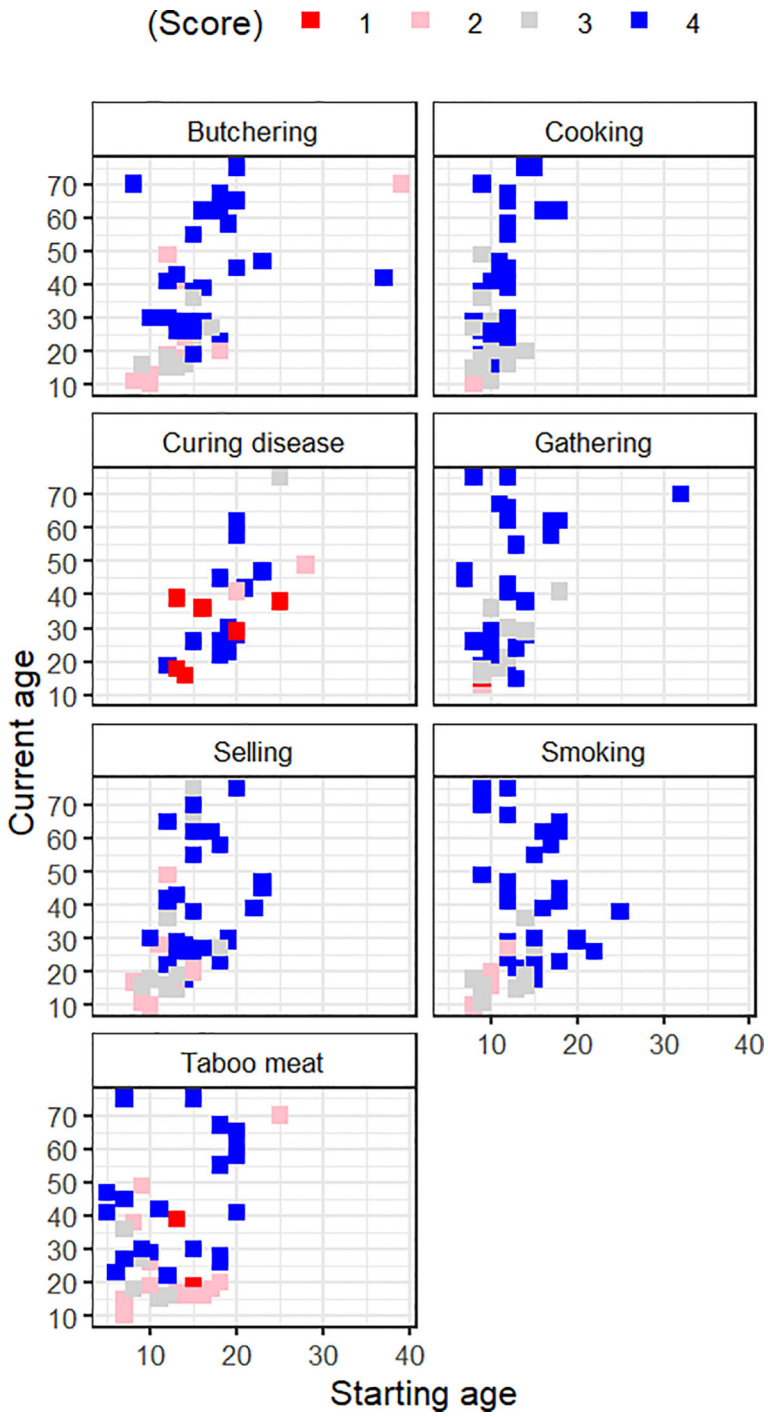

FIGURE 2
Current age (years) of female Turumbu respondents and the age at which they started to learn and participate in each skill. The color of the points indicates their reported level of skill, scored as "I can do it myself and train others" (score 4), "I can do it by myself" (score 3), "I can do it if someone helps" or "I have seen it done" (score 2), and "I have heard about it" or "I have no idea" (score 1).

The original questions and discussions suggested ongoing changes in the level of embodied skills and knowledge among Turumbu men and women. In order to reflect on these results with local people, four separate focus groups were subsequently conducted in Weko and Ngazi villages. There was a group of three old people (men and women) and another of four old people (men and women). There was also a group of 11 young women and finally a mixed group of men from 25-75 years of age. These groups considered outcomes from the primary questionnaire, and a supplementary set of questions was used to further explore perceptions of how young people are now connected to Turumbu traditional knowledge and skills, especially related to hunting and wildlife (Table 2).

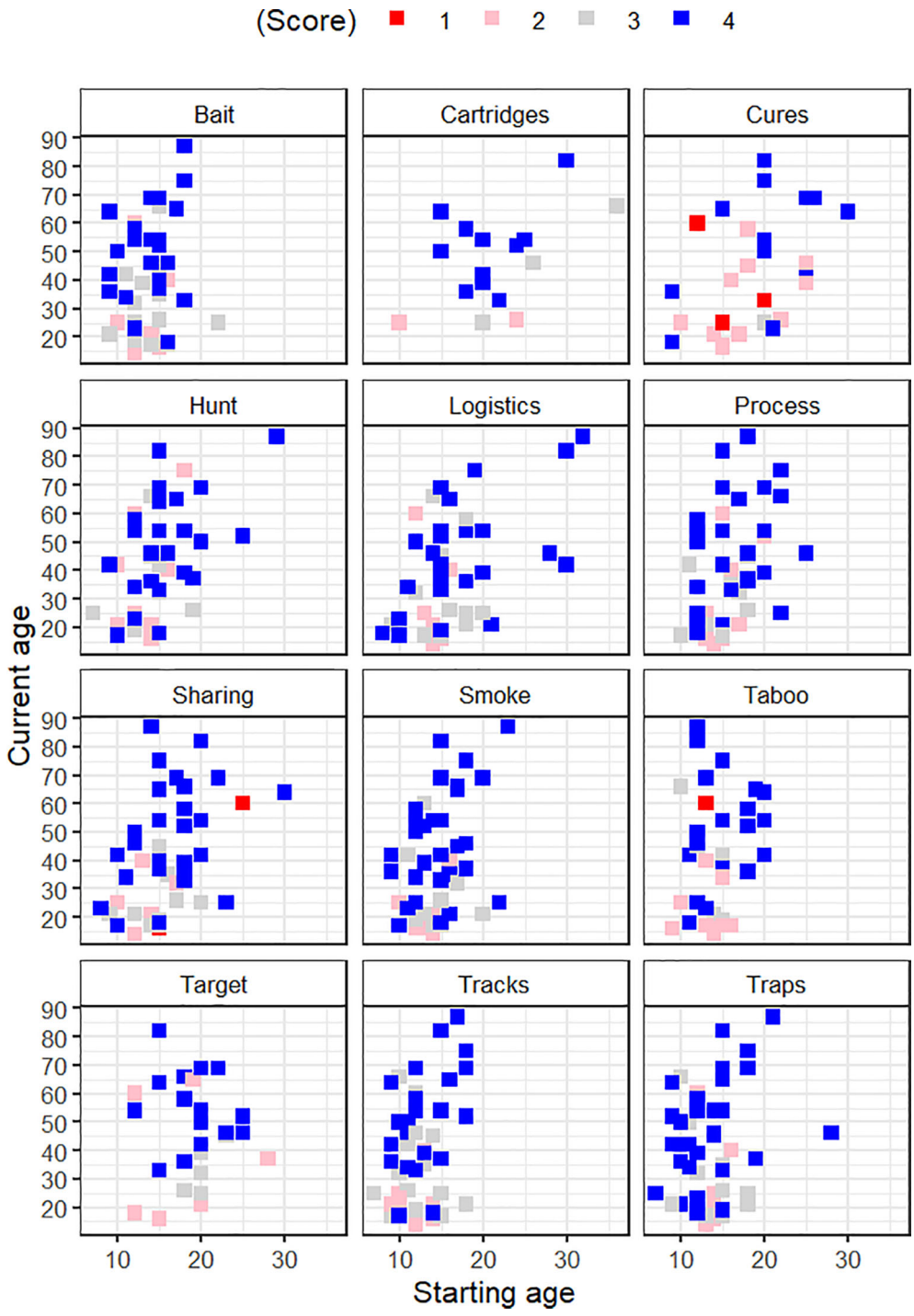

FIGURE 3
Current age (years) of male Turumbu respondents and the age at which they started to learn and participate in each skill. The color of the points indicates their reported level of skill, scored as "I can do it myself and train others" (score 4), "I can do it by myself" (score 3), "I can do it if someone helps" or "I have seen it done" (score 2), and "I have heard about it" or "I have no idea" (score 1).

3 Results

There were a total 47 male and 53 female respondents for the questionnaires. The plots of starting and current age and the level of reported skill showed some visual contrasts among the characteristic tasks of Turumbu. Learning of some skills commenced at a younger age (<10 years), especially cooking, gathering and taboo meat for women (Figure 2), and tracking and trapping for men (Figure 3). Other tasks such as curing disease (women) and making cartridges or aiming a gun (men) started at a later age.

Self-reported expertise in most wildmeat skills appeared lesser among women who entered the wildmeat system in the last 10-15 years. The timing and degree of change differed across questions,

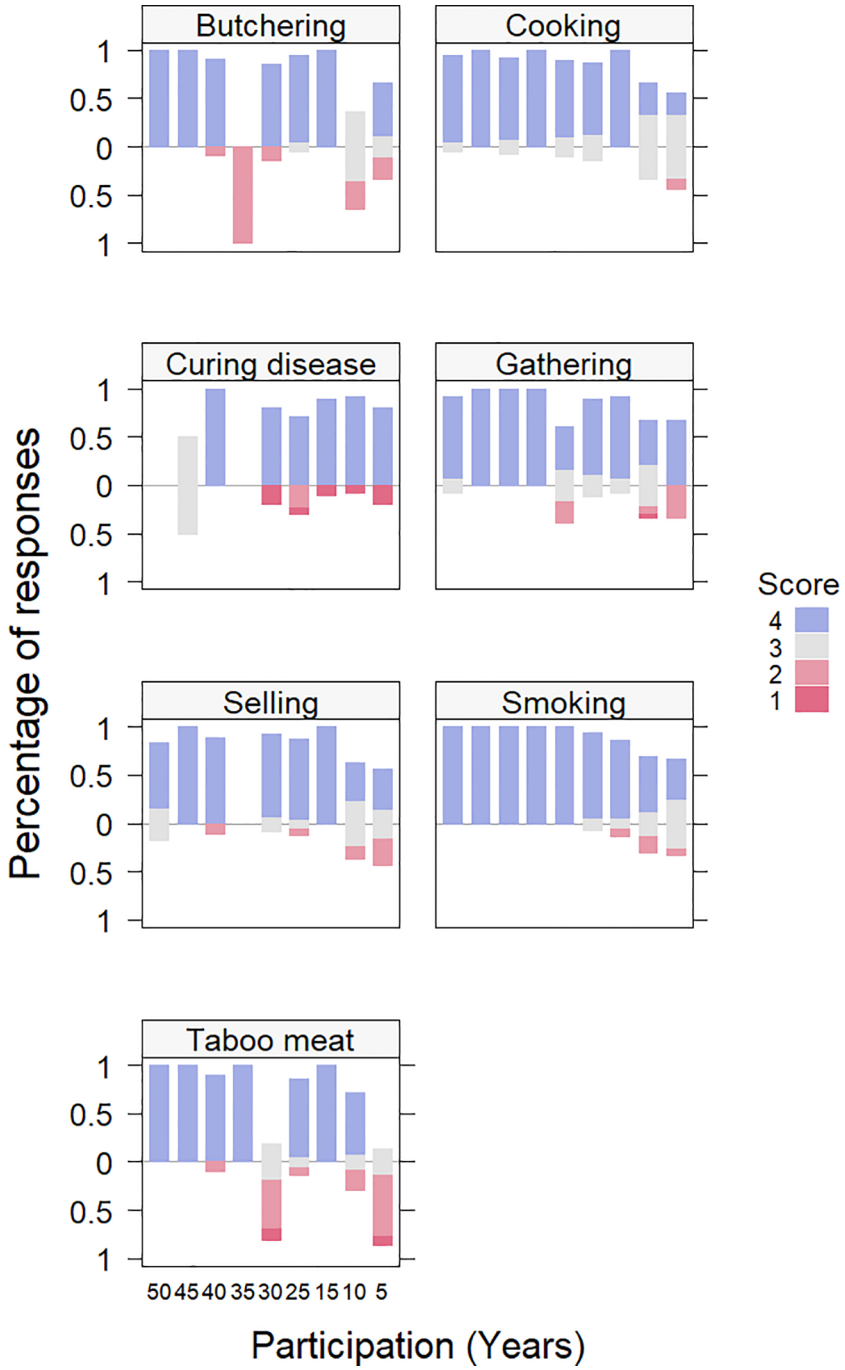

FIGURE 4
The proportion of women at each participation increment giving each of four possible classes of response to seven different questions (Table 1) about their wildmeat knowledge and skills. The four responses are "I can do it myself and train others" (score 4), "I can do it by myself" (score 3), "I can do it if someone helps" or "I have seen it done" (score 2), and "I have heard about it" or "I have no idea" (score 1).

with skills in curing disease and gathering wild produce possibly diminishing earlier (i.e., more Likert scores of 1 or 2) than skills in cooking, smoking and selling wildmeat (Figure 4). The recent lower level of knowledge and skills was much more marked for men, with a diminished level of expertise evident among those with participation shorter than 30-35 years. Diminished sharing and learning of knowledge related to curing disease and wildmeat taboos may have started even earlier and subsequently become more severe (Figure 5).

The fitted regression models showed that the proportion of men reporting a high skill level (score 4) decreased approximately as a straight line with shorter participation, i.e., more recent entrance to the system (Model 1), and this negative effect was strongly significant (Table 2). For women, the participation effect on

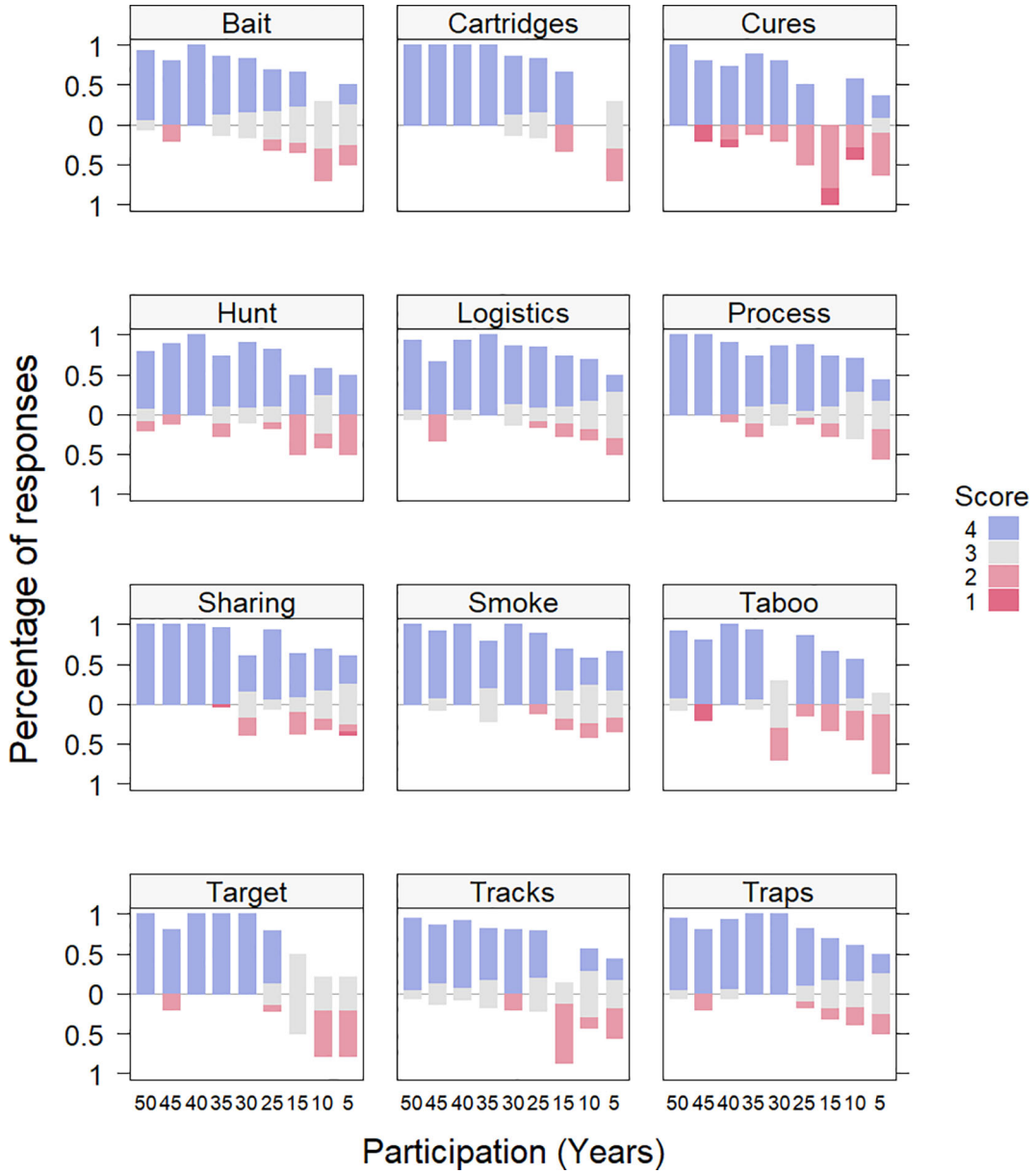

FIGURE 5
The proportion of men at each participation increment giving each of four possible classes of response to 12 different questions (Table 1) about their wildmeat knowledge and skills. The four responses are "I can do it myself and train others" (score 4), "I can do it by myself" (score 3), "I can do it if someone helps" or "I have seen it done" (score 2), and "I have heard about it" or "I have no idea" (score 1).

proportion of high skill level was only important for cooking and smoking, which showed patterns resembling the data for men.

The contrast between men and women in time series of wildmeat skills may be linked to the key mentors that each group reported. Most women indicated that they learnt wildmeat skills mainly from their mother, and to a lesser extent from their father. This pattern did not appear to change much over the observed range of experience in the system (Figure 6). In contrast, men historically tended to be mentored primarily by their father, but there was a strong shift over time toward an important training role for uncles (Table 3, Figure 7). Fathers were important mentors to women, but relatively few men reported being mentored by their mother.

The secondary focus groups helped to clarify local perceptions of current Turumbu identity and maintenance of traditions by young people. Four separate focus groups, each involving 3 to 11 Turumbu men and women provided a consistent picture. The general feeling was that young people are still broadly connected to the tradition but are losing interest in the details and are subject to outside influences. The important role of parents in maintaining transmission of wildmeat knowledge and skills was highlighted (Table 4).

4 Discussion

Traditional ecological knowledge is not just abstract information. It comprises the accumulated environmental

TABLE 2 Outcomes (p-values) from two linear regression models testing the effect of participation (nine increments from 5 to 50 years) on proportion of respondents reporting a high skill level (score 4).

		Participation effect (p)	
	Skill	Model 1	Model 2
Men	Bait	**0.001**	0.083
	Cartridges	0.001	**0.009**
	Cures	**0.010**	0.569
	Hunt	**0.015**	0.159
	Logistics	0.013	**0.010**
	Process	**0.001**	0.090
	Sharing	**0.003**	0.300
	Smoke	**0.014**	0.216
	Taboo	**0.087**	0.442
	Target	0.001	**0.018**
	Tracks	**0.002**	0.246
	Traps	0.005	**0.002**
Women	Butchering	**0.275**	0.900
	Cooking	0.026	**0.054**
	Curing disease	**0.049**	0.741
	Gathering	**0.095**	0.741
	Selling	**0.543**	0.695
	Smoking	0.001	**0.000**
	Taboo meat	**0.143**	0.657

Model 2 allowed a curvilinear (quadratic) fit. The two models for each skill were compared using AIC and the better fitting model is emboldened.

knowing and awareness of an Indigenous community. This insight is typically embodied in practical skills that are critical for survival and sustainable use in a specific social-ecological system and woven into relationships within a broader landscape and cosmovision. Loss of TEK thus diminishes not just practical capacities, but also local environmental stewardship capacity and cultural integrity. We used closed-answer questionnaires to evaluate the level of TEK held by successive living generations of Turumbu people in the Yangambi region, DRC. The focus was on skills and knowledge that were perceived locally as important criteria for being a Turumbu man or woman.

There was strong evidence for a lower level of skills among people starting to learn and participate in more recent years. The most marked effect was for knowledge and skills related to ethnic medicines and wildlife taboos, which might be associated with a more intact traditional lifestyle. However, women seemed to have retained a higher level of learning and skills for longer than men (Figures 4, 5). Women also better maintained pathways of knowledge transmission from mother to daughter, while men showed a shift from father to son transmission toward increased learning from uncles (Figures 6, 7). Learning from uncles may have increased, but it is perceived locally to be grounded in tradition. One of the field team concluded from the focus group discussions that "*Many Turumbu children are raised in their mothers' families, where newborns are given more consideration by their uncles who have a bond of affection without taboo. Young people can sometimes confide more easily in uncles than in their fathers and will learn a lot*". There may also be an effect of fathers living and working elsewhere, e.g., in the mines.

It is very important to recognize that the current results probably reflect two different mechanisms: (1) the likelihood that knowledge increases with age and length of participation in a wildmeat task ("wisdom of the elders"), and (2) the possibility

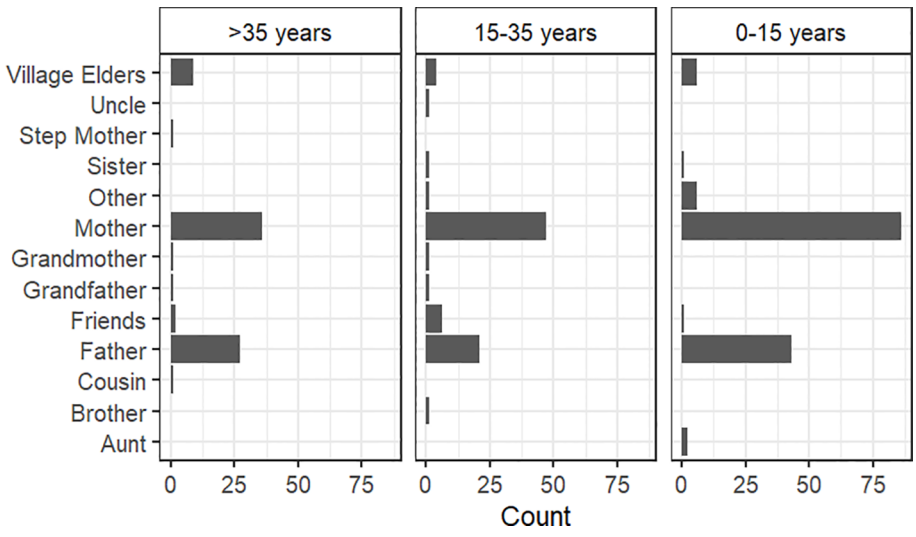

FIGURE 6
Summary of primary mentors for women in three classes of career length. Bars show the number of responses for each mentor class summed over the seven wildmeat questions (Table 1).

TABLE 3 Number of men in each of three participation increments for each skill who reported being mentored primarily by either their father or uncle.

	>35 years		15-35 years		0-15 years	
Skill	Father	Uncle	Father	Uncle	Father	Uncle
Bait	13	0	11	2	10	6
Cartridges	1	0	7	2	2	1
Cures	5	0	6	1	6	2
Hunt	11	0	15	1	5	3
Logistics	12	1	12	2	9	5
Process	12	0	10	3	8	4
Sharing	11	0	14	1	12	4
Smoke	14	0	9	2	10	6
Taboo	9	0	9	1	8	2
Target	7	0	11	0	3	2
Tracks	13	0	14	2	8	4
Traps	15	0	10	2	8	6

that opportunities to acquire knowledge decrease with successive generations ("loss of experience") (Okui et al., 2021). In other words, we need to consider whether apparent lower levels of expertise among younger Turumbu men and women simply reflect that progressively less experienced participants are correspondingly less likely to report a high level of skill. The effects (1 and 2) can be parsed out by asking respondents whether they possessed relevant knowledge and skills during their childhood (suggesting successful knowledge transmission at an early stage, Okui et al., 2021). Alternatively, it could be informative to enquire about how long it takes to become proficient in each skill, and then compare this apprenticeship period to patterns of reported skill level across years of participation. The latter information is presented empirically here and suggests that many men acquired higher levels of skill (score 3-4) in a much shorter period (10-15 years participation, Figure 3) than the observed (and 'statistically significant') period of declining skill levels (35-40 years, Figure 5). This outcome suggests that younger Turumbu men may indeed be less skilled than their elders were *at the same age*. The contrast is less clear for women, where the period of participation required to learn a skill (Figure 2) does not seem to differ so much from the period of lower skill level (Figure 4).

Loss of TEK is often associated with changes in environment and natural resources, and associated livelihood practices (Tang and Gavin, 2016). There has been considerable decline among important hunting species around Yangambi. The presence of armed groups in the forest during conflict periods in 1995-1997 and 1998-2003 imposed substantial pressure on wildlife for meat, as

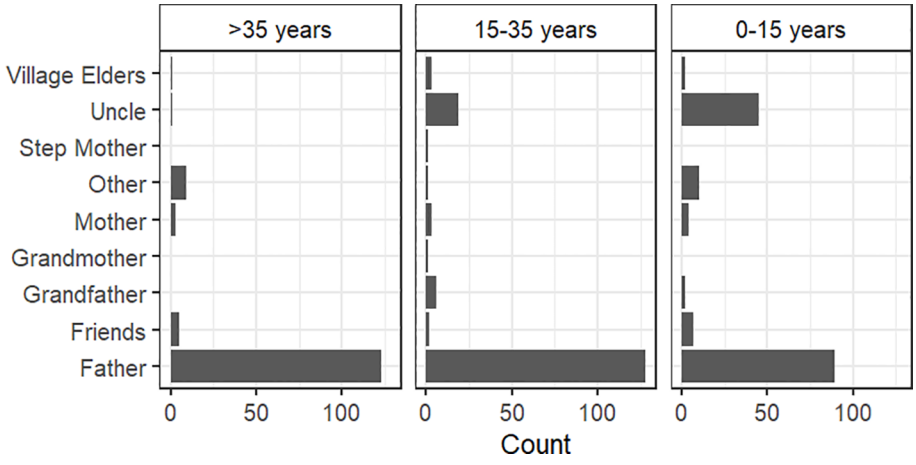

FIGURE 7
Summary of primary mentors for male hunters in three classes of career length. Bars show the number of responses for each mentor class summed over the 12 hunting questions (Table 1).

TABLE 4 Supplementary questions and answers discussed in four small focus groups to help interpret results from the main study.

Question	Summary response
Do you think that there are still many men and women who have all the skills and knowledge to be 'fully' Turumbu?	Yes, they follow the custom and respect it even outside their territory, e.g., they ask permission to hunt, and they have respect for totem animals.
Do you think it is possible to remain fully Turumbu if you leave the hunting lifestyle and work elsewhere, e.g., in the mines?	Yes, they follow the custom and respect it even outside their territory, e.g., they ask permission to fish.
Do you think the young people have less feeling of identity as Turumbu?	Yes, they are Turumbu and know the tradition, but they are suspicious, they take the custom lightly, but they do not respect the whole tradition.
Do you think that the young people are less connected to the Turumbu hunting lifestyle?	Young people are connected to their customary way of life, but they do not fully respect, they neglect.
Do you think that the young people are less connected to the Turumbu hunting territory?	Young people are connected to their hunting ground. Each clan has its forest, and the limits are known by the young people. We respect these group territories.
Do you think that the young people are less concerned about conservation and management of wild animals and the Turumbu territory?	Young people don't care about conservation or wildlife management, but greater awareness is starting to develop. For them, the animals were there, are and will always be there.
Has it become more difficult to help young people engage with certain aspects of hunting practice, e.g., taboos and traditional medicines?	It is not very difficult to help young people to engage in certain hunting practices, but this exposure must be continuous. It is the responsibility of the parents. For traditional medicine, parents should teach their children to trust them and not everyone else. Churches weaken the custom.
If so, how do you feel about these changes?	We think that it is necessary that the parents are rigorous in the application of the tradition – it must start with the leader. The State and the Churches must help to enforce the custom and not abolish it.

well as the trafficking of ivory and skins (van Vliet et al., 2018). Annual deforestation rates on primary forests subsequently increased after about 2010 (Hufkens et al., 2020). These impacts mostly reflect a growing human population as the post-conflict period provided greater stability for people looking to invest in agriculture. The rehabilitation of the road from Kisangani to Yangambi in 2007 may have further favored the attractiveness of the region and subsequent agricultural development (Koy et al., 2019). There is also significant social and economic change around Yangambi, that has been proceeding since the early colonial period (Koy and Ngonga, 2017). Since about 2000, the local market has grown in response to increased demand for food. Trade in wildmeat has gradually become a vibrant and well-structured market chain (Van Vliet et al., 2019). Successful self-governance of common pool forest systems is most likely to occur under a set of conditions that include high salience of specific resources, as well as community trust and autonomy (Ostrom, 1999). These positive factors may have diminished as Yangambi society shifts from subsistence hunting, with its associated local knowledge, skills and communal practices, toward a more externalized urban and market-based economy.

Channels of knowledge transfer frequently change across generations of Indigenous people as the social-ecological environment shifts (Okui et al., 2021). Tang and Gavin (2016) classified "loss of pathways of TEK transmission" as the first category of direct threats to TEK. We noted that the primary mentor reported by respondents across all knowledge and skill questions remained much the same across three observed age groups of women. There is considerable evidence that social networks among women are more connected and show greater information sharing (Szell and Thurner, 2013), possibly providing the cohesion and maintenance of TEK in a changing community (da Costa et al., 2021). Gender differences in retention of TEK may also be linked to the type of skills that remain valuable in a changing social, ecological and economic context. Men traditionally undertake the capture elements of hunting, while women deal with wildmeat processing, marketing and cooking. We found that market-based skills such as food smoking and selling may have endured longer in Yangambi than nature-based knowledge related to tracking animals, using medicinal plants (Aswani et al., 2018), and dietary (wildmeat consumption) taboos. This process could reflect an observed regional shift from subsistence hunting and gathering to a wildmeat market economy (Van Vliet et al., 2019), which would favor lived and practical transmission of tasks and knowledge traditionally linked to women.

There is a considerable literature on "perceptions as evidence", which highlights the role of local knowledge in evaluating state in social-ecological systems (Bennett et al., 2017). Correspondingly, incorporating the knowledge and participation of indigenous constituents strengthens participatory wildlife management (Popp et al., 2019). The knowledge of local people has provided unique insight into ecological change in the Yangambi region, especially among important hunting species. A diminished social role for subsistence hunting likely means that users will have less capacity for assessing ecological state in their local systems (Shephard et al., 2023) and consequently for implementing traditional stewardship principles. This effect may be exacerbated as transmission of knowledge is disrupted by social and economic change (Bafeno and Likunda, 2016), e.g., Yangambi was a regional agricultural research center during colonial occupation from 1934. Situated learning, e.g., where children acquire knowledge by imitating their parents, has a key role to play in the transgenerational establishment of sustainable futures (Giusti et al., 2018). Transmission of practical outdoor wisdom (List, 2013) cannot occur as a theoretical process, it involves "much more than we can tell" (Carolan, 2015) and hence requires participation in a living and embodied tradition. The perceived necessity for active and deliberate transmission of Turumbu tradition was evident during

the concluding interpretive focus groups. Here, the sense was that the tradition is alive but fragile among young people, and that parents remain responsible for passing on important knowledge and beliefs.

Loss of TEK can sometimes seem inevitable, but certain Indigenous communities have managed to consciously offset this trajectory and maintain a continuum between traditional and modern economies and lifeways. The Makushi people of the North Rupununi, Guyana, work deliberately and energetically to maintain transmission of knowledge and skills through traditional situated learning (van Vliet et al., 2022b). In Hawai'i, transmission and storage of TEK and associated community identity helps impart resilience and adaptation to environmental change (McMillen et al., 2017). Similarly, in Sarawak, traditional festivals and oral traditions are still used to foster social networks and institutions of indigenous communities that enable collective action (Hosen et al., 2020). Living TEK, with its associated sense of place and identity has an important role in local environmental stewardship. In this context, actively maintaining and restoring knowledge transfer could be extremely useful to the Turumbu people as they navigate a rapidly changing and increasingly open social-ecological system.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Ethics Review Board of the Center for International Forestry Research. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

SS: Formal Analysis, Methodology, Writing – original draft, Writing – review & editing. JM: Investigation, Methodology, Writing – review & editing. JN: Investigation, Methodology, Writing – review & editing. EB: Investigation, Methodology, Writing – review & editing. SN: Investigation, Methodology, Writing – review & editing. PC: Investigation, Methodology, Writing – review & editing. NvV: Conceptualization, Funding acquisition, Investigation, Methodology, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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